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The potential and challenges of monitoring-supported energy efficiency improvement strategies in existing buildings

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Abstract:
The ongoing EU-supported CAMPUS 21 explores the energy efficiency potential of integrated security, control, and building management software. The main objective of the project is to compare the energy and indoor-environmental performance of a number of existing facilities before and after real or virtual implementation of monitoring-based control improvement measures.

Keywords:
Building Control, Building Systems, Building Operation

1. Introduction

This paper reports on an ongoing project titled “Control & Automation Management of Buildings & Public Spaces in the 21st Century” or CAMPUS 21, which explores the potential of integrated security, control, and building management software systems in improving the energy efficiency of buildings (CAMPUS 2011). The project involves participants from both academic institutions and industry and is supported by the European Union (EU 2012). The premises of the project are as follows:

- In most European countries, existing buildings represent, in terms of volume and energy use intensity, the dominant part of the overall building sector. They should be thus specifically targeted for energy efficiency improvement.
- Through the improved integration of various existing monitoring, security, and access control systems the operation of building control systems can be improved.
- Energy efficiency measures are urgently needed and are of utmost importance in view of ecological and economical sustainability.
- Improving facilities' energy efficiency may not compromise their functional and indoor environmental performance. Ideally, it should go hand in hand with an improvement of indoor environmental quality and services.

To clearly illustrate the project's approach, it is useful to consider the main ways and means to improve buildings' energy efficiency. Generally speaking, a distinction could be made between hardware-centric and software-centric approaches. The hardware-centric approach focuses on the improvement potential of the physical aspects and components of buildings and is not the major focus of the project. On the other hand, it could be argued that the operation of existing buildings often involves inefficiencies that may be labeled as software-related, in that they are due to poor integration of existing IT-systems, including the insufficient interoperability of the underlying data and information processing models. This information-centered aspect represents the main focus of the aforementioned CAMPUS 21 project and this paper. It can be formulated in terms of the project's initial hypothesis: *Utilization of existing buildings' historic and run-time monitoring data (energy use, indoor environment) and the integrated analysis of this data can help to improve energy efficiency through the optimization of buildings' operational regime.*

While the postulate appears plausible (O'Donnell 2009, Raftery et al. 2010), both solid implementation guidelines, advanced benchmarking criteria, and extensive empirical evidence are needed to further promote and popularize the pervasive use of monitoring toward energy efficiency improvement efforts in buildings.

2. Approach

Within the overall framework of the CAMPUS 21 project, a number of steps will be undertaken to facilitate the examination of the above hypothesis:

- Three functionally and morphologically different building complexes in three different locations (Germany, Ireland, and Spain) are selected.
- The buildings' status quo is documented.
- The comparison of the existing and desirable monitoring infrastructures in the existing buildings enables the identification of required supplementary monitoring components. Thereby, alternative options are to be considered and evaluated (i.e., augmentation of existing BMS versus establishing a parallel monitoring grid).
- The facilities' monitoring infrastructure is to be upgraded based on the outcome of the previous step and under consideration of available resources.
- A systematic analysis of data models is to be performed. Thereby, possibilities for the development of an integrated data model shall be explored, which could effectively support the documentation, benchmarking, and operation of building services.
- Given upgraded monitoring infrastructures, an initial monitoring phase is to deliver a signature of the selected facilities in view of their current level of energy and indoor environmental performance.
- Based on a thorough analysis of data collected in the previous step, recommendations and specific measures toward improving the operation schemes of the respective facilities can be developed. Specifically, data pertaining to occupancy, weather conditions, loading level of available thermal storage elements, etc. could be utilized to mine possible inefficiencies in the current operational practices in the selected complexes.
- Subsequent to modifications of the control processes, a second extended monitoring phase is to document the post-modification performance of the facilities.
- Comparison of the performance of the facilities before and after the implementation of monitoring-based control improvement measures shall provide reliable data for the evaluation of the initial hypothesis.

