Chapter 19
Integrated System Concept for Energy Efficient Smart Buildings and Cities

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Abstract The quality of life in Europe's cities states that although quality of life has improved in many areas, in other areas such as environmental issues and energy efficiency have deteriorated. In such places, people, companies and public authorities experience specific needs and demands regarding domains such as energy efficiency, environment and transportation services. These domains are increasingly enabled and facilitated by web-based applications, service oriented architectures, ubiquitous sensing infrastructure, advanced information management applications such as data warehousing and data mining technologies which generate actionable information for intelligent and predictive control for further optimised smart buildings and cities.

The engineering and deployment of off-the-grid energy production systems for buildings addressing the renewable energy technologies (e.g. wind, solar, geothermal) and integration of these systems to the city level grid applications with the ICT-based sub-systems becomes a necessity.

This paper addresses an integrated building concept that operates on energy-efficient basis while capturing retrofit opportunities that scale from a single building to multiple buildings at cities level. The proposed concept is developed based on two research areas; (1) Building energy supply-side (microgrid) management and (2) Building energy demand-side management complementing with the integrated energy production from renewable energy sources, building energy diagnostics and predictive control, ubiquitous wireless sensing technologies, and microgrid power electronics and power control to exploit the potential for reduction of building energy consumption, thus addressing the deficit of insufficient tool support.

The research findings will be demonstrated in an appropriately selected building in Hannover, Germany with EOS Sustainable Energy Solutions GmbH. This will be achieved by integrating different energy generation systems addressing the renewable energy technologies coupled with energy storage systems and building energy management systems comprising scalable and robust sensing network platforms, energy performance monitoring and data warehouse technologies.

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I. Dincer et al. (eds.), *Progress in Sustainable Energy Technologies Vol II: Creating Sustainable Development*, DOI 10.1007/978-3-319-07977-6_19

Keywords Renewable energy • Energy efficiency • Smart buildings • Artificial intelligence

19.1 Introduction

Cities all over the world exhibit complex dynamics. As cities grow, planners devise "complex systems to deal with food supplies on an international scale, water supplies over long distances and local waste disposal, urban traffic management systems and so on; (. . .) and the quality of all such urban inputs defines the quality of life of urban dwellers" [1].

Notwithstanding the enormous formidable challenges and disadvantages associated with urban agglomerations, the world population has been steadily concentrating in cities.

In addition, there is a substantial increase in the average size of urban areas. This has been made possible by a simultaneous upward shift in the urban technological frontier, so that a city could accommodate more inhabitants. Problems associated with urban agglomerations have usually been solved by means of creativity, human capital, cooperation among relevant stakeholders, and bright scientific ideas: in a nutshell, 'smart' solutions. The label 'smart city' should therefore point to clever solutions allowing modern cities to thrive, through quantitative and qualitative improvement in productivity and efficiency.

The concept of smart cities has different meanings. A useful definition is to call a city "smart" when "investments in human and social capital and traditional (transportation) and modern (ICT-based) infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory government" [2]. Other definitions identify significant characteristics such as energy efficiency, environmental issues, productive economy, and define rankings based on measurable underlying indicators. Smart cities can be also understood as places generating a particular form of spatial intelligence and innovation, based on sensors, embedded devices, large data sets, and real-time information processing and response.

A recent and interesting project conducted by the Centre of Regional Science at the Vienna University of Technology identifies six main 'axes' (dimensions) along which a ranking of 70 European middle size cities can be made [3]. These axes are: a smart economy; smart mobility; a smart environment; smart people; smart living; and, finally, smart governance. These six axes connect with traditional regional and neoclassical theories of urban growth and development. In particular, the axes are based—respectively—on theories of regional competitiveness, transport and ICT economics, natural resources, human and social capital, quality of life, and participation of societies in cities.

