INTEROPERABLE ENERGY MANAGEMENT SYSTEM CONCEPT FOR ENERGY EFFICIENT SMART BUILDINGS

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ABSTRACT

Buildings significantly contribute to total energy consumption and CO_2 emissions. Wireless monitoring and optimisation of buildings' energy consumption is of central importance for the renovation and energy-efficient operation of buildings since it allows the identification and correction of inefficient energy usage. Current studies show that improved building control systems can reduce the energy-consumption of buildings by 5 to 30%. In this regard, a single combined information and communication platform would not adequately predict the consequences of the building's behaviour and the needs of the building occupant/operator to manage energy consumption efficiently. In this paper an interoperable energy management system platform integrating IT systems at design, construction and operation stages of buildings is presented to provide optimized building operations. The aim is to create a holistic integrated system architecture for wireless embedded monitoring and control systems to increase the efficiency of the overall system development process and to exploit their potential for reducing building energy consumption. To reach this objective, new methods, tools and equipment covering integrated design, energy simulation models, data warehouse and middleware technologies are introduced.

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.

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.

2. SYSTEM ARCHITECTURE

In this context, an integration methodology is developed to represent the new ICT architecture (see Figure 1) for energy-intensive systems. The provided structure considers the implementation of a modular platform that integrates multiple dimensions of building information such as performance data, system data and process data which supports integration concepts, holistic monitoring and analysis methodologies. In the provided platform, the system architecture is implemented as an extension to international standards (e.g. IFC 2x3 ISO/PAS 16730).

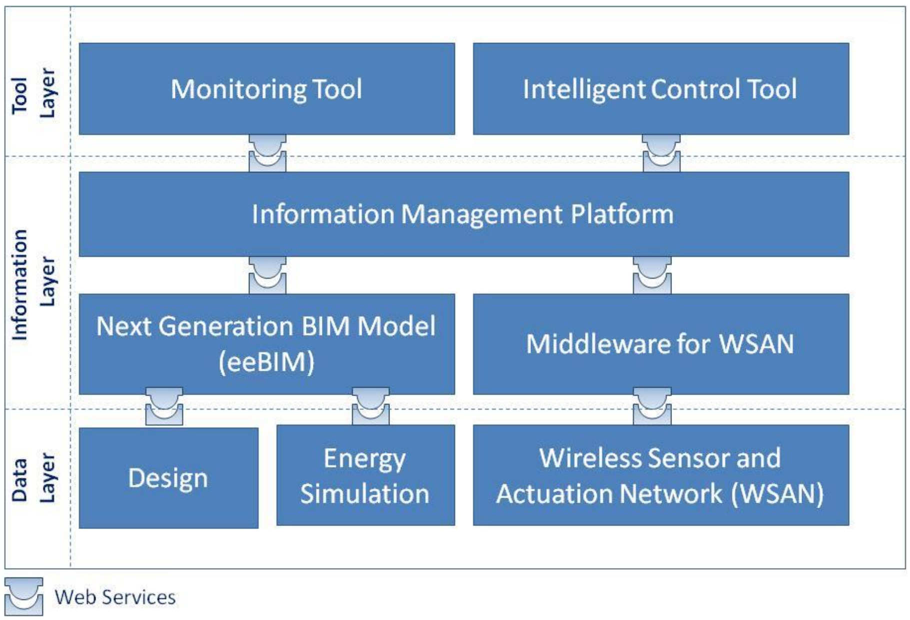

Figure 1: Interoperable Energy Management System Architecture.

The interoperable system platform is provided in three integrated layers.

2.1 Data Layer

- Network Embedded Systems:
  (1) Sensor, (2) Actuation
  - The applicability of flexible wireless sensing infrastructure with novel miniaturized sensor nodes that allow long-term embedding into the building fabric is examined. One of the aims of this layer is to specify self-configurable, self-optimized, and self-healed wireless sensor infrastructures to identify architectural approaches, and to create design support.
- Model Editors:
  (1) Design, (2) Energy Simulation
  - The existing off the shelf design and energy simulation tools is examined to provide 4D design, energy simulation models and associated interfaces.