In the following, we address the work and progress within the initial phase of this project towards achieving the above targets. Specifically, we discuss the relevant performance indicators, monitoring strategies, demonstrator facilities, gap analysis concerning existing facilities' monitoring infrastructures, operational improvement scenarios, and future research plans.

3. Kinds and levels of monitoring

3.1. Performance indicators

As noted earlier, the central objective of the research project presented in this paper is improving the energy efficiency of existing buildings via utilization of relevant monitoring data. It is important to stress that such data is not limited to buildings' energy performance alone. From a global perspective, a system's efficiency is a function of services it provides and the resources it uses. In case of buildings, it can be argued that the indoor climate is the primary service provided, whereas the primary resource used is energy. Proper assessment of buildings' energy efficiency must thus include, at a minimum, energy metering and indoor climate monitoring (resource use category may also include other resource-related and environmental implications of buildings' operation).

3.2. Categories of data

There is no definitive standard for assessing and amending the monitoring infrastructure of existing buildings' data monitoring infrastructures. In fact, given the variety in buildings' type, age, size, and construction styles, and given differences in the level of integration and sophistication of buildings' technical systems, compilation of a general guideline may not be a trivial task. For the purposes of the present research, previous experiences were drawn upon to set up a generic scheme for monitoring domains and levels. Data to be monitored are differentiated in terms of four categories, namely energy use, indoor environment, internal processes, and external boundary conditions. The energy use category involves a further differentiation: Energy monitoring needs to be conducted for multiple energy systems (e.g., thermal, electrical). Moreover, to the extent possible and feasible, high levels of temporal and spatial resolution should be targeted. Temporal resolution denotes the polling frequency of energy metering of various systems. Spatial resolution denotes the extent of existing sub-metering for different parts of a building (per floor, per space, per workstation, etc.).

The indoor environment monitoring category typically addresses parameters that are relevant for the health and comfort of the occupants. Such parameters often represent the target of the building operation process (e.g., indoor air temperature, relative humidity). The internal processes category refers to the presence and activities of the occupants as well as to the position (state) of devices that can be controlled by occupants or the building's control system (Mahdavi 2011). The external boundary conditions denote mainly the weather conditions in vicinity of a building. A dedicated weather station would represent the most straightforward way to collect data pertinent to this category. Such data is critical, if the energy and indoor environmental performance of a building are to be properly evaluated.

3.3. Levels of monitoring

The realization of a new monitoring infrastructure or upgrading of an existing one in a building depends of course on the availability of resources for hardware and software. In the course of CAMPUS 21 project, it was found useful to consider three different levels of monitoring. Simply stated, these levels could be labeled as minimal (M), default (D), and high-end (H). A possible specification of these levels is captured in Table 1.

Table 1. Proposed monitoring levels M (minimal), D (default), and H (high-end) for data monitoring categories energy, indoor environment, internal processes, and external conditions. In this table, θ_{air}: air temperature; RH: relative humidity; E_{glob}: global horizontal irradiance; E_{diff}: diffuse horizontal irradiance; E: illuminance; CO_2: carbon dioxide concentration; v_s: air flow speed; v_{dir},: wind direction pa: atmospheric pressure; prec.: precipitation.

Monitoring data category	M	D	H
Energy use	One meter per building for selected energy sources	1 per floor (or section/block)	1 per room (or workstation) for all energy sources
Indoor environment	θ_{air}	θ_{air}, RH, E, CO_2	θ_{air}, RH, E, CO_2, v_s
Internal processes	One sensor per typical (representative) zone	Sample of zones/occupants	All zones/occupants
External conditions	θ_{air}, RH, E_{glob}, v_s, v_{dir}	θ_{air}, RH, E_{glob}, v_s, v_{dir}	θ_{air}, RH, E_{glob}, E_{diff}, E, CO_2, v_s, v_{dir}, p_a, prec.

