INNOVATIVE IMPLEMENTATION OF FUZZY LOGIC IN PASSIVE HOUSES

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Energy efficiency, user comfort and remote access play an important role for future owners. Thermal comfort perception depends on many aspects. Fuzzy logic is the key on creating an algorithm that can fit the owner preferences. Based on a decision-function policy using fuzzy logic algorithm we can adjust the desired temperature in the house, depending on user comfort.

Current paper presents an experimental case study that was implemented in the passive house of UPB during the last month using fuzzy logic algorithm. The experimental results showed that the optimum temperature was maintained in the house with minimum energy losses.

Keywords: fuzzy logic, passive house, thermal comfort, smart system

1. Introduction

Fuzzy-logic is a concept that has begun to be exploited in the technology area since the results are precise and working under strict limits. In 1965, Lotfi A. Zadeh [1, 2] introduced the fuzzy-logic term as being the future of the applied technology, covering a wide area from control theory to artificial intelligence. In Sendai, Japan, in 1987 the first fuzzy-logic controlled subway was hitting the railway. The project goal was to make the subway journey more comfortable with smooth braking system and acceleration [3].

The fuzzy-logic model does not refer to a specific area and can be applied to different domains including user comfort insurance and energy consumption. The advantage of using fuzzy-logic technology handles the concept of truth-value, and can vary between completely true and completely false. Fuzzy logic models, applied in energy systems have a wide range of complexity due to high number of input parameters.

In order to reduce the amount of energy required for heating or cooling a building, energy efficiency strategies are required. Modeling heating and cooling loads with artificial intelligence can lead to better prediction accuracy and a better analysis over the efficiency of the building [4].

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Four main factors are playing a vital role in the energy consumption of a building: 1) physical properties including location, orientation, type; 2) equipment installed to maintain the desired internal environment such as heating ventilation or hot water; 3) Outdoor environment and the meteorological factors such as temperature, humidity, solar radiation; 4) behavior of its occupants and associated implications of their presence [5].

Artificial intelligence (AI) refers to every system that acts intelligently. Nowadays, the implementation of the AI covers many specialized areas from music, games, and cloud services to building's energy efficiency. The advantages of AI are: less errors and defects, a more accurate output, faster response time and function without stopping. The implementation of an AI system in a building can rely on solving problems regarding energy consumption.

In this paper, an Artificial Neural Networks (ANNs) model is used to simulate the energy consumption of an experimental case study in a passive house in UPB. These procedures are composed by statistical, engineering and artificial intelligence methods. The prediction and the simulation of the interior comfort temperature were made depending on the user needs. The temperature limit of the fuzzy-logic algorithm was set up depending on their own comfort.

Next section focuses on the fuzzy-logic algorithm and laboratory description while the section 3 briefs the summer regime and SBC (Smart Building Controller) for Passive House. Chapter 4 presents measurements and discussions about the achieved interior comfort. Lastly, chapter 5 concludes the paper.

2. Laboratory and system description

The Passive House from University of Bucharest is split in two identical buildings measuring 140 square meters treated area (0).

Fig. 1. Passive House, University Polytechnics of Bucharest

According to Passive House Institute standards from Darmstadt, Germany, a house can be certified as a low energy building, if it meets the following criteria [6]:

- Specific space heating demand lower than 15 kWh/m^2yr of net living space;
- Primary energy demand lower than 120 kWh/m^2yr for all domestic applications (heating, cooling, hot water, and electric appliances);
- Air exchange between the interior and the exterior of the building should not exceed 0.6 h-1 at a difference of 50 Pa;
- Thermal Comfort must meet the requirements for all living areas during winter and summer, with a maximum of 25 °C;

The properties of individual components of the house vary depending on the climate and should be optimized to the local conditions [**Error! Bookmark not defined.**]. The main goal of the Passive House is to reduce energy consumption through a highly-insulated building. A part of the energy consumed for operating the house is provided with a photovoltaic panel system connected to the grid, thus avoiding the need for energy storage system. The total nominal power of the PV panels is 2.9 kW.

