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ScienceDirect

Energy Procedia 83 (2015) 504 – 514

Energy Procedia

7th International Conference on Sustainability in Energy and Buildings

Design of an Embedded Sensor Network for Application in Energy Monitoring of Commercial and Industrial Facilities

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Abstract

The deployment of energy monitoring systems is well established for industrial facilities and commercial buildings, however these systems are insufficient where large variations in activity level (production variation, one-off events) are common. In such cases, accurate analysis of energy usage requires the deployment of a flexible embedded sensor network that can capture data at the required level of accuracy and granularity and can associate the energy usage data with the context and activity that has caused it. This research proposes an approach and a set of hardware and software tools for the monitoring of energy usage in technical building services and the association of that data with real-time production information in advanced manufacturing facilities.

The system developed incorporates an embedded controller with sensors to monitor the physical environment, an integrated energy analyser to monitor electricity consumption and a visualisation interface that associate events in the physical world with the actual energy consumption recorded. The creation of a detailed time-stamped energy profile for the process can then be used in the identification of energy saving opportunities. A case study from a pharmaceutical facility was used to validate the operation of the system.

Keywords: energy monitoring; embedded systems; process chiller; coefficient of performance (COP);

Peer-review under responsibility of KES International

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Peer-review under responsibility of KES International
doi:10.1016/j.egypro.2015.12.170

1. Introduction

Worldwide, industry consumes [1] almost one-half of all commercial energy used and is responsible for roughly similar shares of greenhouse gases. In the EU28 Countries, the industry sector accounted [2] for about a quarter of the final energy consumption in 2012. In absolute terms industrial final energy consumption has decreased from 15.4 million TJ in 1990 to 11.8 million TJ in 2012. This is driven by energy efficiency improvement but also by the slowdown in world production since 2007. The more industrialised nations naturally have higher percentages of consumption, for example, in Germany, industrial electricity consumption accounts [3] for approximately 46% of national energy usage. Similarly in the UK the DUKES Report [4] shows that in 2012 industry accounted for 31% of the total electricity consumed and 25% of the green house gas (GHG) emissions.

To stay competitive in the 21st Century, manufacturing companies need to include sustainability into their manufacturing optimisation schemes. Sustainable Manufacturing (SM) is the new paradigm [5] for manufacturing companies and involves the integration of all relevant dimensions that affect or have effects on third parties while conducting manufacturing operations, including energy, environmental impact and life-cycle analysis. Sustainable manufacturing is basically the process of lowering the use of energy and utilities while producing the same level or greater of product. The US Department of Commerce's Sustainable Manufacturing Initiative [6] sums it up as:

> *"The creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound".*

Energy efficiency, the relationship between production output and energy input, is increasing [7] in its importance to European Industries trying to achieve reductions in Green House Gas (GHG) Emissions, reductions in energy intensity, lower operating costs and progress towards Sustainable Manufacturing.

2. Energy Efficiency in Industry

In productive industries some consumption of energy is necessary and indeed unavoidable as fundamental principles of energy conversion apply. The key principles [8] of energy reduction in industry are;

1. Avoid unnecessary consumption of energy.
2. Turn things off when they are not needed to add-value and ensure that the workforce are engaged with and implement energy efficient operations.
3. Reduce the quantity of energy consumed during the production process.
4. Re-design inefficient products and processes and reduce the supply of services in line with variation production activity.
5. Recover energy from the production process and reuse it, either internally or externally.
6. Generate from alternative energy sources (solar energy, wind turbines).

Studies have shown there is a significant potential to increase the energy efficiency in industry. Potential reductions in energy [9] of 20% and in GHG emissions [10] of 30% 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 [11] are needed. Studies [13,14] have shown that where large industries effectively implementing an energy management system (EnMS) then they can reduce their energy use by between 10 % and 40 %. Despite the efforts made over the last 20 years, the research [15,16] 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 articles [17,18] show that only a limited number of companies actually focus on managing energy and that cost-efficient energy efficiency measures are not always implemented, explained by the existence of barriers [19]. 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 [20] conclude that despite the number of commercial tools being used to track and monitor energy use in a factory and