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Internet Based Energy Services During Cooling Season

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Abstract: Existing advanced and sophisticated building systems combined with emerging IT technologies facilitate the development of a range of new Internet based energy and environmental services. Driven mostly by the deregulation of energy market, energy utilities as well as telecommunication companies build up and test exemplars of new energy services, provided to building occupants.

This paper discusses the general context of the development of e-based energy services and presents a set of such services, developed and tested in Greece. The provided energy services were the remote monitoring of environmental parameters, the remote control and actuation of cooling equipment and the on line prediction of energy consumption and environmental conditions. The services focus mainly on the cooling season, where peak power demand is rising due to the operation of air-conditioning systems. In Southern European countries, the economic and energy efficient operation of cooling appliances as well as energy management and load shedding are very important.

Keywords: Internet based energy services; cooling equipment control; energy use prediction; artificial neural networks.

1. INTRODUCTION

There has been a need for some time for services within buildings to be integrated so that users can benefit from a range of services without having to be fully familiar with a variety of individual systems. It was also recognized that this integration should not affect the individuality, integrity and functionality of those different systems. At the same time, advances in access technologies enable high bandwidth access streams, and unified end-to-end solutions are created for the delivery of multiple services over wide area networks to local networks and devices [1].

A central component in the complete end-to-end architecture from remote service providers to local networks is the services gateway [1]. Services gateways are a new generation of hardware and software that enable the management and connectivity of devices and appliances, acting as a bridge between the access network, usually the Internet, and a local network. This context creates the opportunities for the delivery of a range of services, such as energy management, communication, security, remote health care monitoring, electronic commerce services and more.

The e-based energy services that are enabled are among the most valuable applications. Energy systems are under test and development aiming to address the problem of combining the potential of current building control technologies and IT, where the gateway concept offers some form of integration to all users of building services, being the means of exchanging data between two or more systems.

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Build on Ericsson's existing residential gateway, or "e-box", technology [2], SmartHomes project [3, 4], funded by the EC (2001), aimed at the time to test and prototype new internet-based energy services for citizens and professionals. In the framework of the project, a range of new energy services was defined and tested within field trials in Czech Republic, Sweden, Greece and UK.

E-boxes can be placed in homes, small offices and elsewhere, and be connected to the Internet (xDsl, cable, Ethernet, Wireless) and to the local network of sensors and actuators (RF, cable connections). The measured data are sent from the e-boxes via the Internet to the service center where they can be processed and analyzed. The service center may be located anywhere and is the administrative center of all operation and maintenance activities and also the place where distributed applications designed by Service Providers may be implemented, before a specific service is finally transmitted to the end-users. Service Providers and end-users access the services through standard Web browsers and information and/or control actions may be transmitted back to the end-users. The system overview is described in detail in [3].

This paper presents a set of such services, tested and prototyped in Greece. The provided energy services are linked with the remote monitoring of environmental parameters, the remote control and actuation of cooling equipment and the on line prediction of energy consumption and environmental conditions, using Artificial Neural Networks.

The services focus mainly on the cooling season where e-based energy management systems have the potential to help energy utilities to manage power load and reduce peak loads, as well as end-users to reduce their consumption and possibly increase their comfort. As the real time/time-of-use price of distributed energy fluctuates over a day, significant savings can occur for both utilities and customers; there are some appliances manageable over time, in the sense that it is possible to shift their energy use in time (away from periods with peak prices) without compromising their function. This holds, for example, for heating and cooling equipment (slow distributed processes, responsible for most of the energy use in buildings). Energy distribution companies can importantly improve energy management through the implementation of predictive control schemes while remote control of cooling equipment during the hours of peak power demand, gives the means for load shedding and minimizes the contingency of construction and operation of new plants and the possible danger of a black out.

2. POTENTIAL INTERNET BASED ENERGY SERVICES

New energy services that are enabled vary from automated metering and billing, remote control of appliances and energy load management to indoor climate control. Electronic energy services have special features compared to conventional systems; as on-line energy services involves yet non existing activities, at least not at a great or commercial scale, the requirements have to be created rather than educed [5]. Obviously, there are many opportunities as well as uncertainties here, leading to the necessity of design and analysis. Services and technology are strongly linked, so the design decision about energy services and the associated systems architecture cannot be made in a decoupled way.

