Minimizing energy consumption in heating systems under uncertainty

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Abstract. Energy saving systems are needed to reduce the energy taxes, so the electric energy remains balanced. In Spain, a local company that produces electric heaters needs an energy saving device to be integrated with the heaters. The building regulations in Spain introduce five different climate zones, so such device must meet all of them. In previous works the uncertainty in the process was shown, and the different configurations that must be included to accomplish the Spanish regulations were established. It was proven that a hybrid artificial intelligent systems (HAIS) could afford the energy saving reasonably, even though some improvements must be introduced. This work proposes a modified solution to relax the hardware restrictions and to solve the lack of distribution observed. The modified energy saving HAIS is detailed and compared with that obtained in previous works.

Keywords: Fuzzy systems, Hybrid Artificial Intelligence Systems, Real World Applications, Electric Energy saving.

1 Introduction

As stated in [2,12], only Greece, Portugal and Spain have energy taxes deficit because the price of the energy in the energy market is partially liberalized. In Spain, the deficit is growing since year 2000 –the first year the deficit was accepted; and it is estimated to reach the amount of 15000 millions of euros in 2008.

The deficit is caused by the difference between the electric generation costs and the electric energy price to consumers. With the raise of both the petroleum price and the costs of the CO_2 emissions, the problem is unresolved. It is clear that the electric taxes for small consumers will increase in the next years. Consumers must be aware of

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energy saving methods and devices, in particular, energy saving methods in the heating systems –specially if they are based on electric energy–, which represents the main contribution to the energy consumption-.

In Spain, a local company has developed a new dry electric heaters production line. Just because of previous reasons, a device for electric energy saving is to be included in the catalogue. In previous works, the development of such a device has been analyzed, and a multi agent hybrid fuzzy system has been proposed [7,8,9]. The solution integrates the electric heaters and a Central Control Unit (CCU). The CCU is the responsible for distributing the available electric energy to the heaters based in the energy balance concept and with the objective of keeping the user defined comfort level in the house. Although the proposal was proven to make a suitable distribution of the available electric energy, it suffers some deficiencies. Specifically, some bias was found in the steady state. Also, there was a lack of stability in the electric energy output due to fluctuations that must be faced.

In this work, a new proposal to improve the energy saving system is detailed. In this approach, the CCU is fully integrated with the heaters, which allow that the energy distribution algorithm (EDA) could be simplified. The EDA considers the energy balance and the comfort variables to propose the electric power to be spent in heating in the next period. The EDA makes use of a fuzzy controller to obtain a suitable energy rate for each room. The energy requirement for all the rooms is now obtained directly from the power controller in each of the heaters installed in the room. The pre-process stage is now modified to include the dynamics of each room. Finally, a multi objective algorithm is proposed to train the fuzzy controller in the EDA.

This work is organized as follows. The next section deals with the Spanish regulations and the problem definition. Section 3 details the energy saving system proposed in this work. An analysis of the behaviour of this energy saving system in a specific configuration is carried out in Section 4, and a comparison with previous works results is preformed. Finally, conclusions and future work are presented in Section 5.

2 The Spanish regulations and the problem description

In the first quarter of the year 2007, the Spanish parliament approved a new building regulation [10] (RITE). This new regulation had many consequences, as it determined how the new buildings had to be accomplished: materials, isolation, energy efficiency, etc. Up to five different winter climate zones were defined for Spain –from A to E-, each zone represents specific weather conditions that make the climate more or less severe. Therefore, today, not only the builders are affected but also all the products related to energy consumption, as they are to be installed in those new buildings.

In this case, a local enterprise released a new catalogue of electric heaters, which accomplish Spanish regulations. In Spain, the program LIDER [11] validates the heating power installed in a new building. On the other hand, the electric energy provider establishes the energy consumption contract limits. A problem arises when the total power installed in a new building surpasses the contracted energy consumption limit. A common sense solution is to include energy distributors to limit the energy consumption. This kind of devices do not consider the comfort in the house, only the energy consumption, so the local company looks for a new device that considers both the energy consumption and the comfort in the house.

The design of the new device must consider the new building specifications in order to establish the comfort prerequisites and the items related to energy efficiency. The objective aimed in the energy efficiency is to limit the energy consumption while keeping the thermal comfort in the houses. A study of the thermal system that a house represents is needed to determine the thermal energy requisites, which will depend on the local weather, the season of the year, the isolation, the use of the building and the air purity.

