An Information System to Promote Energy Awareness in the Factory

R.M. Greenough[1], K. Vikhorev[1], G. Stuart[1], M. Whiteley[2]

[1] Institute of Energy and Sustainable Development, De Montfort University, Leicester, UK

[2] Department of Aeronautical and Automotive Engineering, Loughborough University, UK

Abstract

Many factories use visual communication to increase awareness of issues such as quality, safety, cost and schedule adherence. This is particularly common in lean manufacturing where it contributes to the creation of a ‘visual factory’. Industrial energy efficiency is increasingly important to manufacturing managers, yet it is relatively unusual to see energy data presented at the factory floor. This may be because the cost of energy remains relatively low compared to materials and labour in most industry sectors, or it may be because the scope for energy saving at the shop floor is limited, or perhaps because it is technically challenging to provide detailed energy data in a timely fashion that would facilitate a suitable response. This paper describes a method of collecting and presenting energy data to increase operator awareness at the shop floor and suggests how this might influence behaviour towards a more sustainable factory.

Keywords:

Energy awareness; Information system; Sustainable manufacturing; Energy management

1 INTRODUCTION

Between 1990 and 2005, CO_2 emissions from global energy use increased to 21.2 Gt, of which manufacturing industry was responsible for the biggest share, at 38% [1]. Both the direct combustion of fossil fuel and the use of electrical energy by industry cause global environmental impacts, which are reflected in the increasing cost to manufacturers of compliance with environmental legislation. Improvements in industrial energy efficiency are essential to the development of sustainable industrial systems.

Energy can no longer be treated as a fixed operational expense; instead it must be treated as a manufacturing resource to be managed alongside materials, capital and labour. However unlike material resources which can be seen and touched, energy is an abstract concept. It cannot be measured or purchased directly, instead we measure the effects of energy flow (such as force and temperature) and we purchase energy carriers (such as oil or electrical power). Despite the similarity between international standards for quality management and energy management [4], factory personnel tend to have a much greater awareness of the importance of quality compared to their ‘energy awareness’. For the purposes of this paper, energy awareness is defined as *an insight into the performance of energy using devices and systems and the factors that influence patterns of energy use over different timescales*.

Within a typical factory quality management is supported by the calculation of performance against widely accepted metrics such as ‘defects per million opportunities’ and ‘overall equipment effectiveness’ which are then displayed visually in the workplace [5]. To date, there has been no equivalent approach for energy, despite energy management being a familiar concept in some industry sectors.

2 ENERGY MANAGEMENT

2.1 Primary manufacturing industry

Primary manufacturing industries such as those in the iron and steel, chemicals and cement sectors have traditionally placed greater emphasis on energy management than secondary industries; and usually have a clear understanding of the importance of energy prices in their cost structure. For this reason, such industries monitor their process energy use and associated emissions closely, using sub-metering and associated data analysis [3]. Sub-metering refers to metering of energy at a level below the utility company’s fiscal meter, for the purpose of optimising energy use. Other industries outside the manufacturing sector such as retail and financial services tend to monitor and control the energy associated with their use of buildings, since this represents a significant proportion of their costs. They also use sub-meters which are increasingly being combined with information systems known as building energy management systems.

2.2 Building energy management systems (BEMS)

The purpose of BEMS is to maintain a comfortable working environment within a building despite fluctuations in outside temperature, humidity, solar gain and changes in occupancy [4]. BEMS are designed to optimise the use of energy by space heating and hot water systems as well as building services such as air conditioning, ventilation and specialised energy using spaces such as the server room, clean room or X-ray facility. BEMS display energy information to assist facilities managers who are responsible for building energy use and inform building users whose energy using behaviour can significantly affect the building performance. The display of energy information to building managers and users is intended to develop energy awareness which is necessary, but not sufficient, for energy efficiency.

2.3 Domestic energy management

Most domestic users understand their energy use through quarterly or monthly utility bills. In northern Europe, domestic energy use tends to be dominated by space heating. Utility bills aggregate consumption both by household and temporally, making it impossible to identify the impact of behaviour changes with respect to individual energy using devices. This is problematic since studies have shown that use patterns vary widely by household and by device type [5].

