IT4ENERGY 2012

First International Workshop on

Information Technology for Energy Applications

PROCEEDINGS
September 6-7, Lisbon, Portugal

Paulo Carreira
Vasco Amaral (Eds.)

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Organizing Institutions

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Preface

This book contains the proceedings of the first International Workshop on Information Technology for Energy Applications (IT4ENERGY) held in September 6th and 7th 2012 in Lisbon, Portugal. The goal of this workshop is to establish itself as an impacting discussion forum on the topic of Information Technology for Energy Applications and be the first of a series of events on the subject.

Information technology for energy applications is growing in relevance as we assist to an upsurge of interest in energy management systems within homes, in buildings as well as in commercial and industrial facilities. These systems will have the ability to *(i)* coordinate production with consumption in scenarios of demand variability, *(ii)* integrating data from multiple sources and *(iii)* assisting users in the decision-making process as well as *(iv)* intelligently managing equipment and devices on behalf of the user.

Developing IT-based energy applications is a challenging multidisciplinary effort that often requires bringing together distinct engineering disciplines (e.g., Mechanical, Electric and Computer Engineering). We believe that Computer Science will play a critical role as catalyst toward creating a homogeneous body of knowledge regarding information technology for Energy Management. Therefore, this workshop brings together specialists from academia with different backgrounds spanning Mechanical, Electrical Engineering as well as Computer Science; Industry experts active in the fields of Energy, IT, Building Automation and Facilities Management.

Several topics were discussed in this event, namely: Software for energy applications; Data mining and decision support techniques for energy data; Models and techniques for energy consumption forecasting; Descriptions and characterizations of energy consumption patterns; Integration of energy data; Energy data visualization; Sensor networks, metering and energy data acquisition; Interoperability solutions including middleware and protocols for energy applications; Demand-side management; Home and building automation applications to energy; Energy-efficient control techniques; and Intelligent load control.

This event also aims at establishing linking bonds between industry and academia to disseminate know-how and generate economic value regarding this highly relevant subject. Therefore, in this event researchers have an opportunity to present their work and engage in stimulation discussions with peers from different backgrounds, while industry practitioners have the opportunity to discuss relevant issues with specialists. Moreover, students have an opportunity to collect positive and constructive feed-back from a diversified panel.

The first IT4Energy workshop is organized by Professional Association Ordem dos Engenheiros. Being the first of a series of annual events, we were honoured with the presence of Prof. G. Kumar Venayagamoorthy as keynote speaker, a world renowned specialist in Smart Grids with a talk entitled: *"Intelligent Scalable Monitoring and Control Technologies for Smart Micro-Grids and Grids"*. The event was organized and promoted by Ordem dos Engenheiros, CITI research center at FCT/UNL and INESC-ID research center at IST/UTL.

The event counted with the attendance of the successful rounded figure of 70 participants, 9 high quality full papers (out of 20 submissions) and 9 short papers. The first day of the event was dedicated to 8 tutorial sessions and on its second day to research papers organized into 4 presentation sessions on the subjects of Smart Grids, Energy Consumption Profiling, Energy Data Management and Intelligent Load Control.

This workshop would not have been possible without the help of many dedicated people. We would like firstly to thank the authors for choosing to submit to this workshop. Secondly, we wish to acknowledge our Programme Committee and the additional reviewers for their diligence. Thirdly, we would like to thank the organizing institutions whose support by several means has been crucial for the success of this event. Our final word of thanks IEEE Student Section for their enthusiastic support in developing the web site and the event logo.

September, 2012 Paulo Carreira
Lisbon Vasco Amaral

Organization

IT4ENERGY 2012 is organized by the Portuguese Engineering Association (Ordem dos Engenheiros) in cooperation with Instituto Superior Técnico, Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa, INESC-ID, CITI and IEEE Portugal Section.

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SmartSolarGrid
Deciding what to do with Solar Energy production

Diogo Morgado and Paulo Ferreira

INESC-ID / Technical University of Lisbon
diogo.morgado@ist.utl.pt,paulo.ferreira@inesc-id.pt

Abstract. Solar energy has been subject of great development in the past years, which led to the concept of Solar Roads: photovoltaic panels along the highways and roads. SmartSolarGrid is the merge of Solar Roads with Smart Grids, a new electrical distribution grid with improved efficiency and control. The goal of this work is to develop a software tool that further improves the efficiency of the electricity produced by automatically deciding in real time its destination: i) store the energy, ii) sell it to the global national-wide electric company, iii) sell it to the local electric company, etc.. In addition, we developed a software tool for electric cars which gives its driver suggestions about what he can do with the remaining energy stored in the car batteries (e.g. sell if there's enough for that) or where to charge up the battery (e.g. if there's not enough to get to the destination).

Keywords: Smart grid, Decision making, Solar energy, Solar road, SmartSolarGrid

1 Introduction

Mankind is facing a threat from the effects of global warming[1]. Now, more than ever, renewable energy sources should be used instead of fossil fuels, in an effort to fight global warming [1]. Of those types of energy, solar energy is one of the most popular, mostly due to the advances in solar photovoltaic panels technology [2]. The panels are arrays of solar photovoltaic cells that convert the sunlight into electrical energy taking advantage of the photoelectric effect.

One of the disadvantages of solar energy is that, to be produced at an efficient level, a large number of photovoltaic panels has to be used, thus requiring a large area. To tackle this problem, a solution has been proposed to make an effective use of the available area through out the country. It consists in deploying the solar panels in the shape of a tunnel around the highways and roads spread out around the country. This solution is called *Solar Road*. Figure 1 shows examples of such roads.

