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Virtual agent organizations to optimize energy consumption in households

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KEYWORD

Energy; Consumption; Global Warning; Saving

ABSTRACT

Global warming affects us all, that is why we must all act to stop it. It has been shown that this undoubted problem can be solved to a large extend if we make small individual efforts. How can we do this? Making prudent use of electricity. If we manage to make more efficient use of the energy we consume in our homes, we will contribute enormously in this common cause. With the help of virtual agents, we will get a better management of the energy we consume.

1. Introduction

A method of multi-agent systems for the energy saving of a home is explained, focusing on the exterior and interior temperature of the house to manage the use of the different acclimatization systems.

In the original article the authors describe a multi-agent system whose objective is to save energy in a house without affecting the standard of living of the guests (Kok *et al*., 2005). For this, the system would have some temperature sensors located inside and outside the house and movement sensors in each room that would detect where the inhabitants of the house are at each moment. With the combination of these two elements would achieve a saving of energy (Abras *et al*., 2008).

Other articles have also tried to solve some of the problems related. In *Intelligent Buildings: the multi-agent approach* (Errecalde *et al*, 2008) a multi-agent system for the administration of intelligent buildings is proposed, in which attempts are made to solve the problems of planning, optimization of the use of resources, scheduling, machine learning, communication and coordination of agents (Asare-Bediako *et al*., 2013). Special attention has been paid to the problem of energy saving, in this case they pose the resolution of the problem controlling in a flexible and dynamic way the heating, cooling and lighting of the different parts of a building (Gilart-Iglesias *et al.*, 2011). In *Domestic water management in the Metropolitan Region of Barcelona: A participatory approach, based on agents* (López Paredes *et al*, 2003) a multi-agent system for the management of drinking water in the metropolitan area of Barcelona is proposed (Huberman and Clearwater, 1995). The most noteworthy and interesting for us in this article, is the method they use to maintain the level of comfort of the inhabitants whatever the scenario that may arise for the future (Zhao *et al.*, 2013).

In Villar *et al*. (2007) a multi-agent system is proposed for energy saving, in this case, by reducing the consumption of heating systems. In this they propose a different solution to the one that has been carried out in our system, unlike ours, which raises several types of heating with different consumptions, they only use one that consumes more or less power in each of the rooms depending on the needs of each moment (Córdobo Magaña and Muñoz Organero, 2014). Based on the mentioned article, a multi-agent system has been designed to control the temperature of a house without affecting the comfort of the inhabitants and at the same time save energy (Davidsson, 2000). The system will count with a series of sensors that will control the interior and exterior temperature, according to these the acclimatization systems can be managed maintaining the appropriate temperature while using the lowest energy possible (Lagorse *et al*., 2010).

While the solution proposed by the mentioned article uses motion sensors that control the position of the guests and the weather forecasts to optimize the use of the acclimatization systems, this proposal would manage the systems based only on the outside and inside temperature (López Paredes and Galán Ordax, 2003).

2. System Description

A multi-agent system (MAS or "self-organized system") is a computerized system composed of multiple interacting intelligent agents. Multi-agent systems can solve problems that are difficult or impossible for an individual agent or a monolithic system to solve (Lagorse *et al*., 2009).. An agent is an encapsulated computer system, located in some environment, within which acts autonomously and flexibly to meet its objectives (Wooldridge and Jennings, 1995). Agents can, according to their characteristics, be of three types: Reagents that perceive the environment and respond to changes, Pro-active taking the initiative and Hybrids.

The described home will have two heating systems; the first one will be an electric boiler (lower consumption) and will be used when the outside temperature is not extremely low, while the second will mean higher consumption and will be used when the outside temperature is very low or when the interior temperature drops below a determined limit since the heating system of low consumption would not be able to maintain the temperature of the house at its ideal value. This house will also have two refrigeration systems; the first one will be of lower consumption, such as a fan, this will be activated when the temperature of the interior of the house is not much higher than the ideal temperature and another air conditioning system that will be activated when the outside temperature is very high or when the indoor temperature exceeds a certain limit since the low-consumption cooling system would not be able to maintain the temperature of the house and also cooled it more quickly.

