Possibilities of Energy Efficiency Experimental Research Using MLBE Building’s Automation and Control System

Anna Romanska-Zapala¹, Marcin Furtak², Małgorzata Fedorczak-Cisak², Miroslaw Dechnik²,³, Karina Grzywocz¹

¹Cracow University of Technology, Faculty of Electrical and Computer Engineering, Warszawska 24, 31-155 Kraków, Poland
²Cracow University of Technology, Malopolska Laboratory of Energy Efficient Energy Building, Warszawska 24, 31-155 Kraków, Poland
³AGH University of Science and Technology, Faculty of Electrical Engineering, Automatics, Computer Science and Biomedical Engineering, Mickiewicza 30, 30-059 Kraków, Poland

a.romanska@pk.edu.pl

Abstract. Due to the increasing requirements in the field of buildings’ energy saving, impossible to meet only due to the thermal insulation of the building envelope, it is necessary to pay attention to the energy efficiency of technical installations and application of automatic control systems. Computer simulations on the building structure or functioning of its individual installations in the context of limiting its energy consumption, performed by Design Builder – type computer programs, are a very useful tool. However, in the case of simulation studies on the impact of automatic control systems on energy efficiency, the results are often overly optimistic – they are overestimated in comparison to results achieved in actual environments. Therefore, the results obtained should be validated in an actual environment. This paper presents the Malopolska Laboratory of Energy Efficient Building (MLBE) of Cracow University of Technology, which provides an opportunity to perform experimental actual scale research of building automation systems to improve buildings energy efficiency and occupants’ comfort. This paper includes a detailed description of MLBE’s building automation and control system. Furthermore, this paper presents possibilities and an example methodology of energy efficiency’s experimental study using BACS system.

1. Introduction
It is estimated that globally about 30-40% [1, 2] of primary energy and about 60% [1] of electricity is consumed in buildings. In developed countries, 20-40% of final energy is consumed by buildings. In the European Union, the share of buildings in the total energy use is 40%. For comparison, transport absorbs 32% and industry 25% [3].

Currently, the implementation of Directive 2010/31/EU [4] on the energy characteristics of buildings results in special attention being paid to issues related to the energy consumption of buildings. Member countries of the European Union were obliged to introduce regulations for low-energy building. In Poland, in the developed Regional Operational Programme for Malopolska Province for years 2014-2020, one of the of regional development axes concerns energy efficiency in public buildings and in the housing sector [5]. Users’ requirements for e.g. thermal comfort of newly
constructed buildings is rising. In Poland, the comfort of rooms usage is determined by the standard [6]. This results in search for energy saving solutions that enable a high usage comfort while providing the highest possible energy efficiency and the lowest possible operating costs [7, 8, 9, 10].

2. The impact of building automation and control system on a building’s energy efficiency

Due to the increasing requirements in the field of buildings’ energy saving, impossible to meet only due to the thermal insulation of the building envelope, it is necessary to pay attention to the energy efficiency of technical installations. The standard EN 15232 [11] shows the technical installations of the building, which have a decisive impact on the energy efficiency of the building are:

- heating installation,
- cooling installation,
- installation of hot water,
- ventilation and air conditioning,
- lighting,
- sunblinds.

The use of automatic control systems, thanks to the effective management of energy resources, has a significant impact on improving the energy efficiency of a building. The use of lighting control can bring up to 70-80% reduction in electricity consumption compared to a traditional installation [12]. Even the simplest control system for heating, ventilation and air conditioning systems (HVAC) can reduce their energy consumption by more than 5%. However, the use of advanced control and monitoring can provide a 40% reduction in energy consumption [1].

Nowadays the development of building automation and control systems (BACS) is rapid. According to the standard EN 15232 [11], a building automation and control system is the superior control system in the building. The BACS term should also refer to: building management system (BMS) or building energy management system (EMS), as long as they comply with the requirements of the EN ISO 16484 [13]. In EN 15232 standard [11], automation, control and management systems cooperating with technological building systems are divided into classes, according to their impact on reducing energy consumption in a building. The highest level of energy efficiency can be achieved through integrated control of technical systems. In Poland, the issue of standardization in the field of building automation has been clarified. In case of the need to integrate automation systems using various communication standards, problems that arise are fewer. However, in accordance with current legislation the use of building automation is not obligatory.

