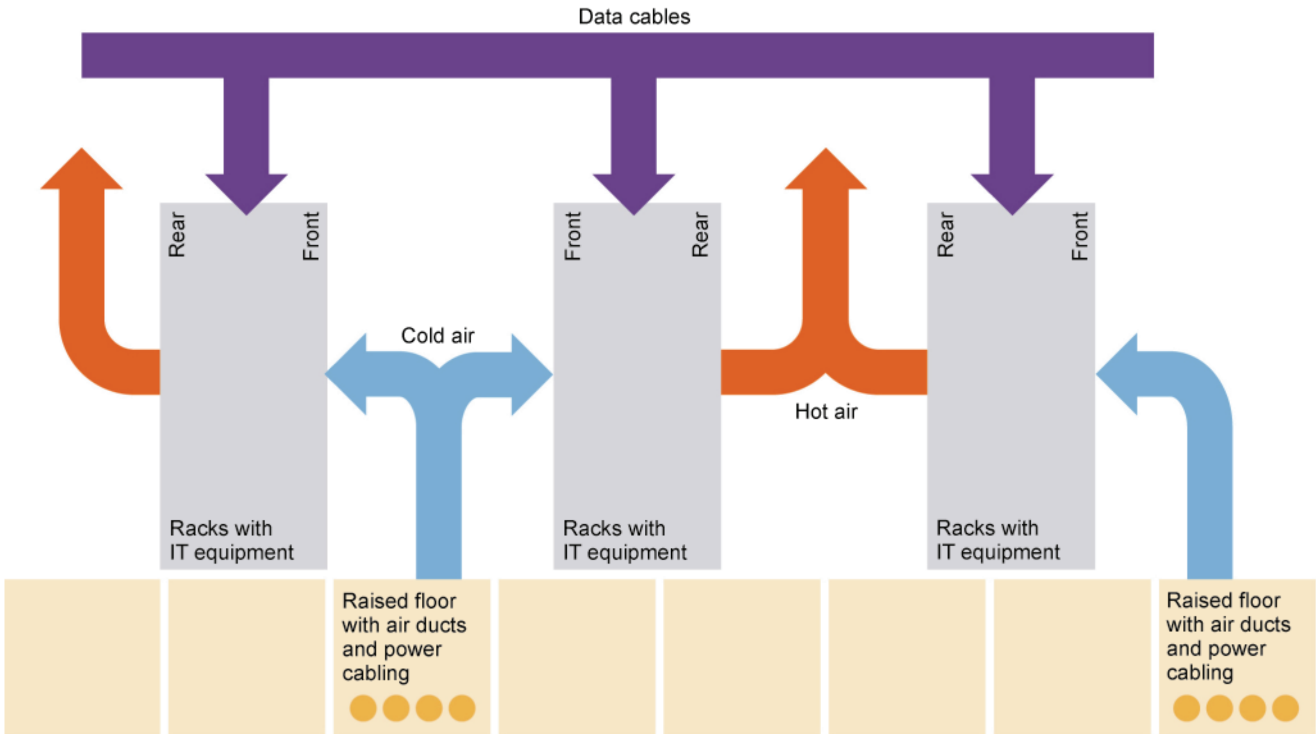
**Green Sustainable Data Centres**

Greening by IT



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**Greening by IT**

Chapter 8

# Greening by IT

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## INTRODUCTION

DCs play a crucial role in a society increasingly concerned with 'green'. Not only should their operation be sustainable but DCs contribute to a greener and more sustainable environment by supporting an ever increasing number of Greening by IT applications, which in some way implement Energy Management and Energy Management Systems. In a broad sense, we may say that DCs support Energy Management and, in turn, Energy Management is required for efficiently managing a data centre. Therefore, the purpose of this chapter is twofold. One hand, present the span of Greening by IT applications and on the other introduce Energy Management Systems along with their requirements, internals and potential.

LEARNING OBJECTIVES
After you have studied this chapter we expect that you are able to
- comprehend the concept of Greening by IT
- explain the main classes of IT systems for greening applications
- explain the Energy Management Process
- distinguish the main components of Energy Management Systems
- describe the main sources of energy data and identify their main limitations
- understand the main intelligent energy-use optimization strategies.

*Study hints*
The content of this chapter is based on recent research and scientific development regarding IT for Energy Management and Energy Management Systems. The material presented herein is mostly self-contained but literature references are provided for those interested in knowing more about the subject.
The workload is 10 hours.

## CORE OF STUDY

### 1 Introduction to Greening by IT

We are living in a new paradigm of collaborative networked digital societies, supported by Information Technology (IT) that increasingly rely on Cloud services (Buyya et al., 2009).

Data Centres (DCs) constitute a critical backbone of this paradigm, as they are the infrastructures that operate all these digital services. From mail servers services, e-commerce services, to data warehousing, or search engines. Thus, the number and size of this type of infrastructure is expected to increase significantly over the next decade.

Due to the high power requirements of the computing equipment and the infrastructure needed to support it, in particular cooling systems, DCs are high energy intensive facilities. The average DC consumes as much energy as 25,000 households, and the impact of the increasing usage of DCs in the energy sector is significant. Energy consumption for DC operation is doubling every five years in the United States and is expected to increase by 85% in Europe over the next 10 years.

*Digitization*

DCs have been allowing the *digitization* of many processes within the organizations across different sectors: from manufacturing to logistics, energy grids or buildings management, which induces significant savings of energy. Thus, a large portion of DC capacity is allocated today to run Green IT applications.

### 1.1 WHAT IS GREENING BY IT?

In Chapter 1 we introduced the concepts Greening of IT and Greening by IT. In broad terms, 'Greening by IT' refers to the employment of IT towards the development and implementation of a greener and more sustainable world.'

*Green IT Systems*

Greening by IT' is gaining increasing ground as organizations including companies and public institutions deploy '*Green IT Systems*' that manage their operation. These systems enable maximizing the product or service output and minimize also the utilization of resources such as energy and water, waste production or the employment of rare materials. Overall, businesses are being more and more operated with 'green' concerns and IT systems are rapidly evolving to support this shift.

*Sensor*

Although virtually every business domain nowadays uses IT as a basis for its operation, 'Greening by IT' is pushed by novel factors. First, *sensors* are becoming ubiquitous and the data they generate is becoming integrated with an ever-growing number of data sources with the purpose of taking more informed decisions. These applications have to process massive amounts of data that reside in data centres. A recent trend is the increasing movement towards the Cloud and outsourcing of the IT infrastructures, in order to better support these applications.

*Social development*

Another important aspect is that, Greening is a concept with multiple dimensions. Although energy is often understood as the main resource, together with water, optimizing more subjective resources such as work force or individual wellbeing, and *social development* also fall under the umbrella of 'Greening by IT'. Nevertheless, not all resources are optimized evenly; some may translate directly to cost, and therefore receive more attention, while others may not. The ever-increasing prices of energy together with stringent environmental regulation are raising the discussion around rational usage of energy to the mainstream.

Thus, a great deal of effort has been fuelled to the development of IT-based Energy Management solutions. Indeed, the implementation of 'Greening by IT' is largely driven by economic or regulatory policies.

## 1.2 IT FOR ENERGY MANAGEMENT APPLICATIONS

Although 'Greening by IT' is applied in multiple domains, its application to the energy domain has been growing in relevance and assumes today a critical role as we witness the widespread adoption of Energy Management Systems within homes, commercial and industrial facilities, as well as vehicles and in many other applications. These systems have the ability to:

1 Integrate data from multiple sources such as sensors and other systems
2 Assist managers and other users in the decision-making process
3 Manage intelligent equipment and devices on behalf of the its users, and
4 Coordinate production with consumption in scenarios of variable energy demand.

*Cyber-physical system*

Ultimately, the problem of energy management and consumption optimization translates into the optimization of a complex system consisting both of computational and physical components (a *Cyber-Physical* System) that is connected to multiple other systems and that requires a complex IT infrastructure.

### 1.2.1 *Intelligent Green Production Systems*

*Efficiency of manufacturing*

Intelligent Green Production Systems are systems that use IT to improve the *efficiency of manufacturing* or, in other words, produce more output using fewer resources. Fundamentally, these systems consist of multiple sub-systems that operate machinery more precisely and give tools for human operators and decision makers to make better decisions faster.

Production management systems enable taking action in real-time. Key conditions are monitored and integrated in real-time with data from external data sources. Therefore, it is possible to achieve precise and cost-effective production by controlling processes, critical points and rates using monitoring infrastructures based on sensors and automation systems. At a higher level, Production Decision Systems enable experts and managers to analyse the performance and service level indicators to perform strategic decisions, improving business performance and contributing to reduce environmental impacts.

As it can be easily seen, this results in huge amounts of data that must be integrated from multiple sources, including suppliers, customers orders and preferences, energy costs, shipment and parts tracking as well as factory floor information regarding on-going manufacturing processes.

### 1.2.2 *Intelligent Transportation and Logistics*

Transportation can be defined as the service of moving people and goods. This service consumes large amount of energy and therefore has been the object of intensive study. Intelligent transportation studies the use of computation techniques and IT to optimize this activity. More efficient transportation means using less energy.

In transportation and logistics, distinct aspects can be optimized using IT. Transportation can optimize its usage capacity, supply chains can be better coordinated to create less stock and minimize production downtime. Vehicles can be tracked to optimize their operation and minimize delays. Transportation can also be coordinated with energy costs and energy production. With respect to people transportation, specifically individuals can coordinate to share transportation.

All the above mentioned applications rely on IT. Vehicles need to be equipped with sensors such as position sensors and vehicle drivers need to access real-time information. Goods are being tagged with *Radio frequency identification (RFID)* in order to be tracked and routed. This information needs to be stored and processed.

