

Data collection systems for the management of building energy system

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Total energy use in buildings analysis and evaluation methods

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Data collection systems for the management of building energy system

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1. Introduction

1.1 Building energy consumption and smart metering

Buildings are responsible for at least 40% of energy use in many countries with this energy mostly derived from fossil fuels (WBCSD, 2008). Monitoring is fundamental when aiming at better knowledge and understanding of the energy behavior of buildings. Until now deficiencies of energy metering and consumption data has been an obstacle for comprehensive analysis and verification of the real energy performance of buildings. Situation is changing however and at the moment the new automated meter reading technology (AMR) combined with modern ICT has been rapidly taking place. Millions of so called smart meter systems comprising an electronic box and a communications link are under installation all over the world.

Typical data sources for monitoring systems

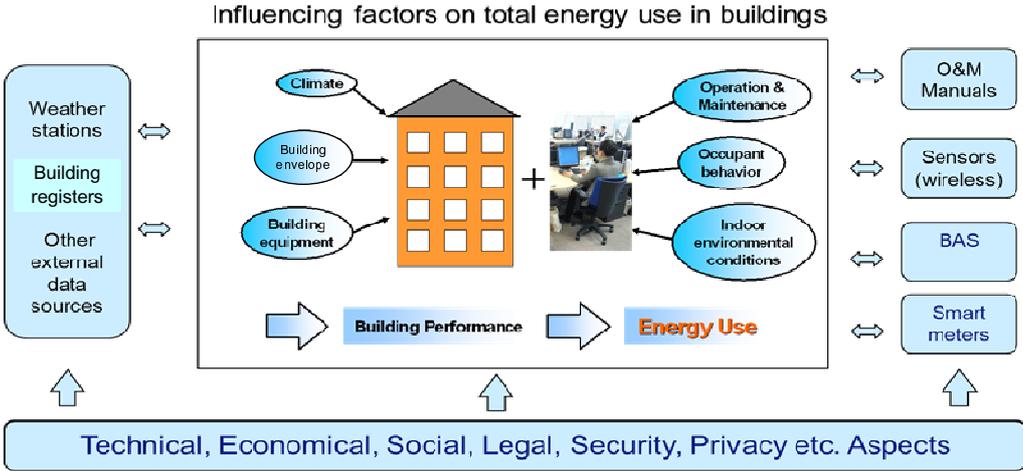


Figure 1.1. Six factors influencing total energy use in buildings and typical data sources

The smart meter measures electronically the energy consumption in short intervals (with hourly or higher resolution), and can communicate this information to another devices or systems. These systems will provide energy users and other factors timely information about their domestic energy consumption. Based on this kind of data, the energy supplier, customer or the service provider can view how much and when energy is used and where might be the biggest saving potentials. Ongoing smart meter rollouts will offer new possibilities for the development of monitoring systems, which will offer accurate and real-time information for various stakeholders. Fast evolving sensor technologies with wireless and other communication capabilities offer cheap means for complementing measurements of various environmental factors. Mass production of new type sensors with wireless communication capabilities offer cheap and flexible means for the monitoring of various

environmental factors and occupation. These are increasingly utilized in building automation systems (BAS), which are typical in office and commercial buildings and include also many functions of monitoring systems.

In addition to the 6 influencing factors presented in the Figure 1.1, the analysis should also take into account the potential data sources for the factors as well as external parameters such as “social and economical aspects”. Besides standardization efforts, these include also legal, privacy, data security and other issues, which might put various limitations for the use of data and publishing of the results. In this way, database typologies become A+, B+, C+. According to this scheme and to the outcomes of the literature review, the possible database typologies are defined as presented in Table 1.1. In the table, it was considered categories of influencing factors.

Table 1.1 Database typologies

Database Typology	Categories of influencing factors			
	I	II	III	+
A Level 1 (basic)	IF1. (Outdoor) Climate IF2. Building envelope IF3. Building equipment			IF7. Social, legal and economical aspects
B Level 2 (intermediate)	IF1. (Outdoor) Climate IF2. Building envelope IF3. Building equipment	IF4. Operation & Maintenance IF5. Indoor Env. Conditions		IF7. Social, legal and economical aspects
C Level 3 (detailed)	IF1. (Outdoor) Climate IF2. Building envelope IF3. Building equipment	IF4. Operation & Maintenance IF5. Indoor Env. Conditions	IF6. Occupant behavior	IF7. Social, legal and economical aspects

This separation in database typologies is important because Annex 53 study is dealing with different contributions and expectations. Most of the available database at present, created before the start up of Annex 53, refers to Database Typology letters A and B. They do not face the issue of “occupant behavior”. Meanwhile, they are very important to understand the potentialities and limitations in the applications of inverse (data-driven) method for different goals.

As a consequence, the analysis of each database typology and of its use to feed inverse method is of great interest. At the same time, it is important that future databases will be created at database typology C+ in order to consider and to highlight the influence of occupant behavior and social/economical aspects. The items inside the database can be different, but they refer to one categories of influencing factors and, for each category, to the items defined by ST-A: in fact, it is working to provide definitions for an homogenous understanding of the meaning of the items inside each category.

1.2 Relevant European directives regarding smart metering

The two recent European Directives: [Directive 2004/22/EC] on measuring instruments (MID) and [Directive 2006/32/EC] on energy end-use efficiency and energy services (ESD) are important regarding smart metering in Europe. Also the Energy Performance in Buildings Directive [Directive 2002/91/EC] and the Commission's third legislative package for Electricity & Gas markets [EC 2007] include issues relevant to smart metering. In addition the European Commission has issued a mandate, see [ESO 2009], to the three European Standards' Organizations (ESO) CEN, CENELEC and ETSI for the standardization of Smart Metering functionalities and communication for usage in Europe for electricity, gas, heat and water applications (M/441– Annex 1). Those systems have the following functionalities and challenges:

- data security, authentication, connectivity management, meter management, installation management
- provision of metered data for balance settlement in the electricity markets
- meter reading services, customer information services, power quality monitoring
- load control and demand response, energy feedback and saving
- load and response modeling, possible other functionalities that need metered data.

The Energy Services Directive (ESD) and the EU directive concerning common rules for the internal market in electricity (2009/72/EC) require the implementation of "intelligent metering systems". Such systems must be in place for 80% of electricity consumers by the end of 2020. The number of electricity meters potentially required to be replaced during the coming years makes this standardization work urgent. In response to European Commission Mandate M/441 in the field of measuring instruments for the development of an open architecture for utility meters involving communication protocols enabling interoperability (smart metering), the European Standards Organizations (ESOs), CEN, CENELEC and ETSI, established together with the relevant stakeholders the Smart Meters Coordination Group (SM-CG) in 2009. This group is a joint advisory body that provides a focal point concerning smart metering standardization issues. The standardization work of the SM-CG focuses on meeting the needs of the residential (household) and small and medium-sized enterprise (SME) sectors. This corresponds to the focus of Mandate M/441 and the need to improve consumers' awareness of their energy and water usage ("consumption").

The first phase of the mandate requests the ESOs to produce a European standard for communications. In this context, the Smart Meters Coordination Group developed a Technical Report, CEN-CLC-ETSI TR 50572:2011 'Functional reference architecture for communications in smart metering systems', which identifies the functional entities and interfaces that the communications standards should address. It is intended to support the development of software and hardware architecture and related standards. The report is as an appendix of this final report.

In addition to energy and water consumption also the main influencing factors discussed earlier should be monitored. Data about outdoor and indoor conditions and occupation should be available on the same frequency (time periods) in order to analyze the interaction with energy consumption. Building automation systems (BAS), if available, can offer this kind of data, but in most cases the influence of human behavior (occupants, operators) is difficult to separate from other factors, or there is no data available for this kind of analysis. An obstacle for the utilization of BAS data is also the fact that there

is no common standard for the identification and format of the data measured and handled in BAS. Systems are closed and proprietary meaning that interfaces for data must be realized case by case. Because of their business models BAS vendors are often not interested in opening their data which hinders the integration of various data sources and systems. Collaboration of big building owners and other stakeholders could help to create common standards and definitions to be used in BAS projects and enhanced data utilization.

New (increasingly wireless) sensor technologies might offer cost benefit solutions for certain needs, but installation and maintenance costs and other reasons have reduced their utilization in buildings for example. Sensor use has been commonplace in industry, cars and consumer electronics for a long time. However, mere baby steps have been taken in the fields of buildings, environmental monitoring and, in particular, health and elderly care. Sensor systems are usually installed where wires can easily be drawn. Where the construction of a wired network is impossible or too expensive, sensor network development has fallen by the wayside, brushed off with a statement that a wireless network will be solution for these applications. Though wireless sensor networks have been the subject of intensive research for two decades, very few have actually been built, with the exception of military applications. Unrealistic expectations placed on wireless sensors might be one of the reasons for the current situation. The future role of sensors and sensor networks in building and other applications is discussed more in details in an article of research professor Heikki Seppä from VTT and it can be found in appendixes of this report.

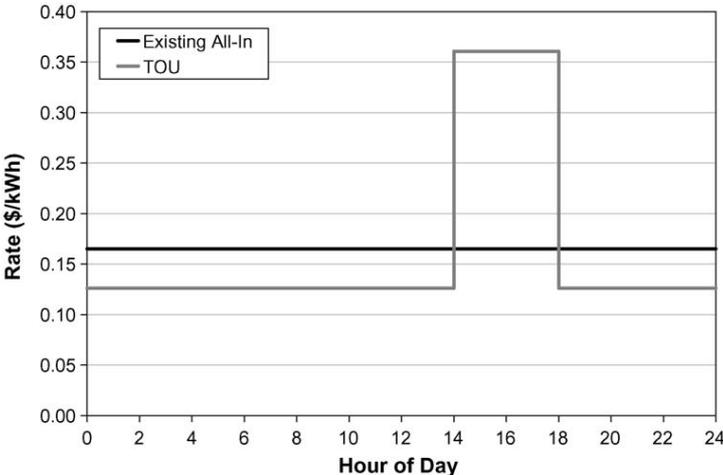


Figure 1.2. Illustration of TOU

The demand for electricity is highly concentrated in the top 1% of the hours of the year. If a way can be found to shave off some of this peak demand, it would eliminate the need to install ‘peak’ generation capacity that is used less than a hundred hours a year. Moreover, peak plant runs infrequently and so investing to make it more efficient is not attractive. The Time of use (TOU) rate divides the day into two or more time periods, with a different rate for each period (Faruqui 2009). For example, a peak period might be defined as the period from 12 pm to 6 pm on weekdays, with the remaining hours being considered off-peak. The rate would be higher during the peak period and lower during the off-peak, mirroring the variation in the cost of supplying electricity during those time periods. With the TOU, there would be no uncertainty as to what the rates would be and when they would occur. In other words, the TOU rate is not “dispatchable,” and would not technically be

considered a “dynamic” rate according to many definitions. Figure 1.2 compares the TOU rate to a flat rate on a weekday.

1.3 Meter reading protocols and application layer protocols

Europe

- A communication protocol widely used for meter reading in the European Union is IEC 61107 that now is IEC 62056-21. It is a half-duplex protocol that uses ASCII data and a serial port such as a twisted pair EIA-485 (formerly known as RS-485) or an optical port. FLAG protocol is a subset of IEC 61107 that leaves less room for vendor specific features, see www.theflagprotocol.com.
- The DLMS/COSEM standard metering object identification system IEC 62056- 61 (OBIS) enables every meter reading system to understand a value by its identification system, irrespective of the meter.

North America

- In North America ANSI C12 standards for metering protocols are used instead of the IEC 62056 standards used in Europe.
- In North America ANSI C12 standards for metering protocols are used instead of the IEC 62056 standards used in Europe.

At present, however, most occupants only have the monthly utility of energy bills to track how energy is used. Very little information is available on the real-time energy consumption in buildings. Therefore, real-time energy consumption monitoring system becomes a very important approach, which will help occupants to manage their properties to save more energy with higher energy efficiency.

1.4 Different technologies used in on line data collection systems

Earlier studies show that on line data collection system may help occupants reduce building energy consumption. So far, various on line data collection systems have been developed for better understanding the real building energy consumption profile. In residential buildings, the power consumption of each whole house was reduced on average by 9% across eight households by a monitoring system, which can measure the end-use electric power and room temperature. Han (2008) suggested that since sensors were resource constrained, the sensor data was often collected into database. The database was created using MySQL, a free data base server, and was used in the work to place the data into database and the control interface was developed using Labview.

Up to now, there are five different common networking topologies, Bus, Star, Mesh, Ring, and Tree respectively, and wireless network was the typical application of Mesh network. At present, wireless sensors and devices were developed very fast but still limited by power. A few operating systems were specially designed to ensure that the node uses very little energy when no action was needed by the sensors (Jang, 2008). Table 1.2 shows different on line data collection systems. It’s been recognized that different systems have various approaches of data acquisition, data collection and data retrieval. Various features change from system to system, e.g. increased complexity in the software, provision of power to wireless device and low transmission rate. Oksa (2008) still presented tremendous

opportunities in energy monitoring system in the future. Sung (2010) introduced the characteristics of the ZigBee wireless communication technology included low power and low-cost, so it fit the control and sensing needs in industry, family, and medicine. The ZigBee software standards were primarily set by IEEE 802.15.4 which defined two physical layers (PHY), the free 900 MHz and 2.4 GHz transmission respectively.

Table 1.2 Different on line data collection systems

Author	Network	Data Acquisition			Data Collection			Data Retrieval		Note
		Hardware	Parameter	Software	Process	Hardware	Software	Hardware	Software	
Jang et al. 2008	W.S. Wireless (BACnet)	Magnetic sensors	Rate: 4.64packets/sec Frequency: 2.4GHz Distance: 25-30m(in) Up to 100m(out)	TinyOS+nesC	A radio node and sensing nodes connected to a special board, receiving data and sending message across RS-232 connection to the computer.	Desktop computer (RS-232)	MySQL+Java	Computer	Web-based+PHP	Increased complexity in the software. Consume more energy. Higher equipment cost. Need to provide power to wireless device.
P.Oksa et al. 2008	Kilavi	Wireless Sensors	Nodes:~100-1000 Rate: ~10kbps Frequency: 433MHz	-	Sensor nodes ↓ Intermediate nodes ↓ Information center	Master	-	Wall panel or Mobile application	-	The wireless device is limited by power supply.
Sung et al. 2010	W.T. Zigbee (IEEE802.15.4)	Sensors	Nodes: up to 255 Rate: 20-250kbps Frequency: 900MHz&2.4GHz	-	Sensor terminal ↓ Routing node ↓ Network server	GIO-ZM PC	Labview	-	-	Low transmission rate.
Bayindir R. et al. 2010	RS485 Ethernet (Modbus)	Power analyzer	I: 5A U: 400V	-	Power analyzer ↓ PLC ↓ PC	PLC PC	SOL DELPHI 6	-	-	-

1.5 Building commissioning (Cx) and owner's project requirements (OPR)

How to verify the performance of the building compared with the requirements, with plans and the real efficiency of the target? Building Commissioning (Cx)-procedure is developed to ensure that the performance of the building will meet the requirements and serves as planned. Commissioning procedure should be a continuous project from the pre-design phase to the use stage and the procedure should be continued during the life-cycle of the building. Often the performance will be checked in testing and balancing stage which may be too short between the implementation and use stage.

The requirements for the building should be set in pre-design phase. In many cases, the final users of the building may not finally defined at that stage, and there can be some limitations or alternative solutions for building services and systems. Depending on the use of the building, the extent and elaborateness of requirements should be determined and fixed in pre-design and design phase according to building code, general requirements and then according to owner's project requirements (OPR) (Figure 1.3).

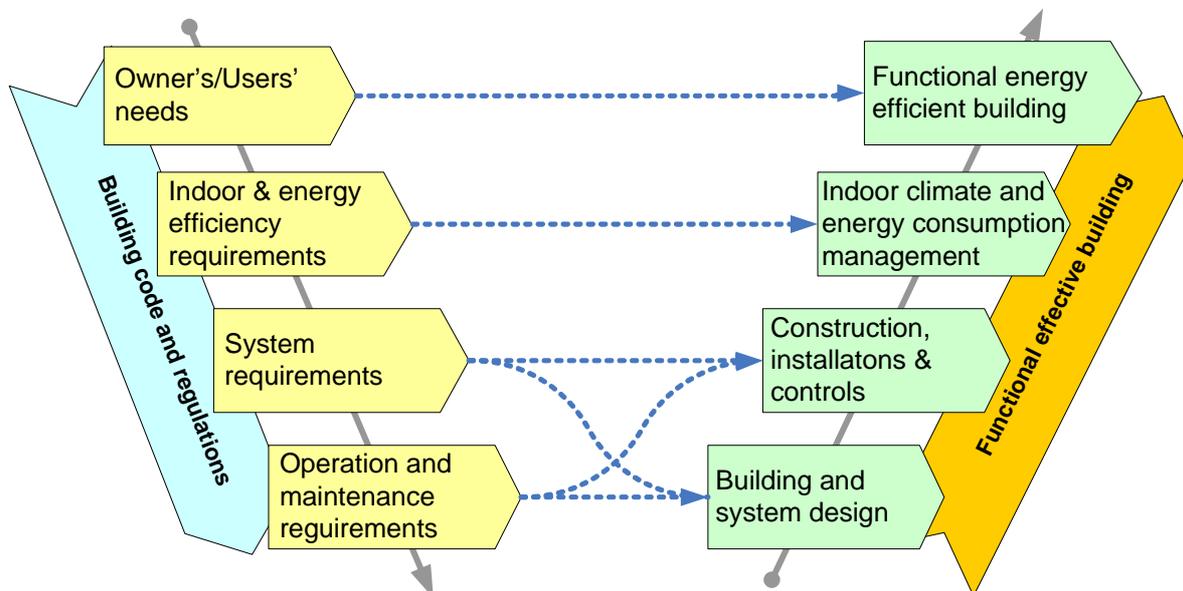


Figure 1.3 Management of needs and requirements during building process

This means in practice, that the essential and significant factors from the owner's and user's point of view must be written in the design documents. These factors can be divided into general and building-specific requirements. The monitoring system must be arranged in a way that these factors could be measured and verified. From the owner's side the question is about key performance indicators.

1.6 Key Performance Indicators (KPI)

According to CEN/TC348:

Indicator:

- Measured or calculated characteristic (or set of characteristics) of a product according to a given formula, which assesses the status or level of performance at defined time

Key performance indicator:

- Indicator that provides essential information about performance of the client organization FM-indicator :
- indicator that measures the quality of FM(facilities management) product

The metrics currently in use can be divided into performance metrics (direct measurable items, such as gross floor area) and performance indicators (how the building is being utilized by measuring data relative to occupancy or floor area). The customer satisfaction is an important metric, and in practice this is typically limited to a post-occupancy evaluation of a new facility. The dissatisfaction of the users usually depends on technical performance - which is the sum of various factors – and also on many non-technical issues. Mostly, to find the reasons for poor performance requires monitoring and measurements. In the best situation, the existing instrumentation and building automation system could report to the facility manager the recent state of the building.

The commonly used building performance metrics and indicators are:

- metrics related to occupancy costs, space use, maintenance and energy costs
- energy and water consumption
- customer satisfaction metrics: indoor air quality, i.e. comfort and healthy, temperatures, cleanliness, lighting levels, etc

Indoor conditions have a great value to productivity. The problem is that the measurement of productivity is extremely difficult. There are studies dealing with the relation between productivity and indoor conditions: -e.g. Seppänen, Tuottava toimisto (Productive office, 2005, figure 1.4)- According to consistent results achieved in different countries good indoor conditions improve productivity.