The materials used for the envelope and the windows of the Laboratory House have high thermal performances. The U-values for the opaque elements (roof, exterior walls, and ground floor) are lower than 0.15 W/m^2/K. The exterior triple-glazing windows have a U-value of 0.6 W/m2/K and total solar absorbance coefficient (G-value) of 50% [7], complying with the recommended values stated in Passive House Standard. The house was built and optimized for Romanian cold climate [8].

The East part of the house is equipped with an Earth to Air Heat Exchanger (EAHX), buried 2 meters in the ground, with a pipeline that measures 38 meters. The EAHX is combined with a Mechanical Ventilation system and a Heat Recovery unit (MVHR) having an efficiency higher than 90% as shown in 0 [9, 10].

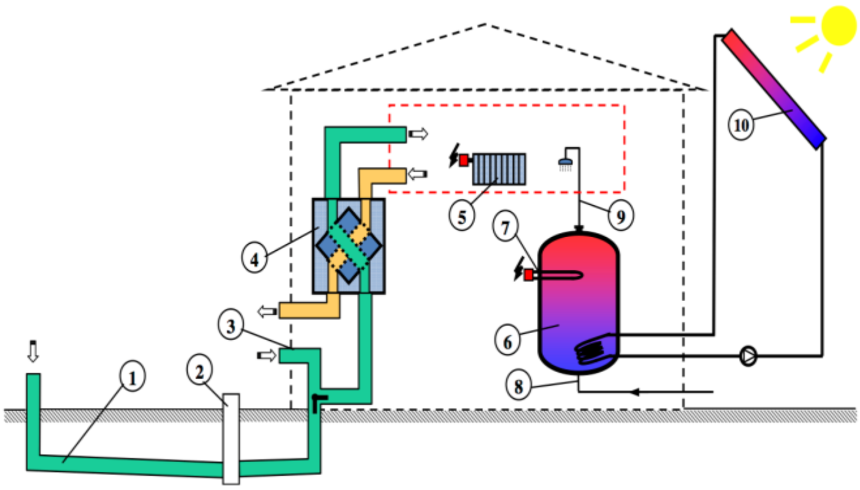

Fig. 2. HVAC system with EAHX [**Error! Bookmark not defined.**]:
1) EAHX; 2) condensate drain well; 3) EAHX by-pass; 4) mechanical ventilation heat recovery unit (MVHR); 5) electric radiant panel; 6) hot water tank; 7) electric resistance Heater; 8) cold water supply; 9) domestic hot water consumption; 10) thermal solar panel

The house is being monitored 24/7 with the help of sensors that provides information about the HVAC inputs (0). The data acquisition system collects through sensors, that are disposed in the house, different parameters such as inside and outside temperature, humidity, luminosity, air flow, interior CO_2, or energy consumption. There are five wireless sensors that measure the temperature, humidity, and luminosity and eight wired sensors that measure the airflow temperature from the HVAC. Our server is being monitored 24/7, and with the help of the software Smart Building Controller (SBC) we collect data as inputs for the model.

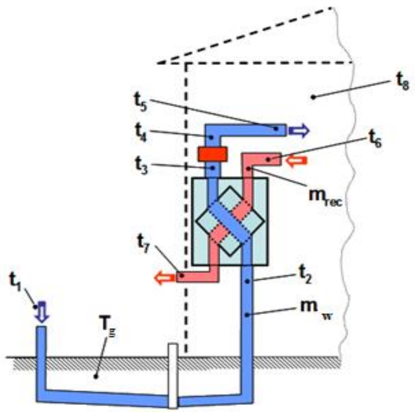

Fig. 3. HVAC sensors position [11]

This paper provides an analysis, using fuzzy-logic technology, of the interior comfort of a passive house regarding the energy consumption. Insulation thickness, heat capacity of the walls and passive energy saving measures are parameters that influence the interior comfort.

