MONITORING FOR SIMULATION VALIDATION

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ABSTRACT

One of the key problems in building simulation is to determine the accuracy of a simulation model. Due to the complexity of a building, a comprehensive and exhaustive mathematical proof is usually not possible. Therefore, an appropriate way to validate a building model is to compare simulation results with measurements obtained from real buildings. Such comparisons not only allow for the validation of simulation models used in the context of building design support, but also provide calibrated simulation models to be applied in the context of real-time simulation-assisted building systems control.

INTRODUCTION

This paper deals with the monitoring infrastructure necessary to validate building simulation models and implement simulation-based control strategies (Mahdavi et al. 2009, Orehounig et al. 2010). Required sensors are discussed and technologies for different domains are compared and assessed. Possible network infrastructures to collect the measured data are discussed. To fully validate building simulation models, a multi-layered architecture for concurrent energy, performance, and occupancy monitoring is defined.

Two buildings in Vienna, Austria are equipped with multi-layered monitoring systems. One is a new building, which already provides some monitoring infrastructure. This paper illustrates how this building can be enhanced with a comprehensive monitoring system, while reusing the existing infrastructure as much as possible. The second building was built more than 100 years ago and provides no reusable building automation infrastructure. Therefore, an independent system must be installed for monitoring.

Motivation

There is currently a paucity of systematic and comprehensive implementations of monitoring infrastructures in buildings (Raftery et al. 2010, J. O'Donnell 2009, Neumann and Jacob 2008). Thus, the critical benefits that could result from the integrated and concurrent analysis of multiple building data streams are not exploited. Such benefits include:

i) Energy optimization through improved management of technical building systems.

ii) Increased awareness of building users regarding their impact on buildings' energy use.

iii) Early detection (and treatment) of deficiencies and malfunctions in energy systems and devices, thus effectively supporting a preventive maintenance regime.

iv) Successive building performance improvement and optimization via the analyses of dynamically updated building energy and performance data bases.

v) Long-term accumulation of empirical information on buildings' energy and environmental performance toward improving the design, construction, and operation of existing and new buildings.

Further, to validate simulation models and to implement simulation-based control strategies, real-time sensor-data is required. Therefore a monitoring network is essential.

APPROACH

Research efforts involve the following steps. First, a network based monitoring in two buildings of the Vienna University of Technology will be realized to obtain real-world data. Then simulation models are validated and improved based on the monitored data. Finally, the models are used to execute simulation-based control strategies in real-world scenarios. The present paper focuses on the required design and implementation of the monitoring infrastructure.

Summary

First, an overview of relevant technologies for monitoring systems is presented. To structure technologies a four layer model is used. Then, two prototypical implementations of the proposed multi-layered monitoring system are described in detail.

The paper concludes with discussion and future outlook.

MONITORING NETWORK TECHNOLOGIES

Usually building communication networks are described with the three layer model defined in ISO 2004. This model is appropriate to describe network communication strategies, but lacks the coverage of sensor/actor technologies. It does not deal with the challenge of getting the information of different physical domains into an electronical signal and their different requirements regarding fieldbus networks. To fully cover monitoring strategies, an additional layer describing sensor/actor technologies is added as shown in Figure 1.

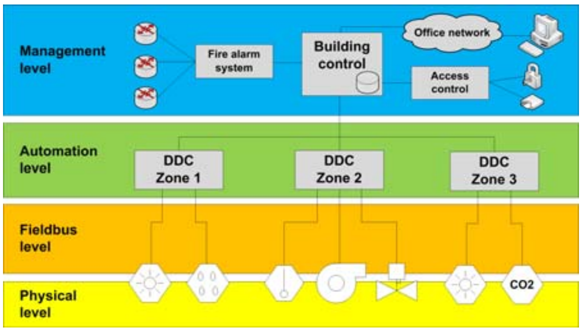


Figure 1 Four layer model of a generic monitoring system

Physical level

The physical level addresses pertinent sensory devices and technologies that are required toward an efficient, dynamic, and scalable acquisition of the required data. Table 1 provides an overview of relevant data streams together with their required sensor technologies.