*Radio frequency identification (RFID)*

### 1.2.3 *Smart Consumption*

Smart consumption aims at enabling end consumers to perform informed decisions about the goods they are buying. The idea is to provide information regarding several aspects of product life-cycle to be made available to consumers. In this way, consumers may adapt their consumption habits opting for products that are greener, thus rewarding manufacturers that are, for example, more green conscientious and use less energy or those that incorporate larger shares of green produced energy.

*Shopping advisory*

Conceivably, consumers will make use of mobile devices running *shopping advisory* software that assists them in their shopping decisions. Those decisions are based on information from multiple dimensions such as the amount of energy consumed in the different stages of production, in assembling, packaging, handling and finally selling the product. All this requires large amounts of data to be collected and integrated for each relevant product.

### 1.2.4 *Intelligent Homes and Buildings*

Intelligent Homes and Buildings refer to the concept of buildings and homes that are capable of some type of autonomous behaviour to create the environment conditions, typically in terms of illumination and climate that optimize the activities that the occupant is engaging in.

Most Intelligent Homes and Buildings are known as such because they make extensive use of electrical and mechanical devices to deliver the required environmental conditions. These devices are coordinated by Building Energy and Management Systems that minimize human intervention and improve energy efficiency. It has been demonstrated that these systems can play a critical role in lowering the energy consumption in buildings and now even international organizations and governments have endorsed their adoption.

In Intelligent Buildings, devices such as luminaries, window blinds or HVAC (heating, ventilation and air conditioning) systems, are still attached to a traditional power network but are also connected to a digital network to exchange messages with each other through a management platform. All these systems maintain large quantities of data and as buildings become increasingly managed digitally more data will be generated and managed.

### 1.2.5 *Smart Energy Grids*

A Smart Grid is a computerized power grid that provides the required flexibility for a new breath of energy services to appear. In a power grid, power production and consumption must always be balanced. Smart Grids *coordinate power consumption with production* enabling, among other, self-energy generation where consumers may also act as energy producers selling energy to one another. A greater coordination of production is also instrumental to achieve higher shares of renewable energy sources which are much more volatile. It enables also to quickly adapt the grid to highly variable demand that is expected by the deployment of plug-in electric vehicles.

*Coordinating power consumption with production*

Smart grids rely heavily on IT to coordinate energy producers and consumers, to monitor and manage the grid to perform metering remotely, and also to implement *Demand Response*, which consists of eliciting costumer behaviour changes by exposing consumers to varying energy prices depending both on production costs and consumption needs. Further techniques regarding Load Management can be found in Section 4.4.1.

*Demand Response*

Therefore, Smart Grids contribute to a greening because they support a different number of new concepts such as producer-consumer, greater shares of renewable, electric vehicles. This concept is already being deployed in several countries and will bring along the required flexibility to enable a number of new services to arise.

### 1.2.6 *Smart Cities*

Smart Cities refers to a concept of IT-enabled cities where IT is used to coordinate city agents and services in a way that is more environmentally friendly and that, at the same time, promotes a greater wellbeing to the city inhabitants and dwellers. A Smart City improves the 'comfort' of the inhabitants reducing the consumption of scarce resources such as energy.

The term Smart City is also related to multiple dimensions and implies the coordination of multiple IT systems. Smart cities also refers to the idea of publicly owned IT services that are made available and that can be integrated by software applications running on citizens devices or supporting innovative businesses in cities such as location services, to name but a few. Smart cities also rely on the extensive use of IT infrastructures.

### 1.3 CHALLENGES OF GREENING BY IT

It is by now clear that an increasing number of new businesses and services are supported by IT systems which incorporate strategies to optimize and rationalize the consumption of green resources, among which, energy is the main resource.

An increasing number of applications is being developed and deployed, spanning from Intelligent Green Production, to Smart Consumption, Intelligent Homes and Buildings as well as Smart Cities and Smart Grids that employ IT for energy applications. It is safe to say that virtually all businesses will embed or have to coordinate with some kind of Energy Management System.

IT for Energy Applications will require a great deal of data coming from sensors and meters to be integrated with data coming from other sources, to be stored and then processed.

*Energy management systems*

In conclusion, 'Greening by IT' services will require the use of *Energy Management Systems* running in Green Data Centres to ensure that the overall goal of using IT to obtain a more sustainable world is achieved.

REFLECTION 1
How do we measure the environmental trade-off between having an increasing number of Greening by IT applications running in Data Centre and the consequent Data Centre energy demand growth?

## 2 Energy Management Processes

*Energy and Work*

*Energy is used to carry out work* or to create an environment that is supportive to work. For example, lighting is used to create the adequate illumination in an office environment, or HVAC systems create the adequate thermal comfort conditions. Machines and equipment, therefore, consume energy to perform work, to support work or both. Energy efficiency is a relative metric that compares the units of work done to the energy required to perform that work. The more units of work get done per unit of energy used the more energy efficient a certain process is.

## 2.1 ENERGY MANAGEMENT PROGRAM

*Energy management*

The term '*Energy management*' has a number of meanings. Herein, we use the definition that relates with the processes that contribute to saving energy in organizations.

Energy management activities are organized according to an Energy Management Program and supported by IT systems known as Energy Management Systems that are detailed in the following.

The implementation of an Energy Management Program in organizations requires the following elements (ISO 50001):

*Policy*

– An Energy *Policy* within the organization where top management defines an energy management policy document where delegates authority to the energy management team to implement energy efficiency measures in the organization, participate in the management decisions that affect energy consumption (production activities, equipment procurement, training). The policy should also define how the information regarding energy management must be disseminated across the organization.

*Plan*

– A *Plan* of Energy Management activities that defines a plan at two levels: at the strategic level, the plan must define the goals, strategies and the general actions to implement the program; at the operational level, the plan must describe the specific actions and measures to be implemented, as well as the evaluation of the measures in order to rank the measures and define a sequence of implementation.

*Team*

– An Energy Management *Team* consisting of an energy manager and other stakeholders that will be responsible for defining the energy management plan, monitor and reporting the energy consumption, identify future energy need, identify technical and financial resources to implement energy efficiency measures, implement energy efficiency measures and evaluate the implementation

*Audits*

– Carrying out Energy *Audits* to measure the energy requirements of the activities performed by the organization and verify if the results are in accordance to the energy policy that was defined. The way the audits are executed is defined in the operation plan

*Dissemination*

– *Dissemination* of information usually in the form of reports, is crucial to implement the energy management programs. Reporting enables the energy manager to present the results of the energy management program implementation to the top management. However, they are mostly a tool for promoting the implementation of the program to other members of the organization, by reporting the anomalies, suggesting changes and quantifying the impact of the different actions.

## 2.2 THE ENERGY MANAGEMENT PROCESS

Several authors point to a framework that clearly distinguishes four classes of activities: data acquisition and storage, data processing and analysis, reporting, control, diagnosis and optimization.

### 2.2.1 *Data Acquisition and Storage*

The first part of the process consists in gathering all the data provided by the multiple sensors spread across the organization, including the energy measurements. This comprises a set of diversified activities, such as complying with different protocols from different vendors or different sampling resolutions from different sensors. It is necessary to perform a series of activities like data validation, transformation and finally storing the data. At this level, the information should be at an abstraction level independent from the sensor or the vendor and accessible to all kinds of data processing and analysis tools.

### 2.2.2 *Data Processing and Analysis*

The second part of the energy management process consists of processing all the acquired data, and in light of the operational plans and energy policy requirements, process all the data using algorithms, from statistical analysis, or the definition of new set-points through optimization or heuristic systems and finally analyse the data, for example by means of evaluating different indicators. The result of the data processing and analysis should be stored in a different layer of abstraction, where only 'digested' data resides, in order to be available for other services like reporting or diagnosis.

### 2.2.3 *Reporting*

The processed data should be used in the first place to disseminate the results from energy consumption, through graphs from different time resolutions (hourly, weekly, monthly), for different areas and services. The dissemination can be done in dashboards, or by generation specific messages (SMS or emails) to different persons in the organization. The reporting may include the information regarding the control actions, or diagnosis triggers or optimization actions.

### 2.2.4 *Control, Diagnosis and Optimization*

Finally, the processing and analysis of the data should generate a set of control actions that must be sent to some controller of some vendor. This includes changing operation parameters of equipment to maintain a certain level of service (for example the temperature of air conditioning units or the opening of some valve to change the flow of water or gas).

*Pre-defined threshold level*

Several diagnosis messages can be generated at this level, usually based on the comparison of real measurements to some *pre-defined threshold level*.

Finally, the control actions may be changed according to different constraints imposed by the energy policy or operational plan, like switching of certain equipment during peak time or adjusting set-point taking into consideration the exterior conditions. All these actions are generated at an abstraction level and they must be communicated to the devices, using the specific hardware and communication protocols.

REFLECTION 2
Should we implement Energy Management Programs in small-medium size DC or should these DC migrate to large facilities with EMSs (Energy Management Systems)?

## 3 Energy Management Systems

*Energy Management Systems (EMS)*

*Energy Management Systems (EMSs)* are IT systems that support the Energy Management processes, including monitoring, analysing, controlling and optimizing energy usage. Data centre infrastructure management (DCIM) systems, as discussed in Chapters 5 and 6, work according the same concept as EMSs. The difference is that DICMs can have a wider range of metrics (also carbon footprint, water usage and so on). In this chapter the focus is on the Business Intelligence side of the EMS.

These systems gather and integrate data from energy meters, sensors and other sources to enable the analysis of how energy is spent, detecting anomalous situations and performing improvements actions to maximize productive conditions while minimizing energy consumption or maximizing energy efficiency.