The use of home energy monitors and the rollout of 'smart meters' has increased awareness of energy use through the use of in home energy displays and web tools. Users of such monitors are now more aware of their energy use (especially electrical energy) even if their options to reduce it may be limited by individual circumstances. A more complete picture would be provided by real-time display of both gas and electrical energy used by each domestic device as well as any local micro-generation. This is the goal of research such as the BeAware project which aims to increase the energy awareness of homeowners through presentation of energy data using mobile devices [6].

3 ENERGY MANAGEMENT IN THE FACTORY

Within the factory, the responsibility for energy management often lies with the maintenance manager who is responsible for process energy use, or the facilities manager who is responsible for building energy use. Responsibility may overlap in factories where process energy is supplied from the same source as building energy, for example where process steam is raised in the same boiler that is used to heat the premises or where energy and heat are both generated onsite using combined heat and power (CHP) plant. In factories that follow lean manufacturing principles, energy may be saved indirectly, for example by tackling the more familiar lean wastes or through total productive maintenance, since energy may be wasted by excessive idling or compressed air leakage, etc. This means that energy saving may be tackled without intentionally developing energy awareness or specific collection of energy data. However a more rigorous approach to targeting energy waste is described by ISO50001, which specifies requirements for energy measurement, documentation and reporting that are similar to those for quality management.

3.1 Automated monitoring and targeting (AMT) systems

As with domestic energy management, energy awareness in the factory can be supported by information technology. ISO 50001 requires a programme of energy data collection such as the installation of automatic monitoring and targeting (AMT) equipment, and this can be used to increase energy awareness at different levels of a manufacturing organisation. AMT systems collect energy data using one or more sub-meters and they can be used to identify opportunities for daily energy savings as well as more strategically, for example when deciding how to prioritise capital expenditure on improvements to the factory buildings or the processes within. They can be used with a range of sensor technologies to monitor energy carried by electricity and gas as well as other energy carriers. They can analyse these data to separate energy use resulting from production schedules from that which is driven by the weather. They can be used to target process, plant or site efficiency improvements and to display information at a range of levels from shop floor to board level.

Commercially available AMT systems have been shown to reduce energy use by 5% [7]; but researchers have proposed energy information systems that go much further, allowing the optimization of manufacturing processes locally and globally by integrating energy management with manufacturing execution systems [8], [9]; using energy signals to indicate process health [10] and scheduling manufacturing to optimise energy use [11].

3.2 Energy awareness and behaviour change

Energy awareness is only valuable in so far as it enables actions to increase energy efficiency. Studies of building information systems and domestic energy monitors have shown how feedback of energy use can stimulate reductions in organisational or household energy use [12]. Such studies examine the motivations of individuals to reduce energy use based on their improved energy awareness, and clearly indicate the different incentives of a householder, who pays for energy, and the occupant of a commercial building who does not.

Factory workers might be expected to share similar motivations to occupants of commercial buildings when presented with information describing their energy use, although their scope for action based on such information is likely to be different. Expected actions will depend on an individual's place in the organisation, the energy use characteristics of the processes being considered and the level of control that the individual is expected to exercise over the process. A cell leader might be able to influence the weekly energy use of the processes within the cell by adjusting the cell schedule to optimise energy use; however the energy manager is likely to have more influence over process design and investments in plant to improve energy efficiency.

3.3 Tactics for reducing resource waste

The range of actions that might be driven by energy awareness can be seen as examples of sustainable manufacturing tactics. Despeisse et al. [13] have produced a library of such tactics that are derived from academic research and industrial practice. Energy awareness can support the deployment of some of these tactics as follows:

- *Prevention* tactics avoid unnecessary resource use, for example by stopping machinery instead of allowing excessive idling
- *Reduction* tactics reduce waste through improved maintenance, for example by sensing machinery health based on energy use. Another type of reduction tactic reduces waste by optimising the manufacturing schedule. Optimisation may be used to reduce energy use, but if it causes excessive resource use elsewhere in a manufacturing system, the schedule cannot be considered optimal. Here energy awareness is therefore necessary but not sufficient to ensure optimality.
- *Reuse* tactics consider outputs from one process to be resource inputs for another, for example energy cascading. The monitoring of patterns of energy flow within a system over time may reveal opportunities for reuse of waste heat and allow calculation of cost benefits of the energy plant required.
- *Substitution* tactics aim to improve the performance of a system by changing processes, for example exchanging an old boiler for a more energy efficient type.