A report of the European Environmental Agency [4] concerning quality of life in Europe's cities states that although quality of life has improved in many areas, in other areas such as health, environmental issues and energy efficiency have deteriorated. In such places, people, companies and public authorities experience specific needs and demands regarding domains such as healthcare, energy efficiency and the environment, as well as safety and public services. These domains are increasingly enabled and facilitated by web-based applications, service oriented architectures, ubiquitous sensing infrastructure, advanced information management applications such as data warehousing and data mining technologies which generate actionable information for intelligent and predictive control for further optimised smart cities.

On the basis of on-going research in the area of energy efficiency and legislative drivers launched by the national and international organizations, the role of integration concepts, performance monitoring and analysis methodologies and sophisticated control strategies through the seamless integration of people, ICT devices and computational resources gain significant importance for reducing the energy consumption and the operational costs for buildings as well as cities. According to European standard "EN 15232 Energy Performance of Buildings-Impact of Building Automation" building operation systems can, depending on building type and equipment standard, produce the following potential savings of energy: restaurants 31 %, hotels 25 %, offices 39 %, shopping centers 49 %, hospitals 18 %, schools/ universities 34 % and residential 27 % [5, 6]. This is a major contribution to the "Kyoto-Protocol-Process" in which the EU outlined the objective to reduce energy consumption by 20 % by 2020. Also, it is often faster and less costly to integrate building energy systems than it is to insulate building shells. At the moment sophisticated building energy management systems are available for facilities management. Most of the larger non-residential buildings younger than 30 years are already equipped with wired building automation systems in Europe. However, their focus on energy performance rating of buildings is at best sporadic often consisting of an ad hoc combination of off-the-shelf building management systems (BMS). This ad hoc combination presents many difficulties for building owners in relation to the management and upgrade of these systems, as the BMS can consist of a number of components utilizing various information exchange protocols that have to be integrated within the monitoring and targeting (M&T) software packages. The optimization of these systems for energy management adds another layer of complexity to the design and management procedures [7]. It requires analyzing the system, developing new interfaces, replacing devices, and optimizing parameters. Furthermore the engineering and deployment of efficient energy production systems for buildings addressing the renewable energy technologies, phase change materials, energy harvesting facades and integration of these systems with the ICT-based sub-systems becomes a necessity. Integrated IT tool support for these activities does not exist; available tools are stand-alone products, often tied to specific standards, and focus on development from scratch. There is not a procedure defined which describe information exchange between different domains for different energy generation and management systems. This lack of appropriate descriptions and tools currently outweighs the benefit of software interoperability. As this technology gap spans for all application domains, it will likely hamper further adoption of IT solutions. In this regard, the prospective consequence of the building behaviour and the needs of the building occupant/operator which would manage energy production/consumption efficiently would not be predictable with a single combined information, communication, hardware and tool platform. A promising approach, to overcome these shortcomings, is the implementation of a holistic, modular infrastructure for building energy supply and demand sides.

19.2 Approach

The agenda in this research is build on the need of integration structures, holistic monitoring and analysis methodologies, life-cycle oriented management and decision support of both facilities and service teams with considering two key research areas; (1) Building energy supply-side (microgrid) management which addresses the energy management systems capable of optimal integration and control of energy production addressing renewable energy technologies such as photovoltaic/hot water solar panels, geothermal heat pumps, small scale wind turbines, biomass and the communication and intelligence required to work cooperatively with local authorities/grid operators and (2) Building energy demand-side management which comprises a scalable, robust wireless sensing/actuation network platform that 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 as well as controlling of appliances to adapt to occupancy, weather loads and their predictions, minimizing total energy consumption and balancing peak demand while maintaining the indoor environment within user preferred comfort parameters.