2.2 Information Layer

- Next Generation Building Information Model (BIM)
  (1) Building Product Model (IFC), (2) Building Performance Model (IFCExt)

- A building information model (BIM) specification utilising formal standard definitions (data & functions) of engineering building components (e.g. pumps, valves), systems (e.g. Air handling units, heat pumps, solar panels) and sensors (temperature, relative humidity, CO_2, VOC's) as specified by professional institutions CIBSE and ASHRAE is developed.
- The BIM specification from using an ISO standard data model (Industry Foundation Classes (IFC) ISO 10303-21) that facilitates seamless interoperability of the BIM with upstream activities that include information management platform and downstream activities that include communication with the design and energy simulation models is implemented.

- Middleware WSAN (Wireless Sensor and Actuation Network)
  - A prototype of an embedded middleware and a web-service based middleware to enable the wireless sensor/actuator network to interact with the information management platform via web-service protocols is developed.
- Information Management Platform
  - Two integrated components: (1) Data warehouse Core, (2) Extraction, Transformation, Loading Tool (ETL), is developed to provide hybrid-systems-based framework that can integrate the heterogeneous models and applications.

2.3 Tool Layer:

- Monitoring Tool:
  - A monitoring tool to perform building performance monitoring enabling more efficient performance analysis is developed. This is achieved based on a Java based interface which enables end users easy querying without dealing with complex SQL statements.
- Intelligent Control Tool:
  - An intelligent control concept is developed which optimizes user comfort and energy efficiency, based on preference-based control system. The learning algorithms which will be used to estimate the expected occupant comfort degree based on a database of previous responses is researched.

3. SYSTEM COMPONENTS

The complexity of the proposed platform requires scenarios. In this context four scenarios are developed: (1) Data Representation and Aggregation, (2) Building Performance Analysis and Diagnostics, (3) Management of Maintenance Activities, and (4) Intelligent Building Control.

In this paper, the details associated with the first scenario, Data Representation and Aggregation, will be presented. In this context, the dynamic data collected from the wired/wireless sensor/meter network and the persistent data extracted from the BIM tools should be stored, aggregated and represented to the stakeholders for performing multi-dimensional analysis of the building performance. The system extracts sensor data from building management systems and from the wireless sensor/meter network. Collected sensor/meter data is stored in the operational data store for data cleansing and redundancy check processes. This pre-processed data is loaded to the fact data section of the data warehouse system via an Extraction, Transformation, and Loading (ETL) tool.

Simultaneously, data gathered from the building information model is loaded to the dimensional data section of the data warehouse. Loaded fact data and dimensional data is aggregated with regards to different stakeholder requirements in the data warehouse system and presented through specific Graphical User Interfaces (Gökçe 2010). The system consists of three integrated components (1) BIM Model with the use of Model Editors, (2) Information Management Platform, (Data Warehouse Services), (3) Monitoring Tool, and (4) Network Embedded Systems, (Wireless Sensor Network).

4. BIM MODEL WITH THE USE OF MODEL EDITORS

The model editor provides required information for the energy simulation module and for the data warehouse. In our case, four different Computer Aided Design (CAD) systems have been considered and their capabilities have been analyzed. For this process, the most recent software was chosen: (1) Autodesk Revit, (2) Microstation, (3) ArchiCAD, and (4) DDS-CAD. The interoperability of these systems, and in particular that of the Industry Foundation Classes (IFC), has been examined. In terms of IFC, all CAD systems are compatible with the latest version of IFC 2x3. From an interoperability perspective, all CAD systems claim to offer some form of import/export functions between systems.

In this regard, Autodesk Revit has been chosen which is composed of Revit Architecture and Revit MEP (Mechanical Electrical and Plumbing). Autodesk Revit Architecture (Autodesk 2013) is a 3-D drawing tool which encompasses all the information aspects necessary to cover the lifecycle of a building. This allows for intelligent, 3D and parametric object-based design (Autodesk 2013). In this way, Revit provides full bi-directional associative integration. A change anywhere is a change everywhere, instantly, with no user interaction to manually update any view. Revit MEP is specialized specifically for design and documentation of building services (Autodesk 2013). It combines all of the tools and capabilities of Revit Architecture with realistic and detailed building services equipment. An important feature of Revit MEP is the availability of product libraries which contain families of accurate parts and equipment used for construction (Autodesk 2013).

