Simulation and Control of Renewable Energy Technology Integrated Within Building Energy Management

Nikos SAKKAS¹, Panayiotis PHILIMIS², Alberto CARRASCAL³, Manuel RAMIRO⁴, Thomas MESSERVEY⁵, Maria KOUVELETSOU¹
¹Apintech Ltd, Souliou 1, Gerakas, 15344, Greece
Tel: + 30 211 1154462, Fax: + 30 211 1154461,
Email: sakkas@apintech.com, kouveletsou@apintech.com
²CNE Technology Center, P.O. Box 16104, Nicosia, 2086, Cyprus
Tel: + 357 22 624090, Fax: + 357 22 624092, Email: p.philimis@cnetechnology.com
³Fatronik-Technalia, Paseo de Mikeletegi 7, Donostia-San Sebastián, E-20009, Spain
Tel: + 34 943 005500, Fax: + 34 943 005511, Email: acarrascal@fatronik.com
⁴Acciona Infraestructuras S.A., Avenida Europa 18, Madrid, 28108, Spain
Tel: + 34 91 7912020, Fax: + 34 91 7912101, Email: mramiro@acciona.es
⁵D’Appolonia S.p.A., Via S. Navaro 19, Genova, 16145, Italy
Tel: + 39 010 3628148, Fax: + 39 010 3621078, Email: thomas.messervey@dappolonia.it

Abstract: This paper presents the objectives and current activities in the course of an FP7 project, entitled EnergyWarden (www.energywarden.net). The project broadly aims at an integrated view of energy management and renewable technology, as deployed in the building domain. EnergyWarden will deliver an integrated toolset including three distinct modules: A Simulator (EW-S), to run long and short time simulations of the renewable energy production at the hourly, daily and yearly level, a controller (EW-C) to control energy flows locally at the building or at a district level and a user information module (EW-U) to deliver a detailed profile of the building energy production and use, to provide a real time calculation of CO₂ savings and to assess energy module performance, based on real time data and according to existing standards.

1. Introduction

The EnergyWarden (EW) project was launched in early 2010 with the ambition to provide tools to manage the prediction, control, and management of energy at the building and district level with special emphasis on renewable energy technologies (RET). EW is a complete system which integrates three features; a simulator, a controller and a user information oriented module, integrating the domains of RET management with building energy management. The EW- Simulator (EW-S) will help building designers and engineers define the potential energy savings possible at a given building through the employment of RET by using such information as the area available for solar installation, the possibility for wind turbines, the feasibility of geothermal energy capture and so on. The EW- Controller (EW-C) will operate via a wireless sensing network connected on the building for real time monitoring and the potential control of energy sourcing decisions. Lastly, the EW- User (EW-U) will provide information such as CO₂ footprint and real time energy module performance.
2. Objectives

Energy Warden (EW) is a practical attempt to merge the broad areas of building energy management and building renewable energy technology deployment into a common management framework. This framework includes both design as well as operational and control issues.

At the design level, the EW-S assesses and proposes specific renewable energy infrastructure suitable for deployment at the building level. The building designer or user defines the context of the building, runs the simulation and the EW-S proposes and financially assesses optimal or user constrained solutions. In addition, the EW-S does not solely operate at the decision making level, i.e., at the yearly time-frame. It is capable of running daily and hourly simulations, thus predicting the building energy income at these time frames and providing respective set points for the EW-C.

The EW-C is the second distinct product of EW, which carries out a dual function:

- Monitoring of the building energy infrastructure, including the renewable producers and related stores. This is based on a sophisticated, yet also cost effective and standards compliant, wireless sensing network (WSN), and, in this way, resembles the typical energy monitoring applications now increasingly entering the market. However, the inclusion of the RET infrastructure provides now a much more integrated view of the building energy flows.

- Rule based and supervisory control of the energy infrastructure. By supervisory, it is implied here that the EW-C does not enter in the details of the low level control of the energy infrastructure devices and systems (heating system, air to air pumps, etc.). Guided by the short term simulation values collected through the EW-S the EW-C functions at a higher level, the one of sourcing and not device control.

Although the EW-S also exists as a web application, the EW-S and EW-C are jointly packaged in a firmware device, the key EW product.

