CASE STUDY OF A SIMPLIFIED BUILDING ENERGY MODELING FOR PERFORMANCE SIMULATION

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Building modeling is a repetitive, costly and fallible task, which has potential to be enhanced through automation. This paper presents a case study of thermal and electrical performance simulation using a simplified building model. The model is based on commonly available building information, such as the Energy Performance Certificate (EPC) and monitoring data. This case study assesses the feasibility and adoptability of simplified models for realistic performance simulation purposes. An existing office building located in Vienna has been selected as a testbed. Preliminary results demonstrate that there is high level of agreement between the model and the existing office building.

INTRODUCTION

Increasing energy prices and ever-higher climatic protection targets require improved energy efficiency in building stock new built objects. However, quantification and comparability of efficiency is often missing: we lack methods to compare the consumption of similar energy systems in order to make statements about the efficiency of the building. In addition it is difficult to represent building data in a simple and fast manner.

Presently, most of the wide-spread data visualization tools are either too complex or require a high expenditure of time to gather and sanitize building data in order to allow a comprehensive building performance assessment. In most cases this may not be done without an inspection of the building. This results in a time consuming and complex set of tasks which could benefit from computational support, by automated building modeling solutions. Both commercial and open-source solutions are unfortunately very scarce due to the uniqueness of each building to be evaluated.

The process described in this paper requires a limited set of data about the building: internal thermal loads of the building can be estimated, based on the Energy Performance Certificate (EPC, in most countries the mandatory legal implementation of Directive 2010/31/EU, 2010) and the energy consuming components in the building. These may include building energy systems, such as heating cooling and air conditioning (HVAC) and lighting system loads, solar loads, computers, and many more. In conjunction with the typical physical properties of the construction type chosen, heating and cooling loads of the building as well as electric load profiles can be computed. The loads may then be compared to actual amount of energy used for heating, cooling and electricity to get an idea of the building performance.

These data are fed into an automated tool, which creates a complete 3D model representing an approximation of the real building geometry and physics, a so-called simplified building model.

Whether the building is monitored or not, this first comparison of the energy consumption should raise the awareness of the user with respect to his energy consumption and the CO_2 emissions that can be derived from this consumption. Figure 1 shows an example of how simplified building model generated for simulation purposes can look like.

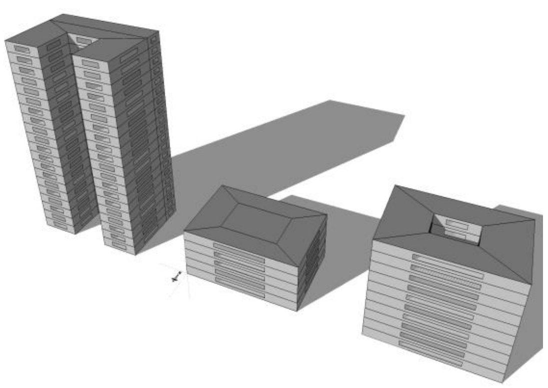


Figure 1: Simplified building model examples.

RELATED WORK

Simplified building models reduce modeling costs [Zucker et al., 2010]. Methods to support the automatic building energy simulation model generation have been presented in [Leal et al., 2012]. This method allows a reduction of the time and cost related to building modeling and simulation process. This way employment of energy performance modeling and simulation on the entire building process becomes more practicable, and can be applied in early conceptual design as well as in refurbishment.

Recent research on model simplification has been reducing the modeling effort and easing the development of dependent technologies (for example in [Thon, 2001] and [Zucker et al., 2011]). The level of detail in the model can be dynamically adapted according to the state of planning [Brychta et al., 2010].

The arrangement of the building into different zones may not be seen as just a division of the built area, but also a detailed breakdown of the entire building envelope up to the zone level [Lichtmeß, 2010]. In addition, individual zones can be further subdivided into areas regarding its usage or purpose. The processing time required for the mathematical description of the building is a predominant part of the surface entry or recording, and the zoning [Erhorn-Kluttig et al., 2005] [Roemmling, 2008] [Maas 2008]. In addition, for example, a transformation of spaces and/or zones in a building requires a redetermination of these areas. Practical experience shows that the processing time and associated costs for creating an energy balance with current software solutions is high. Solutions for automating building energy modeling for simulation purposes have been developed, for example (Leal et al., 2012 and Zucker et. al. 2013), although case studies where simulation results are compared with real consumption values are less common.