Together with a renewable power source like the *Solar Road*, *Smart Grids* [3] represent a big improvement over the older grids. A Smart Grid is an improved

[1] http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/247.htm

Fig. 1. Examples of possible Solar Roads

electricity distribution grid that manages in a very efficient, reliable, sustainable and economic way the electricity flowing through the system. This management, consists in controlling the electricity flow by gathering information from all the participants of the grid: the suppliers and the consumers. In Europe, Smart grid policy is organized as the Smart Grid European Technology Platform.[2]
To further improve smart grids, we must take into account the destination of the energy being produced by the grid. There are several options about what to do with this energy. In the context of the *Solar Road*, it can be stored in batteries for later use, sold to the nearest electric vehicle (EV) charging station, sold to the main distribution grid, etc.. In addition, taking advantage of the *Solar Road* concept, the new generation of electric vehicles can benefit greatly from this technology. If EV charging stations are spread along the highways, cars can use it to charge their internal batteries or to sell it to the grid in case there's room for it.

1.1 Goal and Requirements

The goal of this work is to come up with two software tools (the SmartSolarGrid Panels (SSG Panels) and SmartSolarGrid Cars (SSG Cars), which will be generically known as SmartSolarGrid.
SSG Panels objective is to automatically decide what to do with the energy produced given a few selected criteria. The alternatives include, for example: sell the energy to the nearest EV charging station, sell to the electric grid company, store in batteries, etc. The criteria to be taken into account is, for example: weather prediction, car traffic prediction, electric energy price, etc.
SSG Cars objective is to give suggestions to the driver about what to do with the energy left in case there's room to sell it, or where to charge it up if the remaining energy is not enough to make it to the destination. The criteria to be taken into account criteria are: the distance to the next EV charging stations, distance to destination, energy costs, etc.

[2] http://www.smartgrids.eu/

The requirements for SSG Panels are: decide in real time and in a semi automated way about what to do with the energy being currently produced; provide remote monitoring, control and configuration operations and provide authentication for the all the operations.
For the SSG Cars the requirements are: give suggestions to the driver about what to do with the stored electricity in a fully automated way and provide a route considering a possible chosen location to trade energy as a way point in the route.
Also, both tools are required to have a good degree of scalability, flexibility, system portability, adequate response time, user friendly interfaces, be able to run in real or simulation mode and use open source technologies.

1.2 Outline

This article is organized in sections: section 1 presents the motivation to the topic and describes the goal and requirements of this work. Section 2 presents the most relevant related work for this article. Section 3 describes the high level architecture of the system. Section 4 presents the evaluation and section 5 is the conclusion of the article.

2 Related Work

The main aspect of SmartSolarGrid is deciding what to do with the energy produced by taking into account multiple parameters like the destination of the energy (Sell to the grid, store it, etc..) and criteria like weather and traffic prediction, electricity price, battery level, etc.. As such, the area that presents relevant work to solve this problem is Decision Making. Multiple Criteria Decision Making (MCDM) is the name given to the techniques used to solve decision making problems. It consists in the study of methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the management planning process, as defined by the International Society on Multiple Criteria Decision Making[3].

There are several MCDM techniques that try to give the best result possible given input from the user. The Weighted Sum Method (WSM) and Weighted Product Method (WPM) are the most simple ones, where WSM accepts only units of measurement of the same type and WPM supports any units [4]. Although, they over simplify the problem and are not appropriate when taking into account a decision as complex as SmartSolarGrid requires. SMART [5,6] (Simple Multi-attribute Rating Technique) is also a popular technique due to its simplicity in the user's input required but we ruled it in favour of other techniques out because it involves too much steps. Then we have methods like the Elimination and Choice Translating Reality (ELECTRE) [7], the Technique for Order

[3] http://www.mcdmsociety.org/

A	1	B	4
A	4	C	1
B	9	C	1

Table 1. An example pairwise comparison

	A	B	C	Normalized Principal Eigenvector
A	1	1/ 4	4	0,2200
B	4	1	9	0,7132
C	1/ 4	1/ 9	1	0,0669

Table 2. The resulting matrix

Preference by Similarity to Ideal Solutions (TOPSIS) [8], the Multi Attribute Utility Theory (MAUT) [4,9], Compromise Programming (CP) [10] and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) [11,12], which are methods optimized for specific situations. For these reason, we don't take them into account to SmartSolarGrid. The one we favoured the most is the Analytical Hierarchy Process (AHP) [13,14] due to its flexibility, simplicity and basic user input.

2.1 AHP

AHP decomposes a decision problem into a hierarchy with the objective at the top level, the criteria at the middle level and the different alternatives at the bottom. The alternatives are compared two at a time to access their relative preference with respect to their impact on the criteria. To access the preference between two elements, the decision maker should use their judgement about the element's relative meaning and importance, but concrete data can also be used. It is the essence of AHP that human judgements can be used to perform the evaluation. [15].
The judgements are performed using Saaty's fundamental scale of 1-9 [4], where 1 means equal preference, 3 means moderately more preference about one of the elements, 5 strongly preference, 7 very strongly preference and 9 extremely more importance. The 2, 4, 6 and 8 values are used to express intermediate preference. The pairwise comparison is made in such a way that, for example, to compare alternative A against B taking criterion C1 into account, the decision maker assigns one of the previous values to the preferred option and 1 to the least preferred.
Table 1 shows an example where alternatives $\{A, B, C\}$ are measured against each other in a pairwise manner, taking criterion $C1$ into account. After dealing with the pairwise comparison of each element, the information is converted to matrices, from which the weights will be extracted. The weights are calculated using the matrices principal right eigenvectors. Table 2 shows an example using the comparison from table 1. This technique can be fully applied to make the decisions that the requirements state, where the outcome of the decision process is the destination of the electricity. As such, we chose AHP as the MCDM technique used in SmartSolargrid.

