Overview on Energy Data Reporting

Tiago Cardoso and Paulo Carreira
{tiago.cardoso, paulo.carreira}@ist.utl.pt

Instituto Superior Técnico

Abstract. Energy Management Systems (EMSs) are tools that monitor building energy consumption enabling more informed decisions towards rational usage of energy to be made. Current EMS applications provide high report diversity, allowing their users to gain significant insight to understand how their building is performing. However, to the best of our knowledge, there is no literature available on the different reports and visualizations types available. Report usability towards the user may vary depending on the type of data displayed and how it is displayed. This article tries to define and classify existing visualizations and reports. A reference data model together with an architecture is presented, both avoid having either lack of energy reports and also rigid reporting options, by enabling the generation of new reports.

1 Introduction

Energy Management Systems are tools able to monitor facility operations through the gathering of building data related to environment and equipment operations. Gathered data is used to generate reports that will help increase user awareness on how building operations are performing. Through reports, EMS aims at guaranteeing maximum operation efficiency, reducing energy usage, without adversely affecting the building occupants comfort. Adequate data presentations enable EMS to: *Improve the level of building management*, acting as centralized management system; *Provide a pattern of energy consumption*, through the captured energy data, allowing unexpected consumptions to be identified; *Identify peak electrical demand*, that might be responsible for additional costs.

In order to achieve its purpose, an EMS performs three fundamental operations, *(i)* gathering all energy related data , *(ii)* interpretation of collected data, *(iii)* data presentation to the users in the form of reports [11]. Currently there is not an agreed architecture describing an EMS, actually, most of the systems follow a monolithic approach, unsuited with the idea of having an extensible and flexible system. Allied to the fact that most of the current systems are vendor specific developed as close projects, current EMS systems have a narrow scope on reports, providing only a set of rigid reports. This inability cripples current solutions ability to maintain users informed through the use of reports that transmit raw data instead of knowledge.

The remaining of this document is organized as follows: Section 2 describes the main energy data reporting dimensions. Section 3 overviews which operations are desirable to perform according to dimensions described in previous section. Section 4 presents the report visualizations types. Section 5 describes the required data sources necessary to support the report generation with focus on a reference architecture, data model presented which design was oriented towards flexibility and extensibility and an EMS implementation based on them. Finally Section 6 will summarize this article and present the conclusions.

2 Energy Data Reporting

Reporting is the process of presenting collected data to the user. It is crucial that information is transmitted effectively from the EMS to the user in order to support his decisions [8, 13]. Report effectiveness and quality can be measured in terms of: *Interactivity* with the user; *Time window* needed for user read and understand the report; the *Usability* the report might have to the user and energy manager tasks; *Data exportation* capability allowing data to be captured and transformed freely by the user. In order to better understand report usage, we must study which **report dimensions** are available:

Time dimension allows the system to identify, through the use of a time-stamp, when the data was acquired.

Device and device type dimension is required to identify where the data is being collected from. It is through the device and device type that location dimensions and properties being measured are obtained.

Location dimension enables the user to known which locations are associated to the acquired data.

Organizational data dimension allows the system to relate which locations are associated to which department or individual.

Measured property dimension enables the user to select which properties/ measurement type should be presented in the report.

Energy tariff dimensions enable the system to correlated measurements from energy meters to the tariff in practice at the time of the measurement.

3 Reporting Operations

3.1 Filtering and aggregation

Report information must be filtered, otherwise the user could be overwhelmed with information presented towards him. Filtering is achieved through the manipulation of the data on report dimensions:

Time dimension allow users to select which time period will be analysed. EMSs gather data since the moment they are turned on, so reports need a time dimension filtering option otherwise report data could not be analysed in adequate time. Report data can also be aggregated by time, allowing users to compare energy consumption on different time periods (days, weeks, years).

Device and device type dimension is needed to identify where the data is being collected from, allowing to select only the information gathered by specific devices. This option enhances system capability to debug a problem when the building is not performing accordingly to expectations [8].