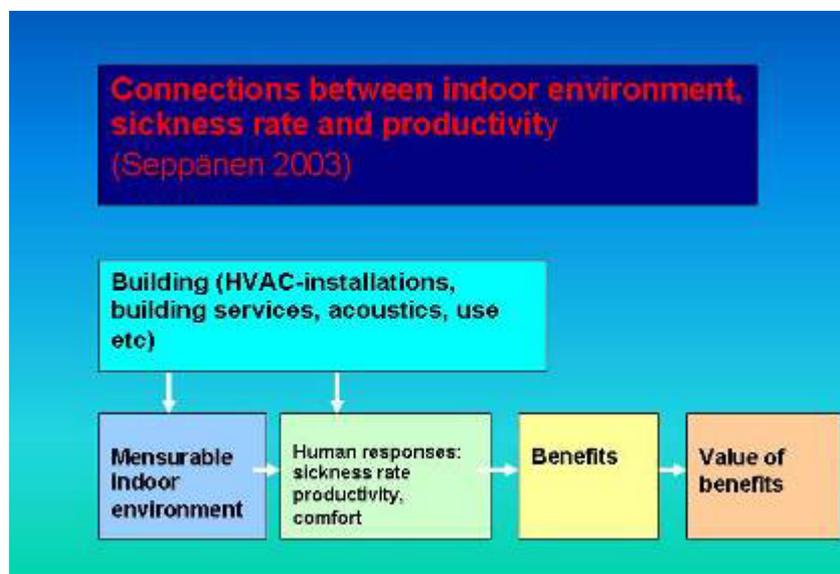


Figure 1.4 Connections between indoor environment and productivity

The performance of a building will be determined mainly during pre-design and the design phase. The essential topic is, that owner's and user's requirements have been determined precisely. By Building Commissioning (Cx) procedure one can verify in the various stages of construction process, that the

owner's requirements will be realized. At the moment, generally, the technical performance of buildings and building services are verified before operation – usually during a very short time.

The level of instrumentation and automation- and facility management systems should have their performance verified by the systems of a building. The connection between a facility management system and building automation systems should allow for exploiting the information generated by building automation systems in full scale. Facility management systems should also include the operation and maintenance manual. Before looking at performance evaluation, it is useful to consider how the performance of buildings can be introduced. Performance measurement is one part of the more extensive concepts covering buildings and building services. The performance-related indicators can be formed in many ways, e.g. rating models like LEED for instance (see LEED web).

1.7 Conclusions

Monitoring is fundamental when aiming at better knowledge and understanding of the energy behavior of buildings. Until now deficiencies of energy metering and consumption data has been an obstacle for comprehensive analysis and verification of the real energy performance of buildings. Situation is changing however and at the moment the new automated meter reading technology (AMR) combined with modern ICT is rapidly taking place. Thousands of so called smart meter systems comprising an electronic box and a communications link are under installation all over the world.

At present, on-line monitoring is fundamental when aiming at better knowledge and understanding of the energy behavior of buildings. Until now deficiencies of energy metering and consumption data has been an obstacle for comprehensive analysis and verification of the real energy performance of buildings. In Subtask B2 the state of art of new on-line data collection systems and technologies will be reviewed, analyzed and reported in order to identify the main features and characteristics of various measurement strategies for on-line data collection and monitoring systems. Also real systems will be demonstrated based on the various existing applications in participating countries.

The smart meter measures electronically the energy consumption in short intervals (with hourly or higher resolution), and can communicate this information to another devices or systems. These systems will provide energy users and other actors timely information about their domestic energy consumption. Based on this kind of data the energy supplier, customer or the service provider can view how much and when energy is used and where might be the biggest saving potentials. On-going smart meter rollouts will offer new possibilities for the development of monitoring systems, which will offer accurate and real-time information for various stakeholders. Smart meters can enable new rates system for peak electricity demand control by the fluctuating price of electricity throughout the day, enabling consumers that have energy management tools to shift energy consumption to the time of day when power is cheapest. For utilities, that can mean better management of the power grid and eliminate the need to build out expensive power generating systems.

Acknowledgements

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2. Energy monitoring, management and information systems

2.1 Introduction

There is widespread recognition that there is often a large gap between building energy performance as designed, and measured post-occupancy energy consumption. A growing body of evidence indicates the value of permanent metering and monitoring, particularly in the context of monitoring-based and continuous or retro-commissioning [Mills and Mathew 2009; Capehart and Middelkoop 2011; Granderson 2010; Motegi 2003; Smith 2011]. Also pointing to the value of monitoring, researchers have increasingly documented the positive behavioral impacts of making energy consumption visible to building occupants and residents. Energy Information Systems (EIS) are viewed as a promising technology to address this gap.

EIS are motivated by two closely related concepts. First is the idea that buildings are complex, dynamic systems, and that realizing optimal energy performance requires higher-granularity data and more time analysis than can be gained from monthly utility bills. Second is the notion that EIS are critically important because they can process data into actionable information, and thereby serve as the informational link between the primary actors who affect building energy efficiency.

As depicted in Figure 2.1, EIS are broadly defined as performance monitoring software, data acquisition hardware, and communication systems used to store, analyze, and display building energy data. Time-series data from meters, sensors, and external data streams are used to perform analyses such as baselining, load profiling, benchmarking, building level anomaly detection, and energy performance tracking. EIS may also include submeter, subsystem, or component level data, and corresponding analyses such as system efficiencies or analysis of end use. At a minimum, EIS provide hourly whole-building electric data that is web accessible, with analytical and graphical capabilities.

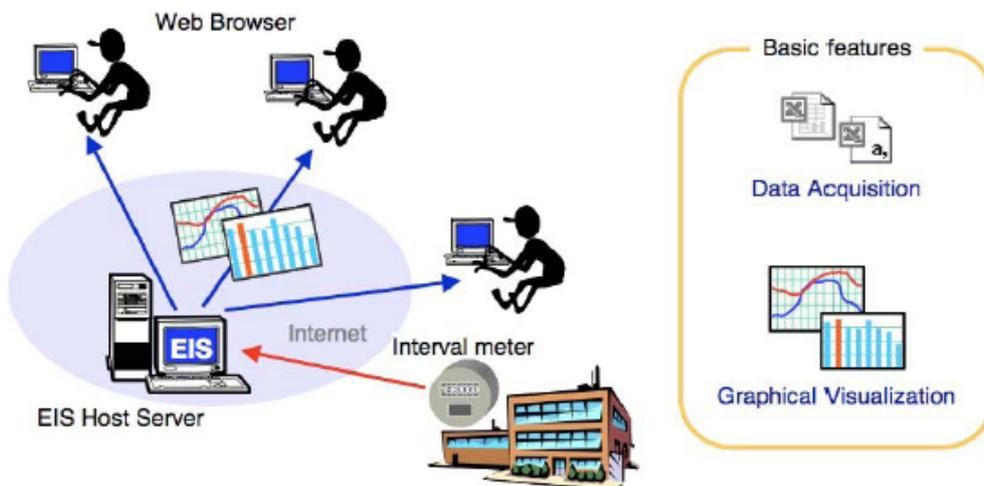


Figure 2.1 Basic energy information system [Motegi and Piette 2003]

Four general types of EIS were identified a 2009 LBNL study [Granderson et al. 2009]: (1) utility EIS, (2) Demand Response (DR) systems, (3) web-based energy management and control systems (web-EMCS), and (4) enterprise energy management (EEM) tools. As shown in Figure 2.2, EIS consist of

the intersection of support tools from a number of domains. More recently, software development companies have begun offering EIS that target smaller, non-enterprise entities.

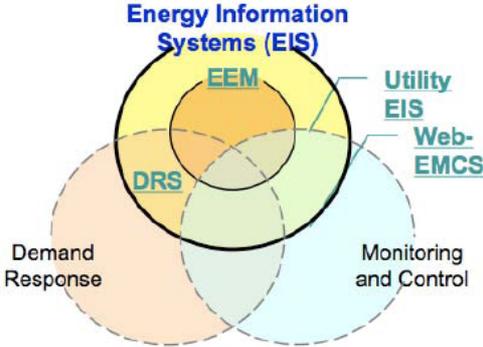


Figure 2.1 Types of EIS and overlapping functional intent [Granderson et al. 2009]

The distinction between what is and what is not an EIS is somewhat fuzzy, and can be understood using Energy Management and Control System (EMCS) as an example. While its traditional design intent is to monitor and control building systems, the EMCS can integrate whole-building utility meters and weather sensors. In turn, these data can be used to define energy performance metrics that can be included in plots, calculations, and reports. In addition, some EMCS are web-accessible. If the monitoring-focused features of an EMCS are implemented and used in this manner, the web-based EMCS can be considered an EIS. That is, the functionality of some EMCS can be applied to whole-building data in such a way that the software serves as an EIS, although scaling issues for data management and storage may be encountered in large enterprises. On the other hand, conventional EIS may not have control capability or subsystem data, but rather embody a design intent to understand patterns of whole-building energy use. EIS provide support for benchmarking, baselining, anomaly detection, off-hours energy use, load shape optimization, energy rate analysis, and retrofit and retro-commissioning savings. In this way, traditional building automation system, and equipment specific diagnostic software tools do not fall within the scope of EIS.

In contrast to EIS software, information "dashboards" are treated according to the traditional definition: single-screen graphical displays of the most critical information necessary for a job or task, commonly used to communicate business information. Dashboards have recently gained popularity in energy applications, because of their ability to distill a large volume of complex data into a summative set of graphics that can be interpreted at a glance. common graphical elements in dashboards include gauges and dial evocative of a vehicle dashboard, as well as graphs and charts that are often color-coded to map quantitative measures to qualitative terms. There is clearly overlap between the two technologies, for example, EIS may include dashboard views or layouts, however, EIS are considered to be full-featured software offerings with a variety of menu, display, and analytical options.

2.2 State of technology

Granderson et al. (2009) presented a characterization framework of EIS features to provide a common terminology and can be used to understand what EIS are and what they do. It characterizes standard out-of-the-box functionality across a broad spectrum of EIS technologies. The framework consists of eight categories with two to ten features each:

- Data collection, transmission, storage, and security - Accepted energy inputs, storage capacity, minimum trend interval, upload frequency, supported protocols and interoperability, archived and exported data formats, and security measures
- Display and visualization - Daily, summary, or calendar potting intervals, daily and trend display overlays, three-dimensional plotting, demand response status and reduction, and x-y plotting
- Energy analysis - Average, high or lows, efficiencies, normalization, carbon tracking, multi-site, historical, and standards-based benchmarking
- Advanced analysis - Forecasting, fault detection and diagnostics, data gaps, statistics, on-site generation, renewables, and load shape analysis
- Financial analysis - Simple and tariff-based energy costing, meter or bill verification, estimation of savings from capital or operational changes, bill processing or payment, and end use allocation
- Demand response - Signal notification, event response recording, manual vs. automated response, opt out, blackout, test dates, response analysis, and quantification
- Remote control and management - Automated and internet remote management
- General information - Browse support, purchase and subscription costs, intended user, number of users, vendor description, traditional and newly targeted markets

The set of features associated with each category are based on typical capabilities as well as leading edge functions that may not yet be widely implemented, for example time-varying analysis of greenhouse gas emissions. These findings represent a snapshot of the state of the technology in a quickly changing field with frequent shifts in offerings and ownership, and they should be interpreted in this context.

The framework was used to characterize approximately 30 EIS. Key findings that are related to distinguishing capabilities, leading edge functionality, and the general state of EIS technology are presented in the following list, grouped by major feature category. It should be noted that the info in the 2009 study is now ~5yrs old, and features, offerings, state of technology has rapidly evolved. So some of these findings may not be longer as accurate.

Business models (General information)

- EIS are most commonly offered through an application service provider with no hardware, or optional hardware based on client needs.
- Optional or bundled services are nearly universally offered.

Display and visualization

- Features have converged to a near common set. Data can be viewed over user-defined intervals of time, trended variables can be aggregated into totals, and the user can overlay multiple datasets on a single plot.
- X-y scatter plotting is offered in only half of the EIS.

Energy analysis

- Two-thirds of the EIS feature greenhouse gas analysis, or provide custom or configurable options to do so. Most apply a simple energy/carbon dioxide relationship, but almost half account for regional differences in generation or other standards.

- Nearly every EIS permits the user to quantify an energy consumption baseline, however weather normalization is rare.
- Every tool that was evaluated supports multi-site benchmarking. Distinguishing aspects include:
 - Composition of the comparative cohort: buildings within the user's enterprise; comparison to buildings from the vendor's database; or less commonly, national data sets.
 - Display of results: static reports versus dynamically accessible functions; results depicted in tables, plots or charts.

Advanced analysis

- About three-quarters of the EIS address data quality, and they do so via three principal means: flagging or summative reporting, cleansing and/or correction, and linking to external or third-party software packages.
- Anomaly detection is typically trend-based and accomplished by identifying departures from normal energy consumption patterns.
- More than half of the EIS forecast near-future loads, usually by coupling historic trends and weather data; very few provide model-based capabilities.
- The large majority of EIS accommodate some form of measurement and verification (M&V) or the ability to track the impact of operational changes.

Financial analysis

- Energy costing is supported in nearly all of the EIS, and more than half have implemented model- or tariff-based calculations.

Demand response

- Demand response capabilities have advanced since early 2000 and have converged to a common set of features.
- Automated response to demand response signals is supported in all but three of the demand response systems that were characterized.

Remote control and management

- Just over half of the EIS surveyed report the ability to control according to a program, and just under half report internet-capable direct remote control.

The EIS product evaluations indicated that, overall, visualization and analytical features are distinguished by the degree to which they accommodate dynamic user-defined selections versus statically defined reporting, calculation, and plotting parameters. Rigorous energy analyses that include normalization, standards-based calculations, anomaly detection, and forecasting are robustly integrated in some EIS products, but less so in others. The fact that EIS capabilities are largely distinguished by flexibility in parameter selection, dynamic versus static options, and robustness of analyses reveals the single most difficult aspect of the EIS evaluations. Figure 2.3 illustrates the hardware, subsystems, and software that comprise or are utilized in a typical EIS.

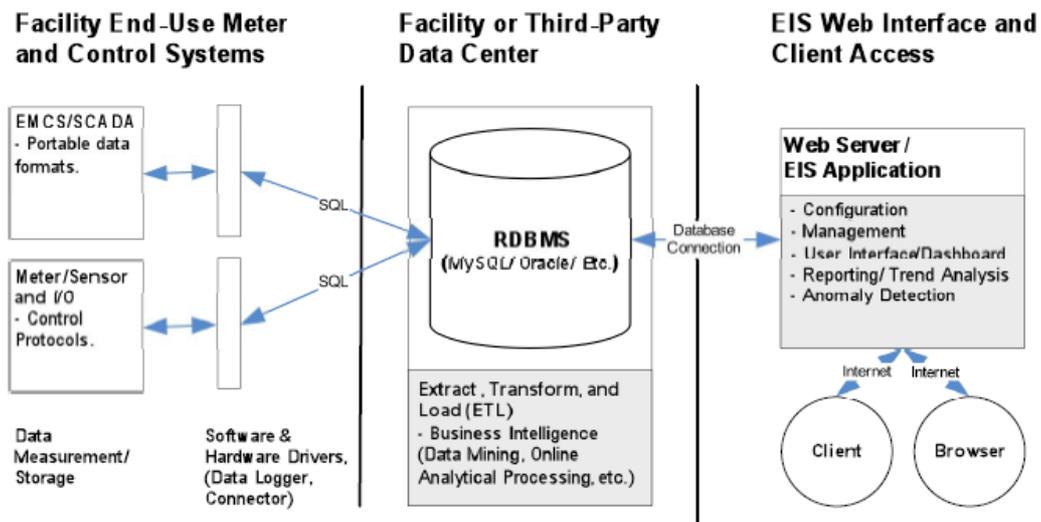


Figure 2.2 Hardware, subsystems, and software that comprise or are utilized in typical EIS [Granderson et al. 2009]

Note:

SCADA = supervisory control and data acquisition;

SQL = structured query language;

RDBMS = relational database management system

The EIS that supports the most features is not necessarily the most powerful solution for a given building. Identifying the most suitable EIS for a commercial implementation must begin with a purposeful consideration of the site's operational and energy goals. Once the immediate and longer-term needs are understood, high-priority features and functionality can help narrow the options, and the most appropriate technology can be selected. For example, an organization that uses custom benchmark models to gauge performance might prioritize flexible definition of metrics and calculations over a dynamic configuration, a geographically diverse enterprise that requires proof of savings from large retrofit initiative may require robust baselining, data cleansing, and tariff-specific energy costing.

2.3 Case studies

Four case studies, documented in [Granderson and Piette 2011], were conducted to identify the energy savings and actions attributable to EIS use, performance monitoring challenges, and successful implementation models. Wal-Mart, Sysco, the University of California (UC) Berkeley, and the UC Merced were selected, representing commercial enterprises and campuses with a diversity of performance-monitoring technologies, commercial building types, and portfolio sizes. These cases encompass buildings that range from Wal-Mart and Sysco's relatively repeatable warehouse and retail designs, to UC Berkeley's legacy and historic sites, to UC Merced's very-low energy new construction.

Wal-Mart

Wal-Mart is a case of "siloed" EIS use by specific groups or individuals for a few key purposes. A group of internal supporters champion the use of the EIS technology and maintain a vision for how its use might be expanded throughout the organization, yet regular operational analytics are not yet widespread vertically or horizontally within the enterprise. The EIS features a custom module for

M&V tasks that has been used extensively, although it has been used on an ad-hoc basis, to determine the effectiveness of energy efficiency improvements. The wholesale power procurement and demand response group also uses the EIS intensively, making considerable use of forecasting and normalization. The EIS is also used to gauge the performance of new designs, particularly at "High Efficiency" supercenters. Each month, the benchmarking analyst identifies the twenty poorest-performing sites; however, custom benchmark models and downloading constraints in the interface require that EIS data be exported to conduct this portfolio tracking.

Sysco

The Sysco case highlighted: (1) enterprise-wide EIS use and information sharing, both vertically and horizontally throughout the corporation, (2) limited, yet powerful, on-site use of the EIS, and (3) use of EIS technology to ensure persistence in savings and energy accountability. Sysco adopted a three-part approach to achieve portfolio savings of 28% in under three years: expert site visits to conduct tune-ups and identify low- or no-cost energy-saving measures; customization of the EIS to accommodate and map to Sysco's goals; and continuous communication and collaboration between corporate managers, energy services contractors, and on-site "energy champions". Sysco performs both site-specific and portfolio analyses on a monthly basis. Managers coordinate monthly group reviews with each site's "energy champion", who is accountable for energy use. The energy champion who was interviewed reports that the EIS is most highly valued for its role in supporting and encouraging accountability and staff motivation, so that efficiency gains might persist over time.

UC Berkeley

There is no central EIS at UC Berkeley; it is a contrasting case that is included to illustrate the challenges that are encountered in the absence of a campus-wide performance monitoring system. Although there is no campus EIS, there is a large volume of energy and system performance data, yet it comes from disparate sources and is used by different staff groups. The utility group uses utility bills and monthly manual meter reads to manage the purchase and billing of all campus energy, performing reviews for approximately 200 utility accounts. The EMCS group uses a web-accessible interface to oversee the campus Barrington control systems. Independently, a number of efficiency and commissioning interventions have implemented remotely accessible electric interval metering at approximately 30 buildings, totaling 11 million gross square feet. UC Berkeley's energy manager identified several energy management priorities including: more remote-access metering to reduce the resources dedicated to manual meter reads, submetering beyond the whole-building level, and access-controlled public data for researchers and special projects.

UC Merced

The UC Merced case illustrated the challenges in using a web-based EMCS as an EIS, the web-EMCS as enabling critical information links, and realization of the campus as a living laboratory. Typically, WebCRTL (the web-EMCS) use at UC Merced is dominated by operational EMCS investigations, however, WebCRTL meter data are used annually to track energy performance. Gas, electricity, hot water, and chilled water consumption are quantified at the campus level for critical buildings. On a monthly basis, the campus energy manager uses the web-EMCS data to determine utility recharges for non-state buildings, and he reported a high level of satisfaction with WebCRTL. He emphasized that UC Merced trends extremely large volumes of data and that intensive monitoring needs to be

undertaken deliberately, with close attention to a spectrum of issues including wiring, system programming, network architecture, and hardware selection.

Table 2.1 summarizes actions that were taken based on building energy data in each of the cases studied, and where available, the associated energy impacts. The most common actions and observations that were encountered concerned incorrect implementation of scheduled load, M&V, and inefficient or excessive operations. Table 2.2 summarizes the challenges, needs, and successes that were found. Note that, in this respect, each case is truly different, and that one case's success may represent another's challenge.