3.4. Sensor specification and data formats

Documentation of the existing and projected monitoring infrastructure and communication of monitoring data represent a common challenge in building automation. A typical problem lies in the difficulties to obtain data from existing building automation systems' often proprietary data processing units. In the initial project phase, communication of existing sensor types and locations as well as historical sensor data are approached in a very simple (flat) manner.

4. Demonstrator facilities

To explore the potential of the project's ideas and objectives in a hands-on manner, three "demonstrators" (existing building complexes) were selected. The first demonstrator, UCC, is a university in Ireland. The second and third buildings, Huerta del Rey in Spain and Commerzbank arena in Germany, are sport facilities.

4.1. UCC Campus, Cork, Ireland

University College Cork (Ireland) has 120 educational, research, and sports buildings of varying age spread over approximately 33 hectares excluding playing fields. Two specific buildings in the campus (CEE, ERI) and its energy network are considered for the purpose of project explorations.

CEE Building

The Civil and Environmental Engineering Building is situated on Main Campus, adjacent to College Road. The building was completed in 1910. The building was initially used to accommodate the college’s physics and chemistry laboratories and its construction is typical of many buildings constructed across a range of institutions in Ireland during the early twentieth century. The building is naturally ventilated and heated by iron cast steel radiators fed from the campus CHP (Combined Heat and Power) system. A major retrofit was undertaken in 2009/10 to improve energy efficiency and provide a full Building Management System and wireless monitoring.

ERI Building

The Environmental Research Building is situated on the west of Cork city, on the Lee Road. The ERI is not part of the main campus but provides a demonstration site with renewable energy sources such as solar thermal and geothermal systems. In addition, it is supplied with gas for hot water boilers and electricity from the national grid for lighting and other electro-mechanical systems. The building was inaugurated in 2006. The two buildings chosen provide a strong contrast in design type, condition, and age.

4.2. Huerta del Rey Sports Centre, Spain

The Huerta del Rey Sports Centre (Valladolid, Spain) was built in 1975. It consists of indoor facilities (sports hall, indoor swimming pool, gym, fitness room), offices for the Municipal Sports Foundation, and a bar. The outdoor area includes two tennis courts, six paddle tennis courts, one football field, three parking lots, and a sunbathing area for the indoor pool.

4.3. Commerzbank Arena, Frankfurt, Germany

The soccer stadium Commerzbank Arena is located in suburbs of Frankfurt near the Airport. The stadium was build in five phases over three years (2002 – 2005). The stadium has the largest moveable steel-rope-membrane cover in the world. It can be closed within 15 minutes. The stadium is usually used by the soccer club “Eintracht Frankurt”. It also hosts concerts and business events. In addition to the standard facilities of a soccer stadium, the Arena hosts special VIP areas with Lodges as well as meeting and event rooms. These areas can be used both in conjunction with the scheduled games and, independently, for special business events.

5. Gap Analysis

The three demonstrators were analyzed to find the extent of the available monitoring infrastructure and if it would allow for a detailed performance evaluation. The initial assessments suggest that the existing monitoring systems do not have the scope to support a detailed evaluation of the buildings' operational processes and alternative (improved) control approaches.

5.1. UCC Campus

The UCC campus provides different types of building automation, security, monitoring, and management systems. There is no real integrated management system for the entire campus. At the campus macro-level, energy use data is monitored and associated trends analyzed. Weekly reports are produced and distributed to all staff for energy awareness. At the micro or building level, the quantity of available data varies from building to building. Currently, hourly campus wide energy data is available for electricity, gas, and water usage.

The CEE Building is equipped with a building management system and a thermal energy meter to monitor the overall energy use. But it does not have a real capability for sub-metering. BMS system data is currently not easily accessible. Most parts of the lighting system are controlled by PIR-sensors or the available daylight. In 2009 the building was upgraded with a wireless system to monitor indoor environmental conditions.