Location is a dimension obtained from the devices installation location or monitoring range. Location can act either as a filtering and aggregation dimension enabling the user to select which data devices should be presented.

Departmental organization is a dimension obtained from the relation between locations and departments. This dimension can be seen as a degenerated dimension from location, clustering locations through *"belongs to"* relationships and offering filtering and aggregation operations.

Measured property dimension enables the user to select which properties being monitored should be presented in the report. Some static data properties such as production line schedules might be available to selection due to their relevance to energy consumption.

3.2 Energy Profiling

Energy profiling consists on tracing an energy consumption pattern based on past consumptions or behaviours. Consumption is highly related to time, usually buildings have patterns that reflect daily scheduled operations or occupants routines. Nevertheless some significant deviations on energy consumption when analyzing collected data shall be found. Finding the sources of those deviations and how they influence energy consumption, will improve forecast effectiveness [10]. Those deviations can be found in data being extracted from equipment across the building. Determine those sources is a process denominated *data normalization* and in energy its main drivers are [2, 17]:

Weekdays influence building operations and building occupancy. Due to their influence on building energy consumption, information must be correlated according to the week day when the consumption occurred [16].

Temperature influence energy consumption due to its impact on HVAC systems, buildings major energy consumers. Systems use two set point temperatures, one to start cooling the building and other warm it up. Data normalization is usually performed according to *cooling degrees* and *heating degrees.*

Lighting equipment are the second largest energy consumer in our buildings [5]. Some buildings try to conserve energy by setting lights according to time schedules. In this case such event will be capture with consumption pattern according to time. However more advanced systems perform according with outside brightness. In those systems brightness levels need to be captured.

Humidity affects HVAC efficiency to cool and warm the buildings environment having direct impact on consumption.

Building occupation has an impact in the usage of most systems on the building [14]. The number of people have an 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 regarding energy consumption.

Equipment status gathers the mode on which systems are operating. For instance, on HVAC systems lowering the set-point might bring energy savings, in spite of affecting occupants comfort [8]. Some energy policies are defined according to the settings on which equipment operate.

3.3 Energy Forecast

Energy forecasting is the process of predict energy consumption based on past events. After data normalization process takes place, is possible to make accurate consumptions forecast according to the expected conditions. Through the forecast process energy peaks can be estimated and actions to avoid them can be deployed, allowing to save associated costs to be saved.

3.4 Cross Operations

A complete solution must offer the possibility to cross the previously stated operations. The raw energy consumption data does not provide any insight on how our building is performing, we need comparative views. By comparing expected consumptions against the real consumption, performance indicators can be found [7]. These will offer an better insight on how current energy policies are affecting the energy consumption. Due to the fact that forecasting the energy consumption results directly from assigning values to the measures used in the profiling operation, forecasting shares profiling dimensions.

4 Report data visualization types

EMS solutions must generate visualizations according to user needs. While performing his tasks, the user is interested to either analyse acquired consumption data or observe data regarding current building state. According to user needs and requirements, three different visualization types can be identified.

4.1 Historical Data Analysis

This approach is used when the user requires access to information regarding gathered data. However, a single query might return hundreds of thousands of points to be evaluated [12]. A data table presenting all gathering points could not be evaluated in adequate time. Charts and dashboards allow EMSs to display all several information data at once. EMS might use charts such as line charts or stream charts to perform analysis over time [13]. Dashboard can be used showing performance indicators, informing the user how energy was consumed during a time period, relative to expected consumption or past consumptions.

4.2 Real Time Monitoring

Real Time Monitoring enables users to see information about energy usage, equipment status and environment conditions on real time. Presenting the last read values from the devices across the building captured provides the current building state. However, metering data presents only values accumulated over time. This information alone unable to tell the user how the building is performing without information about the previous reading, therefore, some data has to be manipulated before being presented to the user.

4.3 Hybrid view

Hybrid view combine the best properties of both real time monitoring and historical data analysis. The user is looking for a correlation between gathered measures with the expected ones. The gathered values from environment sensors can feed the forecasting model (discussed in 3.3) to provide a prevision on real time consumption. A visual indication on how current consumption relates to the expected consumption can be presented, providing an insight on how the building is performing at a glimpse increasing system usability [13].