Table 2.1 Summary of actions taken based on building energy information [Granderson et al. 2009]

Site	Observation/Action	EIS Data Points	Energy Impact
Wal-Mart	Static 225 kW load at dimming control submeter	Submeter electricity	\$35,000/yr avoided cost
	Failed or disconnected VFDs used in retrofit programs		Avoided zero savings at program sites
Sysco	Lights left on after hours	Building electricity	
	Multi-hour daily energy efficiency strategy	Building electricity, control system setpoints and temperatures	35% demand reduction (single observation)
	Identification of low-/no-cost savings opportunities, e.g. retro-commissioning and refrigeration tune-ups	Warehouse electric meters	18% reduction in portfolio energy use. 36% reduction in on site.
UC Berkeley	Excessive ventilation and over illumination identified, leading to lighting retrofit and ventilation schedule change	Whole-building electric meter	30% reduction in whole building energy use
	Multi-week chiller lockout that prevented shut-down	Control system setpoints	
UC Merced	Excessive overnight gas use due to non-zero pressure at steam boilers	Steam plant pressure, gas	30% reduction in average daily gas use, \$4,500/month avoided costs
	False peaks in observed chilled water demand at buildings, due to central plant operations	Building chilled water flow, supply and return temperature, central plant chilled water supply temperature	

Table 2.2 Summary of performance monitoring challenges, needs, and successes [Granderson et al. 2009]

Site	Challenge/Needs	Successes
Wal-Mart	Resources, staffing for more intensive EIS use; Enterprise-wide use of EIS; Portfolio benchmarking within the EIS; Ensuring quality of submetering installs.	EIS forecasting for DR and purchasing; M&V of energy saving measures; EIS fore large portfolio data acquisition.
Sysco	Timely integration of utility data; On-site knowledge and use of EIS features.	Network reliability and data quality; Portfolio-wide energy reductions; Persistence of energy savings; Accountability in energy performance; Enterprise information sharing.
UC Berkeley	Resources, staff to use energy data; Central energy information system; External requests for energy data; Continuous maintenance.	In-house EMCS IT management; Utility invoicing, whole-building meters; Volume of distributed building data; Efficiency intervention meter monitoring.
UC Merced	Network communications - largely resolved; Meter/sensor configuration, and commissioning; Resources, staff, proactive use of data; Commissioning the Web-EMCS as an EIS; Metering aligned with metrics, e.g. sampling vs. tantalization.	Living laboratory realization; Dense instrumentation and data; Meeting energy performance goals.

Resources and staffing were a significant constraint in every case studied, and clearly affect the extent to which energy data are successfully used to identify energy-saving opportunities. They also directly affect a site's ability to make meaningful use of submetered data. Reliable, high-quality data are a critical aspect in automated analysis of building energy performance, and can have a significant impact on EIS usability. The degree to which a site uses embedded analytical capabilities depends on the particular performance metrics and benchmarking data that are utilized. The cases shown that the more tailor-made the calculations, the more likely it is that the data will be exported for analysis in third-party modeling or computational software. Although EIS offer a wide range of features, actual use of these features can be very limited, and it is not clear that users are always aware of how to use the capabilities of the technology to generate energy-saving information.

2.4 Energy information handbook

Modern networked controls, smart interval meters, and systems integration make available a rich set of data that can be used to improve a building's operational efficiency. Meanwhile, myriad tools and methods for analyzing that data are available. With so many options, building managers and operators often are left wondering where to start. What data are required for proactive energy management? Which analyses should be performed, and how frequently? In response, the "Energy Information

Handbook: Applications for Energy-Efficient Building Operations" was developed to provide a resource for users with little or no experience analyzing data and monitoring performance [Granderson et al. 2012]. It includes 18 methods of analyzing utility, interval-meter, and submetered energy and control-system data, as well as overviews of manual and automated fault detection and diagnostics (FDD). The summary tables, shown in Figure 2.3, recognize the fact that readers may not immediately know which methods are most applicable to their buildings, and are not likely to read the handbook from cover to cover. They allow the reader to scan across the full set of analysis methods to identify minimum data requirements, applicable building systems, and the level of expertise needed to interpret or use the method.

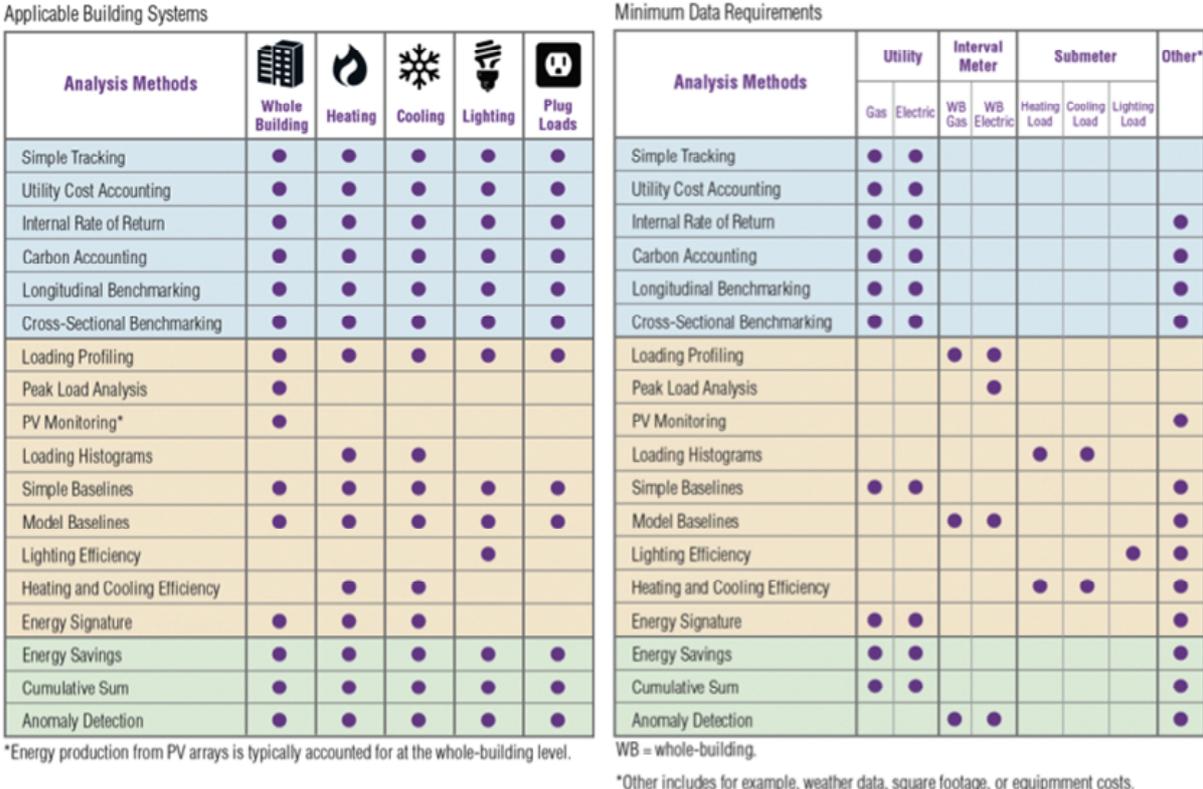


Figure 2.3 Summary tables - applicable building systems and minimum data requirements [Granderson et al. 2012]

The handbook is broken into five chapters—Introduction, Reporting and Tracking Methods, Fundamental Methods, Advanced Methods, Fault Detection and Diagnostics—and an appendix. Reporting and Tracking Methods includes approaches to gauging financial, energy, and carbon performance. The approaches can be applied to specific building systems; however, they most commonly are used at the site or portfolio level. They can use utility billing information and may not require interval meter data or sensor time-series data.

The fundamental methods include system-specific and whole-building analyses and require relatively more user expertise than the reporting and tracking methods and the advanced methods. The analyses tend to require interval-meter data or other time-series data, such as temperature. This core set of analyses is used to reveal energy waste and opportunities for operational- efficiency improvements and includes several methods applying specifically to heating and cooling systems.

Each of the advanced methods requires interval-meter data and (in best-practice applications) a baseline model that can quantify expected or forecasted energy use robustly. Although they are the most sophisticated and computationally intensive methods in the handbook, the advanced methods involve less manual inspection than the fundamental methods and, thus, require minimal expertise for interpretation. The FDD chapter and appendix contain more advanced concepts, technical details, and resources.

The handbook presents each analysis method beginning with a summary of purpose, applicable building systems, frequency of use, target audience, and underlying technical approach. This is followed by an overview of relevant commercial tools and step-by-step calculations. The remaining content is dedicated to interpretation and application examples.

The analysis methods in the handbook are intended to be applied collectively to achieve low-energy building operations. They span several levels of analysis from portfolio to whole-building and system investigations and, used in combination, can generate multiple insights into a common set of “root” aspects of energy performance. The system-level and FDD analysis methods can expose many operational inefficiencies identified during the commissioning process. Performance analyses applied at the whole-building level can reveal inefficiencies in heating and cooling systems, lighting and plug loads, and loads that may not be individually sub-metered.

2.5 Conclusion and future directions

Energy information systems encompass a diverse set of technologies that are sold under an array of business models, with a complicated mix of features, architectures, and optional or required services. The sheer number and variety of options, in combination with rapidly advancing analytical and IT capabilities makes it difficult to distinguish one product from another or to understand the general state of the technology. Vendors’ public domain information is typically vague, demonstration software is often not available, and vendor-documented use cases tend not to critically evaluate the technology usefulness. In response, a framework to characterize EIS market was developed and applied to several dozen commercial products [Granderson et al. 2009]. The framework provides common nomenclature, as well as a structured classification of existing functionality, while the evaluations permit characterization of the state of today’s technology. In addition, four case studies were conducted to explore how the various features and technologies in the framework and evaluations are actually used to achieve energy savings.

Recognizing that building energy data is becoming increasingly available, the "Energy Information Handbook: Applications for Energy-Efficient Building Operations" was developed to assist energy managers, operators, and owners in applying data analysis methods to save energy [Granderson et al. 2012]. These methods, initially created by energy engineers and domain experts, are available in commercial performance monitoring tools, or can be applied using programmable data analysis tools, such as spreadsheets. The technical literature documents the value of these methods, and their application to buildings, however the use of data for operational efficiency is still not business-as-usual in today’s buildings. Development of the handbook was therefore motivated by a desire to make existing technical knowledge widely accessible and usable by non-engineers. Future research in energy information systems will target 3 key areas:

- Features and usability
- Anomaly detection and physical models
- Successful use and deployment models

While the four case investigations generated useful insights as to the value of EIS, questions concerning the most useful features, potentially useful but underutilized features, and energy savings attributable to EIS use merit further attention.

Closely related to features and usability, there is considerable analytical potential in linking EIS anomaly detection methods to physical models. Today's EIS algorithms rely purely on empirical historic performance data to detect abnormal energy consumption. However, they do not provide a means to identify excessive energy consumption relative to the design intent, or to realize model-predictive control strategies. Standardizing the format and structure of information at the data warehouse level could encourage such advancements, as could the development of features to configure exported data files into formats that can be used by modeling tools such as EnergyPlus. Standard formatting of EIS data would also facilitate the transfer of energy information from the building to outside entities, supporting and aligning with current developments in demand side management and the smart grid.

Finally, there remains much to learn about effective EIS deployment and use models within organizations. A potentially powerful approach is to combine in-house use and expert services. This is critical when facility managers have limited time to devote to energy analysis. Additional research is needed to better understand where this approach is most useful and to determine alternate success models that are appropriate to a diversity of organizational sizes, commercial segments, and building ownership models. Neither the EIS evaluations nor the case studies delved very deeply into the costs of EIS. Future investigations into successful EIS use models will be most informative if they are able to link features, whole-building energy savings, the role of services, and EIS cost.

Acknowledgement

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3. Functions of monitoring system

3.1 General data processing

When collecting data of a building for a detailed monitoring, there can easily be hundreds of sensors that deliver their data in intervals of a few minutes for several years. To access the huge amount of information hidden in this data is a challenge that requires suitable means for data handling and visualization. This is even truer when a larger number of buildings are to be benchmarked. This chapter will give an overview of functions a monitoring system should have.

In most cases the data which has to be analysed comes from many different sources – even in one building. There are different recording intervals that induce arbitrary timestamps, some regular some irregular or some only when a state or condition has changed (event sensor, e.g. cooling on/off). However when analysing data, regular time intervals are required, like hourly, daily or monthly averages and consumptions. A monitoring system should therefore be able to interpolate / extrapolate any measurement interval and provide processed data in any desired interval.

Apart from the measurement intervals there are different measurement types to consider as well. To provide values for the mentioned intervals different calculations might have to be made.

- calculate average (like temperatures)
- calculate sum (like consumptions)
- calculate difference (when getting consumption from ascending meter readings)
- calculate prevailing state of event sensors (the state that was dominant in the time interval)
- use formulas to calculate any derived “virtual” value from real measurements

To calculate averages several methods can come into play: arithmetic average, moving average, weighted average and others. Which type is used depends on the task, but a monitoring system for detailed analysis should offer a choice.

Depending on the type of measurement further factors have to be considered. Meters or sensors can be replaced over time. A replaced meter may have a different conversion factor and suddenly deliver MWh instead of kWh. Likewise the first reading of the new meter will be lower than the last reading of the old meter. A monitoring system should therefore be able to apply varying factors to measurements and have means to allow for meter replacements or even detect them automatically.

3.2 Analysis

When analysing buildings, some typical approaches are used most of the time. The most common are:

- Compare values/consumptions to common references
- Compare values/consumptions between buildings
- Compare values/consumptions of the same building in different time periods
- Generate characteristic curves / regression lines to find divergence to “normal” operation
- Use other statistical methods to approach the data
- Compare measured consumptions to simulated energy needs

A monitoring tool should make at least some of options easily available, depending on the nature of the project. An example would be a chart that allows identifying the heating threshold or one to plot measured values to a characteristic curve. When benchmarking buildings it should be possible to enter any reference data or to generate reference data from other buildings.

If a building should be judged according to simulation data, it is helpful if the key figures can be imported to the benchmarking software, because comparison charts can then be generated directly without using external software packages. A useful extension to any monitoring system would be a module for model based simulations. As a result, a building's energy needs can easily be compared with its real consumption.

Likewise, interaction between different modules or charts speeds up the analysis process. For example if a suspicious data point in a scatter chart is clicked, the user could directly get a time series chart around that time period. Similarly, if he clicks on the data line or bar in the time series chart he could get the data in text form to copy if elsewhere. Such interaction quickens up the work flow. Alternatively the user could have a screen with multiple views simultaneously like in the screenshots below.

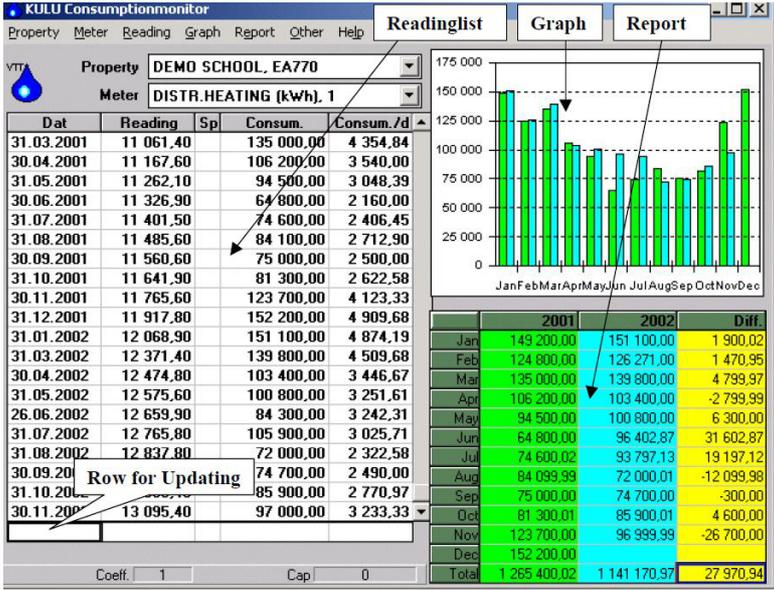


Figure 3.1 User interface of Kulu software

An important aspect is that the software should be as flexible as possible to implement user defined calculations. The more key data figures can be calculated in the software itself the less external software tools are necessary and the time used to export, restructure, import is greatly minimized.

Furthermore the data quality has always to be in mind and the monitoring system should point out abnormal situations wherever possible without action of the user himself (see below).

3.3 Visualization, reporting

Graphs, tables and reports are the results to almost all work that is done to analyse the building behavior. Depending on the purpose, different kinds of charts come into play. In general it is very helpful if the charts are interactive and can be zoomed, panned and are otherwise customizable by the user. For example the ability to change a sensors label in a plot to make it anonymous for public presentation can save a lot of time making amendments.

Charts for general purpose

Time series plots

This is probably are the most used chart type and should therefore be available in all monitoring systems. The time line is represented by the axis of abscissas and the values are plotted on the ordinate. The chosen sensors can then be plotted as lines, bars areas or as simple points. It can be helpful if the sensors can be interpolated or aggregated to different intervals in the same chart, so that you can have a sensor be plotted in hourly means and another in daily intervals. Often there are event-type sensors that only have the values 0 and 1. Those should be plotted as a rectangle function or as a colored band indicating the states.

Scatter plots

Scatter plots are often used to examine the correlation of one or more sensors to a base sensor. One example would be to display the correlation of the energy used for heating to the outside air temperature (to find the heating threshold e.g.). As is not possible to know which time-stamp a certain point in the plot has, it is helpful if the date and time are displayed in tool-tips when the mouse is hovered over the point. Only then it is possible to identify potential outliers.

Charts with free creation and assignment of categories on the x-axis

If the user can create custom categories for the x-axis and link those categories to measurements, a very wide range of usages is possible. To do that the software needs to be able to arrange measured data in a user defined table, like he would do in Excel. That table could not only hold real measurements, but also other data that is manually filled in from other sources.

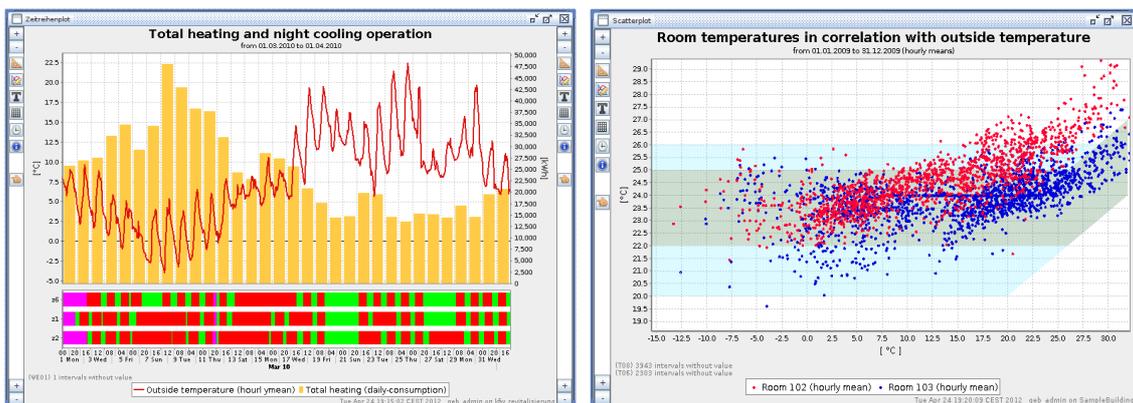


Figure 3.2 User interface of custom categories for the x-axis and link those categories to measurements

Charts for long term examination

Carpet charts

This kind of charts is very clear to depict measurements with a regular structure over a long time period. On the x-axis the date is plotted, while on the y-axis the time of the day is shown. The correct operation of building processes that should have a schematic character can then easily be observed.

Cumulative frequency charts

These charts show how often a measurement is below or above a certain value. They prove useful to find out for how long a certain condition has prevailed, e.g. for how many hours in a year a room temperature has exceeded 26°C.

Charts to detect changes

Comparison of different periods

Sometimes a measurement has to be compared to its historical values – not only by one absolute value but also by the tenor. In comparison charts different time periods can be plotted onto each other and by that allow a direct comparison. The compare-interval should be changeable e.g. to compare different years either by monthly, daily or even hourly values. In the sample chart below the Aprils of 2010 to 2012 are compared on a daily basis.

Table of variations

To get a quick overview of changed consumptions, a colored table can be helpful. Each measurement is compared to its former values, e.g. that of the day before or the average of the last couple of days. The amount of difference can then be mapped to a color which indicates if the consumption was “better” or “worse” than before and by how much.

Charts with calculated historical data as target area / boundary

A chart which shows historical, measured data in the background and the most recent value(s) in the foreground or in a different color or otherwise highlighted. If such chart is reviewed on a regular basis changes to the “typical” behavior of a building or its subsystems can be identified quite easily (as an example see the chart in “Communication” below).

