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ENERGY EFFICIENT SMART BUILDING – THE RESEARCH-DEVELOPMENT AND DEMONSTRATIVE PROGRAM

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Abstract: Paper introduces to the projet prepared by the team of Centre for Energetic Technology in Świdnica and devoted to energy-efficient smart building. The range of possible technical solutions which will be applied in the research-development-demonstrative building has been reviewed, including energy efficiency, operation in a smart technical scheme in aid of environmental and social sustainability, sensing technology, communication protocols, signal processing, building management systems. Presented material also depicts the possible studies in the range of data fusion and complexity measurements in the exemplary object, i.e. the energy-efficient smart house. Telemedical services in the future house are discussed as the main topic for conference presentation.

Keywords: Smart building, energy efficiency, telemedicine, sensing technology.

1. INTRODUCTION

The progress in science is strictly synchronized with a development of the measurement technologies [1]. Complex systems conception is one of the leading thread of the modern science [2]. This conception is investigated both as an abstract [3] and the notion of practical meaning [4]. Observation of the organization in architecture and information flow in the complex systems brings to new facts, which are the triggers for disruptive innovations. As was discussed by Peine [4], the case of smart homes can be the suitable subject for exploration of scientific/technological paradigms in the context of complex technical systems.

Intelligent building accentuates a multidisciplinary effort to integrate and optimize the building structures, systems, services and management in order to create a productive, cost effective and environmentally approved environment for the building occupants [5]. This definition suggest that, apart from the physical fields or the details of technical infrastructure, some social-economic consequences (which can be ambiguous) should be characterized/measured in intelligent building. Finally, the combination of energy-efficiency and intelligence brings the building technologies to the conception of sustainability [6],[7]. Reliable description (qualitative and/or quantitative) of such subject establishes the new directions for measurement techniques. First of all, the following areas should be considered (and optimized) for the energy-efficient smart house:

- environmental friendliness – health and energy conservation,
- space utilization and flexibility,
- cost-effectiveness – operation and maintenance with emphasis on effectiveness,
- human comfort,
- working efficiency,
- safety and security measures – fire, earthquake, disaster and structural damages, etc.,
- culture,
- image of high technology,
- construction process and structure,
- health and sanitation.

The paper concerns the project of energy-efficient smart house which is prepared in the Centre for Energetic Technology (CTE) in Świdnica, Poland. The goal of this research-development-demonstrative initiative is to design and realize the infrastructure which will meet the standard of zero- (zero-energy building ZEB) or positive-energy (positive-energy building PEB) smart house. Original, energy-friendly architecture, building materials and technologies, have been proposed for this task. What is more, environmentally compatible power (heat and electrical) generation, distribution and accumulation systems have been designed, together with building management system. White goods, consumer electronics and telemedical system will co-exist in the building infrastructure. By intention, the inhabitants and building infrastructure will be monitored in the internal and external home environment in order to provide the guidelines for governmental organizations, practitioners, investors and entrepreneurs. But, numerous research should be provided before that, including identification of measurement tasks, designing of original measurement set-ups, construction of the original measures for acquired experimental data, etc. CTE are open for any original input and co-operation with other teams interested in the area of energy-efficient smart building.

2. ENERGY-EFFICIENT BUILDING

Buildings have become one of the main contributor to energy consumption regarding various sectors of social life. Nowadays, where the requirements for the assurance of the necessary thermal comfort, visual comfort and indoor air

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quality are increased, the energy efficiency potential is considered to be extremely significant, taking also into consideration the prevailing situation of price fluctuations, the rapid population and the evolution of technology. In particular, based on numerous studies, energy efficiency could contribute to the reduction of the current energy consumption by at least 20% in the EU [8].

