Available online at www.sciencedirect.com
ScienceDirect
Building and Environment 42 (2007) 3562–3569
BUILDING AND ENVIRONMENT
www.elsevier.com/locate/buildenv

Intelligent building energy management system using rule sets

Haris Doukas*, Konstantinos D. Patlitzianas, Konstantinos Iatropoulos, John Psarras

National Technical University of Athens, School of Electrical and Computer Engineering, Decision Support Systems Laboratory (EPU-NTUA), 9, Iroon Polytechniou str., 15773 Athens, Greece

Received 9 March 2006; received in revised form 28 August 2006; accepted 16 October 2006

Abstract

The current study presents an intelligent decision support model using rule sets based on a typical building energy management system. In addition, the model's impact on the energy consumption and indoor quality of a typical office building in Greece is presented. The model can control how the building operational data deviates from the settings as well as carry out diagnosis of internal conditions and optimize building's energy operation. In this context, the integrated "decision support model" can contribute to the management of the daily energy operations of a typical building, related to the energy consumption, by incorporating the following requirements in the best possible way: (a) the guarantee of the desirable levels of living quality in all building's rooms and (b) the necessity for energy savings.

Keywords: Intelligent models; Building energy management systems; Rule sets

1. Introduction

Buildings are one of the fastest growing energy consuming sectors. It is estimated that the amount of the energy consumed in the European Union's (EU) buildings reaches 40–45% of total energy consumption [1], about two-thirds of which is used in dwellings. In the current decade, energy demand of the tertiary and residential sectors are increasing 1.2% and 1.0%/annual, respectively [2]. As a result, energy usage in the above sectors of EU is responsible for approximately 50% of the greenhouse gas (GHG) emissions [3].

In addition, the requirements for the assurance of the necessary thermal comfort, visual comfort and indoor air quality are increased, especially in the prevailing situation of price fluctuations, the rapid population and the technology's evolution. In this context, efforts are currently focused on the satisfaction of the energy needs for the energy efficient buildings, by assuring the operational needs with the minimum possible energy cost and environmental protection.

Towards this direction, the role of the building energy management systems (BEMS) is known and significant, since these systems can contribute to the continuous energy management and therefore to the achievement of the possible energy and cost savings. The BEMS are generally applied to the control of active systems, i.e. heating, ventilation, and air-conditioning (HVAC) systems, while also determining their operating times. In the above efforts, the performance of the BEMS is directly related to the amount of energy consumed in the buildings and the comfort of the buildings' occupants.

The majority of recent developments in BEMS have followed the advances made in computer technology, telecommunications and information technology. In this context, a number of modern techniques and methods have been proposed in the international literature for improving specific systems' controls. To the best of our knowledge, techniques for HVAC control, such as pole-placement, optimal regulator and adaptive control [4,5] have been presented. More computerized methods, such as genetic algorithms [6] and neural networks [7] have been proposed for the control optimization of specific HVAC systems, too. Other methods for optimized building's systems control have, also, been proposed including empirical models [8], weighted linguistic fuzzy rules [9], simulation optimization

*Corresponding author. Tel.: +30 210 7722084/3583; fax: +30 210 7723550.
E-mail address: h_doukas@epu.ntua.gr (H. Doukas).

0360-1323/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.buildenv.2006.10.024

[10] and online adaptive control [11]. Integrated control systems utilizing genetic algorithms, optimized fuzzy controllers for the indoor environmental management [12,13] and occupancy prediction with knowledge-based system [14] have been developed, applied and tested.

In addition, BEMS are currently being developed to be applied in buildings, namely the "intelligent buildings" and a number of studies [15–17] have been presented for modern intelligent buildings and control systems, revealing the ongoing interest of the scientific community on this topic. Following the above studies, evident is the need for the existence of an integrated "decision support model" for the management of the daily energy operations of a typical building, which can incorporate the following requirements in the best possible way: (a) the guarantee of the desirable levels of living quality in all building's rooms and (b) the necessity for energy savings. In this context, an intelligent decision support model, that could control how the building operational data deviates from the settings as well as carry out diagnosis of internal conditions and optimize building's energy operation, is not present in the literature. In addition, the methods and techniques of rule sets can represent a very efficient approach for incorporating more intelligence in the BEMS.