With this system it would be possible to save energy by maintaining the house temperature in an acceptable range using low consumption systems and only when necessary the conventional systems of high consumption.

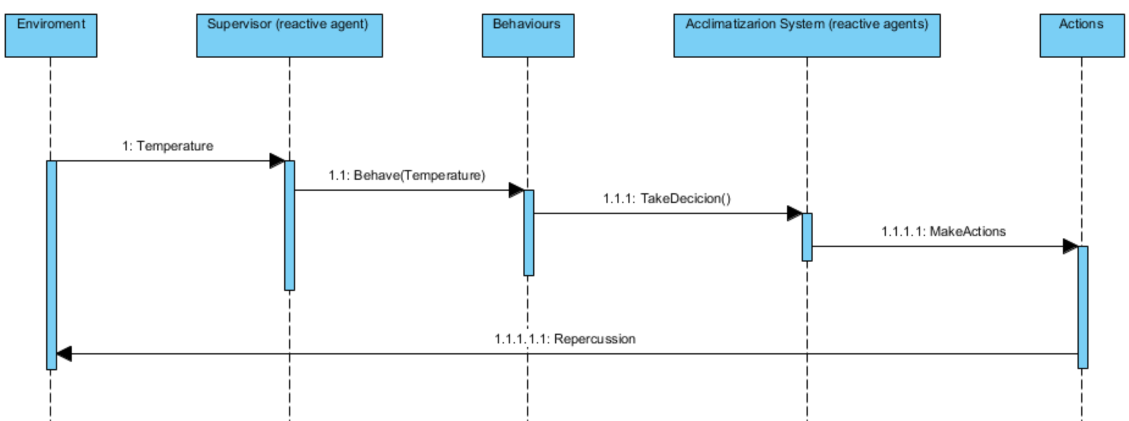

Figure 1: Communication Diagram

2.1. Architecture and Organization

The structure of our system is centralized since it will be a single agent who obtains information from the exterior; this agent will make the decisions and will communicate them to the other agents. This system uses a reactive architecture, the supervising agent contains a set of basic actions (Shokri *et al*., 2019). After obtaining the information from outside, the agent decides through a set of condition-action rules the action that must be performed for the current situation (Hernandez *et al*., 2013). The rest agents are simply activated and deactivated when the supervisor orders it, depending on the input message they will make an action or another. None of the agents acts on their own since their decisions depend totally on what they receive (Klein *et al*., 2012).

From the point of view of the skills and tasks performed by each agent, it is a non-redundant and hyper-specialized organization since each agent has a skill and no other agent possesses it (Wang *et al*., 2016). On the other hand, from the point of view of the distribution of tasks, the organization follows a hierarchical structure, since four of the five agents of the system could be considered "slave" agents since they execute a certain routine when the "master" agent he asks for it.

