

A methodology for verified energy savings in manufacturing facilities through changes in operational behaviour

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Keywords

manufacturing, energy saving methodology, behavioural change, productivity, energy efficiency measures

Abstract

The Manufacturing industry is increasingly accountable for the environmental impact resulting from its activities. Manufacturing operations design has shifted from a traditional strictly cost and quality approach to more recently including energy efficiency, zero waste and reduced carbon emissions. Whilst manufacturing companies have focused on reducing energy at a facilities level, research indicates that specific production processes generate a significant environmental impact through energy consumption, resource depletion and greenhouse gas (GHG) emissions. To understand the consumption of energy in a production environment it is important to relate the specific energy usage to the operating processes and production outputs. This allows the identification of auxiliary (non-value added) energy within production which is as the area with the greatest potential for savings through changes in operational behaviour. This paper outlines the monitoring at a factory and at machine level that can identify where and, more importantly, when waste energy occurs. The analysis of the cost of auxiliary energy is shown to be a motivational factor for company management to engage with energy efficiency measures and finally the paper discusses the eight dimensions necessary to engage employees and to drive cultural change in an organisation. The current state of practice in relation to energy in a case-study in the Precision Manufacturing Sector in Ireland was investigated and the proposed approach was applied and has been shown to successfully deliver verifiable savings with low implementation costs.

Introduction

ENERGY MANAGEMENT IN INDUSTRY

According to the World Energy Outlook Report (WEOR), [IEA, 2013], worldwide, industry consumes almost one-half of all commercial energy used and is responsible for roughly similar shares of greenhouse gases. In 2012, manufacturing accounted for 37 % of primary energy use worldwide and for 40 % of electricity consumption in Europe. According to the 2014 Energy Efficiency Market Report [IEA 2014] even with the energy efficiency initiatives that are underway it is estimated that energy consumption in industry will rise by another 20 % between 2012 and 2020.

In terms of Energy consumption in industry, the WEOR notes that the industry sector is very complex and a detailed understanding of the various processes or product types is necessary to monitor energy efficiency. The smart sustainable factory of the future is described [FoF, 2010] as one where there is full integration between the production activity and the associated energy used and where the operation of the factory can be optimised around its energy and ecological impact.

POTENTIAL FOR ENERGY EFFICIENCY IN INDUSTRY

Potential reductions in energy of 20 % [Costelloe, 2010] and in GHG emissions of 30 % [UKCT, 2014] have been identified on industrial sites where there is an in-depth understanding of energy flows in the manufacturing process and a clear analysis of energy usage. However, to achieve these potential reductions some changes in business practices are needed.

Despite the efforts made over the last 20 years, the research [Jollands et al, 2009], [Granade, 2009] suggests that there remains an important potential to reduce energy consumption in energy intensive industry by 15–25 %. The same research

indicates that energy management and behavioral changes can achieve up to half of this remaining energy efficiency potential. Several studies [Christoffersen et al, 2006], [Thollander & Ottosson, 2010] show that only a limited number of companies actually focus on managing energy and that cost-effective energy efficiency measures are not always implemented, explained by the existence of barriers [Thollander & Palm, 2012]. The main reasons given for not managing energy is lack of time, lack of resources, lack of knowledge and a primary focus on production.

Seow and Rahimifard (2011) provide a product perspective of energy monitoring and means of attributing the energy consumed by the product to both the process and the plant. The approach proposed the breakdown of energy consumption in manufacturing into Direct Energy (DE) and Indirect Energy (IE), which constitute the embodied energy of a product. DE is the energy required to manufacture a product in a specific process and can be subdivided further into theoretical energy (TE), the energy necessary for actual value creation and auxiliary energy (AE), the energy required by supporting activities for the individual machine/process. In an ideal factory all AE is potentially waste as it is not directly contributing to value creation.

In a mechanical engineering facility described as an efficient processing facility, 52 % of the energy consumed by the factory was identified as being used by services and systems not directly related to actual production [Rahimifard et al, 2010]. A detailed review [Harrington et al, 2014] of industrial facilities in Ireland showed that correctly attributing the direct and indirect energy consumption in a large high-volume manufacturing facility gave a split of 57 % direct (process) energy consumption and 43 % indirect (generic) energy consumption. In a similar study [Epstein, 2014] in the United States the analysis shows that the majority of energy at larger industrial sites is used by equipment that is associated with the manufacturing process.

SIGNIFICANT ENERGY USERS (SEUS) IN INDUSTRY

Many sustainable manufacturing projects have addressed the relevance of energy consumption used by ancillary services and systems. These initiatives highlight the critical energy consuming aspects of their industries or what are normally referred as Significant Energy Users (SEUs).