With respect to the above, the main goal of this paper is to present an intelligent BEMS using rule sets for the management of all related energy building's operations. In addition, the model's impact on the energy consumption and indoor quality of a typical office building in Greece is presented. Apart from the introduction, the paper has the following sections:

- The second section is devoted to the presentation of the adopted methodology for the development of the decision support model using expert knowledge for building energy management.
- The third section is devoted to the presentation of the computerized decision support model in terms of its architecture, the developed rules and the appraisal of its pilot application.
- The last section summarizes the main conclusions drawn up from this paper.

2. Methodology

The decision support model's infrastructure is based on the characteristics of a typical BEMS logic [18]. As illustrated in Fig. 1, the model's philosophy is based on the general concept of a model with the capability of being adapted to any building's specific requirements, provided that appropriate "mapping" of the building's areas and its elements is elaborated.

The current model includes the following components:

- *Indoor sensors*: Sensors that measure or record temperature, relative humidity, air quality, movement and luminance in the building areas.

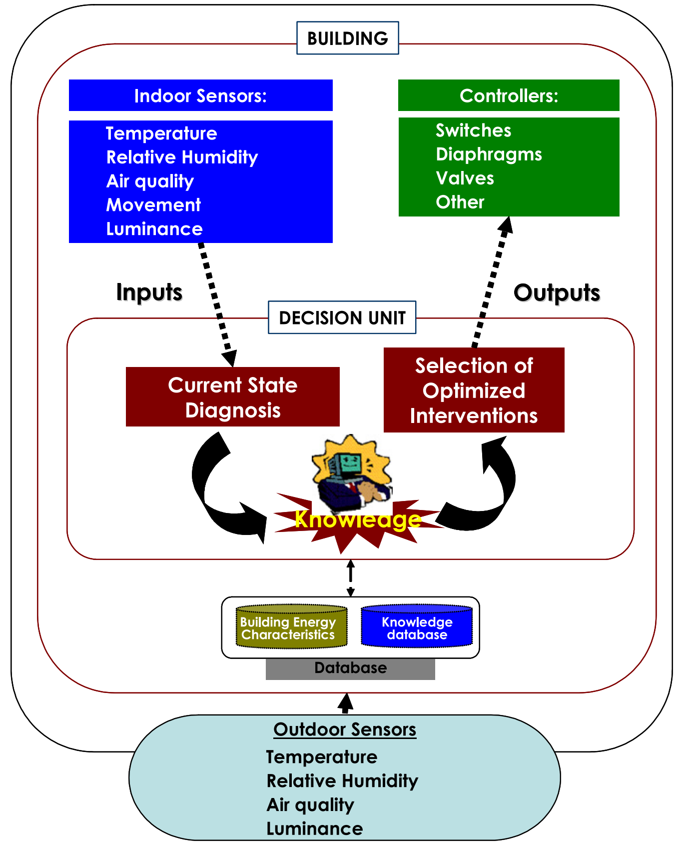

Fig. 1. The model's philosophy.

- *Outdoor sensors*: Sensors for the outdoor conditions such as temperature, relative humidity and luminance, which are essential for the efficient model's operation.
- *Controllers*: This component category contains switches, diaphragms, valves, actuators etc.
- *Decision unit*: A real time decision support unit is included, with the following capabilities:
  - Interaction with the sensors for the diagnosis of the building's state and therefore the formulation of the building's energy profile.
  - Incorporation of expert and intelligent system techniques in order to select the appropriate interventions, depending on the building's requests.
  - Communication with the building's controllers for the application of the decision.
- *Database:* It includes the database for the building energy characteristics and the knowledge database, where all essential information is recorded.

