

# A Holistic View on Energy Efficiency In Manufacturing

Anna Florea\*, Corina Postelnicu, Jose L. Martinez Lastra

Tampere University of Technology, Korkeakoulunkatu 5, 33720 Tampere, Finland

**Abstract.** There are certain similarities in the way how requirement for energy efficiency is being addressed in domain of building and manufacturing. Building and factory automation systems serve as backbone, allowing to make technological components work together to ensure sustainable energy performance. Although both BAS and FAS are deployed at manufacturing enterprises, they function side by side but separately, without concordance in their objectives. The fragmentation is caused by a number of historical and technological factors, which can be now reassessed. Moreover, elimination of that fragmentation facilitates development of effective energy management solutions. In this article we demonstrate conceptual similarities between FAS and BAS systems in order to prove their convergence potential in context of energy management applications for manufacturing and suggest backbone architecture based on web services in order to integrate both worlds.

**Keywords:** energy efficiency; factory automation; building automation; energy management; sustainability.

## 1. Introduction

Energy efficiency has been a hot topic for a long period of time. And it will remain prevalent in future because of the gap between rising need for energy, driven by planet population growth and enhanced living standards, and speed of development and adoption of new energy saving solutions. The research activity in domain is concentrated around solutions aiming to reduce energy loss and energy consumption in various fields through development of new materials, design for energy efficiency, and smart control.

Biggest rates of energy consumption are accounted for building and industrial economy sectors [1]. Energy spent during construction phase, maintenance and consumed by users is included into building sector. In Europe 40% of energy end-use is attributed to buildings [2]. While new solutions aiming to reduce material and energy use in industrial sector find their way to factory floor, the research shows that in past two decades average annual rate of energy savings dropped by half with respect to period of 1973-1990, which puts new challenges to research. According to information, provided in “Energy Use in the New Millennium” IEA report [3], Energy consumption rates have strong dependence on industry structure and mix of energy sources used, with biggest consumption rates in primary metals and chemicals. Solutions looking for reduction of material and energy use through sustainable product design were emphasized to address the issue [4]. At the same time importance of energy efficiency of the manufacturing process was addressed [5].

Present article concentrates on approaches to energy efficiency of post-construction phase of building lifecycle and manufacturing industry. Automation systems deployed in buildings and at manufacturing facilities provide opportunities for integration, allowing development of holistic energy management system of manufacturing enterprise.

## 2. Background

In domain of building sector energy efficiency is considered at design, construction, and maintenance phase. While part of lifetime energy expenses of a building is defined through design is fixed and can be calculated in advance, there is variable component, introduced by inhabitants, which are the main users of services provided within a building. These services are usually managed by Building Automation Systems

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\* Corresponding author. Tel.: +358-40-198-1752; fax: +358-3-3115-2753.  
E-mail address: anna.florea@tut.fi.

(BAS). BAS are able to manage a variety of services, such as climate control, visual comfort, security and safety, supply and disposal as well as peak avoidance [6] in a holistic manner. Climate control and visual comfort functions serve two goals simultaneously. They provide specified level of comfort for inhabitants and also prevent excessive energy consumption; therefore BAS is seen as key enabler of reactive energy savings in post construction phase of building lifecycle.

In context of manufacturing energy efficiency is addressed from several perspectives, which include design and process development, tool design, and control. Design for energy efficiency considers energy aspects to reduce amounts of energy needed to manufacture the product, which can be accomplished through detailed breakdown of energy required to produce one unit [7]. Process development can be considered from two perspectives. The first and narrow one is manufacturing process. In this context energy efficiency is achieved through proper selection of manufacturing methods [5] and shop-floor layout design [8]. In broader scope business process development is considered, which includes product lifecycle [9] and smart supply chain design [10]. Reconsideration of supply chain allowed Jaguar Land Rover reducing by 32% CO<sub>2</sub> emissions, with respect to old material supply scheme [10]. Another approach supporting energy efficiency in domain of manufacturing is development of new materials for cooling [11], lubrication [12], tools, tool design itself, and equipment upgrade. Installation of variable speed drives enables reduction of energy consumption and prolongs lifetime of electrical motors [10].

In contrast to building sector manufacturing environment is very dynamic and requires constant assessment of energy performance from all the perspectives. Therefore energy management solutions play special role in implementation of energy efficient manufacturing facility. Monitoring of energy consumption ensures energy awareness of people in charge and supports development of energy management activities targeting growth of energy efficiency [13]. Factory Automation Systems (FAS) built of autonomous components, arranged in well-structured hierarchy can be used as data-providers for industrial energy management systems.

Manufacturing equipment and featuring ICT infrastructure are not the only components of a manufacturing site. Industrial and administrative buildings, logistics and personnel also influence energy consumption pattern of a manufacturing enterprise. Despite this fact energy efficient performance is being separately addressed for manufacturing associated equipment and featuring building facilities preventing holistic understanding of the energy performance.