The most extensively monitored building of the UCC campus is the ERI Building. It provides a database for historical data with a simple web interface. There is a large dataset of records from wired and wireless sensors and meters throughout the building available to CAMPUS21 researchers. This data has been collected over a period of 5 years for use in another research project titled ITOBO (Information and Communication Technology for Sustainable and Optimized Building Operation).

5.2. Huerta del Rey Sports Centre

The building and control systems of this sports center are, in accordance with its age, very simple. The building has experienced a few updates, such as the integration of a solar hot water plant on the roof and the replacement of the original lighting system. The main deficit of this demonstrator is the lack of an overall building management and control system. There is only a small automation unit associated with general building systems for heating, ventilation, and hot water supply. This unit is used for the basic control of these systems. The control of the zone devices for heating, ventilation, and lighting is done manually. Given the simplicity of control system, no monitoring data of user actions and internal conditions is stored. In addition to the general building system, some zones were equipped with independent air-conditioning (split) units. The interaction with these systems is not monitored or even integrated in the overall control system. Updating the general monitoring system would be, in this case, essential for the evaluation and further improvement of the building's control system. Additional indoor climate sensors, a weather station, and an energy sub-metering system for relevant energy flows are needed.

5.3. Commerzbank-Arena, Frankfurt, Germany

The Commerzbank-Arena is equipped with a modern BMS system. This system is used for the general operation of the HVAC and Lighting systems. A centralized management system is implemented but it does not support any monitoring of indoor conditions, outdoor climate, or energy flows. To meet the project's requirements, data storage capability must be augmented and detailed sub-metering must be implemented. Depending on the optimization scenarios, adaptions of actuators and sensors are necessary.

6. Control System Optimization at Campus21

A general design for an active control system optimization was developed for the Campus 21 Project. The optimization is to be achieved primarily via manipulation of set points and schedules. Figure 1 shows this overall optimization approach in the Campus21 project.

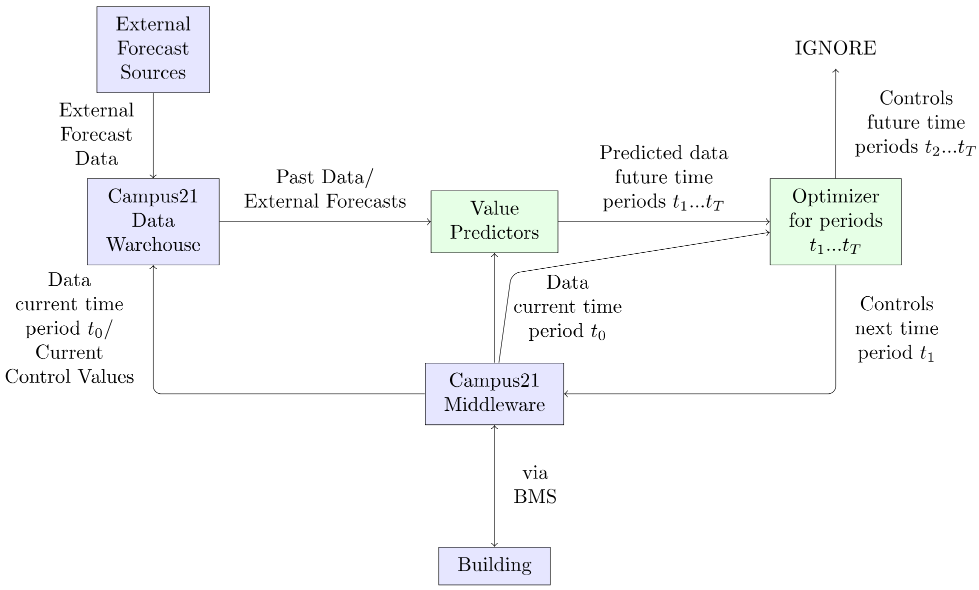

Figure 1: System design for optimization

The optimization works in the following way. Current building data are accessed through the BMS (Building Management System) and the Campus21 Middleware. Historical data can be accessed on the Campus21 Data Warehouse, with communication passing through the middleware. Information from external forecast services is stored in the data warehouse on a regular basis, again communicating through the middleware. Value Predictors, which based on past, current, and external data produce forecasts for system elements over the optimization horizon. The Optimizer, which computes control decisions from the available measured and predicted data produces control values for all time step $t_1...t_T$ of the prediction horizon, but only values for the next time period t_1 are passed back to the BMS through the middleware, all later values are ignored. In the next time step, the whole process is repeated. This receding horizon always produces the set points for current operation, while optimizing the results over the entire optimization period.