  The followed procedure represented by a logical flow diagram is shown in Fig. 2.

More specifically, the procedure is defined as follows:

- *User requirements*: Users inside the building define their requirements for indoor conditions setting values to control parameters, namely the temperature, relative humidity, air quality and luminosity.

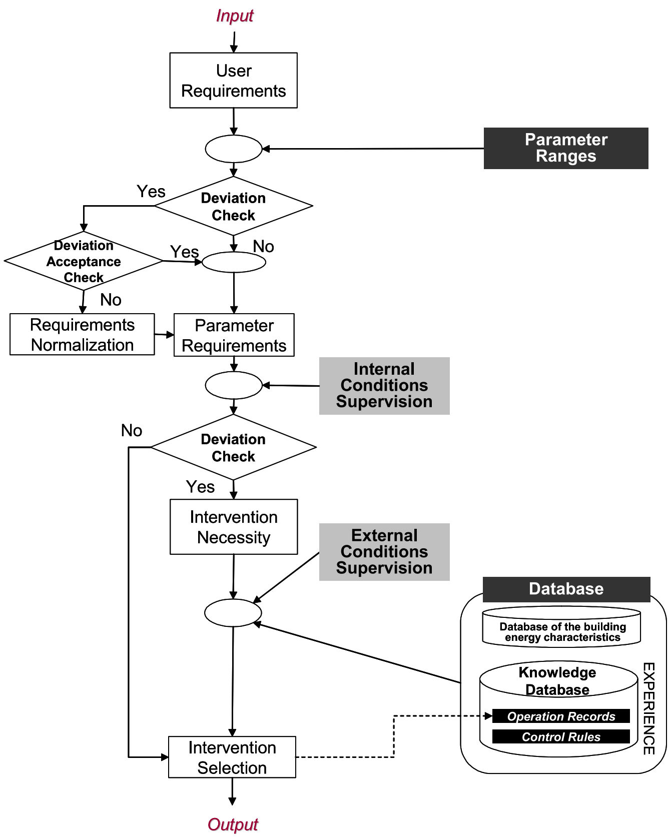

Fig. 2. The model's procedure.

- *Parameter requirements*: Users' requirements are compared to defined parameters' ranges. For each area/room type, specific parameters' ranges have been defined, which provide comfortable indoor conditions. In particular, the standards used to defined air quality (air pollutants concentration in parts per million—ppm), thermal comfort control (indoor temperature and relative humidity) and luminosity were based on the guides of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [19] and the International Organization for Standardization (ISO) standards for thermal comfort conditions [20] and quality of indoor air for human occupancy [21], as well as lighting of work places [22]. The comparison result is the following:
  - If there is no deviation between user's input and the parameters' ranges (no), then, user's input is selected.
  - If there exist a deviation between the user's input and the parameters' ranges (yes), then, the model proceeds as follows:
    - If the model status is set to "manual", the model ignores the deviation and uses the user's input.
    - If the model status is set to "auto", the model normalizes user's input within parameters' ranges, choosing values with minimum deviation from user's input.
- *Intervention necessity*: Following the determination of user's requirements, the recording of current indoor conditions through appropriate sensors and the deviation between them is calculated.
  - If there is no deviation between current and user input state, the control procedure exits without intervention.
  - If deviation occurs, then the intervention necessity appears.
- *Intervention selection*: When intervention necessity appears, the model decides upon the appropriate intervention method. Through a logical and comparative sequence, the decision unit defines the intervention method and produces adequate signals for the building's controllers. In particular, the following data sources are used for the selection of the appropriate intervention:
  - Indoor and outdoor conditions' records as well as the state of the building's openings (such as windows and doors) because the contribution of external conditions is very important for the effective control of the building's temperature and luminosity, in the framework of energy savings.
  - Data from the model's database, which includes the database for the building energy characteristics and the knowledge database:
    - Database for building energy characteristics: It includes information about the building's structural components such as the building's areas or rooms and their cooling, heating, lighting and other units. Moreover, types of areas and rooms in the building are defined through parameterized recording of their characteristics along with their corresponding operation records. In addition, this database contains information about spatial energy consumption in the building and the default internal conditions about each building area. Therefore, a fully updated description of the building's state, including measurements and technical specifications of every component is originated.
    - Knowledge database: Knowledge database stores information, which constitutes the model's expert knowledge and intelligence. Through the knowledge database the model recalls information about building areas or rooms and uses them in the decision process. Knowledge data are divided into the following categories:
      - ☐ Historical records: User's requirements and model's decisions are recorded and stored in the database. This is a very important feature, since it allows tracing of high-consumption situations and their causes, as well as evaluation of areas and rooms behavior, through the intervention methods that are decided by the model.
      - ☐ Expert rules: Rules defined for the decision unit are also, stored in the knowledge database. The rules appropriately combine the building's state with the user's requirements, thus

