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The E.ON ERC Main Building – a Demonstration Bench for Control Research

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Abstract

This paper presents an innovative energy concept, covering requirements for multifunctional office buildings, with the integration of geothermal energy and photovoltaic. This energy concept in combination with various extensions provides excellent demonstration opportunities addressing recent research topics.

The energy concept bases on geothermal energy and heat displacement in connection with a heat pump process, a cogeneration plant, heat to cold shifting sorption-supported air conditioning units and photovoltaic panels. Concrete core activation and façade ventilation units distribute heat and cold base and peak loads within offices, displacement ventilation and active chilled beams supply conference spaces and laboratories.

We added an extensive monitoring system, measuring the energetic flows of every energy source, energy conversion unit and energy consumer, as well as the thermal comfort conditions. Further, we transformed the building into a multifunctional demonstration bench for control research, enhancing the building automation system into a flexibly programmable and interface-able tool. Additionally, we developed dynamic simulation models for a variety of building components and validated them with gathered monitoring data.

While illustrating the building's prospect on control research demonstration, this paper concludes with a specific use case of the application and demonstration of model-based control parameter fine-tuning.

Keywords - Energy concept, monitoring, control research, demonstration bench

1. Introduction

Building energy systems consume energy to provide thermal comfort and further services, such as e.g. process heat or cold. These energy demands remain despite increasing thermal insulation or further passive measures. The goal of the energy concept presented here is to supply a given demand of heating energy, cooling energy, and process heat as efficient as possible. The efficiency of the energy system relies on the flexibility of choosing appropriate energy sources, such as ambient energy, electricity, and gas, as supply or using one of its storages.

The presented energy concept is part of a building, which is the "largest experiment" of the Institute for Energy Efficient Buildings and Indoor Climate at RWTH Aachen University. We use the building to conduct research projects towards different topics, e.g. agent based control, model-predictive control [1], demand response [2], demand side management, active heat displacement, adaptive heat recovery [3], modus-based [4] and exergetically optimized control strategies [5], as well as further advanced control research [6], [7].

The construction started in August 2010 and finished in November 2011. The building houses five institutes and provides space for offices, conference and seminar rooms, laboratories, common areas and further facilities with a usable ground floor of 7222 m².

2. Energy Concept

Following the demand of the building, the system supplies thermal energy on four different temperature levels: cooling energy at 6 °C for laboratory use, cooling energy at 17 °C and heating energy at 35 °C for thermal comfort needs as well as process heat at 80 °C for laboratory use and brine regeneration.

Fig. 1 provides a visualization of the concept, consisting of three layers: the energy conversion layer, the energy distribution layer and the energy demand layer. The energy conversion layer is based on geothermal energy and heat displacement in connection with a heat pump process. The heat pump is equipped with a variable-speed centrifugal compression with magnetic, oil-free bearings, providing a high efficiency in wide areas of partial load. The geothermal field consists of 40 boreholes, each 100 m deep. It serves as a source of environmental energy and as energy storage at the same time. A glycol cooler offers the possibility to dissipate energy directly to the environment. On the 80 °C temperature level, a gas-fired combined heat and power (CHP) unit provides process heat and electric power for heat pump operation. Photovoltaic panels installed on the building's roof support the power production. A condensing boiler system serves as a backup system for the heat pump and as a generation unit of process heat, if the demand exceeds the heat contributed by the gas-fired CHP unit. A sorption-supported air-handling unit converts process heat directly into cooling energy for laboratories, staff facilities and conference spaces. As a further installation, a battery pack for electric energy with a capacity of 66 kWh, a charge power of 72 kW and a discharge power of 18 kW is planned. The battery pack will be situated outside of the building in a container. A 500 kW wind turbine with accessible operation data neighbors the building.