EMSs aim at maximizing energy efficiency by:
– *Improving energy management decisions* by allowing the energy consumption of the facility or business to be integrated and monitored centrally. The energy manager can evaluate more effectively if the facility or building is performing according to their expectations, acting immediately if it is not. EMSs also help in increasing user awareness of how a business is performing in terms of energy usage.
– *Assisting the detection of anomalous energy consumption patterns* warning managers of the need to take further actions. This feature identifies equipment, spaces, users, and periods of unexpected consumption that should be object of further analysis. For example, they might be responsible for additional costs due to the fact that energy companies punish high demand peaks. After identified, those peaks might be lowered or smoothed allowing associated costs to be saved.
– *Tracking improvements* enabling energy managers to determine the effectiveness of actions taken and thus evaluate the overall energy management strategy. This features requires baselines to be established so that the consumption of a given period can be characterized and compared with consumption of another.
– *Assisting in forecasting energy demands* to anticipate distinct energy demand and costing scenarios.

**E**nergy efficiency is not an unconditional reduction of consumption but decreasing energy consumption without compromising business operation or occupant comfort: it optimizes the costs without changes for the user of energy.

### 3.1 FUNCTIONALITIES

Overall, EMSs achieve energy-savings objectives through continuous monitoring and enhancement of equipment operation and characteristics, building envelope and services, as well as occupant behaviour. In order to achieve their purpose, EMSs perform four fundamental operations:
1 Acquisition of energy related data,
2 Integration of collected data,
3 Presentation and exploration of data in the form of reports and dashboards,
4 Control equipment and electric loads in an energy-responsive manner.

#### 3.1.1 *Data Acquisition and Integration*

The sources of excessive energy use can be diagnosed and corrective actions can be planned and implemented after analysing activities, equipment, spaces and occupants that are responsible for the largest spending's. In other words, energy measurements can only be understood in *context* (Gokce 2009, Capehart 2011), i.e. in terms of activities, equipment, space and occupant.

*Context*

Integration and interoperability thus refer to the ability of operating in different environments and in a domain-independent way, in particular:
– *Operation with different protocols (and standards)* at field layer (M-Bus, Modbus, etc.) and transport layer.
– *Aggregation of different sources* refers to the capability of aggregating and matching different types of data, helping to increase data richness.

#### 3.1.2 *Energy Data Presentation*

This refers to features that are related with the process of data acquisition, loading and presentation. These features include
– *Data Mining* features refers to finding energy patterns and evaluating building performance.
– *Historical data* refers to the ability of analysing and correlating data from different periods such as comparing previous month or year.
– *Dashboards*, refers to the user interfaces that monitor operational processes, providing information in real-time.
– *KPI* refers to the capability of the user for creating and modifying key performance indicators (KPI) to evaluate the success and the achieving of his business performance goals.
– *Real-time monitoring* refers to whether newly acquired data will be immediately reflected into database and data visualization area.
– *Web Access* refers to supporting the remote access to the EMS through a web interface.
– *User profiles* refer to supporting multiple users where each type of user has specific energy requirements (building owner, building operator, occupant).
– *Simulation and Forecasting* refers to the application of algorithms, historical data and statistics to predict energy usage.
– *Occupant Interaction* refers to whether occupants can interact proactively with the system providing valuable feedback (better than sensors) and helping to improve building performance.

### 3.1.3 *Energy Data Analysis*

This refers to energy conditions that are related with quality and efficiency, as for example:
– *Power Quality* defines the requirements in terms of stability of voltage, frequency and phase alignment that electric power must have for the correct operation of devices.
– *Power Factor* through the calculation of active and reactive power. For assuring that the level of reactive power is in line and agreed with the supplier.

### 3.1.4 *Intelligent Load Control*

Besides energy monitoring some EMSs are also capable of driving electrical loads and devices on behalf of the users. The system automatically sends messages to equipment to prevent or fix abnormal situations of consumption by setting a new set-point.

## 3.2 ARCHITECTURE OF AN EMS

All operations of an EMS are supported by the acquired data. Therefore one fundamental principle of operation of an EMS is data must be consolidated to be explored by distinct applications. Data must be integrated and preserved efficiently and then fed to a tool layer in the front-end providing end-user tools, graphical interfaces for monitoring, maintenance, data mining and decision support tools that provide most of the functionality to end-users.

*Hardware and Software parts of EMSs*

*EMSs* consist of *hardware* and *software* components. The simple systems consist of a simple microprocessor with a firmware that performs simple fixed routines and controls a specific unit (for example air conditioning unit). This type of systems is simple, cheap and ideal for basic routine tasks. The complex systems are usually implemented at the whole organization level, require a high upfront investment but allow for high control accuracy and flexibility. A detailed cost-benefit analysis should be performed, however, the cost of these systems has been dropping significantly.

The components can be classified in two groups:
– *Hardware* includes sensors for temperature, lighting, humidity, movement, luminosity and energy consumption; controllers to change equipment's set-points like valves or switches; a computer or Programmable Logic Controller (PLC) to process the information in real time, and implement the algorithms that will define the outputs to the controllers; a data base that stores all the historical information from sensors and controllers.
– *Software* supports the implementation of complex EMSs, with multiple sensors and controllers dispersed by the organization requires the existence of a communication infrastructure and a computational tool that perform the data gathering, processing and storage. Two particular aspects are: the transmission protocol, as it influences the rate at which the information is updated; and the integration of components from multiple vendors.

### 3.2.1 *Layered Architecture*

Despite the absence of a commonly agreed architecture, Energy Management Systems are often described according to three layers (Ahamed 2010):

1 A *Data Acquisition Layer*, containing the modules responsible for retrieving information from meters and sensors as well as from other operational data sources;

2 A *Data Integration Layer*, containing the module responsible for ensuring the quality of data, staging and the aggregation of data to support analysis and decision making, and finally

3 An *Application Layer* (or *Tool Layer*), containing the application modules responsible for implementing the features over data.

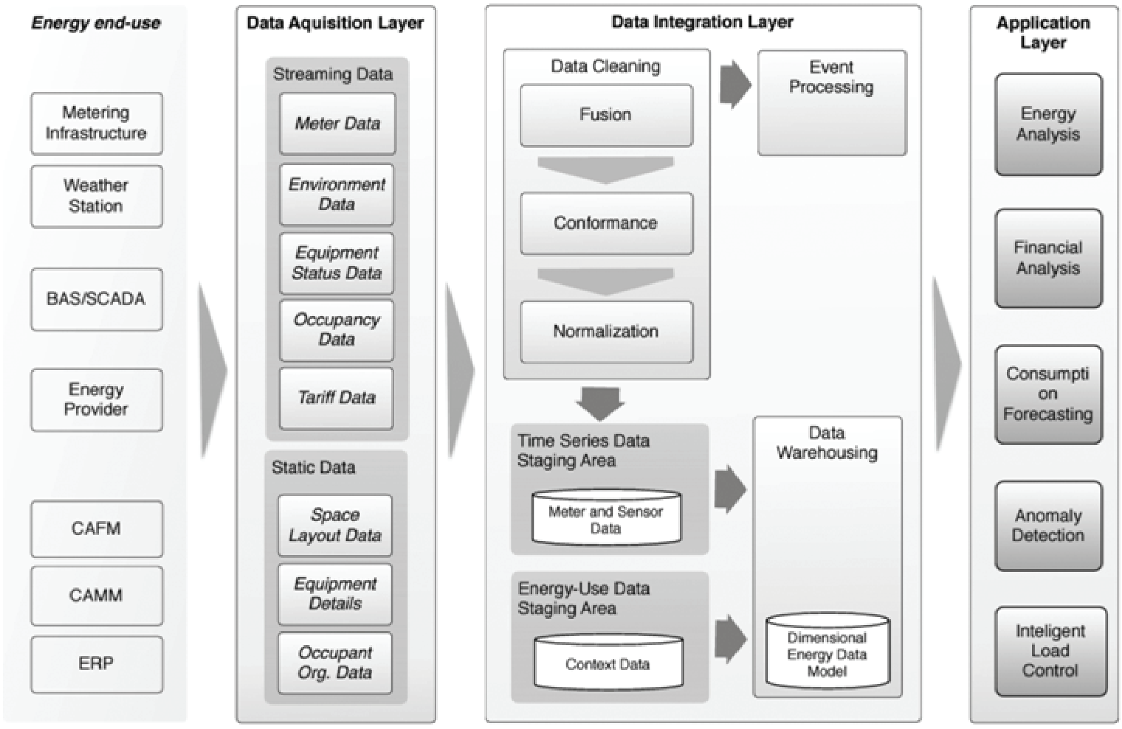


FIGURE 1 Architecture of an EMS consisting of three layers.

One such architecture is depicted in Figure 1. From left to right, the diagram depicts *(i)* the Data Acquisition Layer that gathers data from the distinct sub-systems pertaining to Energy end-use, *(ii)* the Data Integration Layer that is responsible for cleaning and aggregating data, and *(iii)* the Application Layer that implements distinct applications that are independent from the data sources and rely on quality data.

The purpose of data integration is to present data consolidated in a uniform way, abstracting away the details of data sources. This process is fundamental for EMS to be scalable and flexible. In particular it should enable new applications to be built independently of the data sources, and new data sources to be added independently from the applications.

This layered architecture brings several advantages. The first one is that applications are independent of the idiosyncrasies of the energy metering devices. Second, applications can rely on higher quality data and do not need to be concerned with implementing data quality functionality. New applications can be deployed atop of already existing data. New meters and sensors can be added without changing applications.