providing logical and expert reasoning to the model.

Finally, the model's decisions are a sequence of signals and commands to the controllers and actuators for the application of the model's output.

With respect to the above, the model has the ability to modulate (with the help of the rules) intelligent interventions in order to ensure the thermal comfort and the energy savings, such as:

- Evaluate and compare the current building loads with the desirable ones (from the historical data) and in case of extreme energy consumption to cut down some of these, based on each area's special needs.
- Calculate thermal and air quality indices, through the use of historical data and determine the areas' adaptability to the imposed interventions.
- Activate appropriate procedures for the preheating and switching off of the equipment in certain time moments, depending on the registered energy profile.

3. Model development

3.1. Architecture

The decision support unit was implemented with the following software tools and applications:

- "MS Access" was used for the development of the database for the building energy characteristics and the knowledge database.
- "Visual Basic 6.0" was the programming language that provided interconnectivity, through the database, sensors and controllers of the building.
- "Clips", and particularly version 6.2 released in spring 2002 [23], was embedded in the model, to provide processing of model's rules and inference to the decision process.

The architecture of the presented decision unit is graphically illustrated in Fig. 3.

In particular, "Visual Basic 6.0" and "MS Access" were selected since their applications are well known and operate with low hardware requirements. Especially as concerns the databases development, the stored building energy characteristics and the knowledge database are fully dynamic, allowing model administrators to define new buildings, types of rooms or areas, components and rules.

In addition, C language integrated production system ("CLIPS"), which is an expert system shell, has received widespread acceptance throughout governmental organizations, industry and academics due to its portability, extensibility, capabilities and low cost. In the international scientific literature, "CLIPS" has been used for power plant design [24], manipulation of an intelligent database for engineering applications [25] and implementation of various intelligent systems [26–28]. In this context, "CLIPS" was used in the current model to provide a complete environment for the development of a rule based expert system, thus reducing the effort and cost involved in developing an expert system.

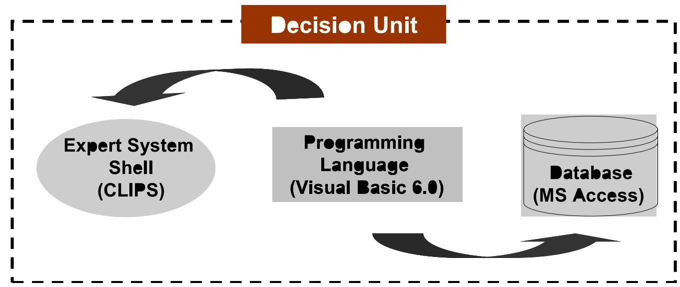

Fig. 3. The architecture of the decision unit.

