ASSESSMENT OF THE IMPROVEMENT POTENTIAL OF INNOVATIVE BUILDING MANAGEMENT SYSTEMS

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1. Introduction

According to the European Commission, buildings are responsible for about 40 % of the end energy consumption and about 36 % of the CO2 emissions in Europe. Improving the building's envelope and integrating energy efficient systems for heating, cooling, and ventilation as well as lighting can decrease the energy consumption of these buildings significantly. In addition, the integration of technologies using renewable energies is helping to reduce CO2 emissions furthermore. However, in many cases, building services are not operated in an optimal way and offer therefore a high potential of improving the energy and comfort performance of buildings.

For a building operation, the energy flows indicated in Fig. 1 can be observed. Here, the energy need of a building is determined by the desired indoor climate and is effected by internal and external gains and loads. The amount of primary energy required to provide this building need depends then on the generation systems and its fossil fuels used, the different distribution systems and the supply systems for heating, cooling and ventilation within the building zones. Covering all these different subsystems, a control system is required to reduce the losses of each subsystem.

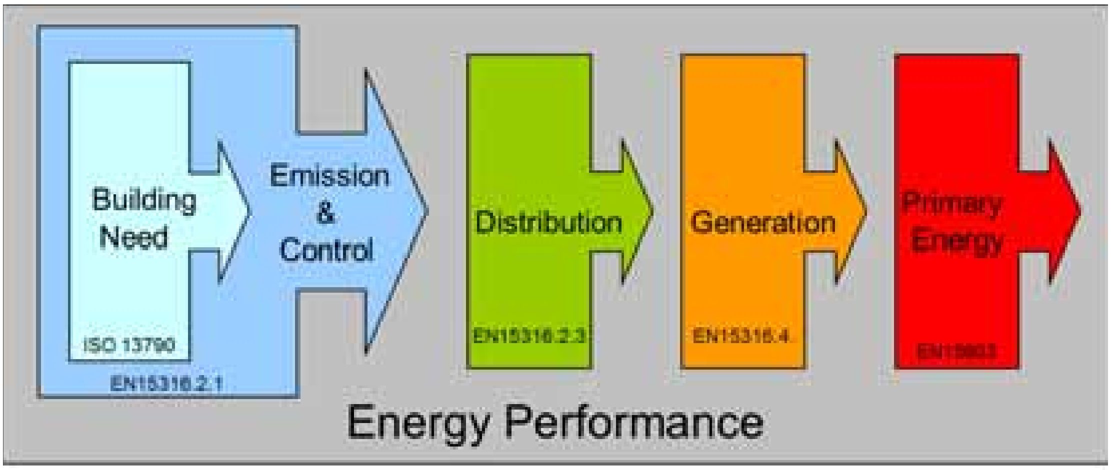

Fig. 1: Energy flows from generation to need

Building management systems can be either fully automatic or can be effected manually by the building users. Innovative building management systems like (Copperman, et.al. 2010) are not only offering a suitable zonal building control of the systems, in addition, the buildings occupancy as well as current and predicted weather conditions are taken into account. However, due to changing occupancy and weather conditions, the performance improvement of a building management system is difficult to quantify in real buildings.

In order to perform such an evaluation, either numerical simulations or real data from measurements at the respective buildings can be used following for example (EN 15232, 2007). Hereby, it depends on the specific building situation which option is more suitable. Within the project "Positive-energy buildings thru better control decisions (Pebble)", funded by the European Commission within the 7th Framework, three buildings around Europe with complete different building histories are used to identify general rules for the evaluation of the performance improvement under consideration of comfort and energetic aspects.

2. Demonstration buildings

For the project, two buildings in Germany and one building in Greece had been identified for the development and demonstration of an innovative building management system based on weather and user occupancy predictions.

The office building of the Centre for Environmental Building, which is shown in Fig. 2 and presented in details in (Schmidt, 2002), is in operation since 2001 and is designed as a very low energy building. The building is situated at the University of Kassel and closes a gap between an ensemble of old houses. An atrium, used as a daylight source, which contains the entrance zone and the staircases, joins the old brick building of the Faculty of Architecture to the modern concrete construction, joining them to form a combination of old and new. The ZUB office building consists mainly of two different parts: one part for exhibitions and events, and one part for offices. The U-value of the exterior walls is 0.11 W/m²K and triple glazing with a U-value of 0.6 W/m²K have been chosen for the mostly south facing large window area. The minimum frame-fraction of the wooden façade construction helps to reduce heat losses and the problem of thermal bridges has been diminished by the careful planning of all joints and details.

