Improved Occupancy-Based Solutions for Energy Saving in Buildings

Ioan Susnea, Emilia Pecheanu, Adina Cocu
Department of Computer and Information Technology
University "Dunarea de Jos" of Galati
Galati, Romania
isusnea@ugal.ro;emilia.pecheanu@ugal.ro;acocu@ugal.ro

Goran Hudec
Faculty of Textile Technology
University of Zagreb
Zagreb, Croatia
goran.hudec@ttf.hr

Abstract — **In the past decades, despite the huge interest for the topics related to energy conservation and reducing the CO2 emissions, it became obvious that there is an economic reason for the weak progress in these fields: the visible correlation between the economic growth and the energy consumption. As a result, it is very likely that the demand for energy will continue to grow. Since buildings are responsible for 40% of the total energy demand, in this paper we review the vast literature dedicated to energy saving in buildings from the perspective of the feasibility on a large scale. We emphasize the solutions based on detecting and forecasting the building occupancy in order to control the HVAC and lighting systems for energy saving without affecting the comfort of the users. Several improvements of these solutions are proposed.**

Keywords — energy conservation; buildings; occupancy detection; occupancy forecasting.

I. Introduction

Buildings – both residential and commercial -are responsible for 40% of the global energy demand and the associated CO2 emissions, ([1], [2], see also figure 1), 15% higher than 10 years ago, and this trend is likely to continue in the near future in proportion with the urbanization. Every year, 5 billions square meters of new buildings are constructed, 2 billions of them in China only ([3]).

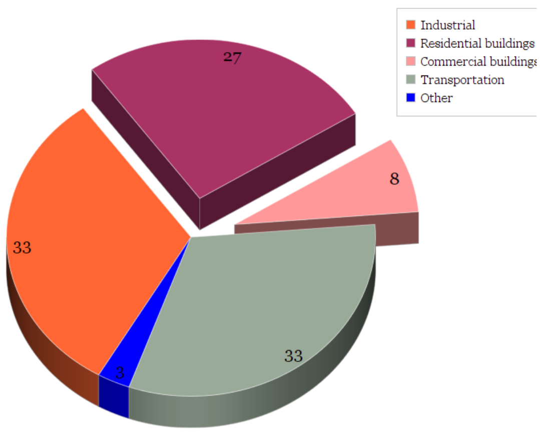

Fig. 1. Sectorial structure of the global energy consumption (data source [1])

With the alarming signs of climate changes, it is pretty clear that this pace is unsustainable on a long-term basis, and this explains the huge interest of the scientific community in finding solutions for this problem A simple search on Google Academics with the key "buildings" and "energy" returns 2.5 millions results. A similar search on the Web of Science returns around 100,000 results. There is also a wealth of patent applications on this topic available in the international patent databases.

Despite the multitude of solutions for energy conservation described in the literature, the energy consumption and the CO2 emissions continue to grow (and expected to double by 2050, according to [1]).

An explanation for this apparent paradox can be found in [4], where it is argued that: there is a significant positive corellation between the economic growth, and the CO2 emissions and energy consumption in all the 27 OECD countries. The chart in figure 2 shows that 4 countries (China, USA, Russia and India) are responsible for more than a half (52%) of the global CO2 emissions. This suggests that the reasons for the lack of efficiency of the campaign for energy conservation and GHG (GreenHouse Gas) emissions reduction are mainly non-technical.

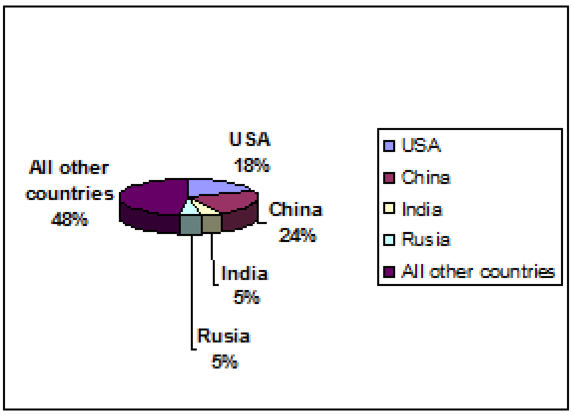

Fig. 2. Percentage contributions to the global emissions of CO2 by country . Four countries are responsible for more than half of the global CO2 emissions (data source [1])

There are, however, technical reasons too for this situation. For example, Lu et al. in [5] have found that the use of

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programmable thermostats *lead to higher energy consumption,* most likely because the users program them incorrectly or completely disable them.