Potential energy services involve many different actors. Consequently, identification of energy services and decision making, demand the specification of all actors role.

New energy services can be grouped considering two actors: i) Service Providers -which implicitly could be utilities, private sector companies, local authorities- and ii) customers, the end-users. Energy services could as well be provided from a utility to private companies, from private companies to local authorities and vise versa etc (Fig. **1**).

Energy services can also be typed according the existence or not of a local control system, in the two following categories:

I). Remote Monitoring of Various Resources and Parameters

Auto metering and remote monitoring of energy use for space heating/cooling, electricity, gas, hot water, as well as indoor parameters (e.g. indoor temperature, indoor concentration levels of CO_2) enable services as follows:

- Real time/time of use pricing of electricity
- Real time/time of use measurement of consumption
- Alarm, if something is not working properly
- Alarm, for adverse indoors conditions
- Show individual current consumption
- Information and statistics
- Estimation of energy efficiency
- Advice on energy actions, e.g. savings that arise by changing the set point temperature, as well as initiation of such actions on request.
- Information about ventilation requirements.

II). Remote Control and Actuation of Appliances

Networking, automation and controlling offer all the energy services mentioned above, but also enable more “refined” energy services. Remote home control and actuation of appliances can be implemented by the tenants as well as by other “third party” services providers (Fig. **2**).

These refined energy services, could be:

- Direct load management (utilities are not only support pricing information in the expectation that customers will accordingly control their appliances. They actually implement the control actions)
- Remote Control of HVAC System
  - Control of the set point Temperature (Home/-Away/Night)
  - On/Off control (Home/Away/Night)
  - Control of the ventilation system through the levels of indoor air pollutants

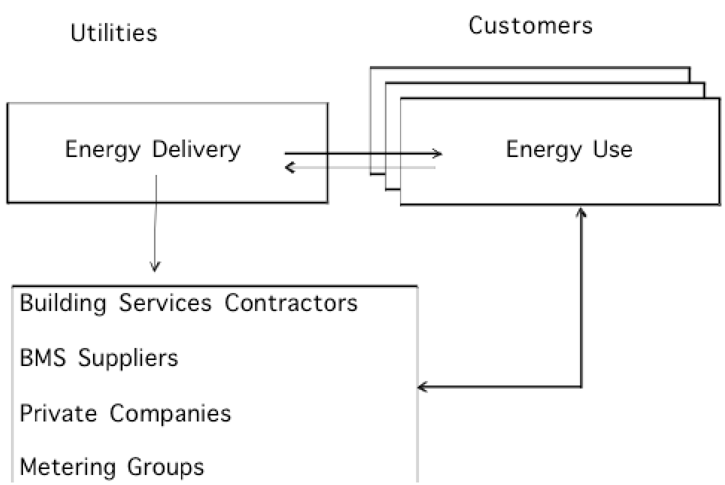

Fig. (1). Identification of the actors.

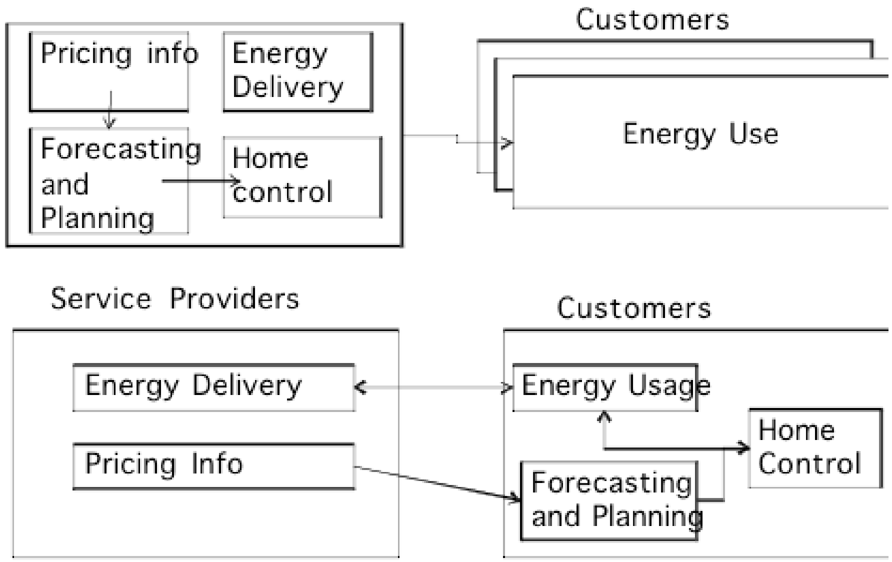

Fig. (2). Different control models.