Last, a special module, referred as EW-U builds on the EW-C and provides for the following functionality:

- Typical building CO$_2$ footprint and energy balances.
- More innovative, real time evaluation of the deployed RET devices performance against their provider specifications.

Figure 1 broadly illustrates the EW tool-set and its module communications.

![Figure 1: Graphical Illustration of EnergyWarden Functionality](image)
3. Methodology

Methodologically the development of the EW tool-set includes the following phases:

- A design phase, whereby the EW-S data model is finalised, the EW configuration and energy use models are developed and the EW-WSN is designed.
- An implementation phase, whereby the EW-S is implemented as a standalone web application, the EW-C firmware is developed, on which the EW-S is integrated and the EW-U is developed as a web application.
- A validation phase, whereby the EW tool-set is tested in two settings in the UK (EU North) and Greece (EU South).

As there is currently nothing similar to the integrated and multi-tier nature of the EnergyWarden tool-set, a patent is planned for submission within the project lifetime.

3.1 Case studies- Technology Validation

Project results will be validated in two buildings in different EU countries, north (UK) and south (GR) under different RET configurations. The description below, focuses on the WSN considerations of GR case study, where the first validation trial will be carried out.

The test building in Greece will deploy solar thermal collectors for hot use water production and space heating (via the existing underfloor heating system). Photovoltaic panels and a residential wind turbine will provide energy to local lighting and home appliances or it will be sold to the grid(s). The WSN will record environmental conditions such as sunlight, temperature, humidity etc. Smart metering will be employed at the device level (e.g. lights and appliances) and on each RET device to measure power consumed and power produced. Flow meters and temperature sensors will be installed on boilers to manage hot water supply for space heating and hot use water. Data from all sensors will be sent to the EW-C for the real time management of the energy modules on site.

4. Technology Description

This section provides a technical overview of the main EW modules and respective functionality.

4.1 EW- Simulator (EW-S)

The EW-S is a professional simulation environment which can serve as a design aid or decision support tool for the design or retrofit of new or existing energy infrastructures for buildings through the estimation and the prediction of energy production, grid exchanges, energy storage and energy use. The EW-S incorporates Renewable Energy Technologies (RET) modules, an Energy Use Model (ESM) and a Graphical User Interface (GUI).

The modelling of RET is based on a database of pre-set configurations; an extendible set of possible technologies including, at the time being, around 50 combinations of heating, cooling and electricity RET generators. To model the energy performance of the individual RET devices, an initial study of RES and storage devices has been performed, including reference to EU or international standards for determination of device performance. Where standards are not available, calculation models and reasonable estimations are being developed. The possibility to expand the solutions database in order to include new emerging RET configurations is taken into account.

Input to the EW-S includes building data, meteorological data, the RET configuration, and energy pricing data. Where site specific data are available, these may be input, resulting
to a more accurate simulation. Where site specific data are not known, the best available averages are utilized (e.g. from a wind chart or solar table).

The EW-S may perform in design (long term) and operational (short term) modes as follows:

- In the yearly, design, time-frame, the EW-S allows to assess various RET investment scenarios, both as technology as well as module sizing.
- In the daily/hourly, operational, time-frame, the EW-S performs short-term simulations, guiding the EW-C to identify the best actual scenario (use, or storage, or buy, or sell, or combination of them) for exchanging energy with the grid and with neighbourhoods, or for in-situ energy storage.

4.2 **EW-Controller (EW-C)**

The core module of the EW tool-set is the EW-C. This module will manage all in-situ energy modules and will define how network inflowing and locally produced energy is allocated between uses, stores or fed back to the utilities’ grid/nets. In addition, it will include a data collection and monitoring module that will use wireless sensors and data loggers/transmitters, which will be deployed at the building and enable the data collection. These data will form the foundation on which the sourcing decisions will be taken.

4.3 **EW-C Monitoring of the Building Energy Infrastructure**

The EW-C will be a piece of intelligent hardware ready for deployment and wiring in built environments. The EW-C will possess the following essential communication features: On the one hand it will integrate a TCP/IP port that will allow it to be managed and monitored locally as well as over the web; on the other hand the EW-C will be designed to interface with WSN (wireless sensor networks), most likely via the 802.15.4 protocol and it will be designed to be compliant with key building automation and communication protocols.