The proposed concept depicted in Fig. 19.1 above consists of three parts: (1) Building Energy Supply (BES) side. This consists of conventional energy supply from the grid and Off-the-Grid energy generation systems such as photovoltaic/hot water solar panels, geothermal heat pumps, small scale wind turbines, biomass and storage technologies maintains optimal integration and control of off-the-grid energy generation systems for building energy supply side, (2) Building Energy Demand (BED) side which consists of HVAC systems, lighting systems and appliances, (3) Multi Dimensional Energy Monitoring, Analysis and Optimisation System consisting of wireless sensors/meters/actuators, multi dimensional information management platform, intelligent control module and monitoring tools.

19.3 Concept

At present, off the grid energy generation technologies are usually provided by the companies which solely focus on specific areas such as wind, solar, geothermal, biomass and storage as there is a very limited number of companies that provide a "*total service concept*." Therefore, holistic design between various energy

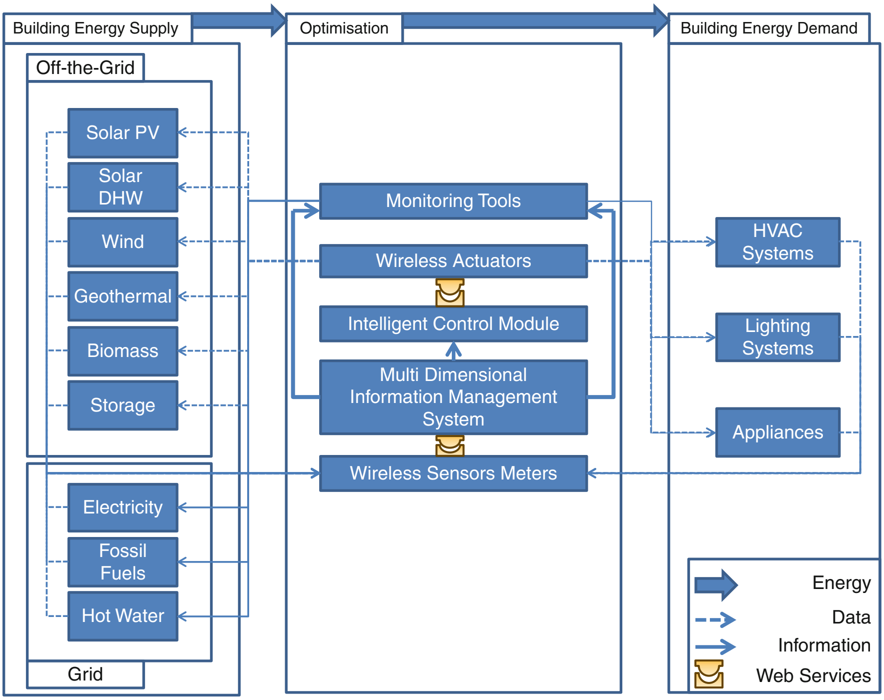

Fig. 19.1 A smart building concept integrated with off-the-grid energy generation systems

generation systems hasn't been provided in an expected granularity due to the lack of integration concepts.

Moreover, the control of energy performance of buildings is often provided by an ad hoc combination of off-the-shelf building management components, distributed data metering equipment, glued together by M&T software tools. The absence of building management systems standardization coupled with competition for market share results in independent and non-compatible system development. In this regard BACnetTM was developed to provide an open, non-proprietary protocol specification that allows building automation controllers of different manufacturers to communicate with each other [8]. However Building Management Systems/ Energy Management Systems still operate on non-standardized proprietary interfaces. Consequently they are becoming more complex over time and are difficult for the average operator to understand given the educational and experience [9]. Additional training overhead is required for each new system or system updates. Moreover [10] states that in the absence of compatible hardware and communication protocols maintenance can become extremely problematic as seamlessly integrating these systems is an inefficient overhead.

However, in conjunction with traditional procurement policy it is conceivable that numerous systems which would provide an integrated system chain enabling the efficient use of renewable energy resources and energy management systems in a holistic building-supply and building-demand side energy management concept complementing with a modular approach should appear, as can be seen in this research.