Table 1
Data streams and required sensor technologies

	DATA STREAM	SENSOR TECHNOLOGIES
i	Energy use	(Sub-)Meters for electricity, gas, oil, water, etc.
ii	Indoor environment	Temperature, humidity, CO2, VOC, illuminance
iii	Outdoor environment	Temperature, wind, rain, solar radiation
iv	Occupants' presence, actions, and feedback	Motion/presence detectors, number of people, location sensing
v	Environmental control systems states	Window and door states, blinds
vi	Economical information	Documents, reports, bills

Different sensor technologies do often require different fieldbus characteristics. For example, a presence-detector to turn on the light needs to send its information in a fraction of seconds while a CO2 sensor for heating, ventilation, and air-conditioning (HVAC) can work with longer intervals (i.e., minutes).

Fieldbus level

The function of the fieldbus level is to transfer the measured data streams to the automation layer, which then acts as a backbone. Common service parameters for networks are throughput, reliability, security, scope, real-time, and power use. These characteristics can be used to describe a fieldbus, but it is not always possible to directly compare them based on these properties. For example, KNX has a much smaller throughput than LonTalk on the wire. But, depending on the system design and the grouping of devices in different KNX lines, the overall network load can be less than in a comparable LonTalk system. To get a starting point for technology decisions, current wired and wireless fieldbuses and their field of applications are listed in Table 2 and Table 3 (Daniels 2003, KNX 2004, LON 2010).

Different monitoring strategies can be used to get the measured data from the sensor to the management level. The sensor can send measurements event triggered when some predefined conditions occur, or periodically with a fixed interval, or the Direct Digital Controller (DDC) can poll the stations.

Depending on the data stream, different strategies fit best. For example, data from a presence detector is most accurate when an event based strategy is used while an electrical meter is usually polled with a periodic interval to obtain a temporal view. An event based strategy can also be used to reduce power consumption of battery or self-powered devices.

Table 2
Wired fieldbuses and their field of applications

FIELDBUS	FIELD OF APPLICATIONS
KNX/TP	General purpose fieldbus. Used for lights, blinds and HVAC systems. KNX is the successor of the European Installation Bus (EIB) and is therefore mostly used in the European Union.
LonTalk	General purpose fieldbus. Used for lights, blinds and HVAC systems.
M-Bus	Used for metering devices (electrical meter, heat meter, flow meter, etc.).
DALI	Used for controlling lights in isolated applications.

Table 3
Wireless fieldbuses and their field of applications

FIELDBUS	FIELD OF APPLICATIONS
ZigBee	Supports the dynamic creation of meshed networks which increases reliability and scope. ZigBee is based on the IEEE 802.15.4 standard and can work in the 2,4 GHz and 868 MHz ISM band. Most devices use the 2,4 GHz band which is often crowded when, for example, wireless local area networks (WLAN) are used too. ZigBee is used as a general purpose fieldbus.
EnOcean	Is optimized for low power consumption, which therefore allows the construction of self-powered sensor/actor devices. EnOcean uses the 868 MHz ISM band with amplitude modulation optimized for short packet transmission time and low power consumption. This increases throughput and reliability. EnOcean is mainly used for self-powered sensors and simple actuators.
KNX/RF	Is the wireless version of KNX. Only a few devices are available on the market at the time.
Z-Wave	Is designed for small systems in the field of home automation.
M-Bus/RF	Is the wireless version of M-Bus. Only a few devices are available on the market at the time.
IEEE 802.15.4	Defines only the lowest levels of a wireless communication. IEEE 802.15.4 is reused in some other standards and proprietary systems.

Automation level

The goal of the automation layer in a monitoring system is to transfer all data streams to a central control station. It therefore acts as a backbone which needs to handle higher data rates then the fieldbus networks.

