Improving Sustainability of Energy Production: Design of a Demand Side Management System Using an Auction Model

Vincenzo Di Lecce, Michele Dassisti, Domenico Soldo, Antonio Giove, Alessandro Quarto, Angelo Galiano, and Michela Chimienti

Abstract. This work presents an intelligent demand side management (DSM) system modeled according to an auction based multi-agent system (MAS). The system is designed to improve the sustainability of energy self-production systems thanks to energy saving features while guaranteeing the maintenance of the user's desired comfort level. The proposed system is composed of a sensor network and a central processing unit. Each network node is handled by an agent and it is able to regulate the power consumption of a single environment (e.g., a room). The first live tests were carried out within a public building. Results seems promising for maximizing the sustainability as well as the profitability of self-production energy systems.

Vincenzo Di Lecce
DEI, Politecnico di Bari, Via Orabona 4, 70126 Bari, Italy
e-mail: v.dilecce@aeflab.net

Michele Dassisti
DMMM, Politecnico di Bari, Viale Japigia 182, 70126 Bari, Italy
e-mail: m.dassisti@poliba.it

Domenico Soldo · Antonio Giove
AEFLAB, Politecnico di Bari, Viale del Turismo 8, 74123 Taranto, Italy
e-mail: {d.soldo,a.giove}@aeflab.net

Domenico Soldo · Alessandro Quarto
myHermes Srl, Corso Italia 63, 74121 Taranto, Italy
e-mail: alessandro.quarto@myhermessrl.com

Antonio Giove · Alessandro Quarto · Angelo Galiano
Dyrecta Lab Srl, Via V. Simplicio 45, 70014 Conversano (BA), Italy
e-mail: maurizio.galiano@dyrecta.com

Michele Dassisti · Michela Chimienti
Laboratorio Kad3 Scarl, Contrada Baione snc, 70043 Monopoli (BA), Italy
e-mail: m.chimienti@laboratoriokad3.com

P.-J. Benghozi et al. (eds.), *Digital Enterprise Design & Management*,
Advances in Intelligent Systems and Computing 261,
DOI: 10.1007/978-3-319-04313-5_9,

1 Introduction

The new “ecological sensitivity” of the last decades pervades each sensible aspect of our lives. Sustainability, the new key word of our societies, refers to the problem of minimizing resource consumption while maximizing satisfaction of human requirements. If left unattended or poorly handled, energy issues could cause problems for future business activities and occupy management’s time for decades to come. Just thinking about the companies that, being heavy energy consumers, create major greenhouse gas emissions through their operations, or those that manufacture energy-dependent products; it must be clear how important is to address this issue by searching for new products able to assure energy quality standards and keep costs down at the same time. From this point of view, the optimal control of energy production and consumption, at any level of the present human activities, is a key element to improve the sustainability.

This paper presents the first outcomes of a project aiming at defining an effective soft technology for monitoring and managing power consumptions based on a self-regulation (say “intelligent”) strategy; this characteristic was obtained through the agent technology, a fundamental paradigm of artificial intelligence.

Within this paper, the proposed multi-agent system technology was implemented in a control system for the management of power consumption of a public building (a University Faculty) equipped with photovoltaic panels. The new renewable energy production systems have brought the Italian power providers to define with the users new kinds of contracts such as the one allowing the user to “sell” the produced energy to the same power provider.

The paper is organized as follow: section 2 introduces the reference case; section 3 describes the MAS focusing on the proposed auction based model while section 4 reports the experiments and results. Finally, conclusions and final remarks are reported in section 5.

2 The Case Study

For the present application it was decided to test the MAS solution adopted to be implemented in a public building hosting an University faculty in southern Italy equipped also with renewable energy sources (solar panels), and in possible coordination with other forms of energy supply such as the thermal one (solar thermal collectors). This kind of application presents strong management criticalities: building is irregular and variously predictable, depending on the activities carried out and on the personnel working time. The preexistence of electrical and thermal plants, allows to evaluate the performance of the proposed system. This implies, consequently, an estimation of the critical zones of operation very far from the reference condition, where a simple controller Proportional-Integral-Derivative (PID) may ensure good regulation.

