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An advanced energy management framework to promote energy awareness

Konstantin Vikhorev*, Richard Greenough, Neil Brown

Institute of Energy and Sustainable Development, Queens Building, De Montfort University, The Gateway, Leicester LE1 9BH, United Kingdom

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ABSTRACT

Increasing energy costs, new environmental legislation, and concerns over energy security are driving efforts to increase industrial energy efficiency across the European Union and the world. Manufacturers are keen to identify the most cost-effective techniques to increase energy efficiency in their factories. To achieve the desired efficiency improvements, energy use should be measured in more detail and in real-time, to derive an awareness of the energy use patterns of every part of the manufacturing system. In this paper, we propose a framework for energy monitoring and management in the factory. This will allow decision support systems and enterprise services to take into consideration the energy used by each individual productive asset and related energy using processes, to facilitate both global and local energy optimization. The proposed framework incorporates standards for energy data exchange, on-line energy data analysis, performance measurement and display of energy usage.

1. Introduction

Energy is an abstract concept. We cannot see it or measure it directly, yet we know that it has value because of the work that it can do and because energy carriers such as electricity and gas are expensive. Although we speak of energy consumption, we know that from a thermodynamics perspective it cannot be consumed, merely converted from one form to another and that such conversions inevitably incur a loss of value. The generation of electrical energy by combustion harms our environment through the emission of greenhouse gases, and the cost of energy carriers is rising. It is therefore important that industries become more energy efficient for the sake of their competitiveness and the global environment.

The global industrial sector used approximately 98 EJ of energy in 2008 and this is projected to increase by 44% between 2006 and 2030. European energy use was 48.5 EJ in 2008, of which the industrial sector used 13.5 EJ (IEA, 2010). Industrial CO_2 emissions are driven by the amount and type of energy used by factories as well as indirect emissions from electricity production. Between 1990 and 2005, global CO_2 emissions from final energy use increased to 21.2 Gt CO_2 of which manufacturing industry is responsible for the biggest share at 38% (IEA, 2008b, 2007).

The development of sustainable industry (Evans et al., 2009) is essential for the transition of developed nations towards low carbon economies and clearly energy can no longer be considered a fixed operational expense, and instead must be treated as a resource to be managed alongside materials, cash and the workforce. Energy management is becoming an essential aspect of operations management for producers and it is now supported by international standards (e.g., BSi, 2009; ISO, 2011). It is also a concern for customers, since it affects their Scope 3 emissions (WRI, 2009). Original Equipment Manufacturers (OEMs) are under pressure to demonstrate how each stage of the supply chain is operated sustainably, and energy management plays a vital role in this. To audit a product's carbon footprint, a manufacturer must be able to trace the emissions produced during each components manufacture along the entire supply chain. This requires detailed knowledge of the energy used by each process and how this can be assigned to specific products. Failure to develop information systems to facilitate such analysis may cost manufacturers through carbon taxes, excessive energy use, and possibly also affecting their corporate image.

Effective industrial energy management is often very context specific, since it depends on many local factors such as product design, process choice, national fuel mix, etc. This means that it can be difficult to replicate energy saving solutions derived from one industry in a different industrial sector and/or location. In this respect energy management differs significantly from quality management, although the ISO standards share many similarities

* Corresponding author. Tel.: +44 116 257 7978; fax: +44 116 257 7977.
E-mail addresses: kvikhorev@dmu.ac.uk (K. Vikhorev), rgreenough@dmu.ac.uk (R. Greenough), nbrown@dmu.ac.uk (N. Brown).

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such as the 'plan, do, check, act' cycle. Energy management therefore requires a flexible approach, but it will benefit from a framework within which good practice can be established. The framework for advanced energy management described in this paper will allow energy managers at all levels to identify the patterns of energy use at different levels of analysis in their factory and thus make meaningful decisions based on performance indicators that are relevant to them.