The proposed design will be used for all scenarios within the Campus 21 project. Virtual Studies for the CHP plant scenarios at UCC Campus and Commerzbank Arena will use an adapted design for the simulations.

6.1. Optimized control and load shifting for building systems

UCC ERI Building

At the UCC Environmental Research Institute building an optimized building system control will be implemented. A simplified optimizer model (see Figure 2) was developed based on the physical models and the related energy flows. The model consists of the main energy sources such as Solar (S), Gas (G), and Electricity (E) together with distribution and storage system.

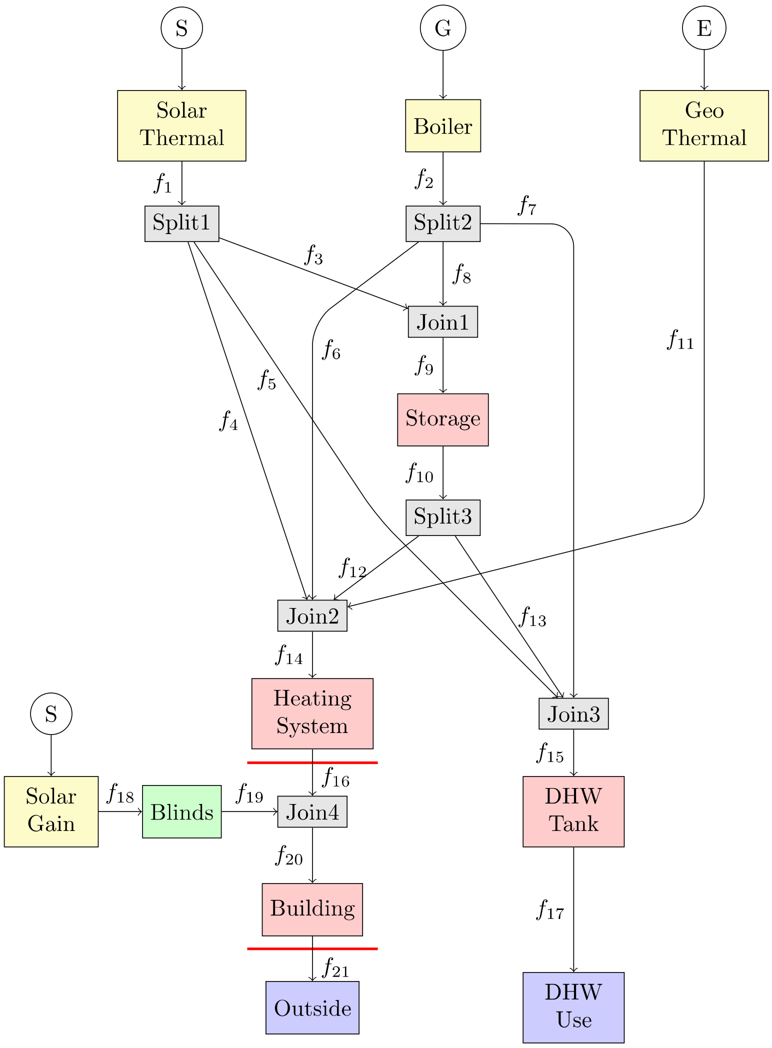

Figure 2: System model for optimized building systems control in the UCC ERI Building

Huerta del Rey Sports Centre

Heating Energy sources at the Huerta del Rey Sports Centre are a solar thermal array on the roof and two gas boilers (treated as a single device within the model). The solar array can be used to either heat the swimming pool (small and large pool are treated as a single element in the model), or to heat water in the storage tanks, which at the moment can only be used to preheat water for DHW (Domestic Hot Water). The boilers can be used to heat the swimming pools, or heat the DHW to the required temperature level. The boilers also feed the air handling units and the building heating system. However, these elements are not considered at the moment. The pools loose heat to the pool space, while hot water is used in the swimming pool area and the sports hall. There is a potential link between the storage tanks and the pool heating, which is currently not used, but which would offer more optimization opportunities.