The office has been planned as an example of a low energy building reaching a heating demand of about 16.5 kWh/m². To save electrical energy, both natural lighting and even ventilation strategies have been implemented. Solar gains are utilized through the glazing of the south facing façade. At the same time, a good thermal and indoor comfort for the occupants was a major demand from the building owner. To achieve the heating and cooling of the offices using one system, only a hydronic conditioning system with embedded pipes has been chosen. In the case of heating, the system works with low inlet temperatures of approx. 24° C. When cooling is required, pipes in the floor slab construction of the basement acting as a ground heat exchanger are cooling the water. Ground coolness, a renewable and environmental energy source is utilized and a mechanical cooling machine is not required. To reduce ventilation heat losses, mechanically balanced ventilation using heat recovery with two cross flow heat exchangers in a series and a thermal efficiency of 0.8 has been installed. In the normal operation mode, fresh air is supplied directly to the office rooms and exhaust air is extracted from the atrium, then transported to the heat recovery unit. The fresh air can be supplied to the central atrium and the exhaust air extracted from the office rooms. Recently, a photovoltaic system of 4.36 kWp has recently been installed on the roof space of the building and supplies energy for the buildings electricity grid.

Fig. 2: Building of the Centre for Environmental Building, Kassel

The building was monitored over a period of four years within a research project funded by the German

Ministry of Economy and Technology. Due to this, approximately 1300 measurement points, such as temperatures and heat and energy flows, are being monitored and used by the central building management system. In addition, the thermal / indoor comfort and indoor air quality is being reported and controlled.

The second German building being investigated within the project is located in Aachen and currently under construction. The RWTH demonstration building is the new main building of the E.ON Energy Research Center of the RWTH Aachen University. The construction started in August 2010 and is supposed to finish in autumn 2011. The building, shown in Fig. 2, integrates office rooms and staff facilities, seminar and conference rooms, laboratories and common areas. The basic heating and cooling supply is distributed by concrete core activation, which is installed holohedral in the massive ceiling area of the office and conference spaces. The office rooms have façade ventilation units with four way heat and cold exchangers as well as waste heat recovery and are automatically controlled. The office room windows can be opened and have window contact sensors installed. The heat and cold distributed is generated by a turbo compressor driven heat pump process with a geothermal field as energy source. Two central air conditioning units with a sorption-supported cooling process are supplying fresh air to conference rooms, CIP-pools and laboratories with higher internal heat loads using a displacement ventilation system. A ventilation system with heat recuperation ventilates the common areas. There is no additional heating or cooling of the common areas except a small floor heating in the reception area. Thus, the climate control of the common areas is influenced by the heating and cooling of the rest of the building. Heating peak loads are covered by the combined heat and power engine and the condensing boilers. During the cooling period the cooling load is covered by the turbo compressor heat pump. Urgent cooling demands can be covered by a small additional cooling heat pump process. The sorption process is regenerated by high-temperature heat provided by the combined heat and power plant as well as the compressor heat pump. For peak loads a gas boiler on the heating side and a heat pump water chiller on the cooling side are installed. The underlying principle of the heating system is the use of geothermal energy and of heat displacement. During winter, heat from a geothermal field and server rooms is integrated in the compressor heat pump. During summer, heat from the building, server rooms and labs is displaced to the geothermal field or cooled down by the glycol cooling system on the roof. Passive cooling can be realized by the concrete core activation using cold water from the ground probes during summer. The necessary cooling supply with lower temperatures for the server rooms and laboratories is again provided by the turbo compressor heat pump.

Fig. 3: Building of the RWTH Aachen

The third building within the project is located in Greece and placed at the Technical University Campus of Crete at the suburbs of Chania. The building is a two storey dwelling with a basement and with total surface area of 304m². The overall construction is currently used for the University’s technical services’ offices. It has a North-North-West orientation with large openings windows and an atrium. The atrium creates the indoor circulation area. The building consists of 10 offices and some common room, such as storage halls, the elevator, corridors and stairs. In current conditions the building is using an oil boiler for heating the building. The efficiency of the boiler is estimated at 0.8 and some extra losses are estimated at 5% from pipes that move the hot water from the boiler to the rooms. For cooling, split units are used during the summer to decrease the temperature in desired levels. The COP of the units is estimated at 2.5 and the losses due to air movement in zone are also estimated at 5%. The electric lighting is offered by low energy lamps.