3. Possible implementation of fuzzy-logic and summer regime for Passive House

In the research the development and application of fuzzy logic technology has been common over the last two decades. In 1992, Yager and Zadeh put the basics of the fuzzy logic, by publishing an introduction book, affirming that the technology is characterized by a qualitative, subjective nature and linguistically values [12]. In other sectors, fuzzy logic has been applied successfully, covering from modeling cooling/heat loads, managerial decision-making [13], optimization of the performance in product organization [14] to supporting capital budgeting investment decision [15].

According to Lau, Cheng, Ho [16], fuzzy logic concept has been applied in many ways to energy consumption-reduction topics. On the other hand, fuzzy logic can also be used to model cooling loads or heating loads by having as inputs, different parameters.

Fuzzy logic is working as a criteria model which have the capability of taking a decision with minimal amount of information as inputs [17]. In the Eastern part of the Passive House UPB that is used as a laboratory, a model similar to fuzzy logic algorithm was implemented during warm season. The laboratory is equipped with a Smart Building Controller (SBC) that gives the opportunity to access a database, to edit policies and to control an electrical resistance for maintaining a good interior comfort level. Another service provided by the SBC is the email alert system, which gives feedback when something is not working properly. Using feedback can be predicted energy consumption and can be imposed limits of inside temperature. A web platform can be accessed from outside the house network to impose inside temperature changing the equipment's working schedule.

In order to reduce and optimize the energy consumption in a Heating Ventilation and Air Conditioning (HVAC) system, fuzzy logic algorithm can be used in combination with artificial intelligence [18]. There are scientists that already made several intelligent approaches that could reduce and optimize the energy consumption via HVAC system [19]. The algorithm that was used in the laboratory follows specific conditions and is working under IF-THEN-ELSE rules.

The temperature is the most significant factor in terms of interior comfort [20]. Achieving thermal comfort implies maintaining the body's internal temperature around 37°C. Temperatures that are recommended for an optimum productivity are situated between 20°C and 28°C [**Error! Bookmark not**

defined.]. The level of humidity influences the perception of the body on the temperature value. Humidity amplifies the sensation of coldness and warmth. The human body doesn't sense humidity level between 20% and 60% [**Error! Bookmark not defined.**]. However, if this threshold is exceeded, the feeling of discomfort appears and influences the perception of the temperature. One of the passive houses concepts is obtaining interior comfort with minimum energy consumption, ether in heating or cooling the interior of a building.

The outside average temperature during summer, in University "Politehnica" of Bucharest campus was 2.32°C and the summer average temperature was 24.64°C. Romanian climate is characterized by cold winters and hot summers. The average solar radiation over these three years was 1428.13 kWh/m^2.

In order to maintain a good level of comfort in the summer, it was implemented a policy that controls the ventilation flow rate in function of the exterior and of the ground temperature. The summer policy line code is presented in 0.

The summer policy has two rules that verify the exterior temperature once a minute, one for daytime and another one for nighttime. According to the exterior temperature the fuzzy-logic algorithm varies the flow rate in terms that when the outside temperature drops below 20°C, the rate flow increases up to 20% of the fans capacity and when is higher than this value, the rate flow decreases down to 7%.

