VIRTUAL ENERGY MANAGEMENT PLATFORM FOR LOW ENERGY BUILDING OPERATIONS

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ABSTRACT

Europe's objective under the 20-20-20 target is to reduce energy consumption by 20% and increase the renewable energy sources by 20% in the overall energy mix. The European Union currently imports two third of its oil and gas which makes it the world's leading importer of these fuels. Due to increasing energy prices and relatively high percentage of building related energy consumption much effort is invested for energy efficient buildings. Apart from meaningful building insulation measures, the only means of achieving marked improvements in the energy efficiency of buildings is to make use of efficient building automation technologies which comprises performance monitoring, analysis and intelligent control. This research addresses the need for integration concepts, holistic monitoring and analysis methodologies, life-cycle oriented decision support and scenario based control strategies through the seamless integration of ubiquitous sensing infrastructures, simulation tools, Building Information Modelling (BIM) tools, service oriented architectures and data warehouse technologies. This paper introduces an interoperable Information and Communication Technologies (ICT) platform integrating IT systems at design, construction and operation stages of buildings so that monitoring, analysis and optimization of building energy performance can be achieved. The developed prototype has been demonstrated with EOS Sustainable Energy Solutions GmbH which is Hannover, Germany based R&D company, on a sample building of Housing Development Administration (HDA) within the scope of Dynamic System Architecture for Energy Efficient Building Operations (DASSEB) Project.

Keywords: energy efficiency, data warehouse technologies, BIM, web services.

1. INTRODUCTION

As contribution to the legislative drivers such as Kyoto-Protocol, Copenhagen Summit (COP15) and Durban Summit (COP 17), the European Union (EU) outlined the objective to reduce energy consumption by 20 % until 2020. The EU currently imports 82% of its oil and 57% of its gas (Gökçe 2010). The EU can have little influence on external energy markets and energy supply but can influence domestic energy demand. One possible solution to both the above problems is to reduce energy consumption by increasing energy efficiency.

In terms of energy efficiency buildings provide significant potential for energy and energy related CO_2 emissions savings since buildings account for 40% of the total energy usage and 30% of total energy related CO_2 emissions in Europe (EC 2007, Itard et. al. 2008, EC 2009).

Apart from meaningful building insulation measures, the only means of achieving marked improvements in the energy efficiency of buildings is to make use of efficient building automation technologies (VDMA 2008). According to European standard "EN 15232 Energy Performance of Buildings-Impact of Building Automation" building automation systems can, depending on building type and equipment standard, produce the following potential savings of energy: restaurants 31%, hotels 25%, offices 39%, shopping centres 49%, hospitals 18%, schools/universities 34% and residential 27% (DIN EN 2007). Also, it is often faster and less costly to automate building systems than it is to insulate building shells (IEA 2008). Thus, flexible and easy to handle monitoring and control technologies are essential. Presently, many sophisticated building services systems are available for facilities management. However, their focus on energy performance rating of buildings is at best sporadic, often comprising an ad-hoc combination of off-the-shelf building management systems (BMS) with some extensions. Such systems provide many problems to building owners with regard to interoperability. The optimization of these systems for energy management adds another layer of complexity to the design and management procedures. It requires analyzing the system, developing new interfaces, replacing devices, newly adjusting and optimizing parameters.

In this regard, the prospective consequence of the building behaviour and the needs of the building occupant/operator which would manage energy consumption efficiently would not be predictable with a single combined information and communication platform. A promising approach, to overcome these shortcomings, is the implementation of an integrated, modular infrastructure.

In order to address this aim, a project named “DASSEB - Dynamic System Architecture for Energy Efficient Building Operations” and the developed concept has been demonstrated with EOS Sustainable Energy Solutions GmbH (EOS 2013) which is a Hannover, Germany based R&D company, on a sample building of Housing Development Administration (HDA) (HDA 2013).

2. RESEARCH OBJECTIVES

The objective of this research is to develop a methodology for creating a system which processes and analyzes building performance data. Ultimately, for the monitoring and intelligent control of building operations to reduce the energy consumption. To reach this objective, new methods and tools are researched which increase system functionality covering the recent building energy regulations, wireless embedded devices, Building Information Modelling (BIM) tools, intelligent control algorithms, monitoring tools and integration of these to the information management backend system(the Data Warehouse (DW) core).

In this paper, a new integrated data aggregation and building management system coupled with open and extensible information exchange facilities to support tool interoperability will be presented. It offers e-services for energy monitoring and control using data warehouse, data mining, intelligent control, and web service technologies.