The local company, which produces electric heaters, wants to produce an energy saving device to be included in its catalogue. The electric heaters and the energy saving device are to be installed in houses. The range of the power rates for the heaters are 500, 1000, 1200 and 1500 Watts. The houses must agree with the Spanish regulations enumerated above, and in Figure 1 an example of a Condo house with a possible indoor partition is shown. The main goal is the design of a system for saving electrical energy while keeping the comfort level of the house considering the current electric consumption (excluding the heating installation) and the contracted electrical power. The comfort level in a house is defined as the ambient variables that the user fixes for each room, in the case of this project, only the temperature in each room is considered. The market area of the product is constrained to Spain, so the product must agree with the Spanish regulations.

There will be a CCU responsible of the energy saving algorithm. Each room in the house will have at least one heater, with a given power rate. It is assumed that each heater will collaborate with the CCU in order to reduce the consumed energy while keeping the comfort in the house. The comfort specifications for each room must be fixed, setting the temperature set point for every hour and day of the week. Moreover, the electrical energy contract for each house limits the amount of energy that could drain in a house.

Besides, the sum of the electrical power of each heater plus the power of the rest of the electrical devices in the house must not exceed the contracted power limit. Finally, the whole saving energy system must be economically viable so that consumers can afford it. Also, the system must be robust so failures in the CCU do not collapse the system.

3 An HAIS solution to energy saving

The objective of this energy saving system is to reduce the energy consumption while keeping the comfort level. Comfort is defined using the temperature in each room. The closer the temperature is to the room temperature set point, the higher the comfort is.

Different to the preliminary works, in which the heaters and the CCU work all together to reach the objective, in this work the CCU and the heaters are fully integrated. This means that all the data from each heater can be used, specifically, the room temperature, the heater power rate and the heater power output –from its internal PID–. The energy consumption measurement – whose sensor is wired to the CCU–, should be known so the energy supplier contracted power limit could not be exceeded.

The same design reasoning presented in preliminary works applied in this work [7,8,9]. Interested readers would find in those papers an in-depth description of the Zigbee microcontroller network based Multi Agent System (MAS) approach used. The main difference is that, as long as the heaters and CCU are fully integrated and the power output of all the heater controllers is accessible, there is no need for

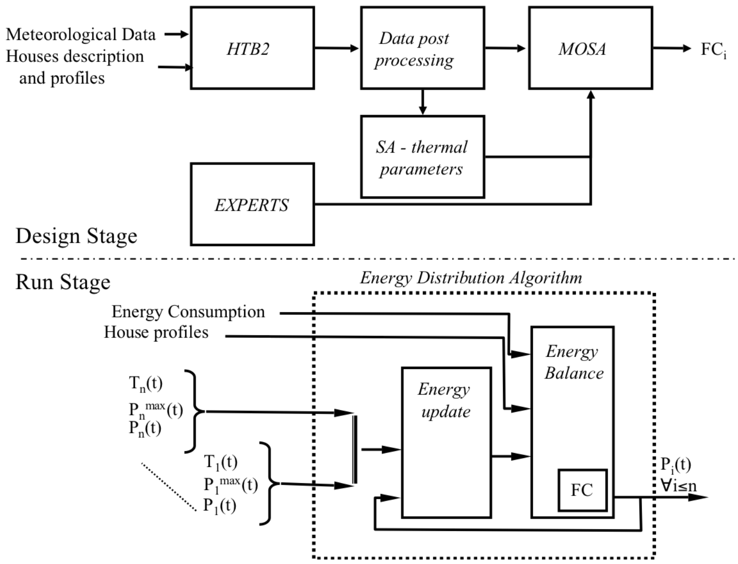

Fig. 1.- The ESS two stage procedure. A fuzzy controller is trained for each configuration pair of climate zone and building topology. The run stage represents the energy saving EDA algorithm.

estimating the power requirement. In the following Figure 1 the energy saving system (ESS) is outlined. There are two stages: the design stage and the run stage. In the design stage a wide range fuzzy controller is trained and validated, while in the run stage the whole algorithm is executed in the embedded hardware. A detailed description of all the parts of each stage follows.

It is called a *configuration* the pair of values <climate zone, building topology>. As stated before, the Spanish regulations define 5 climate zones, from the less severe –A– to the most severe –E–. On the other hand, the ESS must deal with all kind of building: a detached house, a condominium house, a company headquarters, etc. In each building type there is a wide variety in the number of rooms, the orientation, etc. To deal with such different spread of diversity, the EES is designed with a common part –the energy distribution algorithm (EDA)– and a specific part for each room –a fuzzy controller FC–. The EDA concerns with arranging the available power between the heaters and makes use of the fuzzy controllers to propose a heating power rate for each heater; the calculations are based in the energy deficit in the room. The FC is a mamdani FC with 3 membership functions per variable, and a complete set of rules, designed using an Input/Output mapping.