METHODOLOGY

The global aim of establishing simplified building models, enabling reliable energy forecasts, is explored by the linkage of the building's metering data and the simulation output data via a central data server. For the analysis of results, a web portal monitoring platform providing the automated generation of standardized energy performance indicators is used as evaluation tool. As an instrument for the mid- and long-term result documentation, periodical energy reports offering a comparison of metered energy consumptions and forecast data is part of the entire system.

The architecture of the global system is structured in four sub-systems, where the main entities are the automation server, the central data server, the baseline simulation (using the simplified building model) and the web portal (figure 2). The global information management is realized using a proprietary JEVis software package [JEVis 2013].

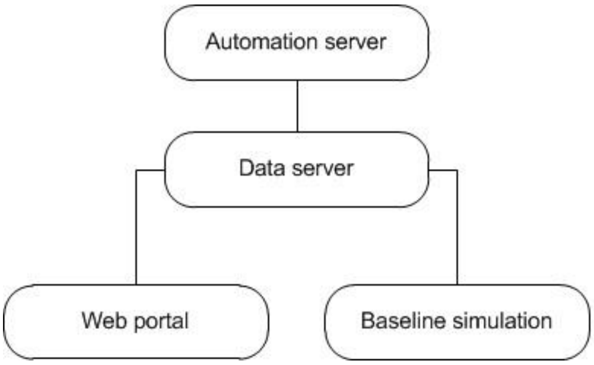


Figure 2: Modular representation of the system architecture

JEVis integrates different protocols and technologies into one database by providing a common abstraction layer. It is implemented in the object oriented programming language Java [Oracle 2013] and is based on and uses open source components. Based on the Open Source version of JEVis, carried out within the OpenJEVis community [OpenJEVis 2013], the system is able to handle large amounts of data coming from the baseline simulation tool. Additional database definitions are available, which represent the information that comes from or goes to the interacting system's entities.

Based on the existing software package, the project's data server was built and improved by additional communication interfaces and logic modules, further described in the following sub-sections.

Automation server

The LINX automation server is the linking part between the field-level measurements in the building automation system (BAS) and the monitoring system, which evaluates the collected data. The automation server is an embedded controller that is capable of integrating metering equipment of different technologies (see Figure 3). This ranges from attaching S0 meters via direct I/O modules (pulse counters) as well as bringing in meter data from fieldbus systems such as M-Bus and Modbus.

Figure 3: LOYTEC LINX-120 Automation Server CEA-709

The automation server is also a multi-protocol device that can integrate into existing fieldbus networks that are predominantly used in modern BAS such as LonMark systems (CEA-709), BACnet, or KNX [Soucek et. al., 2012]. For refurbishment sites, sensor equipment for temperature, occupancy and more can be brought into the automation server via the ZigBee wireless protocol [Zigbee Alliance 2009]. The measurement points are represented as data points in the automation server. These serve as an abstracted view on the BAS. Trend logs can be configured that locally store historic data of those data points. The historic data can then be collected by the head-end system.

Special extensions in the automation server support the automatic browsing and retrieval of energy-aware data points and historic data. Using this approach, the building engineer automatically gets the needed meta-data included in the automation server, which may later be subject to automated data retrieval using a dedicated web service, which exposes the relevant data.

Data server

For the establishment of a seamless communication between the data server and the automation server two communication protocols based on the automation server's existing interfaces were developed.

The existing OPC XML DA [OPC 2013] interface of the LINX automation server was upgraded by an additional vendor specific OPC type representing the "energy awareness" nodes. Based on this improved OPC data structure, the e4 data servers is enabled to request all energy awareness meta-info including the referring ID numbers to the trended data via standard conform OPC XML.

The LOYTEC XML-DL protocol was adapted by the JEVis system enabling the periodical readout of the trended data from the e4 automation server using the trend ID. Trend's meta information such as time change are controlled by the JEVis protocol adaption and are integrated into the data import functionality.