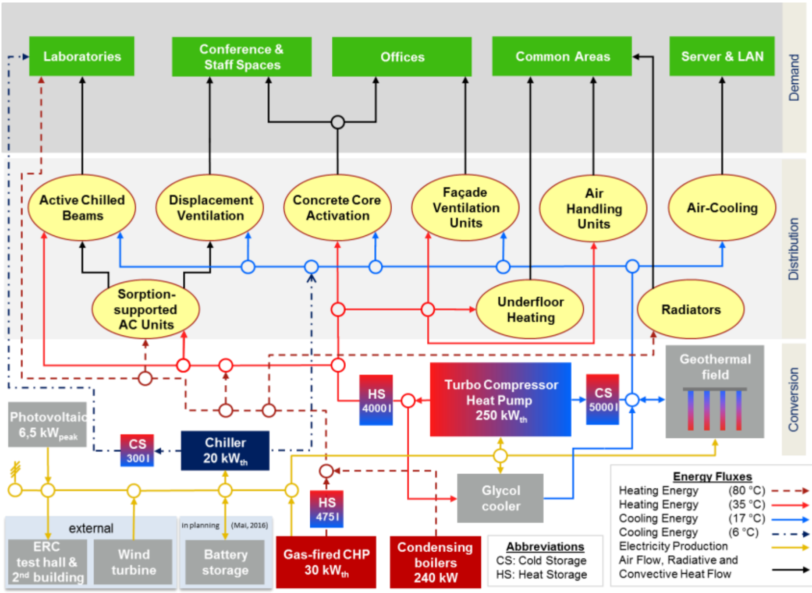

Fig. 1 Schematic of the implemented energy concept

A concrete core activation system distributes the heating and cooling base loads in conference spaces, CIP-Pools and offices. The concrete core distribution system has high thermal capacity. Façade ventilation units cover peak loads in heating and cooling. They have four way heat exchangers that are able to cool and heat directly by air supply consisting either of fresh outside air or re-circulation air, depending on thermal conditions, volatile organic compounds (VOC) and CO2 levels inside the room. Further, the façade ventilation units have the capability to recuperate adaptively heat or cold from the exhaust air with high efficiency. Within conference spaces and staff facilities, displacement ventilation covers peak loads with conditioned air provided by the sorption-supported air-handling unit. Active chilled beams are controlling the thermal comfort within the laboratories.

The underlying principle of the concept is the use of geothermal energy and heat displacement. During winter, the system integrates heat from the geothermal field and server rooms into the heat pump system. During summer, it either displaces heat from the building, server rooms, and laboratories to the geothermal field, or cools down by using the glycol cooling system. Concrete core activation using cold water from the geothermal field provides the possibility to cool down in a passive manner.

The overall control strategy consists of a variety of operation modes. In order to provide an idea of the system's general functionality, we present two exemplary operation modes, the winter and the summer mode.

Winter mode: The heat pump provides the main heating energy while using waste heat from server and LAN cooling as well as geothermal heat. The system can keeps this operation principle until the server and LAN waste heat is enough to supply the heat pump. Then, it no longer extracts heat from the geothermal field.

Summer mode: During cooling periods, the heat pump and the sorption-supported air-handling unit supply the building with cooling energy. As long as the geothermal field is able to store further energy, the waste heat from the heat pump is lead into the field. The glycol cooler dissipates surplus energy. Simulations of the geothermal field show that brine supply temperatures evolve between 4 and 16 °C. In periods with moderate need for cooling, the heat pump reduces power or even shuts down. Directly displacing heat from the building to the geothermal field provides the cooling energy. A full representation of the energy concepts is provided in [8].

3. Monitoring control and interface system

We designed the monitoring, control and interface system (MCIS) to achieve different goals. The goals of the MCIS are to provide

- extensive data for evaluation, optimization, simulation validation,
- prerequisites for automated energy and operation related evaluation and online publication,
- a system interface for flexible user interfaces, such as smart phone and web applications, and
- the capability of interfacing to an external intelligence for building control, such as model-predictive control, demand side management algorithms or further control strategy development.

In order to achieve the goals, we integrated different kinds of data sources into the system. The system now logs all physical input and output signals, network variables and control strategy parameters of the building automation system and all data points from different BACnet devices. In order to gather further relevant data, we added an extensive monitoring system, that we call the "user-added monitoring system". The user-added sensors are mainly magnetic-inductive volume flow sensors, temperature, humidity and electrical power sensors.

