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BUILDING MECHATRONICS SIMULATION SYSTEM

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Abstract**—** In international references a net zero-energy building (NZEB) is defined as a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies. According to this general term definition, the essence of the concept is that by using low-cost and locally available nonpolluting sources, they generate energy onsite, in a quantity equal or greater than the total amount of energy consumed onsite in the building. By using integrated design and building technologies, designer engineers are able to determine which energy efficiency strategies and what type of renewable onsite generation will contribute to higher energy performance to meet the requirements of the residential or commercial building considered. Therefore, it can be clearly established what kind of design and development strategies must be adopted in order to ensure an adequate energy balance, and as a result, comfortable and healthy home or workplace is possible to be created, with general characteristics that make NZEB buildings desirable and financially rewarding as well.

Keywords**—**energy, energy efficiency, energy in buildings, energy supply, renewable energy sources, sustainable energy management

I. INTRODUCTION

NOWADAYS, there is a growing demand for the application of renewable energy or the optimised use of conventional forms of energy. The main key is building mechatronics which can optimise the current, in-use systems, provides a higher level of security, the supervision and control of the building depending on the demands of the consumers.

It is no doubt among scientist focused on this research area that nowadays the net zero-energy goal becomes more practical and has been emerged among the most important research tasks of the engineering community. Therefore, not only the progress made in the new renewable technologies makes possible a rapid advancement in this scientific area, but it is highly improved by academic research as well. As a result of these efforts, in the last decade a high amount of leading-edge case studies have been published in international journals to demonstrate the progress toward achieving net zero-energy goal in concrete examples [1]-[4]. Without entering in detailed theoretical approaches, it is mentioned here that according to reference [1], four commonly used definitions are discussed in the international references: net zero site energy, net zero source energy, net zero energy costs, and net zero energy emissions. This classification is mentioned just to outline that the zero-energy concept allows for a wide range of approaches due to many options for producing and conserving energy combined with the many ways of measuring energy. Additionally a particular difference is made in usage between North America and Europe regarding the ZEB concept and its definition. However, here the commercial and residential buildings that uses non-polluting sources, they generate energy onsite, embedding complex heating, ventilation and air conditioning systems (HVAC), supervising and event monitoring systems, or other complex automation systems that operates together to achieve the above mentioned NZEB goal, will be referred in a short way as “intelligent buildings”. Obviously, the main goal of this paper is not to unfold the theoretical considerations regarding the above referred theoretical concepts, but rather to introduce our design and development strategies regarding the intelligent buildings implementation that are capable to reach as much as possible the mentioned NZEB goal.

In the University of Debrecen, Faculty of Engineering, Electrical Engineering and Mechatronics Department a unique form of education came to existence. Building Mechatronics is educated only there in Hungary. The researchers of this department had published many of their results during the last years [5], [6], [7]. The Department has a Bachelor of Science Program and since 2013 a joint Master of Science Program in Advanced Mechatronics Systems together with the Department of Mechatronics and Robotics, University of Oradea (Romania). The primary goal of the HURO 0802 Hungary-Romania Cross-Border Co-operation (HURO Intelbuild project) is to implement a Hungarian-Romanian development platform which is built in Debrecen and in Oradea, two laboratories complementing each other to serve the researchers and PhD students and become a knowledge base in both countries. The results of the research project can be multiplied in the building energy domain by not studying the building materials, construction and construction methods, the buildings energy consumption cannot be only examined from the perspective of energy consumption, but with use of mechatronic devices based on artificial intelligence, the power consumption can be regulated and controlled based on effectiveness [8]. With the development of the research platform at both universities in the field of artificial intelligence, building mechatronics new and innovative knowledge will be generated. To carry out the developments, the Energotest Ltd was invited. They constructed two heat pump systems in the Intelligent Building.

II. LabView Software-based Building Supervising

In the initiation of the high level and technically sustainable development and infrastructure are keystones of the National Instruments' software and hardware means. Our Department and the Faculty of Engineering is obliged to the technologies of the NI. The Faculty provides LabVIEW tuition each student for at least a semester. The units driven by renewable energy are controlled by an NI compact controller. We chose the NI sbRio technology which is an FPGA-based technology. There can be built reconfigurable, parallel working real-time embedded controllers.