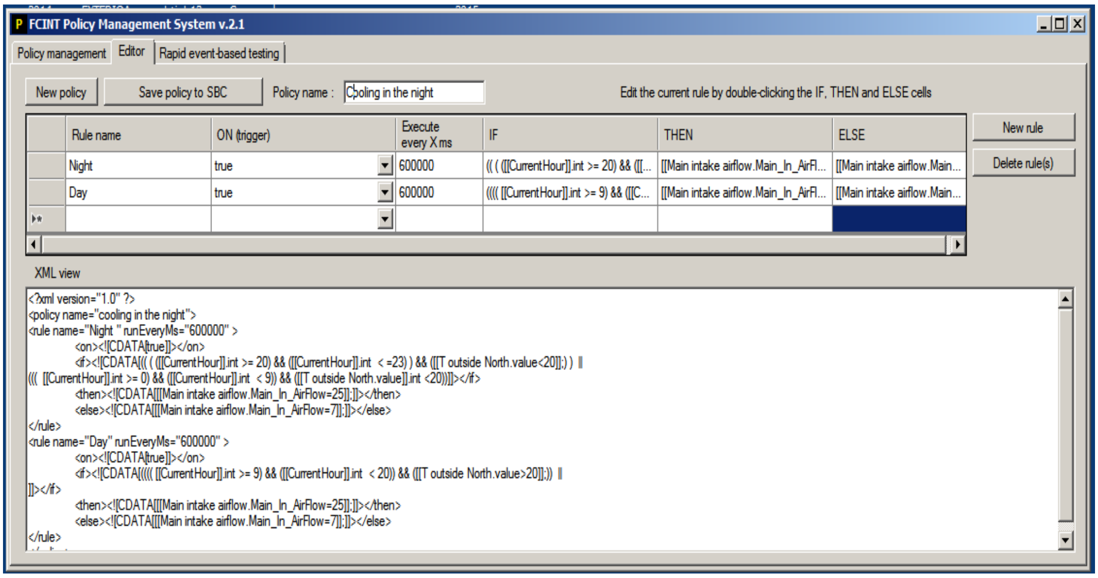

Fig. 4. Summer policy for air volume rate

The heating and cooling energy demand were reduced up to 90% compared with standard building and up to 75% compared with new buildings [**Error! Bookmark not defined.**, 21, 22].

4. Measurements and discussions

In the summer, the interior temperature varied between 18.73°C and 30.96°C with minimum of energy requirements and following the out-side temperature trendline as presented in 0. The total energy required for ventilation was 362.1 kWh over entire year. From May 2014 to October 2014 was a total consumption of 166.08 kWh, which represents 1.19 kWh/m^{2}yr.

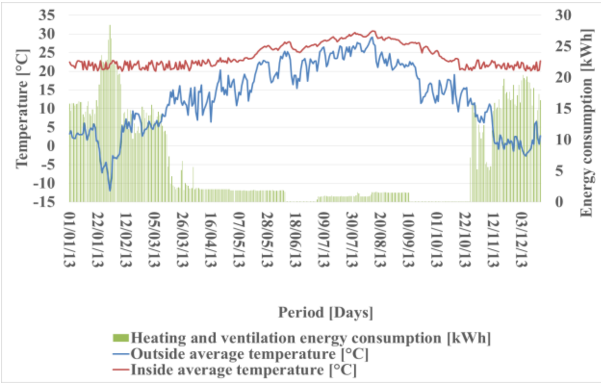

Fig. 5. Variation of inside average temperature in the passive house of UPB during one year

During the warm season a passive house passes through various stages as can be observed in 0 and 0.

The average temperature during summer days was 26.46°C as can be observed in 0.

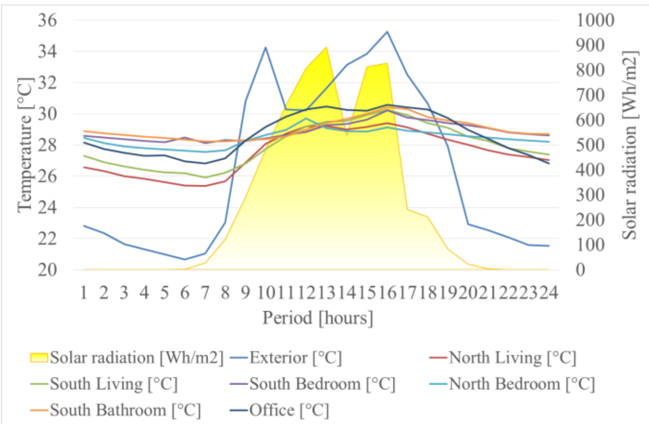

Fig. 6. Evolution of the interior and exterior temperature on 22nd of July 2014

The solar mean radiation was 406.53 W/m^2 and had a big influence on the inside temperature through the large windows from the South of the house on the interior temperature.