Fig. 4: Building of the Technical University of Crete

3. Building Management System

Each of the three demonstration buildings is on the way to receive an innovative building management system. In contrast to existing building optimization and control systems, efficient systems should be able to address a significantly more complicated and hard-to-attain objective than just minimizing the current energy consumed within the building. Based on long-term (e.g. >10 hours) weather and occupancy predictions, efficient systems should be able to optimally schedule the operation of all available energy-generation and energy-consumption elements over a long period of time (typically, >10 hours) in order to minimize the building's energy requirements from external (non-renewable) sources. Such an optimal scheduling requires that the operation of all available energy-generation and automatically and manually-controlled building elements is intelligently combined so that not only energy consumption is minimized but, most importantly, that energy is "stored" within the building for future use. For instance, efficient control systems may decide to operate their HVAC systems, even when the occupants are not present or the current in-building conditions do not require HVAC operation, in order to take advantage of the energy surplus being currently available.

Apparently, the intelligent combination of all available energy-generation, automatically- and manually-controlled building elements cannot be achieved if simple data-driven control strategies are employed. The complex interplay of all these elements with the building's dynamical behavior, and its complex dependence with the weather and other environmental variations and the occupants' behavior call for the development and deployment of control systems that take into account all these interactions and dependencies. For this, the control system needs to accurately predict the overall building performance with regard to different control and human actions and – based on these predictions – compute the optimal control actions each time. Hereby, model-based control systems, i.e. systems that compute their control and optimization decisions based on efficient and accurate building models are required in order to obtain efficient and nearly-optimal operation of buildings. The curse of dimensionality in combination with the fact that the efficiency of model-based optimization & control systems crucially depends on the accuracy of building models and weather forecasts, renders the use of model-based control systems not only practically infeasible but also non-robust: the inevitable inaccuracy on EPB models and weather forecast, may lead model-based control systems to quite poor performance that may not only be far from its optimal level, but also not significantly better than standard control cases. Due to the complexity and required computational effort, the project Pebble aims at developing control rules based on adaptive optimization approaches, which carry out a learning process during implementation.

In order to install such a control system at the three demonstration buildings, the buildings are equipped with central monitoring and control systems, which offer the performance of dynamic building simulations (e.g. TRNSYS, Energy Plus, Modellica) with actual building performance data. The simulations will suggest the scheduling of building control elements which will be used for the adaptive optimization procedure. In addition, building simulations and real-time measurements offer the comparison and evaluation of the new control strategy with the conventional design.

4. Evaluation strategy

In order to evaluate the performance improvement of a new control strategy, the main challenge is to define the performance criteria used and the base-case to compare with. Regarding the performance criteria different values can be assessed. If only looking at energy related values, end-energy consumption or primary energy consumption would be most appropriate. In case of on-site energy generation, parameters like net energy consumed are required. However, building control systems need to provide an indoor climate within a fixed comfort range regarding temperature, humidity, noise, air flows, etc. Usually, exceeding of these limits is accepted for a few hours within a year. With respect to temperature, the definition of degree-hours for exceeding the temperature limits is often used. These degree hours can be then integrated into the objective function of energy consumption minimization. Regarding the definition of the base-case, the project and its selection of three different buildings offers a large variety of states, which requires different evaluation procedure for all buildings:

- **Kassel**
  Existing building, very high energy standard, very high number of sensors, good historical data, low number of active buildings systems, average size building and complexity, some extensions planned
- **Aachen**
  New building, very high energy standard, very high number of sensors, no historical data, high number of active building systems, large building, very complex, difficult integration situation
- **Chania**
  Average energy standard, only few sensors so far, no historical data, mostly decentralized systems, average size building with low complexity, major extensions planned In order to evaluate the performance improvement of a new control strategy for different boundary conditions as described above, different approaches are possible:

Considering this, different optimization potentials for the new control algorithm can be expectted. In case of different numbers of sensors and norms considered, Fig. 5 illustrates the dependency of the performance improvement on the building equipment. In this example, an improvement of energy efficiency can be caused by:

- Integration of more sensors which enable a more accurate actuator control
- Different limits regarding comfort norms
- Improved and building adjusted control strategies

However, if within building retrofitting, measures like the ones described are mixed, the effect of a single measure like new algorithms is almost impossible to detect only with an overall building monitoring.