3 Architecture

We developed two tools: SSG Panels is responsible for the Solar Road infrastructure and SSG Cars takes care of the system that is used by the electric vehicles.

3.1 SmartSolarGrid Panels

The photovoltaic panels are organized by what we call **Production Sites (PS)**. A Production Site is an agglomerate of photovoltaic panels seen in the system as a single production entity. This means that, for the system, the amount of energy being produced by each PS is equal to the sum of the energy produced by each individual photovoltaic panel contained in that PS.

The infrastructure that supports SSG Panels is a N level hierarchy of servers, where the typical value for N is 3. The top level is composed by the **Central Server (CS)**, which is responsible for computing the decisions based on input from a human operator. The middle level contains the **Zone Servers (ZS)**, which are responsible for relaying any messages received from the CS to the panels. The bottom level is composed by what we call **Location Servers (LS)**, which are in charge of managing one Production Site based on information received from the CS. Figure 2 depicts the architecture described. The PS is composed by hardware dependant on the infrastructure operator, and as such is out of the scope of this article. We abstract this fact and assume the connection between the LS and PS is already in place and working. All the communication is performed through the internet, using a custom and secure (authentication) string based protocol. A private network can be used, since the software is designed to handle any kind of communication network, as long as it supports the typical TCP/IP stack. The Central Server is the core of the system. The main functionality and the decision algorithm is implemented here. We use a straightforward implementation of the AHP algorithm. This means that for each PS, there will be a set of criteria (e.g. Weather Prediction, Electricity Price, etc.) and alternatives (e.g. Sell the energy to the distribution grid, Store in batteries, etc.), that in conjunction with decision input from an operator, will allow the CS to calculate the decisions. To accomplish the flexibility requirement, for each PS, both the criteria and alternatives can be dynamically added or removed and can exist in any number. This way, different Production Sites can have different criteria and alternatives. To help the operator filling the decision matrix required by AHP, each criterion will have an associated value. The values' only purpose is to help the operator filling the decision matrix. However, this introduces a flexibility problem, because each criterion will have different ways of being updated. This problem is partly solved by the use of plugins. This means that each time a criterion is added, if the operator wants its value to be updated, a plugin to update the criterion is necessary. If it is already installed then the criterion is automatically updated. Otherwise, a plugin has to be coded and installed. The application automatically compiles and loads plugins when starting.

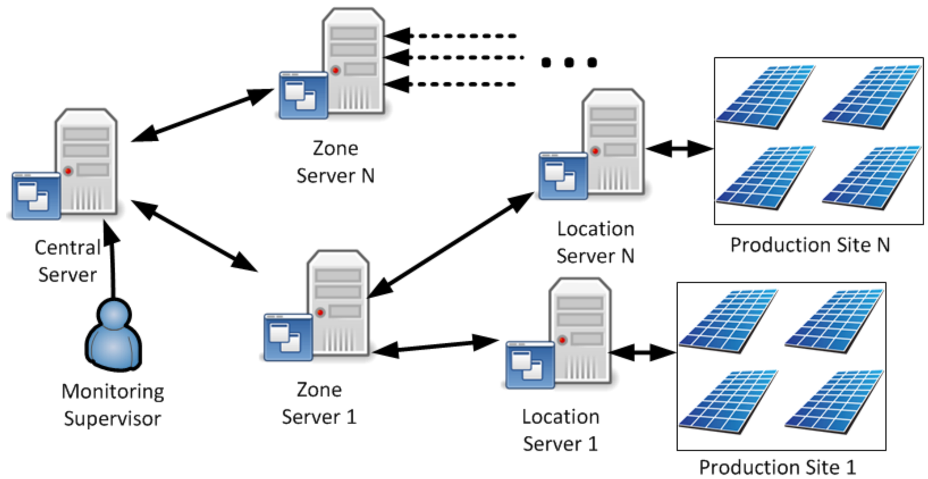

Fig. 2. Overview of the panels' system architecture. The dashed lines mean hypothetical connections.

3.2 SmartSolarGrid Cars

The Cars' application consists of a traditional Client-Server architecture. The client is executed on a portable device in electric cars, while the server can be executed any where (e.g. in the cloud). As with SSG Panels, the communication is performed through any TCP/IP network using the same string based protocol. The necessity of a server arises from the intensive calculations and data transfers necessary to compute the suggestions for the driver. A portable device like a tablet or a smart phone poses several limitations regarding battery consumption, CPU power and memory size and as such a server is necessary.
As with the SSG Panels, the availability of the system wasn't a primary concern, but this tool is also flexible enough to allow an integration with existing solutions. When using the application for the first time, we request the user to introduce the price he pays per kWh at home. We store this value and use it later to aid the suggestions algorithm. He then has two options: get driving directions either with or without suggestions. With this we mean energy trade suggestions, that is, sell or buy energy. We implement an algorithm to calculate them. Either way, the request always goes to the server which responds with the route or the suggestions. If suggestions are requested, the application will give one of three possible options: buy energy, sell energy or do nothing. If the suggestion is to buy or sell energy, a list of recharging stations will be presented on the map and the user can choose which one he will use. After that, the application shows the route taking the chosen station as a way point. To search for EV charging stations, the application is flexible enough to use any kind of searching service.