In this regard two research concepts are provided by defining: (1) Integration and optimisation of off-the-grid energy generation systems. (2) Multi Dimensional Energy Monitoring, Analysis and Optimisation System.

19.3.1 Integration and Optimisation of Off-the-Grid Energy Generation Systems

Integration and optimisation of off-the-grid energy generation systems involves two complementing phases (1) the design of small scale house type renewable energy technologies e.g. wind, solar, geothermal and storage systems for off-the-grid energy generation and storage in buildings through an integrated structure based on the requirements analysis including energy demand and grid supply patterns and (2) the development of an optimisation middleware for energy-supply, in order to control the various systems in an integrated and optimized way.

19.3.1.1 Off-the-Grid Energy Generation and Storage Systems

Off-the-grid renewable energy technologies for energy generation for buildings usually addresses individual systems integration, e.g. a wind turbine is combined with adequate storage devices or energy harvesting facades are combined with actuators or blind control systems. Several tools supporting the integration of these components exist with manufacturers having usually their own preferences.

Therefore the definition of optimal processes and interfaces allowing the integration of different systems e.g. integration of small scale battery charging wind turbines and photo-voltaic solar cells which feed a common storage system (battery bank) and control of energy production on the basis of environmental conditions e.g. wind speed, day light period, etc. can be accepted as one of the prerequisites of a holistic, modular approach.

In this research, in order to integrate different type of systems in an optimized way, the requirement and the state-of-the art analysis which would allow optimized integrations have been obtained with researching the systems given below. This preliminary state-of-the art analysis will be used to develop the middleware for building energy supply.

Small Scale Battery Charging Wind Turbines

After examining, different type of home use small scale wind turbines in the market, 600W 24VDC battery charging wind turbine with 6 Blade type has been chosen to optimise small scale renewable energy output which is compatible with our application scenarios. Its cut-in speed is low in order to facilitate continuous generation and auxiliary energy source. The wind speeds in excess of 150 km/h has been approved. This type of home use wind turbines generally comprises of a single axial flux permanent magnet brushless alternator. The six blade design supports a self-regulating aerodynamic rotor that achieves speed control through blade turbulence, which controls the speed of the rotor with no moving parts and no obtrusive noise. The diameter is 1.5 m.

Solar Panels Made of Photo-Voltaic Solar Cells

In this research, four major types of Solar Technology Panels have been examined (1) polycrystalline cells which are the most common and cheapest panels with conversion efficiency 13–15 % (sunlight to electricity), however, under elevated temperatures of 50 °C panel temperature, the efficiency drops by around 20 %, (2) panels made from monocrystalline cells which are used in high reliability applications such as telecommunications and remote power with conversion efficiency is typically 14–17.5 % (higher than the polycrystalline cells), however, at elevated temperatures, the efficiency only drops by 10–15 % so they are more consistent in output (3) Panels made from amorphous cells which have been used in portable items for many years with conversion efficiency of sunlight to electricity is 5–7 %, about half that of the other panels but unlike the other types, their output does not decrease in elevated temperatures. Panels made of thin film cell CIGS technology (Copper, Indium, Gallium, diSelenide) are flexible, durable, and provide slightly higher efficiency than other flexible solar cells, typical sizes less than 60 W and can be mounted to curved surfaces. The critical item that delivers the current to charge the batteries is the solar controller. There are 3 major types of controller: (1) Standard single phase controller, (2) Multistage controller, and (3) Maximum Power Point Tracking Controller (MPPT). The first 2 controllers provide roughly 70 % of the panels power to the batteries as they reduce the voltage of the solar panels but do not increase the current. MPPT Controllers are true “State of the Art” technology with 96 % + output. The final critical factor is the location of the controller, the mounting the controller at the battery end of the solar panel cable allows batteries fully charged. In summary, the way to compare the relative output capacity of panels is by the current output charging batteries at around 13.5 V.

In our case with considering the current systems, the high quality polycrystalline solar panels for home solar power systems and MPPT controllers are used in this research.