Computer simulations on the building structure or functioning of its individual installations in the context of limiting its energy consumption, performed by Design Builder – type computer programs, are a very useful tool [8, 14]. Simulations are very useful, even at the design stage, as a means to choosing heating or cooling variants or individual installations and systems. However, in case of multivariate analysis of processes with respect to energy consumption and comfort of occupants, using cooperating systems supported by automation, such as ventilation, heating, lighting, and air conditioning, this type of computer calculations is not sufficient. Simulation tools have a limited application and accuracy, therefore the results obtained should be verified in an actual environment. In the case of simulation studies on the impact of automatic control systems on energy efficiency, the results are often overly optimistic – they are overstated in comparison to results achieved in actual environments [12]. In order to validate the results obtained, it is therefore necessary to conduct experimental research in an actual scale (in situ). This was the justification for the idea of creating the Małopolska Laboratory of Energy Efficient Building (MLBE) at the Cracow University of Technology. The whole Laboratory – its body, equipment, installations and applied automation system – can be used for research in actual usage conditions. Furthermore, the laboratory building, creates a possibility to conduct multidisciplinary research programs at the frontiers of scientific fields.
3. The characteristics of the BACS system in the MLBE building

In September 2014, the construction of Malopolska Laboratory of Energy Efficient Building (MLBE) at the Cracow University of Technology was finished, which enabled the possibility for conducting a wide range of experimental research. The construction and equipment of the MLBE were financed by the Project MRPO.05.01.00-12-089/12-00 – funded by the Malopolska Regional Operational Program for the years 2007-2013. The creators of the project were DSc arch. Marcin Furtak and PhD Małgorzata Fedorczak-Cisak. The Laboratory is the first place in Poland which conducts such a large-scale research on energy efficient technologies and the comfort of the occupants of low-energy buildings. This interesting project gives the University the leading position in the sector of energy efficient buildings. The innovative building is situated on the University campus in Warszawska street.

It has 5 floors (the building area is 258.41 m², the utility space is 1039 m², the front elevation is 17.02 m wide and 19.24 m high). It is a slab and column construction with self-supporting external walls and glass elevations. Owing to this, materials and construction can be changed to meet research needs. The object comprises of 14 thermal zones working independently of one another so as to make their comparative analyses possible. Various types of heat and cold sources have been used, including renewable ones. At a room level, heating and cooling is implemented via fan coils, surface systems (under the floor, wall or ceiling), and a ventilation system with preconditioned air [15, 16].

The MLBE is equipped with integrated building automation and control system, based on LonWorks technology. The control system integrates of all building technical installations (lighting, ventilation/air conditioning units, heat pumps, cooling unit, rooms’ fan coil units, surface heating and cooling: underfloor, wall and ceiling systems, variable air flow regulators VAV, regulating dampers, fire dampers. This functionality can be expanded by planning and adding additional devices. The technical installations are equipped with measuring devices so as to allow on-going monitoring. Thus, the system includes both systems of automation, control and data acquisition (including lighting, heating, air conditioning and ventilation control, and monitoring the measurement systems). Moreover, the automation system was integrated on object level with the building security systems such as the intruder alarm system and access control system. This solution allows to carry out research on the impact of integration on the energy efficiency of the building in accordance with EN 15232 [11] standard.

To facilitate the work of users, the monitored data are presented using visualizations system. In addition to presenting values of the parameters that are important for the process control, the created systems give also full control over installations. The visualization system is built in such a way that enables each person to use this system after a brief training. The graphical visualization is still evolving and is being developed by MLBE’s scientists. Figure 1 shows a control panel of individual heating and cooling sources, installed in the MLBE building. An another example, shown in Figure 2, presents the control panel of ventilation unit connected with horizontal earth-air heat exchanger system. Figure 3 shows an overview of the second floor of the MLBE building, with information about the condition of rooms and devices.
Figure 1. Cooling (marked blue) and heating sources (marked red) control panel with circulation pumps and energy storages (water tanks) shown. PC1 – ground heat pump with AWS heat exchanger; PC2 – natural gas heat pump; PC3 – chiller with heating function; VSC – vacuum solar collectors; FSC – flat solar collectors; NW1, NW2 – solar collectors’ pump units; ZG – hot water storage tank; ZCH – cold water storage tank; Wc.w.u – domestic hot water tank; BUFOR – transitional water buffer; WC1, WC2, WC3 – heat exchangers.

Figure 2. Control panel for ventilation unit – horizontal earth-air heat exchanger system [17]
The system network architecture includes three levels:

- the master level (its task is operator support, as well as data collecting, processing and storage),
- the automation level (includes controllers; implementing control algorithms of individual subsystems such as lighting, heating, air conditioning, ventilation, etc.),
- field level (includes sensors and actuators; implementing components related with the researched technology).