Other drawbacks of the advanced control systems for the energy management in buildings are accounted in [6] and [7]. Among these, the most important are:

- Many solutions need a model of the building, and local parameter tuning. This makes them difficult to reproduce on a larger scale, e.g. for residential buildings;
- Some need to make real-time parameter estimation, which makes them vulnerable to noise;
- Complex systems tend to be less user-friendly;
- Some of the existing solutions use video cameras and microphones as input devices, which are perceived as intrusive.

Finally, one of the most important drawbacks of many existing solutions is that they neglect the users' comfort.

In this paper, we focus on the user-centered energy conservation systems for buildings, in an attempt to identify the most "realistic" solutions from the perspective of a possible large scale application. After defining the key features of such a system, based on the existing literature, we suggest several possible improvements.

II. BRIEF REVIEW OF THE STATE OF THE ART

According to [8], 75% of the energy consumption in buildings is residential. The structure of the energy consumption in this sector is shown in figure 3.

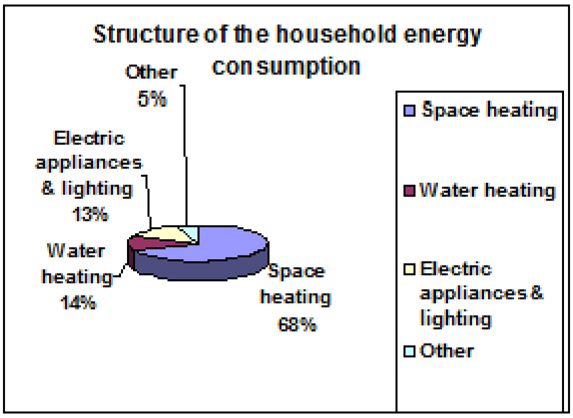

Fig. 3. Structure of the energy consumption in an average European residential building (data source [7])

Nguyen & Aiello ([6]) argue that up to 40% of this energy can be saved using appropriate technical solutions for controlling the HVAC and lighting systems.

Though these relative proportions of the possible savings are impressive, at the level of the individual homeowners, the economic motivation to invest in sophisticated energy conservation systems is very weak. According to [5], a reduction of 20%-30% of the energy used by HVAC would result in a reduction of the energy bill of just about 15 USD/month, for an average US household, which – obviously – is not a real incentive.

This detail gives a hint about the first and most important feature of an ideal energy saving system for residential buildings: in order to be effective, such a system should be easily applicable at *a very large scale*. Small scale solutions simply don't count.

To this purpose, *besides the low cost*, such a system should be:

- Not just user friendly, but totally "transparent" for the user, if possible, i.e. incorporated as a new feature in existing devices and appliances (e.g. in "smart" PIR motion detectors or security panels, or smart HVAC systems). Any system requiring complex programming or operation is likely to be incorrectly programmed or completely disabled shortly after the installation.
- Easily adaptable to (almost) any household.
- Scalable. The system should be able to accommodate with adding new sensors, and/or new users.
- Non-intrusive. Systems relying on video cameras, microphones or wearable sensors (e.g. RFID badges) are likely to be rejected as intrusive.
- Finally, the energy saving system should not affect the comfort of the users. Features that sensibly reduce the comfort of the users are likely to be permanently disabled. Obviously, this requirements links the control system of the HVAC with the presence/activity of the inhabitants of the building.

With these requirements in mind, we performed a literature review, starting from a selection of recent and comprehensive surveys on the research regarding the energy efficiency solutions based on user activity, and/or building occupancy ([6],[7],[9-19]).

We derived a general structure of the control systems as shown in figure 4.

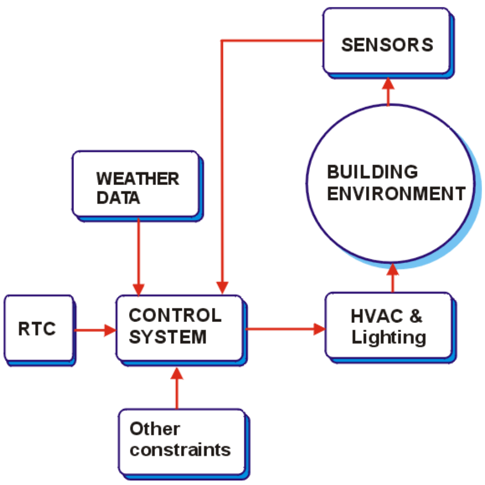

Fig. 4. General model of the building energy management system

According to this model, the building environment, including its human inhabitants, is monitored by means of a variety of sensors, connected to the HVAC control unit, preferably using the WSN (Wireless Sensor Network), or IoT (Internet of Things) technologies (see figure 5).

