An expert model for monitoring building's operations via BEMS

K. Iatropoulos, H. Doukas, D.K. Patlitzianas and J. Psarras
Decision Support Systems Lab (EPU-NTUA), School of Electrical and Computer Engineering, National Technical University of Athens, Greece

N. Tourlis and S. Louizidis
LDK Consultants, Athens, Greece

ABSTRACT

Nowadays, the necessity for the reservation of comfortable living conditions as well as energy efficiency in the buildings sector is more and more emerging. Towards this direction, an expert model for the intelligent monitoring of the energy efficiency in conventional buildings has been developed. A description of this model will be the aim of this paper. The general philosophy of the model is based on the principles of the "Building Energy Management Systems (BEMS)". The innovation lies on the usage of an appropriate experienced decision support unit, which supplements the main components of BEMS, making a diagnosis of the internal conditions for each situation. Through the "experience", the unit decides about the necessary interventions, giving thus the suitable commands to the devices' activators. The model was applied to an office building of a Greek company with satisfactory results.

1. INTRODUCTION

The requirements for the assurance of the necessary thermal comfort, visual comfort and indoor air quality in buildings are increased. Efforts are currently focused on the satisfaction of the energy needs for buildings, by safeguarding operational needs with the minimum possible energy cost and the environmental protection.

The Building Energy Management Systems (BEMS) can contribute to the achievement of the possible energy and cost savings. 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 (Zaheer-Uddin, 1994; Zaheer-Uddin, 1993) have been presented. More computerized methods, such as genetic algorithms (Huang et al. 1997) and neural networks (Kanarachos et al. 1998) 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 (Yao et al., 2004), weighted linguistic fuzzy rules (Alcala et al., 2005), simulation-optimization (Fong et al., 2006) and online adaptive control (Wang et al., 2001). Integrated control systems utilizing genetic algorithms, optimized fuzzy controllers for the indoor environmental management (Kolokotsa et al., 2002a, b), and occupancy prediction (Clark, 1997) have been developed, applied and tested.

Furthermore, BEMS are currently being developed to be applied in buildings, namely the "intelligent buildings" and a number of studies (Al-Rabghi et al. 2004; Kua et al. 2002; Wong et al. 2005), 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: the guarantee of the desirable levels of living quality in buildings and the necessity for energy savings. With respect to the above, the main aim of this paper is to present an intelligent BEMS using rule sets for the management of all related energy building's operations. Moreover, 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.
- The third section is devoted to the presentation of the computerized decision support model.
- The last section summarizes the main conclusions.

2. METHODOLOGY

The decision support model's infrastructure is based on a typical BEMS logic (Levermore, 2000).

As illustrated in Figure 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, can be easily elaborated.

The model includes indoor - outdoor sensors, controllers and a decision unit with the following capabilities:

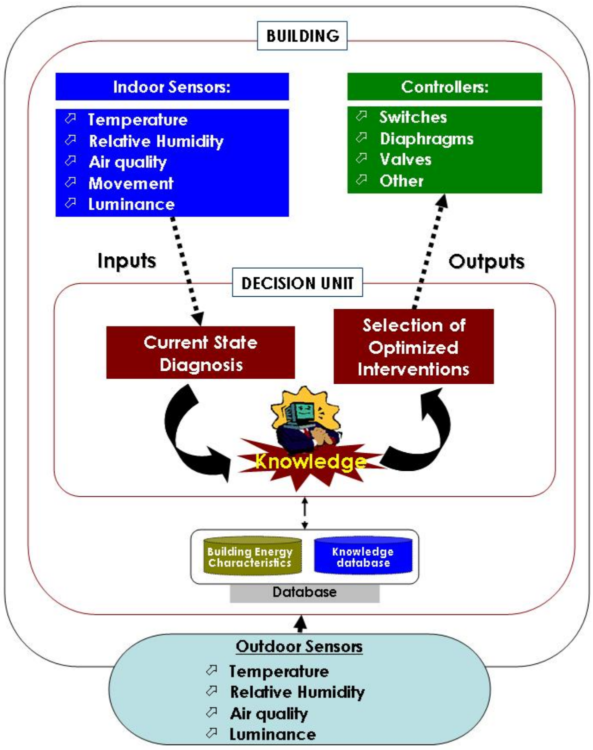

Figure 1: The Model's Philosophy.