We use Google's Places API[4], which has limits regarding the number of queries per second. This has a tremendous impact on the algorithm's performance. As such, when the system is used in a real business situation, a professional service to search for the stations should be used instead.
For paths that take more than one battery recharge (recharging step), we calculate the next station when the user reaches the previous one. This repeats until the last recharging step. In case that, while the user is driving, the battery consumption rate changes more than 5% in comparison to the value used to compute the suggestions, we present the user with two alternatives: a safe-to-use-while-driving option that requires him to just push one button and the system recomputes the suggestions and automatically chooses the best one, or the normal way, where the user must choose the station from the map. By best station we mean: if he's buying energy, the one where the amount of money he'll have to spend is the lowest or, if he's selling energy, the one where the amount of money he'll receive is the greatest.

4 Evaluation

We adopted a Test-Driven-Development (TDD) process in which we thought of a testing case for a new function or functionality and then wrote the code in order to pass the test. This means that many implementation errors that might occur on normal development are taken care of and as such, the main evaluation of our software will be performance tests on the decision algorithm for the SSG Panels and on the suggestions algorithm for SSG Cars. The testing set-up, consisted on an Intel Core i7 720QM CPU with a 1.6GHz frequency together with 4GB of RAM memory at 1333MHz. We used the 64 bit Professional edition of Microsoft Windows 7, running JDK 6 Update 33 - 64 bit. It is worth noting that both algorithms should be executed on server grade machines, which implies more computational resources when compared to the machine where we performed the tests. This means that, in a real situation, the execution times are supposedly to be equal or better than the ones achieved in our tests.
The user interfaces were developed having one aspect in consideration: simplicity. Although, the system is flexible enough to allow changes to the interfaces without changing the logic of the tools. In the case of the CS, as the interface is made by html/php files, it is completely independent from the business logic. As such it's easy for a graphical designer to create more eye candy interfaces. Figure 3 show the decision input page of the SSG Panels and the screen to select the route for SSG Cars.

4.1 Decision algorithm

The decision algorithm has a computational time of O(ca), where c is the number of criteria and a the number of alternatives. This time can easily turn into

[4] https://developers.google.com/places/documentation/

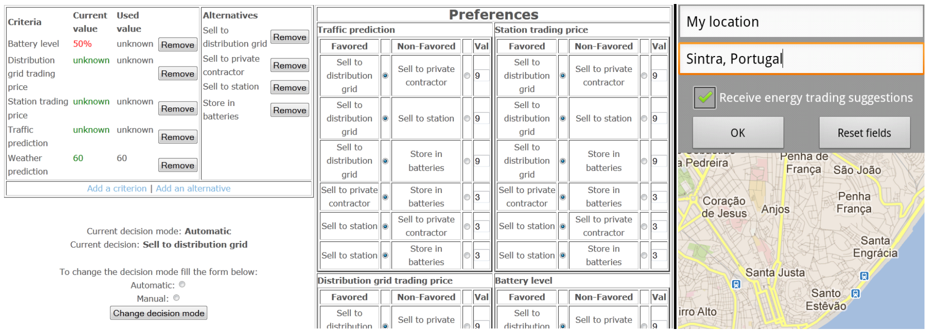

Fig. 3. Interface of the tools. On the left is the panels' and on the right the cars'

O(n^2) if $c = a$, which is the worst case scenario. Using $c = a$, we performed a test to evaluate the response time and memory used by the algorithm. The test consists on measuring the time to compute the best alternative and the amount of memory used. We repeated this test increasing the number of criteria and alternatives by one until a maximum of 100 criteria and alternatives. Due to storing the persistent information in a database, the time taken to read the information from it to memory is also important and as such we also measured this time. When the system is deployed in the field and being used in a real situation, we have to take into account the number of Production Sites, because each PS has an independent set of criteria and alternatives. This means that the results presented in this evaluation have to be multiplied by the number of Production Sites, which is dependant on a specific application of the system to a real situation. Figure 4 shows the results of the tests. We can clearly see that reading the database is the event that takes the most time. However it is well within an acceptable time for the typical case of 5-6 criteria and 3-5 alternatives even when multiplied by a reasonable amount of Production Sites. For example, in the case of $c = a = 10$, that takes only a few milliseconds to read the DB, even if there are hundreds of Production Sites, it should not take more than a few seconds. Even more, we only read the database when the CS is first started and then only on specific events, like changing the preferences, etc.

The time to compute the decision proves to meet the requirements. Even with $c = a = 100$, it takes only about 0.05 ms to compute the decision, which is considered a real time response. The time interval between the several tests is so low, around 0.06 ms, that the variations that appear as huge spikes in the middle of the chart have no practical meaning. This means that the objective was accomplished and the algorithm meets the time requirements to be used in a real situation.