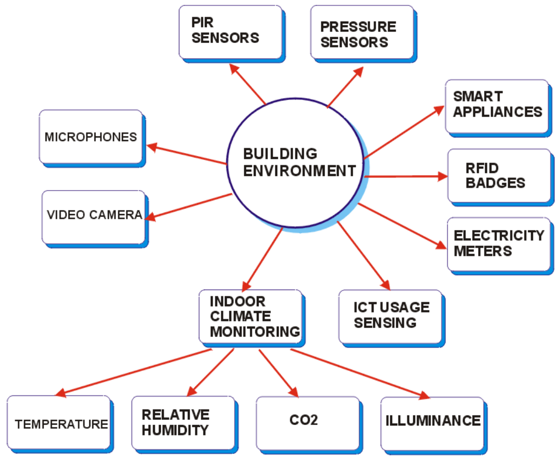

Fig. 5. Typical sensors used in energy management systems

In what concerns the control strategies for the HVAC, the simplest solution is to turn the HVAC ON and OFF at predefined times of the day, according to a predefined schedule that assumes a certain work program of the inhabitants of the building. It is also assumed that the users are present in the premises in accordance with this work program, which obviously is not always true. Another complication comes from the fact that most buildings have more than one inhabitant, with more than one work program. This is the "classic" smart thermostat, which needs only a temperature sensor and a real-time clock (RTC).

A large number of solutions attempt to improve this design by including additional sensors in order to *detect* or *predict* the actual occupancy of the building and control the HVAC accordingly (see and example of improved smart thermostat in [5]).

A definition of "occupancy" is offered in [20]: "A house is said to be occupied at a time instant t if at least one of its residents is at home; otherwise, it is said to be unoccupied. The occupancy state of a house can thus be represented as a binary value (1 for occupied and 0 for unoccupied)."

An illustration of the elementary occupancy-based control strategy is shown in figure 6.

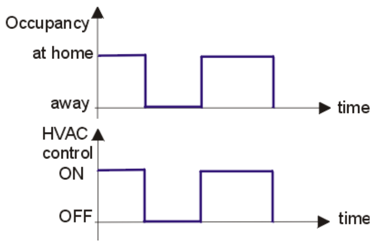

Fig. 6. The simplest occupancy based control strategy for HVAC

Considering the fact that heating and cooling of a building are relatively slow processes, a better strategy from the perspective of the users' comfort is to *predict* the occupancy levels of the building, and to turn the HVAC ON at a certain moment (Tp-preheat time) before the users actually arrive home (see figure 7). Similarly, the HVAC can be turned OFF some time (Tc – cooling time) before the users leave the building. This allows saving additional energy without affecting the users' comfort.

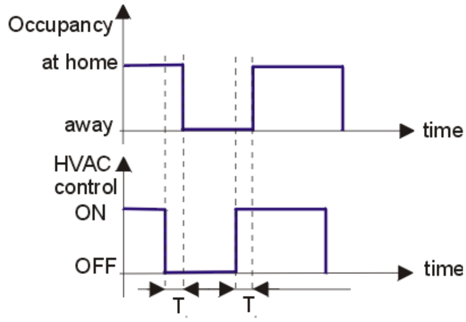

Fig. 7. Using predicted occupancy to control the HVAC system

The prediction accuracy is defined in [20] as follows:

$$PA = \frac{tp + tn}{tp + tn + fp + fn} \qquad (1)$$

Where tn is the number of time slots with true negative predictions, tp is the number of time slots with true positive predictions, fn the number of time slots with false negative predictions, and fp the number of time slots with false positive and.

There are, literally, thousands of HVAC control systems described in the literature that follow the design principles presented in this paragraph.

Many use PIR motion detectors plus door mounted reed relays as input devices for occupancy detection ([5], [21]). Other (like in [22]) use RFID tags to detect the presence of the users in the proximity of a number of readers deployed throughout the building. Data collection is performed using IoT ([23]) or WSN ([24]).