Figure 3 shows the energy flow model for the Huerta Del Rey sports center in Valladolid. S donates the Solar source and G stands for Gas.

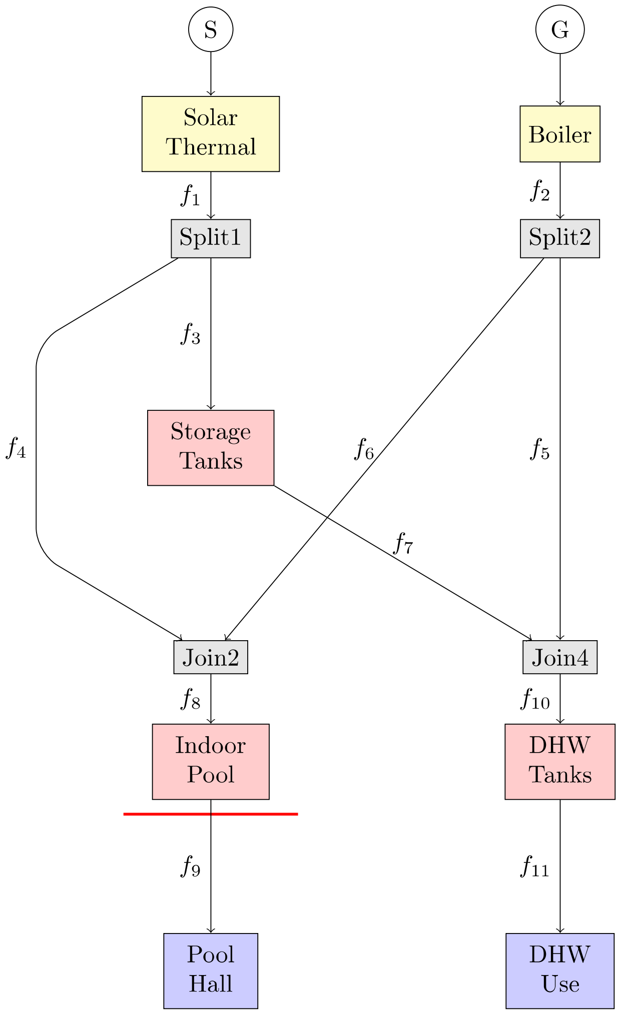

Figure 3: Overall system design for Huerta Del Rey sports center.

6.2. Load Shifting and optimized CHP plant operation

UCC Campus

As the current agreement on electricity tariffs for the UCC CHP plant runs out in 2014, it is interesting to consider the impact of different tariff models on the operating cost of the CHP plant in the future. For this purpose, we can run the UCC campus model with different alternative pricing models on the same forecasted demand profiles and compare total operating costs as well as operating hours of the equipment and total greenhouse gas production.

The demonstrator will produce schedules for the operation of the CHP plant, which can then be checked by UCC Building and Estates and the plant operator for feasibility. The schedules produced will not be actually tested as long as the current operating scheme is running.

The CHP plant delivers both heat and electricity. Backup gas fired boilers can augment heat production. The produced heat is used to satisfy consumer's demand. Hence we may need a heat dump to release unneeded heat, if the CHP unit is producing more than required. The electric output of the CHP plant goes to a switch which redirects all output to the grid, while satisfying the internal demand from the grid. In simulations we can explore other operating modes of the switch to compare the resulting price structure. Both heat and electricity consumers are represented by single sink component, we do not differentiate between the different users on the campus and predict only total consumption. Figure 4 illustrates the corresponding model for a virtual implementation.