The master level of the integrated control system was created using three computer stations. Each of them has specific functions. The first is the system operator station and includes the following software: MSDE SQL Server, Lon Maker software (an example of system configuration is shown in figure 4), NL-OPC Server, L-LOGICAD (see figure 5) and L-WEB. The employed L-WEB software allows direct access to the data and drivers functions of automation system from the operator station and from the external terminals. At the second station LabView software was installed, which is used to manage research experiments. The third computer contains specialist software dedicated to specific research. Devices of master and automation levels are connected by a separate computer network based on structured cabling (Ethernet IP). Object devices are connected either with controllers, via direct connections with individual driver inputs and outputs, or by local data fieldbuses, specific for a specific industry. For example, heat meters are connected to M-bus, the ventilation/air conditioning control cooperate by BACnet MS/TP fieldbus, while lighting system elements are connected by DALI fieldbus. The rooms’ automation and, among others, metering of weather stations parameters and heat pump control was carried out using LON bus. Modbus protocol was used in the control process for AWS YOSHI unit (refrigerant R410A / water heat exchanger), air-glycol heat pump or sensors of atmospheric conditions. Thanks to application of the number of international data transmission standards found in building automation systems, using the MLBE system enables easy implementing in the system and monitoring the work of external devices.
For the laboratory rooms, freely programmable controllers (in accordance with IEC 61131-3 standard – an industrial standard for programming PLC drivers) were used, in order to implement any control strategy within a given space. In selected laboratory rooms, touch panels were installed that offer preview of the current parameters (e.g. temperature, relative humidity, air velocity and flow rate on supply and exhaust, equipment condition), and control of individual local systems: lighting and heating/cooling, as well and programming the required parameters. On the roof of the building and on elevations weather stations with control module are located. Some rooms can be controlled in relation to the supply air temperature, extract air or room temperature. All the measured parameters and modulations are visible and archived in BACS system. Measurements of heating and cooling energy consumption are possible in selected places of heating/cooling installation. Heat meters with M-Bus interface were used for measurements. They provide the ability to read – besides the basic parameter that is the use of energy – such parameters as flow rate, supply air temperature and extract air.
temperature. Furthermore, the selected electrical installation circuits are monitored by power analyzers, with LON interface.

In summary, the system of automation, control, data acquisition and building management of Małopolska Laboratory of Energy-Efficient Building is a distributed control system (DCS), which in addition to the standard functions performed by the modern BACS systems enables research in the field of energy efficiency of different technologies used in building installations.

4. An example methodology of energy efficiency’s experimental study using BACS system

The study of systems’ energy efficiency using selected technologies and systems of the MLBE building is a multistep process. Provisionally, computer simulations are conducted, for which simplified models of examined rooms, installations and processes are built, using, among others, computer simulation tools such as ANSYS or Design Builder. Then, after evaluation of obtained results, parameters of examined system are selected and a schedule of experimental research in actual scale is established. Free programming in a wide range is possible (figure 4, 5).

In order to make an objective assessment of the analyzed parameters, the measurements can be made in two identical rooms. One of them acts as a room with assumed control parameters, while the other acts as a reference room. Application of an integrated LonWorks technology process control during the research enables reproducibility of experimental conditions and automatic data collection in SQL database. In addition, some rooms allow connecting additional devices which are not elements of the existing building infrastructure, such as fan coil units and various types of heating or cooling devices. Additionally, in two rooms used for research on the integration of building automation systems programmed in different standards, a KNX bus system was installed. Using these hardware capabilities, it becomes possible to conduct research on the effectiveness of building devices in a very wide range in all basic automation standards. Experimental studies in MLBE building are carried out monthly, quarterly and annually in natural conditions typical for using the building in urban areas in Polish climatic conditions.

After taking a cycle of experimental measurements, the obtained data are processed using programs such as STATISTICA, which use statistical methods to search complex relations between the measured parameters [11]. The results and statistically significant dependencies are the basis for the correction of process control algorithms. The final effect of such actions is to develop optimized process control algorithms, and – subsequently – to carry out an attempt to implement, among others, self-learning or predictive algorithms.

5. Conclusions

Simulation tools have some limitations, therefore the results obtained should be verified in an actual environment. In the case of simulation studies on the impact of automatic control systems on energy efficiency, the results are often overly optimistic – they are overestimated in comparison to results achieved in actual environments. In order to validate the results obtained, it is therefore necessary to conduct experimental research in the actual scale. This was the justification for the idea of creating the Małopolska Laboratory of Energy Efficient Building. The laboratory provides an opportunity to perform experimental, actual scale research of building automation systems to improve buildings’ energy efficiency and occupants’ comfort.

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