5 Energy Data Integration

5.1 Data Acquisition

Data gathering is the process responsible for acquiring data that might concern energy consumption. Gathered data might come from three different source types: energy meters, environment sensors, equipment status sensors [11]. Data retrieved from meters enable the EMS to gain insight on building energy consumption. Environment data will allow the EMS to correlate energy consumption to monitored conditions. Collecting data regarding equipment status enables correlations between consumption and operational status to be found.

Energy Metering Meters are cumulative reading devices, designed to measure the amount of consumed energy [1]. Their installation location might dictate the insight possible to be obtained.

In order to achieve a better resolution regarding energy consumption, some solutions might install meters on locations that were already monitored by other meters, this approach is named **sub-metering** [6]. Bigger insight on energy consumption can be achieved following this approach, allowing unexpected consumptions to be diagnosed and its root to be found.

Environment conditioning monitoring Energy consumption is highly related with external factors such as weather and building occupation, so they must be monitored and acquired in order to be correlated with energy consumption. Environment can be monitored through sensors, which provide an instant reading over the measure being monitored. These relations between environment and energy consumption enable EMS to profile consumption and forecast consumption based on the expected conditions.

Equipment status monitoring Equipment status data enables the EMS to obtain information about which devices were operating and under which conditions when a consumption pattern occurred. Therefore, collecting these data enable the EMS to establish a relation between energy consumption and device operation status. Usually energy policies are equipment settings definitions, such as HVAC set points, collecting this data will allow to identify which measures provided better savings.

With this knowledge the energy manager might decide the best path to achieve a desirable condition, e.g. lowering building temperature using the less amount of energy.

5.2 Data Quality

To ensure that reports are precise and accurate, faulty data must be identified and its integration into the repository avoided. Faulty data can be identified as incorrect, inconsistent or noisy. These type of data are determined through a data quality process, in which several quality dimensions must be evaluated [3]:

Accuracy dimension relates to the precision of the data being captured. All equipment have a known precision, however due to equipment malfunction or lack of maintenance its precision can be affected, leading to incorrect data.

Timeliness dimension reflects data quality according to how long is it valid. For instance, on real time monitoring data must be updated constantly.

Volatility dimension reflects data *expiration date*. Meters and sensors do not store data. EMS needs to keep acquiring devices to obtain their value, otherwise the time gap between reading intervals will have to be interpreted has missing data and be estimated leading to incorrect results.

Consistency measure evaluates if the equipment readings are non-conflicting. For instance, in a room with two temperature sensors, if they measurements are inconsistent it is impossible to say what the real temperature was.

Completeness dimension evaluates if all required information is available. Collecting data from a meter which monitoring range is unknown is an example of incomplete data. In this example sub-metering operations could not be tracked.

Duplicate dimension evaluates if gathered data was already acquired and added to the system repository. Acquiring duplicate values can lead to misleading information being presented on reports (energy peaks that didn't occur).

Acquired data that does not meet those measures must be identified as faulty data and the system must correct them. On EMS the mostly common issues are related to network failure, duplicate data, misread information and human error while inserting data manually. Having identification, EMSs have to either discard them or by correct faulty data. On EMS where data quality analysis is performed, error rate is expected to be in order of approximately 1-5%, although error rate can go up to 30% where the process is non-existent [15]. After extracted data is analysed and corrected, it might need transformations to fit system data model. [9]. The entire process of data extraction, cleaning and transformation is also known as the process of Extract Transform and Load (ETL) [12].

Data Mining Data mining is the process of data exploration aiming to find patterns in data in order to "extract" knowledge. [9] These patterns can aid determine if data is being retrieved correctly, measuring data quality. If some retrieved data is outside the range of expectable value according to other measurements, data can be seen as an "outlier" and be discarded or being simply market as having highly inaccurate. Furthermore, this process can be particularly useful for retrieving consumption patterns, identifying what are the most frequent causes of consumption peak responsible for high price tariffs and high billings. After retrieving an energy consumption pattern, the energy manager might prevent those peaks by managing the energy load. Is through Data Mining process that energy consumptions variables are found, allowing energy consumption and energy profiling to be made [4].