Energy efficiency in buildings can be reached by optimization in planning of the investment, optimal designing and realization of the building, which influence a reduction in energy consumption, harmful gas emission and decreasing the costs of living. Working in the field of energy efficiency, leading to sustainable building technologies, needs co-operations of interdisciplinary teams: urban planners, architects, civil engineers, material scientists, environmental engineers, specialists in control systems, electrical engineering, photovoltaics, metrology, biomedical sciences, sociology, etc. To achieve the goal, i.e. successfully responding on demands of human and environment, they need to operate on subjective and objective parameters. Attaining the standard of energy efficiency, e.g. zero- or positive-energy building, is a stage on the sustainability roadmap. Since the target of the CTE's team is to equip the energy-efficient building with the associated infrastructure, e.g. the telemedical system, thus finally the building will approach nearly the sustainable standard.

The energy-efficient smart house will exploit the passive and active sources of energy. Passive source of energy are connected mainly with the photo-thermal conversion of sunny light. Apart from direct thermal input to the room spaces, accumulation of this kind of energy is planned in the CTE's house by using the appropriate accumulative materials in the chosen zones of the building. On the other hand, the profiling of the thermal characteristics of the building will be enhanced by appropriate control of the window blinds. Similarly, the thermal energy produced by installed in the smart house the active sources of thermal power, e.g. the solar-thermal collectors, heating pump, bio-mass furnace, etc., will be accumulated in the earth deposit. Generally, the technology of thermal and electrical energy accumulation, demanded to fulfil the needs of the household during the whole year cycle of its exploitation, will be one of the leading thread in the project. This task is strictly related to the issue of designing of optimal scenarios of energy management, important for the project of CTE in Świdnica.

Electrical energy generation will be connected with photovoltaics (PV) installation. Permanent monitoring of the installation and output power from the PV system will bring to the new schemes in exploitation of energy resources in the building. Apart from supplying of the household with the electric and heat power, the devices used in the smart home will be selected according to the rules of minimized energy consumption. The components of a model ZEV/PEB was shown in Fig. 1.

3. SENSOR TECHNOLOGY IN SMART HOMES

Smart home integrates devices and services into intelligent, interconnected and interoperable systems (Fig. 2). Many smart homes today adopt the concept of ubiquitous sensing where a network of sensors integrated with a network of processing devices yield a rich multi-modal stream of data. These sensory data are analysed to recognize and monitor basic and instrumental activities of daily living performed by the residents such as bathing, dressing, preparing a meal, and taking medication. This approach has the potential to allow smart homes to capture patterns possibly reflecting physical and cognitive health conditions and then recognize when the patterns begin to deviate from individualized norms and when a typical behaviour that may indicate problems or require intervention [11]. Exemplary projection of the model of smart house reveals a plenty of

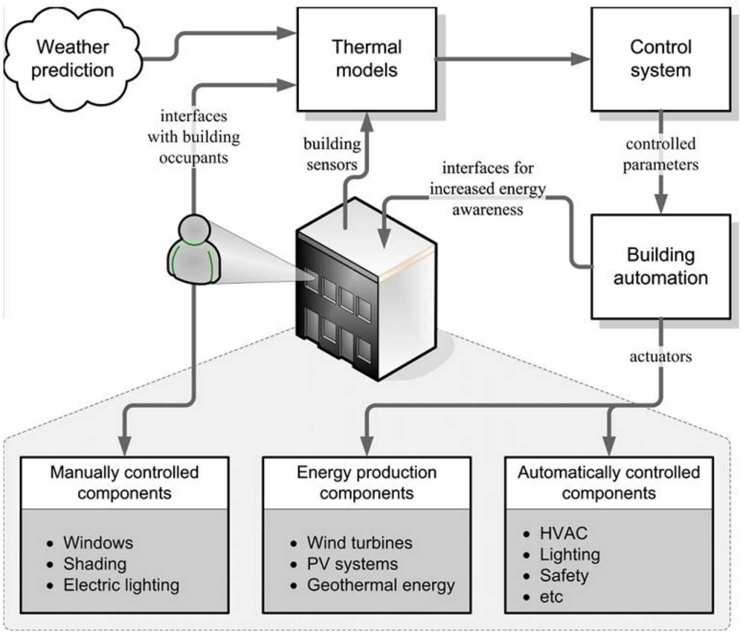

Fig. 1. The components of a zero-/positive-energy building [9].