This system consists of the following key elements to research (Gökçe 2012):

(1)A new, model-based device development approach based on software product lines allows for accelerated development of dedicated, interoperable, resource optimized, and energy-efficient device applications according to the user and system requirements. (2) A novel modular modelling approach targets the optimization of existing components and the handling of upgrades with minimum effort. (3) A unique, multi-dimensional information management platform offers e-services for energy monitoring and intelligent control using data warehouse technologies, data mining, and web-services. (4) A new, open, extensible data exchange method named the Extraction, Transformation and Loading (ETL) Tool facilitates the interoperability of the tools. (5) An Intelligent Control module optimises the energy consumption of the building systems for the different use cases and scenarios. (6) Context sensitive, web-based, Graphical User Interfaces for multiple stakeholders.

3. MULTI DIMENSIONAL ENERGY MONITORING & OPTIMISATION SYSTEM

Recent advancements in building technologies and building control strategies coupled with the introduction of new building codes have contributed to the improvement of poor energy performance in commercial and residential buildings.

A holistic approach for building performance monitoring requires consistent and simultaneous access to the data and information extracted from different sources. Energy efficiency reports and trend analysis should be accessible to energy managers also, other stakeholders but this is often not the case (Piette 2005).

In order to address these issues a methodology leading to a system appropriate to process and analyse building performance data named as “Multi Dimensional Energy Management and Optimisation System” is developed to store, integrate, analyse complex data sets from multiple data and information sources such as wired/wireless sensing devices (sensors and meters) and BIM tools.

Data collected from the sensing devices is classified and categorised by the information collected from BIM tools and used for performing multi-dimensional analysis of building performance data to support decision-making process of the end users and to provide actionable information for the intelligent control of the building systems.

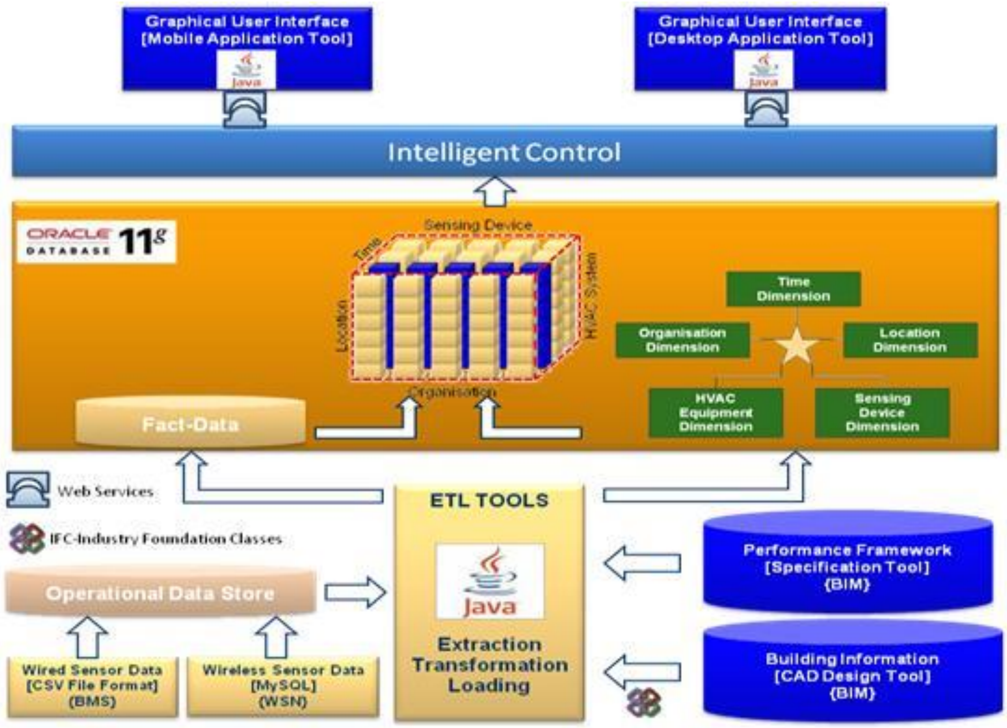

Figure 1: Multi dimensional energy monitoring and optimisation system architecture (modified from Gökçe 2010).

The system consists of four integrated main components, which will be explained in the following sections. These components are: (1) Data Warehouse Core, (2) Extraction, Transformation, Loading (ETL) Layer, (4) Intelligent Control Module, and (5) Information Representation Layer.

3.1 Data warehouse core

The data warehouse stores summarized information instead of operational data. This summarized information is time-variant and provides effective answers to queries such as ‘‘Energy consumption of a particular room in a particular building when the outside temperature is 21oC.”