Solar Vacuum-Tube Collectors for Hot Water

In order to heat water using solar energy, a collector, often fastened to a roof or a wall facing the sun, heats working fluid that is either pumped (active system) or driven by natural convection (passive system) through it. Residential solar thermal installations fall into two groups: passive and active systems. Both typically include an auxiliary energy source (electric heating element or connection to a gas or fuel oil central heating system) that is activated when the water in the tank falls below a minimum temperature setting such as 55 °C. Hence, hot water is always available. The combination of solar water heating and using the back-up heat from a wood stove chimney to heat water can enable a hot water system to work all year round in cooler climates, without the supplemental heat requirement of a solar water heating system being met with fossil fuels or electricity. For this research Viessmann Vitosol 300T type SP 3A Vacuum-tube solar collectors with dry connection heat tubes have been chosen. The system has gross area of 2.88 m^2 and the absorber area of 2.00 m^2.

Geothermal Heat Pumps

A geothermal heat pump, ground source heat pump (GSHP), or ground heat pump is a central heating and/or cooling system that pumps heat to or from the ground. It uses the earth as a heat source (in the winter) or a heat sink (in the summer). In a fridge, heat is transferred from the inside to the outside. With a heat pump, this happens exactly the other way round. Heat from the air or the ground is transferred into the living space via the heating system. Vapour from a refrigerant is compressed to increase the temperature, to make it high enough for central heating and DHW (Domestic Hot Water) heating. For this research, the selected Viessmann Vitocal 350-G reaches up to 72 °C. These heat pumps can therefore also be used for modernisation as they can provide a sufficiently high flow temperature for central heating with radiators. The compression process is vital for the efficiency of a heat pump. To generate heat, for example, heat is extracted from the ambient air and used to evaporate a refrigerant that boils at low temperature. Getting hotter towards the centre—from an initial temperature of between 5 and 18 °C, a flow temperature of up to 72 °C is achieved. The gas created is compressed by the scroll compressor, which causes it to heat up. The gas heated in this way transfers its heat via the condenser to the heating water or DHW heating system, and thereby condenses again. Finally, the refrigerant, which is still under pressure, is expanded in an expansion valve, and the circuit begins again. A heat pump can make use of the following energy sources: (a) Air—practically unlimited availability; lowest investment costs (b) Ground—via geothermal collector or geothermal probe. (c) Water—efficiency depends on the water temperature. (d) Waste heat—subject to availability, volume and temperature level of the waste heat. In this regard, the best heat source for each individual case depends on local conditions and the actual heat demand.

Energy Storage Systems

For energy storage systems two types of batteries have been examined, (1) Lead Acid Deep Cycle Batteries which are designed to have stored current discharged between charging sessions, with very heavy non-porous battery plates to withstand repeated major discharging and charging cycles (deep cycles) and (2) Nickel Alloy Batteries Nickel Cadmium (NiCad) and Nickel Iron batteries, rather than consisting of lead plates submerged in a sulfuric acid solution, feature nickel alloy plates in an alkaline solution.

In this research, we have chosen nickel alloy battery types for our experiments with considering the facts such as they are well suited for home power use, although much less common and much more expensive than lead acid types. The nickel alloy battery can have up to 50 years of useful life, compared to 20 years with a well-maintained lead acid battery. They can also sit for extended periods of time partially or fully discharged without suffering damage, unlike lead acid types and they need lower maintenance. On the other hand a lead acid battery should never be completely discharged, meaning they need to be more closely monitored. Nickel alloy batteries operate better at lower temperatures, and can discharge more of their total amp-hour capacity as useful current.