An on-site weather station, delivering precise weather data and a detailed weather forecast is integrated. The system is equipped with a flexibly expandable wireless auto-routing sensor network. Further, it is possible to store results of additional temporary measurements within the system's database. The MCIS provides interfaces for data analysis, remote control and external control algorithms.

Fig. 2 shows a schematic of the functional principle. Data sources and sinks are directly connected to C#-services (C# is a computer programming language) or connected to an OPC-server (OPC is an abbreviation of object linking and embedding for process control). C#-services access the OPC-server, the weather forecast and a wireless sensor system. They store the data within two MySQL-databases, for weather data and all other historic data. The C#-services provide an interface for storing data of temporary measurements. External intelligence and user interfaces can communicate to the building via a TCP-interface, which makes it easier to connect with compared to a direct OPC connection. The weather station, the building automation system, larger units of the technical building equipment and the user-added monitoring system are integrated within a BACnet/IP network.

For quick development of control software, simulation of thermal building behavior as well as for simulation of control logics, we connected a flexible virtual server infrastructure to the building control system. For quick re-programming of building's programmable logic controllers, we implemented two virtual workstations for control logic engineering which are remotely available for all employees.

A full representation of the MICS is provided in [9].

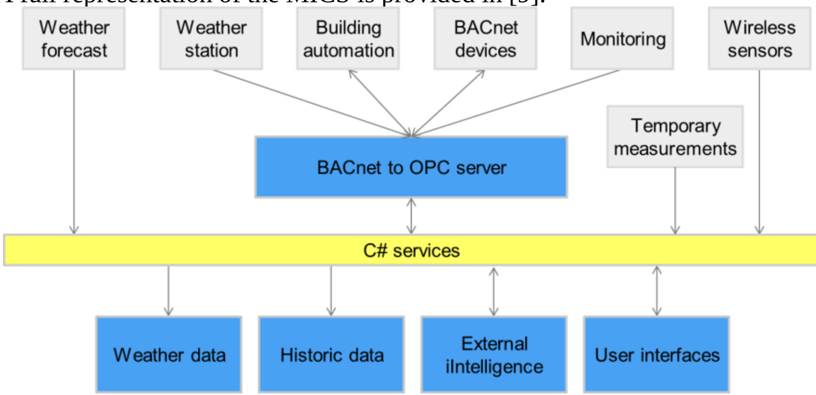

Fig. 2 Schematic of the data management system.

a. Monitoring Principle

In order to gather detailed energy data we installed additional sensors. These sensors extend available data from the building automation system to provide complete energetic monitoring data within four specified layers.

The global consumption layer consists of all energy and mass flows that enter or leave the building. The electricity, water, and gas consumption, as well as the transfer of ambient energy are part of this layer.

The energy conversion layer consists of all energy conversion related energy and mass flows. For every energy conversion unit inlet and outlet energy flows occur. For the heat pump, these flows are e.g. the electrical energy, the absorbed ambient energy and the emitted heat flow. Furthermore, sensors that map and image the conversion and generation process internally, such as temperature, pressure, control parameters, etc. within conversion units belong to this layer.

The energy distribution layer consists of flows that are allocated and distributed within the building. Buildings can be separated in zones, following their use, their energy distribution principle and/or their geographical orientation. For each distribution system, and for each use of the building's zones, the energy consumption has to be calculated. The distribution layer's monitoring sensors are gathering the energy flows supplied to, or extracted from these different zones.

Finally, the utilization layer measures the real benefit of supplied energy. Each energy or mass flow serves to satisfy a certain need, within multifunctional buildings e.g. thermal comfort in office rooms or staff facilities, heating for test benches or cooling for server rooms. The evaluation of the need-satisfaction is the last elementary monitoring layer.