- Control of lighting System
  - On/off control (Home/away)
  - Dimming: maintenance of predefined lighting levels through dimming.

An integrated energy management system should combine all the aforementioned services and provide the means to realize the idea of the "managed comfort". Usually comfort is confused with thermal comfort, although it equally involves visual comfort and indoor air quality. It should be considered that managed comfort requires additional activities that deal with information about: home comfort control actions, energy usage predicting and planning, delivering real time energy price information.

3. ON-LINE PREDICTION OF COOLING ENERGY CONSUMPTION AND CONTROL OF COOLING EQUIPMENT

It is estimated that the impact of cooling, during summer months, is around 1.8 GW of peak power demand, representing the necessity to operate for this season additional six power plants, of 300 MW each. In this framework, the following two services were developed and provided:

- Prediction of the cooling energy consumption of buildings
- Control of the cooling equipment

The prediction of the cooling energy consumption of different buildings or of different areas of buildings, with lead times from one hour to the next 24 hours, is important for energy distribution companies. Joint with the remote control of cooling equipment during the hours of peak power demand, both these services provide the means to manage energy effectively, as well as minimise the contingency of construction and operation of new plants.

Incentives do exist as well for other involved parties. Building occupants can organise remotely the schedule of the cooling unit operation, in a weekly basis. They may also enable intermittent operation of the cooling equipment in order to reduce energy consumption. Building energy managers represent another target group; the knowledge of future cooling energy consumption helps them to decide the right energy conservation strategy especially for techniques, like night ventilation, that affect the next day energy demand of the building. In the following we shortly describe the concept and the framework of these services.

3.1. Prediction of the Cooling Energy Consumption for the next 24 Hours in an Hourly Basis

The service consists in the prediction of the cooling load profile of the next day, for residential and office buildings.

The problem with accurate prediction of the cooling load is that it depends on the weather conditions, which are not known in advance. Artificial Neural network models (ANN) offer a powerful predictive tool, and thus are used to perform real time predictions.

ANNs have been widely used for a range of applications in the area of energy modeling. The literature has demonstrate their superior capability over other methods, such as times series, or regression, their main advantage being the high potential to model non linear processes, such as utility loads or individual buildings energy consumption. The application of the ANN methodology to the problem of short term load forecasting for electric power utilities has received much of the attention and excellent results have been achieved in real applications [6-10].

As far as it concerns energy modeling for the building sector, many studies have been reported on the use of neural networks. These can be divided mainly into two groups: models to predict building energy use and algorithms for a wide range of HVAC applications, such as design, operation and fault detection [11-14].

As ANN with a single hidden layer of neurons with hyperbolic tangent activation function and a linear output neuron are universal function approximators, we don't consider more complex architectures. In this way, the determination of the best model structure reduces to the determination of the appropriate number of hidden units and inputs.

We thus use feed forward neural networks with a single hidden layer of tanh units, and a single linear output to predict hourly energy consumption, where the number of hidden units and the relevant inputs are selected, using a methodology that mainly consists in three parts: (i) the identification of all potential relevant input, (ii) the selection of hidden units for this preliminary set of inputs, through an additive phase (iii) the remove of irrelevant inputs and useless hidden units through a subtractive phase [15].

In general, models that include environmental variables as inputs can be be used to get predictions for 1 to 24 hours ahead, but this require a pre-process before the prediction can be made, as one must first predict the weather data for the next our or day.