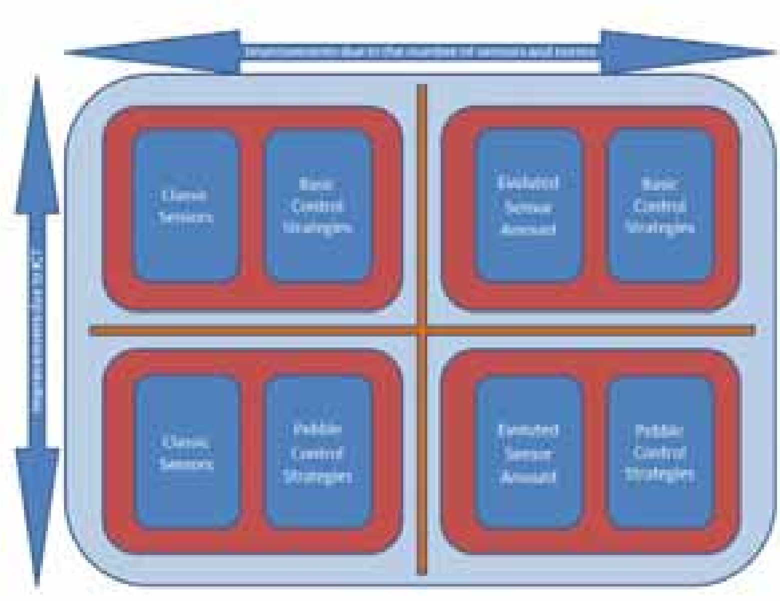

Fig. 5: Dependency of performance improvement on building sensor equipment

With respect to this, a clear base-case definition is necessary, which needs to be different for each investigated building. Base-cases, which can refer either to the whole building or to limited numbers of rooms and zones, can be:

- Long-term operation performance with conventional control strategy
- Instantaneous building operation with conventional control strategy but new sensor installations, new indoor climate limits and new technical installations
- Simulated base cases

With respect to this, evaluation strategies can be:

1. **Longer-term** performance measurements of new and old control strategies **of the whole building**
2. **Simultaneous** and comparative performance **measurements of identical building zones** (same geometry, same internal and external loads, etc.) within a building in which one zone is operated with a conventional control and one zone with the new improved strategy
3. **Alternating operation of the complete building** (or building zones), e.g. for a complete week, with old and new control strategies
4. **Numerical investigations** of the performance with old and new strategies using dynamical system simulations, either on a zonal perspective or with respect to the whole building including all building services
5. **Combinations of measurements and simulations**, in which the building is simulated using one control and in real-time measured using the other control.

The different options of this are displayed in Fig. 6. Here, the procedure can be used to evaluate different performance indicators like "Net Energy Consumed", "Primary Energy Consumed" or even values like "Net Expected Benefits".