A battery bank is the main part of the energy storage systems and enables a constant level of power to the house. Without the battery bank, the entire electrical system of a house would be limited by the immediate output of renewable energy resources. A wind turbine would be subject to constant power fluctuations as the wind speed increased, dropped or disappeared entirely. At night, a solar-run house would have no electrical power available. Therefore in order to provide a constant level of power without causing problems for households, a grid connection to the battery banks would be necessary during non-peak hours, thereby the house-use power can be available regardless of weather conditions with convenient electricity prices.

In our case, we designed our system based on three separate battery sections composed of nickel alloy batteries. The first section is connected with the small scale battery charging wind turbine, the second section is connected with the high quality polycrystalline solar panel while the third section connected to the central electricity grid. Therefore the wind generator and solar panel can deliver power to the battery bank regardless of current power usage, so excess power can be stored during low use times (generally the middle of the day and middle of the night) and be available during high use times (usually morning and evening). In our case an inventer DC–AC which is used to convert the DC power from the battery bank to AC power for the house power systems, a rectifier AC–DC which converts AC grid power to DC power for the use of battery charging, a control relay which provides a direct connection between the house and the grid in the event that all stored energy is depleted or a problem occurs in the battery bank.

19.3.1.2 Optimisation Middleware for Building Energy Supply Systems

This is considered for the integration of off-the-grid power generation systems and central electricity/gas/water grid and optimal control of these systems on the basis of occupant needs and environmental factors. In order to provide this, a novel model-based system development approach is investigated that automates code development. In the model-based system development approach, we propose to adopt the software product line paradigm. It starts with requirement engineering for the envisaged systems specifying the functionality to be implemented. From these requirements the source codes are individually generated from software modules to fulfil the requirements and optimally use the system resources. Information about the implemented functions, requirements, and software function blocks are stored in the form of Electronic System Descriptions. This repository contains descriptions of individual systems for integration purposes. Consequently on the basis of specified descriptions which allow controlling of optimal management of wind turbines, solar panels, geothermal systems etc. The middleware is designed with considering the functionalities given below.

The middleware is in control of charging the batteries when out of power from either the grid or renewable energy systems occurred. It will supply the hot water by taking into consideration of the occupant requirements and environmental factors. The middleware also be in control of providing stored power to the house whenever possible. It is designed for running the system in the most cost effective manner by considering carbon emissions. It would decide when to charge the batteries and from which source. The middleware is designed to provide stored power to the house whenever present and only switch to grid power if all stored power is depleted. Moreover it provides charging the batteries from the grid power during non-peak hours and only if the systems could not provide enough power for the house use.

19.3.2 Multi Dimensional Energy Monitoring, Analysis and Optimisation System

Multi Dimensional Energy Monitoring, Analysis and Optimisation System is implemented on the basis of four complementing components as (1) Building Information Model, (2) wireless sensor/meter/actuator network platform, (3) multi dimensional information management platform, (4) Intelligent Control Module and (5) Monitoring tools.

19.3.2.1 Building Information Model (BIM)

In order to simplify the requirement engineering, information about the building (location, building systems, etc.) can be imported from the systems which support architectural and building systems design. Architectural designs are typically developed with the Computer Aided Design (CAD) tools such as Autodesk Revit, Microstation, ArchiCAD and DDS-CAD. They support standardised, extensible Building Information Models (BIM) based on product modelling standards such as IFC (Industrial Foundation Classes).

The concept of a BIM describes an integrated data model that stores all information relevant to a building throughout the building life cycle. In our case, it is envisioned to extend the BIM with the system design, e.g. the number and kind of wireless sensors and communication devices in order represent deployment in different rooms and their interaction within each other and with the building itself.

In order to predict and model building energy performance, energy simulation models should be considered. These models enable the building operator to perform comparisons between design intent and actual energy performance data. For example, in order to perform an energy simulation on the Revit MEP model, the IES plug-in is used in our simulations to complete BIM Model comprising energy performance aspect.