5.3 Centralized Model

The EMS architecture solution proposed is designed oriented towards flexibility and extensibility. This solution aims to gather data from several heterogeneous sources that might be added or removed from the system, while implementing a platform to develop new reports.

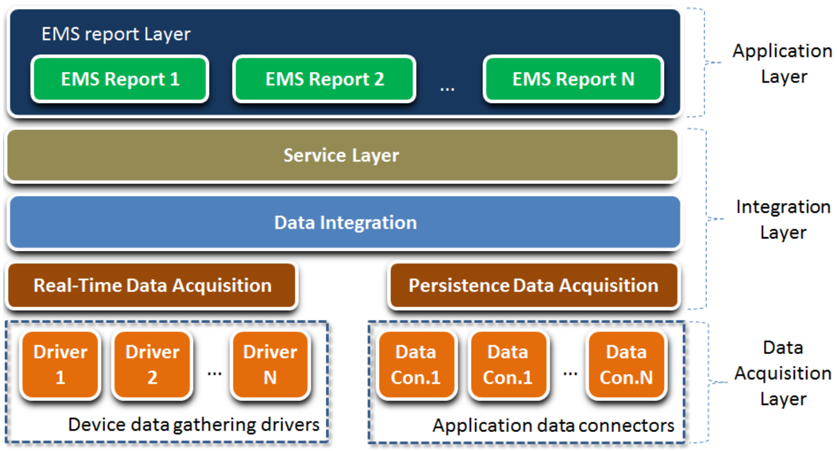

Fig. 1. Proposed architecture.

The proposed solution is a three layered architecture presented in Figure 1. *Data Acquisition Layer* oversees data acquisition from meters and sensors, *Integration Layer* is responsible for collecting, storing and granting access to the gathered data and *Application Layer* is responsible for the data visualization. *Real-Time Data Acquisition* module allows the addition of new devices through the implementation of a new *Device Data Gathering Driver*. These drivers are responsible for implementing the communication protocol, enabling them to collect data from the devices they are designed to. They are connected to the real-time data acquisition module through its exposed interface. For instance, if data from *deviceA* is required, the solution only needs to *know* that the *deviceA* is reachable through *driverX*. If a new device is created, to use it we simple develop a new driver and add it to the solution by linking the device to the driver.Data will be integrated in the solution data repository by the *Data Integration* module. This module is also responsible for dealing with data quality issues, identifying data errors and correcting them. Unexpected data, that is, data that is not coherent with the energy profile or forecast, will be marked as being inaccurate for further analysis. The frequency on which it occurs might trigger a warning about a required maintenance check. A *Service Layer* will be placed over the remaining solution providing access to gathered data through services exposure. This module serves as an abstraction layer between the data model and the applications demanding its data. Third party applications, represented as *EMS Reports* can be deployed using Service Layer exposed services. The underneath architecture serves as framework to the EMS applications deployed on top. They will be responsible for showing data and information to the user. This conception allows new data visualizations to be added to the deployed solution, offering another expansion capability without impacting the remaining solution.

5.4 Data Model

The data model is the conceptual design of a data warehouse where information collected from multiple data sources is stored into a coherent repository [9]. Having all information stored in a DW, makes information available even when is collected on different locations, enabling data analysis and data mining to be performed at a single point. All collected data will be stored in it supporting system reports generation. The schema model is represented in the Figure 2.

In this model there are three data gathered types needed to be modelled: (i) meter data, (i) environment data and (iii) equipment maintenance. Each measurement will be identified according to the time in which the measurement was performed, the device that performed the reading and which measurement (property) is being captured. Measurements performed by energy meters might have a tariff model associated to it, enabling energy costs to be obtained from a set of readings. Each measurement will have a data quality dimension associated, indicating if the measurement appears to be correct, doubtful according to expected results, or has been programmatically estimated to overcome missing data. Through the device dimension, we can access information regarding the device measurements range, an important aspect once a single device might be monitoring several locations. A location in this model can be seen as a tree, where each node is a distinct location. This hierarchical view allows sub-metering to be performed and tracked by the system. The tariff model relates to the meter data fact table, through the *TariffModel* dimensional table which might present several values.