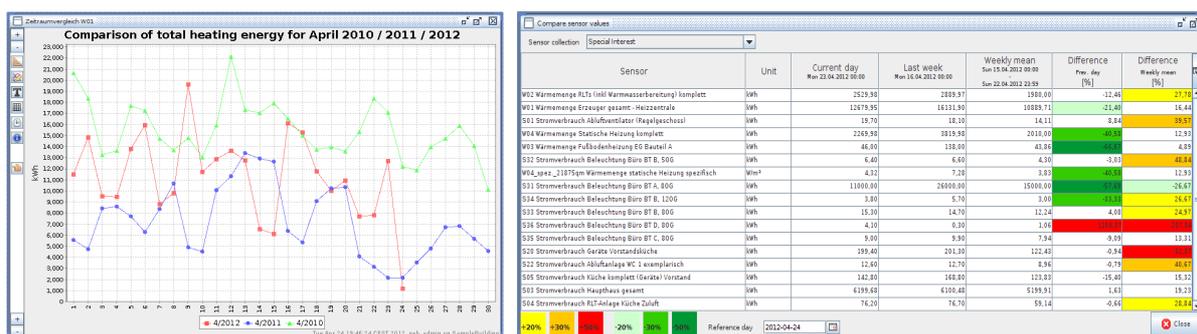


Figure 3.3 A chart which shows historical, measured data in the background and the most recent value

Presenting general information

Sankey diagrams

Sankey diagrams are a kind of flow chart where the width of the arrows is proportional to the respective value. They can be used to illustrate the energy flow of building, a complete building asset

or even building subsystems. At the time of writing, special software has to be used to generate such diagrams.

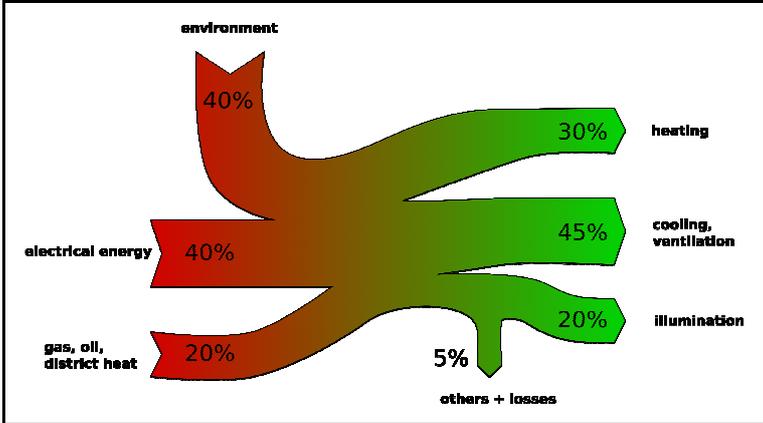


Figure 3.4 Example of sankey diagram

Savable charts

When monitoring a building, the same bunch of sensors and meters is looked at for most of the time. Once a chart that has some statement is arranged, it is therefore very helpful to be able to save that arrangement to a “chart description” which defines all included sensors, axis settings, colors etc. This “chart description” can then be used to generate the same chart for different periods of time and to include them in reports, websites or use them in the daily monitoring routine. The last two options are even more powerful when the chart can be created automatically by a command line interface to the monitoring software or during the starting procedure of it.

Export of pictures

The charts, tables and diagrams that comprise the result of a monitoring campaign should directly be suitable for a report without much editing. Being able to produce files in vector format is preferred, because these can be scaled as needed without losing quality. PDF or SVG files e.g. can be edited very easily to change text or colors etc.

Reporting

When producing output for periodical documentation, many of the charts are used over and over again with an updated time period. A monitoring system that has a report framework will simplify that task. A report is a document where the user defines the layout and links fields to named charts or pictures. Textboxes can be filled at the time of report creating with recent information or be filled automatically with text modules. A quarterly report e.g. could include some default charts with up to date data which the user can then complete by describing text and adding other, more special charts. A sophisticated report system could even allow for automatic report generation. If not the user should at least have the possibility so use “chart descriptions” to generate the same chart for different time periods so that they have a consistent appearance.

No matter how sophisticated and versatile a monitoring system is, there will almost certainly be the need to communicate all or a subset of the data. A flexible data export module is therefore mandatory.

Exported data can be used in a number of ways. It can be used for simulations, to populate databases for other purposes or a subset of data can be made accessible to someone without giving him access to the monitoring system itself.

Communication

In a benchmarking project a lot of participants may be involved – maybe one person per building. They have to share their building's data and other information. Beyond that, someone who is responsible for the whole project has to keep track of everything to write a report. In cases like that communication is a major factor.

One solution would be that the benchmarking system is built up of a website, where each user has its own account. By that the system would be easily accessible from everywhere. Another possibility would be a stand-alone client, which has to be installed on every participant's computer. Both solutions share the feature that they have a common database in the background containing the data. While a website may have some limitations of what can be done in terms of operability, client software can be very complete, though the difference decreases all the time by means of new web technologies.

An element to consider, when multiple people share data, is access rights management. Not all data of a building may be public to other participants. Each operator should have the possibility to limit access to certain sensors for others, though he needs to have the chance to analyze them himself. The benchmarking system should thus have a privilege system where different roles can be defined. For example there could be a three level system which grants access to each sensor for:

- Everyone (for public presentation)
- Involved persons (e.g. all building managers)
- "Owner" of the sensor (private access only)

That is not only true for access to a sensors measurement data itself but also for the generated charts and resulting key figures which may or may not be open to everyone.

3.4 Benchmarking

Benchmarking is a process where several buildings are compared by their individual consumptions. In general this is done on a yearly basis but can also be done for other time periods. Because every building is unique there has to be a common parameter which makes them comparable – a reference value, most commonly some floor area. If the buildings are located in different areas a climate correction of the heating consumption (and maybe others) has to be made. Moreover the occupant behavior has to be taken into account, the same single building will have very different energy consumptions depending on how many people work or live there.

Reference values

For benchmarking capabilities the software tool should provide the possibility to create any kind of reference value the user may want to have. Normal reference values like net floor area are mandatory but the user might also choose to introduce something like "number of occupants", "number of meals served", etc. A reference value should be available for all buildings if possible.

Calculating annually and monthly consumptions

The basis for comparing buildings is their consumption data. If the data is wrong or incomplete (e.g. failure of logging system) the result will be useless. Therefore the user has to be made aware of such problems and should be able to correct the faulty data. Because benchmarking most often only refers to monthly and yearly data the benchmarking system should provide a summary of all monthly consumptions and highlight where something is missing. The user can then try to find a solution. In some cases the consumption might be available from other sources (e.g. manual readings) or must be extrapolated or guessed from historic values. Once all months have valid consumption figures, a benchmarking can safely be done.

Displaying / presenting the benchmark results

The display of benchmarking results is mostly done by bar charts which can be sorted. If the consumption of all energy flows to the buildings is known, stacked bars can show the total energy consumption of all buildings and their proportional distribution.

Often the performance of the measured buildings is compared to that of other reference buildings or target values which can be fixed or be calculated from the building stock (e.g. one bar could represent the performance of the best 25% of the buildings). The benchmarking system should allow for such calculations and allow the user to enter any target values manually to show them in the charts.

Sometimes the user wants to only show a subset of the buildings, use another reference value or switch to another year of examination. All that should be possible without any data copying or much calculation time because when comparing many (hundreds of) buildings a lot of data has to be processed. Apart from bar-chart-type charts, a characteristic diagram of building performance can be helpful to identify the buildings with the highest potential for optimization. The buildings specific consumptions are plotted over their total consumptions, thus inefficient buildings, based on the chosen reference value for specification, will be plotted on the top right.

Climate correction

When comparing heating or cooling consumptions of buildings in different locations or the consumption of the same building in different time periods, climate correction is mandatory to get resilient results. A good monitoring system should therefore be able to do the required calculations. The basis for the correction is actual weather data or, where available, direct correction factors for the desired region and time. In case weather data has to be used, the software tool should be able to calculate heating- and cooling degree days and to apply them on the data if climate correction is needed.

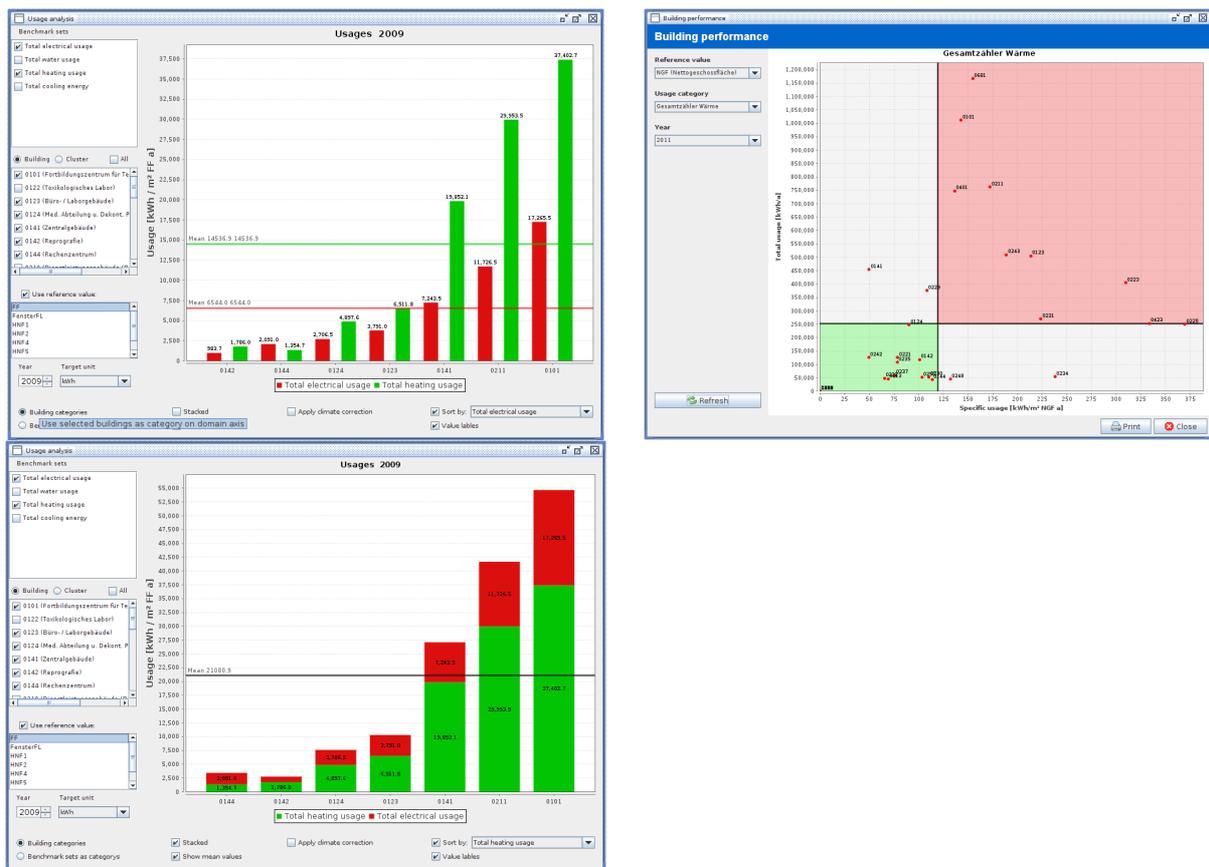


Figure 3.5 Comparing measured results

3.5 Fault detection, anomalies

Measuring data implies dealing with errors. Sensors or a component in the communication-chain can fail, resulting in bad values or missing data. The user has to be pointed to a problem if one occurs because otherwise he may get wrong results which he thinks are resilient. There are several instruments for that which will be mentioned here.

Plausibility check

When data gets written to the target database (the one which is the basis for all analysis) the first thing a monitoring tool should do is to check data quality. That is:

- Inspect data for completeness
- Inspect value ranges
- Use statistical tests to find anomalies

Testing for completeness can be done with the help of a sensors assigned target interval, if desired with a little allowance. To verify the value ranges each sensor has to be given such a range if possible. The ranges could be used to detect real malfunctions or to detect particular conditions (e.g. if a room temperature gets higher than a maximum desired temperature). Using statistical tests can help to find anomalies in the data if the sensor in question has certain characteristics. A continuous sensor (e.g. a temperature) will in most cases have no abrupt value changes, while a consumption of electrical

energy could have that (consumer load switched on/off). On the other hand, meter values should only deliver ascending values, with the exception of meter replacements. It is clear that the possibility to use statistical test is dependent on the sensor type in question. All found incidents should at least be written to log files for later examination.

Quality overview

When dealing with hundreds of sensors it can be a painful task to master the data quality of all sensors. When viewing log files it can be very hard to find the needle in the haystack because there usually are so many warnings that the real problems may be suppressed. One aid that a monitoring system could give is a striking overview of the data quality. This could be a table where sensors that have a problem are colored or a data quality view where the user can judge the data quality of all sensors over a longer period of time. In the sample below the sensors are mapped to the y-axis. Green bars mean everything is ok, red means the data is missing and yellow means the data value out of its target range.

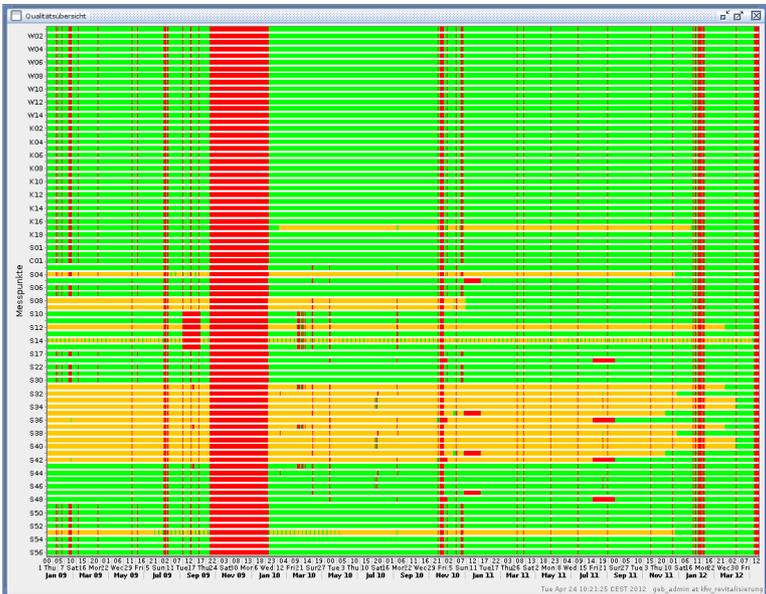


Figure 3.6 Quality overview

Hints in charts

When working in the daily routine of analyzing, data quality easily slips out of mind. Major failures will for sure attract attention but sometimes the resulting figures will be so close to the assumed values that the problem will not be recognized. A bar chart with monthly electrical consumptions e.g., will not look suspicious even if it shows a month where the meter had an outage for a few days and no consumption was recorded. In those cases it is important that the user gets some feedback by the monitoring system. This should at least be a popping up window or a message in a text console. This information is lost however, if the chart is saved and then used later without remembering the issue. A better solution would be to write that information directly to the chart and have it visible whenever the chart is used. An example can be seen in both pictures in the section “Charts for general purpose” above.

Communicating anomalies

Many procedures are handled by automated processes where the user is not involved. Because of the large number of things that can go wrong in the chain of actions, it is very important that the user is informed at certain incidents, be it failures or just the exceedance of target values. Besides writing incidents to log files, the software should therefore be able to send messages over at least one communication channel. This could be a generated mail, a SMS, or at least a warning on a website that is viewable from outside and which is regularly checked.

4. Different online data collection systems

4.1 Definition of on line data collection system

All online data collection systems require components for measuring, getting external data such as weather information, data transfer, data analysis and reporting. Typical most of these five parts are implemented by one company who manages a closed system where no-one else has access, here is called ‘Individual online data collection system’. Another type is ‘open access’ online data collection system, which allows the data transferring two directional. The open type online data collection system can interact with systems.

4.1.1 ‘Open access’ online data collection systems

An on-going project in Finnish high-technology cluster for energy and environment CLEEN Ltd offers a completely new approach shown in Figure 4.1. The idea in CLEEN MMEA project is to establish an online market place where services and data from different companies can meet. The interfaces are made public so that any company can easily join the network to buy or sell services. A company can bring all the measured information to the platform and buy different analysis services from several different companies, which will return the results back to platform for other companies to report to owners of the original company – or the analysis results can be given to an energy energy services company which can then make a service offer to the owners. Naturally everything works with secured connections that only show data to those who have been given rights to see it. In the next chapter some examples on existing systems has been introduced. They could well be connected to MMEA platform to offer energy analysis and reporting services.

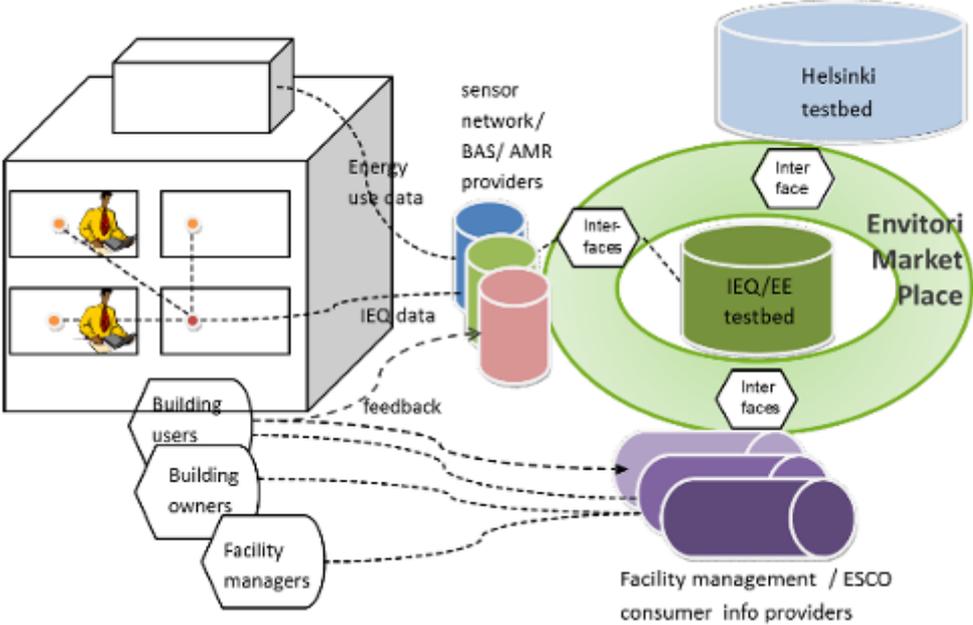


Figure 4.1 Data collection structure of MMEA project

As another quite a typical example of open access data collection system can be mentioned e3Portal (<http://e3portal.vtt.fi>) developed by VTT in collaboration with Finnish municipalities. e3Portal is targeted especially to municipal building owners and offers general information about energy monitoring, management, auditing etc. In addition it includes also continuously updated data about energy and water consumption in thousands of municipal buildings like schools, kindergartens, offices, hospitals, other health care facilities etc. Heating energy is made comparable between years and different locations (climate) based on heating degree days. e3Portal acts as a kind of benchmarking platform for individual towns and other municipalities but individual buildings as well. Anonymous aggregated yearly data is available for all users of internet but access to building level data requires password. The main user interface is shown in Figure 4.2.



Figure 4.2 Main user interface of e3Portal (<http://e3portal.vtt.fi>)

Portal includes also tools for the updating of basic building information and yearly consumption figures via standard browser. Various kind of reports are available (an example in Figure 4.3) on building level and user can easily make performance ratings for chosen building type for example according to the Finnish energy performance certification system implemented according to the EU's EPBD Directive (Building Energy Performance Directive). Preliminary map based reporting features are implemented as well. In addition to the consumption data also reports of implemented energy audits are available and summaries about implemented saving measures can be produced too. An Estonian version has been developed as well including similar information about municipal buildings there. Comparisons on real energy and water consumption in similar building types both in Estonia and Finland can be produced. Thus e3Portal offers also an example about international cross border data exchange. An extension to Russia is under discussion at the moment.