Common network technologies in the automation level are Ethernet/IP, BACnet, KNX and LonTalk. Ethernet/IP provides high bandwidth, cheap mass-components and flexible integration possibilities and is therefore the most common technology for backbone networks. Underlining fieldbus packets can be encapsulated in Ethernet or IP frames (e.g. BACnet/Ethernet, BACnet/IP, KNX/IP, etc.) or the measured data can be directly transferred with pure Ethernet/IP communication (OPC Unified Architecture, proprietary Ethernet/IP protocol, etc.). Because Ethernet/IP provides only limited support for real-time data transfer and bandwidth allocation, a combination with an unpredictable office network is not recommended (Kastner et al. 2005).

Pure BACnet, KNX or LonTalk provides only limited bandwidth which is usually not sufficient for monitoring systems in the automation level.

Management level

The management layer handles the data storage, the visualization and the further processing of the data streams. Possible technologies for historical storage and abstract data representation are OPC (Data Access - DA, Historical Data Access - HDA, Unified Architecture - UA), BACnet/Web-Services (WS), oBIX and custom database designs.

OPC DA is highly used to provide a common interface to different automation and fieldbus networks in the management layer. So called OPC DA servers abstract the sensors and actors as data points. The data of the OPC servers can then be accessed with OPC clients, which can be a user interface or any other processing application. OPC DA server provide only live data and run only on windows operating systems. To provide historical data access the OPC HDA standard or a custom database is usually used (Iwanitz and Lange 2002, OPC 2010).

To overcome the restriction of running OPC DA and OPC HDA server on windows only and to integrate all OPC sub-standards (DA, HDA, etc.), the OPC UA standard was created. It provides high potential, but is not fully supported by common products yet (Mahnke et al. 2009).

The standards BACnet/WS (ASHRAE 2004) and oBIX (OASIS 2006) provide comparable functionality as the OPC standards, but are only rarely supported by available products at the time.

PROTOTYPICAL MONITORING IMPLEMENTATIONS

To validate real-life simulation scenarios, two buildings used to house offices, labs and lecture rooms of the Vienna University of Technology are partly equipped with necessary monitoring infrastructure.

One of the building is finished 2010 and provides reusable building automation infrastructure to various degrees. The second building was built more than 100 years ago and provides no reusable building automation infrastructure.

As such, these buildings are representative for a large number of existing building stocks in Vienna. They thus represent a wide range of technical challenges that need to be met in order to realize the postulated dynamic data acquisition and processing architecture in the context of existing buildings. Such challenges pertain specifically to the technology update requirements for incorporation of high-resolution sensory and metering capabilities, device connectivity, and cross-platform data transfer.

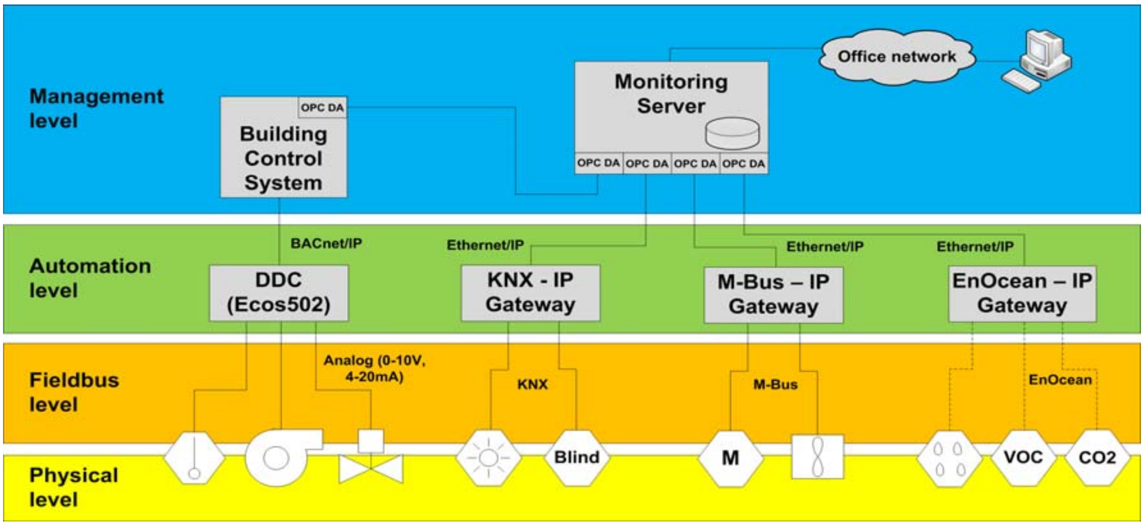


Figure 2 Four layer model of the monitoring system in Lehartrakt

Lehartrakt

Lehartrakt is a new building to be completed in 2010. It is equipped to various degrees with current building automation technologies. Therefore the monitoring system can reuse some of the sensor and network infrastructure to reduce installation efforts.

