ABSTRACT

The aim of the specific paper is the analysis of the efficiency of power lines as a communication media for Building Energy Management Systems. The reason behind this scope is the ability of power lines to be installed in existing buildings without extra wiring. Building Energy Management Systems (BEMS) constitute a part of automation systems. BEMS implement control the indoor environmental parameters while minimizing energy consumption. This work aims to analyze the ability of installing Building Energy Management Systems (BEMS) in any building while simultaneously improve the energy efficiency and the indoor comfort. The easiest and most economic way to construct a BEMS in an existing building is to use the existing technologies of the building. These are power lines and Local Area Networks (LANs). Another way to develop and implement BEMS is radio frequencies (RF). These technologies can be used to existing buildings because they need no wiring and the installation cost is very small. Before choosing the devices that will formulate the BEMS, the parameters that affect the indoor conditions must be determined. Those are thermal comfort, visual comfort, indoor air quality and acoustic comfort. In order to check the efficiency of communication protocols that use power lines as a mean to communicate, a test installation is implemented in laboratory. This installation is performed via two development kits: the Power Line Development Support Kit (PL DSK) and Mini Evaluation Kit (Mini EVK). The test included a temperature sensor as a controlled variable and a decentralised heating control system with a central heating unit for the control signal. The results of the testing as well as specifications for installation in existing buildings are described focusing on disseminating such technologies in meeting the continuously increasing energy demands of the buildings in Crete, Greece.

1. INTRODUCTION

The scope of the present work is the inspection of the existing energy management systems and the development of specifications of energy management systems in the region of Crete, using power lines as a communication media. The overall work is divided into the following phases:
- Phase 1: Review of the existing technological developments in the sector of energy management and existing applications.
- Phase 2: Steps for development of specifications of energy management system according to the building demands and climatic characteristics of Crete.
- Phase 3: Development of energy management system specifications and cost analysis for two different types of buildings at the region of Crete.
- Phase 4: Development of a test installation aiming to check the integrity of power lines as a communication media.

2. STATE OF THE ART

Numerous experimental tests and installations have been developed aiming to improve the energy and indoor environmental management. Some examples include intelligent energy management systems using rule sets (Doukas, 2006), the development of energy planning in specific building type (Mavrotas, 2002) and demand side management of a region using smart controllers (Antonidakis, 2001). Experimental applications have also been developed and tested for the indoor environment and energy management system of greenhouses (Saridakis, 2006), the indoor energy management using fuzzy logic controller for a building zone (Kolokotsa, 2003) or the development of a test chamber where many different types of controllers can be implemented and evaluated (Kolokotsa, 2006).

Power lines as a communication media is a cost effective way for developing automation systems. No extra cabling is needed and that makes it an exceptional choice in cases that new wiring is not an option. An application for lighting using Digital Signal Processing (DSP) controller and communication over power lines (Hagen, 2006) has been developed. Power lines can also be used for Demand Side Management (DSM) (LONWORKS, 1996) and Integrated Resource Planning.
3. BEMS SPECIFICATIONS USING POWER LINES

The development of an energy management system requires a certain procedure that contains four steps. These steps include the analysis of buildings’ characteristics, the analysis of the building’s type, use, occupancy patterns and users’ demands on energy management.

Step 1: Analysis of buildings’ characteristics such as the building’s shape, occupancy patterns and use. This procedure is essential as each building’s zone may have different occupancy patterns and may belong to a different building type (offices, retail, residential, mixed-use). This step will assist the division of the building in control zones in order to achieve optimum settings for the energy management system.

Step 2: Analysis of the building’s services, i.e. electrical and mechanical equipment. This step is essential for the compatibility between the existing building mechanical and electrical equipment and the necessary devices of the energy management system. For example if there is no compatibility between an existing device and the devices of the energy management system then an interface must be interconnected.

Step 3: The next step is the determination of control strategy that will be followed and the users’ requirements on heating/cooling, indoor air quality and lighting. At this part building control zones are defined. Control zones are the separation of the building in smaller parts so to achieve distributed and optimized control. This may combine for each zone different control strategies such as time programming, night set-back, on-off programming, PID programming, and artificial intelligent techniques (fuzzy control, neural network for load prediction, etc).

Step 4: The major cost of energy management system installation is the procurement of sensors and actuators that use power lines as a communication media. The most important sensors required for the development of an energy management system are the following: indoor temperature, relative humidity, carbon dioxide and indoor luminance as well as devices for energy consumption monitoring Table 1 illustrates the most common devices that constitute an energy management system. The price for each sensor varies and depends on the manufacturer and the type of the sensor (analogue or digital). The analogue sensors’ price oscillates from €50 to €150 and the digital sensors’ price oscillates from €100 to €600.

4. CASE STUDIES IN CRETE-GREECE

According to the specifications presented to the previous paragraph, two different types of buildings were chosen to develop energy management system specifications. The first type is a residential building and the second refers to offices’ area. Both buildings are located at the prefecture of Chania, Crete, Greece.

4.1 Residential building

This building is divided in five different areas. The ground plan of the building is illustrated in Figure 1. These areas are (1) kitchen, (2) bedroom 1, (3) bedroom 2, (4) bathroom and (5) living room. The usage of each area varies during day time period.

For the heating of this house a central heating system is used for the winter period. In each space a radiator is installed except the living room where three radiators are installed. The indoor temperature monitoring and the operation of the heating unit are done by a typical thermostat. The heating system is quite old and there is no compatibility between the existing devices and the necessary devices for the energy management system. Therefore interface devices must be used in order to achieve interconnection.