Between 8:00 AM and 20:00 PM the outside average temperature was 30.49°C and the inside temperature was 28.40°C. The air was cooled using only the ground temperature. 0 are presented the HVAC temperatures. On the day light, when the air flow is low in order to have time to exchange heat with the ground, it can be observed how the temperature enters in the house with values lower than the outside ones.

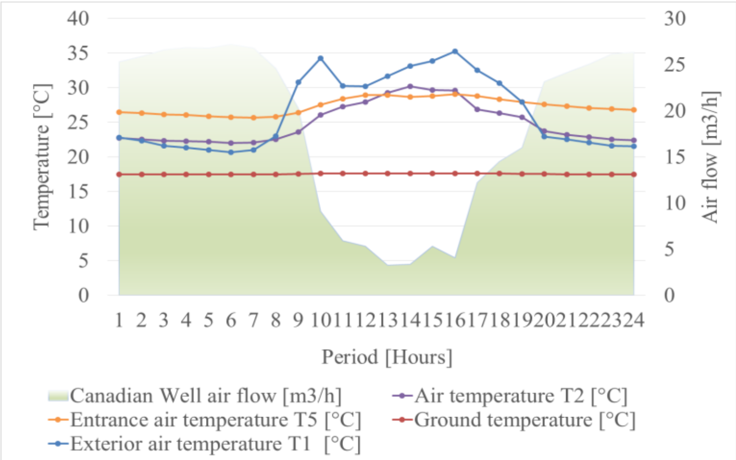

Fig. 7. Evolution of the HVAC temperatures on 22nd of July 2014

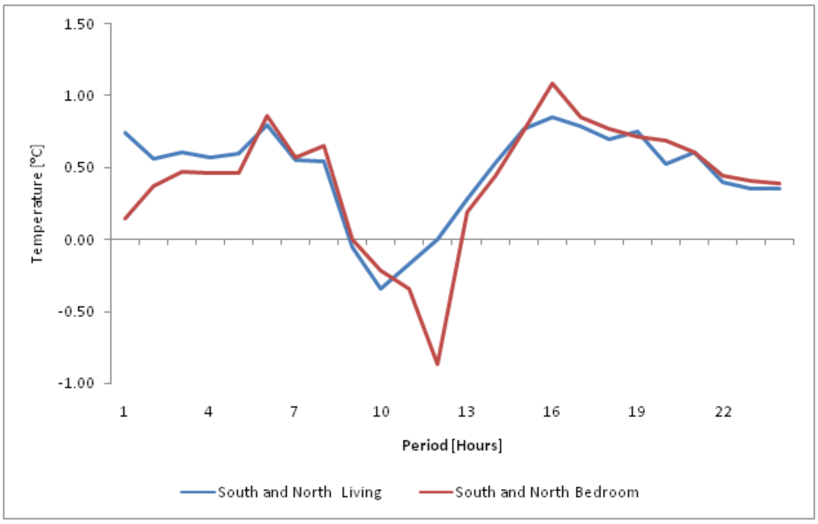

Fig. 8. Differences between temperatures from Passive House 22nd of July 2014

0 presents the difference between South and North of the house. The average difference was 0.47°C in the living and 0.41°C between the bedrooms.

5. Conclusions

The paper describes a real case study of an approximate fuzzy logic functionality implemented in the passive house in order to maintain a good level of inside temperature. The purpose of the algorithm was to choose the right strategy for achieving thermal comfort with minimal energy consumption.

This study is important for both future research and development of mechanism management based on house occupancy, user needs and energy reduction. The implementation of fuzzy logic technology in the presented laboratory is an efficient tool that allows multiple policy implementations. Using fuzzy logic algorithms may lead to low energy consumption in buildings.

Current research is focused on the development of a future fuzzy logic implementation, giving the opportunity of optimizing the existing policies, and increasing the capacity of decisions of the program based on a small number of input variables.

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