Figure 2 shows a four layer model of the entire monitoring infrastructure. Many sensors in the existing BACnet, KNX and M-Bus networks are reused. Electricity meters are added to the M-Bus system. All other sensors are added with the wireless fieldbus EnOcean to reduce installation costs.

To provide a common interface in the management layer, all building automation networks are accessed with OPC DA servers. The data-points in the central building control system are accessed through an OPC-tunnel. Since OPC-DA provides only live data, historical storage is achieved by storing all data points in a mysql database.

Because some sensors push their measured values sporadic (depending on local changes) to the OPC server, it is necessary to store this data event based too. Therefore, data is only written to the database when a value changes in one of the OPC servers. To prevent flooding the database with unnecessary data, a value dead band is set depending on the sensor measuring range and accuracy. This event based data storage strategy maximizes temporal accuracy while minimizing the database size. To simplify data processing in some applications, periodic values can be generated with a 5 minute interval too.

To provide a scalable database design, all sensor data is written into one fixed table with the columns keyid, name, timestamp, value and quality. The keyid is the primary index for the table. The name field is the identifier of the sensor and needs to be unique for each sensor. To prevent overlapping data sets during the switch of summertime and wintertime the Coordinated Universal Time (UTC) is used as timestamp. The value field contains the measured data represented in units of the International System of Units (SI) where possible. The quality field

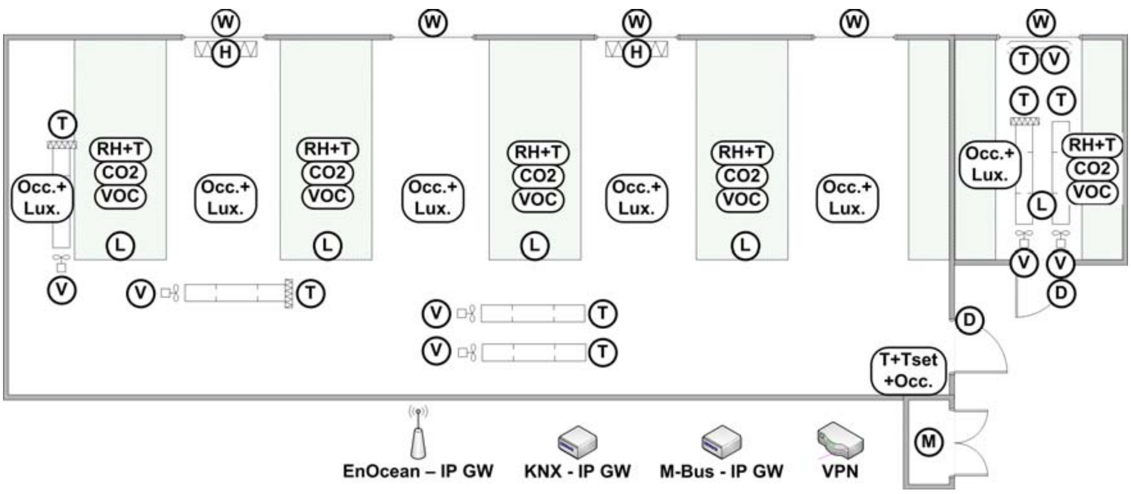
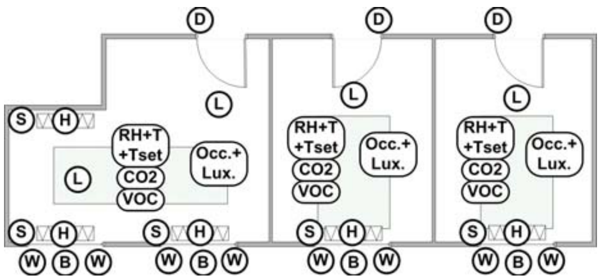


Figure 3 Floor plan including sensors of two laboratories in Lehartrakt

contains information about the measurement and network transfer accuracy where possible. Using this scalable database design, additional sensors can be easily added in the future. The user interface and other processing applications can access the current value directly from the OPC DA servers or use the mysql database for historical data access.