The Industrial Innovation for Energy Efficiency (I2E2) Centre [I2E2, 2013] focuses on energy efficiency improvements in factories, plant, equipment and buildings in Ireland. Based on feedback from over 30 large industrial sites their priority areas for action are compressed air systems, HVAC, heat recovery and production machines. The EU Project – “SurfEnergy: Path to Energy Efficiency” [SurfEnergy, 2014] is driven by the electronics assembly industry in Europe. Their targeted SEUs are Heating Systems (Boilers, CHP) and Production Machines. In India, Deshpande et al (2012), reported on the best practices in energy efficiency adopted by the Indian manufacturing sector. Their targeted SEUs were VSDs on motors, particularly in pumping, machines and conveyor applications. The University of Daytona Industrial Assessment Centre (UD-IAC) [UDIAC, 2013] helps small and medium-sized industries to reduce energy costs. Their targeted SEUs are Compressed Air Systems, Heating Systems and Production Equipment. In Canada, the state body – Natural Resources Canada – have produced an Energy Savings Toolbox [NRCAN, 2015] to guide industry

on energy efficiency. Their targeted SEUs are Compressed Air Systems, hot water/steam for production processes, production machines and building envelope measures.

These initiatives and others, across many sectors and different industry sizes, demonstrate the savings that can be achieved through the optimisation of the technical services in Industry (Air, Heat, Water) but they also highlight the significance of also addressing production equipment, machines and processes.

May et al, (2013) carried out a comprehensive review of industrial needs for energy efficient manufacturing. In their view, industry still lack approaches and tools to better understand their energy consumption behaviour and the inefficiencies of machine tools, particularly with a focus on synergies and trade-offs with other production management decisions (e.g. quality, maintenance, production planning, etc.). According to [Salonitis, 2015] and [Fysikopoulos et al, 2012] a common characteristic of almost all manufacturing processes is that even when the machine is idle, it is consuming more than 50 % of its maximum power. [Vikhorev et al, 2013] describe a study on an automotive manufacturing line which showed that one of the main energy losses in the factory relates to production machine idling. For the monitored machining line, idling accounted for 23 % of the lines annual energy consumption. The report states that the idling energy losses are usually caused by inefficient operation by line personal.

The primary motivation of a manufacturer is to keep their production operating [Sandberg & Söderström, 2003] because this generates their income and increases shareholders' value. Anything, including a seemingly simple energy efficiency measure that can be perceived as threatening this primary motivation needs to be carefully brought to the decision-maker. The energy efficiency projects most likely to be implemented [Martin et al, 2000] are characterized by lower initial costs. These initial costs (adaptation costs, engineering/contractor fees, equipment purchases) were identified to be particularly critical for SMEs.

BARRIERS TO ENERGY EFFICIENCY IN INDUSTRY

In Belgium, over 4,000 companies participated, between 2005 and 2014, in a voluntary Benchmarking and Auditing Covenant which is a state run programme on energy efficiency that targets medium sized enterprises. The analysis [Cornelis, 2014] of the results showed an 8–10 % improvement in energy efficiency over the period. Of note, 59 % of the energy saving measures stemmed from process-related activities. In Sweden, a study [Backlund et al, 2014] based on data from 58 industrial firms in the spring of 2012 returned an analysis that they had achieved an energy efficiency improvement of 12 % on average through both technology and energy management measures.

Despite the efforts made over the last 20 years, the research [Jollands et al, 2009], [Granade et al, 2009] suggests that there remains an important potential to reduce energy consumption in energy intensive industry by 15–25 %. The same research indicates that energy management and behavioural changes can achieve up to half of this remaining energy efficiency potential. Management in Industry are aware of the need for energy efficiency measures to minimise energy consumption, however, as reported by [Wijnants & Wellens, 2013], although the measures are known, they are not being implemented.

Fawkes et al, (2016) identified the key internal barriers within firms to energy efficiency measures as; lack of knowledge, lack of finance and the improved efficiency not being regarded as strategically important. Sorrell et al. (2004) developed a taxonomy to describe six different barriers to energy efficiency. These included; Risk, Imperfect Information, Hidden costs, Access to Capital, Split-incentives and Bounded Rationality. A key finding from this study was that multiple barriers to energy efficiency coexist and reinforce one another and that these barriers are interdependent. [Sorrell et al, 2011] reviewed 160 recent studies of energy efficiency drawn from both the academic and 'grey' literature. Their main findings are that 'Hidden costs' are real, significant and form the primary explanation for the 'efficiency gap'. In SMEs these hidden costs frequently outweigh the potential saving in energy costs. In addition they highlight [ibid] the cumulative effect of barriers and that senior management in industry is frequently unaware of the opportunities available.