The amount of memory used is also within acceptable ranges for the typical use case described above: it takes only around 1 MB of memory to hold the data structures. Even multiplying by a large number of Production Sites it shouldn't need more than a few dozens of MBytes. Also, since the CS should be executed

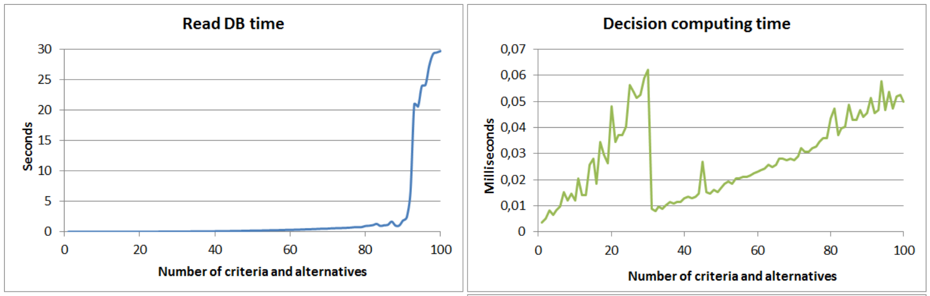

Table 3. Suggestions algorithm results

Locals	Distance (Km)	Time (Secs)	Memory (kB)
Sintra-Lisboa	31,331	2,409	50,227
Sintra-Faro	299,862	3,146	126,734
Sintra-Porto	336,713	3,788	180,680
Sintra-Bragança	541,408	17,852	267,164
Sintra-Madrid	647,858	19,259	224,320
Sintra-Bilbao	884,614	16,945	307,609
Sintra-Barcelona	1.276,972	20,717	386,180
Sintra-Paris	1.762,351	17,243	467,547
Sintra-Brussels	2.067,276	19,066	518,781

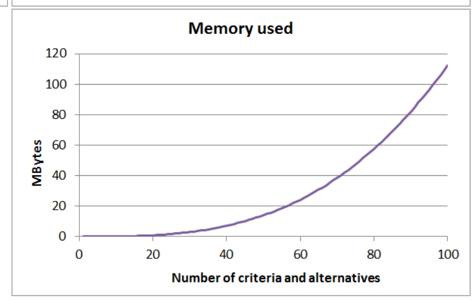

Fig. 4. Decision algorithm results

on a server machine that typically has dozens of GB, the amount of memory needed by the program isn't a problem.

4.2 Suggestions algorithm

The suggestions algorithm performance depends on trip's distance, because as it increases, so does the distance to search for EV charging stations. However, we implemented the algorithm to search only for stations that are within range of the car's current autonomy, which limits the searching distance in case the trip's longer than the autonomy range. This means that when the trip's distance is greater than the autonomy, the algorithm's performance depends on the car's autonomy only. We searched for examples of electric car's range: Nissan Leaf with 175 Km[5] and Tesla Roadster with 394 Km[6]. To perform the tests we used a value of 500 Km autonomy, because it is more than what electric cars can achieve at the present and as such, allows us to test the algorithm having some years in advance. The test consisted of a normal request to the server, using the 500 Km autonomy value and a source and destination city. We then repeated the test using ever increasing trips' distance. We measured the time it took for the algorithm to execute and the amount of memory used. As we mentioned on section 3 we use the Google Maps Places API to retrieve the EV charging

[5] http://newsroom.nissan-europe.com/media/articles/html/75281_1_9.aspx
[6] http://www.greencarmagazine.net/2009/07/tesla-motors-moving-quickly-to-commercialization-of-an-electric-car/

stations, which has usage limits and affects the algorithm's execution time. Table 3 shows the results. From there, we can see that indeed the calculation time increases when trip distance increases, with a considerable increase from around 350 to 500 Km. However, we can make a distinction between the trips. For the average person daily trip ($<$ 100 Km) the response time is within an acceptable range ($<$ 3 seconds). For longer trips, with a distance greater than the car's autonomy (500 Km), it can take up to 20 seconds to perform the calculations. This is not an optimal response time, but given the context of the application, we consider that this time is acceptable. Sometimes, it can take several minutes to acquire a GPS signal and users of this types of applications are used to waiting a few minutes. Also, these values will tend to be lower in cars with lower autonomy, which is the case today.

5 Conclusion

We present a new way to improve the efficiency of electric production in a Solar Road/Smart Grid context. The use of a Multiple Criteria Decision Making technique allow for a semi automated way of choosing the best decision regarding the destination of the energy being currently produced in the system. We also presented a way to give suggestions to drivers of electric cars about what they can do with the energy stored in their car's battery or where to charge it up. The results of the evaluation show that we achieved the objectives. We can conclude that the requirements were met.

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A Wireless Sensors Suite for Smart Grid Applications

António Grilo[1], Helena Sarmento[1], Mário Nunes[1], José Gonçalves [2], Paulo Pereira[1], Augusto Casaca[1], Carlos Fortunato[3]

[1] INESC-ID/IST/TULisbon, Portugal
{Antonio.Grilo, Helena.Sarmento, Mario.Nunes, Paulo.Pereira, Augusto.Casaca}@inesc-id.pt
[2] INOV, Portugal
Jose.Goncalves@inov.pt
[3] EDP – Energias de Portugal, Portugal
Carlos.Fortunato@edp.pt

Abstract. This paper presents a demonstrator of a Wireless Sensor and Actuator Network (WSAN) for Smart Grid applications, developed in the context of project WSAN4CIP. This WSAN is formed by WSAN nodes equipped with sensors and a wireless radio interface, which monitor key parameters of power grid equipments belonging to the Medium Voltage (MV) and Low Voltage (LV) segments. The measurements are reported to the SCADA system and constitute the basis of both safety and security services to improve the power grid distribution dependability. This paper describes the hardware of the sensor nodes and presents the respective performance results, attesting the feasibility of the proposed solutions.