The hypothesis is that the Italian power provider offers the user the possibility to sell a quote of the produced power. In this case, the limit of users' power consumption has an economical nature: having a power consumption smaller than a given threshold means having an increase of the power sold.

At a first analysis, considering the University building energy requirements, it is clear that the major power consumption is due to the air conditioning system. In particular, each room has its own air conditioner and other fixed loads such as computers, printers, lights, etc.

As a working constraint, the auction system has been tuned to manage the power consumption of the air conditioner for each room. This constraint does not affect the generality of the proposed approach, but it is useful to define the sensors and the relays to be installed at each sensor node.

The multi agent-based energy management system implemented is aimed at monitoring and controlling complex power systems. The proposed approach acts as a multi-objective scheduler, having the following objectives:

- minimizing the power consumption;
- giving maximum comfort to user, namely satisfying as many requests as possible, by spending the minimum time (and/or money).

These objectives are achieved through the competition of more agents [1]. Each agent manages a room of the building. The proactivity features of agents and their communication ability give the proposed system a great scalability potential. Each user (owning a power production plant) can sell the provider the difference between the power produced and consumed. This fact translates a power consumption optimization into a monetary gain for the user and thus, the research for smart energy management systems is having a new impulse. The proposed agency uses the set of distributed measurements performed in each facility room as if it was a knowledge base.

This DSM system could be also adopted in large business facilities, as well as machine halls, and wherever electrical devices are used with the presence of a power production plant.

The proposed system was modeled using a simulation realized in Matlab® code. For testing the performance of the proposed system, also without using the data measured in the field, the authors have defined a model simulating the thermal behavior of a building. This model considers the following aspects affecting the building thermal: 1) seasonal thermal variations; 2) thermal behavior of the building envelope; 3) thermal behavior of the partition walls; 4) daily variation of the people's flow in the various rooms; 5) the impact of the air conditioner on the thermal conditions of the rooms.

For the sake of brevity, since data are easily found and does not bring new hints to the discussion, these aspects will not be reported.

3 MAS Architecture for DSM Application

A lot of different software architectures are presented in literature. Many of them are based on the use of a specific communication language. Other authors produce high level contributions about the structural approach of internal agent organization. The innovation proposed in the approach proposed, according to [2,3], are the interaction rules of the multi agent system architectures, where agents belongs to three macro classes:

- Interface area: the agent translates the message from external source (also human/natural language) into an Agent Communication Language (ACL). Its goal is to interpret external queries according to services offered by the MAS.
- Brokerage area: it analyzes a local database where services offered by MAS are stored. In this way, starting from one query, it produces as many messages as the request needs. It aims at managing internal information traffic flows.
- Analysis area: this group of agents attempts to validate data, using the knowledge of the system regarding their own interpretability.

Five sub-classes are introduced to enhance system scalability: Interface (one agent), Broker (one agent), Validation (more agents), Forecast (more agents) and Coach (one agent). The innovation presented in the application concerns the management strategy to allow the architecture to “intelligently” behave, thus devising appropriate interaction rules to let the system perform coherently with the customer’s needs as well as to be consistent with unpredictable changes in energy demands.

Taking the faculty application as reference, here the design and implementation solutions are explained in detail. For the DSM application in object, the following agent areas were defined. A schematic overview of the proposed MAS is reported in Figure 1.

- **User Area**. In this layer there is the association between each monitored room and a corresponding “Room Agent”. The Room Agent is the interface between a room and the auction agency. The main task of this agent is to manage an acquisition node from the real world allowing to evaluate environmental conditions and apply the MAS rules by acting on a relay. Each Room Agent produces a detailed profiling of users’ habits in order to define a user’s behavioral model. Each acquisition node is equipped with a dedicated sensor set. The specific sensor set composition is defined following the room characteristics, such as: main destination, dimensions and plant, furniture, number of doors and windows. Outputs required for each sensor set are:
  - **Environmental Information**: this kind of information is provided by a multi-source environmental monitoring system for indoor workplace. The environmental conditions are monitored in order to define the necessity or not to provide energy to the room (e.g., turning on/off the air conditioner).

The main components of the proposed Environmental Condition Detector are: a temperature evaluation block; a humidity evaluation block; an air quality monitoring block. Data collected from the previous blocks can be processed to obtain indirect information, such as the number of workers being contemporarily present as consequence of air quality degradation and/or temperature variation [4].