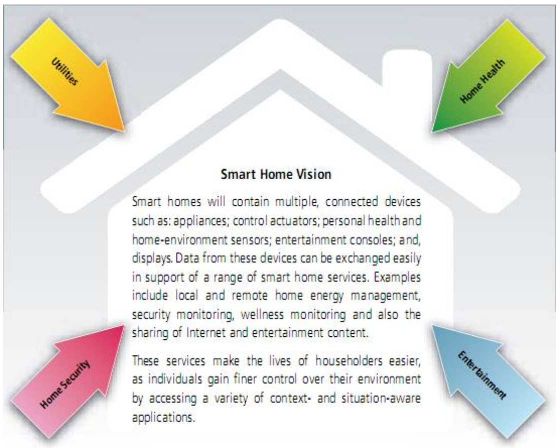

Fig. 2. Smart home vision according to [10].

possible smart realizations (Fig. 3).

Environmental sensing for monitoring of inhabitants. Simple binary sensors deployed throughout the home, video cameras, microphones and RFID technology were used for direct environmental sensing.

Binary sensor detect the state of an object or movement with a single digit '1' or '0'. Various types of binary sensors have been inserted in the project of the smart home, including motion detector, pressure sensor and contact switches. Since the building located in Świdnica will have a demonstrative role, various strategy for detection of the same quantities/activities is acceptable in the project. Thus, in the ground floor space, the binary pressure detection units were installed throughout the floor to track residents and detects furniture positions. On the other hand, a section of passive-infrared motion sensors spaced throughout the first floor of the smart house was proposed to locate the occupant at key areas. Duplication of the technical solutions for similar task will bring to at least two advantages. Firstly, various alternative technology will be tested, which enhance the knowledge and experience of installers and specialists involved in sensing technology and experimental data processing. Secondly, This demonstration will indicate the optimal (cheap and reliable) solution for described task.

Contact switches will be installed on the doors in a smart home, such as the front door and doors of cabinets and appliances to provide information on the specific interaction that the occupant performs with objects and appliances.

Various types of video cameras were used in the project to localize the occupant, monitor his/her behaviour/posture or critical events, and to reconstruct some physiological parameters. For example, a system comprising the video camera and accelerometer will be tested for the task of fall detection. Typically, using the video recording for object monitoring needs a lot of space on a hard drive and efficient signal processing procedures. On the other hand, information acquired from accelerometer signal can be insufficient to unambiguously conclude about occurrence of the critical event. Thus, we are going to verify the various working configuration of the system video camera-accelerometer. Initially, the cameras will be triggered when a fall will be detected based upon the accelerometer signal. Then, the real-time image processing will be used to analyse the data and estimate the occupant's posture. Further, infrared cameras and microphones will monitor the