Keywords: Smart Grid, WSAN, Sensor, Energy Harvesting

1 Introduction

The Smart Grid (SG) is an emerging concept where information technologies are used to provide embedded intelligence to the electrical grid, encompassing all of the latter's segments: power generation, electricity transmission, electricity distribution and consumption. According to this concept, the SG will have such capabilities as to integrate micro producers of energy (possibly coinciding with customers), to perform automatic fault detection and self-reconfiguration according to supply and demand patterns. In order to allow these advanced functionalities, the power grid must first be sensorized, i.e. fit with sensors that are able to collect and deliver relevant measurements to the processing systems, as well as electro-mechanical actuators that are used to change the configuration of the grid.

The SG is expected to gradually evolve from the legacy power grid. At the current stage, the deployment of extra technology can already improve the latter's dependability. For example, monitoring of power system parameters in the transmission and distribution segments, such as voltage, current and equipment temperature, as well as monitoring and control of substation devices is crucial for the efficient operation of the power grid, namely regarding early detection of fault conditions [1]. Wired communication could be used, but wireless technologies usually constitute a less expensive option. The use of wireless sensors and actuators can also lead to a more powerful and efficient solution due to the deployment flexibility, besides avoiding the deployment of cables in already cluttered power grid facilities [2].

The FP7 project WSAN4CIP[1] has selected the power grid distribution segment as the specific target for one of its two demonstrators. This segment receives High Voltage (HV) lines from the transport segment of the grid, delivering Low Voltage (LV) and Medium Voltage (MV) lines to customer premises. It mainly consists of HV/MV substations, connected by MV power lines to industrial customers or secondary substations (where MV is converted to LV), as well as the LV power lines connected to LV customers. A SCADA system is used as a supervisory control and data acquisition system for this infrastructure.

This paper presents a demonstrator developed within the scope of the WSAN4CIP project, which addressed the protection of critical infrastructures through the use of Wireless Sensor and Actuator Networks (WSAN). The demonstrator includes sensor nodes developed within the project. This paper focuses the hardware of the sensor nodes and presents the respective performance results, attesting the feasibility of the proposed solutions. The detailed description of the WSAN architecture is presented in another paper [3].

The rest of this paper is organized as follows. Section 2 presents and overview of the WSAN demonstrator. The deployed sensor node hardware is described in detail in Section 3. The sensor performance results are presented in Section 4. Finally, Section 5 concludes the paper.

2 WSAN demonstrator overview

The WSAN4CIP project focused on improving the dependability of critical infrastructures. This demonstrator was intended to validate the research done for the specific case of the power grid distribution system.

A proof-of-concept demonstrator was deployed at EDP Distribuição[2] premises, more precisely at the São Sebastião primary substation, located in the neighborhood of the city of Setúbal, in the west of Portugal. The São Sebastião substation provides electric energy to the Setúbal region. Fig. 1 sketches the WSAN demonstrated in WSAN4CIP, where wireless sensor nodes and their links are also represented.

The power grid distribution infrastructure mainly consists of a set of substations, MV power lines connecting substations to Medium Voltage/Low Voltage (MV/LV) power transformers residing in the secondary substations and LV power lines from the secondary substations to the customers. Some industrial customers may also get direct MV power lines. Associated to this infrastructure we consider also the SCADA system, which is a supervisory control and data acquisition system dedicated to the

[1] Wireless Sensor and Actuator Networks for the Protection of Critical Infrastructures http://www.wsan4cip.eu/

[2] EDP Distribuição is the main company that carries out the function of electricity distribution operator in mainland Portugal.

infrastructure. Remote surveillance of the power grid is already done to some extent based on wired sensors. The use of wireless sensors can, however, lead to a more flexible and powerful protection scenario for the substations, power lines and power transformers. The deployment flexibility of WSAN allows capturing more status parameters than the currently deployed wired sensors and the wireless nature of the communication can contribute to avoid critical points of failure.

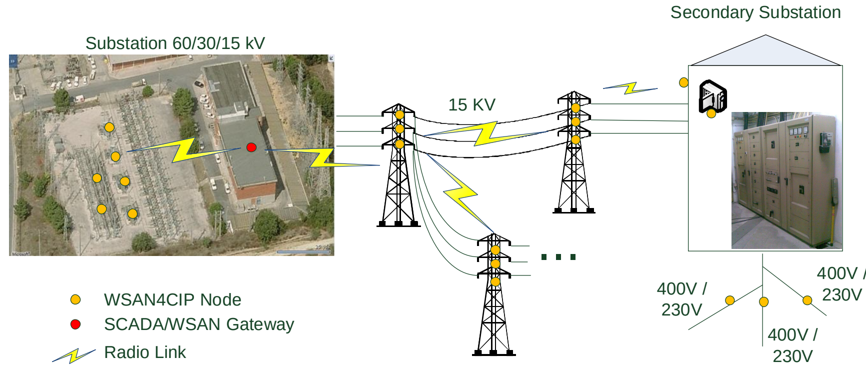

Fig. 1. WSAN for the electrical distribution segment of the power grid.

In the WSAN4CIP project we focused into improving the dependability of the substation components, MV and LV power lines, and MV/LV power transformers in the secondary substations. We have defined solutions for the remote active monitoring of: i) substation circuit breaker trip coil status; ii) temperature of the substation power transformer oil, substation neutral reactance oil and substation neutral resistor coil box; iii) MV and LV power line current activity; iv) MV/LV power transformer hotspot detection; v) human activity in the secondary substation through the use of movement detectors and video cameras. All the monitored parameters and images are visualized at the SCADA system, through a special-purpose graphical user interface.