- **Presence Information**: the systems monitor the human presence in order to avoid energy consumption in case of long worker absence. Starting from these data, a user behavior analysis for profiling activities is realized. The provider of presence information can be a commercial presence detector. The detector should be characterized by a square configurable detection area, so as to avoid the risk of unrevealed workers in particular conditions like the room corners.
- **Energy Consumption Information**: these data are acquired in reference of real-time power consumption. The detector device adopted should be based on different monitoring levels. In particular, for a DSM aimed at air conditioning system regulation, it is possible to acquire information about: power consumption of each air conditioner installed in the room, power consumption of the whole room, power consumption of the area where the room is. The Energy Consumption Detector is based on a commercial energy monitoring system.

- **Interface Area.** This area is designed to allow the communication between the agents in the User Area and those in the Analysis Area. In particular, this layer is responsible for the evaluation of information produced by Room Agents in order to extract additional information (e.g., user presence probability, unease level perceived by user in function of air conditioning necessity). Evaluations realized by Agents operating in the Interface Area produce the auction bids.
- **Analysis Area.** The Analysis Area hosts two kinds of agent: the Auction Manager and the Power Manager Agent. The Auction Manager, responsible for the auction management, acquires and evaluates each bid that Interface Agents produce. In particular, the Auction Manager verifies that bids are proposed with respect to specific and predefined bidding rules. For each bidding round the Auction Manager communicates the winners to Power Manager Agent and collects money from winners. The Power Manager Agent defines power supply available for bidding round and authorizes winning Room Agents to acquire required power supply in function of air conditioning systems.
- **Knowledge Area.** The Knowledge Area is responsible for the storage of historical data acquired during system activity. The stored logs are related to: electrical consumption, environmental condition, and user presence. This knowledge base permits to deduce additional information such as: typical working hours and typical working day for each monitored room.