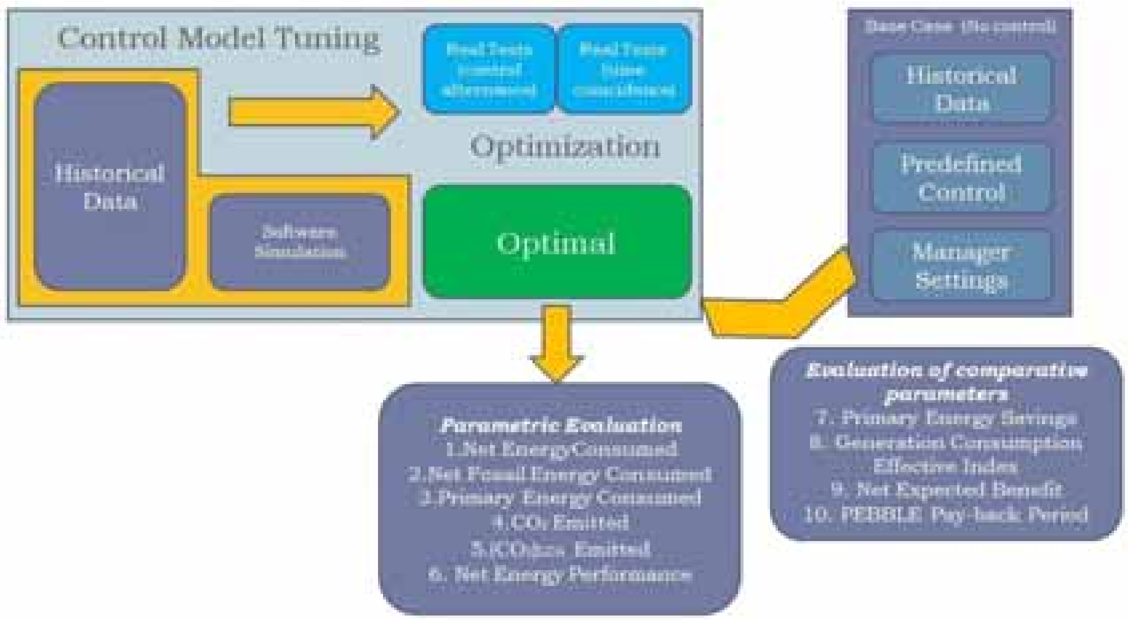

Fig. 6: Evaluation methodologies using real-time measurements and simulations

However, the accuracy of each procedure needs to be considered for the different situations. Hereby, the comparability depends on the different situations in terms of different use of the building, different weather situations, and possibly different building service systems. Only if the influence of these parameters on the performance indicators is significantly lower than the effect of improved control strategies, the suggested procedure can be used to evaluate the performance improvement.

1. **Long-term of the whole building:**
   For this, an estimation of the similarity of the use of the building, the building services and the weather situations over the years is required. In case of changes occur after the installation of new control strategies, the impact needs to be calculated, e.g. using simulation methods.

2. **Simultaneous measurements of identical building zones**

   Here, the two building zones need be selected according to minimal differences of for example zone orientations, dimensions and building use. For this, the impact of these differences usually remaining outside of laboratories needs to be calculated.

3. **Alternating operation of complete building**

   As for option 1, the similarity of the use of the building and the weather situations need to be considered. In addition, the dynamic behavior of the building and the respective effect on the alternating building operation influences the comparability. In order to minimize the effect of this, a high number of alternating states (weeks or months) need to be integrated in the evaluation.

4. **Numerical investigations**

   Numerical simulations using dynamic simulation programs like TRNSYS can help to identify performance differences with control strategies, since all boundary conditions can be kept identically. However, simulation tools and models are often limited in their accuracy and especially control strategies are different to be implemented.

5. **Combinations of measurements and simulations**

   The combination of measurements and simulations is a very attractive solution. However, in order to achieve identical results for simulations and measurements a lot of effort in adjusting the simulation models is needed. Thus, following the argumentation of 4, the possible deviations within the simulations must be considered for the performance evaluation of new control strategies with this procedure.

5. Conclusions and Outlook

Within the third year of the research project, the new strategy of using weather and occupancy predictions for the control of buildings will be installed and tested at the three demonstration buildings presented above. For the different buildings, different evaluation strategies as described above will be applied to identify the performance improvement. So far, simulation models have been developed for the three buildings and additional sensors have been installed. Based on this, several performance indicators like “Net Expected Benefit” or “Pay-back Period” will be investigated. Regarding this, first results are expected for summer 2012.

6. References

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7. Acknowledgment

This research was supported in part by the PEBBLE Project, funded by the European Commission FP7-ICT-2007-9.6.3, ICT for Energy Efficiency, under contract #248537. The coordination is done by the Technical University of Crete. Other participants are: Fraunhofer-Gesellschaft zur Foerderung der Angewandten Forschung E.V; Rheinisch-Westfaelische Technische Hochschule Aachen; Technische Universitaet Graz; Association pour la Recherche et le Developpement des Methodes et Processus Industriels – ARMINES; CSEM Centre Suisse D’Electronique et de Microtechnique SA; and, Saia-Burgess Controls AG.

The authors wish to thank those project partners not listed as authors for contributing information to this paper.