### **3. Comparing BAS and FAS**

#### **3.1. Approaches to energy saving**

The energy flow and transformation is a complex process that needs to be perceived and grasped as a whole. Pre-sets and patterns of climate or lightening control systems affect the manufacturing process condition in many ways: they affect the state of environment, under which process is accomplished as well as state of operators present at the shop floor, and therefore their performance and decisions. On the other hand the process and operators influence the ambience and the pattern of that influence may be important for controlling the HVAC system. Moreover, certain parallelism exists between energy saving strategies in buildings and manufacturing. Approaches to sustainable energy performance in both domains are summarized in the Table 1.

As energy consumption has to be reduced with no effect on core function on the system, there are limitations, preventing achievement of possible saving maximum. These are comfort and safety in case of building environment and technical constraints such as line throughput and process requirements in case of manufacturing domain. Considering light management, process requirements is the only factor that is present in manufacturing facilities, but missing for houses. Aspect named “Consume to live” means energy consumption pattern when energy is consumed to fulfil basic needs of the end user (human or machine). It cannot be controlled by BAS in houses and requires a mindful effort from humans. However it can be handled by FAS through complementation of timely maintenance and calibration of equipment. A very significant factor for energy suppliers is management of consumption peaks. Again, it is more of conscious effort from humans to avoid energy intensive activities during the peak hours. Instead manufacturing facilities may apply advanced consumption rate prediction algorithms to inform suppliers timely about foreseen consumption rates [14]. Finally while there are obvious energy savings could be obtained by switching home appliances off instead of keeping them in stand-by mode, complex manufacturing machines require sufficient times to start and go off, thus the decision of keeping machine in stand-by mode, or switching it off requires knowledge on process state and machine parameters.

Table 1. Comparison of approaches to sustainable energy consumption strategies in household and manufacturing domains.

Aspect	Buildings	Manufacturing
Limitation	Comfort and safety of inhabitants	Workers safety and comfort, technical constraints
Smart Lightening	Illumination level, occupancy, activity	Illumination level, occupancy, activity, process requirements
Consume to live	Reasonable use of resources	Monitoring, calibration maintenance
Stand-by vs. Off	Avoid living home appliance in stand-by mode	Finding compromise between cold start and stand-by mode consumption
Peak hours consumption	Avoid consuming in peak hours	Forecast consumption rates to make precise orders from the supplier

It can be noticed, that almost same components constitute energy-saving aspects in domain of manufacturing and buildings. While some of the sources for energy saving in houses are subject to human behaviour, in manufacturing they are quantifiable and manageable. Moreover almost all the factors coming from household domain are included in manufacturing domain.

### 3.2. Targeting sustainable energy performance

The notion of smart building begins with use of advanced materials reducing energy loss, low consuming appliances and lightening, integration of renewable energy sources. BAS is enhancing the effect through incorporated control techniques that vary in function of particular implementation. Recent research in domain of energy efficiency in built environment proved that even more gain on reduction of energy consumption can be achieved. This requires consumers mind shift towards sustainable energy consumption. Energy awareness is seen as key driver, and a number of projects, such as BeAWARE<sup>b</sup> or Save Energy<sup>c</sup>, were researching the opportunity.

Similar situation takes place in domain of manufacturing. Sufficient effort is put and rewarding results are being achieved at level of solutions addressing specific fragments of energy efficiency. The key difference is that opportunity of paradigm shift, opening new prospects for even greater advancements remains yet not exploited. We believe that eliminating fragmentation between manufacturing line and buildings will allow making a step forward from energy efficient towards sustainable energy performance.

It is important to realize, that buildings and manufacturing facilities are not autonomous, but interdependent systems instead. Making difference between building and factory automation system in context of energy efficient manufacturing would mean leaving out of the scope important factors influencing energy performance.

## 4. Integrated energy management

Solutions addressing energy efficiency today have a limited scope, as it was previously explained. They use fragmented components to manage energy consumption. This prevents from building a holistic energy management system. An Integrated Energy Management System (IEMS) is needed to overcome the fragmentation is introduced in this section.

Historical, conceptual, architectural and technological aspects of BAS and FAS are investigated in article called “The Evolution of Factory and Building Automation” [6]. Although some noticeable differences can be found between two systems, there are key features that allow implementation of integrated energy management architecture. Both BAS and FAS incorporate SCADA functionality, which provides possibility to access real-time and historical data gathered by systems and use standard high level networking technologies. Both systems have a similar hierarchical structure and levels of this hierarchy can be easily mapped to each other. At the level of SCADA system it is already technologically feasible to apply internet communication technologies and take advantage of web-based solutions.