The monitored area in Lehartrakt covers two labs, two office rooms and one conference room. Figure 3 and Figure 4 show the floor plans including all sensors.



B	Blinds	RH	Relative humidity
CO2	Carbon dioxide	S	Servo-valve-drive
D	Door-contact	T	Temperature-sensor
H	Heat meter	Tset	Temperature-setpoint
L	Light	V	Volume
Lux.	Illuminance	VOC	Volatile organic
M	Electrical meter	W	Window-contact
Occ.	Occupancy		

Figure 4 Floor plan including sensors of two office rooms and one conference room in Lehartrakt

Karlsplatz

The building Karlsplatz provides no reusable building automation infrastructure at all. To reduce installation costs, a fully independent wireless approach for the fieldbus network is used.

EnOcean was chosen as the wireless fieldbus system because of its optimized design for low power consumption. It allows the construction of self-powered sensor devices which reduces installation efforts and increases installation flexibility. Nevertheless, some sensors still need a power supply due to the energy use of the sensor technology. For example, a CO2 sensor needs a significant power supply to drive its heating coil.

Many sensors with integrated EnOcean communication technology are available on the market. Missing sensors can be easily extended with EnOcean-wireless support by using the EnOcean-modules of the STM and TCM series.

Figure 5 shows the four layer model of the entire monitoring infrastructure in Karlsplatz. To transfer the measured data from the EnOcean - IP gateway to the monitoring server, a Virtual Private Network (VPN) is used.

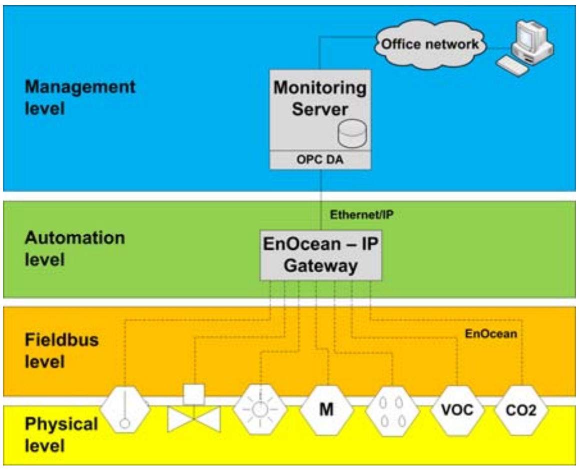


Figure 5 Four layer model of the monitoring system in Karlsplatz

Figure 6 shows the floor plan of the monitored area including all sensors. The heating energy of the radiators is calculated by measuring the temperature of the radiator and the room. Using the K values described in DIN 1994 an adequate calculation of the heat energy can be done.