### 3.2.2 *Network Architecture*

*Device Control Network*

*Enterprise Network*

The EMS infrastructure typically consists of two different kinds of networks. First, a *device control network* that connects different types of devices is used in order to acquire and transmit data and to send commands to devices. Second, the *enterprise network* where the server that runs the EMSs and the applications are installed.

Usually these networks use different communication protocols. The device control network might be using protocols such as *Modbus*, *BACnet* or *LonTalk*. These are low-bandwidth protocols that are specially designed to support very large numbers of devices on the same network segment that have stringent limitations on power consumption (sometimes running on batteries) and have also limited computing capabilities. Device networks often have to operate in adverse environments exposed to climate elements or to electromagnetic interference. Enterprise networks use *TCP/IP*, to connect the EMS Database server to Applications and to external data sources. Gateways are protocol converters, enabling communications between two networks that use different protocols. A diagram of the network architecture is presented in the Figure 2.

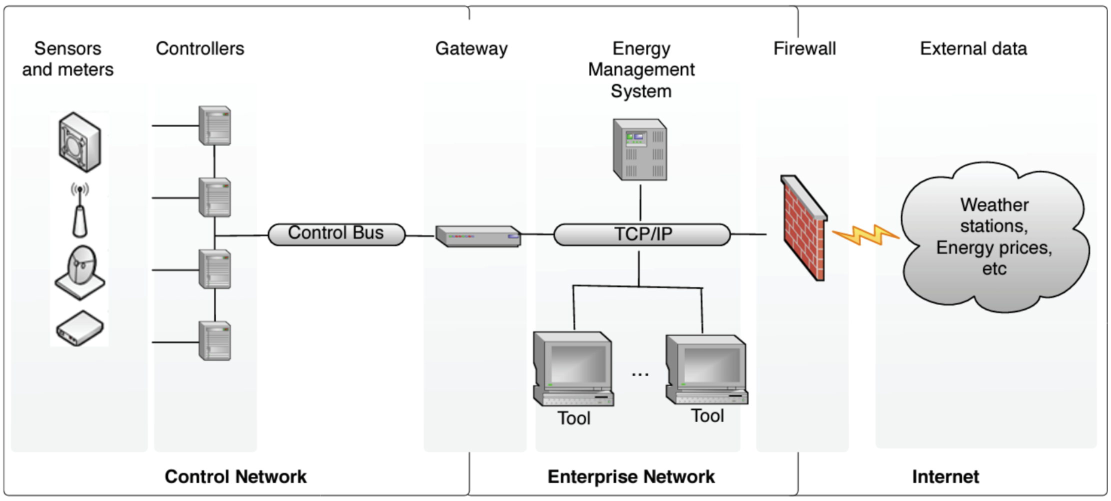


FIGURE 2 EMS device network topology

This figure is an illustration of an EMS device network topology consisting of 2 networks: the enterprise network and the control network.

## 3.3 ENERGY DATA ACQUISITION

Energy metering data must be integrated with several other sources of data that provide additional context. Building Automation and SCADA systems, weather stations and also energy tariff schemes data made available by the Energy Provider are valuable sources of information that is crucial understand energy data.

Data acquisition is the process responsible for acquiring data from devices. This process requires data to be read from devices, transported and then interpreted to match the representation of the EMS. Device data might originate from three different sources: energy meters, environment sensors and equipment status sensors. Then it must be transmitted to a central system. This may require using different types of transport protocols. Data must be interpreted and matched to a common format to be further processed and persisted in the energy database.

### 3.3.1 *Sources of Energy-related Data*

*Context*

Energy data must be given *context*. Energy data acquired from meters must be correlated with data from sensors and then analysed according taking into account data regarding the space layout, equipment break-down, and occupant organization. Other relevant sources of information such as weather data and energy prices are obtained from external data sources over the Internet. Therefore, besides the typical data acquisition, data from Facility Management, Business Support Systems, and Internet data sources also needs to be acquired and integrated. In particular, the following sources of energy data can be distinguished (Table 1 presents a set of external data sources):

*Energy Meter data*

– *Energy Meter data* refers to the actual data measured by energy meters responsible for measuring energy such as electricity, gas and heat. Typically, smart metering solutions are employed to describe energy usage and to provide timely energy profiles and consumption trends.
– *Environmental data* measured from sensors, such as luminance sensors, presence/occupancy sensors, or through external data sources such as weather stations. Environment data will allow the EMS to correlate energy consumption to environment status. Environment data is crucial to understand and forecast seasonal peak demands (Capehart 2011). Climatic parameters such as temperature and solar radiation can be used to estimate energy consumption.

*Equipment Status and Commissioning data*

– *Equipment Status and Commissioning data* providing details about the operation of the equipment such as temperature, pressure levels and set-points, helping to determine the cause of peak-demands and ab-normal situations (Capehart 2011). In the case of facilities, the Building Automation System (BAS) provides information about the control points (events, alarms) and monitoring points (temperature, pressure) of each system being monitored. It is important to correlate this information with energy meter data to identify the root cause of energy consumption and to verify if the equipment are working under the specified conditions (below the alarm threshold).

*Activity data*

– *Activity data* related to activities that are performed by the organization. These activities are energy-related because different types of activities exhibit different energy consuming patterns. For example, a company from a labour-intensive industry who works 24 hours per day has a different energy pattern compared to a government agency. Activity data has a direct relation with the business process of the organization and how the company performs its core activities. More activity typically implies using more energy. Activity data is useful for comparing labour periods with rest break periods to detect patterns of consumption (Capehart 2011). Activity data can be obtained from some business support information system, or inferred from room scheduling or from occupancy sensors.

*Energy tariff data*

– *Energy tariff data* capturing distinct rates, taxes and power factor level (Capehart 2011). This information could be stored for distinct energy providers enabling comparing distinct building scenarios. This information can be useful for a comparison between meter data acquired and real costs.

*Space Structure and Layout data*

– *Space Structure and Layout data* refers to the structure of the space that is used to characterize how energy is used. Energy can be used differently in distinct areas, zones and rooms. Classification of spaces and adjacency relations between distinct spaces are often important for further analysis. Space data is often introduced manually or imported from some type of building description file such as a Building Information Model (BIM) used by Computer-Aided Facility Management Systems employed in Facilities Management.

*Occupant organization dat*

– *Occupant organization data* conveying the breakdown about the organization structure. This information is required to compare each department or business unit according to its location and space used in the building, or it can reveal the departments that are over-consuming energy. The organization breakdown information must be re-adapted in the case of a possible change on the organizational structure. Occupant organization and cost structure data can be extracted from existing ERP systems.

*Equipment structure data*

– *Equipment structure data* enables to capture equipment break-down and characteristics so that energy consumption can be correlated and analysed according to these characteristics. Equipment data can often be imported from Computer-Aided Maintenance Management systems.

### 3.3.2 *Classes of Data*

Data coming from sensors and meters are updated more frequently than data regarding tariff or data regarding the space layout. Energy data can be classified according to its update frequency (Capehart 2011) into:

*Streaming data*

– *Streaming data* which often vary, so it must be continuously retrieved from devices or on-line sources in order to keep it updated. New data are periodically arriving into the EMS and it needs to be stored and kept. Due to the high frequency updates and the number of data records requiring integration into the database, the integration process is much more complex when dealing with dynamic data.

*Static data*

– *Static data* that is not frequently loaded into the system. This data is usually related to building properties such as location, room areas, organizational data or energy tariffs. Static data are commonly gathered or read from configuration files. Although this data might change, the frequency of change is low.

TABLE 1 Summary of the external data sources that are integrated in an EMS along with the typical data formats

| Data Sources | Type of information | Data Format |
|---|---|---|
| Energy Meter Data | Continuous energy consumption reads. | Energy Meter message formats |
| Environment Data | Climatic conditions in a facilities and surroundings | Provided by weather stations connected to the EMS, from external sources or from other sensors (as those attached to the Building Automation System). |
| Equipment Status and Control Information | Building equipments control variables and sensor data (e.g. Setpoints, Circuit status, Valve positions, etc.) | Standard Protocol (e.g. BacNet, LonWorks). Proprietary Software (e.g. TAC Vista, Metasis). |
| Activity Data | Information about the occupant activity | Business operation systems. Scheduling databases. Occupancy sensors |
| Energy Pricing Data | Information about tariffs from different energy service providers. | Paper form (non-structured data) |
| Space layout and function | Supports operational management and activities related with Facility Management (FM). Provides functional space information. | CAFM specific software. Building Information Model (ifcXML, gbXML). |
| Occupant Organizational Information | Information about the organization and the way it is structured to perform the core activities. | ERP system |
| Equipment Characteristics | Information regarding equipment organization (parts) and power consuption regimes | CAMM specific software |

### 3.3.3 *Direct and Indirect Data Acquisition*

*Data collector*

Data acquisition typically follows a hierarchical network architecture in which meters and sensors are connected to a *data collector*, sometimes also referred to as `a gateway', that stores data from meters until it is requested by the central system that will store data for later analysis. This central system is typically the EMS itself. Therefore, we may say that a hierarchy of devices exist to support data acquisition, communication and storage.

Regarding the connectivity of the EMS to the devices, two approaches can be distinguished: a *direct* approach where the EMS is responsible for direct communications with devices to retrieve data, or an *indirect* approach, where device data is collected through a device controller. The direct approach provides EMSs full responsibility for data gathering. However if the EMS fails to collect data due to network problems, data will be lost. The indirect approach allows the EMS to collect data even if the network link to the collector device is lost.

## 3.4 ENERGY DATA ANALYTICS

*Business Intelligence (BI)*

The idea of creating and exploring an integrated data repository aiming at gaining insight over business operation has been successfully applied in virtually all business domains with marked success became known as *Business Intelligence (BI)*. Financial institutions, utilities, telecom, and retail operators are among the champion users. The same principles of operation can be applied in EMSs.