4 ENERGY AWARENESS CASE STUDIES

The case studies below were carried out by the authors and are used here to illustrate the benefits of improved energy awareness in different industrial contexts. They suggest how much scope exists in some industries for improved sustainability based on energy awareness.

4.1 The biscuit manufacturer

Company A is a large biscuit manufacturer which operates all year round and occasionally through the night. The company operates five ovens at the site of the study, where it produces a wide variety of types of biscuits that are sold under both their own brand and the brands of large retailers. A detailed analysis of energy data collected in the factory during the study allowed energy saving opportunities to be identified.

Overall energy use

In 2010 the company used 6,200 MWh of electricity and 12,200 MWh of gas. These data were collected from the company's electricity and gas providers in a half-hourly format. The company spent €545K on electricity and €234K on gas during 2010. The company did not employ sub-metering and since it was quite clear following a brief tour of the facility where savings were likely to be found, energy data collection focused on the air compressors and the ovens.

Compressed air

According to the Food and Drink Federation, compressed air represents about 2% of the food and drink industry's overall CO_2 emissions yet the poor overall efficiency of such systems (typically 10%) means that small reductions in air leakage can lead to large energy savings [14]. Leaks can mean that merely maintaining system pressure when no air is needed can cause a compressor to draw between 20% and 70% of its full load power [15].

A portable data logger was used to record the electrical power used by Company A's compressed air system. Data were logged at half-hourly intervals over a period of 24 days to examine the pattern of energy use. These data are shown in Figure 1, which shows that electrical energy used by the compressed air system during production periods and at weekends (when the system was pressurised for occasional use by the maintenance department, but when no production took place). Energy used during idling was shown to be approximately 74% of peak use, representing energy that is wasted due to leaks.

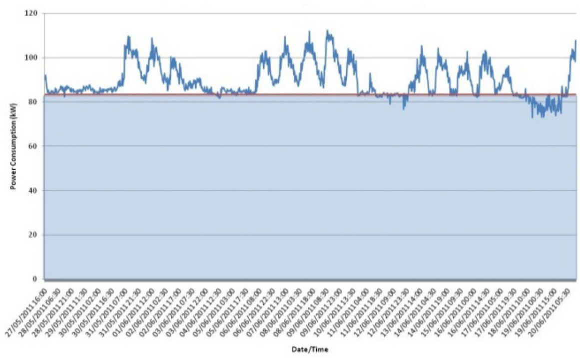

Figure 1: Half-hourly profile of Company A's compressor

Based on these data, it was shown that if the compressed air system was switched off during non-production periods (a prevention tactic), over 18,000 kWh could have been saved during the period recorded. This could be extrapolated to give a potential annual saving of 148 MWh, which would save the company €13K per year. In fact savings would likely be higher since this calculation only considers switching off the compressors for full days, whereas the periods from 18:00 onwards on Friday and from 0:00 to 06:00 on Monday are outside shift hours. When discussing these figures in the factory, it emerged that Company A had actually invested in time switches for the compressors to eliminate out-of-hours energy use, but these were not in use at the time of the study.

Another energy saving tactic would be to fix the leaks in the system (reduction). Reducing the leak rate from 74% to the Carbon Trust minimum figure of 20% would save Company A €61K per year. This would be relatively inexpensive to achieve through a combination of regular visual inspection and use of ultrasonic leak detectors to compensate for the noisy factory environment. When discussing this in the factory it emerged that the company had purchased leak detectors that were not in use.

Gas ovens

Company A uses five gas ovens and these were monitored over a three month period to plot energy used against production weight. Regression analysis allowed a comparison between the ovens, highlighting occasions when excessive gas was being used during non-production periods (idling). As expected, the analysis showed significant scatter due to the wide range of recipes used in the factory and variations in the weather during the period of the study. Nevertheless, it was possible to identify a significant difference between the energy efficiency of oven 1 and the other four ovens. This was confirmed by a thermal scan which suggested that the insulation of oven 1 was relatively ineffective (Figure 2).