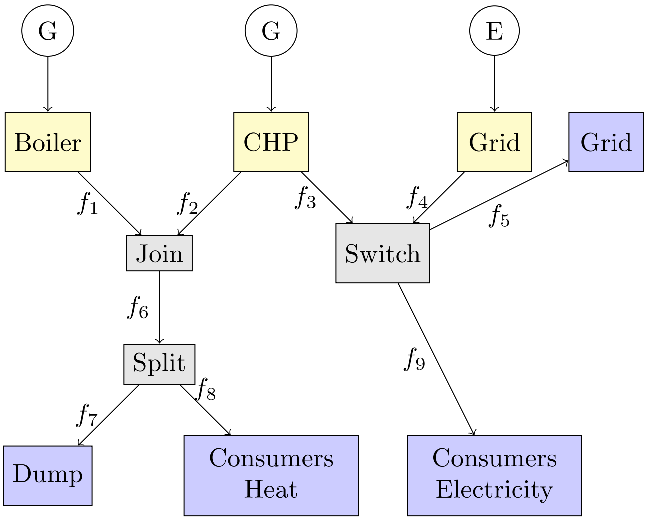

Figure 4: UCC Campus System model for CHP operation optimization.

CHP System at the Commerzbank Arena

This demonstration scenario is based on the idea of replacing the existing power plant with an CHP plant. The objective of this scenario is to estimate the total cost of operation of a CHP plant installed in the stadium, compared to the cost of operation using the existing or a replacement boiler in the current operational design. This could provide a more accurate picture of potential savings than can be achieved with a CHP plant, thus helping to determine if such an investment would make sense for the Commerzbank Arena. Figure 5 illustrates the associated model. The three energy sources of the arena are Electricity (E), Gas (G), and Diesel-fuel (D). AHU stand for Air Handling Unit

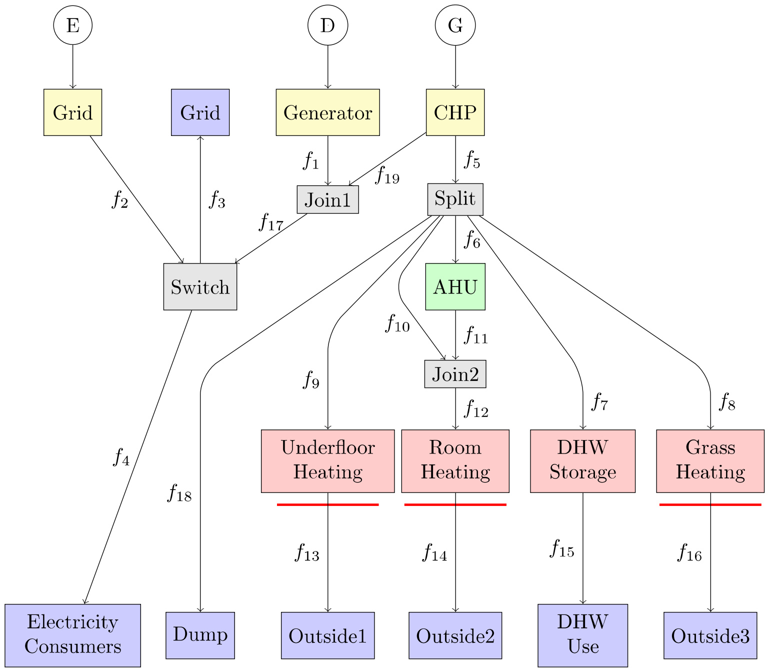

Figure 5: Commerzbank arena System model for CHP operation optimization.