The requirement for video transmission and the long distances between MV power line towers place additional requirements in terms of the communications and processing capabilities of the WSAN nodes, prompting the use of a broadband medium-range technology such as IEEE 802.11g for WSAN communications.

3 Wireless Sensor Nodes

Wireless sensor nodes include the sensor with the conditioning electronics, an IEEE 802.11g module, a DC-DC converter and an external power supply. WSAN4CIP has integrated two solutions: one based on a Silex SX-560 core[3] and a second solution based on a Beagleboard[4]. While video compression at the secondary substation requires a more powerful processing node such as the Beagle, scalar sensor

[3] http://www.silexeurope.com/en/home/products/wireless-modules/sx-560.html
[4] http://beagleboard.org/

nodes can be based on a less powerful board such as the Silex SX-560 that requires less energy to operate (an energy analysis of the SX-560 is presented in [4]). The Beagleboard is also able to support a secure operating system. The inclusion of two different solutions allows also the demonstration of a heterogeneous scenario.

Sensor node PCBs integrating the Silex SX-560 SOC were developed at INOV. The external power supply is either MV power-line energy harvesting or 230 V AC, depending on the node. Conditioning electronics depend on the sensor type. Next subsections describe the hardware of the sensors for current intensity measurement, temperature measurement, and circuit breaker status detection.

3.1 MV current sensing node with energy harvesting

The MV and LV power line scenarios aim to monitor the status of particular power line sections. It is therefore possible to know centrally the location of a power line failure. The chosen MV power line has a voltage of 15kV and feeds a set of MV/LV power transformers in secondary substations. The line topology is a tree shape with several leaves consisting of secondary substations (see Fig. 1). The physical measurement to be done is the electrical current flowing through the line; a current transformer is used to measure its value and to derive a parasitic power source for the wireless sensor, reducing the power constrains on the wireless protocols through this energy harvesting technique. The current sensor samples the current on the line every second. This section describes the MV sensor only. The LV sensor is similar, but sensor nodes are in this case attached to public lamps, being fed directly from the monitored AC power line.

The electrical current flowing through each line (phase) is sensed and measured, using a current transformer (CT). The current to charge the battery is also obtained from the MV line, using the same current CT. Therefore, two working modes are defined for this WSN node: current sensing and energy harvesting. In the current sensing mode, the current in the line is estimated based on the current passing in the secondary winding of the transformer. The harvesting mode uses the secondary current to charge the battery. Modes are controlled by the microcontroller of the wireless module.

Fig. 2 depicts the block diagram of the circuit that implements the conditioning electronics and the energy harvesting from the line.

A CT is an instrument transformer intended to have its primary winding connected in series with the conductor carrying the current to be measured or controlled. In a window type CT, the secondary winding is insulated from and permanently assembled on the core, but no primary winding exists as an integral part of the structure. Primary insulation is provided in the window, through which one turn of the line conductor can be passed to provide the primary winding. A large current in the primary winding is reduced to a lower level to be more easily measured. The number of secondary turns determines the amplitude of the output current.

The used CT is a split core CT that can be temporarily opened to be place around existing wires, without disconnecting the primary circuit. Other specifications are:

minimal current value in the line is 5A; maximal current value is 300 A; and accuracy in current measurements up to 10%.

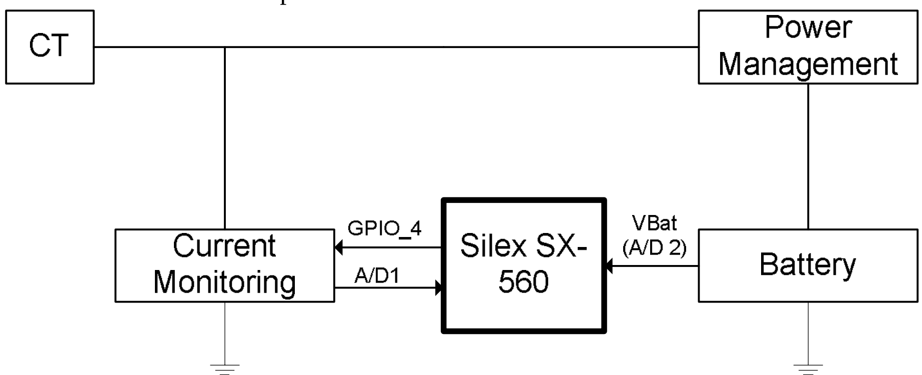

Fig. 2. Electronic circuit for current sensing and energy harvesting

The Hobut CTS80-1[5], with a ratio of 400/5 was selected. It supports a primary current up to 400A. This CT is suitable for three classes of accuracy: 0.5% up to 2.5 VA; 1% up to 6 VA; and 3% up to 10 VA, being adequate to the specifications for current measurement accuracy (10%).

The GPIO_4 signal (Fig. 2), from the microcontroller in the Silex SX-560 module, controls the energy harvesting and sensing modes. It switches on/off a NMOS transistor in the Current Monitoring module. When the transistor is switched on, the sensing mode is on and it avoids current to pass to the battery circuit. The voltage at A/D1 is converted by an ADC and sent to the microcontroller. It represents the secondary current, permitting to determine the current in the MV power line.

The transistor is switched off in the energy harvesting mode, when the current is allowed to flow to the battery. The battery charge can be monitored, reading VBat that is connected to an input port of the ADC.