The backbone of Business Intelligence is a persistent repository of information collected from multiple sources and stored under a global unified schema known as a Data Warehouse (DWH). This repository keeps data ready to feed energy data analysis tools and abstracts data analysis from the details and intricacies of data sources (Kimball 2013).

### 3.4.1 *Energy Data Warehousing*

Data Warehousing is a generic term that refers to the complete processes of data acquisition, integration, aggregation and presentation. In fact as stated by Ahamed et al in 2010, DWH can fulfil a central position in building performance management as they cover different aspects from data gathered from different sources, to data storage and to data 'aggregation' (Ahamed 2010). In our context, however, Data Warehousing refers to the activities that lead to the creation of the dimensional model.

In an Energy Management context, DWHs aggregate energy data enabling the identification of energy patterns that will be useful to find energy-saving opportunities. A DWH for energy can maintain a historical data report enabling to analyse the performance of different periods. Several DWH architectures have been described in literature to enhance real-time decision in Energy Management contexts.

According to different authors the main goals of a DWH are:
1 Supporting data analysis and decision-making,
2 Making information easily accessible and
3 Presenting information in a way that is consistent with the business requirements while being flexible and resilient to changes (Han2006, Kimball2002).

Despite of DWH being widespread, the majority of energy managers are still using spreadsheets to process and analyse energy data (Capehart 2004a). Since these tools are very easy to use and to share, they provide a cheap solution for energy managers (Capehart 2011). However the range of these applications is very narrow, lacking the ability to correlate and aggregate data according to different dimensions and hierarchies.

### 3.4.2 *Energy Dimensional Model*

A DWH data store keeps pre-computed data with the most frequent aggregations and to speed up the data analysis and enabling viewing data from different perspectives. In order to understand energy usage, energy data should be presented at distinct levels of granularity with respect to the following dimensions:

*Time dimension*

– *Time dimension* enabling the energy consumption to be seen by at the minimum interval (typically at 15 min) or according to longer periods such as hours, days, weeks, months, quarters of years.

*Equipment dimension*

– *Equipment dimension* is used to aggregate consumption according to a device hierarchy. First by device and then by sub-system or by system. Consider for example analysing the energy consumption of an HVAC system which may require aggregating energy consumption of distinct sub-systems such as hot/chilled water or air-handling units. In turn, each subsystem has distinct loads that consume energy that may be measured.

*Space dimension*

– *Space dimension* enables analysing how energy measurement can be related to space. Space dimensions can be understood according to a physical hierarchy or according to a logical hierarchy. The physical hierarchy decomposes a facility according to its physical taxonomy, e.g., room, floor, building, while the logical hierarchy decomposes the building according to a logic space organization, e.g., room, area, zone, building.

*Occupant dimension*

– *Occupant dimension* captures the hierarchy of the occupant. Although this hierarchy may vary, conceivably we may start with individuals and then group their consumption according to the organic unit they work on, and then by department, and finally by the organization or business operation.

*Cost structure dimension*

– *Cost structure dimension* reflects the structure of the cost centres that are paying the energy, which if often distinct from the structure of the occupant.

The DWH multidimensional model is organized in six dimensions with a star schema for building performance data management (as illustrated in ***Fout! Verwijzingsbron niet gevonden.****3)*. Dimensions were chosen based on their relevance for energy management discussed above. Therefore, the dimensions are organized in the following way:

1 Time dimension,
2 Cost dimension (reflecting the structure of energy costing in the organization)
3 Physical Space dimension (reflect the structure of the building or facility),
4 Logical space dimension (reflect the organization of the space by area, zone, or function)
5 Occupant organization dimension (range from a single person to a department or business group), and
6 Equipment dimension (reflecting the structure of the equipment in terms of systems and subsystems),

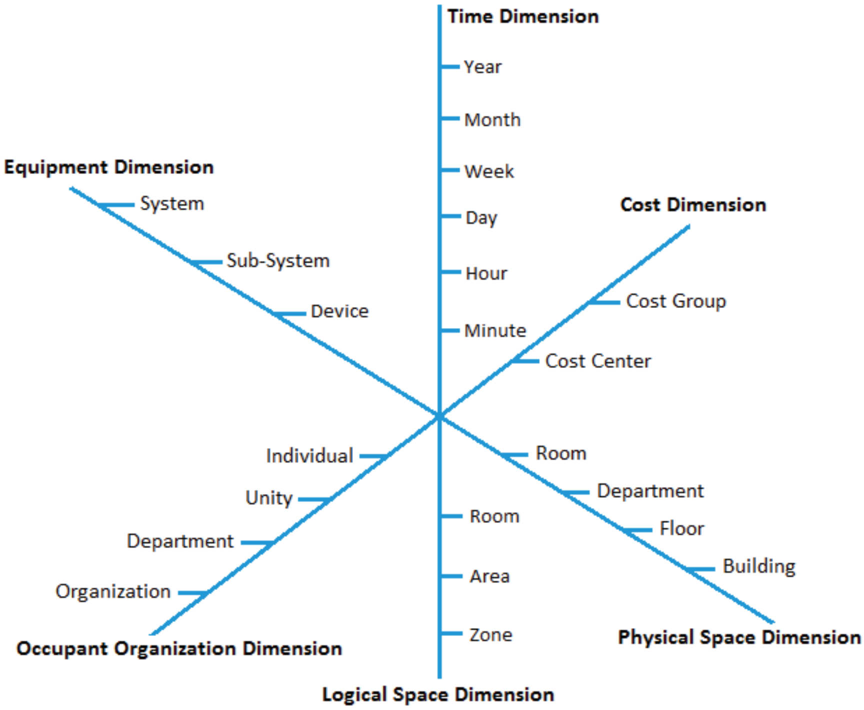


FIGURE 3 Illustration of the aggregation dimensions of energy data in a Data Warehouse.

In each one of these dimensions OLAP operations can be performed to analyse different granularities, for instance, time dimension can be roll-down from year, quarter, month, week or day (Ahamed 2010). In spite of the contribution of this DWH architecture for building management, there are several points that need to be more refined in an energy management DWH such as the process of integrating heterogeneous external sources.

*On-line analytical processing (OLAP)*

Technically, data are stored according to a structure known as multi-dimensional data cube, and also the fast computation of summarized data (Han 2006). The multidimensional data cube allows data to be modelled and viewed in multiple dimensions. Tools known as *on-line analytical processing (OLAP)* tools are used for analysis of multidimensional data in different granularities. Figure 4 depicts the concept of an Energy Data Cube, adapted from (Han 2006). A 3-D data cube with dimensions Time, Zone Space and Equipment and aggregate measures for equipment-time and zone space-time.

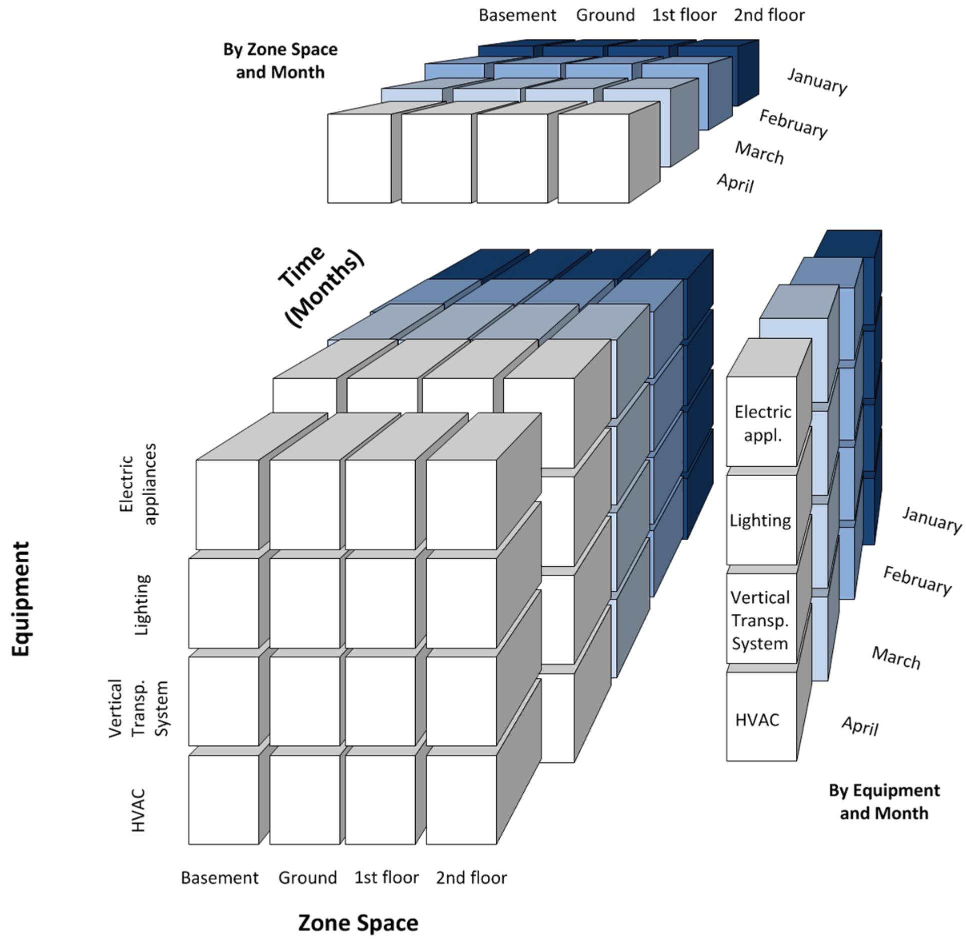


FIGURE 4 Example of a multidimensional energy data cube.