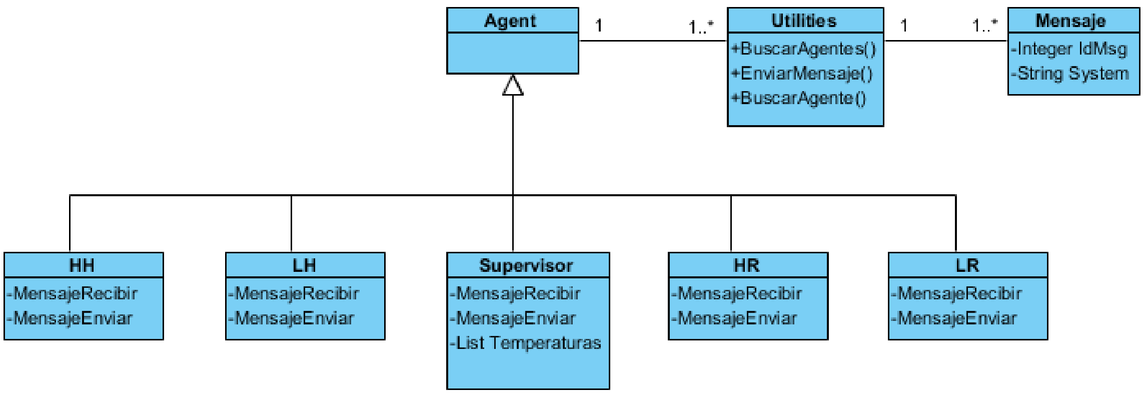

Figure 2: Class Diagram

2.2. Agents

The description of the system focusing on the type of agents is:

Reactive agents: the supervisor agent (S) and the four acclimatization systems: high consumption heating (HH), low consumption heating (LH), high consumption refrigerator (HR) and low consumption refrigerator (LR).

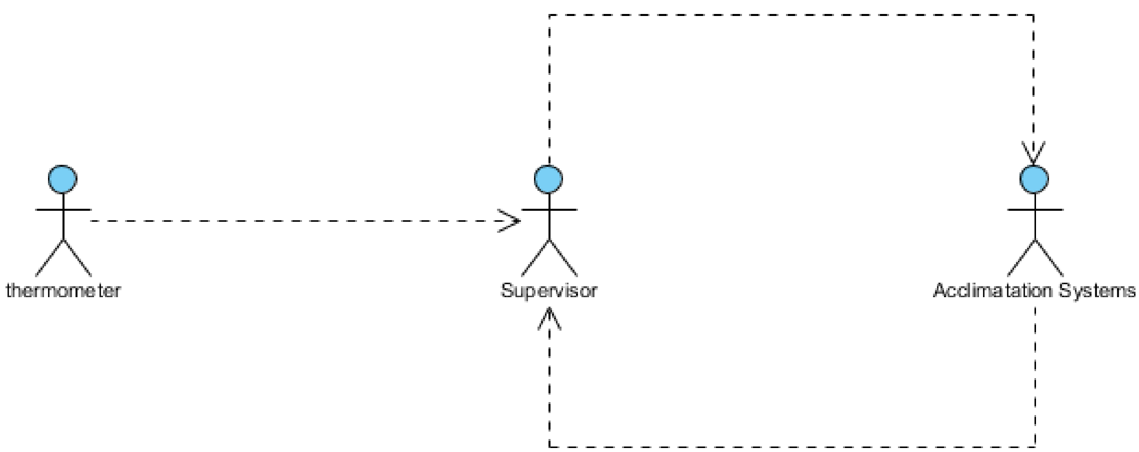

Figure 3: Group Architecture

Supervisor Agent (S)

The supervisor agent is a reactive agent that, depending on the outside temperature, will control the acclimatization systems. It will take the temperature from a file, depending on this temperature the agent can take one of the five possible decisions:

1. Temperature between 19 and 22 ºC: The Supervisor will not activate any of the acclimatization agents.
2. Temperature between 23 and 26 ºC: The Supervisor will order the activation of the low consumption refrigerator (LR) system.
3. Temperature higher than 26 ºC: The Supervisor will order the activation of the high consumption (HR) refrigerator system.
4. Temperature between 16 and 18 ºC: The Supervisor will order the activation of the low consumption heating system (LH).
5. Temperature lower than 16 ºC: The Supervisor will order the activation of the high consumption heating system (HH).

In addition, if the device that the supervisor chooses to activate is different from the one previously activated, it will order disactivate the previous one in order not to have two active systems simultaneously.

Code Description

The supervisor agent uses three variables, the first is a String list ("temperatures") that will be responsible for storing the temperatures obtained from the file that represents the thermometer, the other variables represent the messages that are sent or received that allow the communication with the other agents ("send" and "receive"). The supervising agent will go through the String list ("temperatures") using a for loop, this loop will contain conditional if-else statements that will decide the behavior of the system for each temperature.