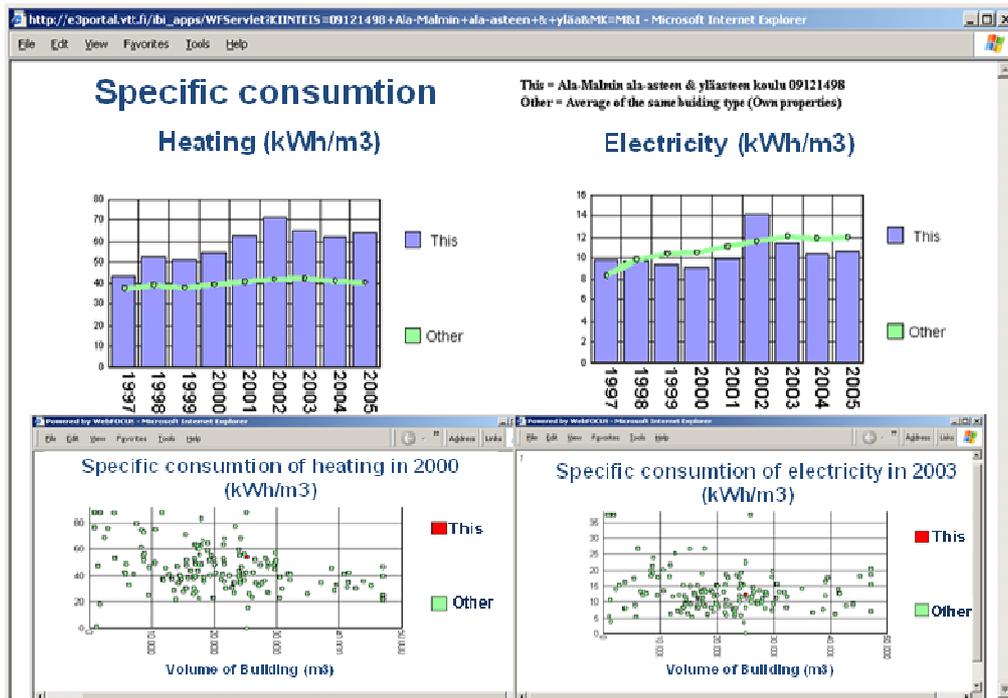


Figure 4.3 Example of an output of e3Portal

The concept realized in e3Portal has been replicated and utilized at VTT also for the development of open data collection system for certain special building types. At the moment same kind of energy performance information service is available for hundreds of public swimming halls in Finland (<http://uimahallit.vtt.fi>). Web based tools for updating of building characteristics and consumption data are available but require password in order to ensure reliability of data. Access to various reports including “ranking lists” of specific energy and water consumption e.g. per user (customer) etc. is open to everybody. Swimming pool operators for example can easily locate their position in in the performance ranking and compare it to similar kind of pools (some examples in figure 9.6). But then they can also find contact information to those halls performing better and ask more information about their technologies and saving measures. Building type specific benchmarking reports can be produced as well like yearly amount of energy, water and users per pool sq. meter in addition to the “normal” m²-, m³- and user/customer related specific consumptions. Similar type open access data collection and reporting services are under construction for hundreds of Finnish ice skating rinks (<http://jaahallit.vtt.fi>) but concept can be easily applied to other – at least public - building types as well like schools, kindergarten, hospitals, theaters etc. For buildings hosting commercial activities like shopping malls, department stores, hotels etc. competitive factors can make an obstacle or at least restrict the openness of data and service.

4.1.2 Individual online data collection system

The individual online data collection system can have different focuses, for example: benchmarking, monitoring or commissioning. Firstly, one example of benchmarking online data collection system will be presented here.

Secondly, a monitoring system WebKulu is introduced here shown in Figure 4.2. The user-interfaces of WebKulu are made with standard html. Therefore it's compatible with most browsers. Information Builders' BI-tool WebFOCUS is used to perform the analyses and create the reports. Information can be added to WebKULU either by reading it from a data storage or manually by using an html form type interfaces via browser. WebFOCUS uses iWay adapters to connect to different data sources and monitoring results of WebKulu can be shown and delivered to various stakeholders via e3Portal as well.

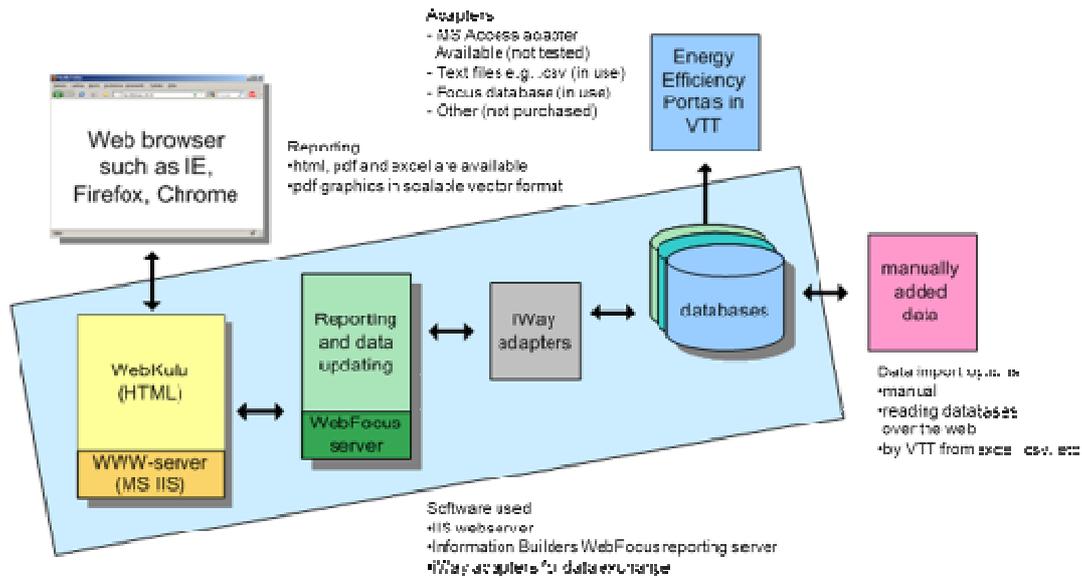


Figure 4.2. WebKulu technical overview

4.2 Finnish versions

Finnish systems are introduced in this section, including KULU and WEBKULU.

KULU

Background of KULU

Kulu is a Windows-application for monitoring, analyzing and management of energy, water etc. consumptions in buildings, in industry and in other types of consumers. Kulu serves effective and user-friendly tools for all kind of organizations from big companies and public bodies to small individual consumers like households etc.

With the help of Kulu abnormal consumptions, wasters of energy, water and other resources can be easily found. Kulu's versatile analyzing and reporting capabilities give a good base for the planning of saving measures and for the monitoring of their effects. Clear graphs and comprehensive reports improve the feedback activities so that the saving motivation can be kept up on all levels of the organization. The standard version of Kulu is an offline tool. It has all the features that are required for effective consumption monitoring and energy management. Standard version can be tested with the free demo.

Features of KULU

The most advanced users select Kulu Options kit, which adds the capabilities of Information Builders Business Intelligence tools (WebFocus) to the Kulu. All the wide capabilities of WebFocus can be utilized in the further development of reporting, analyzing etc. Tailor-made options according user needs can be made easily with the help of WebFocus. The newest program in the Kulu family is the online tool WebKulu. It is used with a standard web browser. Kulu's standard version is an user-friendly application, which requires no previous knowledge or training efforts to make use of it. It suits for the novices and end users as well as qualified professionals. In the standard version all the main routines from updating the meter readings to graphical analyses of consumptions and feedback production can be easily managed in the same window of the program. Kulu user interface consists of seven parts: choose of the object (property) and meter, updating the date and meter reading, consumption table and graph and the menus. Figure 1 shows Kulu user interface which consists of different part data input.

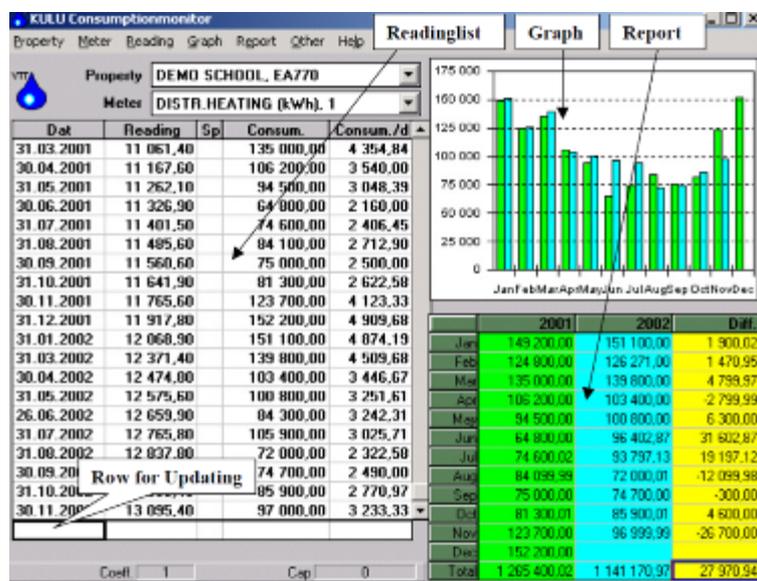


Figure 4.3 Kulu user interface

VTT Vuorimiehentie 3 ----- 00046183

Select meter:
Sähkö = electricity, loisteho = reactive power, vesi = water
01 SÄHKÖ

- Select report
- Daily and hourly consumption
 - Daily and weekly consumption
 - Daily and weekday consumption
 - Daily trend
 - Weather effect
 - Missing data

Run

01 SÄHKÖ , kumulatiivinen tuntikulutus (Kwh)

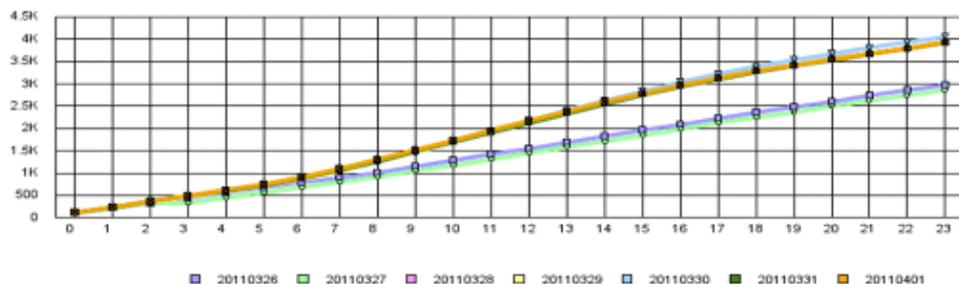


Figure 4.4 Electricity consumption shown in Kulu

In the property-field, it can be seen the name of the active object of monitoring. It can be a building, a group of buildings, an apartment, an industrial process etc. The list of objects (properties) can be opened by clicking the field (or the arrow). The objects in Kulu's main database are alphabetically sorted in the list. In a long list of properties a certain one can be found easily by pushing the first letter in the name of the property. There are no limits for the amount of properties (objects of monitoring). Figure 4.5 shows one example of Kulu database, which includes annual consumption of heat, electricity and water.

Specific Consumption of a Health Care Centre (Tämä) and Reference Group (Vert.)

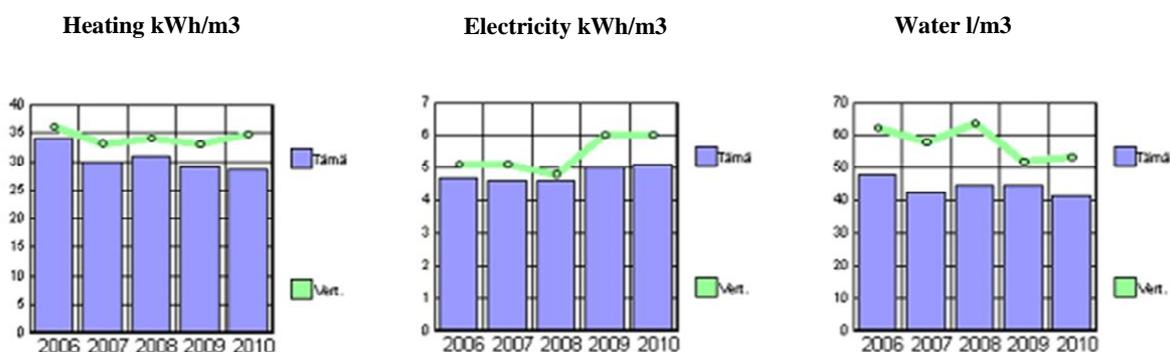


Figure 4.5 Kulu database - annual consumption of heat, electricity and water

In the meter field, it can be seen the name of the active meter in the chosen property. The list of meters can be opened by clicking the name of the meter or the arrow on the right side of the field. Also the meters are sorted alphabetically in the list. The active meter can be chosen from the list by clicking the name of meter. There are no limits for the amount of meters in one property. In most cases however the number of meters in one property will be below ten. In the demo there are only some typical meters. In addition to the typical consumption meters like heating, electricity, water etc. there can also be meters for the outputs of the property like units of production, amount of services or selling, number of users, served people.

WebKulu

Background of WebKULU

WebKulu is on-demand software for energy monitoring including a versatile set of tools available via a standard web browser. Figure 4.6 shows the monitoring processes, in which the measured results will be analyzed and benefit the users. All the required routines for monitoring as updating meter readings, analysis, reporting and benchmarking are available. There is a very wide list of the adapters available, but so far only Microsoft Access have been installed to WebKulu system in addition to always included standard adapters such as Focus database (which is currently used for WebKulu's internal data storage) and adapters for csv and html files.

Features of WebKULU

Typically WebFocus uses the data sources to create the reports when the report is requested in the browser. The reports will therefore contain all the data that exists. Pre-made reports are only needed if

there is so much information or computation that the processing time after the request would be too long, but this hasn't happened in WebKulu so far.

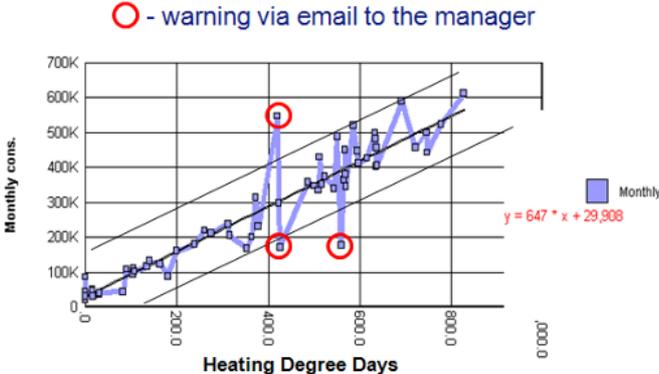


Figure 4.6 The monitoring processes using WebKulu

WebKulu makes Benchmarking over internet possible and it can be used for other kind of energy efficiency purposes as well. Real impacts of new saving technologies, best practices etc. can be concretized - in longer term too. Tools and services for performance based contracting, third party financing can be developed.

Energy weather data

When calculating the monthly consumption Kulu can make also so called weather correction for the heating energy. This presupposes that monthly heating degree days are updated into the weather database and right weather area is given in the property data. Based on the monthly degree days weather corrected monthly consumption of heating energy will be calculated for meters which have the consumption type beginning with letter L (look the meter data). Whether degree days are updated or not Kulu calculates always monthly consumptions for all meters of the property. So the weather correction can be seen just as an additional option for heating (cooling) energy meters. Because needs and practices of weather correction vary from country to country, this option can be developed further in collaboration with the users. At the moment Kulu offers however some tools for recording the very basic monthly weather data, which then can be used for calculations as described below.

Data already entered into the database is shown in the form. For the year 1960 long term average (so called normal year) from years 1960-80 is stored. The data of the year 1961 shows the latest normal year available (long term average of years 1960-90). You can scroll the list up and down with the scroll bar on the right side of the list. On the top of the form there is the field 'weather area' including identity codes for weather stations. Weather data of a certain area (weather station) is joined with the help of this code to the weather code included in the property information. By clicking the field the list of weather areas entered into the database will be displayed. By clicking the code in the list you can choose the weather area (station) and it's data will be displayed. Basically there is no limit for the amount of weather areas (stations) but because the current version is developed originally for Finnish circumstances no routines for creating new areas are included yet and new codes (weather stations) can not be added by the user. New weather database for a certain country can be easily made however in collaboration with VTT. For the most of users the existing codes (stations) can be used too, because

their weather data (for the so-called normal year and other years) can be changed/updated according national needs.

4.3 Chinese version

Access to the on line data collection system

Tsinghua University will open the on line data collection of one office building you for information exchange within Annex 53. It can be found by the following link:

<http://202.85.214.161:9999/content/index.html?buildingsign=1101050025&username=admin&password=password>

The link is and designed only for the usage in Annex 53 at this moment without user name and password.

General description

iSagy is an integrated building energy management system (BEMS) developed mainly for large-scale public/commercial buildings, which generally consume more energy than other types of buildings. The system may assist property managing staff to improve energy efficiency of their buildings. The system is also valuable to researchers, in terms of modeling and benchmarking, and to regulatory bodies, in terms of standard setting. By obtaining non-stop and real-time energy consumption data of a building, the system is able to track daily operation of the building's energy consuming subsystems and thus is useful in energy problem identification and post-retrofit evaluation. A typical iSagy system can be divided into three main parts, namely, data acquisition/transmission, data processing, and data mining, which are designed collectively to form an accurate, reliable, safe, and open energy managing tool.

The system is aimed to cover the whole process of building energy conservation including current status observation, problem identification and solution implementation, effect observation, and post-retrofit evaluation.

A typical iSagy system consists of a number of smart end-devices (e.g., power meters, sensors, etc), one or more data acquisition gateways, and an integrated software platform, and can be divided into three main parts, namely, data acquisition and transmission, data processing, and data display, which are designed collectively to form an accurate, reliable, safe, and open managing tool.

The integrated software platform is the core of an iSagy system. Major building energy managing functionalities such as real-time monitoring, data analysis, equipment management, and efficiency diagnosis are integrated on the platform. By using a proven reference model for characteristics of equipments and building energy use, the system is able to monitor buildings of different scales or purposes of use in a unified way, making it possible to compare a certain subsystem (e.g., ventilation) among a large number of buildings. The user interface is web-based to ensure ease of use for end users and is highly visualized to facilitate more intuitive and efficient data analysis.

Data acquisition / validation

Real-time energy consumption data is collected by using a purpose-built data acquisition gateway. Based on PowerPC + Linux architecture, the gateway is highly competent in data processing, thus reducing burden of the data acquisition server. In order to be compatible with widely-used industrial

standards, the gateway adopts EIA/RS-485 interface at the metering side and Ethernet/3G wireless technologies at the network side, both of which ensure that the majority of existing metering and transmission devices can be connected. For safety, data encryption and remote identity verification are implemented, and in order to save IP resources, DNS and NAT protocols are supported at the acquisition gateway.

At the data acquisition server, data integrity check is performed, and data error or data loss due to device or network failure can be recovered by using data repairing algorithms so as to guarantee the continuity and quality of energy consumption data. By separating the raw data and the processed subsystem-level/tenant-level data to different servers, the system is more robust against faults or failures.

Automation

The system is highly automatic in terms of data acquisition, transmission, processing, and displaying (e.g., chart generation). By using a complete set of detailed building information, energy consumption of each equipment or equipment subsystem is automatically monitored and stored for further inspection. Data report can be automatically generated based on predefined spreadsheet templates. The system is also featured by automatic detection of system changes or faults such as failure or replacement of power meters, transfer switching, etc.

Tools for analysis

- Benchmarking and indexing of total weekly energy consumption of a building or an equipment subsystem
- Equipment and tenant-level monitoring
- Daily, weekly, monthly, and yearly analysis of energy consumption of an equipment/subsystem or a tenant by using bar chart, flexible time range is also supported
- User-defined comparison of different equipments/subsystems or tenants by using line chart
- Ranking and proportional analysis by using bar and pie charts
- Auxiliary index (e.g., max, min, average, and reference values, environmental parameters, etc.), unit conversion, and coordinate transformation are supported
- Branch monitoring
- Real-time monitoring of power distribution branch circuit
- Automatic fault detection and alarming
- Data report
- User-defined MS-Excel spreadsheet of energy consumption data
- Energy efficiency diagnostics
- Detecting instant operational problems of equipments such as abnormal power changes, three phase imbalance, etc.
- Algorithm-module-based energy efficiency diagnosis for important equipments and subsystems

Error detection

Data error including data loss can be mitigated by using automatic data repairing techniques. Each reading from power meters is judged at the server and, if a data error is determined, the data error can be corrected based on historical data.

Export features

Raw and processed data can be exported in MS-Excel format based on user's configuration.