Since data is organized in a multidimensional model the user is able to view data from different perspectives.

### 3.4.3 *Data Analytics Operations*

In each one of these dimensions OLAP operations can be performed to analyse different granularities, for instance, time dimension can be roll-down from year, quarter, month, week or day (Ahamed 2010).

OLAP operations allow the presentation of data at different levels of abstraction, materializing different views. Common OLAP operations include roll-up, drill-down, slice and dice, pivot among other. The *roll-up* operation performs aggregation on a data cube by climbing up hierarchies; grouping data to a less detailed perspective (navigates from more detailed data to a less detailed data (Han2006). The *drill-down* operation aggregates data by stepping down hierarchies, adding more detail to the given data (navigates from less to more detailed data) (Han2006). The slice and dice operation performs selections on dimensions. If the selection only occurs in one dimension we are referring to the slice operation if the selection is performed on two or more dimensions is the dice operation. Pivot operation consists of a visualization technique that rotates the data axes in order to provide a different perspective over data.

### 3.4.4 *Energy Data Storage*

The most common conceptual model used in DWH is the Star Schema, in which a DWH contains a large central table (known as the fact table) and several smaller tables (dimension tables) that are connected to the fact table (Han 2006). The fact table contains the facts, which are the records that we want to measure such an energy readings and sensor readings with keys pointing to the dimension tables (Han 2006). The dimension table contains attributes that describe the business conditions and are organized through hierarchies. As such, the data cube is defined by dimensions and facts, its edges correspond to the different dimensions and the intersections of the dimensions correspond to aggregation facts that are under those conditions.

### 3.4.5 *Energy Data Normalization*

Important statement

Energy consumption is directly correlated to the level of energy service that is being provided: it depends on the number of lights that are on, on the temperature set-point of the air-conditioning units, the speed of the machines that are producing, the number of kilometre that are being travelled. This means that when the energy manager is analysing the energy consumption of a certain organization and is trying to evaluate if the efficiency of energy system is higher or lower than a certain indicator, it is necessary to take into consideration the level of service that is being provided, i.e. to normalize the energy consumption value to the level of service that is being provided.

There are many examples of energy data normalization: for transportation, it is necessary to know the fuel consumption per travelled kilometre and/or tone of goods that were transported and/or number of persons; for space heating in buildings the area that was heated and/or the number of degrees above exterior temperature; for agriculture the energy consumption per area or per tonne of crop; for industrial plants, the energy consumption per product.

It is then critical for energy management systems to process not only the energy consumption data, but also the service that is being provided. Otherwise, it is not possible to normalize the energy data, by adjusting the values to the level of service that is being produced. Only in this way it is possible to evaluate the efficiency of an installation and compare the historical values or benchmark against similar facilities.

A common example of the error related to energy management that arises when comparing non-normalize values is when a manager presents a graph reporting that in a certain month, the energy consumption decreased compared to the same month in the previous year. If the weather was milder this year (less hot or cold) and air conditioning is a large part of the energy consumption, it is expectable that the consumption is lower. This does not mean that the installation is more efficient, it only means that the required service was lower.

To avoid this type of errors, it is important that the energy management system is able to compute the baseline consumption.

### 3.4.6 Baseline Consumption

*Baseline Consumption*

The *baseline consumptio*n is the energy consumption within a certain period of time that represents the operation of the facility or system before the implementation of energy efficiency measures. This period maybe as short as the time required for an instantaneous measurement of a constant quantity, or long enough to reflect one full operating cycle of a system or facility with variable operations, like one year in buildings to reflect weather changes or seasonal occupation.

*Testing period*

The period after the implementation of the energy efficiency measures are called the *testing period*. Energy savings are accounted by comparing the values in the test period with the ones in the baseline consumption.

*Normalized consumption*

The baseline should be adjusted to different operational factors, i.e. the baseline should represent the *normalized consumption*. The adjustments can of two types:
– *Routine Adjustments* account for changes in selected variables that are expected to change regularly and have a measurable impact on the energy use of a system or facility, like temperature or occupation.
– *Non-Routine Adjustments* account for permanent changes in static factors since the baseline period, like the expansion of a facility or the replacement of an equipment.

The baseline usually refers to a certain specific boundary, which may refer to an equipment, a specific area in the facility.

### 3.4.7 Key Performance Indicators (KPI)

*KPI*

*KPIs* are accessible numeric metrics of energy usage or observed facility characteristics that can be associated with better or worse than expected energy performance (i.e. lower or higher energy use). Much like KPIs in other business organizations, these are intended to yield the best information for the least cost and analysis time using the available metered data and observable characteristics.

*Comparison*

In general, KPIs are calculations based on energy usage over a period of time. These calculations may be simple or complex. The resulting metric is made meaningful by *comparison* to predefined goals previously established in the Energy Plan document (see Section 2.1). These goals are drawn from historical data, from benchmarking against similar installations/organizations, or established by management.

The KPIs depend very much on the activity of the installation, but the most common ones can be summarized as follows:

*Energy/are*

– *Energy/area* – in many types of facilities, from buildings to farms, a very often used indicator is the energy consumption per unit of area, where area is correlated to the activity level (a larger farm produces more than a small farm, larger hotels have more guests, larger power plants produce more goods). The considered area should the specific area that is used to perform the activity and not the total area.

*Energy/product*

– *Energy/product* – another indicator is the energy consumption per product that is produced in the facility. Product can be tonnes of crop in a farm, number of guests in hotels, km travelled or passengers or tonnes of freight transported.

*Energy/revenu*

– *Energy/revenue* – an indicator that derives from the previous one is the consumption per monetary unit of revenue. This indicates the overall economic efficiency of the activity - for countries it is often used the energy consumption per Gross Domestic Product. This KPI has the advantage of providing a clear insight of how much of the potential earnings associated with the implementation of energy efficiency measures.

### 3.4.8 *Energy Consumption Forecasting*

Modelling the energy usage of a facility is an important step to improving the efficiency of the system. An accurate model of future energy usage can be compared to actual energy usage to look for anomalies in the actual data that may represent wasteful usage of energy.

The short-term predicted energy usage, if accurate enough, could also be used to determine how much energy should be used now. For example, if the model predicts a large increase in energy usage in two hours, a moderate energy increase could be forced now to help combat the high future demand reducing for example peak loads. Alternatively, if a low energy requirement is predicted for the day, pre-heating or pre-cooling times can be pushed later to decrease total consumption.

There are different methodologies that can be used to forecast energy consumption. One option is to use mathematical algorithms based on the measurement of the energy consumption and the related variables. Within algorithmic methods we have:
– *Historical trend* methods where forecasting is a simple function of time. It works well when growth is constant and is effective on short run for much aggregated levels, as it does not describe the dynamics of the activity within a day or even a month.
– *Time series* with only a function of past values of only energy (uni-variate) or other variables (multi-variate). This is the approach that is most often used, but implies that the model is linear which may hinder important dynamics.

Another option is to have an end-use model, where a detailed model of all the equipment consumption and its operation scheduled is built. This type of models provides a good insight regarding the operation of the facility but it does not include information regarding external variables like weather, hence its scope of application is limited.

REFLECTION 3

Does the complexity degree of an EMS system depend directly on the complexity of the system that is being managed? Explain your answer.

## 4 **Energy Use Optimization**

The implementation of energy efficiency measures related with equipment substitution, processes and tariff changes does guarantee that the most significant part of the energy savings will be achieved. However, this does not necessarily mean that the job of the energy manager is done.

*End-use optimization*

In fact, the remaining potential of savings is usually related with the end-use of the facility. This phase, called the *end-use optimization*, deals with changing the users behaviour and is eventually the hardest part of the energy management program, as the savings are smaller and the payback periods maybe less interesting from the economical point of view.

In particular, this phase may require the use of control and automation processes that help the users to 'behave better'. However, the automated processes must be implemented in such a way that the users do not feel that they lost power to control their uses. This is the case for example with the optimization of temperature set points, which should to be a compromise between users comfort and optimal energy use. Users need to feel involved in the decision process and that requires that the energy management system also shares information with the users and includes their feedback

In this section we describe how users can interact with energy data to gain insight and what types of energy-use optimization approaches can be used to improve end-use energy efficiency.

## 4.1 ENERGY DATA REPORTING

Reporting is the process of presenting collected data to users. It is crucial to transmit information effectively to the EMS users in order to support their decisions towards energy savings.

### 4.1.1 *Classes of Users*

*Usability Understandability*

A recent research surveyed energy web portals to evaluate their compliance with dashboard design. The main characteristics that were established as relevant in the energy context were the *usability* and *understandability* of the information provided and how people react to the dashboard. Particularly if they felt curious about it and wanted to explore it.

Energy data reporting targets distinct classes of users that depend on the position and the responsibilities within the organization. Three types of users can be defined:

*Executive user*

1 The *executive user* who is responsible for analysing financial metrics and the budget performance of energy usage,

*Energy manager*

2 The *energy manager* who is responsible for analysing energy information from different perspectives and taking actions to reduce energy consumption and

*Occupant user*

3 The *occupant user* who interacts with the system and expects alarms or reports, and to take measures (Capehart 2011).

Reports have to be provided to fulfil the requirements of distinct user profiles, highlighting the most important information.

Another classification of user profiles can be considered according to business areas (Capehart 2011). In that case, four functional areas can be categorized as finance, operations, procurement and commissioning. The finance area is responsible for allocating and processing cost, validating bills and defining new budget targets.
The operations area performs benchmarks and baseline measurements, monitors the energy consumption and compares it with historical data. The procurement area is responsible for risk analysis, pricing model selection and contracting suppliers, processing and comparing different alternatives and discussing SLAs. Commissioning performs field actions to solve errors, forecast and simulations to prevent abnormal situations.