Baseline simulation

To implement a service to calculate an approximation of the energy performance of a building object, we should have under regular conditions, a 3D building model based on a simplified geometry (building area, height, type, construction year, ration of windows), the geographic location of the object, physical parameters deducted from the construction type of the building and further internal loads estimated from the usage of the object. These building data may be obtained from the EPC. Most import is the thermal characteristics, consisting of the U-values of the building envelop, but also wall type (heavy or light), fenestration (%), infiltration rate and/or ventilation and internal gains. A modular software implementation allows the simplified model generation as shown in Figure 4.

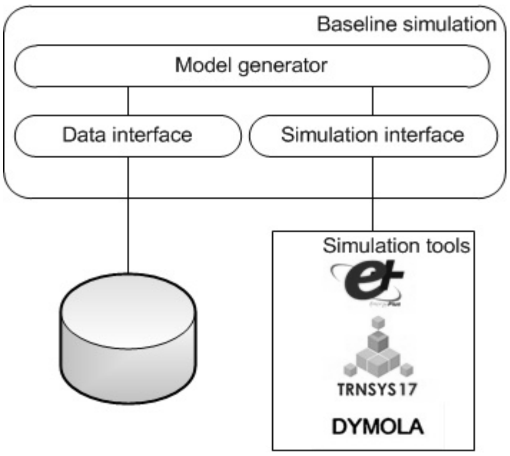


Figure 4: Baseline simulation module overview [Leal et. al. 2012]

The simulation software is divided into three different modules, namely the data interface, the model generator and the simulation interface.

The data interface module is responsible for the communication with the data server web service. As such, it must query input data for modeling purposes, and retrieve output data from the simulation results. The input data is sent to the model generator module, in order to support the model generation.

The output data is received from the simulation interface and routed to the data server for final storage.

The model generator module is responsible for generating a simulation model based on basic building information from the database given by the user in combination with standard values if further building data are missing. The model generator creates then an appropriate input file (simulation model) which is necessary for the simulation tool to be able to run a simulation and finally give an approximation of the energy use of the building.

The simulation interface module is responsible to, on the one hand, establish communication with the simulation tool (such as TRNSYS [TRNSYS 2013], EnergyPlus [EnergyPlus 2013] or Modellica [Wetter and Haugstetter 2006]) and initiating a simulation, on the other hand, to read the simulation results and deliver them to the web service interface for final storage in the database.

Web portal

A suitable representation of the energy use of the facility has been automatically created and presented to the user by an electronic medium of his choice. After this first rough estimate, the user can input further parameters of the building not known to the automation system (area, geographical location, construction type, usage) to get a refinement of his energy efficiency analysis.

The loads calculated by the baseline simulation may then be compared to the actual amount of energy used for heating and cooling, allowing a first performance assessment of the building.

It shows users their energy efficiency compared to other facilities with similar building parameters, as well as the average energy consumption of all monitored structures, e.g. on regional level.

The energy report functionality is generally separated into two parts. The management of scheduled reporting tasks on the one hand, and the creation and sending of the reports based on a cluster specific document template on the other hand. Within the continuous system working process, the report task handler scans the JEVis database for report nodes and checks the generation conditions. If the generation conditions become true, the report task handler triggers the report generation engine and provides all necessary parameters for the creation of the energy report. The report engine supports both Microsoft Excel and Open Office calculation sheets for report templates, where all standard office functions can be used and can be connected to the data stored in JEVis by using a variable syntax. The report engine automatically fills the template according to the actual data situation.

After the filling of the template, the report engine uploads the finished report into the JEVis database, triggers the conversion to .pdf file, and sends the finalized .pdf report to the customer's email address.

CASE STUDY

An existing office building located in Vienna has been selected as a testbed (Figure 5*:*).

Figure 5: Testbed building located in Vienna.

An embedded automation server has been installed on-site to measure energy data of the building (total electrical, heating, A/C, air flow). The acquisition, monitoring and verification of the measured and simulated data, as well as the implementation of the simulation model were realized entirely on an Open Source software environment.

The office building was built in 2006, located in Vienna's 17th district (Figure 6*:*) featuring a gross building area of 1079 m².

The test building hosts office units along production unit. The test building obtains its thermal energy from distributed heating and electrical energy from the grid. The deployment will be made in the entire building.