The aim of the data warehouse component of the system is to: (1) Collect dynamic data (streaming data) which is data that is asynchronously changed as further updates to the data become available, from different sources such as wired/wireless sensors and meters. (2) Map the dynamic data with the persistent data, which is data that is infrequently accessed and not likely to be modified, extracted from BIM tools to define and categorize dynamic data. (3)Perform multi-dimensional data aggregation to support decision-making process (Gökçe 2010).

Components of the Data Warehouse Core are briefly described as (Gökçe 2010, 2012);

Operational Data Store: The Operational Data Store (ODS) is a database designed to integrate current valued subject oriented, volatile and real time data from multiple sources such as building management system and wireless sensor/meter network. An ODS is usually designed to contain low level or atomic (indivisible) data (e.g.

measurements) with limited history that is captured "real time" or "near real time" as opposed to the much greater volumes of data stored in the data warehouse generally on a less frequent basis.

Fact Data: Fact data is the main repository for long-term storage of dynamic data. A fact table is the primary table in a dimensional model where the numerical performance measurements of the business are stored (Kimball 2008). A measurement is taken at the intersection of all the dimensions (e.g. Time, Location, and Organisation). This list of dimensions defines the grain of the fact table and depicts the scope of the measurement. A row in a fact table corresponds to a measurement.

Dimensional Data: As explained above the Fact Data table contains the data, and the Dimensional Data identifies each tuple (row) in that data. A dimension table consists of tuples of attributes of the dimension. Dimension attributes are very crucial in the data warehouse. These serve as the primary source of query constraints, groupings, and report labels. For example, a user request stating “Minimum temperature of the offices which are occupied by Energy Systems Engineering Department staff in the Engineering Building for the last 3 months” is only achieved with time, location, sensing device and organisation dimension attributes.

Aggregated Data: Aggregated data is the decision support level of the multi-dimensional data warehouse core. Every data warehouse contains pre-calculated and pre-stored aggregated data. In the context of the work, sensed raw data collected from wired/wireless sensors and meters populates the Fact Data table of the data warehouse. Fact data becomes meaningful when it is associated with the dimensional data and provides the end user the means to create data cubes.

3.2 Extraction, transformation and loading layer

Data need to be loaded to the data warehouse core regularly. To do this, data from one or more operational systems needs to be extracted and loaded into the warehouse. The processes of extracting data from source systems and bringing it into the data warehouse are commonly called ETL, which stands for Extraction, Transformation, and Loading (Loney 2004).

In the data warehouse, raw operational data is transformed into a warehouse deliverable fit for user query and consumption (Kimball 2008). This is executed by a set of processes called ETL processes, which involves: (1) Extracting data from multiple sources such as wired/wireless sensor/meter readings and BIM tools. (2)Transforming it to fit data warehouse requirements which might be inconsistent with the outside data sources, e.g., data type inconsistencies and (3) Loading it to the data warehouse core. For the developed system, the ETL tool is used to populate the fact data table, which stores long-term dynamic data such as measurement streams. In addition, the ETL tool is used to populate Dimensional Tables, which store persistent data extracted from BIM tools.

3.3 Intelligent control module

Building energy demand-side management a scalable, robust wireless sensing network platform that integrates sensing network platform, computation and actuation to collect build-use data through advance data monitoring and data mining technologies which lead to develop optimal control algorithms that adjust Lighting, Heating, Ventilation, Cooling set points to adapt to occupancy, weather loads and their predictions, minimizing total energy consumption and peak demand while maintaining the indoor environment within user preferred comfort parameters.

An Intelligent Control module which contains algorithms for the defined building operation scenarios (e.g. heating, cooling, and lighting) and with the DW core to compute control parameters, which are then passed to the wireless network for actuation. Initially the following optimisation scenarios are determined for the developed intelligent control module (Gökçe 2010):

Energy Consumption Monitoring

- Objective: Real time visualization of energy consumption.
- Data Source: Wireless Gas/Electricity/Water meters.
- Data Aggregation: Time based (hourly/daily/weekly/monthly/yearly)

Heating System Controlling

- Objective: Controlling the temperatures of individual zones (rooms) via controlling wireless controllers/actuators for panel radiators in each zone (room). For example, “Maintain 24 °C of room temperature unless occupant leaves the room for longer than X amount of minutes.”
- Data Source: (a) Wireless temperature sensors. (b) Temperature set point entered by the end user (occupant).
- Actuators: Wireless Controllers/Actuators for Panel Radiators.
- Constraint: (a) Temperature set point (b) Presence