Other solutions rely on monitoring the use of certain ICT devices (computers, network equipment, WiFi) to extract occupancy information ([25]).

Finally, some solutions add weather forecasting data (obtained, for example, by accessing certain dedicated web pages) to improve the overall performance of the entire control system ([26]).

In what concerns the processing of the sensor data and the actual control algorithms, a comprehensive survey is available in [7]. It is worth to emphasize the solutions based on artificial neural networks ([15]), hidden Markov models - HMM ([5],[11]), and fuzzy logic ([6],[7]).

Given this wealth of innovative solutions, one may legitimately ask whether it is still possible to propose any new, or improved solution.

In the next section, we argue that this question can be answered affirmatively.

III. POSSIBLE IMPROVEMENTS OF THE EXISTING SOLUTIONS

In the patent application [27] (also described in [28]), we proposed a solution wherein, rather than turning the HVAC ON and OFF, we generate variable reference values for the thermostat using an artificial neural network - ANN (see figure 8).

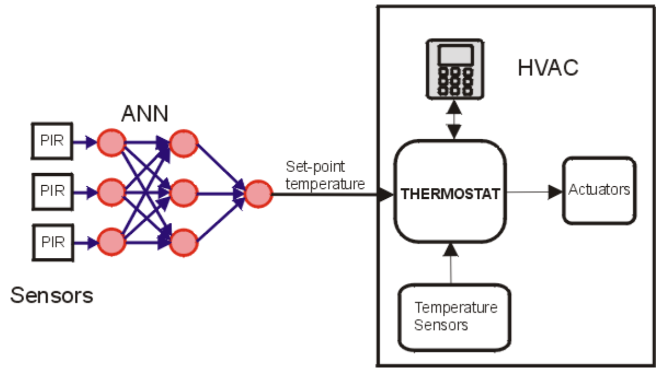

Fig. 8. A thermostat having ANN generated set-point temperatures

Unlike other similar solutions that use ANNs to process the sensor data, in this implementation we used a distributed ANN, created according to the principles described in [29]. The core idea of this solution is that the functions of the input and hidden layer neurons are assigned to low cost microcontrollers located in the nodes of a communication network (see figure 9). In practice, these "detachable neurons" can be located inside some "intelligent PIR sensors".

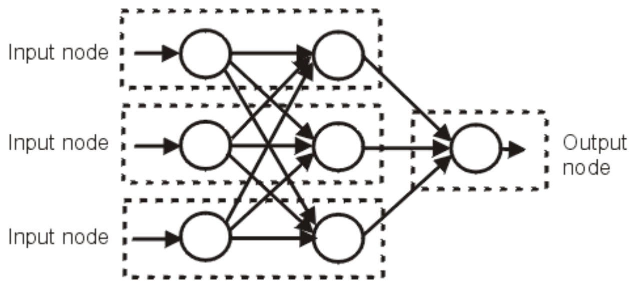

Fig. 9. The task allocation for the neurons of the distributed ANN

Another novelty of this solution resides in the definition of the occupancy. Instead of considering occupancy as a binary variable as proposed in [20], we deal with the concept of a "degree of occupancy", which can take continuous values in the interval [0,1].

A model of how to estimate the values of this parameter starting from PIR sensors data is shown in figure 10. Basically, it's a (software implemented) dual slope integrator: any time a PIR detects motion, its output contact connects a current generator *Ic* to the capacitor, which starts charging and increases the "belief" about the occupancy of the premises. In the time intervals when all the sensors are inactive, the capacitor discharges with a slower slope, controlled by a distinct current generator *Id*. This simple scheme allows the fusion of the sensor data with unlimited scalability.