High Consumption Heating Agent (HH)

The heating agent of high consumption is a reactive agent that will be activated when the supervisor orders it to raise the temperature of the home, its consumption is high. It will also be deactivated when the supervisor considers it necessary.

Code Description

The agent HH uses two variables representing the messages that are sent or received that allow communication with the Supervisor agent. The agent waits to receive a message (blocking Receive), if it receives it it turns on and sends a confirmation message to the Supervisor.

Low consumption heating agent (LH)

The agent Low consumption heating is a reactive agent that will be activated when the supervisor orders it to raise the temperature of the home. It will also be deactivated when the supervisor considers it necessary.

Code Description

The agent LH uses two variables representing the messages that are sent or received that allow communication with the Supervisor agent. The agent waits to receive a message (blocking Receive), if it receives it it turns on and sends a confirmation message to the Supervisor.

High consumption Refrigerator Agent (HR)

The high consumption Refrigerating agent is a reactive agent that will be activated when the supervisor orders it to lower the temperature of the home, its consumption is high. It will also be deactivated when the supervisor considers it necessary.

Code Description

The agent HR uses two variables representing the messages that are sent or received that allow communication with the Supervisor agent. The agent waits to receive a message (blocking Receive), if it receives it it turns on and sends a confirmation message to the Supervisor.

Low consumption Refrigerating Agent (LR)

The high consumption Refrigerating agent is a reactive agent that will be activated when the supervisor orders it to lower the temperature of the home. It will also be deactivated when the supervisor considers it necessary.

Code Description

The agent HH uses two variables representing the messages that are sent or received that allow communication with the Supervisor agent. The agent waits to receive a message (blocking Receive), if it receives it it turns on and sends a confirmation message to the Supervisor.

2.3. FIPA Performatives

Supervisor Agent(S)

:receiver <temperature>

:sender <Sensor Update>

Receives the outside temperature of the file and sends sensor update (Power On/Off) to temperature control system agents so that they are activated and deactivated.

High Consumption Heating Agent(HH)

:receiver <Sensor Update>

:reply-with <Ok>

Receive sensor update and reply with Ok. This will turn high consumption heating On/Off.

Low consumption heating agent(LH)

:receiver <Sensor Update>

:reply-with <Ok>

Receive sensor update and reply with Ok. This will turn low consumption heating On/Off.

High consumption Refrigerator Agent(HR)

:receiver <Sensor Update>

:reply-with <Ok>

Receive sensor update and reply with Ok. This will turn high consumption refrigerator On/Off.

Low consumption Refrigerator Agent(LR)

:receiver <Sensor Update>

:reply-with <Ok>

Receive sensor update and reply with Ok. This will turn low consumption refrigerator On/Off.

Acclimatization agents will always respond to the Supervising Agent with Ok and will act upon the order received. And it will be the supervisor who will determine which agents should be activated or deactivated.

2.4. Communication and Coordination

The communication between agents allows them to exchange information in order to properly manage which system is activated at each moment. For this system, global coordination is used, that is, the multi-agent system is able to determine and plan globally the actions of the different agents. Communication in the system consists of message passing functions. The messages will have the following structure:

Agents	FROM S TO HH
Message Structure	POWER ON / POWER OFF

Agents	FROM S TO LH
Message Structure	POWER ON / POWER OFF

Agents	FROM S TO HR
Message Structure	POWER ON / POWER OFF

Agents	FROM S TO LR
Message Structure	POWER ON / POWER OFF

Figure 4: Message Structure

This message structure allows the following sequence:

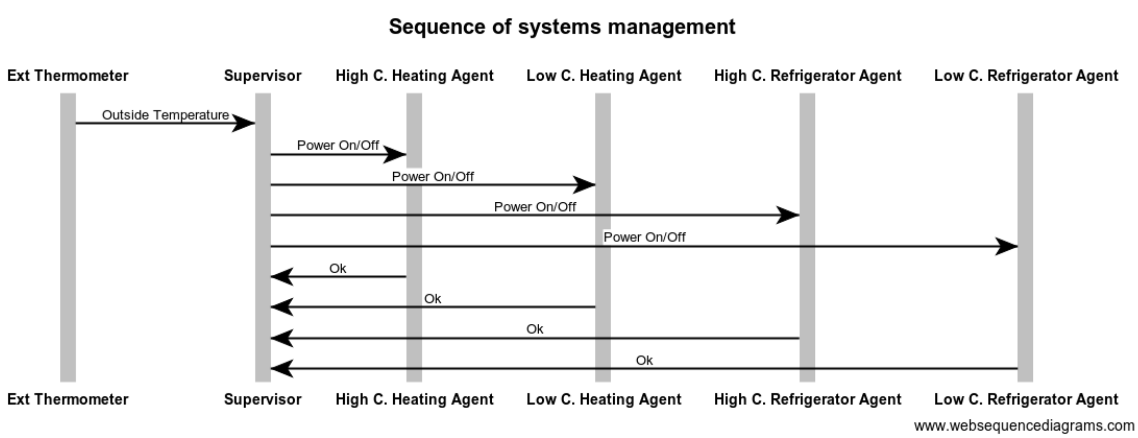

Figure 5: Communication Diagram

3. Results

The objective of this multi-agent system is to achieve energy savings in a home, to know if the system is capable of achieving this goal, it has been chosen to observe what the system's behavior has been when exposed to different situations with different temperature ranges, in order to check if thanks to the behavior generated by the system has been achieved saves energy (Koen *et al.*, 2008). The results obtained from the tests have been the following:

```
-----------------
Temperatura exterior: 20
Sistema Utilizado: None
-----------------
Temperatura exterior: 21
Sistema Utilizado: None
-----------------
Temperatura exterior: 23
Sistema Utilizado: Low Consumption Refrigerator
-----------------
Temperatura exterior: 24
Sistema Utilizado: Low Consumption Refrigerator
-----------------
Temperatura exterior: 24
Sistema Utilizado: Low Consumption Refrigerator
-----------------
Temperatura exterior: 21
Sistema Utilizado: None
-----------------
Temperatura exterior: 20
Sistema Utilizado: None
-----------------
Temperatura exterior: 18
Sistema Utilizado: Low Consumption Heating
-----------------
Temperatura exterior: 17
Sistema Utilizado: Low Consumption Heating
-----------------
Temperatura exterior: 16
Sistema Utilizado: Low Consumption Heating
-----------------
Temperatura exterior: 14
Sistema Utilizado: High Consumption Heating
```

Figure 6: Results 1

In this first example, temperatures close to the ideal value have been used simulating a day with mild temperatures, the following is observed; In a large part of the time, if the outside temperature is close to the set comfort temperature, none of the acclimatization systems of the home is activated, and because temperatures farther from the ideal value do not go too far, only They activate the lowest-cost, lowest-cost acclimatization systems throughout the day. In defined, the house can be maintained at a constant temperature during the whole period without activating the acclimatization systems of higher consumption.

```
Sistema Utilizado: High Consumption Heating
-----------------
Temperatura exterior: 11
Sistema Utilizado: High Consumption Heating
-----------------
Temperatura exterior: 13
Sistema Utilizado: High Consumption Heating
-----------------
Temperatura exterior: 14
Sistema Utilizado: High Consumption Heating
-----------------
Temperatura exterior: 17
Sistema Utilizado: Low Consumption Heating
-----------------
Temperatura exterior: 18
Sistema Utilizado: Low Consumption Heating
-----------------
Temperatura exterior: 17
Sistema Utilizado: Low Consumption Heating
-----------------
Temperatura exterior: 15
Sistema Utilizado: High Consumption Heating
-----------------
Temperatura exterior: 11
Sistema Utilizado: High Consumption Heating
-----------------
Temperatura exterior: 10
Sistema Utilizado: High Consumption Heating
-----------------
Temperatura exterior: 9
Sistema Utilizado: High Consumption Heating
-----------------
Temperatura exterior: 7
```