Energy Simulation Models can be used to predict building energy performance and to compare design intent and actual performance data. In this research, the Integrated Environmental Solutions (IES) plug-in which provides energy simulations on the Revit MEP Model has been chosen. IES is an energy simulation software package (IES 2012). IES's Revit plug-in Toolbar allows Revit Architecture and MEP to import a 3D BIM model into IES's software and undertake energy and thermal analysis (IES 2012). Information is required regarding building type, construction materials, and heating and cooling system types. This information can be entered for the whole building as one set of data or at room (space) level depending on the stage of the design or results required (Gökçe 2011). Once the model is established, all IES performance analysis products are accessible for the model. While Revit has excellent drafting and 3D modelling properties, and often plays a central role in projects, it currently does not perform its own energy simulation. Rather, it relies entirely on IES. Therefore, from an energy simulation point of view, the use of Revit MEP cannot be justified. In this sense, its only function is to create the building geometry and properties before exporting to IES.

5. INFORMATION MANAGEMENT PLATFORM (DATA WAREHOUSE SERVICES)

The proposed system enables continuous monitoring to tune building systems for optimal comfort and peak efficiency based on current operational requirements. As a result, the holistic multi-dimensional information management system, which is supported by data warehouse technology to provide required tools and methods for building performance monitoring, enables more efficient performance analysis and dramatic energy savings (Gökçe 2010, 2012). In this case, the Information Management Platform consists of two components: (1) Data warehouse Core, (2) Extraction, Transformation, Loading Tool.

5.1 Data Warehouse Core

Data warehousing systems provide a number of alternative ways to integrate and query stored information. Thus, a data warehouse coupled with On-Line Analysis Processing (OLAP) enables end-users to creatively approach, analyze and understand the building performance under different circumstances (Gökçe 2010). 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." (Gökçe 2010).

The aim of the data warehouse component of the proposed system is to:

- Collect dynamic data from different sources such as wired/wireless sensors and meters.
- Map the dynamic data with data extracted from CAD tools, energy simulation tools and performance specification tools.
- Perform N-dimensional data aggregation to support the decision making process.

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The Data Warehouse component consists of three sub-components (Gökçe 2010):

a. ***Operational Data Store:*** ODS is a database designed to integrate current valued subject oriented, volatile and real time data from multiple sources such as the building management system, wireless sensor network and energy unit prices.
b. ***Fact Data and Dimensional Data:*** This is the main repository for long term storage of dynamic data. Data collected and temporally stored in the ODS populates the fact data table.
c. ***Aggregated Data:*** This is the decision support level of the multi-dimensional data warehouse. Fact data become meaningful when it is associated with the dimensional data and provides the end user the means to "slice and dice" data.

5.2 Extraction Transformation and Loading Tool

Data needs to be loaded to the data warehouse regularly. To do this, data from one or more operational systems needs to be extracted and loaded into the warehouse. The process of extracting data from source systems and bringing it into the data warehouse is commonly called ETL, which stands for Extraction, Transformation, and Loading (Loney 2004). For the proposed system, the ETL tool is used to populate the fact data table which stores long term dynamic data such as the measurement stream. Also, the ETL Tool can be used to populate Dimensional Tables which stores relatively static data such as architectural data and building HVAC systems data (Gökçe 2010).

The ETL process developed for this research populates the fact data table:

- Extracts data from the current building management system (BMS) comma separated values (CSV)
- file archive,
- Eliminates inconsistencies such as duplicate rows,
- Transforms the CSV file structure to the data warehouse fact data table structure,
- Loads the CSV files to the data warehouse fact data table.
- Also, the ETL tool is used to populate the dimensional tables which can be populated by extracting data from the CAD tool.