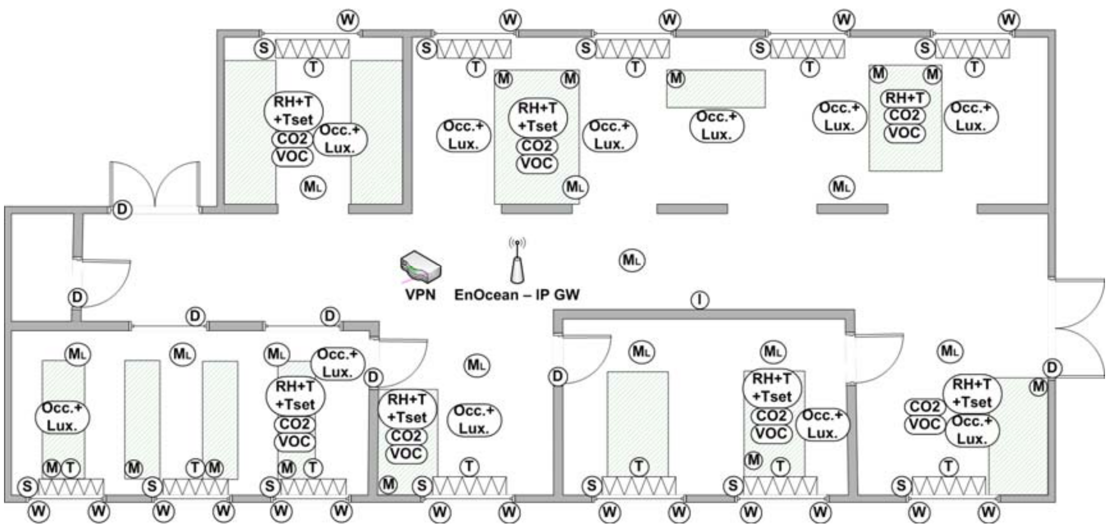


Figure 6 Floor plan including sensors in Karlsplatz

CONCLUSION AND DISCUSSION

The described monitoring infrastructure provides a flexible base to validate simulation models and to realize simulation-based control strategies.

Future research and development challenges involve the validation and improvement of thermal simulation models based on the monitored data. Two different building model validation techniques are possible. Firstly, the energy usage of the respective building/room is taken as input value for simulation and the calculated temperature trend is compared with the measured data for validation. Secondly, the temperature is taken as input value for simulation and the calculated energy usage is compared with the measured data for validation. Finally, the models will be incorporated in the control unit of these buildings toward a simulation-powered building system control strategy.

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REFERENCES

ASHRAE 2004, ANSI/ASHRAE, Std. 135, BACnet – *A Data Communication Protocol for Building Automation and Control Networks*

Daniels K. 2003, *Advanced Building Systems, A Technical Guide for Architects and Engineers*, Birkhäuser

DIN 1994, DIN EN 834, *Heat cost allocators for the determination of the consumption of room heating radiators - Appliances with electrical energy supply*

ISO 2004, ISO 16484-2, *Building automation and control systems (BACS)* – Part 2: Hardware

Iwanitz F and Lange J 2002. *OPC: Grundlage, Implementierung und Anwendung*. Heidelberg: Hüthig. ISBN 3-7785-2866-1

Kastner W., Neugschwandtner G., Soucek S., Newman H.M. 2005, *Communication systems for building automation and control*, Proceedings of IEEE, vol. 93, no. 6, pp. 1178-1203

KNX 2004, Konnex Association, *KNX Specifications*, Version 1.1

LON 2010, LonMark International, June 2010, *http://www.lonmark.org*

Mahnke W, Leitner S-H, Damm M 2009. *OPC Unified Architecure*. Springer-Verlag Berlin Heidelberg. ISBN 978-3-540-68898-3

Mahdavi A, Schuss M, Suter G, Metzger S, Camara S, Dervishi S 2009. *Recent advantages in simulation-powered building systems control*. July 27 – 30, Glasgow, Scotland, Eleventh International IBPSA Conference.

Neumann C and Jacob D 2008. *Guidelines for the evaluation of building performance*. Freiburg, Germany: Fraunhofer Institute for Solar Energy Systems.

OASIS 2006, *oBIX 1.0* Committee Specification 01

O'Donnell J 2009. *Specification of Optimum Holistic Building Environmental and Energy Performance Information to Support Informed Decision Making*. Doctorate, University College Cork, Ireland.

OPC 2010, OPC Foundation, June 2010, *http://www.opcfoundation.org*

Orehounig K, Mahdavi A, Pröglhöf C, Schuss M 2010. *Virtual implementation of a simulation-assisted passive cooling strategy in buildings*, 9 – 12 May, Antalya, Clima 2010, International Conference on Sustainable Energy Use in Buildings.

Raftery P, Keane M, O’Donnell J, Costa A 2010. *Energy Monitoring Systems: value, issues and recommendations based on five case studies*. 9 – 12 May, Antalya, Clima 2010, International Conference on Sustainable Energy Use in Buildings.