An embedded LINX-120 automation server (Figure 3*:*) has been installed on-site to measure energy data of the building (total electrical, heating, A/C, air flow) as well as environmental data such as outdoor temperature. The automation server was added to an existing LonMark system. Meter data of different floor metering equipment was brought in together over CEA-709 fieldbus cabling. The outdoor temperature sensor was integrated over ZigBee wireless. The energy-awareness data logs have been exposed over the web service. The automation server has been assigned a public IP address and was registered over the embedded web starter with the data server. For network security reasons the automation server was placed into a DMZ and isolated from the remaining BAS.

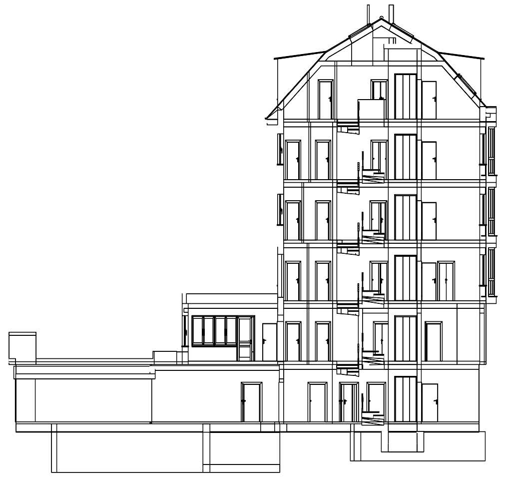


Figure 6: Cross section of the test building

An embedded LINX-120 automation server (Figure 3*:*) has been installed on-site to measure energy data of the building (total electrical, heating, A/C, air flow) as well as environmental data such as outdoor temperature. The automation server was added to an existing LonMark system. Meter data of different floor metering equipment was brought in together over CEA-709 fieldbus cabling. The outdoor temperature sensor was integrated over ZigBee wireless. The energy-awareness data logs have been exposed over the web service. The automation server has been assigned a public IP address and was registered over the embedded web starter with the data server. For network security reasons the automation server was placed into a DMZ and isolated from the remaining BAS.

Historical data has been used to verify the building model accuracy and corroborate the agreement between measured and simulated data.

Regarding the purpose data, it was determined that the main objective of the deployment process is to predict the electrical energy consumption for a period of one year for the entire building. This improves energy consumption awareness and allows reducing electrical energy consumption by quantifying the predictive consumption.

The building data has been maintained using Envidatec's JEVis energy monitoring system. It has a database supported by a software tool which allows storing and communicating building data to the simulation services.Envidatecs's JEVis web service offers an application interface for model related data transfer. EnergyPlus was selected as thermal simulation service.

A simplified testbed geometry model has been automatically generated using the baseline simulation module (figure 7).

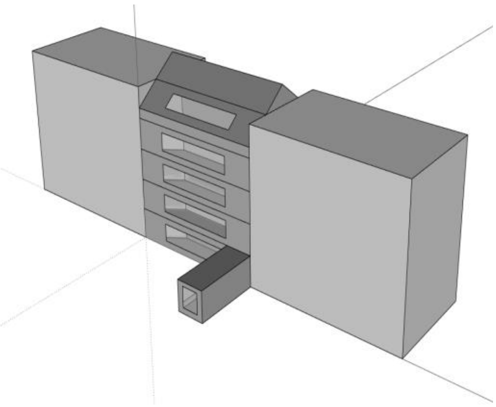


Figure 7: Simplified geometry model of the testbed office building in Vienna

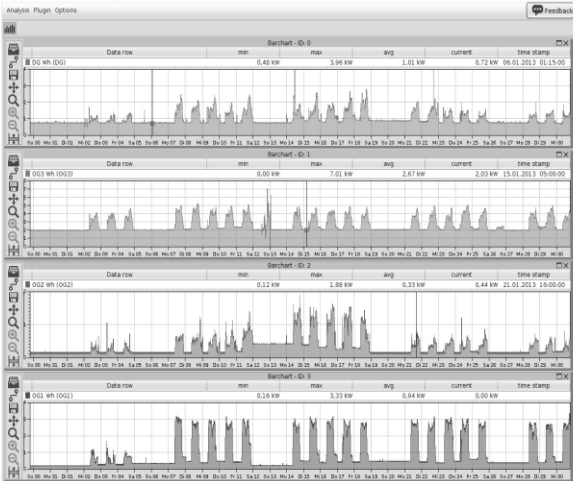
Internal thermal loads of the building could be estimated, based on the EPC input and the energy consuming components in the building.