The US Department of Energy (USDoE, 2015) report to congress on Barriers to Industrial Energy Efficiency highlights four main informational barriers to industrial end-use energy efficiency. These are; failure to capture the value of cost-effective energy savings, lack of knowledge of incentives and risks, lack of disaggregated energy consumption data, such as process unit and equipment-level energy consumption data, and lack of in-house technical expertise.

[Lunt et al, 2014], analysed a wide range of literature and projects related to barriers to energy efficiency in industry and developed a cognitive map of 20 barriers showing interlinked causality. This work identified three barriers as root causes to all other barriers. These were these were found to be a lack of accountability, no clear ownership and no sense of urgency. From a practice perspective, the contribution of this research has been to demonstrate how energy-efficiency projects can be hindered by organisational issues.

O'Malley et al, (2003) completed a study of seven multinational manufacturing companies in the Mechanical Engineering Sector in Ireland. The top barriers to the implementation of energy efficiency measures were analysed as; access to capital, hidden costs, imperfect information and values & organisational culture. The access to capital generally referred to tight payback rules on investments that restricted good energy efficiency measures. The hidden costs included the lack of time, the cost of identifying and assessing the investment, the cost of retraining staff to use new equipment, potential disruption and loss of product quality. Imperfect information referred to the lack of knowledge on how, where and when energy was used in the facility as well as little understanding of energy efficiency measures. Culture is driven from the top and energy efficiency performance was found to decline where top management was not concerned about energy and/or environmental matters.

To promote a culture of effective energy management in industry [Wising et al, 2014] proposed a novel approach that draws inspiration from both behavioural models and theory of change. The approach is based on eight different dimensions: Visibility, Accountability, Collaboration, Targeting, Commitment, Motivation, Learning and Progress. These dimensions highlight the Leadership, Communication and Engagement that is necessary in a company to overcome the barriers listed

above and each of them are addressed in the following case study.

The references to ownership and imperfect information as barriers suggests a view that managers may invest more in energy efficiency measures if they had better data and analysis on the opportunities and potential benefits. [Brundage et al, 2015] suggest that the current methods fail to provide the plant manager with accurate information to determine the least energy efficient machine. They set out an improved method to provide the floor manager with quantitative tools for decision making. [Vikhorev et al, 2013] also propose a decision support framework for the monitoring and management of energy consumption in a factory, focusing on the energy used by productive resources. [Trianni et al, 2013] describes how relevant attributes of Energy Efficiency Measures (EEMs) are not sufficiently transferred to industrial decision-makers. In particular, indications of the impact in production, issues related to the effective implementation, as well as its interactions (if any) with other parts of the production system are not generally considered.

RESEARCH METHODOLOGY

The key research question was whether the energy efficiency of a Manufacturing SME in the precision engineering sector in Ireland could be significantly improved through low-cost changes to operational and behaviour practice in their production operations. This question was broken down into three parts;

- a. Situated Context: What was the current state of practice, knowledge, competence and operations relating to energy use in the factory.
- b. Data Gathering: Where, when and how was energy consumed particularly in relation to SEUs in production operations.
- c. Engagement: Could a culture of energy conservation be embedded and sustained in the Company's production operations.

A three phase research plan was developed in conjunction with the company as shown in Table 1.

Energy Management in Practice

INDUSTRIAL CASE STUDY

The research was based in a contract Precision Engineering Company that employs approximately 50 highly skilled personnel. The Company operates over two shifts, days and evening, Monday to Friday and also has some limited production over the weekend. The facility covers an area of 2,050 m² and in 2015 consumed roughly 680,000 kWh of electrical energy with an annual electricity utility bill of €109,000.

The production operations of the factory consists of the following machinery; thirteen Computer Numerical Control (CNC) vertical machining centres (milling machines), nine CNC lathes of various configuration (turning centre, sliding head and twin spindle), four CNC Electrical Discharge Machining (EDM) machines, four coordinate measuring machines (CMM), and associated technical services equipment and office pcs.

Table 1. Research Plan.

Research Question	Research Method	Justification
Situated Context	Semi-structured Interviews	Semi-structured interviews were held with management and employees to establish current practice and to solicit tacit knowledge relating to operations.
Data Gathering	Case Study with graphical data analysis	Production operations were mapped to identify SEUs, a baseline (time-series) of relevant energy consumption was gathered using temporary energy loggers and changes in usage verified empirically.
Engagement	Action Research	Workshops were held with production associates and technical staff, energy displays were installed and a key performance indicator (KPI) established to communicate change in practice and ongoing progress.

The Company manufactures precision components in steel, aluminium and plastics to supply to Original Equipment Manufacturers (OEMs) in the medical devices, aerospace, automotive and pharmaceutical sectors.