The Design stage deals with the generation of a FC for each configuration. This stage includes several steps: the HTB2 simulation, the data post-processing and the generation of the best suite FC. All of the heaters will have the same initial FC, but the ESS includes an auto-tuning facility to fit the FC to its room requirements. The HTB2 simulation software [5], in following HTB2, is a well known tool suitable to analyze the dynamics of heating systems and the energy consumption in buildings using the concentrated parameter model [1,4]. The HTB2 is a totally parameterized simulation tool, its main output is the heating power requirements and temperature for each room in the modeled house, both logged at each time interval.

For generating the dataset, all the topologies of the houses and the geographical zones to be covered must be defined, which are market decisions. Then, each building topology and geographical zone must be defined for the HTB2, and a set of simulations for each season must be carried out using realistic profiles of occupancy, set point temperature, small power devices consume, etc. Also a simulation for determining the dynamics of each room in the building is needed. This simulation is the *step response of the house,* where a change in the temperature set point while the rest of parameters are kept constant is analyzed.

The post-processing stage should select two subsets, each one containing ten significant parts from the HTB2 output datasets for a certain configuration: this will represent the training and validation datasets to be used in the third step. Finally, with the step response of the house the thermal resistance and the thermal capacitance for each room are determined [3]. Using the simulated annealing heuristic the best pair of thermal parameters for each room are found.

Finally, the MOSA step is the 10 k fold cross validation multi-objective simulated annealing for training the fuzzy controller for each configuration. The MOSA is the multi-objective adaptation of the simulated annealing presented in [6]. Each individual is the consequent part of the fuzzy controller, and the fitness function is the EDA algorithm. The two objectives to reach are minimizing the energy consumption and keep the house in comfort by means of the EDA. The initial individual has been obtained from expert knowledge, and the antecedents and rules are kept the same for all individuals. At the end of the Design stage a base fuzzy controller for each configuration is obtained. The fuzzy controller will be used in the energy distribution algorithm as follows.

The Run stage is the energy distribution algorithm, named EDA. This algorithm is to be executed in a microcontroller unit, so its complexity should be kept low to avoid getting the CCU collapsed. The EDA request all the heaters for the room temperature, the power rate and the power output they would accomplished if they would were stand alone. The latter is called the *required power*, and the integral of the required power is the *required energy*. The EDA will propose to all the heaters a *heating power*; its integration represents the *heating energy*. The integrals are computed in using a 20 periods window. The *energy deficit* is calculated as the difference between the required energy and the heating energy. Using the room temperature error –the temperature set point minus the room temperature– and the energy deficit the FC proposed a heating power for each heater. The heating power for all the heaters is then fitted to do not surpass the available power neither the heaters power rate. The available power is the power contract limit minus the small power devices consumption –that is, the power that is available for heating purposes–. Also a minimum heating power is assigned to all the heaters with energy deficit to keep them warm.

4 Experiments and commented results

This work concerns the evaluation of the best approach to energy saving and deals with the drawbacks found in preliminary works. The experimentation will determine, if the current approach does fulfill better the two objectives than the preliminary approaches: to minimize the energy consumption and to keep the comfort level in the house. The ESS market area is Spain, thus it must accomplish with the Spanish regulations. Before analyzing the ESS with the whole set of different configurations the system should be valid for only one of the possible situations for a given configuration. The climate zone chosen is the city of Lugo, a D1 city, and the building topology is the condominium topology, in particular, a three bedrooms condo house, with orientation North-South. The original FC will be used: the MOSA step is to be implemented once this approach gets validated.

The set of configuration files for the HTB2 simulations can be designed once the configuration and the specific situation are chosen. This configuration files must represent real and realistic data. The environmental data such as the outdoor temperature or the solar radiation have been gathered from statistical data for the city of Lugo in three different seasons of year 2007: mid of autumn, mid of winter and mid of spring. Other files, as occupancy file, temperature set point profile for each room in the house, small power devices profile, etc. have been designed attending to realistic profiles. Finally, files like ventilation file have been generated attending to the regulations.

The HTB2 simulation produces two datasets: the step response of the house and the evolution of the heating power required in the house to keep the comfort level. The former is used to obtain the thermal dynamics of the house, the latter for evaluating the EDA. The last step in the Design stage is not used in this work as long as it is desired to compare results with preliminary works, which make use of the FC generated by the experts for calculating the heating power. The thermal dynamics of the house is used to calculate the evolution of the temperature in each room with the heating power proposed by the CCU.