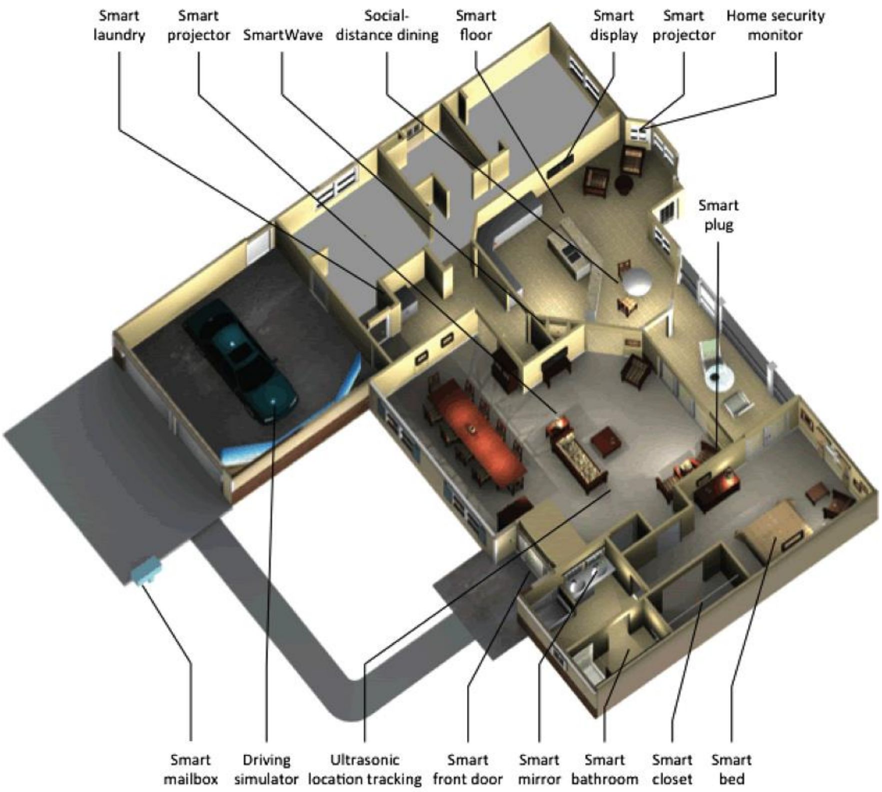

Fig. 3. The exemplary arrangement of spaces in the smart house – the Gator Tech Smart House [12].

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respiration parameters during the sleep. It was shown that recording of thermal infrared camera provide sufficient output to reconstruct respiratory rhythm and the profile of airflow at the mouth [13]. During analysis, this signal will be coupled with the information obtained from microphone, which can bring to the information on wheezing episodes. In this way, a telemedical service of the nocturnal critical events in breath will be realized. Audio signals captured in the smart home can support (improve accuracy) recognition of different types of events, e.g. fall of inhabitant, house-breaking, etc. Similarly, alternative attempt(-s) will be tested in the smart home for monitoring of the same process, e.g. a sensory mat. As was shown in [14], a pneumatic strip installed under the bed linens can detect presence, respiration (normal/abnormal), pulse (low, normal, or high) and movement in the bed, and reported forum levels of bed restlessness to remote caregivers. We will also test a practical sense of using the miniature omnidirectional microphones placed near the sink to detect and classify major activities occurring within a bathroom. The goal of this monitoring action will be to obtain an automatically generated report on custom personal hygiene behaviour, which can be informative for caregivers/inhabitants and personal medical doctor.

From a technological point of view, one of the goal of the project is to assess the advantages of RFID sensors in monitoring of everyday habituation of the occupants. RFID is a technology that uses communication via radio waves to exchange data between a reader and electronic tag. As regards the sensing technology, interesting for the project realization team will be to verify the reliability and stability of observations provided with the RFID sensors. On the other hand, very perspective for smart home application seems to be the batteryless mode of working of sensor tags. In initial stage of the project devoted to energy-efficient smart home, the RFID temperature sensors and accelerometers will be tested.

Usefulness of other mobile devices, e.g. the telemedical system for monitoring respiration mechanics with the use of interrupter technique [15], textronic shirt [16], integrated with the infrastructure of smart building will be assessed during realization of the project.

Communication protocols. As regards new buildings, communication between the devices in the smart home are realized rather in the wireless mode. This attempt enables to avoid the installation of the cable network. On the other hand, wireless communication can be unreliable when the distance between the transmitter and receiver is too long and/or when the radio signal meets the barrier in its pathway which significantly attenuates the propagation conditions. The last case (with deterioration in propagation conditions of the radio signal within the building) is especially important when the smart network realizes the action of directly meaning for the health and/or life of the inhabitants. Thus, the other requirements are established in international norms for the reliability of communication in the technical and medical systems. The problem is even more true in the big buildings, with several floors, large number of rooms, each equipped with hundreds or thousands of peripheral devices/sensors, e.g. hospitals, centre for eldercare. The everyday practice of the team of the Center for Energetic Technology in Świdnica has shown that the problem with wireless communication can be also vivid when there is an order for automatic control and monitoring system made by the administrator of museums, castles, etc., where problematic is not only a large number of rooms, but also a large dimensions of wall barrier in the radio signal pathway. In connection with the above mentioned problems, we decided to test in the research-demonstrative energy-efficient smart house the redundant system of communication, with various possible modes of work i.e. wireless, wired (Ethernet), and hybrid wired/wirelss with communication realized in standard line of ~230 V. Technically this communication protocols will be realized in building according to EIB/KNX standard. The last case with hybrid mode can be especially efficient in old buildings, where there is a large number of rooms, long distance with wall barriers for propagation of radio signal, and no permission for changes in the building construction given by the conservator (no permission for installation of Ethernet network).