Access to system/data

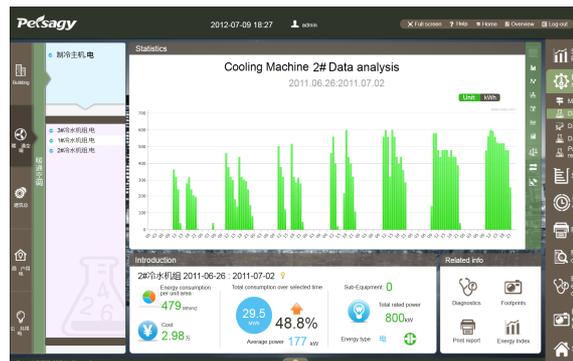
The system is designed based on browser/server (B/S) structure and users may login to the system anywhere via a web browser. Data access is also designed as a web service by providing a web service interface. Integration of 3rd party data is feasible based on this type of interface-based data access.

System requirements

- Java Runtime Environment (JRE) v1.6.0 or above
- MySQL v5.1.4 or above
- Apache Tomcat v6.0.10 or above
- Microsoft Silverlight v4.0 or above



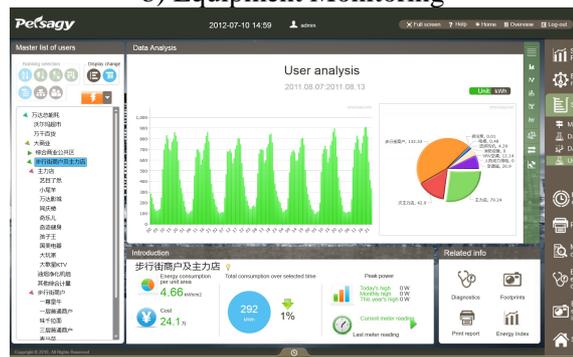
a) Homepage



b) Equipment Monitoring



c) Equipment Comparison



d) Tenant Comparison



e) Energy Consumption Index



f) Branch Monitoring

Figure 4.8 Screen of the monitoring system

Table 4.1 Comparison of iSagy and MoniSoft

System	Technical features										Analysis features										Fault detection							
	Including hardware for acquisition	Automatic data acquisition	Manual data entry	Automatic data processing	Platform independent	CSV-Import	CSV-Export	Interfaces to BMS	Automatic chart generation	Interactive charts	Stand-alone software	Web frontend	Interpolation if arbitrary measure intervals	Virtual sensors	Definition of any reference values	Comfort analysis	Statistical analysis	Real-time diagnosis	Climate correction	Report system	Tools for benchmarking	Prediction of energy savings	Prediction of cost savings	Analyze building subsystems	Data integrity validation	Check by value ranges	Email notification	
MoniSoft																												
iSagy																												

Description of the building/buildings monitored by the on line data collection system

Basic information of Beijing Development Building (BJDB): it is a high-grade office building built in 1980s located at East 3rd Ring Rd in Beijing, China. Floor areas: 54490m², height: 80m, 20 floors on the floor and 2 floors underground. It uses centralized HVAC system with VAV terminals.



Figure 4.9 Photo of Beijing Development Building

Description of the on line data collection system

iSagy is a building energy management system (BEMS) developed mainly for large-scale public/commercial buildings, which in general consume more electricity than other types of buildings. The system may assist property managing teams to improve the operation of their buildings including but not limited to increasing energy efficiency. The system is also valuable to researchers, in terms of modeling and benchmarking, and to regulatory bodies, in terms of standard setting.

Description of the structure/ typologies /metering system used in the on line data collection system

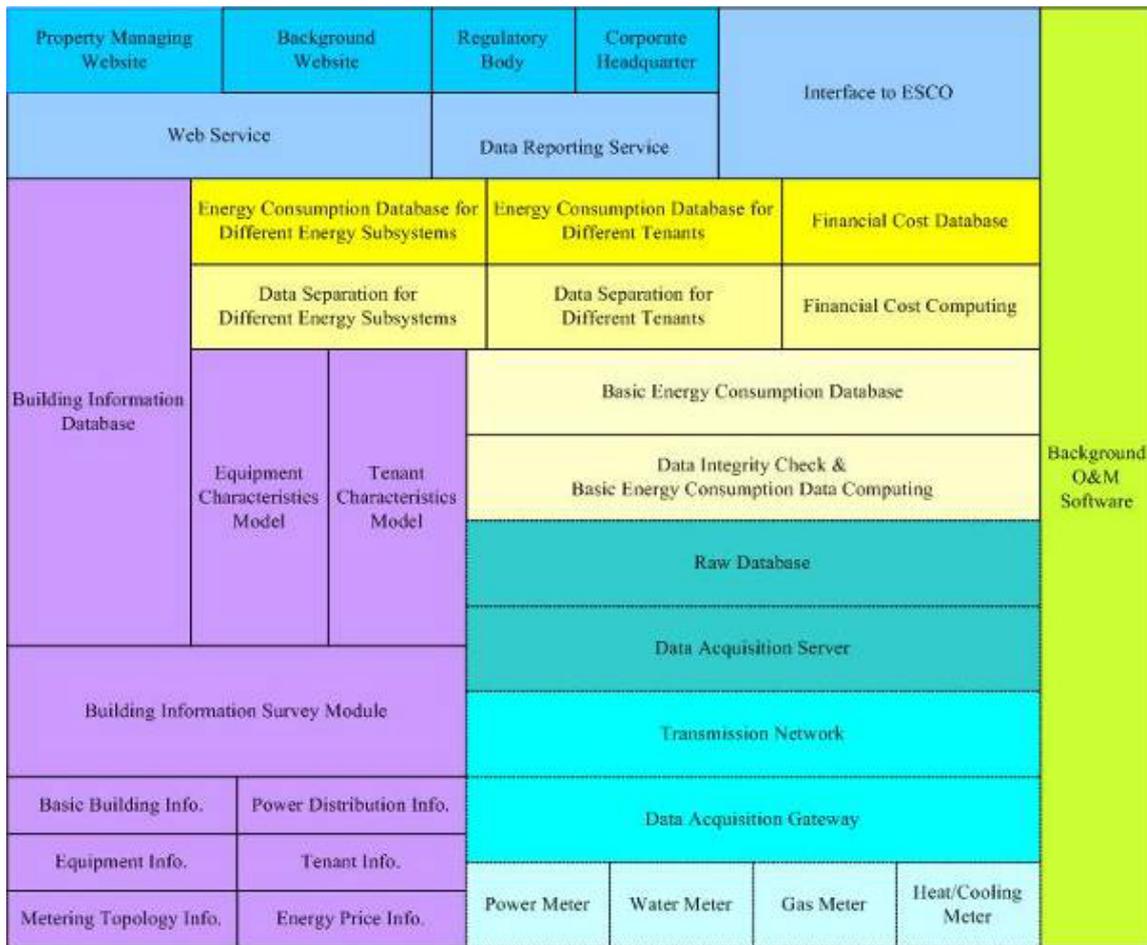


Figure 4.10 Block Diagram of a typical iSagy system for a building

As mentioned above, three major subsystems are included in an iSagy system:

Data Acquisition & Transmission

This subsystem is responsible for acquiring readings from end-devices and transmitting raw data to the server.

Based on ARM + Linux architecture, the purpose-built data acquisition gateway is highly competent in data processing, thus reducing burden of the data acquisition server. In order to be compatible with widely-used industrial standards, the gateway adopts EIA-485 interface at the device side and Ethernet or 3G wireless technologies at the network side, both of which ensure that a large majority of existing devices can be connected to the gateway. Moreover, in order to ensure safety of transmission, data encryption and remote identity verification are implemented, and in order to save IP address resources, DNS function is supported.

Data Processing

This subsystem is responsible for maintaining the integrity of raw data obtained from end-devices and processing the raw data to derive basic energy consumption data and more detailed energy consumption data for different subsystems or tenants within a building.

Data integrity check is performed so as to recover from data loss due to device or network failure. By separating the raw/basic data and the processed subsystem-level or tenant-level data to different servers, the system is more robust against miss-operations or attacks. In addition, database technologies such as NOSQL, BigTable, and MapReduce are deployed for mass data processing.

Based on a reference model of 31 nodes, data for each power distribution branch are further separated based on the statistic and characterized models of the equipment that belong to the branch so as to obtain specific energy consumption data for a certain energy subsystem or a tenant (e.g., a supermarket, a restaurant, or a cinema). Our experience indicates that, in order to achieve accurate separation, a complete and specific survey of the building to be monitored is crucial, and, by using various building information as variables of the data separation algorithm, a close estimation of each energy subsystem can be achieved.

Data Display

This subsystem is responsible for displaying building energy consumption results to end users in various dimensions and providing an interface to the ESCOs for energy efficiency diagnosis.

The display and management interface for end users is web-based and designed based on the concept of Rich Internet Application (RIA) so as to minimize the requirements on the user's PC without compromising user experience (please see below for an exemplary page of a monitoring website).



Figure 4.11 An example of iSagy user interface

4.4 Japanese version: Residential data collection system

Access to the on line data collection system

You can download the data measured by “HEED” at the following link:

<http://buffalonas.com/konasapporo2/>

Description of the building/buildings monitored by the on line data collection system

The northern views and the floor plans of the investigated house before/after the retrofit are shown in Figure 4.12. The description of the house is shown in Table 4.2. The house built in 1984 is two-story and made of wood located in Sendai, Japan. A cogeneration system (CGS) was installed in Nov. 2008. The insulation retrofit was started in Nov. 2009 and completed in Jan. 2010. After that, a 3.04kW photo voltaic system (PV) was installed in Feb. 2010. In Figure 6.8, annual energy consumption and CO₂ emission before/after the installation of CGS and the insulation retrofit are shown. Energy consumption and CO₂ emission decreased by 4% (4.3GJ) and 28% (2.32t-CO₂) after the installation respectively. Energy consumption and CO₂ emission decreased by 37% (40.1GJ) and 56% (4.57t-CO₂) after the insulation retrofit respectively compared with the results before the installation of CGS.

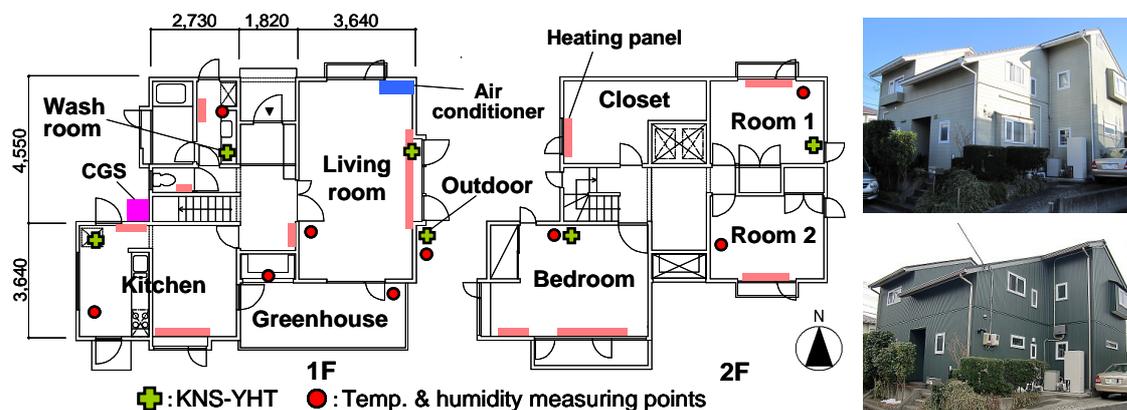


Figure 4.12 Floor plans and northern views (above: before the retrofit, below: after) of the investigated house

Table 4.2 Description of the investigated house

	Before the retrofit		After the retrofit
Completion year	Jan. 1984	CGS: Nov. 2008	Jan. 2010 (PV: Feb. 2010)
Investigation period	Jul. 21, 2008~Nov. 18, 2009		Jan. 8, 2010~
Construction & Floor area	Wooden two-story house (2x4 construction), 124.2m ²		
Heating transmission rate	3.5W/m ² K		1.2W/m ² K
Equivalent leakage area	3.6cm ² /m ²		2.1cm ² /m ²
Space heating	Hydronic heating panels (all rooms)		
Space cooling	Air conditioner (living)		
Cooking stove	Gas range		
Hot water supply	Gas water heater	Gas-engine cogeneration system (& auxiliary boiler)	
Energy source	heating: oil hot water & cooking: city gas others: electricity	heating & hot water: generated heat (& city gas) cooking: city gas others: electricity	

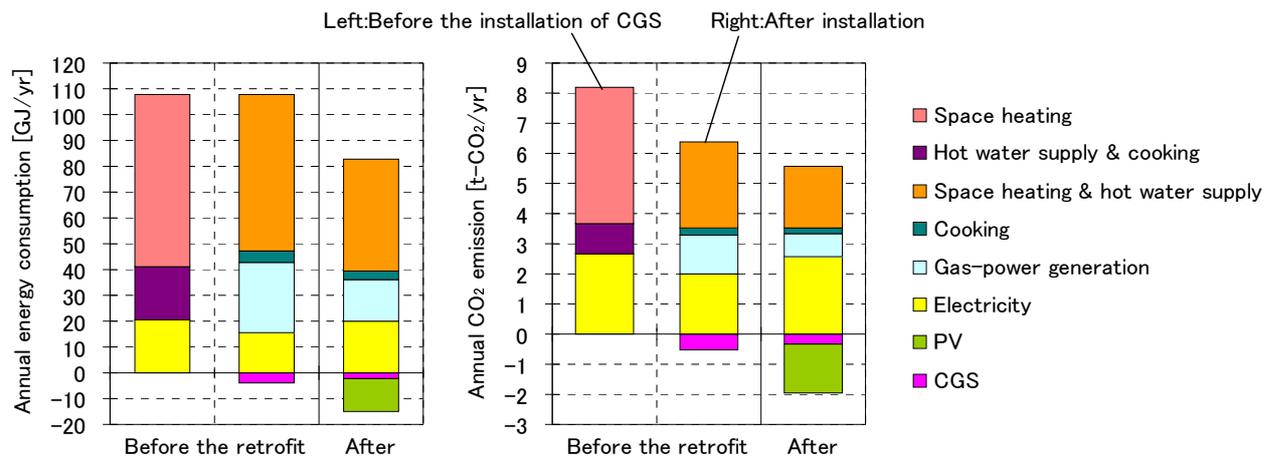


Figure 4.13. Annual energy consumption and CO₂ emission in the investigated house before and after the insulation retrofit

Description of the on line data collection system

The flowchart of the measurement and diagnosis system for energy saving and indoor healthy environment is shown in Figure 4.15. We named the prototype of the system “HEED” (Healthy Environment and Energy-saving Diagnosis system). This system is composed of “the real-time measurement system” and “the diagnosis system”. The development of “HEED” was promoted in each system, and the whole system was designed together. Finally, the system was installed and tested in an actual residential house, and the results were fed back to the development of the system.

The system flowchart shows that energy consumption and indoor environments are measured by the real-time measurement system firstly. Secondly, the diagnosis system gives the occupants the real-time and long-term diagnoses using the measured data. In addition, predictions of energy consumption in the cases of insulation retrofit, installation of high efficiency equipments and so on are made. The diagnoses and predictions stimulate occupants to act for energy savings. After that, the effects of the occupants’ acts are verified by measurements.

The relation of the prototype system and relative equipments is shown in Figure 4.14 and Figure 4.15. The data measured by the measurement equipments are analyzed and displayed by the monitoring computer in the house (Real-time diagnosis). At the same time, the data are saved in a file server on the internet. After the data are stored to some extent (for a month or a year), the diagnosis system gives occupants long-term diagnosis and some advice. Moreover, the stored data can be browsed from outside. An estimator (at the present stage, the researcher) calculates energy consumption in energy-saving cases and gives occupants the results.

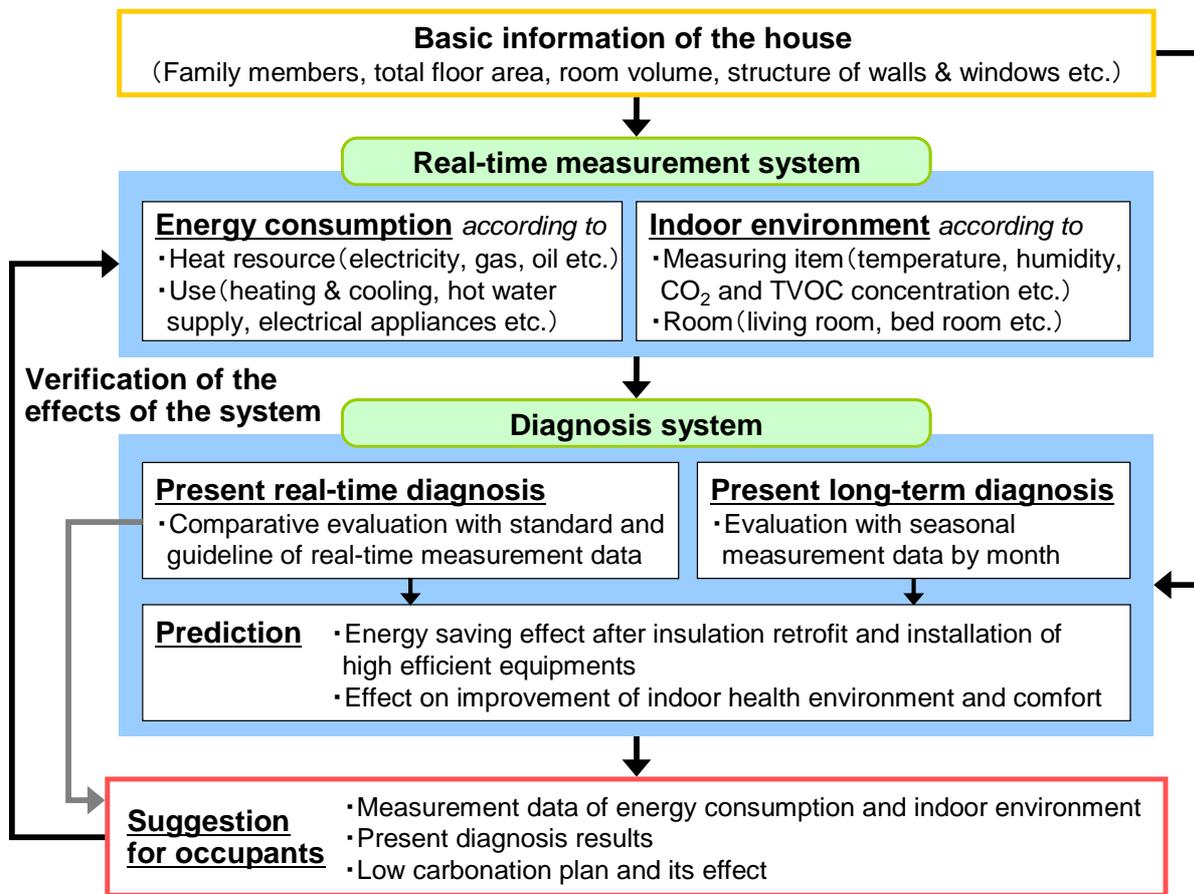


Figure 4.14 Flowchart of the prototype system "HEED"

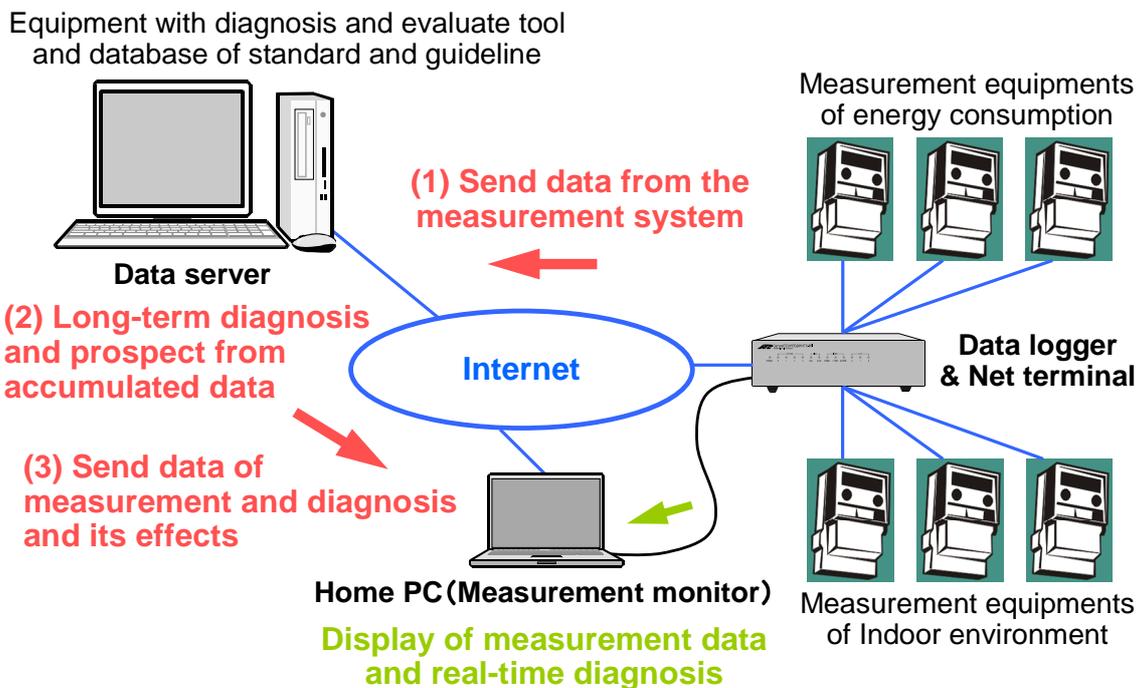


Figure 4.15 The relation of "HEED" and relative equipment

Description of the structure/ typologies /metering system used in the on line data collection system

Development of measurement system

Based on the previous studies and field measurements, the measurement equipments considered compositions, measurement items, measurement intervals and so on. The measurement system was easily made at low cost for existing houses. The development of the system was advanced while doing test experiments and measurements. The measurement equipments used in the measurement system are shown in Figure 4.16.