With respect to the above, the selected development platform provides scalability, reliability and compatibility with most desktop personal computers. In this context, it was assured that the presented model can be readable and accessible to everyone from novice programmers to advanced system architects.

3.2. Development of rule sets

The aim of the decision support unit design was to utilize rule sets altered by the data recorded from the BEMS's operation. In this context, a typical building was modeled and control points were defined for the indoor conditions and the electro-mechanical components of the building and were parameterized. In particular, the parameters were categorized as follows:

- *Input*: The first set includes parameters concerning the indoor conditions and the time scheduling.
- *Output*: The second set of parameters concerns the model controllers and actuators.
- *Supportive:* This set of parameters registers the room's convenience or difficulty to be controlled.

In this context, a set of rule sets has been created, covering all probable requests of a typical building. These rules, which combine input and output parameters, have the following categorization:

- Internal comfort conditions.
- Building energy efficiency.
- Compatibility of decision support unit.

The first rule set ensures indoor comfort conditions for every area or room in the building and can be divided into the following four subcategories:

- *Indoor temperature/relative humidity*: It includes rules for the supervision of temperature and relative humidity

levels, so as to be in consistency with the default levels for each room type.
- *Air quality*: It incorporates rules for the monitoring of indoor air quality (via CO_2 concentration sensors) and appropriate adjustment to default levels for the specific area or room.
- *Luminance*: It includes rules for the monitoring of luminosity levels (via sensors) as well as the necessary adjustments to the lighting appliances, based on the default levels for each room type or use.
- *Movement*: It incorporates rules for the monitoring of movement inside building areas and rooms (via movement sensors) and the appropriate modifications of the electro-mechanical components' operation, according to the presence or not of people in the building.

The second basic rule set includes rules concerning the energy efficiency of a typical building. This category consists of the following subcategories:

- *Starting/ending optimization*: Rules about model starting and ending, according to each area or room working hours have been composed including pre-warming and smooth power down procedures for accomplishing the possible energy savings.
- *Procedural hierarchy*: Rules concerning the intervention hierarchy for the temperature, relative humidity, air quality and luminance adjustment for the optimum operation have been formulated. In this context, rules about cooperation between building's electro-mechanical components and outdoor conditions are included, such as the use of fresh air for cooling and the use of outdoor lighting through moving shutters for increasing indoor luminance.
- *Energy management optimization*: Rules that control energy consumption of each area or room in the building have been elaborated. The main objective of these rules was to locate high-consumption periods during operation and the electro-mechanical components that are responsible. In this context, rules that perform actions for elimination of consumption peaks without discomfort whenever possible are elaborated.

Based on these rule sets, the decision unit procedural steps are the following:

- *System initialization*: The rules define allowed ranges for input variables about temperature, relative humidity and air quality that should be used for comfort and energy savings.
- *Intervention necessity*: The rules determine appropriate thresholds for interventions in heating, cooling, hydration, dehydration, ventilation and lighting.
- *Deviation scaling of indoor conditions*: The rules identify deviations between user requirements and current area or room conditions for all control parameters.
- *Intervention selection*: The rules define the selection of actions in order to cover the intervention needed. These actions include switching on/off of buildings' components and determine the components that will be used to adjust indoor conditions.
- *Intervention intensity determination*: The rules determine how intense the interventions will be, according to each area or room indicators and the scaling of the electro-mechanical components' controllers.

3.3. A pilot appraisal

The use of energy in buildings such as public and private buildings, schools, hospitals, hotels and athletic facilities, constitutes 30% of total national energy demand and contributes about 40% of the carbon dioxide emissions in Greece [29]. Heating and refrigeration of buildings consume the largest part of energy expended in domestic uses [30,31]. Taking into consideration the above, it can be considered that intelligent BEMS can significantly contribute to the minimization of the buildings' energy losses in Greece.