Fig. 1. NI sbRio 9606 Card

NI sbRio 9606 Card integrated into heat pump system:

1. 400 MHz processor, 512 MB non-volatile storage, 256 MB DRAM for deterministic control and analysis

2. Reconfigurable Xilinx Spartan-6 LX45 FPGA for custom timing, inline processing, and control

3. 96 3.3 V DIO lines

4. Integrated 10/100BASE-T Ethernet, RS232 serial, CAN, and USB ports; 9 to 30 VDC supply input

5. -40 to 85 °C local ambient operating temperature range

The NI sbRIO-9606 embedded control and acquisition device integrates a real-time processor, a user-reconfigurable FPGA, and I/O on a single printed circuit board (PCB). It features a 400 MHz industrial processor, a Xilinx Spartan-6 LX45 FPGA, and a RIO Mezzanine Card connector, which is a high-speed, high-bandwidth connector providing direct access to the processor and 96 3.3 V digital I/O FPGA lines. This device features a built-in 10/100 Mbit/s Ethernet port that can be used to conduct programmatic communication over the network and host built-in web (HTTP) and file (FTP) servers. The sbRIO-9606 also features integrated CAN, RS232 serial, and USB ports for controlling peripheral devices. The professionals of Energotest built a carrier for the "mother card":

1) 32 digital inputs,

2) 16 Push-pull outputs, 16 relay outputs

3) 16 PWM (analogue) outputs and

4) 32 (16 differential) analogue inputs

It is realized on printed circuits. It has also a standby battery. In performance it is similar to the sbRio 964x. The overall amount of the execution: 40 hours + 25 technician hours.

Fig. 2. NI sbRio 9606 Card on the carrier panel

Because of the drastic decrease of the information technology solutions and the increase of individual solutions, the FPGA provides a flexible and reconfigurable system; it can extend the life of electronic devices. The NI LabVIEW provides the option to create real time simulation systems in parallel processing. With the appropriate extensions, the LabVIEW (short for Laboratory Virtual Instrumentation Engineering Workbench) is a system design platform and development environment for a graphical programming language from National Instruments. The programming language used in LabVIEW, also referred to as G, is a dataflow programming language. Execution is determined by the structure of a graphical block diagram (the LV-source code) on which the programmer connects different function-nodes by drawing wires. These wires propagate variables and any node can execute as soon as all its input data become available. Since this might be the case for multiple nodes simultaneously, G is inherently capable of parallel execution. Multi-processing and multi-threading hardware is automatically exploited by the built-in scheduler, which multiplexes multiple OS threads over the nodes ready for executions. The graphical programming user interface and philosophy provides further didactic chances. LabVIEW has plenty of implementations in industry as it can be used to test many important aspects of mechanical signals and systems; stress, strain, heat dissipation, moments and fluid dynamics are just a few examples. Information can be logged and rigorous automated DAQ (Data acquisition) schemes can be implemented entirely from within the LabVIEW environment. Our department colleagues also develop Object oriented programs (Building-Mechatronic) in LabVIEW environment. The fully modular character of LabVIEW code allows reusing code without modifications: as long as the data types of input and output are consistent, two sub VIs are interchangeable and it can increase the productivity. Building Mechatronics simulation system has two sbRio FPGA card controllers: Master and Slave. The Master is for measurement control and makes building engineering simulation. The Slave is responsible for the regulation, the broadband communication and the treatment failure. This way a wide-range Building Mechatronic simulation is created. The Master sbRio (Test controller) is the communication master. It produces building simulation by sensors, actuators, building engineer modelling and uploads the test exercise to the data base. The Slave sbRio (DUT: Device Under Test) provides the communication tests, the test of the regulation functions and exercises as well as the test of the maintenance and alarm functions.

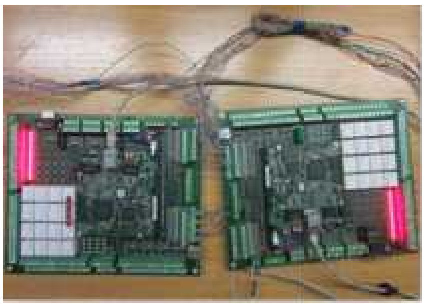

Fig.3. The Master and Slave sbRio cards

The advantages of choosing NI FPGA based technology: sbRio is a real-time, parallel processing embedded device. The LabVIEW software provides the development of the programs on PC with TCP/IP. The Slave sbRio software is embedded into building engineering/ building management system without modification. The LabVIEW software can communicate directly with SQL-compatible data base. In other words it can realise direct data collecting and analysis.

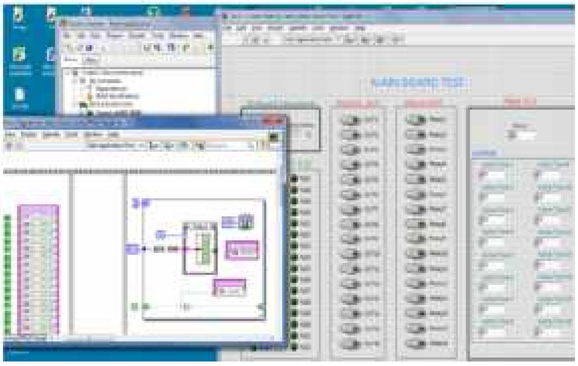

Fig.4. LabVIEW graphical environment

We chose NI LabView and sbRIO because of their reliability and easy-to-fitting-in. Furthermore, the software development is not difficult and the price/performance rate is prominent. Another reason was to find easy devices which have easy software complexity for our students to learn quickly. The Mechatronics Department use the National Instruments devices in various fields in the education: e.g. the ELVIS technology, in the education of digital circuits or the NI DAQ and other measurement, data collection for mechatronic projects.