Figure 7: Results 2

In this second example an attempt has been made to simulate a day in which the temperatures are colder, as a consequence, it will be necessary to activate the heating system with the highest consumption, in order to maintain the home at the ideal temperature, if we observe the sequence of activations From the example, we can observe that in the hottest hours of the day it has not been necessary to activate the high consumption heating, but with the low consumption it has been enough to maintain the temperature. In this example we also observe an energy saving due to the deactivation of high consumption heating in the hottest part of the day.

```
Sistema Utilizado: None
-----------------
Temperatura exterior: 21
Sistema Utilizado: None
-----------------
Temperatura exterior: 23
Sistema Utilizado: Low Consumption Refrigerator
-----------------
Temperatura exterior: 25
Sistema Utilizado: Low Consumption Refrigerator
-----------------
Temperatura exterior: 27
Sistema Utilizado: High Consumption Refrigerator
-----------------
Temperatura exterior: 30
Sistema Utilizado: High Consumption Refrigerator
-----------------
Temperatura exterior: 28
Sistema Utilizado: High Consumption Refrigerator
-----------------
Temperatura exterior: 26
Sistema Utilizado: Low Consumption Refrigerator
-----------------
Temperatura exterior: 24
Sistema Utilizado: Low Consumption Refrigerator
-----------------
Temperatura exterior: 23
Sistema Utilizado: Low Consumption Refrigerator
-----------------
Temperatura exterior: 22
Sistema Utilizado: None
-----------------
Temperatura exterior: 21
```

Figure 8: Results 3

In this last example a range of higher temperatures have been used, typical of a hot day, observing the results I could see how the system only activates the high consumption cooling system in the hottest hours of the day, in the challenge of time is able to maintain the temperature of the home with the system of low consumption and even in some moments there is no activated system. For which an energy saving is also confirmed in this last example.

Therefore, after analyzing the data of the various examples, we can say that the system achieves energy savings, keeping the house temperature at an acceptable level, in almost any situation.

4. Conclusion

The article has described a solution to save energy in the home in order to stop global warming. To this end, a multi-agent system has been designed which, with the help of an external thermometer, will activate or deactivate the acclimatization systems, thus saving energy without disturbing the quality of life of the guests (Rodríguez Fernandez *et al*., 2019).

Based on contributing to curbing the more than obvious problem of global warming, the aim was to create a system that would save energy and thus curb global warming (Errecalde *et al.*, 2008). One of the biggest challenges was to achieve this without sacrificing the quality of life of the guests. To this end, a multi-agent system has been created that allows us to automatically save energy in a home by managing the most appropriate heating or cooling devices at any given time according to the outside temperature of the house. In this way, energy is not wasted unnecessarily, using low-consumption appliances in the right situations. About the construction of this platform has opted for an architecture based on agents where there will be agents representing the systems of acclimatization and another that will be a supervisory agent responsible for decision making. One of the great advantages of using agents is the speed of development, since being independent execution units greatly reduces coupling, making it easier to divide the tasks of the development process. This type of approach also greatly improves scalability and maintenance. If any of the devices need to be added or replaced, simply modify the agent that manages the device in question.

However, problems were also found in this type of development, and the greatest of them is the complexity that the system acquires when adding new agents, since in case of failure the monitoring and error control becomes more obfuscated due to the number of processes involved. In this project, a functional prototype of a system based on agents that manages the energy of a home has been proposed, designed and created, developing the advantages and disadvantages of this type of architecture.

In custom developments or with large-scale commercialization this could be a viable alternative for reducing energy consumption. But to introduce this product in the market would have a great complexity associated since it was necessary to develop specific agents that interacted with the different models of current temperature control devices.

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