4.4 **EW-C Supervisory Control of the Energy Infrastructure**

The EW-C decision module will be based on a combined neural network and on rule-based approaches and will provide real-time control of the energy infrastructure. This hybrid system allows taking advantage of the best qualities of each artificial intelligence technique. Neural networks are massive parallel processors that have the ability to learn patterns through a training experience. These computer algorithms are a form of artificial intelligence that is non-linear and learns from feedback. As such, neural networks are excellent candidates for the modelling of complex non-linear processes such as those found in the heating, ventilation and air conditioning (HVAC) industry [1].

![Figure 2: Jordan’s Neural Network Model to be Applied in ENERGY WARDEN](image-url)
The EW-C will use a Jordan recurrent neural network [2]. This ANN architecture seeks to conduct pattern completion. With only partial (and changing) model input, the network can fill the remaining pattern in and set the appropriate linkage between the input vector and the expected output values (see Figure 2). Last, the EW-C will manage a number of filed parameters (meteorological data) as well as EW-S residing data (pricing information).

4.5 EW-User (EW-U)

The EW-U will be a real-time web-based software, database driven application of higher level functionality which will support policy conformance and emissions trading, allowing to monitor the building performance, for compliance with existing policies and standards. The performance of RET producing modules with regards to applying standards will also be achieved.

The EW-U application will use the RET producing module/ building operational data collected by the EW-C and those calculated by EW-S to run a number of applications related to:

- Policy support and conformance to directives for calculation of carbon emissions savings from the use of renewable sources (2009/28/EC) as well as link with the energy performance of building directive (2002/91/EC).
- Real time validation of the performance of energy producing devices according to EN/ISO standards (e.g. Solar PV Systems EN 61724, Small wind turbines EN 61400 etc.).

The precise contribution from renewable energy to the user energy requirements and its contribution as a green feedback to the network will be calculated.

5. Current Development Status

This section elaborates on the current (spring 2010) activities within the EW project.

5.1 EW-S Development

The consortium is currently developing the RET models. These will be entered in a MatLab environment and exported to the web where they will be accessed by the EW-S. At this moment is time it is not however yet decided if MatLab will be eventually used, especially as web enabling the MatLab models is not a fully streamlined process.

5.2 Input Data to the EW-S

An initial study is under development for the development of a full entity – relationship (ER) schema of the EW-S required input data. This data model includes several subsections, as follows:

1. Manufacturer: Technical specifications data for RET producing and storage devices as shown in Table 1. The web-based application will allow the registration of such devices by manufactures including technical and product cost data.
2. RET context: Data related to the actual installation of the device on the specific building. Such data could be the orientation of the solar panel, the altitude of the anemometer for a wind turbine etc. In some cases, default values could be suggested by the EW-S to facilitate the user.
3. Meteorological: Data related to the location of the building under study such as temperature, humidity, wind speed, solar radiation, ground temperatures etc.
4. Building/User: Data related to the building.
5. Pricing: Data related to prices of RET devices including installation and maintenance costs, fuel, electricity etc.

Table 1: Modelling of sourcing, storage and use modules

<table>
<thead>
<tr>
<th>Sourcing</th>
<th>Storage</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>solar/ thermal</td>
<td>batteries</td>
<td>local electricity loads</td>
</tr>
<tr>
<td>solar/ photovoltaic</td>
<td>hot water</td>
<td>use water heating</td>
</tr>
<tr>
<td>wind</td>
<td>hydrogen/ fuel cells</td>
<td>space heating / cooling</td>
</tr>
<tr>
<td>geothermal</td>
<td>phase changing materials</td>
<td>selling to the grid, district</td>
</tr>
</tbody>
</table>

5.3 Modelling of Energy Producing and Storage Devices

Mathematical models for each Energy and Storage Modules are currently under development based on various sources of information e.g. [3,4]. The simulation is energy oriented, meaning that what is expected after the simulation is the energy into/out from, or within each module as a function of time (preferably hourly). For each module the simulation runtime input data are specified through the web-application templates such as power input characteristic curves given by manufacturers, meteorological data, energy use patterns etc. It should be noted that the models use the same variables as the real time monitoring parameters from wireless sensors. In this way, simulation and real-time data can be compared after installation for the verification and updating of EW-S. Validation of models will be performed initially using existing installations data and later on with two demonstration sites in the UK & Greece.