1.1. Research focus

The focus of the research described in this paper is the feedback of energy usage information in real-time to facilitate action by those responsible for industrial processes. This feedback is intended to foster an awareness of process energy use in the same way that domestic energy monitors are intended to increase energy awareness (i.e., understanding of energy use) in the home. Domestic energy monitors usually display electrical energy data only and these data are aggregated at dwelling level, making it difficult to compare historical energy use by different devices. Signal processing techniques have been applied to separate and display the energy used by individual domestic devices (Patel et al., 2007; Hart, 1992). There is no such equivalent for industrial processes, although in many facilities sub-metering and half-hourly reporting facilitate energy management at a departmental and facility level. Studies of household energy use have identified energy savings of over 20% simply by providing energy information through monitoring (Darby, 2006; Meyers et al., 2010; Hargreaves et al., 2010; Lertlakkhanakul et al., 2010).

Industrial energy management has many similarities with quality management, as can be seen by comparing the energy management standard ISO 50001 (ISO, 2011) and the quality management standard ISO 9001 (ISO, 2008). Quality managers understand the importance of developing a 'quality culture' on the factory floor and this is fostered by display of quality related information such as such as defect rates, process control charts and overall equipment effectiveness. Conventional energy management methods at the factory floor are limited because the energy performance of individual processes cannot be understood without continuous measurement of energy consumption and an infrastructure to map process energy data onto relevant business performance measures. This lack of insight (which we can call 'energy awareness') limits the scope for timely decisions to reduce energy use.

The research question that arises in this context is: "How might the presentation of real-time energy information at the process level reduce the energy used in production?" This research question is based on two assumptions: 1) that the presentation of suitable decision support information at the shop floor will allow operators to save energy by temporarily shutting down a process that has excess short-term capacity; and 2) that operators will be given the training, authority and motivation to make process shutdown decisions. The human behavioural aspects of this question will be the subject of a future paper. This paper describes an advanced energy management framework and a prototype information system.

2. Methodology

Two methodological approaches are relevant for this paper: an action research (AR) framework (Greenwood, 1999) and case study research (Yin, 2008). The overall research is embedded into AR framework to ensure a structured research process and its continual improvement. Case study research was applied as the main source of data collection and to test research hypothesis within its real-life context. In order to address the research question above, the following four steps were adopted:

1. State-of-the-art analysis

Literature was reviewed on existing energy management systems, international energy standards used in manufacturing, performance measures, and visual interface design. A comprehensive overview of the required elements of an energy management framework was generated.

2. Energy survey

A preliminary energy survey was conducted at the premises of a major European automotive manufacturer in order to identify the relative proportions of energy losses and saving potential. It involved minimal interviews with site-operating personnel, energy measurements and a review of facility utility bills and other operating data, and a walk-through of the facility to become familiar with the building and equipment operation.

3. Design & Implementation

Based on results the state of the art analysis, the requirements for an advanced energy management framework were identified, including data standards and data processing, key performance indicators, and graphical user interface elements.

4. Evaluation

The framework is currently being deployed via a prototype information system situated on a machining line at the case study facility. The case study will used to evaluate the deployed system and the energy management framework by comparing the energy consumption of each production asset before and after system deployment. The nature of the energy decision process used by the factory personnel will also be analysed. The qualitative results of the evaluation are presented.

3. Elements of industrial energy management

One cannot manage what one does not measure, so data collection is fundamental to energy management. Industrial energy data are collected at all levels of granularity from the sub-process level to the global industry sector and at different temporal levels from milliseconds to yearly, depending on the nature of the analysis to be performed. At the industry sector level, organisations such as International Energy Agency (IEA) collect, analyse, and disseminate energy information. At a company level, organisations carry out energy audits to understand energy flows in buildings, manufacturing systems or processes and thus reduce the amount of energy used without negatively affecting productivity. However energy management goes beyond energy monitoring and targeting; the deep integration between the factory floor and factory building must be understood. Energy data gathered from all layers of an organisation need to be correlated and evaluated together to develop holistic energy efficiency strategies (Karnouskos et al., 2009). The most significant energy consumers, be they electrical, thermal, chemical or mechanical (e.g. compressed air) need to be identified, monitored and analysed in real-time to increase industrial energy efficiency. This requires standardisation of data collection, on-line data processing and visualisation techniques.

3.1. Energy data standards

For the sake of accurate and meaningful analysis, standards should be defined and applied at each level of the organisation at which energy data are collected. An energy data standard specifies