19.3.2.2 Wireless Sensor/Meter/Actuator Network Platform

Wireless Sensor Network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors that allow the physical environment to be monitored at high resolution. These sensors also called motes are installed in particular locations or can be deployed in a particular zone to gather information such as temperature, humidity, CO_2, lux level, etc. The real functionality of sensors comes with wireless sensor networks when these sensors start communicating with each other through wireless protocols. 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 analysed.

In this project the wireless sensor network architecture is implemented based on the recently released IETF 6LoWPAN (RFC 4944) open standard for IP communication over low-power radio links—IEEE 802.15.4 represents one such link. WSN LoWPAN networks are connected to other IP networks through one or more border routers forwarding packets between different media including Ethernet, Wi-Fi or GPRS. The IP architecture offers widespread commercial adoption and broad interoperability due to its attributes such as openness, flexibility, scalability and manageability. Many industrial standards, including BACNet, LonTalk, CIP and SCADA, introduced an IP using either TCP/IP or UDP/IP over Ethernet.

In this research the wireless sensors have been chosen to detect and measure various parameters such as temperature, humidity and water/gas/electricity meter readings. In our case the motes, mainly consists of 3 components; the sensor interface which actually measures the physical attributes like 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 is equipped with an Atmega1281 MCU and EM2420 radio chip. The platform includes sensors for monitoring air-temperature, air-humidity and light. Moreover 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. Soekris embedded PC boards [11] with Atheros CM9 Wi-Fi cards and a single IEEE802.15.4 node form a backbone network will be used in all the rooms of the sample building.

19.3.2.3 Multi Dimensional Information Management System

The objective of the data warehouse development is to provide a multi dimensional information management platform to store integrate and analyse complex data sets from multiple information sources such as model editors, energy simulation tools and performance framework specification tools as well as data streams collected from wired and wireless sensors and meters in order to analyse building performance data and to support decision making process of the stakeholders. The data extracted from the Building Information Model and from the wireless sensor/meter/actuator network platform is aggregated in the data warehouse core in order to provide actionable information to the intelligent control module. Simultaneously aggregated data is presented through specific Graphical User Interfaces (GUIs) concerning different stakeholder requirements. The developed system is explained in detail by [12–14].

19.3.2.4 Intelligent Control Module

The actionable information generated by the Multi Dimensional Information Management System is processed within the intelligent control module for low energy building operation in order to control and optimise both building energy supply side and building energy demand side in run time.

The intelligent control module contains algorithms for the defined building operation scenarios (e.g. heating, cooling, and lighting) and interacts with the data warehouse core to compute control parameters, which are then passed to the wireless network for actuation. The detailed description of the intelligent control module has been provided by [12–14].

19.3.2.5 Monitoring Tools

The common goal of the graphical user interfaces is to represent the building performance information to the end users at the Building Energy Demand (BED) side and to the grid operators (stakeholders) at the Building Energy Supply (BES) side concerning their roles and functions. The aim of the proposed system's monitoring tools is designing and implementing user friendly, customized and context sensitive Graphical User Interfaces (GUIs) for defined end users and stakeholders. In order to achieve this, Java and Service Oriented Architecture (SOA) based interfaces are developed which enables end users automated querying without dealing with complex SQL statements [12–14].

19.4 Conclusions

In this paper an integrated building energy management system composed of (1) Building energy supply-side and (2) Building energy demand-side management is described. The proposed concept integrates energy production systems from renewable energy sources, building energy diagnostics and predictive control, ubiquitous wireless sensing technologies, and microgrid power electronics and power control. The research focuses on an innovative model-driven development approach that integrates systems in building energy supply-side and building energy demand-side to provide optimized energy production/consumption. The research findings will be demonstrated in an appropriately selected building in Hannover, Germany with EOS Sustainable Energy Solutions GmbH [15] integrating different energy efficient production/consumption systems addressing the renewable energy technologies, energy storage systems and building energy management systems comprising scalable and robust sensing network platforms, energy performance monitoring and data mining technologies. The initial research findings will be used to extend this research to the smart cities level.

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