The main idea of our proposed and implemented predictors is to eliminate the necessity of environmental variables prediction, by using as inputs only past values of the input variables [15]. The neural network models, are executed on line, and estimate the cooling energy consumption the next 24 hours, on an hourly base [3,15,16]. The set of inputs consist of past values of AirConditioning power consumption, the minimum and maximum ambient temperature of the previus day, and a set of calendar variables and variables associated with occupancy [15,16]; the occupancy of the building has a strong effect on the energy use, and whether the building is in sesssion or not is important. Thus, weekend and holidays were identified and days were classified and encoded as 1 (weekday or working day) and 0 (weekend or holiday).

Many tests have been conducted in order to identify the training patterns that yield to the best results, as in general, too large training data sets contain obsolete data and require high training times. Thus, the selected training data set, for both type of buildings consists of one month, that is, if the forecast day is the 1th of August, the training data set consist of input-output data patterns created from 1 to 31 July.

Results are quite different for the two types of buildings. For the residential buildings, the accuracy of the implemented model is close to 7% for 1-step prediction and close to 30% for 24-step prediction (Fig. **3**). For office buildings, where the schedule of use of the cooling equipment is repeated on a daily basis, the accuracy of the ANN approach is increased and is close to 4% (Fig. **4**). As far as it concernes office buildings, is was clear that even a short data set is adequate to determine the structure of the neural network model and establish its parameters. In contrary, for residential buildings and even for such a short prediction as the one step, in which ANN models can be highly accurate, errors are higher. The main reason is the combined effect of occupants and weather: cooling equipement may not operate on extremely hot days due to the occupants absence. However, a domestic cooling energy consumption load predictive model of 1 hour would be useful as well, as being able to estimate the next hour's total load is crucial in a context where the cooling comprises approximately 2GW of the peak power demand.

The service was tested during a whole summer period, where a web server tool had at the time the role of the service provider. Each time the user desires a prediction, the web tool requests the previous measurements (required for the forecasting) from an SQL server and executes the corresponding ANN model, presenting the results to the user (Fig. **5**).

3.2. Remote Control of Cooling Equipment

This service is provided with two different versions, depending on the control strategy that is implemented to control the cooling equipment:

- Scheduled control
- Intermittent control

The first strategy allows the user to define in the corresponding web page a weekly schedule of operation on an hourly basis (Fig. **6**). After the activation of the service, the operation of the A/C unit follows the defined time schedule. The control of the A/C unit, implemented in Greece, concerns local split units commonly used in residents and offices that do not have a central HVAC system. In order to avoid the intervention on the electronic part of the internal

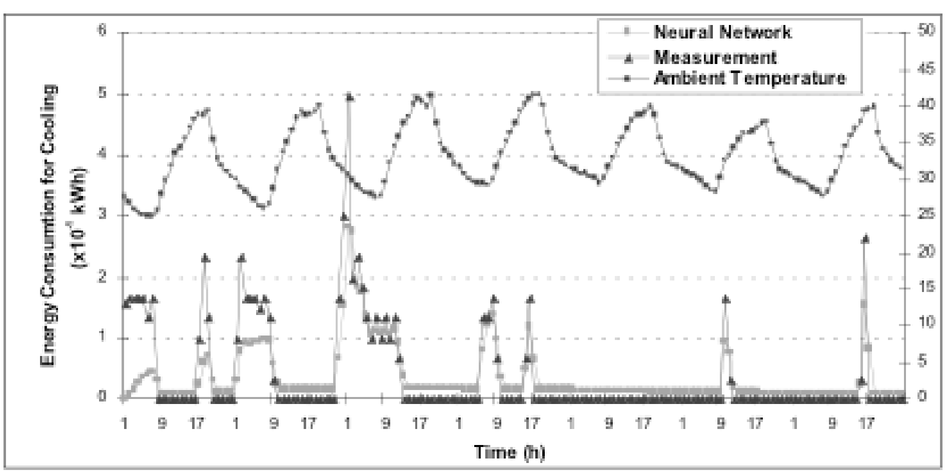

Fig. (3). Predicted (Neural Network), measured (Measurement) Cooling Load and Ambient Temperature profiles for a Residential Building