Having sufficient monitoring equipment at all four layers enables to derive meaningfull performance indicators and conclusions on the building operartion. At the same time, such a monitoring system is a prerequisite for evaluating different control strategies.

A full representation of the monitoring technique within the E.ON ERC main building is provided in [10].

4. Control research possibilities

With the developed test bench, it is possible conduct control research in a flexible way through different demonstration and experiment possibilities during the whole development process at different stages.

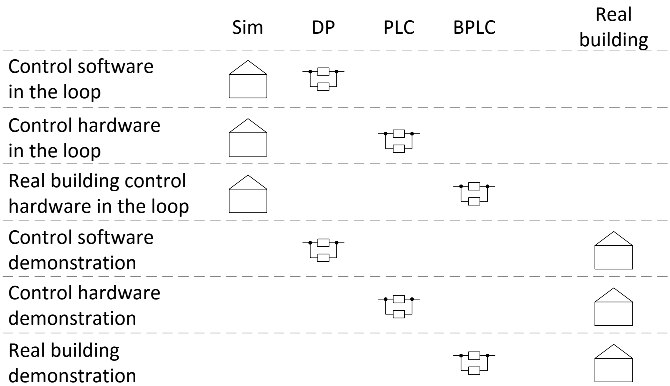

Fig. 3 Test bench’s flexibilities.

Fig. 3 visualizes the demonstration and test flexibility. The development platform (DP) in MATLAB/Simulink allows for quick logic development as well as for integration of complex control algorithms. For a first test, such developed control logic can be tested with a physical simulation with our Modelica libraries following the so-called “control software in the loop” principle.

A next step can be either the implementation of the developed control logic on a programmable logic controller (PLC), the so-called “control hardware in the loop” or the direct application of the control logic in the real building, the so-called “control software demonstration”. The implementation effort of new control logic on a PLC is usually higher than its implantation effort within the MATLAB/Simulink development platform but provides further applicability insights. The direct demonstration of the new control logic with the building provides more insights of its real behavior, outweighing the disadvantages of building simulations.

Further, it is possible to connect directly the real building programmable logic controllers (BPLC) to the Modelica simulations, following the so-called “real building control hardware in the loop” principle. This demonstration principle has its main advantage in testing the stability of a newly developed control logic within the real automation hardware but without threating the building operation or its hardware.

If the focus lies on developing a control component and demonstrating it within the real building, the “control hardware demonstration” would be the principle of choice. Here, the idea is to connect a third party PLC digitally with the building in order to avoid physical wiring and further installation effort. Our system supports different standards, such as BACnet, OPC or TCP communication, which is much more flexible as a physical wiring.

Finally, the last demonstration stage would be a real life implementation of the newly developed control logic within the real building automation hardware controlling the real building. This is the so-called “real building demonstration”.

With the help of the development platform, it is flexibly possible to integrate external signals and further control relevant third party signals, such as weather forecasts, demand side management signal, or energy prices.

5. Research example

Within the Positive Energy Buildings thru Better control dEcissions (PEBBLE) EU-project, we use the MCIS to demonstrate a model-assisted control parameter fine tuning algorithm. We set up the experiment environment for the PEBBLE system, which consists of an interface server and an optimization server within our development environment. Special PEBBLE services have been developed within the project together with different partners. A weather forecast service gathers the weather forecast, a data logger logs relevant data points into the experiment database and an interface service allows for communication between the algorithm itself and the building. The interface service uses direct OPC connection to communicate with the building. Fig. 4 shows a schematic of the experiment set up.

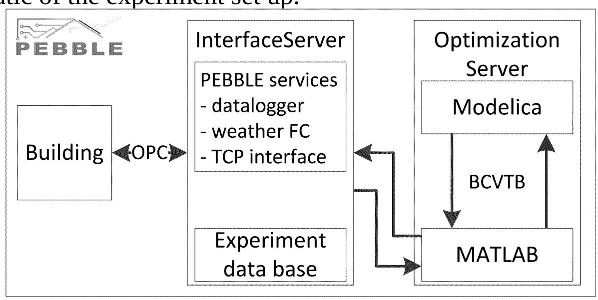

Fig. 4 Experiment set up for model-assisted control parameter fine tuning

We use the PEBBLE system to fine-tune set points of two energy distribution systems for office rooms. For each office, the algorithm individually fine-tunes the room temperature set point for façade ventilation units and it globally fine-tunes the set points of a four point heating curve within a concrete core activation zone. The experiment's scope is 39 office rooms, orientated northeast and northwest, and the building's concrete core activation zone north.