III. BUILDING MECHATRONICS SIMULATION SYSTEM

In accordance with the adopted development strategy, the first layer implementation requires the input information regarding the architectural features and specifics of the building considered for experiment. For this reason a LabView software-based supervising and event monitor system has been designed, of which's input information is considered the building's cadastral plan in a .jpeg or .bmp file format. This plan indicates all the building rooms, the sizes of these, annex buildings, existing basements, the number of doors and windows, or other important particularities. The program fixes this file on the design desktop of the LabView toolkit and places it as a background element. At the same time, it is also necessary to indicate the lighting elements placement, the fan coils or other heating elements arrangement in the building. If this information is available, the designer marks all them on the desktop as shown in Fig. 5. Here an arbitrary chosen building plan is indicated, free downloaded from the www.schwabinvest.hu internet page.

In the considered building are also placed motion detection sensors, therefore if there are no persons in the building (or at nighttime) the entrance door and all the lighting elements switches off. It is self-understanding that the sensors can be programmed for arbitrary timing intervals and the garage doors closes automatically as well. The program supervises all the doors and windows status (open or closed), the lighting system of the building, and the state of the heating elements (turn off/turn on).

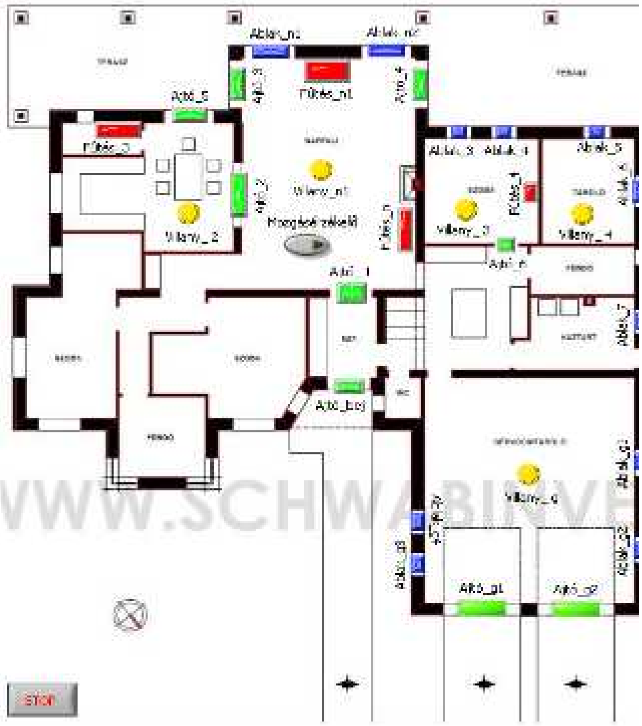

Fig. 5. The arrangement of the LabView graphical elements on the design surface

The graphical elements placed on the desktop surface are arranged after the following rule:
1) the doors are marked with green squares;
2) the windows are marked with blue squares;
3) the lighting elements are yellow circles;
4) the motion sensors are marked with gray oval circles;
5) the fan coils and heating elements are marked with red squares.
This monitoring system can be arbitrary linked with the alarm system of the building. In the given example the alarm system operates only if all the windows of the building are closed, otherwise turns off and indicates this state. Of course, according to the customer needs, the building alarm system could be operated after any other programmed logic required.

IV. Conclusion

For the modern and qualified tuition, the effective co-operation of industry and academy is required. There can be special demands of laboratories: industrial technologies and results are needed to be taught and open technologies for researches: scientific works, thesis on the level of MSc and PhD. The heat pump system installed in the Intelligent Building is controlled by the NI sbRio 9606 card. It is flexibly reconfigurable according to the building services demands. We built up a Master-Slave Simulation System from two FPGA controlled sbRio card which is able to simulate the building, the building services, supervision and communication. One sbRio 9606 is built in the Heat pump system with solar collectors. The tested programs can be transplanted without any change into the heat pump systems' control. The sbRio simulation system is up-to-date and can be used any times. There are some basic building services implemented in the system which proves the reliable working of the Simulation System. The test operations of this graphical oriented program show that it is well feasible for the above mentioned purposes, representing an efficient real-time operating program with user-friendly interface. At the same time it remarks with an immense flexibility, it is easy-to-use, and allows rapid configuration facilities. These abilities recommend to be used as a general framework for a wide range of residential or commercial building applications, without any major changes in its structure or additional reprogramming efforts. By using the given results, the energetics simulation can be realized without operating the building. Based on the simulation system, the regulation system can be regulated, can be made unique.

V. Acknowledgement

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