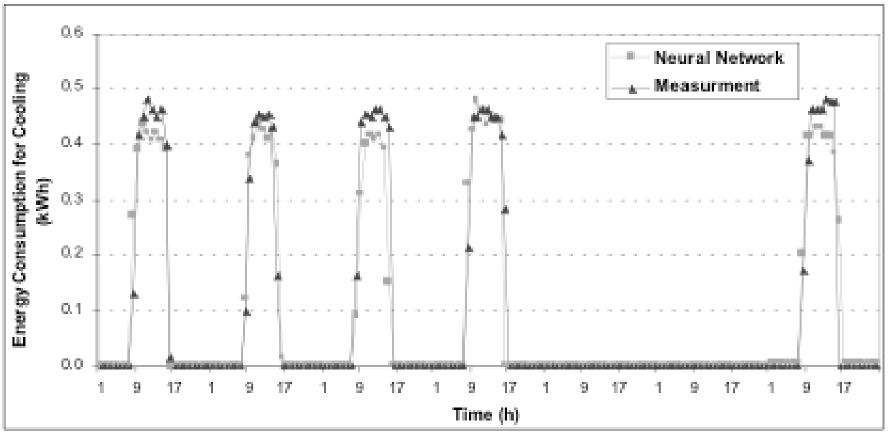

Fig. (4). Predicted (Neural Network) and measured Cooling Load profiles for an office building.

part of the A/C unit and the corresponding wiring, a programmable remote control is used, connected with a relay actuator. Sending socket commands to the service center performs the control. These commands open or close the relay.

By using this service the occupant of the building can remotely operate an A/C unit. Also, this service is appropriate for building energy managers who want to remotely control a large number of local A/C units.

The second control strategy (Fig. **7**) concerns mainly building energy managers and Energy Distribution Companies rather than building occupants. This strategy enables the intermittent operation of the controlled cooling equipment, an approach that leads to energy conservation and permits to improve the energy management.

From the Energy Distribution Company's point of view, this kind of control together with the cooling consumption prediction permits to enhance the management of the energy distribution at a city or region level. The knowledge of the next day cooling energy requirements and the ability to reduce the peak energy load of a whole region by using intermittent operation of the A/C units, gives the possibility to better distribute the energy and avoid "black out" problems, a dangerous situation that big cities in south Europe are facing during the summer season.

From the building energy manager's point of view, intermittent operation of cooling equipment allows the reduction the cooling consumption of the building especially when building occupants regulate the local A/C units in very low set point temperature during summer. Even though a set point temperature of 26°C is sufficient to maintain the indoor thermal comfort, frequently users in Greece select temperatures lower than 23°C. In this case A/C unit operates constantly in full capacity, as it is difficult to cover the corresponding cooling load. In addition to the increased energy consumption, the use of low set point temperature, raises the temperature difference between indoor and outdoor environment leading to problems like thermal shock of people that exit the building, illnesses due to entrance from a hot environment (outdoor) to a cold one (indoor), etc.

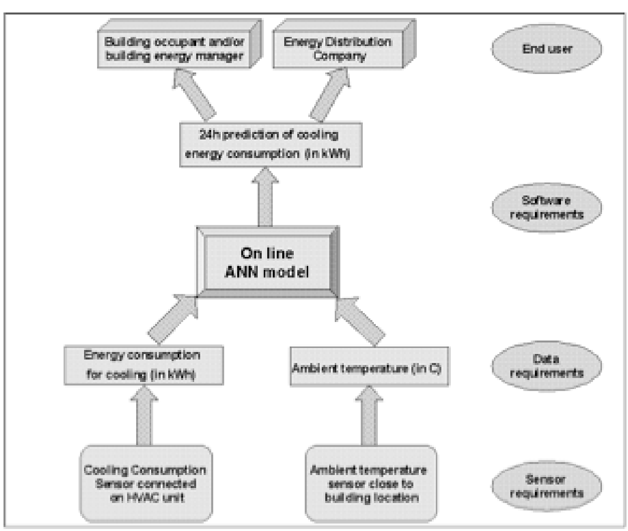

Fig. (5). The model of the "Prediction of cooling consumption" service.