CURRENT INDUSTRIAL PRACTICE

Semi-structure interviews were carried out in September 2015 with key personnel including the Managing Director (MD), the Facilities and Maintenance Manager and the Production Manager, who outlined current practice in the Company. The MD confirmed that in over 18 years in operation the Company had not undertaken any energy efficiency investigations or implemented any energy efficiency measures. The goal for the MD in facilitating the research was for the company to gain an in-depth knowledge of its electrical energy use and consequential costs, to develop strategies to reduce those costs and to implement methods to ensure that all initiatives introduced are maintained.

The Facilities Manager highlighted that the Company had been contracted to their current electricity supplier for a number of years, that the contracting of energy was a function of the accounts department and that the supplier had been originally chosen on the lowest price per unit of electricity. [Cosgrove et al, 2016] demonstrate from bill analysis that the unit price makes up less than 40 % of the total electricity bill).

The Production Manager highlighted that the Company is expanding more and more into the aircraft component industry and with this expansion production will continue to increase. The increased production is expected to increase energy consumption and therefore to drive up the overall costs to the business.

The Facilities Manager expressed the view that as the Company is a contract engineering company there is a very large variation, both in product volumes and product run times, and he would not expect energy use to closely track turnover. Some parts produced may have short cycle times but have high value due to the complexity involved in the materials and machining. Other parts may have long cycle times but have low value due to their overall simplicity. In his opinion, turnover would only be expected to track energy use if the company produced a set range of parts with only the quantities changing and if the energy used to make the parts was considerably greater than the idle non-production energy use.

Interviews with Machine Operators highlighted that they do not have the authority and or required knowledge to turn off idling machines. The main priority of the machine operators was to produce the target number of products for their shift and to maintain their machine in good order. The practice in the company was to load long-run jobs into the machine at the end of the shift and to leave the machines processing for a time after the operators were left. In addition, there was reluctance to shut the machines down due to perceptions of machine mis-alignments or increased set-up time necessary at the start of the next shift. In general the machine operators welcomed the research and were enthusiastic to save energy and to contribute to reducing unnecessary costs to the business.

Energy Monitoring

FACTORY LEVEL MONITORING

Temporary electricity consumption data was gathered using a range of data-loggers and electricity monitoring meters and systems to show the baseline auxiliary power consumption of the factory. Figure 1 shows the total electricity consumption for the factory from 1:00 am Thursday the 18th of September 2015 to 9:00 am on Saturday the 20th of September 2015. The auxiliary idle energy of the factory can be clearly seen after 17:00 on Friday the 19th after which there was no production or other activities running in the factory. This auxiliary energy was recorded at 60 kW per hour and stayed constant from Friday evening until Saturday morning, which is when the data collection for this graph was ended.

Further electricity logging was carried out in October 2015. In Figure 2 the measured kWh of total factory consumption of two days, 25th and 26th October 2015 are graphed. No production was carried out on Sunday and the level of consumption in kWh is steady all day. On Monday morning a small number of employees arrive around 05:30. They turn on the lights and begin operating some machines. All other day shift employees arrive at 08:00 and the factory goes into normal production. From this graph and calculated from the measured data, the average auxiliary energy use was 51.59 units per hour (51.59 kWh).

This was already an improvement from the previous month due to some leaks in the compressed air system having been ad-

dressed. In a normal week the total non-production hours can be calculated as 02:00 to 08:00 Monday to Thursday (4 × 6 hrs = 24 hrs), Friday 14:00 to 24:00 (10 hrs), Saturday and Sunday (48 hrs) which gives a total of 82 hours or 48.8 % of total available hours per week are non-production hours. From this the total non-production auxiliary energy for a week can be calculated.

$$82\text{Hrs} \times 51.59 \text{ kWh} \\ = 4,230 \text{ kWh Auxiliary Energy per week}$$

The average weekly energy consumption over the year (2015) was 14,252 kWh so the non-production energy use accounts for a minimum of 30 % of weekly electricity (KWh) consumption. The non-production hours are split into 41 hours at the electricity day-rate and 41 hours at the lower night-rate. The night-rate electricity tariff is charged from 11 pm to 8 am during winter time and from 12 am until 8 am during summer time. Summer and winter time is defined as when the clocks change in October and March. Therefore, from [Cosgrove et al, 2016] the cost of auxiliary energy during non-production hours is calculated as:

Electricity_AuxE_Factory

$$= \sum_{m=1}^{12} (\text{AuxE_DayUnits} \times \text{Day_UnitCost}) \\ + (\text{AuxE_NightUnits} \times \text{Night_UnitCost})$$

The total approximate cost for auxiliary energy is €30,512. This cost is approximate because each month the effective unit rate varies slightly due to the number of units used, which effects the calculation of the applicable unit rates. The cost of this auxiliary energy represents 28 % of the total annual electricity utility bill in euros.