SOA and Web Services are seen as key technologies for architecture deployment. Each of the Integrated Energy Management System (IEMS) building blocks, except the reference model, can be encapsulated into web services, and effectively communicate with each other using standard messaging techniques. Same

<sup>b</sup> <http://www.energyawareness.eu/beaware/>

<sup>c</sup> <http://www.ict4saveenergy.eu/>

approach can be applied to implement Data Access Interface. On the other hand synchronisation engine (SYNC) should be implemented as a CEP engine in order to ensure faster reasoning.

A conceptual architecture of IEMS aiming to eliminate boundaries separating the FAS and BAS is provided in Figure 1.

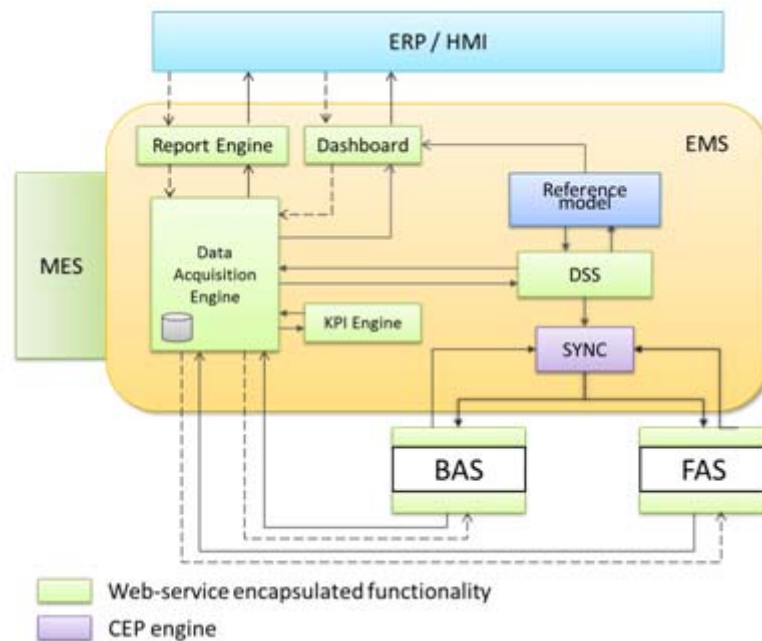


Fig.1. Conceptual architecture of IEMS

Key components of IEMS are Data Acquisition Engine (DAE), KPI Engine, Dashboard, Reference Model, Decision Support System (DSS), and Report Engine. DAE receives from DAS and BAS all the data, needed to execute energy performance analysis: rough data, locally calculated KPIs, relevant warnings and alarms. The KPI Engine receives from DAE information for computation of integrated KPIs. After KPIs are computed, relevant data from DAE are fed to DSS which reasons about systems performance, using reference model as the second input. The Reference Model, an ontology-based representation, which contains semantic and quantitative definition of the functional optimum for both FAS and BAS. Two main functions of DSS are elaboration of commands targeting reduction of energy use and updating the reference model. The second function is needed in order to dynamically reflect changes affecting the energy performance pattern occurring in either of two automation systems.

The Dashboard receives data from DAE and parameters from the reference model to build a comprehensive picture of system state in context of energy consumption, which then can be used by personnel responsible for plant energy performance. Another component serving the end user is the Report Engine. Enterprise applications can use Report Engine to obtain structured reports about energy performance of the plant. Report Engine is being activated from outside and initiates a data acquisition procedure different from process dedicated to on-line performance assessment.

Another important component of the IEMS is SYNC. While DSS reasons about energy performance and proposes compensation or reduction procedures, SYNC continuously monitors state of BAS and FAS avoiding instructions from DSS incompatible with current state of the systems propagating towards them. DSS interfaces both FAS and DAS in the same way as an operator. It may update or modify set-point values, mode, but has no access to low level control and execution.

Finally both FAS and BAS system have special interfaces to make communication with IEMS. There are two kinds of interfaces: Data Access Interface and Synchronisation Interface. Data Access Interface provides secure interconnection of system related databases with DAE. Respectively Synchronisation Interface serves for interconnection with SYNC.

The described architecture allows concentrating on essence of energy flow and transformation, reflecting objects and processes through provisioning of relevant information. Due to its structure it provides possibility for implementation of secure data access and prevents command conflicts. Intensive adoption of ICT in domain of BAS and FAS allows system implementation relying on state-of-the-art technologies.

## 5. Conclusions

Conceptual and technological similarities between BAS and FAS were provided to increase motivation for integration solutions and backbone architecture was proposed. Both systems incorporate tools, which are aiming to reduce energy consumption. The systems are functioning along each other in factory environment, which provides background for potential enhancements in domain of energy efficiency. Their collaborative functioning is seen as a sufficient contribution to sustainable energy performance of a manufacturing enterprise.

Proposed architecture is based on web services and follows SOA principles to achieve interoperability, scalability and facilitate integration of FAS, BAS and IEMS.

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