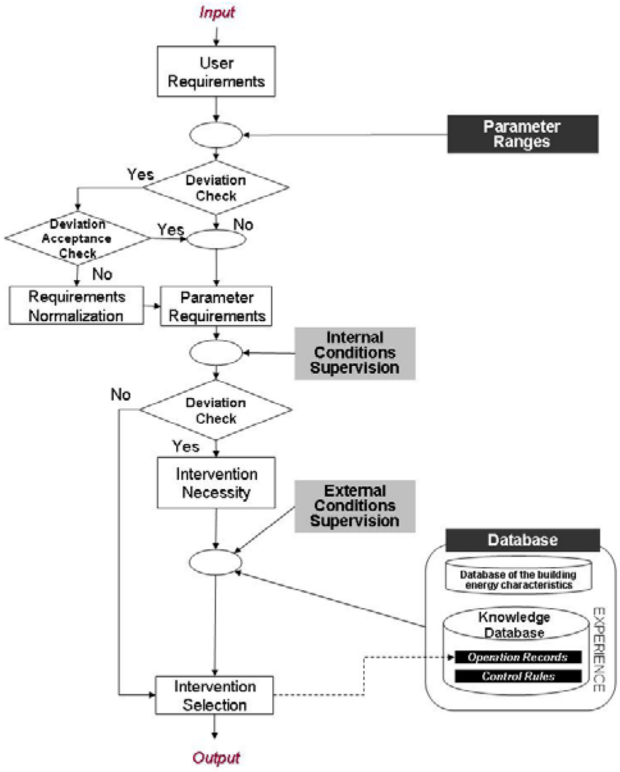

Figure 2: The Model's Procedure.

- Interaction with the sensors for the diagnosis of the building's state.
- Incorporation of expert and intelligent systems techniques in order to select the appropriate interventions.
- Communication with the building's controllers.

Furthermore, it includes the database for the building energy characteristics and the knowledge database, where all essential information is recorded.

The procedure represented in the Figure 2 is defined as follows:

- *User Requirements*: Users inside the building define their requirements for indoor conditions by setting values to control parameters, namely the temperature, relative humidity, air quality and luminosity.
- *Parameter Requirements*: Users' requirements are compared to defined parameters' ranges. For each area type, specific parameters' ranges have been defined, which provide comfortable indoor conditions (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2003). The comparison result is:

- If there is no deviation between user's input and the parameters' ranges (No), then, user's input is selected.
- If there is a deviation between the user's input and the parameters' ranges (Yes), then, the model proceeds as follows: (a) If the model status is set to "Manual", the model ignores the deviation and uses the user's input; (b) 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*: 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.
  - 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.

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.

3. MODEL DEVELOPMENT

3.1 Architecture

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

- The "MS Access" was used for the development of the database for the building energy characteristics and the knowledge database.
- The "Visual Basic 6.0" was the programming language that provided interconnectivity, through the database, sensors and controllers of the building.
- The "Clips", and particularly version 6.2 released in spring 2002 (Giarrantano, 1998), was embedded in the model, to provide processing of model's rules and inference to the decision process.

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.

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 and compatibility of decision support unit. The first rule set ensures indoor comfort conditions for every area or room in the building. The second basic rule set includes rules concerning the energy efficiency of a typical building. Based on these rule sets, the decision unit procedural steps are the following: system initialization, intervention necessity, deviation scaling of indoor conditions, intervention selection and intervention intensity determination.

3.3 A Pilot Appraisal

The specific building, used for the presented model's application was an office building consisting of three (3) floors and a total surface of 485.22 m^2. Energy demands of the building are fully covered by electricity, whilst other primary energy sources are not used. More specifically, building energy loads consist of lighting (indoor and outdoor), hydraulic elevator, HVAC, office equipment and electric pumps.

The building is equipped with a typical BEMS and the presented model elaborated the appropriate «mapping» of the building areas and its elements. A fully updated description of the building's structure, including technical specifications for every component was originated. Thereafter, the model was applied for a time period of about a year (from the model's operation from December 2004 to December 2005). The building's annual electricity consumption was reduced from 106,5 MWh to 100,5 MWh in this year mainly due to the intelligent unit's effective management of all indoor building operations, by applying the optimal actions such as shutters closing, preheating, etc.