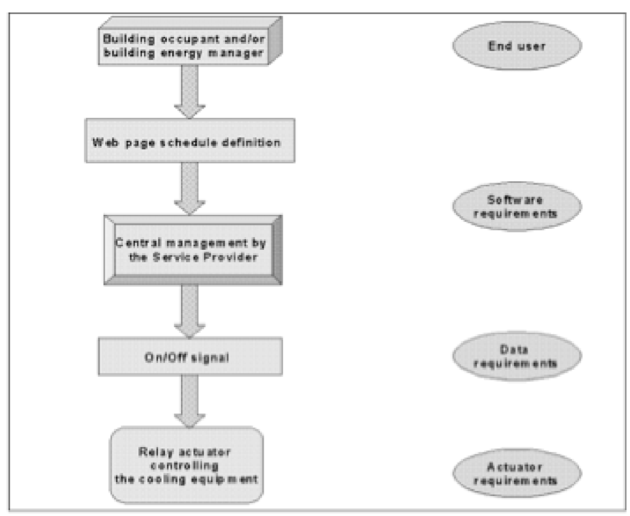

Fig. (6). The model of "Scheduled Control" service

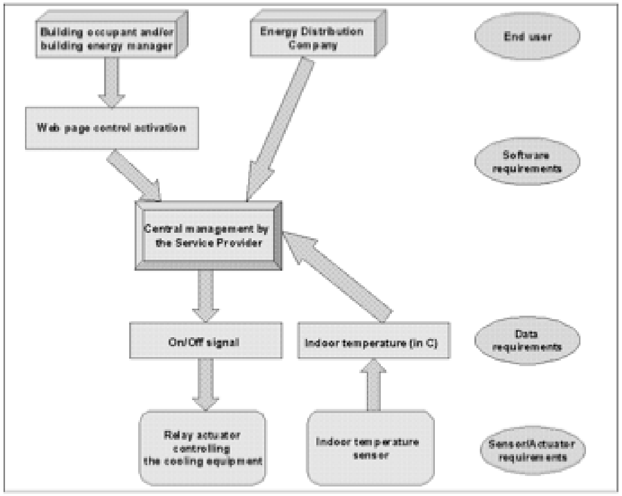

Fig. (7). The "Intermittent Control" model service.

The strategy on which intermittent control is based requires the definition by the user of a threshold value of the indoor temperature under which the A/C unit operates intermittently. When the service is enabled, the infrastructure that supports the control services, checks every 15min if the indoor temperature is lower than the threshold value. If this is true, the A/C unit is turned off for 5 min. It is not allowed to turn off the unit more than 2 times per hour and the time interval between two turn off operations cannot be less than 20 min, in order to respect in a certain degree the preferences of the user. This kind of intermittent operation of A/C units can lead to cooling energy conservation up to 17%. The fact that when the A/C unit turns on, consumes about 6 times the energy that requires during its normal operation is negligible because this occurs for less than a second.

Both control services are supported by an additional software tool that runs in the service provider server side, developed in the frame of Smart Homes project. This tool manages the operation of the connected cooling equipment through a socket connection with the e-sc, checks the users' indoor temperature conditions through the SQL server and updates the preferences of the users according to their selection in their private web page.

4. REMOTE MONITORING OF VARIOUS RESOURCES AND ENVIRONMENTAL PARAMETERS

This category of energy services concerns mainly information services that require the remote monitoring of various parameters. The end-users (the occupants of the building or a specific indoor space) can have information on the set of the monitored parameters such as ambient and indoor temperature and energy consumption for cooling (Fig. **8**). They have access to previous measurements and the corresponding services offer a graphical representation from any time period in the past. Therefore the user can compare different time periods and evaluate the influence of various energy related strategies on the indoor thermal environment and the energy consumption for cooling.

The monitoring of the aforementioned parameters enables in addition the following three services.