The simulation of the EDA has been carried out with the HTB2 datasets and the thermal dynamics of the house. The results are shown in Figure 2 to Figure 5, solid line is the required power and the dash and dotted line is the outcome of the EDA; left side corresponds with the house being cold, right side corresponds with a warm state of the house. As can be seen in Figures 2 to Figure 4, the lack of stability in the heating power output has been eliminated, not only for the aggregated heating power but also for the heating power corresponding to each room. Also in Figure 3 and Figure 4 it is shown that the bias in the steady state has been fixed. Finally, in Figure 5 the ability of the FC to calculate a heating power based in the error temperature and in the energy deficit under the variability of situations –the different rooms and their geometrics and uses– has been proven, and must be tested with all of the possible situations of all the configurations.

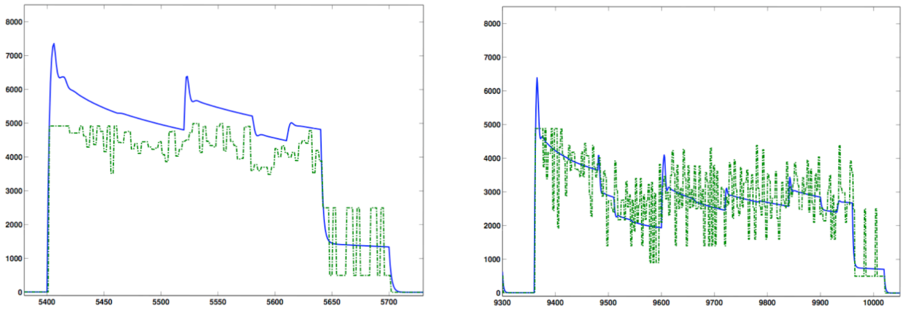

Fig. 2.- Aggregated heating power evolution for the house.

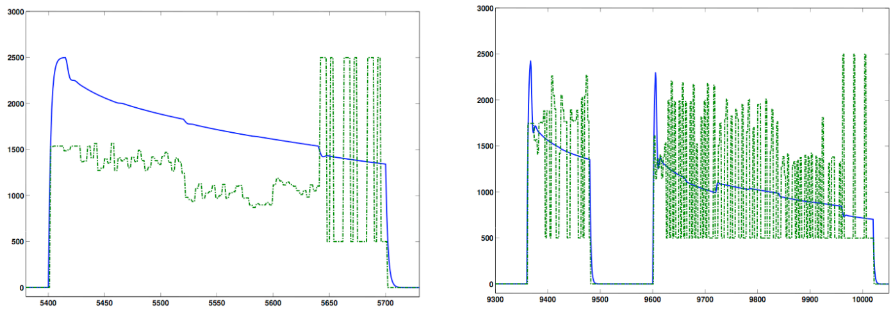

Fig. 3.- Heating power evolution for a room in the house.

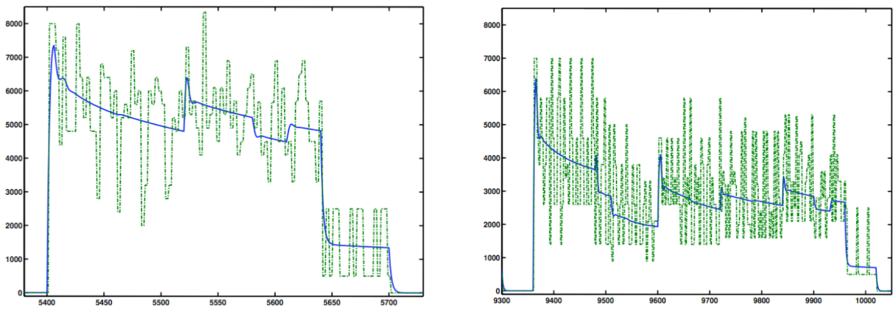

Fig. 4.- Aggregated heating power evolution for the house when no Contracted Power Limits is used.

5 Conclusions and future work

This work applies different AI techniques in energy saving. The use of a specific software to train and validate the FC, the simulate annealing to obtain the thermal parameters that define the dynamic of each room, the multi-objective simulate annealing, a fuzzy controller in the EDA and the MAS approach. The results have proven the ESS to be valid if only a situation is faced. The ESS has reached all the challenges that preliminary works has left, and the fluctuation heating power and the errors in the steady state has been fixed while the comfort in the house is kept.

Future work includes the training and validating of the FC for each configuration and the validation of the ESS in all the configurations. Finally, the implementation of the MAS and the ESS in the embedded hardware accomplishing the time and computing complexities needed to make a competitive product.

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