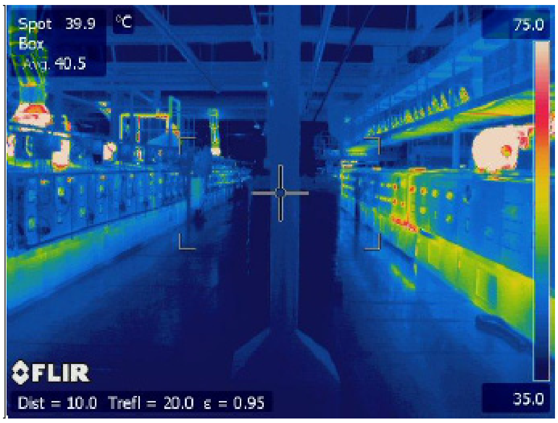

Figure 2: Thermal image of oven 1 (right) and oven 2 (left)

4.2 The foundry

Company B is a medium sized iron foundry casting products such as turbochargers and gearbox casings from selected scrap metal, using induction furnaces and heat treatment. During 2011, the company used almost 10GWh of electricity at a cost of €1,150K. In such an energy intensive industry, large reductions in emissions may result from small percentage savings in energy, which might be identified through careful analysis of energy data. Since energy represents such a large part of the cost structure of the foundry industry, such companies typically use an AMT system, although the half-hourly electrical energy sub-metering system installed at Company B is obsolete and was not working at the start of the project. Once the system had been reinstated, it was used to record electricity logged by three phase pulse meters attached to the 23 most significant electrical circuits used in production.

Data analysis

Analysis of historical data showed that the total energy logged by the AMT system between 0:00 on 15th December 2011 and 23:30 on 23rd January 2012 was 838,526 kWh, whereas the utility company's fiscal meter measured 872,184 kWh. The difference in power drawn over the period analysed averages at 36 kW, which is probably due to small un-metered single phase loads such as office lighting and electrical sockets.

Analysis of the sub-metered data shows that the induction furnaces represent 59% of the total electrical load when in melt mode and 7% of total load when in hold mode. These data are typical for the industry [16] and since upgrading the furnaces was not an option, the melt data were eliminated from the analysis in order to focus on the other electrical loads. The two compressors represented the next highest energy use category with 20% of the non-melt energy use, followed by the heat treatment process with 14% and an electrical circuit called *Input 22* whose purpose could not be identified during the study. This last circuit used 10% of non-melt energy. The furnace 'hold' processes and other electrical loads such as shot blasting, extraction and the mould handling system made up the remainder of the sub-metered loads. The energy data associated with both the air compressors and the heat treatment process were felt to be excessive, so these were investigated further.

Compressor energy

Analysis of compressor energy use between 9th and 24th of January, 2012 showed a high idling load when the compressors were not delivering valuable energy yet were typically consuming 65% of peak power, which is evidence of significant leakage. Unlike Company A however, the compressors were usually (though not always) switched off during non-production periods. Further analysis shows that switching off during all non-productive periods during the period of monitoring would have saved €884. More significantly, if energy losses due to leakage were reduced to the Carbon Trust minimum of 20%, this could yield annual savings of €55K if the production period analysed is typical.

Heat treatment

The heat treatment process was analysed with a thermal imaging camera, which showed localised temperature readings of 284°C around the door and several hot spots on the external walls of the oven. This confirmed what the area manager had suspected, that both the door seal and the insulation in some areas were inadequate.

4.3 The research centre

Company C is a research centre for a large pharmaceuticals manufacturer. Their laboratory building is designed to be thermally efficient and the company estimates that only 10% of the 167MWh used per week by the building is lost through the building fabric. However up to 85% of the energy used by the laboratory building is for heating and cooling, the majority of this being lost through ventilation. The company keeps animals for use in the laboratories and EU regulations stipulate a relatively high number of air changes per hour. The company had considered heat recovery to minimise the energy loss associated with ventilation, but rejected this due to the fear of contamination of heat exchangers by the chemicals used in the laboratories. Since the energy used is dominated by space heating and cooling loads, the company keeps accurate records of energy use and monitors performance by correlating energy use with local weather data.