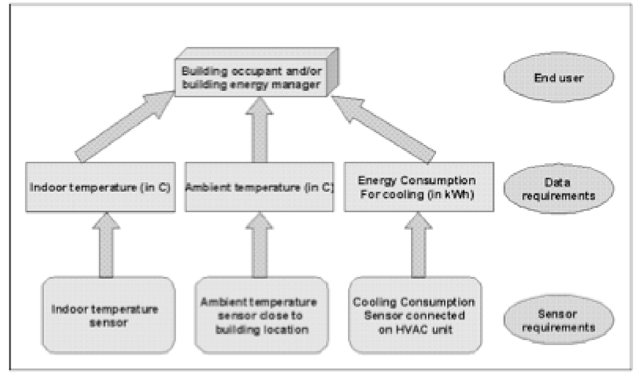

Fig. (8). The model of the various parameters monitoring services

4.1. Indoor Temperature Alarm

This service (Fig. **9**) concerns an indoor temperature alarm for overheating by comparing the monitored indoor temperature with a predefined threshold value. A specific receiver is then automatically notified about the overheating conditions. This service focuses on occupants of buildings that need a real time monitoring of the indoor conditions, but it is also important for specific applications in cases where the temperature conditions are crucial (e.g. a computer server room where the air temperature affects the operation of the equipment). Furthermore, potential users of the service are health care and social services departments that support elderly people in Greece. During summer, a number of elderly people present unstable or dangerous health conditions due to the increased levels of temperature (especially during heat waves). By using the present service, health care and social services can have a real time image of apartments where the indoor conditions are exceeded specific levels according to criteria based on the specific health conditions of each person (heat exhaustion, asthma suffering, etc.) and perform all the necessary actions.

The concept of the service is based on the monitoring of the indoor air temperature, which is compared with a thresh-

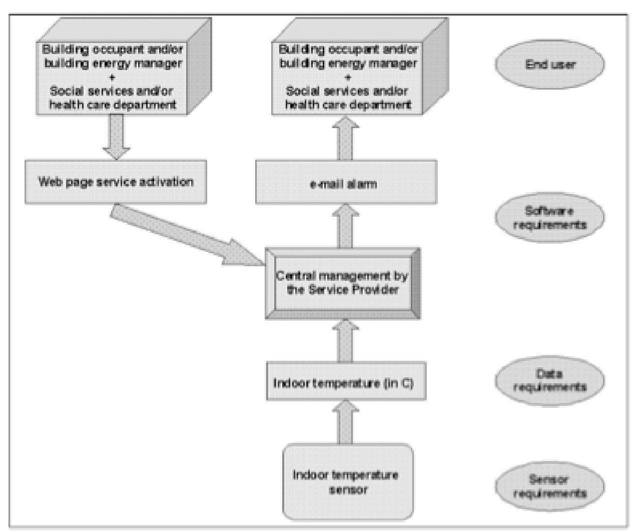

Fig. (9). The "Indoor temperature alarm" service old value defined by the user in his private web page. When the indoor temperature is higher than the threshold value an e-mail message is send automatically to the e-mail address that is also required when the service is activated. The message includes the actual indoor temperature, the threshold value and can include any desirable text or information.

The present service is necessarily supported by an additional software tool installed in the service provider's server. This tool manages the users according to their preferences and sends automatically the e-mail messages when required. It checks every hour the indoor temperature of the homes of the users that have activated the service, through the SQL server. An additional available option is the definition of an e-mail address that supports SMS notification. In this case the user in addition to the e-mail message receives and an SMS message to the corresponding cellular phone

4.2. Energy Rating for Cooling

In the frame of EU policy, Greece prepares a new regulation, based on the Energy Performance Building Directive (EPBD). Part of this work is the energy certification of buildings according to their energy consumption for cooling and heating. According to the annual energy consumption of the building (in kWh/m^2) for heating and cooling, the category of building (residence, office, school, hotel, etc) and the climatic zone (there are 4 climatic zones in Greece), buildings are classified in 5 categories (A to E). Based on this approach, expected soon to be a national regulation, a service (Fig. **10**) that concerns the energy rating for cooling is provided. Through the measurement of the real energy consumption for cooling, knowing the necessary parameters (type, location and floor area), it is possible to classify buildings under monitoring.