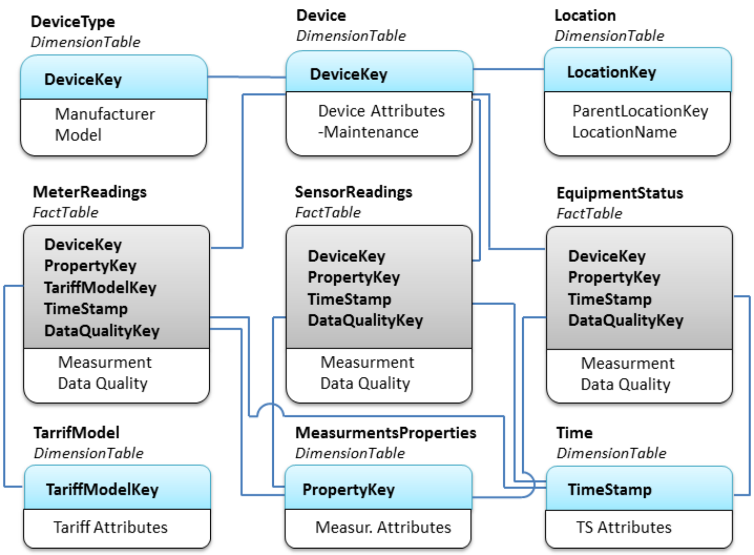

Fig. 2. Conceptual view of the data model.

5.5 Prototype Deployment

The final prototype will be deployed on Tagus Park installations using Tagus Park monitoring equipment and energy meters provided by QEnergia. QEnergia energy meters will be the S-Energy Manager [1] controller that can be connected to several devices collecting their readings. A driver will be implemented to collect data from QEnergia devices, as well as other available sensors and meters available at the laboratory. The real time data acquisition module will periodically retrieve information from the assigned drivers. Before being stored into the system data model, collected data will be analysed and its quality evaluated. Collected data must meet all quality measures (discussed in the Section 5.2), so data must be compared against data retrieved from other devices to check its veracity and only then can be stored into the system. Gathering data from several sources allows more interesting data correlation to be found allowing data analysis and energy forecast to be performed and evaluated more accurately.

[1] http://www.saia-energy.com/14-0-Energiemanager.html

Static data referring to Tagus Park class rooms and other areas as well as locations assigned to each department (organization data), will be loaded into the system. The energy cost plan in use at Tagus Park will be modelled into the system.

To test EMS extensibility, two applications will use the solution service layer. One application will use real time monitoring visualization, testing application capability to send events back to the applications connected the it. The second application will implement an interface that will allow to set energy price tariffs, and extract summarized reports regarding energy costs.

In the end the prototype development will result in a tool able to monitor the building operations, helping reducing the energy costs associated to them. Notice that although the final result will consist on an ordinary EMS application, this will be able to be expanded. New drivers can be developed in order to support new devices or even retrieve data from other sources such as available online web services to gather weather data. Due to the developed data model, the system will be able to support data from several types of devices relating energy, building data, organizational data and even equipment operations. On top, new visualizations can be developed and added to the existed solution, offering an expansion possibility to add new reports, visualizations and mechanism that will inform and aid both energy managers and building occupants.

6 Conclusion

In this paper we discussed the main features presented by current EMS systems, as well as their limitations. Energy Managers are fully aware on the potential offered by these systems towards energy savings. Nevertheless they are unaware on the fact that most of these systems only offer a narrow view over the available data. Most developed solutions are able to present a lot of data, but with little knowledge over the collected data. The system must be able to provide, effectively, an insight on energy consumption. A related issue relies on the fact that few systems are able to perform data analysis and detect problems with data. Faulty data must be handled by these systems, warning users about a potential lack of accuracy when presented.