MACHINE LEVEL MONITORING

With the appropriate electricity monitoring and data logging equipment [Doyle et al, 2015] the auxiliary energy was looked at on a range of individual machines. For example, the auxiliary idle energy of a Miyano Twin Spindle 3 turret CNC lathe is shown in Figure 3. This is referred to as the Machine Power Profile which will vary for each product type being manufactured. The auxiliary idle energy can be seen before and after a single part has been manufactured.

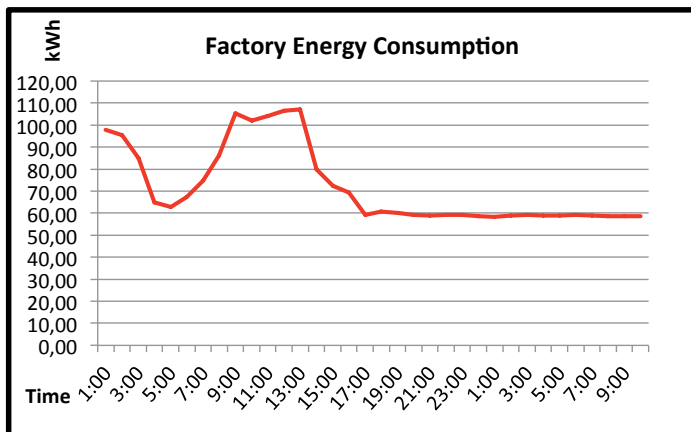


Figure 1. Factory auxiliary energy in kilowatt hours (kWh) on a Friday/Saturday.

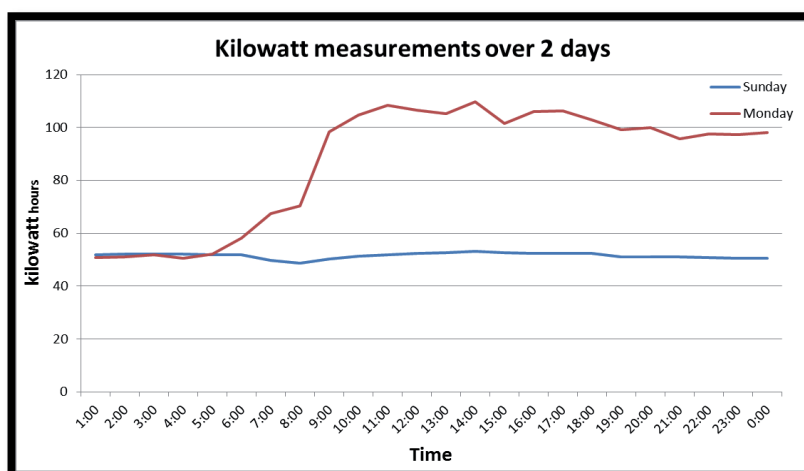


Figure 2. kWh measured for 2 days; Sunday and Monday.

From the graph it can be seen that the auxiliary idle energy of the Miyano lathe is 2,000 W. The potential for energy saving by simply powering off the machines when not in use can be clearly seen. Depending on the specific maintenance history, age and performance characteristics of the machine, simply powering off the machine when it is waiting for the next part may not be feasible. In some instances, shutdown and restart times can be very long due to the complexity of the machine, high precision tolerances can be lost due to temperature changes and high start-up energy consumption could negate any savings made. It was the view of the Facilities Manager that frequent switching on/off of some machines could lead to failures in the sensitive electronic equipment and that careful decision making would be required to decide which machine can be switched-off and when and how that may occur.

Following a review of the technical specifications and consultations with the machine manufacturers it was apparent that many of the concern raised about powering off the machines could be allayed by switching the machines into emergency stop (E-Stop) modes rather than powering-off or electrically isolating the machines. E-Stop mode is a normal operating

mode where the machines electronics and some critical circuits are kept powered and the machine can quickly be reset back to operating mode. The energy consumption of every CNC machine was measured in the both idle and emergency stop conditions and Table 2 shows the summary of these measurements.

From Table 2 it can be seen that almost 75 kW of power is consumed by these machines alone when they are in a non-productive idle state. But 60 % of this wasted energy or 42.7 kW can be saved by simply putting the machines into E-Stop mode. In addition, through a small modification to the electrical circuits of these machines, in order to disconnect the compressed air supply while in E-Stop mode, further energy can be saved by reducing the load on the air compressors. Assuming that the factory operates from 8 am to 2 am each day and closes on Friday at 2 pm then €574 can be saved each week by simply putting the above machines into E-Stop mode during non-production hours.