5.4 Modelling the Management of Electricity and Thermal Energy Produced

One of the main features of the EW-S is the modelling of the management of the electricity and heat produced. The simulation will initially run time-dependent models of energy (electricity and heat) produced, used and lost. Based on the instantaneous data the models will be programmed to take smart decisions for the management of electricity and heat produced. In the case of electricity produced from RETs, as shown in Figure 3, several conditions exist where the energy can be fed to a number of storage devices, building electrical loads and grids, but at the same time energy can be transferred in various directions e.g. stored energy fed to different electrical loads and grids etc. In the same way modelling of heat produced from RETs as shown in Figure 4 is based on the heat transferred to a number of storage devices and from there to a number of building heat loads and districts.
5.5 Wireless Sensor Network

Monitoring of the building energy infrastructure in EW will be carried out by means of a Wireless sensor network (WSN), based on a cost-effective and standard compliant technology solution. Wireless sensor networks have an enormous potential as a tool for performing energy monitoring in buildings. The fact that these sensors are easily deployed, their low cost and their small size makes them especially suitable for performing energy monitoring in existing buildings, from heritage buildings to residential dwellings.

A Wireless sensor network consists of spatially distributed devices using sensors to monitor conditions at different locations, such as temperature, sound, light, humidity, vibration, motion, pressure, pollutants, etc. Usually these devices are small and inexpensive, so that they can be deployed in large numbers. The size and price requirements imply that the devices' resources in terms of energy, computational speed, memory and throughput are constrained. Each device is equipped with a radio transceiver, a microcontroller and an energy source, usually a battery. Each device relays information from other devices to transport data to a gateway.

WSN in design for the EW-C is based in the standard IEEE 802.15.4, a standard which specifies the physical layer and media access control for low-rate wireless personal area networks. IEEE standard 802.15.4 intends to offer the fundamental lower network layers of a type of wireless personal area network which focuses on low-cost, low-speed ubiquitous communication between devices.

The EW-WSN will provide for two types of monitoring capabilities:
- Energy consumption/production.
- Environmental conditions.

A sub-network of metering devices will be deployed at the relevant points of the building to log energy data. RET source and storage infrastructure also will be equipped with metering devices. Two objectives will be achieved in this way:
- Provision to the EW-C of detailed power consumption data from the different energy loads of the building.
- Provision to the EW-C of data on RET production and storage units (capacity status).

Another sub-network will be in charge of providing the EW-C with environmental data collected from outdoor/indoor sensors such as temperature, humidity, light, anemometer, water flow, water temperature, flow meter, etc.

The architecture of the EW-C, (see Figure 5) includes an embedded WSN gateway to link data directly from sensor nodes to the EW-C Database over internet (LAN, GPRS, 3G, WiFi). The WSN devices designed for monitoring, interface with low power sensors able to provide accurate data. The WSN protocol offers minimal beacon message needs for network composition, low power consumption algorithm, self-forming and self-healing network and fully bi-directional communication.

![Figure 5: EW-WSN Architecture](image_url)
6. Results

EW is currently in its early stages. It is reaching half way through its design phase, as presented above in the “Methodology” section and is planning to embark on the EW-S implementation within the summer of 2010. The wireless network of the first validation site is also under design and is expected to include between 20- 25 sensors (water temperature, water flow, electric current, environmental data). It will be set up at the site early 2011. The EW-C will be largely developed within 2011 and early 2012.

7. Business Benefits

The benefits of Energy Warden can be summarised as follows:

• User awareness and cost savings: Energy and operational cost information will empower the user to take actions for energy/cost saving measures.
• Standard compliance: Users can meet current or future regulations and be supported in their certification procedures.
• Increase of RET deployment: Contribute to the RET penetration in buildings as these are now optimally controlled, and their tight performance monitoring allows their operation to be more transparent to the user.
• Financial benefits: Advanced support for RET, building level, investment appraisal, facilitation of the use of financial or other instruments using RET devices i.e. market-based tools, reduced taxes, subsidies etc., emission calculations and trading.

8. Conclusions

Building renewable energy and building energy management are often considered in an isolated and therefore suboptimal way. EW provides for an integrated, though also modular, approach, bridging effectively these two broad areas.

Also, district level energy management is often highlighted as promising concept for energy optimisation. EW, by networking its EW-C devices will offer technology that may be deployed at the district level, enabling important data exchanges and optimizations at this level.

References