The addressed control problem is the minimization of the cost function for the energy demand. Façade ventilation units and concrete core activation deliver thermal energy. The main constraint is thermal comfort. For the quantification of thermal comfort we use the Fanger's Predicted Percentage Dissatisfied index [11].

Fig. 5 and Fig. 4.15 illustrate exemplary experiment results for the PEBBLE-controlled room. The system dynamically adjusts the set point for the façade ventilation unit within a bandwidth of 22° C to 25° C. It reacts to changing user occupancy, varying ambient temperature condition and varying global radiation. Further calculations show that it successfully maintains the thermal comfort within its constraints.

Fig. 6 presents the energy consumption of the PEBBLE-controlled room in comparison to a room on the same floor where the default control strategy was used. The demonstrated algorithm leads to a lower total energy consumption, mainly due to the reduction of heating and cooling energy distributed via the façade ventilation unit. Further results and a detailed discussion can be found in [1].

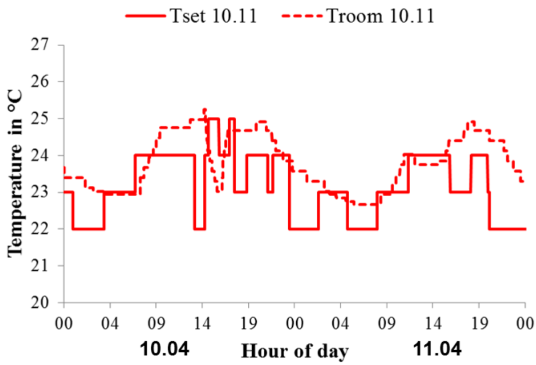

Fig. 5 PEBBLE set temperature and actual room temperature

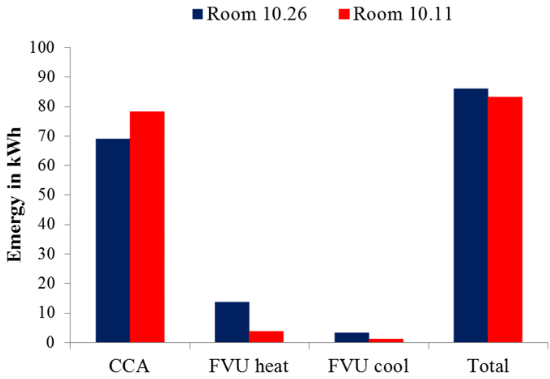

Fig. 6 Energy consumption in a PEBBLE controlled room (10.11) versus energy consumption in a conventional controlled room (10.26)

The PEBBLE server infrastructure has been set up in the MCIS' flexible server environment. The MCIS' data logging enabled the evaluation of the PEBBLE experiment. PEBBLE's performance was assessed by the MCIS' automated data processing and report system.

6. Conclusion

This paper presents the energy concept of the new E.ON ERC main building, its monitoring, control, and interface system, as well as the applied principles for the monitoring. Further, it goes into detail with the different possible simulative and demonstrative research opportunities. Finally, it concludes with exemplary research results from the PEBBLE EU-Project.

We have introduced and validated an innovative, flexible and efficient energy concept under full operation, which we equipped with a modus-based control strategy that allows for demand side management and demand response. The demonstration bench is available for a variety of experiments along the process of control component and strategy development.

The limitations of the presented demonstration bench are that, compared to an experimental test bench, ambient conditions are given and not freely adjustable. Our research prospect is to conduct further research towards innovative building control with a special focus on integrating the demand flexibility of the building and its surrounding buildings into the German energy system.

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