### 4.1.2 *Common Data Interaction Operations*

Important statement

The main goal of presenting data is to enable the user to get in-depth knowledge over the data and to draw conclusions. Furthermore, to ensure the effectiveness of energy data reports it is important to include a way in which the user can interact with the data exploration process.

Report effectiveness and quality can be measured in terms of *flexibility* of the operations that the user can perform on data and *usability* measured in terms of the number of interactions required to obtain the required reports for the user to read and understand the report.

Literature classifies interaction techniques that enable users to interact directly with data, dynamically changing the visualizations according to their objectives. Data exploration tools should therefore provide two main classes of functionality:

*Interactive Zooming*

– *Interactive Zooming*, which consists of presenting data in a more detailed way, providing different resolutions for analysis (Keim2002). In this way it is possible to identify different patterns and to select accurately the data that is important, discarding all the rest.

*Interactive Filtering*

– *Interactive Filtering*, which enables users to interactively constraint a data set into a smaller subset, splitting it for further analysis (Keim2002).

As it is possible to understand, these techniques rely heavily on the user interaction and his capacity to explore and evaluate information. Another way to look at reporting operations is to consider them as data transformations performed over the retrieved data that enable users to obtain knowledge regarding energy consumption. Distinct report operations enable users to be provided with different perspectives over the gathered data. These help EMSs to provide users with a better understanding regarding their building performance. The identified report operations are further addressed through this section.

## 4.2 TYPES OF REPORTS

In order to satisfy user needs, EMS solutions can resort to several types of visualizations able to provide different insights over captured data.

#### 4.2.1 *Timeliness of Reports*

Energy managers are interested in either analysing the acquired energy consumption data or observe data regarding the current status. According to user needs and requirements, three different visualization types can be identified:

*Historical Data*

– *Historical Data Analysis* is used when the user requires access to information regarding persisted data. However, a single query might return hundreds of thousands of points to be evaluated. A data table presenting all gathered points could not be evaluated in adequate time. Charts and dashboards enable EMSs to display all information data while providing a quick overall insight to users requiring such information.

*Real Time Monitoring*

– *Real Time Monitoring* presents the current building status regarding the current energy usage, equipment status and environment conditions by presenting the last measurements acquired. Real time monitoring visualizations enable energy managers to troubleshoot and verify building condition. However, energy managers provided only with the current measurements are unable to state how the building is performing. In order to assess building performance, gathered data must be correlated with historical data.

*Hybrid view*

– *Hybrid view* combines the most beneficial properties of real time monitoring and historical data analysis. Commonly users demand for a comparison between gathered measures with the expected ones. Often real time dashboards benefit from performance indicators able to inform users how energy is being consumed by correlating consumption with expected consumption. Furthermore, gathered values from environment sensors can feed the forecasting mode enabling energy consumption

*Forecasts*

*forecasts* to be provided along with real time consumption. There are several visual indicators that visually correlate current consumption with expected consumption or past consumptions. These increase EMSs usability, by enabling these systems to provide an insight on how the building is performing at a glimpse.

#### 4.2.2 *Consumption Breakdown*

Some EMS characterize electric load into four categories: energy consumed by IT equipment, energy consumed by lightning equipment in the building, energy consumed by plug loads and energy consumed by mechanical systems. This categorization is important to understand which equipment is over-consuming energy, when compared with the other categories. However, in our opinion this information is insufficient and does not provide the required energy profiling. To understand energy consumption we must correlate all energy-related data, for instance, by associating energy with location breakdown (room, floor, and building).

#### 4.2.3 *Comparative Views*

Comparative views are required in order to understand how the building is performing according to the real time measurements. Comparing expected consumptions against the real consumption allows EMS to provide performance indicators. An interesting performance indicator is a feedback measurement on how the building is consuming energy at the present. By comparing current values to past consumptions for the equivalent time period, it is possible to validate whether energy policies introduced are affecting energy consumption.

#### 4.2.4 *Correlation data visualization*

Energy management is required to model several variables of energy usage as well as spatial and temporal variations and environmental factors. In a recent project, an energy dashboard is proposed to improve the visibility of energy consumption at a university campus. This solution presents the data spanning over a year to highlight the seasonal changes and the direct correlation with the energy consumption.

#### 4.2.5 *Eco-Visualization*

Eco-Visualizations (EV) can be defined as 'any kind of interactive device targeted at revealing energy use in order to promote sustainable behaviours or foster positive attitudes towards sustainable practices'.

According to specialists, the feedback provided from electricity usage reports has a relation with the reduction of energy consumption, since it can trigger an environmentally-friendly behaviour. The human-computer interaction it's an important topic because these kinds of work should provide easy access to information and also raise the interactivity with the system in a way that can influence the user to make better decisions.

*Policy Enforcement*

In large building context the dweller has less control over the energy usage (compared with home context), nevertheless managers should *enforce* them to reduce energy consumption since there is no direct financial incentive for them. This is also the case of professional drivers in transportation organizations or workers in a factory.

There is a set of strategies that highlight data about energy consumption and tempt the user to act pro-actively. Providing real-time feedback (for instance, through numerical display of the energy consumption in buildings or sound warnings for drivers when they are above recommended speed), use brightness schemes to illustrate different levels of consumption, offer tools that can be deeply explored to find consumption patterns and raise user's curiosity, create social incentive (for instance comparison between historical data), show the material impacts of energy consumption and integrate scientific data (graphs) with direct-feedback (for instance cost of energy usage). Creating a competition will result in the largest savings.

*Competition*

## 4.3 ENERGY PROFILING

Energy profiling consists of tracing an energy consumption pattern based on past consumptions and behaviours of end-users.

Usually buildings have patterns that reflect daily and seasonal scheduled operations as well as occupant's routines. Nevertheless significant deviations on energy consumption arise when analysing collected data.

Finding the sources of those deviations and how they influence energy consumption, will improve energy forecast effectiveness, leading to energy savings. Capturing sources that influence energy consumption enable EMSs to produce an Energy Profile.

*Drivers of energy consumption*

The main drivers of energy consumption identified are:
– *Work-schedule* (time and weekdays) due to their correlation with time-scheduled operations and users' routines;
– *Temperature and humidity* as a result of their impact in HVAC system.
– *Day brightness* through its effect on building lighting
– *Equipment status* as device set-points or operating modes affect energy consumption, furthermore capturing their status enables the EMS to avoid equipment to breakdown or to run inefficiently.
– *Building occupation* has an impact in the usage of most systems on the building. The number of people has a direct influence on the effectiveness of HVAC system, because air needs to be recycled more often to reduce the amount of $CO_2$ and body heat production. Furthermore, the increase of building occupation might relate to the use of additional electrical equipment such as computers.
– *Production schedules* might have a huge impact on energy consumption. In some cases, due to the heavy machinery being used during those periods, this factor overshadows other factors.

## 4.4 ENERGY-USE OPTIMIZATION TECHNIQUES

### 4.4.1 *Load Management*

Load management is the process of balancing energy consumption in order to avoid high energy price periods. High energy demand periods might have an aggravated energy tariff associated with them - the energy cost and the required power. The objective is to incentive users to have flatter load diagrams. If peak periods were left uncontrolled, energy suppliers could require backup energy plants to keep with power demand.

*Demand Response technique*

Load Management can be also perceived as a *Demand Response technique*, a term used for programs designed to encourage end-users to make short-term reductions in energy demand in response to a price signal from the electricity hourly market or even a Demand Side Management technique, a broad term used for programs that encourage the end user to be more energy efficient and include retrofits, automation, ore equipment improvement.

In order to avoid aggravating energy consumption costs due to high power demand periods, two main Load Management techniques might be implemented by the building automation system (BAS):

*Load-Shifting*

– *Load-Shifting* also known as Flexible Load, is a technique where the energy load period is modified, reducing demand on time slots with higher prices by shifting them to time slots with lower prices. As a result, although the same amount of energy is used, overall costs associated with energy consumption will be reduced. Theoretically buildings can implement this technique by either changing production schedules or by conserving energy on low demand periods when the energy price rates are lower. Energy can be stored in the form of thermal storage such as boilers or cold water units known as chillers (used by the HVAC systems). This technique allows energy managers to control building comfort levels while reducing operational cost.

*Load-Shedding*

– *Load-Shedding* also known as Demand Limiting or Peak Clipping, is a technique where energy peaks are reduced by restricting energy consumption. To accomplish this goal, EMS starts to take actions that have none or little impact on comfort, such as turning off some equipment, reducing equipment load or delaying energy demanding tasks that can be performed on a different schedule. If those actions fail to bring consumption below the established limit, minimum comfort ranges can be momentary reduced. This approach is known as *set-point relaxation*, where equipment settings might suffer little changes to bring power consumption down. It can be achieved by changing HVAC systems set-points, stopping some elevators or lower the light brightness through dimming. However, changing the comfort settings does not mean occupant's productivity would be affected. In fact a study performed by Mancini shown that in a windowless environment, 50% of the participants found that a reduction in light level of 20%–30% was acceptable. In this study, users were aware that light would be dimmed, thus they would be more susceptible to light changes.

*Set-point relaxation*

Both techniques might be used simultaneously. Avoiding energy high priced time slots and shedding energy consumption at those time periods might bring significant energy cost savings.

### 4.4.2 *User Behaviour Transformation*

Energy behaviour represents a significant untapped potential for the increase of end-use energy efficiency. Although energy behaviours are a major determinant of energy use in buildings, energy savings potential due to behaviour are usually neglected. Yet studies suggest that potential savings can be as high as those catered by technological solutions.