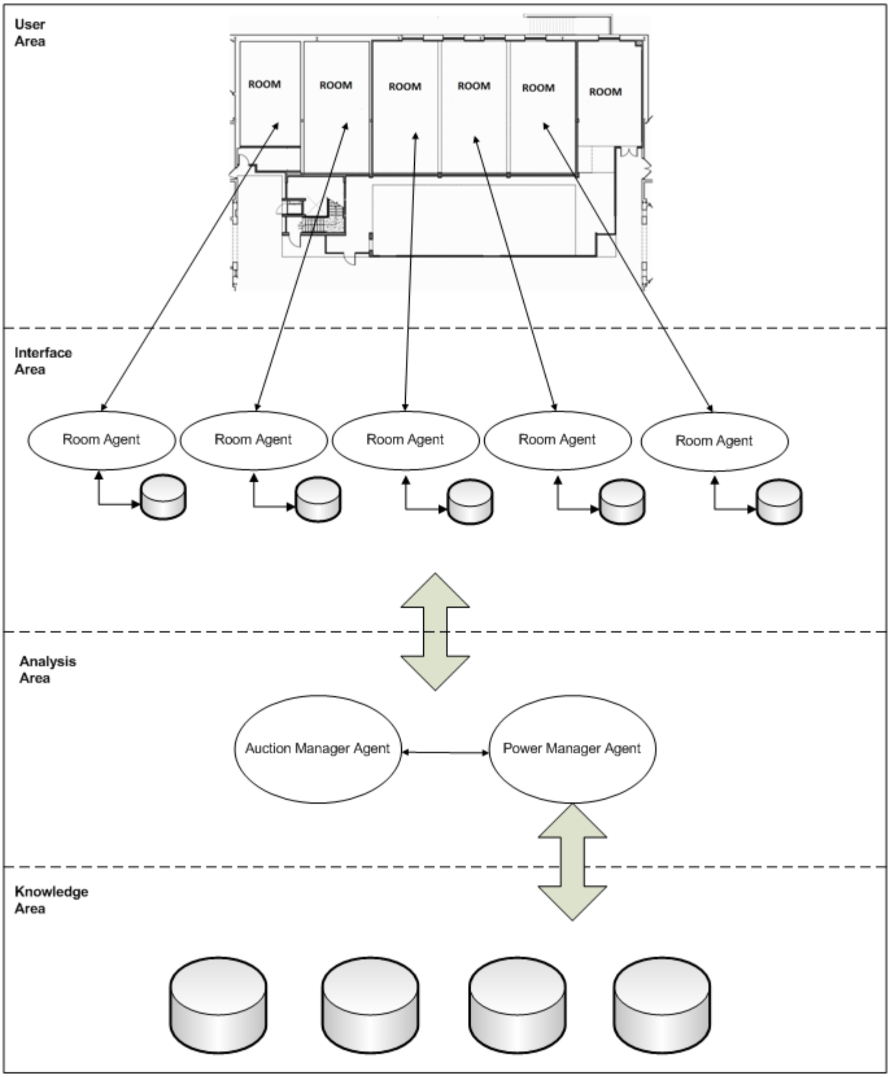

Fig. 1 A schematic overview of the proposed MAS

3.1 Implementation of the Proposed Auction Model

The kernel of the proposed power management system is an auction based MAS. The cooperation between the agents described in the previous sections, is aimed at defining of an auction model. This means that the whole agency behavior is organized according to specified rules. Rules are short declarations finalized to define each agent behavioral model. A rule is composed of two parts: a conditional clause and a declarative part [5].

The process rules are defined in relation to different aspects of the negotiation to manage the auction: starting auction rules, bidding submission rules, and auction management rules. A detailed list of these rules is reported in Table 1.

Table 1 Auction based MAS behavior rules

Starting auction rules	
1	If a room exists then a Room Agent exists
2	If the last auction was realized G hours before then there would be an auction round
3	If a Room Agent participates to an auction round then this pays F coins
4	If a new day of biddings is instantiated then each Room Agent holds T coins
5	For each Room Agent there is a wallet W containing coins available for bidding
6	If a new auction round is realized then a global amount of power supply H is available
7	If a new auction round is realized then H is completely assignable
8	For each Room a required power supply Q for Air Conditioning system exists
Bidding submission rules	
9	For each Room and each auction round there is a presence probability PP – range [0;1]
10	For each Room and each auction round there is an unease level UL – range [0;1]
11	For each Room and each auction round there is a Room Agent's bid B of U coins where B = f(UL,PP,W) – range [0; W]
12	If a Room has PP = 0 then the Room makes B = 0
13	If a Room has UL = 0 then the Room makes B = 0
Auction Management Rules	
14	For each B an Auction Manager evaluation exists
15	For each auction round the Auction Manager produces a standing ordered by B's amount (starting from bigger B to lower)
16	For each auction round a set of winning Rooms exists
17	If a "Room Agent 1" bids U1 coins and a "Room Agent 2" bids U2 coins where U1>U2 then the "Room Agent 1" has priority on power supply than "Room Agent 2"
18	If a winning "Room Agent" requires a power supply Q then the residual power supply available is delta H=H-Q
19	If a winning "Room Agent" requires a power supply Q > deltaH then the bid is considered NULL
20	If a Room Agent wins an auction round then this pays the bid coins
21	For each auction round the Auction Manager acquires a jackpot J = SUM (winners's B)
22	For each auction round a Room Agent receives (J/number of Room Agents) coins
23	If a Room Agent wins an auction round and requires Q<=deltaH then the Power Manager Agent assigns him Q

As shown in Table 1, the main MAS target is the minimization of daily power consumption. For this target the system organizes a new auction instance each G hours, where G is a configurable parameter. The minimal auction round granularity is set to one hour in order to consider a minimal lot of time for guarantee user's perception.

During auctions, each Room Agent has a personal budget (the wallet W in rules of Table 1). Each Room Agent has an attitude to offer virtual money directly proportional to the user requirements. For example, if an agent has revealed a comfortable temperature in the room, it will enter in the auction with a low bid and vice- versa. The condition where an agent finishes too early its budget raises an alarm for the system manager. Indeed, in normal conditions, an air conditioner should be able to reach a stable condition in the room in a reasonable time. If this does not happen it is possible that the air conditioner is not well sized for that room or that there is an inappropriate user's behavior (e.g., the air conditioner is on while the door or windows are opened).