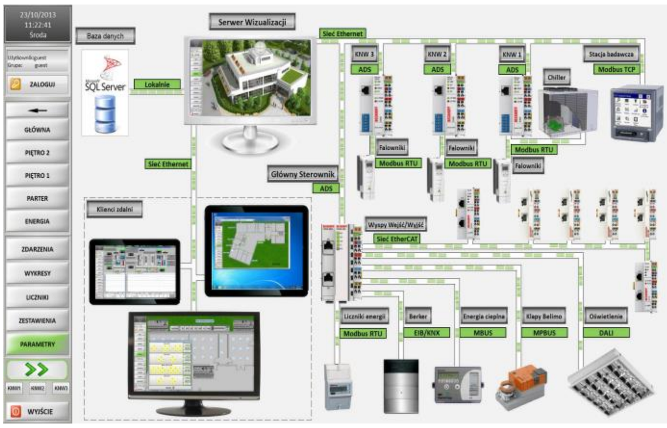
Finally, the signal communication infrastructure installed in the energy-efficient smart house will be tested from the point of view of the limit number of peripheral devices/sensors handled in each of the mode of the communication protocol and also the ability to structural self-organization [17].

Empirical data processing. Energy-efficient smart home is a proper object to observe the rules inherent for the complex systems. From a technical point of view, the main difficulty is an entanglement of processes of various nature flowing in a communication channel, i.e. deterministic, (quasi-)periodic, chaotic, stochastic, stationary, non-stationary, etc. Thus, the main challenge is to create and test the new algorithms of experimental data processing. Project organized in CTE in Świdnica assumes the research work in this domain, but exploration of existing tools is also valid in this case.

Application of the methods of artificial intelligence, e.g. artificial neural network, fuzzy logic, genetic algorithms, agent-based techniques, etc. has been provided by other research-development teams working in a field of control and monitoring of infrastructure in the smart home (e.g. [18, 19]). All these experience will be considered during research on energy-efficient smart house. What is more, recurrent plots attempt, power law rule, entropy measures, and a bench of original algorithmic tools associated with complexity measurements will be tested [20-23].

The output of the work in this domain will be the guidelines for control and monitoring of energy-efficient smart house, but the conclusions will concern also the generalized complex system and data fusion.

Building management system. Building management system (BMS) is the hardware-software level of the smart home which is responsible for monitoring the processes occurred within the building infrastructure and control the installed devices in order to create better living environments, including also the issues of an optimized usage of energy resources, cost-effectiveness, environmental a)



b)

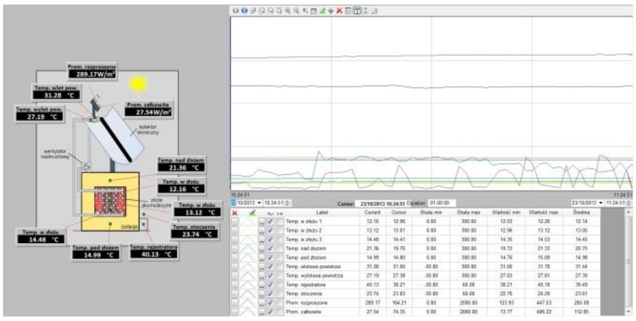


Fig. 4. a) General scheme of the control system designed for CTE's office building and the e-service of BMS application, b) Control and monitoring of parabolic collector performance.

and social sustainability [6]. Building energy management system (BEMS) is an important layer in the BMS, especially in the context of the optimization of energy efficiency of the research-development smart house designed by CTE's team.