These included building energy systems, such as heating cooling, air conditioning (HVAC), lighting system loads, solar loads, and computers. In conjunction with the typical physical properties of the construction type chosen, heating and cooling loads of the building as well as electric load profiles have been computed.

The building model has been stored in an idf file. This file encloses a description of the building model for thermal simulation purposes.

Temperature and humidity sensors and electricity/thermal consumption meters are already available in the building. Initial analyses have been performed with the data server module, namely JEGraph.

Figure 8 shows an example of historical data visualization for the electrical consumption per floor (OG1, OG2, OG3 and DG) for the period of January 2013, using the JEGraph tool.



Data row	min	max	avg	current	time stamp
DG Wh (DG)	0,48 kW	3,96 kW	1,01 kW	0,72 kW	06.01.2013 01:15:00

Data row	min	max	avg	current	time stamp
OG3 Wh (OG3)	0,00 kW	7,01 kW	2,67 kW	2,03 kW	15.01.2013 05:00:00

Data row	min	max	avg	current	time stamp
OG2 Wh (OG2)	0,12 kW	1,88 kW	0,33 kW	0,44 kW	21.01.2013 16:00:00

Data row	min	max	avg	current	time stamp
OG1 Wh (OG1)	0,16 kW	3,33 kW	0,94 kW	0,00 kW	

Figure 8: JEGraph analysis of historical consumption data

Historical sensor data were collected and stored in the database. Data analysis was performed using the e4 data server module. Then sensed data and simulation result data have been compared using the web service module, consequently generating an energy report. This energy report was sent to the user by email.

RESULT ANALYSIS

In order to have realistic system tests, these have to be performed at least for a period of one year. This ensures that system performance is tested for at least one heating season, one cooling season and two intermediate seasons, which makes system testing extremely long and resource intensive. Due to time limitation it was not possible to test system performance for this period of time. Although preliminary results, for the last quarter 2012, suggest that there is high level of agreement between model and standing office building. Table 1 shows a comparison between simulation and measured result for a period of three months.

Table 1
Simulation and measured comparison

BUILDING SYSTEM	**SIMULATED in kWh**	**MEASURED in kWh**
Electrical	12.917,04	11.005,74
Heating	6.458,6	6.781,83
Cooling	-	-

The results obtained from the preliminary analysis of the simulated and measured data suggest that there is a high concordance between them. Comparing the two results of the electrical consumption it may be seen that there is a variation of -17,4%. Comparing the heating consumption it can be seen that the variation is about +5%. Cooling consumption could not be measured, since results are from a heating time period.

It must be taken into account that this measurements were made for a limited time. It would be desirable to analyse at least a whole year. Due to resource limitations this could not be accomplished currently.

CONCLUSION

This paper has shown a case study of a simplified energy modelling for simulation purposes. Here an energy awareness system prototype with the ability to present results of the energy efficiency evaluation mathematically based on consumptions, characteristic energy values and the scale of point values of the question guide is shown.

Both the integration into an existing system as well as building a new system was possible with the presented automation server equipment. The extension of the embedded device by the energy-aware data points and web service made it simpler for the customer to add the energy monitoring system.

This allowed on the one hand users to receive an estimation of their energy consumption, on the other hand to be able to compare their building with others within the same cluster.

Preliminary results demonstrated that there is high level of agreement between model and existing office building.

The field test has identified crucial system parts that need further development in the future. Especially, the exposure of sensitive operational data of the building over a web service is critical. The chosen concept of placing the equipment in a Demilitarized Zone (DMZ) solves the security issues as the building automation system (BAS) is isolated. However, for wide-spread acceptance a more general security concept is required. This is beyond the scope of the project and left as future work.

NOMENCLATURE

BAS = Building Automation System
DMZ = Demilitarized Zone/perimeter network
EPC = Energy Performance Certificate
HVAC = Heating Ventilation and Air-conditioning

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