Lighting System Controlling

- Objective: Controlling the lighting levels (Lux Levels) of individual zones (rooms) via controlling wireless adjustable lighting switches. For Example “Maintain 500 Lux in the room unless the room is not occupied.”
- Data Source: (a) Wireless lux level sensors (b) Presence sensors.
- Actuators: Wireless adjustable lighting switches.
- Constraint: (a) Lux level set point (b) Presence

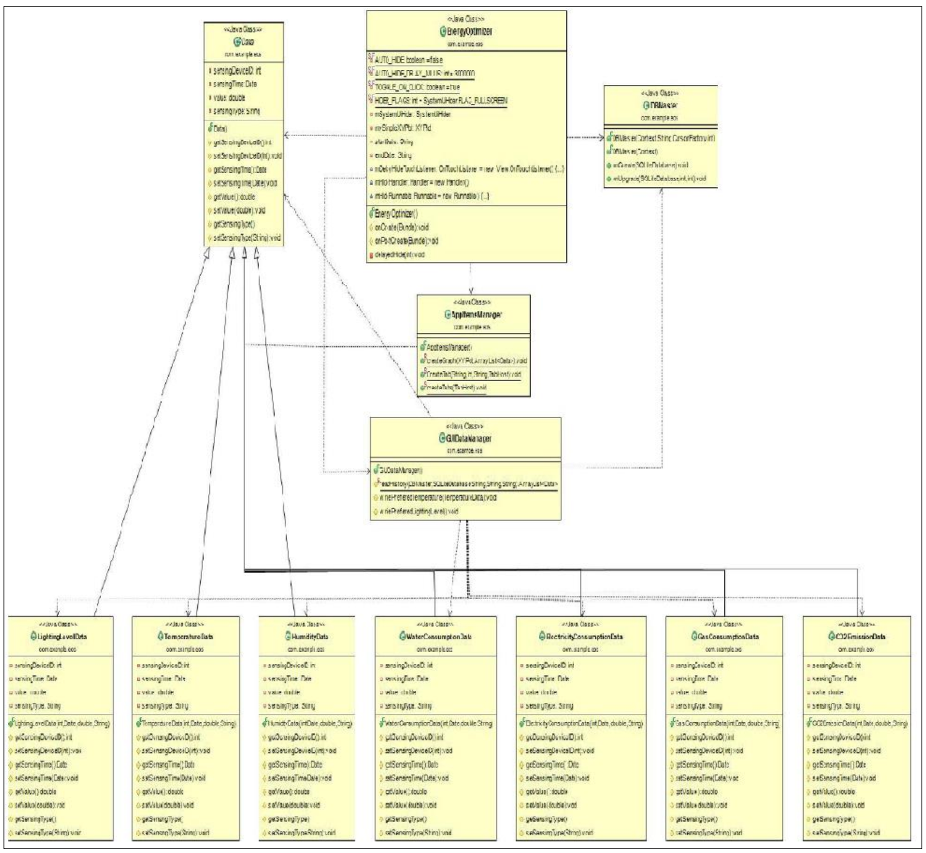

Figure 2: UML Diagram for Java Classes.

Location based intelligent lighting and heating controller algorithm is created and coded to the system using java with “thread + asynchronized task structure”. Thread of Intelligent Control is started in main activity to control automatically and determine actuator set points. State changes to determine if the room is occupied, might-be-occupied or not-occupied are coded into thread structure and worked. Fixing light level and heating level on selected value, (i.e. 500 LUX and 21 °C) is coded.

As a secondary function It also can feed information to the diagnosis activities regarding control problems (i.e., the control system is not behaving as expected), as well as the Maintenance Management System, to request repairs of known faults. The developed system can be further expanded to predictive control. Through the implementation of KDD and data mining methodologies, the data aggregated within the DW core can be used to discover predictive patterns such as the user preferences and the weather predictions (Gökçe 2010, 2012).

3.4 Information representation layer

The common goal of the graphical user interfaces is to represent the building performance information to the end users (stakeholders) concerning their roles and functions. The aim of the proposed system's information representation layer is designing and implementing user friendly Graphical User Interfaces (GUI). In order to achieve this, a Java based interface is proposed which enables end users easy querying without dealing with complex SQL statements.

Stakeholders include any person or organisation that may be affected by the success or failure of the software (Marinilli 2006). Four principle stakeholders identified for the developed system. Their data requirements and roles are described below:

Building Owner: (a) Reviews the overall energy consumption and CO_2 emissions of facilities. (b) Reviews the energy consumption and CO_2 emissions of a particular organisation, occupant or zone (c) Generates consumption bills and audits the costs of facilities.