The agency is organized on stable amount of global money. In particular, for each auction round, money acquired by Auction Manager, is equally distributed to all the Room Agents. This condition allows for the persistent participation of any Room Agent to any auction round. So it is possible to get a greater success chance for those bidders that had a conservative approach in previous auction round.

At the same time, it is important to avoid that a Room Agent corresponding to a long time empty room collects the whole money available in the agency. This is realized with a daily auction initialization (Rules 4 in Table 1). This permits to make bids for any Room Agent starting from a common daily condition.

4 Experimental Live Tests

In order to show the functionality of the system a set of tests were performed. During these tests all the possible (real) combinations of outdoor and indoor parameters are used. The mean values of the results obtained are reported in this section. In order to highlight the impact of the proposed power management system on the power consumption optimization and on the level of guaranteed wellness, the system was tested with and without DSM. In particular, the building thermal behavior and the level of wellness achievable inside are here presented for the system with the air conditioner plant.

The results obtained for two reference months (January and July) are reported. These two months are the most expensive from an energetic point of view because they are respectively the coldest and the hottest months when the academic activity is intense.

4.1 System with the Air Conditioner Plant Managed by the Proposed Power Management System

This section shows the results obtained in the same conditions described in the previous sections but with the presence of an air conditioner plant managed by the proposed auction based power management system. This system automatically shut down the air conditioner in the rooms where there are no people.

Figure 2 and Figure 3 show the obtained results respectively in January and July. In both figures there is a green line highlighting the periods of time when the analysed room (lecturer theatre) wins an auction (and so, it can turn on its air conditioner).

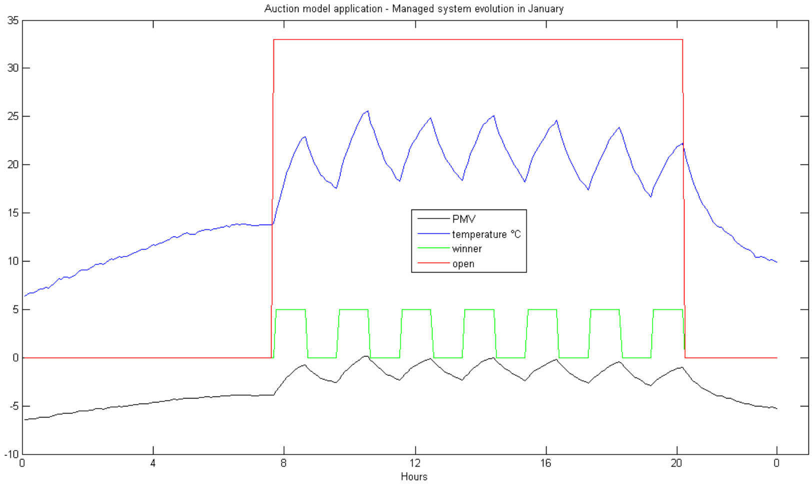

Fig. 2 Daily system evolution in January using an air conditioner plant managed by the auction based power management system

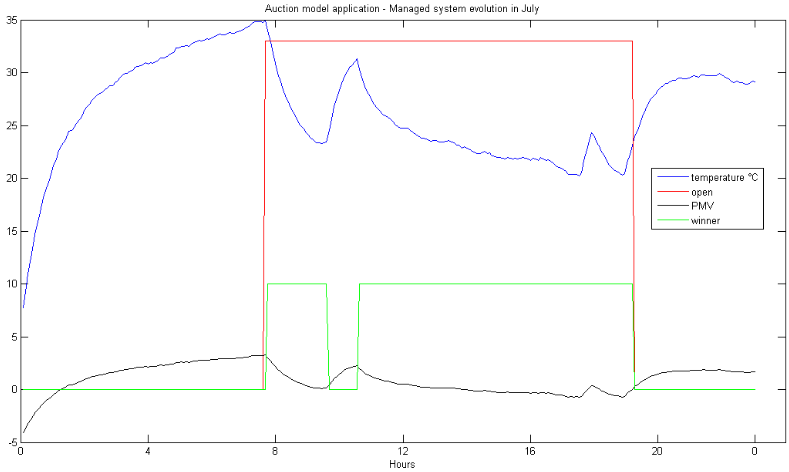

Fig. 3 Daily system evolution in July using an air conditioner plant managed by the auction based power management system

In order to show a quantitative evaluation of the effectiveness of the proposed system, Table 2 reports the mean values of temperature, the PMV index obtained in each room. In January it is possible to save the 33% of energy obtaining a good mean level of wellness in all the rooms. Only in library there is a mean value of PMV equal to -1.12 that is out of the optimal range ([-0.5; +0.5]), this value corresponds to a percentage of satisfied people greater than 75%. In July, in order to obtain good value of wellness it is necessary to increase the quantity of used power energy. Indeed, the percentage of saved energy is 25%.