It is not immediately feasible to put every machine into E-Stop mode at the end of a shift. Existing procedures require the operator to load a final part into the machine before he or she leaves. If the part has a long running time (30 minutes or more) then

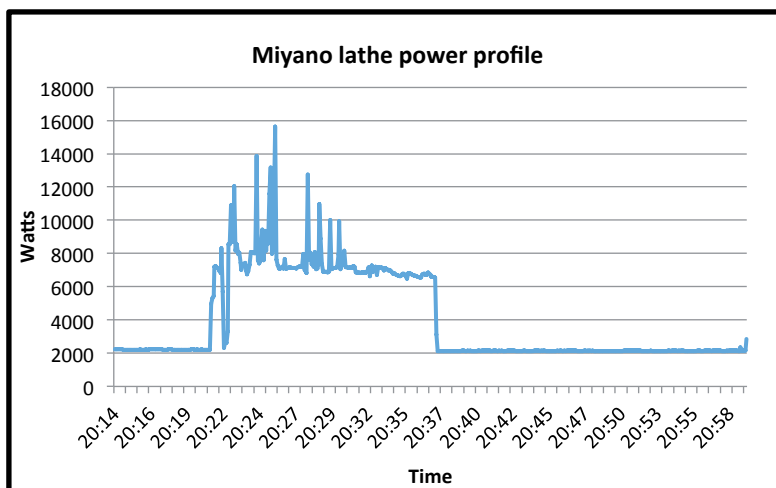


Figure 3. Miyano Lathe: Power Profile (Watts (W)) for one part.

Table 2. Measurements of CNC machine power consumption in Idle and E-Stop conditions.

Machine	Idle Power (W)	E stop Power(W)	Difference(W)	No. of machines	Total Difference(W)
Doosan CNC 5AX Mill	4954	759	4195	2	8390
Doosan CNC Lathe	4155	1985	2170	2	4340
Lamb CNC Mill	2186	310	1876	3	5628
Spinner CNC Mill	2043	830	1213	1	1213
Arrow 750 CNC Mill	2508	2475	33	3	99
Arrow 1250 CNC Mill	1442	631	811	1	811
Miyano CNC Lathe	978	488	490	1	490
Agie EDM	2347	768	1579	1	1579
Agie Spark EDM	1644	820	824	1	824
Sodick EDM	5565	1255	4310	1	4310
Mori Seiki CNC Mill	3457	2979	478	1	478
Deco CNC Lathe	3872	1694	2178	3	6534
Hawk CNC Lathe	2966	1010	1956	2	3912
Doosan CNC 5AX small	2519	790	1729	2	3458
Doosan CNC 3AX small	1865	1308	557	1	557
Doosan CNC 3AX	762	670	92	1	92
Totals (Watts)	74989	32274		26	42715

this is very effective from a production capacity point of view. However from the Facility Managers point-of-view leaving a machine running unattended also carry risks as tools can wear and break and significant damage can occur if this happens. Having reviewed the cost effectiveness and risks involved, the Company management revised the standard operating procedure to only leave the machine running unattended for parts with a cycle times of 20 minutes or less otherwise the operators are required to put the machine into E-Stop Mode at the end of the shift.

EMPLOYEE ENGAGEMENT

During the second last week of October 2015 all employees received informal training on energy awareness and simple energy reduction techniques. This involved short workshops with groups of Takumi production associates and engineering staff to discuss the aims of the research with 3 key goals:

- Reduce energy use and make the Company a more environmentally friendly company.
- Reduce energy costs, which makes the Company more economically viable.
- Prevent unnecessary waste, in-line with other Lean and 5S projects.

Once the energy initiative was discussed with all employees, signage was fixed to all room and building exit doors as a reminder. On the following Friday, 23rd October, before the shift ended for the bank holiday weekend a short review was held to remind the employees and re-enforce the project objectives. Once everybody had left the factory a walkthrough was carried out and in general all the discussed actions were carried out, however three machines had not been E-Stopped. Over the following weeks more short workshops were held with individuals and groups to help reinforce the idea of energy saving and it became obvious that an awareness was building up as individuals would ask if when it was “ok” to turn off or E-Stop particular machines and would also explain, without being asked, why certain equipment had been left on. Weekday and weekend walkthroughs were carried out and fewer unnecessary machines and equipment were left on or not E-Stopped. One specific CNC machine had problems with accuracy when it was reset after being E-Stopped. The machine works on medical implants at micron tolerances so it was decided to exempt it from the trials.

SPECIFIC ENERGY KPI

Difficulties were encountered in the development of an energy KPI. It has already been discussed that turnover does not track energy use due to the nature of the contract engineering business. The number of parts produced per day or week is also not applicable as some parts take minutes to produce and others take hours and the mix of which parts are produced each day depends on customer priorities. The volume of raw material received is also not applicable as material volume has no bearing on the energy required to manufacture the final part. Sometimes grams of raw material take several hours of machining to make the final part and at other times kilos of raw material are turned into a final part in minutes. The ideal indicator to rate energy consumption against would be machine production time i.e. the actual time the lathe is cutting a material. This would closely represent the theoretical (or value creating) ef-

forts expressed in production hours which could be compared to the total machine energy consumed in kWh per machine. As machining in production hours would increase so too would kWh and any variation from that linear relationship would represent auxiliary energy or waste. Unfortunately the company does not have the appropriate data at a machine level for this type of analysis although an Overall Equipment Effectiveness (OEE) system is now being considered which would provide that capability.