Facilities Manager: (a) Monitors and analyses the building performance data with regards to particular zone, organisation/occupant, building system and/or time interval. (b) Maintains optimum occupant comfort level.

Occupant/Tenant: (a) Monitors relevant energy consumption and CO_2 emissions. (b) Views real time energy consumption costs. (c) Requests user comfort.

Building Technician: (a) Compares actual and intended performance of building systems (HVAC Systems) in order to perform preventive maintenance activities.

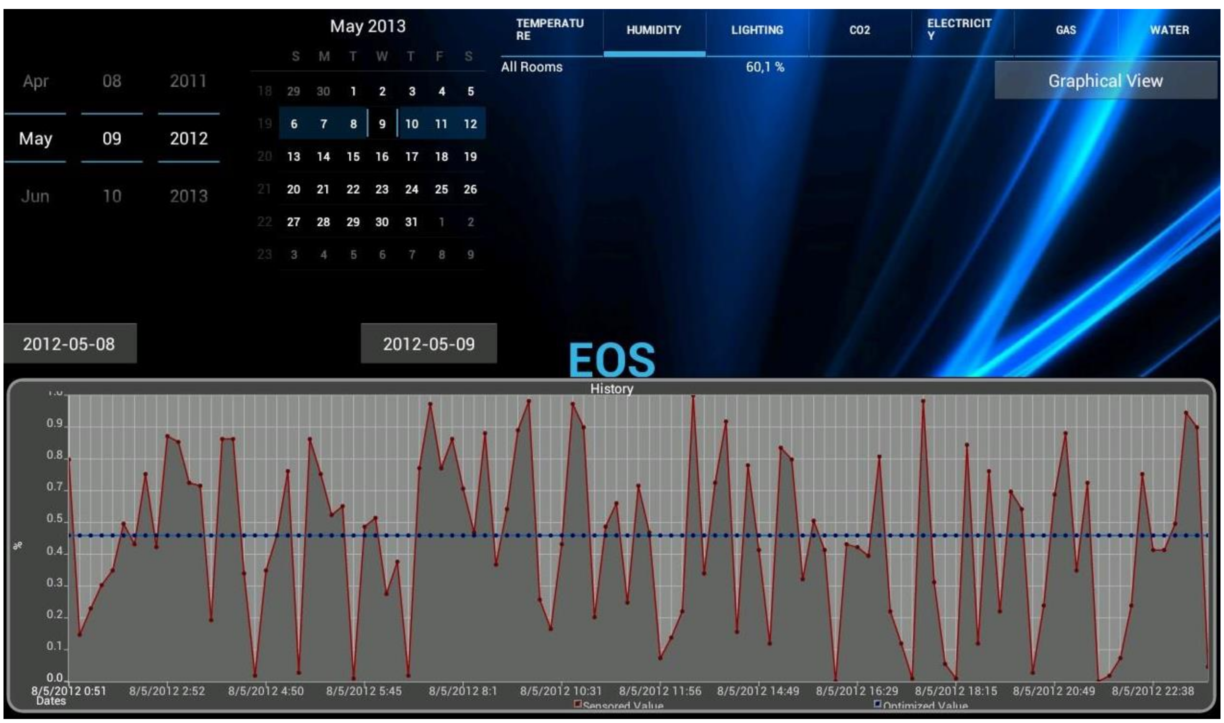

Figure 3: A Graphical User Interface Screenshot for the Developed System.

4. CONCLUSION AND FUTURE WORK

In this research, the Multi-Dimensional Energy Monitoring and Optimisation System which is a virtual energy management platform, was described with its components: Data Warehouse core, Extraction, Transformation and

Loading (ETL) tool, Intelligent Control module and Information Representation tools. The purpose of the developed system is to store, integrate, analyse complex data sets from multiple data and information sources such as wired/wireless sensing devices (sensors and meters) and BIM tools. Data collected from the sensing devices is classified and categorised by the information extracted from the BIM tools and aggregated for performing multi-dimensional analysis of building performance data to provide actionable information to the Intelligent Control module and to the specifically developed GUIs.

The developed system is open to further expansions. Since the system stores all building related information, it offers a high potential for building performance monitoring and multi-dimensional analysis as a powerful tool for data aggregation. This aggregated data can be used and be further developed for more advanced data analysis techniques like Knowledge Discovery (KDD) and Data Mining to perform predictive control for further energy savings.

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