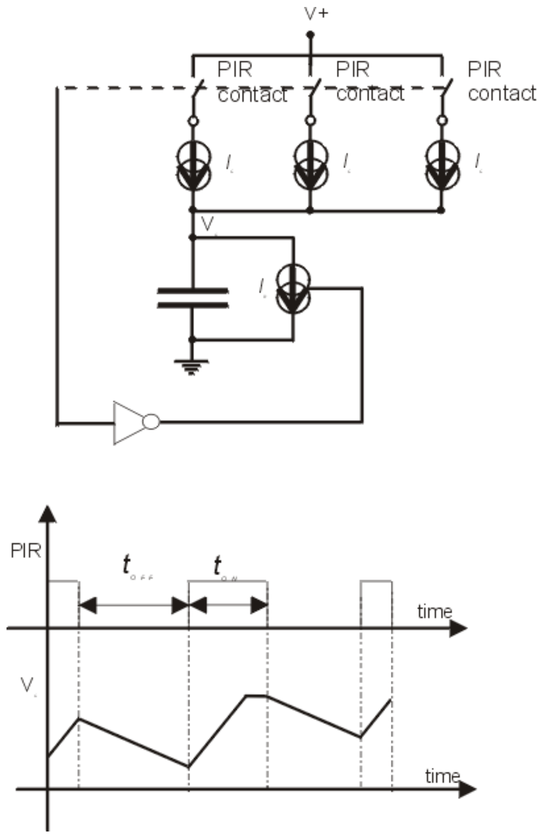

Fig. 10. The principle of estimating the degree of occupancy starting from PIR sensors data

In what concerns the prediction of the future occupancy degrees, the ANN can be trained to directly learn the future values of the set-point temperatures starting from the current values of the occupancy. In this case the training data set can be created by means of a set of rules like this: "If the occupancy is LOW, and the current time is MORNING, then the reference value for the thermostat must be LOW".

In an alternative approach, the distributed ANN operates as universal estimator, but the microcontrollers that implement the neurons of the input layer predict the future occupancy starting from a locally recorded time series with the previous states of the attached PIR sensors.

A final note: the entire concept described in this section can be easily implemented as an additional feature of the "standard" security panels present in most residential buildings. Another advantage is that the proposed solution is totally transparent for the users.

In fact, the proposed solution matches all the features listed in section II for an ideal building energy saving system: it is cheap, non-intrusive, scalable, transparent for the user, can be integrated in existing devices, and does not affect the users' comfort.

IV. CONCLUSIONS AND FUTURE WORK

This paper is aimed to offer a bird's eye view on the state of the art of the systems for energy conservation in buildings. While the majority of commercial and office buildings are new, and use modern isolation technologies and expensive Building Management Systems (BMS) that minimize the energy losses, the residential sector is still in need of solutions applicable at a large scale capable to produce significant energy savings.

The improvements proposed in this paper may be the starting point for new designs of security panels with increased functionality.

Further research is needed for a precise estimation of the energy savings generated this way.

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REFERENCES

[1] P. Nejat, F. Jomehzadeh, M. M. Taheri, M. Gohari, & M.Z.A. Majid, 2015, A global review of energy consumption, CO 2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries). Renewable and sustainable energy reviews, 43, 843-862.

[2] A. Allouhi, Y. El Fouih, T. Kousksou, A. Jamil, Y. Zeraouli, & Y. Mourad, 2015, Energy consumption and efficiency in buildings: current status and future trends. Journal of Cleaner production, 109, 118-130.

[3] J. Laustsen, 2008. Energy efficiency requirements in building codes, energy efficiency policies for new buildings. International Energy Agency (IEA), 2(8), 477-488.

[4] B. Saboori, M. Sapri, & M. bin Baba 2014, Economic growth, energy consumption and CO 2 emissions in OECD (Organization for Economic Co-operation and Development)'s transport sector: a fully modified bi-directional relationship approach. *Energy*, *66*, 150-161.

[5] J. Lu, T. Sookoor, V. Srinivasan, G. Gao, B. Holben, J. Stankovic, & K. Whitehouse, 2010, The smart thermostat: using occupancy sensors to save energy in homes. In Proceedings of the 8th ACM Conference on Embedded Networked Sensor Systems (pp. 211-224). ACM.

[6] T.A. Nguyen, & M. Aiello, 2013. Energy intelligent buildings based on user activity: A survey. Energy and buildings, 56, 244-257.

[7] A.I. Dounis, & C. Caraiscos, 2009. Advanced control systems engineering for energy and comfort management in a building environment—A review. *Renewable and Sustainable Energy Reviews*, *13*(6), 1246-1261.

[8] IEA International Energy Agency 2013, World Energy Outlook 2013.

[9] X. Guo, D. K. Tiller, , G. P. Henze, & C. E. Waters, 2010. The performance of occupancy-based lighting control systems: A review. *Lighting Research & Technology*, *42*(4), 415-431.