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Table 1: Indicative sensors of an energy management system

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor temperature</td>
<td>0 to 50°C</td>
</tr>
<tr>
<td>Outdoor temperature</td>
<td>-10 to 50°C</td>
</tr>
<tr>
<td>(analogue or digital)</td>
<td></td>
</tr>
<tr>
<td>Indoor Relative Humidity</td>
<td>0-100%</td>
</tr>
<tr>
<td>Outdoor Relative Humidity</td>
<td>0-100%</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>0-2000 ppm</td>
</tr>
<tr>
<td>Indoor illuminance</td>
<td>0-2000 lux</td>
</tr>
<tr>
<td>Outdoor illuminance</td>
<td>0-150000 lux</td>
</tr>
<tr>
<td>Energy meter (analogue or digital)</td>
<td></td>
</tr>
</tbody>
</table>

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Figure 1: Ground plan of a typical house at the region of Crete
The appropriate thermal comfort management requires the division of the building in control zones. As it was mentioned before, the usage of the building varies during the day. Occupants’ schedule gives the ability to divide the 24-hour time period in time zones. In this case the energy management system will operate more accurate and the energy savings will be respectable. The area control zones are the following:

- AZ1: kitchen
- AZ2 and AZ3: bedrooms
- AZ4: bathroom
- AZ5: living room

According to the above and occupants schedule Table 2 was made. This table illustrates the desired temperature levels in each area control zone in each time control zone. The devices that will comprise the energy management system must have a common characteristic: they must use power lines as a communication media using the same communication protocol. For each area control zone is needed one temperature sensor for the monitoring of the indoor temperature. For the control of the indoor temperature, an actuating device is needed. This device controls the hot water flow at each radiator. The last device that is needed is an actuating device for the central heating unit. These devices are presented in Table 3. The total cost of this installation depends on devices’ manufacturer and the company that will make the installation. According to the above the total management system cost varies from €2000 to €4000.
The artificial lighting for each office is comprised from 8 fluorescent lamps controlled manually from wall switches. The incoming lighting that comes from the outdoor environment is controlled with venetian blinds. The desired temperature level for all the offices is 22°C and the desired luminance level is 500 lux.

As it was mentioned before, each space is used according to employees’ schedule. In this case the approach for the energy management system should be different. The most suitable methodology that can be ensued is setting the temperature level at 18°C when the office is not occupied and when someone enters the then temperature level is set back to 22°C. This procedure can only be applied for the central heating system due to the time needed to heat a single space. In order to prioritize the two available heating systems an outdoor temperature sensor is installed. For the indoor lighting control the indoor illuminance must be monitored as well as the outdoor illuminance. According to these two parameters the energy management system determines the operation of the electric lighting lamps. The devices that are needed for each space are one temperature sensor and one illuminance sensor for the indoor temperature and the indoor illuminance monitoring correspondingly, one motion detection sensor, one actuator for the artificial light control, one actuator for the venetian blinds angle control, one actuator for hot water flow control at the radiator, and finally one actuator for cooling unit control. For the monitoring of the outdoor conditions one temperature sensor and one illuminance sensor are also needed. One actuator for the central heating unit must also be installed and also two electrical sluice valves for the central hot water flow control. These devices are presented in Table 4. As it was mentioned before the total cost of the installation depends on devices’ manufacturer and the company that will make the installation. For this installation the cost varies between €7000 to €7500.

5. TEST INSTALLATION

In order to check the integrity of power lines as a communication media in buildings’ automation, an installation was developed at the Laboratory of Renewable Energy Engineering of Technological Educational Institute of Crete. This installation deals mainly with the regulation of indoor temperature while all the other indoor parameters are not considered. The devices used for the tests are two development kits from Echelon Corporation: Mini Evaluation Kit (Mini EVK) and Power Line Development Support Kit (PL DSK). Each kit contains two devices with the necessary hardware so that new applications can be developed and tested. The devices are able to communicate over power lines.

To control the indoor temperature in various zones, a number of devices were programmed operating as a typical thermostat of an existing installed heating system. In particular, each device monitors the indoor temperature. If temperature is below the desired level the user has assigned, then a signal is sent to the heating unit to heat the specific space. If the temperature is below the desired level then device sends a signal to stop heating this room. This procedure is illustrated to the diagram on Figure 3. These signals are sent to an actuating device that controls the heating system operation. According to the signal this device receives turns on or turns off the heating for the particular room.

6. DISCUSSION AND CONCLUSIONS

Early installations that have been developed (Koloko-
tsa, 2003) prove that the reduction of energy consumption and cost using an energy management system is respectable. The energy saving on this project was calculated for three different control schemes: Fuzzy Logic Control (FLC), ON-OFF Control (ON-OFF) and No Control (NC) (Table 5).

At the present moment the installation of an energy management system using power lines is higher than a conventional one. However there are parameters that cannot be measured and taken into account in a quantitative way, such as the ease of installation, the increase of occupants productivity due to the improvement of indoor conditions, the integration to the power grid and demand side management procedure, etc. that play a significant role to the promotion and establishment of energy management using power lines as communication media.

ACKNOWLEDGEMENT

The work described in this paper has been supported by the ARCHIMEDES project of the Operational Programme for Education and Initial Vocational Training (EPE-AEK II) under the 3rd European Community Support Framework for Greece and Hellenic National resources.

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