In particular, 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. Preheating and switching off procedures contributed to the energy comfort both in summer and winter. Thus no irregular indoor conditions occurred, but energy savings were recorded.

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. Within the evolution of those systems the role of the decision support models will be significant. Those models 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.

The presented intelligent model using rule sets for Building Energy Management can be an innovative and useful decision support system that will secure the desirable levels of indoor quality as well as energy savings. 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. 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.

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 Ministry for Development and funded by 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

Alcala, R., J. Casillas, O. Cordon, A. Gonzalez and F. Herrera, 2005. A genetic rule weighting and selection process for fuzzy control of heating, ventilating and air conditioning systems. Artificial Intelligence 2005; 18: 279-296.

Al-Rabghi, O.M. and M.M. Akyurt, 2004. A survey of energy efficient strategies for effective air conditioning. Energy Conversion and Management 45: 1643-1654.

American Society of Heating Refrigerating and Air-Conditioning Engineers, 2003. ASHRAE Handbook - HVAC Applications.

Athanasakou, E., December-January 1996-1997. Solar passive systems and technologies [in Greek]. Energy [in Greek] 24: 55-66.

Clark, G., 1997. Artificial intelligence and networking in integrated building management systems. Automation in Construction 6: 481-498.

Dong, Y. and A. Goh, 1998. An intelligent database for engineering applications. Artificial Intelligence in Engineering 12: 1-14.

European Commission, 2003. European Commission Directorate - General for Energy and Transport. European Energy and Transport Trends to 2030. Brussels.

Fatima, D.C.C. and E.W. Perz, 1998. A decision support system for power plant design. European Journal of Operational Research 109: 310-320.

Fong, K.F., V.I. Hanby and T.T. Chow, 2006. HVAC system optimization for energy management by evolutionary programming. Energy and Buildings 38: 220-231.

Giarrantano, J.C., 1998. CLIPS User's Guide.

Huang, W. and H.N. Lam, 1997. Using genetic algorithms to optimize controller parameters for HVAC systems. Energy and Buildings 26: 277-282.

Kanarachos, A. and K. Geramanis, 1998. Multivariable Control of Single Zone Hydronic Heating Systems with Neural Networks. Energy Conversion and Management 39(13): 1317-1336.

Kolokotsa, D., K. Kalaitzakis, E. Antonidakis and G.S. Stavrakakis, 2002a. 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 43: 119-134.

Kolokotsa, D., G.S. Stavrakakis, K. Kalaitzakis and D. Agoris, 2002b. Genetic algorithms optimized fuzzy controller for the indoor environmental management in buildings implemented using PLC and local operating networks. Artificial Intelligence 15: 417-428.

Kua, H.W. and S.E. Lee, 2002. Demonstration intelligent building-a methodology for the promotion of total sustainability in the built environment. Building and Environment 37: 231-240.

Lee, S.-J. and C.-H. Wu, 1995. CLXPERT: A Rule-Based Scheduling System. Expert Systems with Applications 9(2): 153-164.

Levermore, G.J., 2000. Building energy management systems. London: E & FN Spon.

Simic, G. and V. Devedzie, 2003. Building an intelligent system using modern Internet technologies. Expert Systems With Applications 25: 231-246.

Wang, S. and J. Burnett, 2001. Online adaptive control for optimizing variable-speed pumps of indirect water-cooled systems. Applied Thermal Energy 21: 1083-1103.

Wong, J.K.W., H. Li and S.W. Wang, 2005. Intelligent building research: a review. Automation in Construction 14: 143-159.

Yao, Y., Z. Lian, Z. Hou and X. Zhou, 2004. Optimal operation of a large cooling system based on an empirical model. Applied Thermal Energy 24: 2303-2321.

Zaheer-Uddin, M., 1993. Optimal, Sub-optimal and Adaptive Control Methods for the Design of Temperature Controllers for Intelligent Buildings. Building and Environment 28(3): 311-322.

Zaheer-Uddin, M., 1994. Intelligent Control Strategies for HVAC Processes in Buildings. Energy 19(1): 67-79.

Zhang, W.Y., S.B. Tor, G.A. Britton and Y.-M. Deng, 2001. EFDEX: A Knowledge-Based Expert System for Functional Design of Engineering Systems. Engineering with Computers 17: 339-353.