Apart from the implementation of the modern and original procedures devoted for data exploration and system control (described in section C), the project team will meet the directions enumerated in [24]. Technologically it means the migration of the building managements tasks to the cloud computing. In a sense of security of personal data (including the details of medical tests) this attempt triggers the new challenges for algorithms of data protection. Other domain in the range of BMS is to propose the user-friendly interface and language of communication between the occupant and the machine. Thus, apart from the typical access solutions applied in BMES, i.e. manual centralized (realized with the personal computer) and/or distributed (where the mobile devices like smartphones, touch-pads, etc. are used) access, the verbal mode of communication, including context interpreter, is assumed in the energy-efficient smart building designed by CTE in Świdnica. But, regarding the various users of the system, i.e. inhabitants, medical doctor or worker of healthcare centre, technical service agent, etc., the authorization principle will be introduced. Graphical mode, including system elements and performance reports, will be inserted in the BMS work, similarly like in the CTE's research-demonstrative office building (see exemplary Fig.4).

4. HOME-BASED TELEMEDICAL SOLUTIONS & HEALTH IMPACT

One of the main goals of the project will be to embed the medical devices in the infrastructure of smart building. Telemedical solutions will be preferred working as an integral part of building management system. Since the monitoring of the smart building inhabited by young and old people is assumed for several years, advantageous for the project is to provide an 'open' telemedical system, i.e. the system which can be supplemented by new technical solutions working remotely for medical tasks and enclosed to the infrastructure in the consecutive phases of project duration. Both diagnostic and therapeutic devices (e.g. the system for supporting the elderly in their ambient conditions [25]) will be tested in order to assess their effectiveness, to provide an original measures of comfort and to report on influence of smart building on change of quality of human life. Exemplary general organization aimed to implementation in the project was shown in Fig. 5. First premises from other pilot studies have shown a positive impact of the telemedical infrastructure on health and everyday welfare [27],[28]. The other issue of the project will be to overcome the social fear of new medical technologies/services – as was shown, e.g. in [29],[30], this social prejudice importantly limits the growth of telemedical market and finally limits the progression in health improvement throughout the societies.

5. CONCLUSIONS

The paper introduces to the project prepared by the team

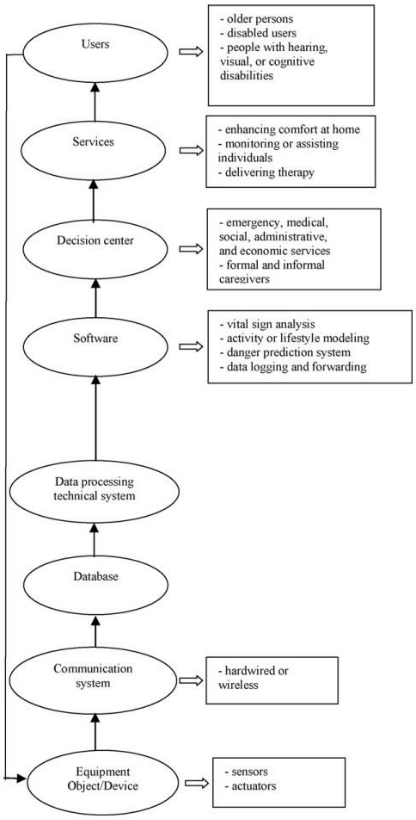


Fig. 5. General organization of smart telemedical system [26].

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of Centre for Energetic Technology in Świdnica and devoted to energy-efficient smart building. The range of possible technical solutions which will be applied in the research-development-demonstrative building has been reviewed, including energy efficiency, operation in a smart technical scheme in aid of environmental and social sustainability, sensing technology, communication protocols, signal processing, building management systems, telemedical systems. We have not reported here on the location of parcel, architectural conceptions, details of building technologies, environmental engineering solutions applied in the project, etc. Regarding the large scale of the project, the goal of the project team is to discuss with the conference participants the main directions described in the paper for designed building before its practical realization. We are also open for any initiatives of co-operation in a range of energy-efficient smart building, both during its designing and long-term exploitation. This exploitation will consist in long-term monitoring of building infrastructure and chosen occupants living in the smart home, optimizing the building performance and reporting the results to the scientific journals of technical, medical and social scopes. Especially advantageous results during the realization of the project will apply to the monitoring of various aspects of telemedicine. There is still lack of multi-criteria and long-term reports on the exploitation of the telemedical systems embedded in the ambient environment of smart building and their impact to inhabitants health.

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