In this context, the Hellenic General Secretariat for Research and Technology (GSRT) has funded the project "Building Intelligence: Energy Savings in Buildings via Intelligent Control and Communications (ESBi2C)", where the authors' team participated, aiming to develop an intelligent BEMS based on state-of-the-art building automation and networking technology coupled with advanced multi-objective optimization techniques. With respect to the above, the presented model was applied to one of the project contractor's facilities, namely the office buildings of the "ZENON S.A." company in Athens, Greece.

The specific building, used for the presented model's application consists of three (3) floors and a total surface of $485.22\,m^2$. Energy demands of the building are fully covered by electricity and other means of energy production are not present. More specifically, building energy loads consist of the following:

- Lighting (inside and outside the building).
- Hydraulic elevator.
- HVAC central system.
- Computers and office equipment (printers, faxes).
- Server room (including telephone center, servers, routers and networking equipment).
- Electric pumps used to discard pluvial water.

The building is equipped with a typical BEMS, with the following components:

- Separate micro-controllers, sensors and actuators for luminance, temperature, air quality control.
- HVAC central system with local controllers for each area or room in the building and central computer assisted control.

- Air distribution system of the HVAC system, which can be characterized as local (or decentralized), as the air flows is introduced without any previous heating or cooling procedures, while afterwards it is adjusted to the appropriate temperature through the use of internal units. Moreover, the flow of the incoming air can be generally characterized as variable, due to the existence of scales in the internal units' ventilators. The incoming air does not come from a central air management unit but from a pipeline, which introduces ''outdoor'' air to the system.
- Sensors for presence of occupant control (movement or not in the building's areas).
- Energy consumption devices.
- Separate central control management software for areas or rooms.

With respect to the above, the appropriate ''mapping'' of the building areas and its elements were elaborated by the presented model, as shown in Figs. 4 and 5. In particular, the mapping of building's rooms and the assigned room types are illustrated in Fig. 4. Each room's equipment and sensors are configured through the ''DEVICES'' and ''SENSORS'' buttons. The screen illustrated in Fig. 5 is used for determining and configuring the devices in each room of the building. The types of every component are defined before the equipment is added to the rooms.

In this context, a fully updated description of the building's structure, including technical specifications for every component was originated. Following this, the model was applied, tested and optimized on the building for a time period of about a year. The application was really

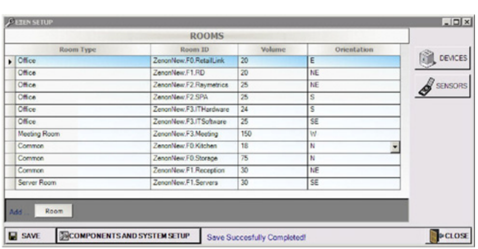

Fig. 4. Room type specifications.

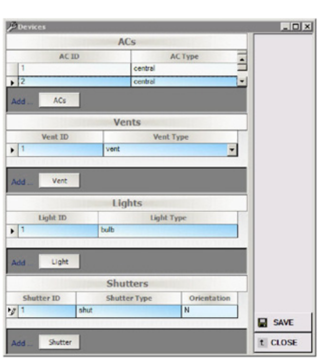

Fig. 5. Sensor type specifications.

necessary for the model's fine tuning as well as for the judgment of its operation in a real life building.

Application results from the model's operation from October 2004 to October 2005 were categorized according to the managed indoor comfort conditions (temperature, relative humidity, air quality and luminance) and energy consumption. The results for each category are presented below:

- *Temperature–relative humidity–air quality:* Room condition measurements showed that temperature, relative humidity and air quality levels were in the defined ranges varying according to user requirements. Discomfort situations almost never occurred especially due to the effective relative humidity and air quality control. Preheating and switching off procedures contributed to the energy comfort both in summer and winter. Especially in winter, external air was never used for heating but, shutter control allowed sun light to improve heating procedures.
- *Luminance:* Luminance levels inside building areas or rooms also ensured comfort conditions. In addition, satisfying control of building shutters and lights was achieved. Sometimes, the priority to save energy through HVAC operation lead to closed shutters during summer sunny very hot days, which proved to be more energy efficient.
- *Energy saving:* Cumulative operation data about building energy consumption compared to previous year consumption records revealed a significant energy saving result of approximately 10%. In particular, the building's annual electricity consumption was reduced from 106.5 MWh (October 2003–October 2004) to 95 MWh (October 2004–October 2005). More detailed examination of collected information showed that energy savings were higher during warm days. The achieved energy savings were mainly due to the optimized utilization of the building's electro-mechanical equipment and avoidance of HVAC and lighting loads in areas with no occupancy.

The current model, which used a knowledge-based expert system to control the building's operational data, carry out diagnosis of internal conditions and optimize building's energy operation, reduced the energy consumption in satisfactory levels. Additional and not so sophisticated measures can be elaborated so as to reduce more energy consumption without jeopardizing the health of occupants. In particular, for the specific examined building, some viable measures are the following:

- Replacement of existing low efficiency lamps (incandescence) with more efficient fluorescent lamps in the areas for public use areas;
- Installation of heat-insulating curtains in the offices with a south orientation, so as to minimize the penetration of the solar radiation, especially in the summer region;

- Installation of "motors" for the automatization of the existing shades in the office areas;
- Installation of variable speed drivers—VSD in fans and pumps.

4. Conclusions

The integration of computer and information technology into the BEMS has been very popular recently. Such central co-ordination systems are able to monitor and control many of the activities and services associated with buildings. In this effort, significant is the role of the decision support systems, which can contribute to the continuous energy management of the daily operations of a typical building, aiming to preserve the comfort conditions of buildings' occupants and minimize the energy consumption and cost.

In the above context, the presented intelligent model using rule sets for building energy management can be an innovative and useful decision support system, aiming at guarantying the desirable levels of living quality as well as energy savings for environmental protection. The system enables central monitoring of energy consumption in buildings, by translating the building's energy knowledge into several rules and finally into electronic commands to actuator devices. In particular, a reliable energy profile can be created by the system, using expert knowledge, and "wrong" decisions can be detected and eliminated, through the intelligent monitoring and optimized start/stop of HVAC and lighting controls.

Based on the results of its pilot application, it can be considered that the current model's operation was satisfactory, since it contributed to the improved indoor air quality of the building, while assuring the possible energy saving. In addition, its interface was characterized as very friendly and facilitative, based on the users' comments on its pilot application. Moreover, its open architecture allows easy and continuous updates and unlimited horizontal and vertical expandability. Therefore, the model's design allows its application to a large number of building categories so as to assure its flexibility. Finally, based on the current study, it was clearly illustrated that expert knowledge has significant potential for improving buildings energy management, since it provides the ability to modulate, with the help of the rules, intelligent interventions.

Acknowledgment

This paper was based on research conducted within the "Building Intelligence: Energy Savings in Buildings via Intelligent Control and Communications (ESBi2C)" project of the Hellenic General Secretariat for Research and Technology (GSRT). The content of the paper is the sole responsibility of its authors and does not necessarily reflect the views of the GSRT.

References

[1] Eurostat. Energy balance sheets. Data 2002–2003. Luxemburg: Eurostat; 2005.

[2] European Commission Directorate General for Energy and Transport. European energy and transport trends to 2030. Brussels, 2003.

[3] European Environment Agency (EEA). Annual European community greenhouse gas inventory 1990–2002. EEA report, 2004.

[4] Zaheer-Uddin M. Optimal, sub-optimal and adaptive control methods for the design of temperature controllers for intelligent buildings. Building and Environment 1993;28(3):311–22.

[5] Zaheer-Uddin M. Intelligent control strategies for HVAC processes in buildings. Energy 1994;19(1):67–79.

[6] Huang W, Lam HN. Using genetic algorithms to optimize controller parameters for HVAC systems. Energy and Buildings 1997;26: 277–82.