Results

The eight dimensions identified by [Wising et al, 2014] to promote energy reduction through management and behavioural change were adopted and applied in the Company as follows below.

BEHAVIOURAL CHANGE DIMENSIONS

Accountability

Due to the projects undertaken, and the alignment with his current role, responsibility for energy use, costs and monitoring was assigned to the Maintenance and Facilities Manager from October 2015 onward.

Commitment

The Directors and Managers of the Company hold a monthly management meeting where key aspects of the company are discussed and the Key Performance Indicators (KPIs) of each department are reviewed. It was agreed that energy costs and an appropriate energy reduction KPI would be presented at the monthly management meeting. A target of a 10 % reduction over the next quarter (Q4, 2105) in the 13 week average weekend energy use was specified.

Visibility

An energy awareness board was set-up in a prominent location where information on the Company's' energy use and energy costs as well as active and completed energy project will be displayed. The data chosen for display was;

- A chart of the previous 12 months of energy costs totals and breakdown (updated monthly).
- A graph of the previous 12 months of energy units consumed (updated monthly).
- A graph of the energy KPI (updated weekly).
- A list of on-going and completed energy projects.
- A list of recommended actions and energy saving ideas to be considered.

The energy awareness board was setup on the 29th of October 2015 and energy awareness signage was also posted on all room and building exits.

Collaboration

Short briefing sessions were held with all groups of employees on energy awareness. An energy awareness suggestion box was positioned with the energy awareness board so that ideas and suggestions can be sought, collected and acted upon.

Targeting

A specific KPI for energy consumption was developed and achievable targets set.

Motivation

An incentive scheme was considered for individual ideas or actions and for group activity outcomes but was put on hold until the energy KPI is established and until the energy efficiency measures show consistent financial return for the company.

Learning

The Company has committed to developing an awareness of energy use through group training and knowledge schemes. Initial micro-training on simple energy reduction techniques had been completed with production operators and production teams.

Progress

Any progress being made will be reported to management and on the energy awareness in order to highlight successes (or set-backs) to all.

The application of these eight principles will bring a focus and awareness of energy use to the company and make energy use reduction a group activity rather than an individual crusade. This should greatly improve the outcomes and ensure the on-going pursuit of energy use reduction and efficiency.

AUXILIARY ENERGY KPI

As the most significant energy waste by the Company was in unnecessary electricity consumption in non-productive Machines at the weekends and as the data to track the weekend electricity consumption was available from the utility supplier, the chosen indicator to track was a thirteen week average (simple moving average) of the total weekend energy units. The thirteen week average is commonly used in Takumi as an indicator of Tooling costs, material spend, weekly turnover, etc. so it is familiar to both the management team and production staff. The total Saturday and Sunday energy units were averaged over a rolling thirteen weeks and graphed to show a trend. This KPI will show any movements in the non-production energy

consumption of Takumi precision and highlight any emerging trends and quantify any savings achieved.

$$KPI_{Weekend\ Energy}$$

$$= \frac{\sum_{0}^{13} WeekendEnergyUnits\ (KWh)}{13}$$

The results for the weekend energy usage for the Company's total energy consumption are shown in Figure 4. The target of 10 % savings was quickly exceeded and the reduction achieved by the end of November 2015 (Week 48) was closer to a 50 % reduction in week-end energy consumption.

DISCUSSION OF RESULTS

The current state of practice in the Company was established and communicated to the management. The initial estimates for energy wasted through idle running of machines at weekends drew the attention of senior management and provided impetus for further investigation, energy monitoring and logging. A detailed analysis of the SEUs in production was undertaken and a case study establishing their baseline energy consumption (time-series) and potential energy set-back through the use of the E-Stop functionality was completed and presented to management and staff. A series of actions were approved by the company including an energy board, employee workshops and changes to operating procedures which resulted in targeted reductions in energy waste and have contributed to an improving culture of energy conservation in the Company's production operations.