4.3. Ambient Temperature Prediction

One of the measured parameters at the three areas where the selected buildings are located is the ambient temperature. This information is used as an input to an ANN model that can forecast the next 24 hours with accuracy close to 6% (Fig. **11**). The ANN model requires measurements of 5 days

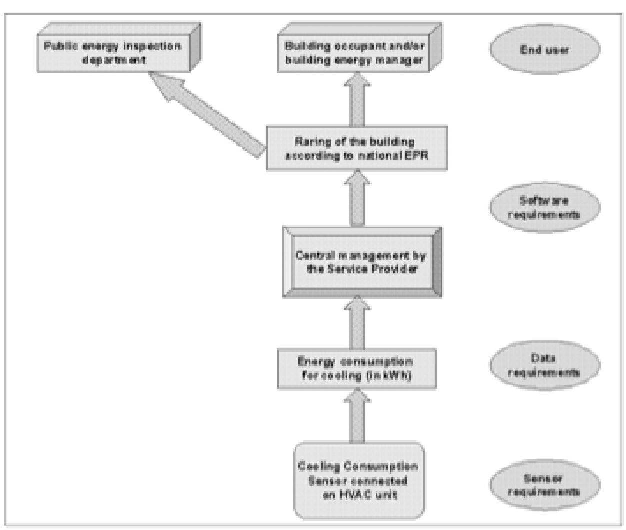

Fig. (10). Aspect model of the "Energy rating for cooling" service

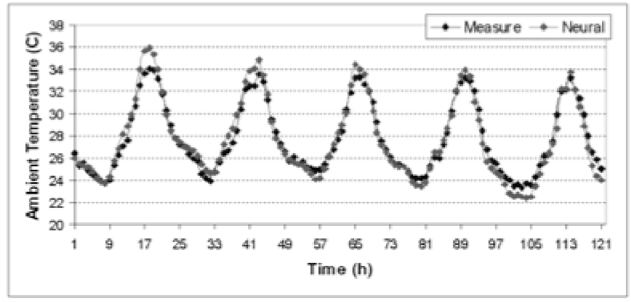

Fig. (11).. Comparison between measurements and predictions of the ANN model for the ambient temperature

before the day of prediction and it is executed on line upon the user's request (Fig. **12**). It is developed under Matlab environment and the system that supports the service is similar to the prediction of cooling consumption.

5. CONCLUSIONS

This paper has indicated a range of possible new energy services and has focused on their implementation in Greece, during cooling period.

The provided services mainly cover two general areas: the one concerns the energy and the indoor thermal conditions, while the other is related to the environmental conditions. Concerning energy, the related services are focused on the energy use for cooling of buildings. In Greece, the energy consumption for cooling in residential buildings represents 2-3% of total consumption. Of the supplied electrical energy, about 10% is produced from renewable sources of energy. Thus, the reduction of CO_2 emissions will be about 0.45%, if the saving of cooling energy is 20%.

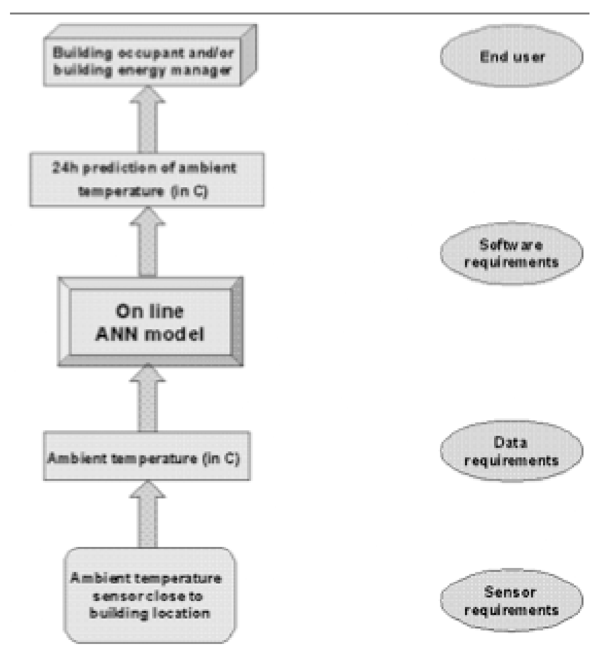

Fig. (12). The model of "Ambient temperature prediction" service

There are various end users such as building occupants, building energy managers, energy distribution companies, social services departments, health care departments and public departments that are involved with the energy rating of buildings.

The experience gained from prototyping and testing the described services, shows that obstacles may arise from the access network requirements, in cases where the IT infrastructure is relatively weak. Yet, the massive rise in home Internet connections, and the xDSL spread give now the means for a massive implementation of e-based energy service, as well as a range of other services too.

ACKNOWLEDGEMENTS

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