6.3. Predictive model-based concept for zone control

A model-based control strategy (Mahdavi 1997, 2001b, 2008) is considered as implementation concept for an intelligent facade zone controller. In this model-based control approach, control decisions are made upon evaluation of the computed implications of virtually enacted control options. This implies that at each control decision making instance, available control options (i.e., the alternative set points or actuator positions) are virtually realized by at the zone level. The model results (projected values of the control parameter for a specific point of time in future) are then compared to identify the most promising option. A generic simplified room model for predictive zone control was developed for a test room of the UCC Environmental Research Institute building. This model is illustrated in Figure 6.

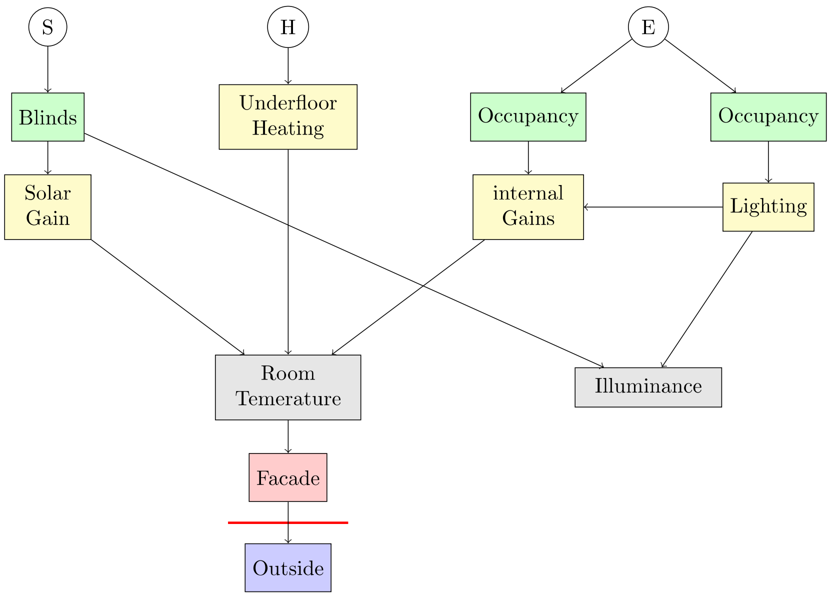

Figure 6: UCC ERI Building general room model for predictive zone control.

The model captures the main energy flows caused by solar radiation (S) and heating (H) as well as internal gains caused by occupants and electrical equipment (E) together with status variables such as air temperature and Illuminance. This model will be integrated in the proposed online optimization and adapts the related set points in the existing control.

The overall control objective is the optimized zone control based on predicted performances in terms of comfort and energy usage. A weighted sum of specific performance indicators, related to the different domains (thermal and visual aspects, air quality) will be used for the optimization.

7. Outlook

The project has thus far not only generated a basic conceptual and methodological foundation for monitoring-based energy efficiency improvement approaches in buildings, but has also led to the formulation of a number of concrete procedures and schemes for the realization of such approaches. Some of these schemes are projected to be implemented in the demonstrator facilities in the near future. Other measures shall be virtually realized to estimate their potential effectiveness. Comparison of the performance of the facilities before and after the real and virtual implementation of monitoring-aided control improvement measures is expected to provide useful data for the evaluation of the initial hypothesis. Moreover, generic features of the approach and results are to be documented for the benefit of the relevant professional community involved in the building delivery and operation process.

Acknowledgments:

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References:

Commerzbank 2012. Commerzbank Arena in Frankfurt am Main, http:// www.comerzbankarena.de.

CAMPUS 2011. Control and Automation Management of Buildings and Public Spaces in the 21st Century. http://zuse.ucc.ie/campus21/.

EU 2012. FP7 - ICT - Information and Communication Technologies. http://cordis.europa.eu/fp7 /ict/.

Mahdavi, A. 2011. People in building performance simulation, Chapter 4 in Building Performance Simulation for Design and Operation, edited Jan L.M. Hensen and Roberto Lamberts, Spon Press, Oxon, ISBN: 978-0-415-47414-6.

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

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.