[10] F. Oldewurtel, D. Sturzenegger, & M. Morari, 2013. Importance of occupancy information for building climate control. *Applied energy*, *101*, 521-532.

[11] V.L. Erickson, M.A. Carreira-Perpiñán, & A.E. Cerpa 2014. Occupancy modeling and prediction for building energy management. *ACM Transactions on Sensor Networks (TOSN)*, *10*(3), 42.

[12] B. Chenari, J.D. Carrilho & M. G. da Silva, 2016. Towards sustainable, energy-efficient and healthy ventilation strategies in buildings: a review. *Renewable and Sustainable Energy Reviews*, *59*, 1426-1447

[13] D. Chen, S. Barker, A. Subbaswamy, D. Irwin & P. Shenoy, 2013. Non-intrusive occupancy monitoring using smart meters. In *Proceedings of the 5th ACM Workshop on Embedded Systems For Energy-Efficient Buildings* (pp. 1-8). ACM.

[14] K.J. Chua, S. K. Chou, W.M. Yang, & J. Yan, 2013. Achieving better energy-efficient air conditioning – a review of technologies and strategies. *Applied Energy*, *104*, 87-104.

[15] R. Kumar, R.K. Aggarwal & J.D. Sharma, 2013. Energy analysis of a building using artificial neural network: A review. *Energy and Buildings*, *65*, 352-358.

[16] T. Hong,, S.C. Taylor-Lange, S. D'Oca, D. Yan & S.P. Corgnati ,2016. Advances in research and applications of energy-related occupant behavior in buildings. *Energy and Buildings*, *116*, 694-702.

[17] V. S. K. Harish, & A. Kumar 2016. A review on modeling and simulation of building energy systems. *Renewable and Sustainable Energy Reviews*, *56*, 1272-1292.

[18] M.F. Haniff, H. Selamat, R. Yusof,, S. Buyamin & F.S. Ismail 2013. Review of HVAC scheduling techniques for buildings towards energy-efficient and cost-effective operations. *Renewable and Sustainable Energy Reviews*, *27*, 94-103.

[19] D. Lee & C. C. Cheng, 2016. Energy savings by energy management systems: A review. *Renewable and Sustainable Energy Reviews*, *56*, 760-777.

[20] W. Kleiminger, F. Mattern,& S. Santini, 2014. Predicting household occupancy for smart heating control: A comparative performance analysis of state-of-the-art approaches. *Energy and Buildings*, *85*, 493-505.

[21] Y. Agarwal, B. Balaji, R. Gupta, J. Lyles, M. Wei & T. Weng, 2010 Occupancy-driven energy management for smart building automation. In *Proceedings of the 2nd ACM workshop on embedded sensing systems for energy-efficiency in building* (pp. 1-6). ACM.

[22] N. Li, G. Calis & B. Becerik-Gerber, 2012. Measuring and monitoring occupancy with an RFID based system for demand-driven HVAC operations. *Automation in construction*, *24*, 89-99.

[23] K. Akkaya, I. Guvenc, R. Aygun, N. Pala & A. Kadri, 2015. IoT-based occupancy monitoring techniques for energy-efficient smart buildings. In *Wireless Communications and Networking Conference Workshops (WCNCW), 2015 IEEE* (pp. 58-63). IEEE.

[24] Y. Tachwali, H. Refai & J.E. Fagan, 2007. Minimizing HVAC energy consumption using a wireless sensor network. In *Industrial Electronics Society, 2007. IECON 2007. 33rd Annual Conference of the IEEE* (pp. 439-444). IEEE.

[25] M. Milenkovic., & O. Amft 2013. Recognizing energy-related activities using sensors commonly installed in office buildings. Procedia Computer Science, 19, 669-677.

[26] D. Yan, W. et al. 2015. Occupant behavior modeling for building performance simulation: Current state and future challenges. Energy and Buildings, 107, 264-278.

[27] I. Susnea, G. Vasiliu, 2013. Temperature control system for buildings, Patent application RO128439-A2

[28] G. Vasiliu, 2016.A decentralized approach for energy management in buildings, The Annals of the University "Dunarea de Jos" of Galati, Fascicle III, Vol 39(1).

[29] I. Susnea, 2012. Distributed Neural Networks Microcontroller Implementation and Applications. *Studies in Informatics and Control*, *21*(2), 166.