Greening et al, (2000) described the 'rebound effect' for energy consumption manufacturing operations as the approximately equal to the product of the increase in output and the cost share of energy as a percentage total production costs. They estimated that savings of 10 % in energy consumption could drive increased production and consequent annual increases in energy of 2.5 % thus wiping out the gains in 4 years. This research highlights the need for continuous monitoring and tracking of energy so that longer-run trends can be identified and necessary actions taken and the need for specific KPIs that closely link energy consumption with production activity so

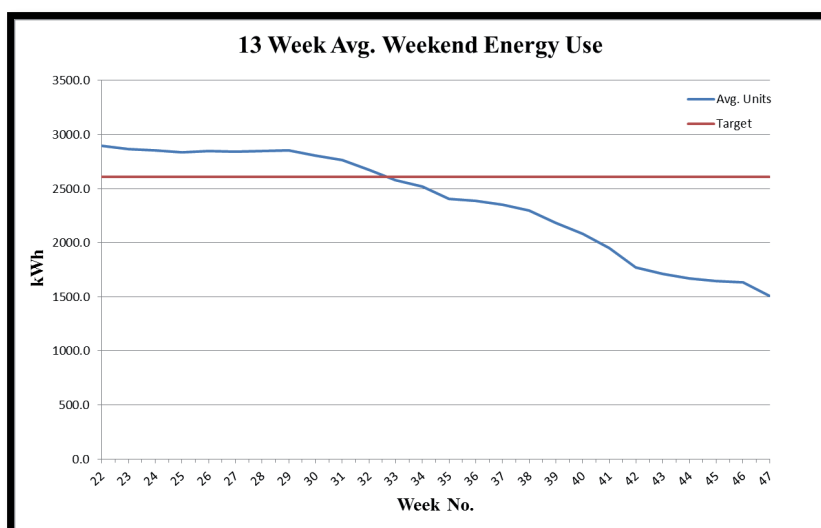


Figure 4. The 13 week moving average weekend energy use graph.

more meaningful comparisons can be made. This study piloted a KPI of energy waste which can be continuously tracked however the capability to link that KPI through direct correlation with production activity was not possible as the appropriate machine level sensors are not available.

The study demonstrated a reduction in annual energy consumption of 12 % in a Manufacturing SME in the precision engineering sector in Ireland through low-cost changes to operational and behaviour practice in their production operations. The company have acknowledged that the approach proposed by [Wising et al, 2014] provided a framework for the company to drive change in its practice and to manage its energy policy into the future. The Company propose to continue the energy management and to further investigate the development of a suitable energy KPI which will track energy consumption in conjunction with some specific weekly production/product parameters.

Conclusions

Potential reductions in energy consumption of 20 % [Costelloe, 2010] and in GHG emissions of 30 % [UKCT, 2014] have been identified on industrial sites where there is an in-depth understanding of energy flows in the manufacturing process and a clear analysis of energy usage. However multiple studies [Thollander & Ottosson, 2010], [Backlund et al, 2014], have found that actual savings of 10–12 % are more likely due to identified barriers [Fawkes et al, 2016] such as; lack of time, lack of resources, lack of knowledge and a primary focus on production. Some changes in industrial practice is required to achieve the full potential savings that are available, such as the eight dimensions identified [Wising et al, 2014] to influence behavioural change and improve the energy culture in a company.

Detailed investigations and semi-structured interviews in a Manufacturing SME in the contract precision engineering sector identified the opportunity to reduce electricity by 30 % through reductions in the consumption of electricity by idle machines running through the weekends. The set-back of energy use in the machines through the activation of the E-Stop modes was investigated and found suitable to be applied to most of the machines in the Company. This effectively reduced the idle energy consumption of 25 machines by 60 %. Through a process of employee engagement, training and changes to operating procedures a 50 % reduction in weekend energy consumption was achieved without any significant cost of investment thus highlighting that the elimination of auxiliary energy represents the best opportunity to gain energy savings through operational and behavioural changes at the lowest possible cost. The study demonstrated a reduction in annual energy consumption of 12 % in a Manufacturing SME in the precision engineering sector in Ireland and established an energy KPI to provide continuous monitoring of progress.

The study was limited by the lack of dis-aggregated data at a machine level for both energy and production information. The findings are applicable to discrete manufacturing and batch-type operations where production is primarily through 5-day shifts leading to significant non-production time in any given week.

The company under study is representative of approximately 40 precision engineering Manufacturing SMEs who are members of the Irish Turned Parts Manufacturing Association

(www.ptma.ie). Replication of this work within these 40 factories could lead to savings of €2.5 m in energy consumption with significant carbon emission reductions. Supports should be developed to encourage such SMEs to access independent energy efficiency expertise, monitoring tools and operator training through grant aid, tax credits and/or low-cost finance.

The Company have recognised the benefits from the research study in relation to identifying non-energy benefits such as better productivity and improved production information. Further work will investigate the deployment of a wireless sensor network on all production machines which will enable regression analysis on energy data, better KPIs linking energy to production activity and beneficial information on machine throughput.

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Acknowledgements

The research work was supported by Enterprise Ireland (EI), the Sustainable Energy Authority of Ireland (SEAI), Science Foundation Ireland (SFI), and the Industrial Development Agency (IDA Ireland) and has been carried out in collaboration with the Limerick Institute of Technology.