The description of measurement items by “KNS-YHT” (a) is shown in Table 4.3. “KNS-YHT” measures mainly indoor air environments and has sensors of air temperature, relative humidity, CO₂ concentration and TVOC concentration in its body (). Moreover, six optional sensors can be added at a maximum. In Figure 4.16, illuminometer and sensor to detect people () are added to “KNS-YHT”. Both of “KNS-WP1” (b) and “KNS-WP2” (c) measure electric consumption. “KNS-WP1” is installed to a plug of household electrical appliance and measures electric consumption of the appliance. “KNS-WP2” is installed to the power distribution board and measures total electric consumption and so on.

These measurement equipments have wireless Bluetooth (one of wireless communication standards for digital devices) devices and send the measured data to the monitoring computer in real time. The measurements can be done at one-minute intervals. However, the measurements had better be done at ten-minute intervals because of time lags of moving data.

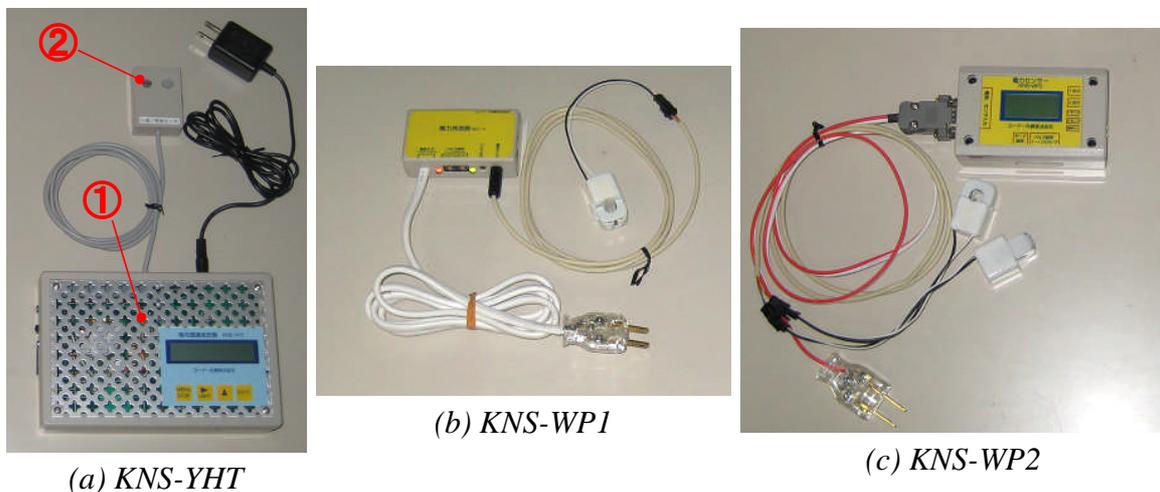
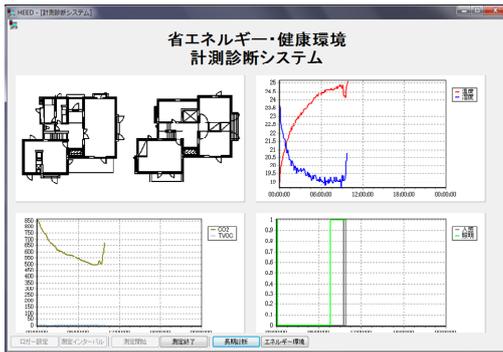


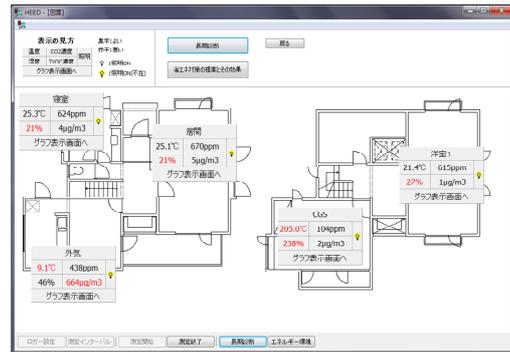
Figure 4.16 The measurement equipments developed

Table 4.3 Measurement items of “KNS-YHT”

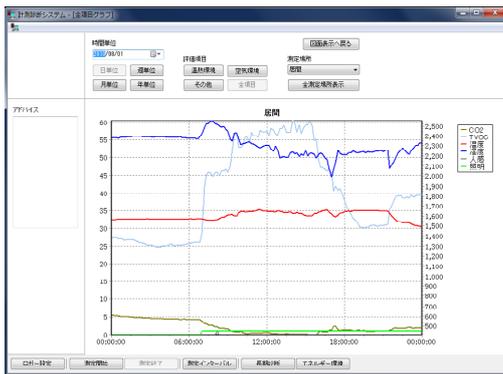
Sensors	Measurement items	Number of ch.
Basic	Air temperature, Humidity, CO ₂ concentration, TVOC concentration	4ch.
Optional	Illuminometers, Sensors to detect people, City gas consumption, Globe thermometer, Temperature & Humidity (to measure vertical distribution etc.) etc.	6ch. (Max.)



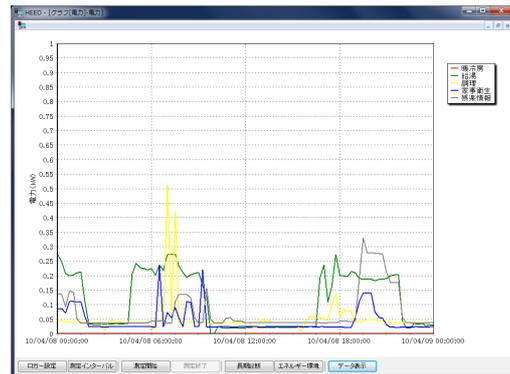
(a) Top page



(b) Present values in each room



(c) Indoor environment of a room



(d) Electric consumption by use

Figure 4.17 Typical screenshots of “HEED”

Development of diagnosis system

The diagnostic system consists of three parameters; “view of measurement data and real time diagnose”, “long term diagnose” and “proposal of improvement of building operation for energy saving with prediction results”. “View of measurement data and real time diagnose” not only can show in real time, but also can show the past measurement data on a day a week, a month, and a year. In addition, it evaluates each measurement item in real time based on measurement data, and encourages residents to improve their lifestyle. “Long term diagnose” evaluates items based on measurement data on a month and a year, and advises residents. The valuation items are the achievement ratio of comfort zone of the measurement item of indoor environment and comparison with the standard energy consumed, etc. In “proposal of improvement of building operation for energy saving with prediction results”, after comparing calculation value to measurement value, numerical analysis of improvement of building operation for energy saving is conducted based on long-term measurement data. In addition, the effective measure against energy saving is shown to residents.

Examples of typical screenshots in the prototype system are shown in Figure 4.17. (a) is an initial screen when "HEED" is started, and shows the floor plan and measuring situations, such as the present temperature and relative humidity. If the floor plan of (a) is chosen, the screen changes to (b) and shows the value such as the temperature and relative humidity of each room in the floor plan. In addition, by choosing each room in this plan, the detailed information on the room can be checked. If one room is chosen, a screen as shown in (c) is displayed and shows detailed measuring results such as only temperature and relative humidity in the room. In (d) the measurement result of power consumption are shown. In this screen, a time interval and the energy consumption for every apparatus can be changed.

Description of the measured parameters of the on line data collection system – the link to Annex 53 Subtask A

Table 4.4 Database typologies

Database parameters	Levels of monitoring		
	Level 1 (basic)	Level 2 (intermediate)	Level 3 (detailed)
Electricity [kWh] (data frequency)	- total electricity (10 min)	- total electricity and split-up by: - cooking equipment - audio visual equipment - healthcare equipment - lightning & others (10 min)	- electricity of each equipment (10 min)
Gas [m3] (data frequency)	- total gas (10 min)	- total gas (10 min)	- total gas (10 min)
Comfort parameters (data frequency)	- T living room, bedroom, outdoor etc. [oC] - Rel. humidity living room, bedroom, outdoor etc. [%] - CO ₂ concentration living room, bedroom etc. [ppm] - TVOC concentration living room, bedroom etc. [ppm] (10 min)	- T living room, bedroom, outdoor etc. [oC] - Rel. humidity living room, bedroom, outdoor etc. [%] - CO ₂ concentration living room, bedroom etc. [ppm] - TVOC concentration living room, bedroom etc. [ppm] (10 min)	- T living room, bedroom, outdoor etc. [oC] - Rel. humidity living room, bedroom, outdoor etc. [%] - CO ₂ concentration living room, bedroom etc. [ppm] - TVOC concentration living room, bedroom etc. [ppm] (10 min)
Illuminometers (data frequency)	- light turned on or off in living room, bedroom etc. (10 min)	- light turned on or off in living room, bedroom etc. (10 min)	- light turned on or off in living room, bedroom etc. (10 min)
Sensors to detect people (data frequency)	- occupancy in living room, bedroom etc. (10 min)	- occupancy in living room, bedroom etc. (10 min)	- occupancy in living room, bedroom etc. (10 min)

“HEED” can be used to report and monitor measured information in any of the above categories.

4.5 German version: MoniSoft –the monitoring software

Access to the on line data collection system

MoniSoft is a monitoring application that runs on the user's computer in the Java-Runtime-Environment which is a System Requirement. If not already installed it can be downloaded here:

www.java.com

A DEMO-Version of MoniSoft itself can be downloaded from this site:

<http://www.fbta.uni-karlsruhe.de/enob/ANNEX53>

Username and password for download, installation and database access are:

Annex53 / 4nnex5e

The database behind the software is locked and cannot be changed.

Description of the building/buildings monitored by the on line data collection system

The demo-version of the software connects to a fixed sample database. It contains data in the time range from 01.01.2009 to 31.04.2009 for detailed charts and includes the year 2009 for larger scale analysis. The 2 sample buildings are fictional buildings. The data is compiled of real data of a building in Frankfurt build in 1968 and refurbished in 2007. Part of the data is generated and is not related to real values, but for demonstration purposes only!

Description of the on line data collection system

MoniSoft is a database driven monitoring software that is aimed mainly for research but which provides means to be configured for the use of laypersons. All data can be checked with plausibility parameters on import to the database. Special states, missing data, etc. will be shown in the charts as remarks which may be important if a certain time period is analyzed. The software interpolates/aggregates data of different (regular and irregular) time intervals, event data and even manual readings. Virtual sensors can be created to map the energy structure of the building. Charts for detailed analysis of building equipment include: typical time-based charts in combination with color-bars for event data, scatter plots, carpet plots, frequency plots, and plots to compare different time periods. The data can be filtered by the values of other sensors (e.g. "if outside temperature > 15°C"), by day of week (e.g. "show only working days") and by time (e.g. "show only from 7:00 to 18:00").

To compare buildings the user is free to create reference values of any type which will be used to compare the buildings in the respective usage category (e.g. "electrical energy"). Climate correction will be used for the categories the user selects. In addition to standard bar charts to compare the buildings, there is a building characteristics diagram which easily identifies buildings with capability for optimization. Most charts can be saved as chart-descriptions and regenerated later for different time periods. This can even be done automatically by a command line (e.g. to generate charts for web sites at night) or at the time when the software starts, with the data of the last couple of days ("favorites").

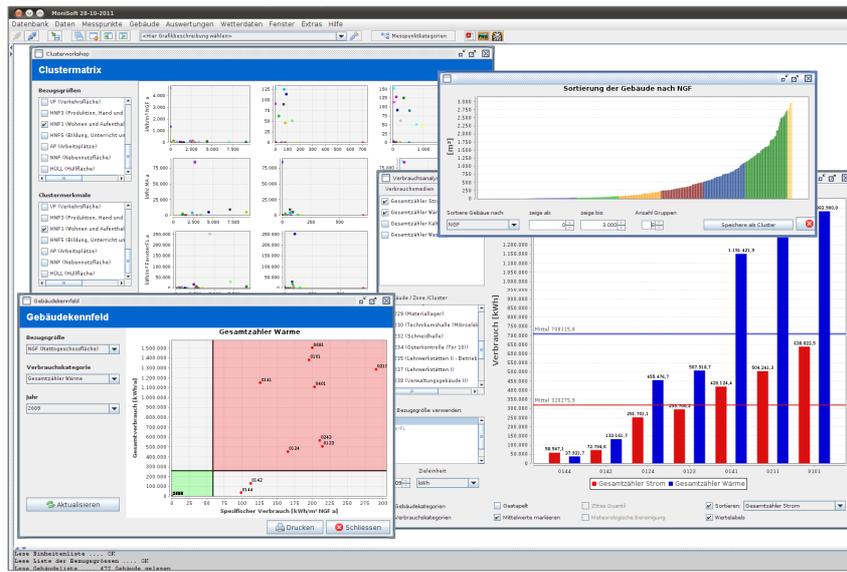


Figure 4.18 Interface of the MoniSoft

Description of the structure/ typologies / metering system used in the on line data collection system
 MoniSoft is an application based on the Java-Runtime-Environment which is freely available for almost every operating system. The software can be installed or just be downloaded and launched. A WebStart-Version may be built in the future. MoniSoft consists of its MySQL-database which is (can be) located on an online accessible server. The Software itself acts a client which can be used on any number of computers. It has a GUI but some functions can be automated by a command line.

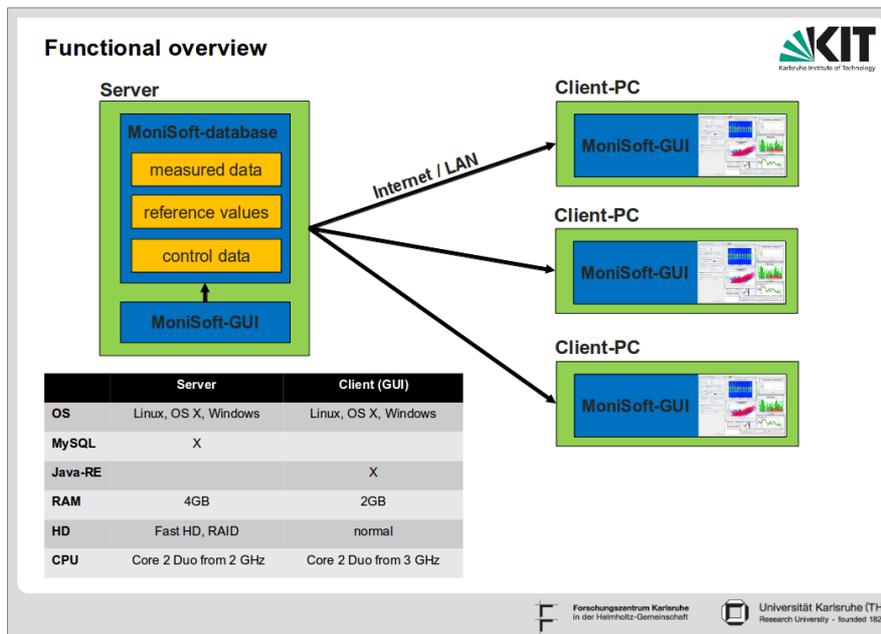


Figure 4.19 MoniSoft's environment - Java-Runtime-Environment

At the moment data can be imported from CSV- or MON-files or directly to the database with external scripts (any programming language that has MySQL-drivers). MON files have three columns (Timestamp, value, sensor-id) which makes them efficient in buildings with irregular measurement intervals.

MoniSoft is by design independent of any metering system, manufacturer or typology. The next picture shows a typical data flow.

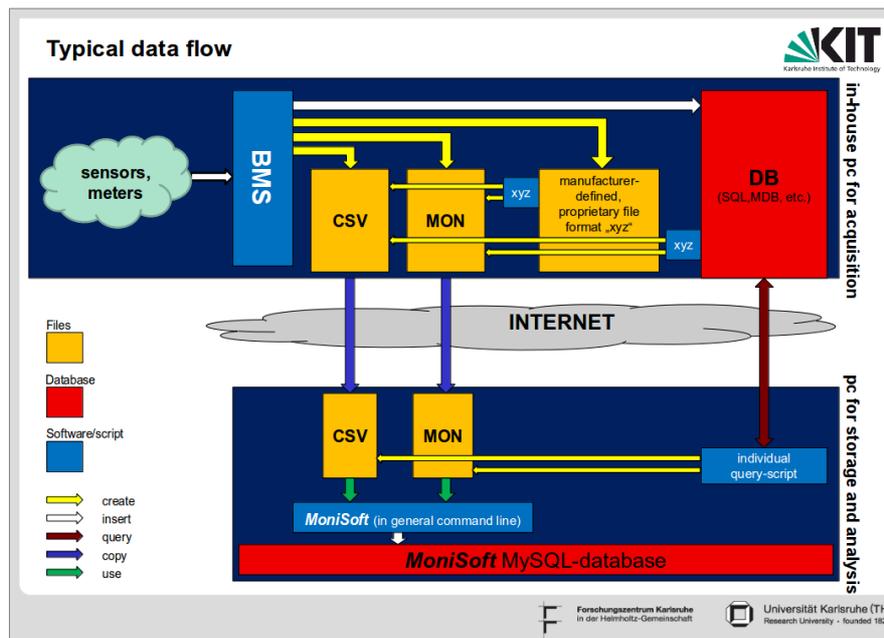


Figure 4.20 Typical data flow

Description of the measured parameters of the on line data collection system

There is no restriction whatsoever in the type, structure, detail and frequency of the measured parameters. The user can define his own structure / levels and organize the data. The online database holds data for the following sensors:

Sensor Name	Unit	Factor	Description	Frequency
WE01	°C	1	Outside air temperature	10
WE02	%	1	Outside relative humidity	10
WE03	lux	1	Illuminance north	10
WE04	lux	1	Illuminance south	10
WE05	lux	1	Illuminance west	10
WE06	lux	1	Illuminance east	10
WE11	m/s	1	Wind speed	10
WE13	°	1	Wind direction	10
WE14	bool	1	Rain state	1
W01	kWh	1	Heating energy for heating	10
W02	kWh	1	Heating energy house B	10
W04	kWh	1	Heating energy house A	10
K16	kWh	1	Cooling energy	10
T01	°C	1	Temperature of exhaust air	10
C01	ppm	1	CO2-concentration in exhaust air	10

S03	kWh	0.01	Electrical energy	10
S17	kWh	0.1	Electrical energy for House A	10
S31	kWh	0.1	Electrical energy for House B	10
S37	kWh	0.001	Electrical energy for lighting	10
S43	kWh	0.001	Electrical energy for offices	10
S50	kWh	0.001	Electrical energy for ventilation	10
T04	°C	1	Room temperature room 102	10
RF01	%	1	Relative humidity room 102	10
C02	ppm	20	CO2-concentration room 102	10
DD01	Pa	3	Difference in pressure (inside/outside)	10
P01	bool	1	Presence detector room 102	1
SS01o	%	1	Sunshade position room 102	

4.6 Spanish version: Online database for multi-family residential buildings

The present application of energy monitoring of multi-family residential buildings is located in Cerdanyola , Barcelona (Spain). The monitoring system is installed in two social residential buildings (constructed in 2009) with co-financing from the European Commission's ICT Policy Support Program within the project eSESH . The objective of the application is development and provision of web-based Energy Awareness and Energy Management Services aiming to achieve energy savings by influencing on the human behavior. The services are directed to the tenants and to the housing company staff responsible for the building maintenance and management.