Through the presented proposal, we believe those problems can be overcomed. Presented data model enables gathered data from multiple sources to be stored under the same repository, enabling the system to collect data regarding energy consumption, equipment condition and environment status. To enhance system's flexibility, new data sources can be added to the system through the implementation of data gathering drivers. Data quality issues can be found with data analysis and a quality measurement can be presented on the report. The solution service layer allows third-party software to use the underneath solution as a framework, enabling it to retrieve gathered data by the solution. New data reports can be added easily with minimal impact to the remaining solution. Prototype evaluation will be performed by system deployment, testing the solution capability to add new data sources and expandability. We expect to assist dissemination of EMS systems in buildings, through the developing of a state of the art system that will bring together features that will help to monitor and predict the cost of energy consumption in a single tool, enabling energy managers to make informed decisions to save energy.

References

1. Y. Agarwal, T. Weng, and R.K. Gupta. The energy dashboard: improving the visibility of energy consumption at a campus-wide scale. *Embedded Network Sensor Systems, SenSys*, pages 55–60, 2009.
2. Ammar Ahmed, Joern Ploennigs, Karsten Menzel, and Brian Cahill. Multidimensional building performance data management for continuous commissioning. *Advanced Engineering Informatics*, 24(4):466 – 475, 2010.
3. C. Batini and M. Scannapieca. *Data quality: Concepts, methodologies and techniques*. Springer-Verlag New York Inc, 2006.
4. B.L. Capehart and T. Middelkoop. *Handbook of Web Based Energy Information and Control Systems*. Fairmont Pr, 2011.
5. F.M. Courtel, D. Duguay, Y. Abu-Lebdeh, and I.J. Davidson. The potential for demand responsive lighting in non-daylit offices. *Journal of power sources*, 202:269–275, 2012.
6. S. Drenker and A. Kader. Nonintrusive monitoring of electric loads. *Computer Applications in Power, IEEE*, 12(4):47–51, 1999.
7. S. Few and Safari Books Online. *Information dashboard design*. O'Reilly, 2006.
8. A.E. Guntermann. Are energy management systems cost effective? *Industry Applications, IEEE Transactions on*, pages 616–625, 1982.
9. H. Jiawei and M. Kamber. Data mining: concepts and techniques. *San Francisco, CA, itd: Morgan Kaufmann*, 5, 2001.
10. Ricardo Sosa Liliana Argotte, Manuel Meja-Lavalle. Business intelligence and energy markets: a survey. *Intelligent System Applications to Power Systems*, page pages 74?84, 2009.
11. X. Ma, R. Cui, Y. Sun, C. Peng, and Z. Wu. Supervisory and energy management system of large public buildings. In *Mechatronics and Automation (ICMA), 2010 International Conference on*, pages 928–933. IEEE, 2010.
12. D.Y.R. Nagesh, J.V.V. Krishna, and S.S. Tulasiram. A real-time architecture for smart energy management. In *Innovative Smart Grid Technologies (ISGT), 2010*, pages 1–4. Ieee, 2010.
13. D.Y.R. Nagesh, A. Sowjanya, and S.S. TulasiRam. Real time decision support for energy management. In *Proceedings of the World Congress on Engineering*, volume 1, pages 16–22, 2008.
14. Luis Prez-Lombard, Jos Ortiz, and Christine Pout. A review on buildings energy consumption information. *Energy and Buildings*, 40(3):394 – 398, 2008.
15. T.C. Redman. The impact of poor data quality on the typical enterprise. *Communications of the ACM*, 41(2):79–82, 1998.
16. S. Rojchaya and M. Konghirun. Development of energy management and warning system for resident: An energy saving solution. In *Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, 2009. ECTI-CON 2009. 6th International Conference on*, volume 1, pages 426–429. IEEE, 2009.
17. J.C. Van Gorp. Enterprising energy management. *Power and Energy Magazine, IEEE*, 2(1):59–63, 2004.