Potential savings of energy behaviours are reported to reach 20%. Different modelling techniques have been used to model energy behaviours: qualitative approaches from the social sciences trying to interpret behaviour; quantitative approaches from the engineering and economics that quantify energy consumption; and hybrid approaches that integrate multiple dimensions of energy behaviours.

Energy behaviours have a crucial role in promoting energy efficiency, but energy behaviours characteristics and complexity create several research challenges that must be overcome so energy behaviours may be properly valuated and integrated in the energy policy context.

*User engagement*

The success of new technologies to improve energy savings rely heavily in the *user engagement*. In this context, visual information is required in order to foster actions that raise energy efficiency. Besides giving the possibility to visualize consumption information, it also serves the purpose to help understand what behaviours and actions influence the energy consumption.

End-users need a motivation to change their behaviour. Motivations, from an individual perspective, are categorized into perceived costs and benefits, moral and normative concerns, and affection. The first motivation considers that individuals weigh the pros and cons, making rational choices in order to maximize their benefits. It also considers how much effort the behaviour takes; so behaviour that is facilitated will be adopted sooner. The second is related to the valuation of environmental beliefs and environmental concerns, the moral obligation to act pro-environmentally and the influence of social norms on behaviour. Finally, the third makes use of affective and symbolic factors to explain environmental behaviour. End-user transformation can be seen as a process with three phases: educate, motivate and prompt the change.

REFLECTION 4

Should energy end-use optimization rely more on hardware and software elements or on human behaviour adjustments? Explain your answer.

## 4.5 ENERGY-USE OPTIMIZATION IN DATA CENTRES

Important statement

The state-of-the-art DC must definitely include Energy Management Systems to reduce energy consumption to the minimum possible.

### 4.5.1 *Applying Energy Management in DCs*

*Efficiency of the DC*

As a starting point, it is essential to measure the *efficiency of the DC*, using the PUE metric or other. This requires the separate measurement of the energy consumption in the IT systems and on the remaining systems (UPS, Cooling, etc.). Nowadays, the PUE is only estimated taking into account the installed power in the IT system, disregarding the fact that many times the DC is not operating at full capacity. In practice, this means that the IT consumption is smaller than the nominal value. Therefore, the PUE metric estimation is an upper bound to the real value.

*Control of the cooling system*

Secondly, the *control of the cooling system* should definitely be done by an EMS. Instead of comfort parameter, the EMS must balance energy consumption with very stringent reliability issues from the IT equipment: as we have seen in Chapter 5 ASHRAE's 'Thermal Guidelines for Data

Processing Environments' (2012) recommends a temperature range of 18–27 °C (64–81 °F), a dew point range of 5–15 °C (41–59 °F), and a maximum relative humidity of 60% for data centre environments, so the temperature can never go beyond 27°C, the humidity can never go beyond 60%. Further, if the system is taking advantage of free cooling, the information regarding exterior conditions is crucial.

#### 4.5.2 *Energy Efficiency Policies for DC*

According to the EPA, if some energy efficiency measures are applied to the DC facilities the electricity use could be reduced by up to 43% compared to 2006. These scenarios are based on the following assumptions:

*Improved operation*

– *Improved operation* scenario includes energy-efficiency improvements beyond current trends that are essentially operational in nature and require little or no capital investment. This scenario represents the 'low-hanging fruit' that can be harvested simply by operating the existing capital stock more efficiently (e.g. airflow management, elimination of unused servers, adaptation of 'energy-efficient' servers to modest level, as discussed in Chapter 4).

*Best practice*

– *Best practice* scenario represents the efficiency gains that can be obtained through the more widespread adoption of the practices and technologies used in the most energy-efficient facilities in operation today. It includes all measures in the 'Improved operation' scenario, plus the improvement of transformers and UPS, improvement of the chillers, fans and pumps efficiency, and the use of free cooling, adoption of 'energy-efficient' servers.

*State-of-the-art*

– *State-of-the-art* scenario identifies the maximum energy-efficiency savings that could be achieved using available technologies. This scenario assumes that U.S. servers and DCs will be operated at maximum possible energy efficiency using only the most efficient technologies and best management practices available today. This includes all the measures in the 'best practice' scenario plus the use of direct liquid cooling solutions, Combined Heat and Power systems (CHP), aggressive consolidation of servers, enable power management at DC level of applications, servers, and equipment for networking and storage.

The actual high energy consumption of the DCs and its forecasted consumption raise significant concerns to Europe and U.S.'s energy and environmental policies. It is very important to ensure the minimization of the energy use in DCs in order to reduce the greenhouse gases emissions and impacts in energy infrastructures. It is imperative to establish energy efficiency policies and promote the development of Sustainable DCs.

REFLECTION 5

What are the risks of implementing EMS systems for DC in the cloud?

# 5 Further Reading

## 5.1 BOOKS

Capehart, B. L. & Midelkoop, T (2011). Handbook of Web-based Energy Information and Control Systems, CRC Press, Taylor & Francis.

*This is a book that edits several industry case study articles in the application of Energy Management Systems across various industries.*

Han, J. & Kamber, M. (2006). Data Mining: Concepts and Techniques. Morgan Kaufmann.

*This book presents the principles of operation of Data Analytics and Data Analytics that are now recognized as standard across industry.*

ISO 50001, (2011). Energy management systems – Requirements with guidance for use. International Organization for Standardization, ISO 50001:2011

*This ISO standard presents in details the distinct phases of an Energy Management Program as presented in this chapter.*

Kimball, R. & Ross, M. (2013). The Data Warehouse Toolkit: The Definitive Guide to Dimensional Modelling. John Wiley & Sons; 3rd Edition.

*This book presents the principles of operation of Data Warehousing that are now recognized as standard across industry.*

Turner, W. C. & Doty, S. (2006). Effective Energy Management. In: Energy management handbook. s.l.:Fairmont Press.

*This book is an authoritative guide on Energy Management that is used as reference guide by energy management practitioners worldwide.*

## 5.2 SCIENTIFIC ARTICLES

Ahamed, A., Ploennigs, J., Menzel, K. & Cahill, B. (2010). Multi-Dimensional building performance data management for continuous commissioning. Advanced Engineering Informatics, 466 – 475.

*This article is among the few sources that clearly makes the case for the use of Data Warehousing for Energy Management and describes in details the variables to be used in dimensional modelling and where to find the data sources.*

Buyya, R., Yeo, C. S., Venugopal, S., Broberg, J., Brandic, I. (2009). Cloud Computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility. Future Generation Computer Systems, 25, 599-616.

*This article presents the long term vision for the evolution of data centres and the trade-offs that will have to be made.*

Gokce, H., Browne, D., Gocke, K. & Menzel, K. (2009). Improving energy efficient operation of buildings with wireless IT systems.

*This article presents the architecture of an Energy Managements System that closely follows the principles presented in this chapter with the particularity that data acquisition is performed using wireless nodes.*

Wilkinson, R. (2000). Become a BAS master. Engineered Systems, 2(17), pp. 44-49.

*This article details the issues of interoperability and integration which are pervasive in Building Automation Systems and also apply to Energy Management Systems.*

## SELF–ASSESSMENT

1 Please define the 'Greening by IT' concept?

2 Please enumerate possible applications of 'Greening by IT'.

3 What is the difference between an Energy Management Program and Energy Management Process?

4 What are the main data sources for Energy Management Systems?

5 What optimization strategies can be implemented automatically?

6 What are the requirements of an EMS to improve the energy efficiency of a Data Centre?

MODEL ANSWERS

## 1 Answers to Reflection Questions

1 The trade-off between the number of Greening by IT applications running in Data Centre and the consequent Data Centre energy demand growth can be evaluated by the ratio of energy savings promoted by the ICT application and the energy consumed to run the application. The ration has to higher than 1. This is difficult to measure for two reasons: calculating energy savings is a complex and uncertain problem and it is also difficult to measure the specific consumption of an application in a server.

2 In terms of energy management it is better to migrate all small to medium size DC to large facilities with EMS. However, the criticality of the operations may constrain this migration. In any case, an EMS system should be installed.

3 The complexity degree of an EMS system depends more on the complexity level of the energy services required by the facility than the complexity of the facility *per se*. For example, an industrial facility may have a larger degree of complexity compared to an office building, however, the use of energy in office-buildings may require a higher degree of sophistication of the EMS.

4 Hardware and software elements may promote a higher robustness in the implementation of an optimized end-use solution. However, the cost and complexity of implementing such a system may not be cost-effective. Further, even automated systems require up to a certain degree some level of interaction with users. Thus, changing behaviour should always be implemented and, if possible, with some help from hardware and software.

5 DC are critical facilities so, paradoxically, the EMS system should be resident in the DC and not in the cloud.

## 2 Answers to Self-Assessment questions

1 'Greening by IT' refers to the employment of IT towards the development and implementation of a greener and more sustainable world.

2 Smart consumption, smart energy grids, intelligent houses and buildings, smart cities, intelligent transportation and logistics, intelligent manufacturing

3 An Energy Management Program is a set of actions defined by the organization that create the context to promote energy efficiency practices; the Energy Management Process refers to the operationalization of these actions, which include data acquisition and storage, data processing and analysis, reporting, control, diagnosis and optimization.

4 The main data sources of EMS are the energy consumption of the facility (total and disaggregated by service, space, etc.) and the variables that influence energy consumption (activity level, weather, equipment inventory, etc.)

5 The optimization strategies that can be easily implemented automatically are the ones related to Load management: load shifting and scheduling. However, some activities related to behaviour transformation can also be automated, like information display and alarm settings.

6 The requirements of an EMS to improve the energy efficiency of a Data Centre are mostly related to the control of the cooling system, in particular in the case of free-cooling systems to take advantage of the exterior weather conditions.