Table 2 Mean values of temperature and PMV obtained in each room and percentage of saved power in January and July

January	PMV	Temp. (°C)	July	PMV	Temp. (°C)
Bar	-0,53	23,58	Bar	0,29	23,98
Library	-1,12	21,86	Library	0,99	26,57
Classroom 1	0,66	27,05	Classroom 1	-0,08	22,64
Auditorium	-0,28	24,30	Auditorium	0,04	23,08
Classroom 2	0,27	25,92	Classroom 2	0,25	23,84
Classroom 3	0,01	25,16	Classroom 3	-0,02	22,86
Classroom 4	0,36	26,17	Classroom 4	-0,06	22,72
Classroom 5	0,56	26,76	Classroom 5	-0,16	22,34
Classroom 6	0,30	25,99	Classroom 6	0,60	25,12
Classroom 7	0,47	26,50	Classroom 7	0,09	23,26
Classroom 8	0,49	26,55	Classroom 8	0,03	23,02
Classroom 9	0,73	27,23	Classroom 9	0,00	22,92

5 Discussion and Conclusions

The paper presents an innovative intelligent DSM system managed according to an auction based multi-agent system. It has been tested within a project aiming at defining a technology monitoring and management of power consumption for real civil applications. The solution adopted for the application discussed, based on the characterization of the habits of individual users, allows to obtain the best control practice.

The proposed system showed a good capability to optimize energy consumption in the test case addressed. The results shown in Table 2 demonstrate the effectiveness of the rules adopted for the proposed system in energy saving while maintaining a good level of comfort to the users. In particular, in January, it was possible to save the 33% of energy obtaining a good average level of wellness in all the rooms. The worst results are obtained in the library room where there is a mean value of PMV index equal to -1.12 that is out of the optimal range ([-0.5;

+0.5]). In July, in order to obtain a good value of wellness, it is necessary to increase the quantity of used power energy. Indeed, the percentage of saved energy is 25%. It should be highlighted that these two months are the most critical ones from a climatic point of view in the analysed area. For the other months, it is possible to achieve also better results in terms of energy saving.

This model may become the starting point of a path aiming at satisfying the needs of individual users in order to minimize the overall energy consumption of any requirement.

Acknowledgments. The innovative contents described in this paper are disclosed after the permission of TES Energy System S.r.l company, which committed to Laboratorio Kad3 S.c.a.r.l. the research project called "Power Consumption Monitoring and Optimization (Po.Co.Mo.Pti.)".

References

[1] Nadel, S.: Utility Demand-Site Management Experience and Potential - A Critical Review. Annual Review of Energy and the Environment 17, 507–535 (1992)
[2] Di Lecce, V., Pasquale, C., Piuri, V.: A Basic Ontology for Multi Agent System Communication in an Environmental Monitoring System. In: Proc. IEEE CIMSA, Boston, MA, pp. 45–50 (2004)
[3] Di Lecce, V., Calabrese, M., Soldo, D.: Semantic Lexicon-based Multi-Agent System for Web Resources Markup. In: Proc. ICIW 2009, Mestre, Italy, pp. 143–148 (2009)
[4] Di Lecce, V., Calabrese, M.: Describing non-selective gas sensors behaviour via logical rules. In: Proc. IEEE/ACM SENSORCOMM 2011, Nice/Saint Laurent du Var, France, pp. 6–11 (2011)
[5] Koppensteiner, G., Merdan, M., Lepuschitz, W., Reinprecht, C., Riemer, R., Strobl, S.: A Decision Support Algorithm for Ontology-based Negotiation Agent within Virtual Enterprises. In: Proc. IEEE FITME 2009, Sanya, China, pp. 546–551 (2009)