Energy awareness

Company C logs the half-hourly meter readings from the utility companies supplying electricity, gas and water and uses these data to monitor energy performance using a commercial energy management system. The energy manager uses this information system to monitor the performance of the facilities management contractor used by the company and those departments who have been given specific targets for energy reduction. Energy performance against targets is displayed to the entire workforce on a screen located in the canteen.

4.4 The engine machining line

Company D manufactures diesel engines for commercial vehicles. The company has carried out a survey of its machining operations that has suggested that 20% of the energy used in machining is wasted in the form of idling losses. If this energy can be saved by switching the machines into a standby mode then the potential savings across the site could be as high as €600K per annum. This has prompted the company to investigate the nature of idling losses on its machining lines in more detail. The company has a policy of giving machine operators the authority to decide when to switch machines into standby and to create machining schedules that minimise energy use without impacting line productivity. This requires much greater energy awareness than they currently have, so the company has identified a requirement for an information system to display an energy dashboard at each machine that can distinguished in near real time between:

1. Value adding energy use,
2. Necessary but non-value adding energy use, and
3. Non-value adding energy use

The latter will represent an opportunity for energy saving and it is hoped that by increasing energy awareness, operators will learn how best to optimise energy use in machining.

Research project

The creation of an information system for energy aware machining is being carried out as part of an EU research project in which Company D's machining line is one of the use cases. The aim of this use case is to provide both a visual representation of the energy performance of each machine tool as well and a decision support tool to the machine operators. This will be achieved by sensing energy use in real time at each machine, analysing these datastreams to identify the energetic state of each machine and flagging any abnormal process conditions based on a comparison between the energy signal and a known 'good signal' for the components concerned. Energy datastreams will then be further processed using complex event processing (CEP) to derive decision support information and to visualise process performance according to agreed key performance indicators [9]. As well as providing actionable information to operators, the proposed system will feed energy performance information into an optimiser that will inform the company's manufacturing execution system and allow the derivation of more energy efficient schedules. The proposed energy awareness framework is shown in Figure 3.

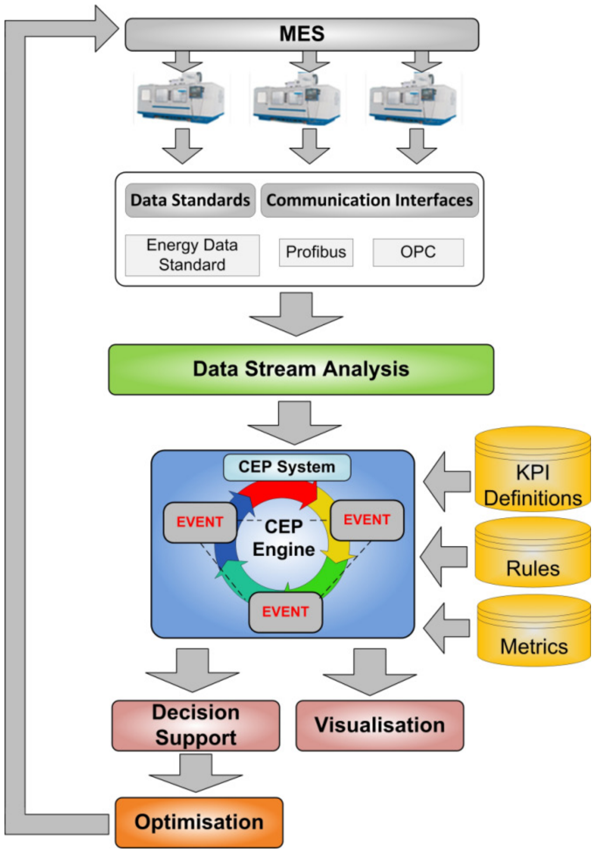

Figure 3: Proposed framework for energy awareness

Project status

At the time of writing, the prototype information system was able to analyse energy data that had been collected from Company B's machine tools using a portable data logger and separate the energy signal into the three energetic states shown above, according to a pattern matching algorithm based on the SPRING algorithm [17]. It presents these data in the form of a moving histogram, dynamic pie charts and simple performance measures including peak power, average power and specific energy use. A screenshot of the prototype energy awareness graphical user interface is shown in Figure 4 and this version will be developed further according to feedback from the eventual users of the system. The ability to recognise and record the exact energy signature of each part on each process will allow the company to create an energy history for its products. This can be used to derive a much more detailed understanding of the environmental impact of the manufacturing phase of the life cycles of its products.