6. MONITORING TOOL

The common goal of the Monitoring Tool is to represent the building performance information to the end users in regards to their roles and functions (Gökçe 2011). The aim is to design and implement a user friendly Graphical User Interface (GUI). In order to achieve this, a Java based interface is developed which enables end users to query without dealing with complex SQL statements. Also, this GUI can represent query results both in graphical format and/or tabular format according to the end user’s preference. There are two main utilization scenarios considered for the system, performance monitoring and on-site diagnostics, resulting in the application of two different types of user interfaces: (1) Desktop Application for performance evaluation (2) Mobile Application for facility management and building diagnostics.

7. NETWORK EMBEDDED SYSTEMS (WIRELESS SENSOR NETWORK)

A Wireless Sensor Network (WSN) consists of spatially distributed autonomous devices using sensors that monitor the physical environment at high resolution. These sensors, also called motes, are installed in particular locations or can be sprayed in a particular zone to gather information such as temperature, humidity, CO2, and Lux level. The real functionality of these sensors is demonstrated when they start communicating with each other within wireless sensor networks (WSN). WSN can shuffle the information collected through the sensors and transfer it to the public internet and or a local area network. Finally, the information is collected in the data warehouse where it is analyzed.

7.1 Wireless Sensor Network Design for Prototype Development

Wireless systems are composed of wireless sensors, meters, and actuators, on top of which rests a wireless network platform. In this research the wireless sensor network architecture is used based on recently released IETF 6LoWPAN (RFC 4944) open standard for IP communication over low-power radio links – IEEE 802.15.4. LoWPAN networks are connected to other IP networks through one or more border routers forwarding information packets between different media including Ethernet, Wi- Fi or GPRS. The IP architecture offers widespread commercial adoption and broad interoperability due to its openness, flexibility, scalability and manageability. A number of industrial standards, including BACNet, LonTalk and CIP, introduced an IP using either TCP/IP or UDP/IP over Ethernet.

7.2 IEEE 802.15.4 sensor nodes forming 6LoWPAN network

Wireless sensors can be developed to detect and measure various parameters such as temperature, humidity and water/gas/electricity meter readings. A sensor node in a network, called a mote, mainly consists of 3 components: the sensor interface, which measures the physical attributes such as the humidity level; the radio interface, which communicates with other motes; and the CPU, which performs computations and transfers information between the two components. The used board in our case is equipped with an Atmega1281 MCU and EM2420 radio chip. The platform includes sensors for monitoring air-temperature, air-humidity and light. Moreover the platform incorporates electricity meters as well as the interface for controlling (on/off) an AC load are utilised. The platform runs the recently released b6LoWPAN stack.

7.3 IEEE 802.11 gateways as 6lowPAN/IPv6 routers

Soekris embedded PC boards (Soekris 2011) with Atheros CM9 Wi-Fi cards and a single IEEE802.15.4 node form a backbone network spanning all the rooms of the HDA building. Soekris net4521 is a compact, low-power, low-cost computer based on a 133 Mhz 486 class processor which supports power over Ethernet (PoE). These features make Soekris an attractive solution when selecting a wireless communication backbone for the sensor networks. It has also been optimized for use as wireless router and has been designed for FreeBSD, NetBSD, OpenBSD and Linux.

8. CONCLUSION AND FUTURE WORK

The European directive EPBD (Energy Performance Building Directive 2002/91/EC-2006/32/EC) requires a dramatic change in the way buildings are analysed. Current building performance analysis focuses on assessment at earlier stages of the building life cycle (BLC) with less analysis at the later stages of operation and maintenance. The Interoperable Energy Management System Concept for Energy Efficient Smart Buildings described in this research enables a continuous assessment process throughout the BLC by combining the data from different sources and phases in a single data repository. A single data warehouse processing geometrical, material, simulated and real time data provides enhanced decision making capabilities to the stakeholders. Model editors and simulation tools with industry standardised interoperability capabilities provide a dynamic information flow for efficient building operations. An appropriately selected residential building located in Hannover Germany will be used as a case study in order to demonstrate the potential of the proposed system architecture. Based on initial results of software development tests, it enabled continuous building energy analysis from design through building operation. Finally, the system maintains the basis for: improving building performance, developing intelligent control routines, and implementing fault diagnosis measures.

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