[7] Kanarachos A, Geramanis K. Multivariable control of single zone hydronic heating systems with neural networks. Energy Conversion and Management 1998;39(13):1317–36.

[8] Yao Y, Lian Z, Hou Z, Zhou X. Optimal operation of a large cooling system based on an empirical model. Applied Thermal Energy 2004;24:2303–21.

[9] Alcala R, Casillas J, Cordon O, Gonzalez A, Herrera F. A genetic rule weighting and selection process for fuzzy control of heating, ventilating and air conditioning systems. Artificial Intelligence 2005;18:279–96.

[10] Fong KF, Hanby VI, Chow TT. HVAC system optimization for energy management by evolutionary programming. Energy and Buildings 2006;38:220–31.

[11] Wang S, Burnett J. Online adaptive control for optimizing variable-speed pumps of indirect water-cooled systems. Applied Thermal Energy 2001;21:1083–103.

[12] Kolokotsa D, Stavrakakis GS, Kalaitzakis K, Agoris D. Genetic algorithms optimized fuzzy controller for the indoor environmental management in buildings implemented using PLC and local operating networks. Artificial Intelligence 2002;15:417–28.

[13] Kolokotsa D, Kalaitzakis K, Antonidakis E, Stavrakakis GS. Interconnecting smart card system with PLC controller in a local operating network to form a distributed energy management and control system for buildings. Energy Conversion and Management 2002;43:119–34.

[14] Clark G. Artificial intelligence and networking in integrated building management systems. Automation in Construction 1997;6:481–98.

[15] Wong JKW, Li H, Wang SW. Intelligent building research: a review. Automation in Construction 2005;14:143–59.

[16] Al-Rabghi OM, Akyurt MM. A survey of energy efficient strategies for effective air conditioning. Energy Conversion and Management 2004;45:1643–54.

[17] Kua HW, Lee SE. Demonstration intelligent building—a methodology for the promotion of total sustainability in the built environment. Building and Environment 2002;37:231–40.

[18] Levermore GJ. Building energy management systems. London: E & FN Spon; 2000.

[19] American Society of Heating. Refrigerating and air-conditioning engineers (ASHRAE). ASHRAE handbook—HVAC applications. 2003.

[20] The International Organization for Standardization (ISO). Moderate thermal environments—determination of the PMV and PPD indices and specification of the conditions for thermal comfort. 2nd ed. ISO 7730:1994, December 1994.

[21] The International Organization for Standardization (ISO). Building environment design—indoor air quality—methods of expressing the quality of indoor air for human occupancy. ISO/DIS 16814, April 2006.

[22] The International Organization for Standardization (ISO). Lighting of work places—part 1: indoor. ISO/CIE 8995-1:2002, June 2002.

[23] Giarrantano JC. CLIPS user's guide. 1998.

[24] Fatima DCC, Perz EW. A decision support system for power plant design. European Journal of Operational Research 1998;109:310–20.
[25] Dong Y, Goh A. An intelligent database for engineering applications. Artificial Intelligence in Engineering 1998;12:1–14.
[26] Lee S-J, Wu C-H. CLXPERT: a rule-based scheduling system. Expert Systems With Applications 1995;9(2):153–64.
[27] Zhang WY, Tor SB, Britton GA, Deng Y-M. EFDEX: a knowledge-based expert system for functional design of engineering systems. Engineering with Computers 2001;17:339–53.
[28] Simic G, Devedzie V. Building an intelligent system using modern internet technologies. Expert Systems With Applications 2003;25:231–46.
[29] Regulating Authority for Energy (RAE). The energy system in Greece. June 2004.
[30] Paravantis J. Energy savings in buildings: heating and passive cooling. Energy 1995;17:49–59 [in Greek].
[31] Athanasakou E. Solar passive systems and technologies. Energy 1996–1997;24:55–66 [in Greek].