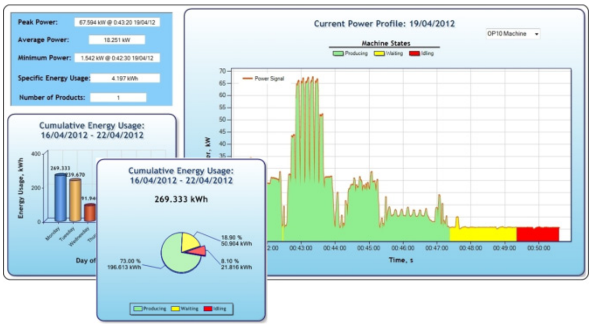

Figure 4: Visual display of information system at Company C

Future development work at Company D

In future, the company will replicate the prototype system across all machines in a new machining line as well as the technical building services that support them (such as compressed air, coolant filtration, etc.). The company will use the system to develop energy awareness in machining line operators via a web based tool and optimisation routines that are being developed by the project partners.

5 DISCUSSION

The case studies illustrate four different approaches to industrial energy awareness. Company A has identified an energy champion who is a member of the maintenance department. Although he has a good knowledge of the energy used by the range of processes and supporting equipment for which he is responsible, he does not use all the energy reduction techniques available to him, nor does the company display any energy information to the workforce. As an organisation, Company A seems to have a low level of energy awareness.

Operations at Company B are highly energy intensive and the company uses an automatic monitoring and targeting system to manage its electricity use. However, this system is obsolete, poorly supported and was not working at the start of the case study. As with Company A, energy management is a part-time role as it is one of the responsibilities of the safety, health and environmental (SHE) manager. In the visitor area, there is a display of electricity use and power factor variation over the previous year. The AMT system had given key managers at Company B a high degree of energy awareness, but there was no evidence of energy information in the factory itself.

Despite having the lowest proportion of energy use from its operations (the majority of the energy used being related to its building services) Company C employed a dedicated energy manager and used an advanced commercial energy management system to inform both the managers and the workforce. This company represented the current state of the art in energy awareness.

Company D also has a dedicated energy manager and has a research organisation that is participating in a project to develop advanced techniques for industrial energy awareness that it believes will allow it to make significant financial savings and emissions reductions from reducing energy use in machining operations alone. Elsewhere in the organisation, there is evidence of a high degree of energy awareness and commitment to reducing waste. For example, waste heat from the foundry is used both to heat the factory buildings and to feed the district heating system.

6 CONCLUSION

This paper has described some of the principles of industrial energy awareness and used four case studies to show that greater energy awareness can lead to significant savings for relatively little financial outlay. In Company A, monitoring of the compressors merely showed what the company knew already, that they should be shut down during non-production hours and that existing maintenance procedures should be used to identify and fix air leaks. A relatively cheap thermal imaging survey showed what could be felt during a visit to the factory, that the ovens were poorly insulated. In Company B, a combination of a broken AMT system and leaks in the compressed air system were the main problems. Although managers seemed aware of the causes of wasted energy, reducing these wastes did not seem to be prioritised as it could have been. Company C was well aware of its energy use and how much it was wasting through its approach to building ventilation. It seems prepared to accept this situation for the time being and to look for energy savings elsewhere. Energy reduction progress is displayed to all in the organisation through the use of an advanced energy management system. This company demonstrates what can be expected from an information system based on half-hourly data. Research in the domestic environment, has shown the energy awareness benefits of real-time display of energy use at the device level and this is one of the goals of the project in which Company D is participating. It is only by displaying the consequences of energy saving actions in near-real time that individuals develop a true sense of energy awareness. Furthermore, this information must be presented to each individual at a level of granularity that matches that individual's responsibility for energy saving. An organisation's energy manager needs a different level of energy awareness from that which is appropriate for a machine operator. Company D will expect machine operators to be able to manage their local schedule to minimise idling losses based on energy awareness derived from advanced processing of energy signals in an information system. The results of the research to develop this system will be described in much more detail in future papers from the project partners.