The services are developed over an online database and offer access of tenants to detailed energy consumption data in different time scales. Some features of the services are the anonymous comparison with energy consumption of other tenants, previous period consumption comparison and personalized automatically generated energy saving tips according to tenant specific energy consumption pattern.

Building description

The energy monitoring system is installed in two multi-family residential buildings: the Cordoba and Clota street buildings. The Cordoba street building is 4 floor, with 24 equal size dwellings with area of 77 m² The Clota street building has 9 floors and 53 dwellings, each with area of 41 m². The building architectural design follows high energy standard and includes series of energy efficiency measures as increased insulation and passive solar elements. Trombe-wall elements are incorporated in the façade of the Cordoba building, and glazed galleries are installed in the Clota building. Both buildings are provided with summer solar shadings and arrangements for natural crossed ventilation. The design, in principle, excludes the need for mechanical air-conditioning and by contract this is not permitted to be installed in the dwellings. Both buildings are provided with centralized solar systems for domestic hot water. Each dwelling is equipped with individual gas boiler with two independent loops for heating and domestic hot water. The cooking ovens use gas, and the rest of equipment is electric.

Monitoring system

The installed energy monitoring system is for individual (per dwelling) measurement of the energy consumption. The energy billing is also individual and is done directly by the electric and gas utility company with which the tenant has contracted the services.

In order to assess different cost-benefit options, the energy monitoring of the dwellings is implemented at three levels of detail. The measured parameters range from overall electric and gas

consumption (first level), up to sub-metering of main electrical consumption, comfort parameters measurement (internal temperature, relative humidity, thermostat setting) (second level), and energy for heating, hot water, and solar system energy input for the third level of detail. Each level includes the measurements from lower levels of detail. All the measured data is stored on a web server and is available online.

The monitoring system is heterogeneous and assures interfacing between different types of sensors and communication protocols. The total electricity consumption is measured using electricity meters installed in the supply control room of the buildings, and is recorded in 15 minute intervals. The gas consumption measuring for the first level of detail is done by the gas utility company and the daily consumption data is transferred to the web server via FTP. For the detailed monitoring (levels 2 and 3) wireless sensors have been installed within the dwellings. The readings with frequency of 15 minutes are concentrated and send by gateways through internet to the web server.

A scheme of the overall architecture of the system is presented below.

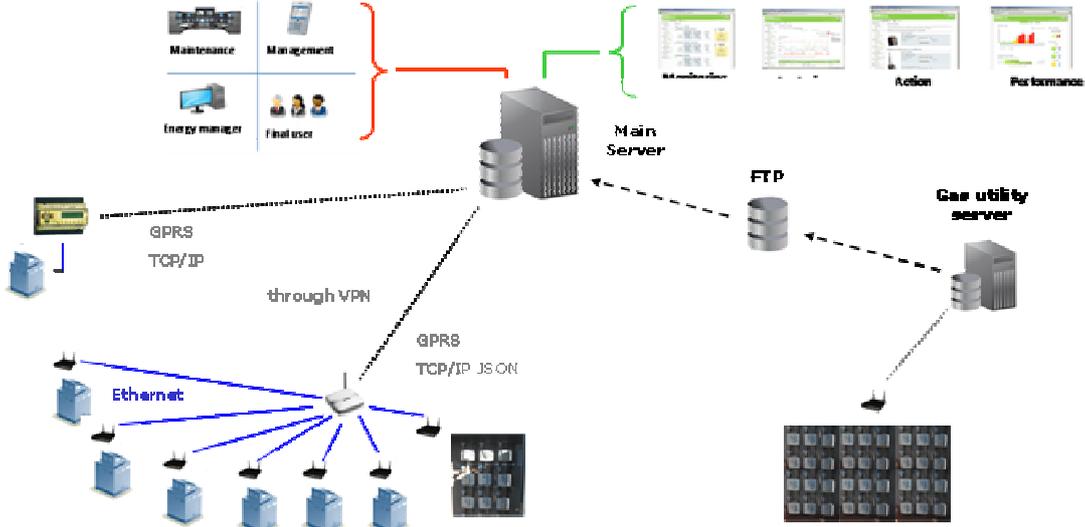


Figure 4.21 Schematic overview of the on line data collection system



Figure 4.22 User interface of the online database

Table 4.5 Three-level specification in the online database

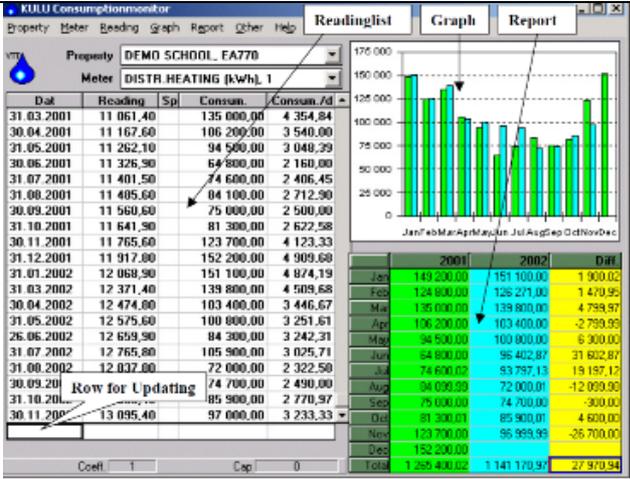
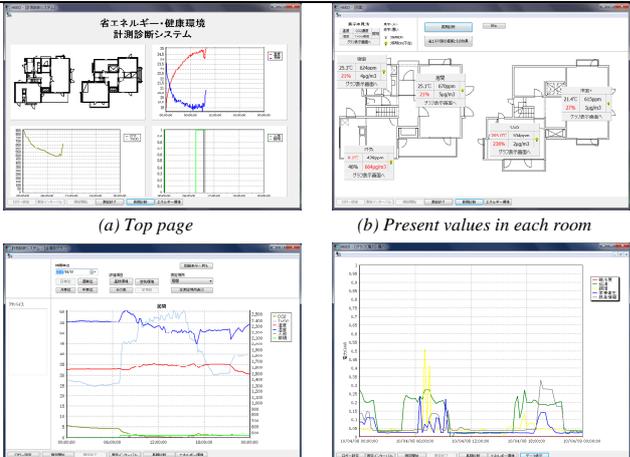
Database parameters	Levels of monitoring		
	Level 1 (basic)	Level 2 (intermediate)	Level 3 (detailed)
Electricity [kWh] (data frequency)	- total electricity (15 min)	- total electricity and split-up by: - kitchen equipment - lightning - plugs (15 min)	- total electricity and split-up by: - kitchen equipment - lightning - plugs (15 min)
Gas [m3] (data frequency)	- total gas (daily)	- total gas (15 min)	- total gas (15 min)
Comfort parameters (data frequency)	N/A	- T living room, [°C] - T sleeping room, [°C] - T heat setpoint, [°C] - Rel. humidity sleep room, [%] (15 min)	- T living room, [°C] - T sleeping room, [°C] - T heat setpoint, [°C] - Rel. humidity sleep room, [%] (15 min)
Thermal energy [kWh] (data frequency)	N/A	N/A	- heating energy - DHW energy - Solar energy (15 min)
Dwelling occupancy (typical week, 3 holiday periods)	number of occupants for each hour of the week and 3 holiday periods (no	number of occupants for each hour of the week and 3 holiday periods (no	number of occupants for each hour of the week and 3 holiday periods (no

	occupation)	occupation)	occupation)
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4.7 **Summary**

So far, five online data collection systems, collected from Finland, China, Japan, German and Spain, have been reviewed. The user interfaces of those systems are summarized in the table below.

Table 4.6 Summary of different on-line data collection system

	Main features	User Interface
<p>Finnish version: vtt kulu For public buildings</p>	<p>Versatile monitoring tools into standard web browsers!</p> <p>No installations - only access to internet will be needed.</p> <p>Updating of meter readings, analysing, reporting can be carried out over internet.</p> <p>Readings from smart meters and other data sources can be automatically transferred to the database of Kulu.</p>	
<p>Chinese version: Energy Sage 1.0 For public buildings</p>	<p>Electricity distribution system and energy consumption features of terminal equipment</p> <p>Multi-layer data collection system</p> <p>Breakdown of HVAC system electricity consumption</p> <p>Hourly data in one sub-system of the data collection system</p>	
<p>Japanese version For residential buildings</p>	<p>Real time measurement system: Energy consumption, Indoor environment</p> <p>Diagnose system: Real time diagnose, Long term diagnose,</p>	 <p>(a) Top page</p> <p>(b) Present values in each room</p> <p>(c) Indoor environment of a room</p> <p>(d) Electric consumption by use</p>

German version:
MoniSoft – the monitoring software
 For all buildings

Unified, scalable database structure for all buildings

automatic interpolation of different measure intervals

calculation of specific consumptions with user definable reference values



Spanish version:
 for multi-family residential buildings

Three levels system:

The measured parameters range from overall electric and gas consumption (first level), up to sub-metering of main electrical consumption, comfort parameters measurement (second level), and energy for heating, hot water, and solar system energy input for the third level of detail.



5. Alternative business models

5.1 Background

Measurement and monitoring of the building energy performance can be difficult and challenging due to, for example, technological issues, lack of expertise and poor communication between players during the building lifetime, building age, and building operation and maintenance economy. Technological issues in the building monitoring are caused by chosen monitoring platform and interoperability among equipment and the platform. Currently, different monitoring platforms for building energy management system (BEMS) have limitations related to number of measurements and storage of measurement history. Further, energy metering data from BEMS can be transferred further to energy monitoring platforms. Data from energy monitoring platforms are used by energy consultants, energy service companies, etc. Even though many manufactures of equipment claim that monitoring of the equipment is simple and open because the control unit of the equipment is interoperable with the BEMS platform, the communication between the equipment and BEMS can be problematic (Djuric et al. 2012). Consequently, energy data transferred to energy monitoring platforms can be changed, labeled wrongly, or lost due to different issues in the data transfer. As explained in Report 2 of Annex 47 (Annex 47 Report 2010), existing buildings pose additional constraints compared to new constructions. For new construction, monitoring may already be considered during the design phase and thus be integrated in planning HVAC systems and BEMS. In existing buildings this is not the case and monitoring has to build on the given system which is generally not geared for performance monitoring. Depending on the available measurement and data handling equipment the requirements and cost for additional installations can vary widely. Furthermore, in existing buildings problems typically arise from the HVAC system's structure that can make additional installations difficult even impossible (Annex 47 Report 2010).

On the other side, the building lifetime includes different players, such as, designers, managers, caretakers, users, owners, etc. Due to this diversity among the players and their expertise, there is a lack of communication between them. In addition, they have different interests about building, lifetime cost, and operation cost. For example, there are developers and contractors who are only interested in fast and chip development, without considering further lifetime and operation cost. On the other hand, big building owners, like governmental building owners or hotel chain owners, are interested to improve their buildings and decrease operation cost. However, BEMS with many measurements, a large history database, and a good user interface can be expensive. Depending on the building ownership relationships to a building, the interest in good building operation and maintenance can be different. Hence, the building ownership relationships, building owner and user expertise, and energy efficiency awareness can strongly influence the choice of monitoring platform. Regardless of all the above mentioned issues in performance monitoring, in order to properly maintain the building plants, it is necessary to develop tools that could encourage proper building operation and maintenance (Djuric et al. 2012). Based on all the above listed issues in energy monitoring and utilization of the energy measurement data, it is possible to develop some new businesses that would enable improved use of energy measurement data. Since there are two sides of this problem, technological and data use, two types of new business could be suggested:

Program development for communication improvement and data transfer.

Energy analysis and database development.

5.2 Program development for communication improvement and data transfer in building performance monitoring

Monitoring systems for nuclear power plants, gas turbines, and oil industry are more advanced than building energy monitoring platforms. Communication technologies are in constant development. However, due to diversities in building industry, low economical possibilities, still not well established awareness of good building energy monitoring, advanced systems for building energy monitoring cannot have breakthrough in the market. Therefore, it is important to develop programs that can enable an open data transfer and manipulation. Currently, some open energy monitoring platforms are available on the market. However, most of these platforms are not capable to capture all the energy performance data. Reason for that might be difference in building age and installation of energy monitoring system or lack of interoperability between BEMS and energy monitoring platform. Therefore, it is necessary to enable a reach and safe data transfer from sensors to BEMS and further to energy monitoring platform with necessary data manipulation. Systematic approaches for the energy evaluation of data - that go beyond simple benchmarking - are often missing. Therefore it is often unclear to the building owner or operation staff which measurements (sensors) are necessary (Annex 47 Report 2010). Therefore, one task within this business would be establishing relations with data from building, HVAC systems, and energy supply system. Unfortunately, still there is no available a general monitoring manual or standard (Djuric et al. 2010). The Japanese document Energy Performance Measurement Manual for Building Equipment gives good starting point for this work (MMPE 2005). Finally, it can be concluded that this business should cover: development of the generic energy performance data framework, enable data transfer among different applications, enable simple and open data manipulation, and give guideline on further use and data manipulation.

5.3 Energy analysis and database development

As mentioned in A Specifications Guide for Performance Monitoring Systems, those who evaluate the performance of buildings and their energy using systems have long known that it takes the attention of a knowledgeable and dedicated team to obtain the quality of data necessary to determine how well a building is actually performing as well as identify means for improving it. This team may include a measurement analyst, instrumentation vendors, an installation contractor and the owner's staff. The problem is that buildings are not designed for measuring their performance. This is particularly true of flow. It is also believed that obtaining such data is a luxury; that it is not needed for system control or day to day operations (Gillespie 2007). Therefore, experiences and tools developed under this Annex 53 have to be transferred further to enable a smart use of energy data. Regardless of decision level (planning, retrofitting, energy labeling), the same energy data are used for different purposes. The only difference in the energy data is their frequency and if and how they are normalized. These energy data are also coming from the same information source. Therefore, a new possibility for business can be organizing energy data for different purposes and producing relevant energy indicators. Owners of big building stocks have usually good energy monitoring data and good knowledge about their buildings. Their operation staff can make additional use of this available data. Energy service or savings companies could develop more sophisticated tools for estimation of their activities. High quality estimation of energy parameters could encourage energy contracts in building industry.

References:

- [1] Djuric, N., V. Novakovic, F. Frydenlund, Improved measurements for better decision on heat recovery solutions with heat pumps. *International Journal of Refrigeration*, 2012. 35(6): p. 1558-1569.
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6. Conclusions

Monitoring is fundamental when aiming at better knowledge and understanding of the energy behavior of buildings. Besides meters and/or sensors a typical monitoring system consists of three elements visualized in the Figure 6.1. This is based on metering guideline of U.S. Department of Energy [U.S. DoE 2007]. These main elements are data retrieval and collection, data transfer including also processing and storage of results. Very essential is also the delivery of produced information to various stakeholders in order to improve their awareness and motivation, which finally can lead to the real actions and measures.

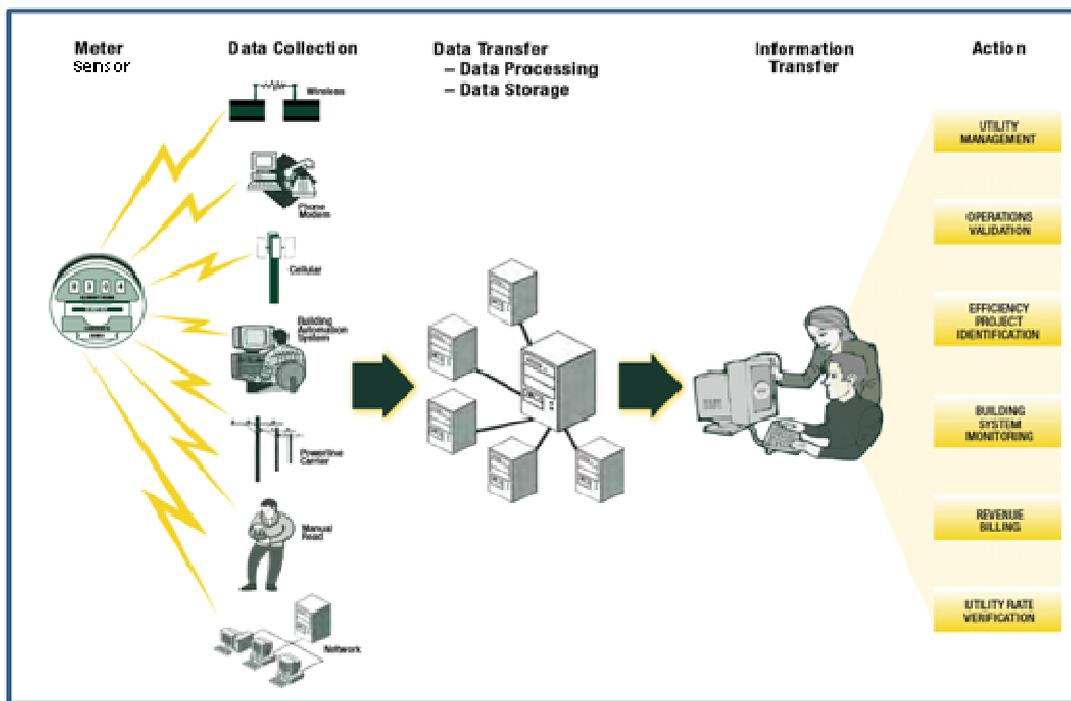


Figure 6.1 Basic elements of a monitoring system

Until now, deficiencies in energy metering and consumption data have been an obstacle to comprehensive analysis and verification of the real energy performance of buildings. The situation is changing, however, with the current rapid introduction of the new automated meter reading technology (AMR) combined with modern ICT. Thousands of so-called “smart meter” systems, comprising an electronic box and communications link, are being installed all over the world. The smart meter measures consumption electronically at short intervals (hourly or higher resolution) and can communicate this information to other devices or systems. These systems will provide energy users and other actors with timely information about their domestic energy consumption. Based on this kind of data the energy supplier, customer or service provider can view how much and when energy is used and, for example, where the greatest potential for savings may lie. On-going smart meter rollouts will create new possibilities for the development of monitoring systems, offering accurate and real-time information for various stakeholders. However, a lot of work for standardization and interoperability will still be needed to make utilization of smart meter data easier and more efficient. Something is going on in the European Union for instance and results will be available soon. However, big

energy companies having often a monopolistic position on the market don't have shown interests in opening the data for new actors. In addition there is also legal and privacy issues which must be solved before new type "open" services - typical nowadays in internet – will be seen in energy monitoring.

Besides energy data also information about influencing factors should be available for a well working monitoring. New (increasingly wireless) sensor technologies might offer cost benefit solutions for certain needs, but installation, maintenance costs and other reasons have reduced their utilization in buildings for example. Sensor use has been commonplace in industry, cars and consumer electronics for a long time. However, mere baby steps have been taken in the fields of buildings, environmental monitoring and, in particular, healthcare. Sensor systems are usually installed where wires can easily be drawn. Where the construction of a wired network is impossible or too expensive, sensor network development has fallen by the wayside, brushed off with a statement that a wireless network will be solution for these applications. Though wireless sensor networks have been the subject of intensive research for two decades, very few have actually been built, with the exception of military applications. Unrealistic expectations placed on wireless sensors might be one of the reasons for the current situation. The future role of sensors and sensor networks is discussed more in details in an article of Heikki Seppä from VTT, which can be found in the appendix of this report. About non-intrusive appliance load monitoring system based on a modern kWh-meter, another article can be found in the separate report (Pihala, 1998).

Mass production of sensors has led to dramatic decrease in sensor prices but installation costs are still at place. Especially in wireless applications also maintenance (like change of batteries) work and costs can put limitation for the use of sensors though they could offer flexible means for the monitoring of various environmental factors and occupation for example. Sensors are increasingly utilized in building automation systems (BAS) however, which are typical especially in office and commercial buildings and include also many functions of monitoring systems. However there is no common standard for the identification and format of the data measured and handled by sensors in BAS. Typically systems are closed and proprietary meaning that interfaces for data must be realized case by case. Because of their business models BAS vendors are often not interested in opening their data which hinders the integration of various data sources and systems. Collaboration of big building owners and other stakeholders would be needed to create common standards and definitions to be used in BAS projects enabling flexible use of the data for monitoring and other purposes.

References:

- [1] Heikki Seppä, The future of sensor networks, VTT Impulse 2/2012
- [2] Hannu Pihala, Non-intrusive appliance load monitoring system based on a modern kWh-meter, VTT report 356, 1998.

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