7 ACKNOWLEDGMENTS

This paper includes work that is funded by the European Union FP7 'Factories of the Future' research project called 'KAP: Knowledge Awareness and Prediction'. We acknowledge the support and contributions of KAP's industrial and academic partners in the development of the work.

8 REFERENCES

[1] IEA, 2008, Worldwide Trends in Energy Use and Efficiency: Key Insights from IEA Indicator Analysis, OECD/IEA, Paris.

[2] ISO, 2011. ISO 50001:2011 Energy management systems: Requirements with guidance for use, International Organization for Standardization, Geneva.

[3] Thollander, P. and Ottosson, M., 2010, Energy management practices in Swedish energy-intensive industries, Journal of Cleaner Production, 18:1125-1133.

[4] Djurica, N. and Novakovicb, V., 2012, Identifying important variables of energy use in low energy office building by using multivariate analysis, Energy and Buildings, 45:91-98.

[5] Richardson, I., Thomson, M., Infield, D. and Clifford, C., 2010, Domestic electricity use: A high-resolution energy demand model, Energy and Buildings, 42/10:1878-1887.

[6] Jacucci G., Spagnolli A., Gamberini L., Chalambalakis A., Björksog C., Bertoncini M., Torstensson C., Monti P., 2009, Designing Effective Feedback of Electricity Consumption for Mobile User Interfaces, PsychNology Journal, 7/3:265-289.

[7] Carbon Trust, 2008, Automatic monitoring and targeting equipment: A guide to equipment eligible for Enhanced Capital Allowances, report number ECA756, available from www.carbontrust.co.uk, accessed 4th July 2012.

[8] Karnouskos, S., Colombo, A.W., Martinez Lastra, J.L, and Popescu, C., 2009, Towards the energy efficient future factory, in: Proceedings of the 7th IEEE International Conference on Industrial Informatics (INDIN 2009), 367–371.

[9] Vijayaraghavan, A. and Dornfeld, D., 2010, Automated energy monitoring of machine tools, CIRP Annals-Manufacturing Technology, 59:21–24.

[10] Chiotellis, S. and Grismajer, M., 2012, Analysis of electrical power data streams in manufacturing, in: Proceedings of the 19th CIRP International Conference on Life Cycle Engineering, Berkeley, 533-538.

[11] Chiotellis, S., Seliger, G., Weinert, N., 2009, Energy-aware Production Planning and Control, in: Proceedings of the 16th CIRP International Conference on Life Cycle Engineering, 310-315.

[12] Darby, S., 2006, The Effectiveness of Feedback on Energy Consumption, Environmental Change Institute, University of Oxford.

[13] Despeisse, M., Ball, P.D., Evans, S., 2011, Modelling and Tactics for Sustainable Manufacturing: an Improvement Methodology, in: Proceedings of the 9th CIRP Global Conference on Sustainable Manufacturing, 20-25.

[14] Saidur, R. Rahim, N.A. and Hasanuzzaman, M., 2010, A review on compressed-air energy use and energy savings, Renewable and Sustainable Energy Reviews, 14/4:1135-1153.

[15] Carbon Trust, 2006, High temperature industry: Introducing energy saving opportunities for business, publication number CTV011, available from www.carbontrust.com, accessed 10th November 2011.

[16] Department of Energy, 2005, Metal Casting Industry of the Future, Fiscal year 2004 annual report for the Industrial Technologies Program, available from www.eere.gov, accessed 4th July 2012.

[17] Sakurai, Y., Faloutsos, C. and Yamamuro, M., 2007, Stream monitoring under the time warping distance, in: Proceedings of 23rd IEEE International Conference on Data Engineering (ICDE 2007), 1046 –1055.