The ADC (ADC122S021) is a two-channel 12-bit successive-approximation ADC converter, suitable for sensing applications, with a serial interface compatible with the Serial Peripheral Interface (SPI) of the SX-560.

The electronic circuit is enclosed in an aluminum alloy box with a cubic shape (Fig. 3). The aluminum box is completely covered with a Scotch™ 23 Electrical tape, a highly conformable Ethylene Propylene Rubber (EPR) based, high voltage splicing tape. It is a non-vulcanizing, shelf-stable tape with excellent electrical properties. Tape can be used as insulation for low-voltage applications as well as insulation for splices up to 69kV.

To guarantee high resistance to outdoor weather conditions, namely to humidity, rain and UV rays, the box is then painted with liquid silicon. This node was designed as to be suspended on a 15 kV aerial power line (Fig. 3).

[5] 6. http://www.hobut.co.uk/current-transformers/split-core-cts/series-80U

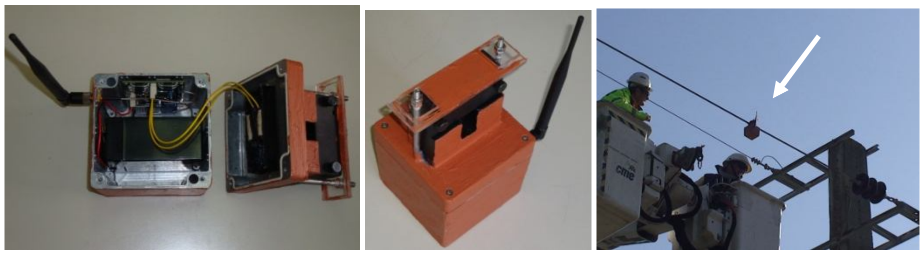

Fig. 3. MV power line current sensing wireless node.

3.2 Trip coil sensor and actuator

The trip coil is the component of the circuit breaker that permits to interrupt the electrical current flow, by applying 110 V at its terminals. After the activation of the circuit breaker, the coil can be damaged. A sensor and an actuator periodically evaluate the operating status of the circuit breaker. In order to verify the status of circuit breaker status, a 5 V DC voltage is applied every 60 minute by an actuator. If there is current flow, the coil is working properly.

To verify the existence of a current flow, a magnetic sensor is used. The selected sensor (KMZ10C) is a magnetic field sensor, employing the magneto-resistive effect of thin-film permalloy. Four sensors, connected in a Wheatstone bridge configuration, define the complete sensor. Conditioning electronics includes an instrumentation amplifier (MAX4208) with adjustable gain defined by two external resistors. The analog amplified voltage is converted to a digital value by an ADC that includes an internal sample and hold circuit. The digital signal is connected to the microcontroller of the Silex SX-560 Module by an SPI interface. As the 110 V DC voltage can be simultaneously applied to the coil terminals, a optocoupler is used to provide electrical isolation.

3.3 Temperature sensors

At the distribution substation, failures in power transformers affect a series of power lines and all the downstream secondary substations, resulting in problems for homes and businesses. Some failures can be detected just by monitoring the oil temperature of the 15 kV power transformers. The Neutral Reactance oil tank and Neutral Resistor coil box temperatures are also monitored as a means for failure detection. Their temperature can significantly rise during phase-earth failures during which these devices have to dissipate very high currents while the power line connectivity is not interrupted by the circuit breakers.

The selected sensor (LM70) is a silicon temperature sensor, detecting the voltage change across a *pn* junction. Temperature resolution is 0.25°C while operating over a temperature range of −55°C to +150°C. Depending on the temperature range, accuracy changes from ±2° up to +3.5/−2°C. The LM70 is an integrated circuit, including the temperature-sensing element, the signal conditioning electronics, an ADC converter and the SPI serial data link. Therefore, it connects directly to the microcontroller of the Silex SX-560 module.

3.4 Video Surveillance, Intrusion and Hotspot Detector

This WSAN node is the result of mixing different technologies, all interconnected to a Beagleboard WSAN node:

- Video surveillance: Logitech's Quickcam Sphere AF Webcam connected through a USB interface. To ensure the goal in harsh illumination conditions, it was implemented a small device of illumination composed by a light-emitting diode (LED) device controlled through GPIO;
- Motion detection: passive infrared (PIR) sensor communicating through GPIO;
- Hotspot detector: IRISYS IRI 1011 Thermal Infrared Camera communicating through a RS232 serial data link. Due to unavailable RS-232 ports on the Beagleboard, the interface with the Thermal Camera was made with a RS-232 to USB adapter.

4 Tests and results

The current sensor was tested separately at special lab facilities before the WSAN integrated tests and trial deployment. This was due to the harsh electromagnetic conditions to which it would be subject during the trial, as well as the high costs of retrieval and redeployment. The other sensors were tested both in lab and *in situ*, i.e. already coupled with the monitored equipments. This section will cover the individual sensor performance tests. The integrated WSAN performance tests are described in another paper [1].

4.1 MV current sensing node

In order to find potential EMC (ElectroMagnetic Compatibility) problems, the wireless current sensor node was tested under exposure to the electromagnetic fields generated by the 15 kV power line. Fig. 4 presents the testing environment. Firstly, the node behavior was tested for voltages of 9kV, 13 kV and 20 kV. No problems were detected on the wireless communication or on the node functionality. Only for 20 kV, the corona effect [5] starts to be noticed.

Fig. 4. High Voltage Tests

Accuracy was also analyzed in the MV environment. Results are depicted in Fig. 5. Measured values present an offset to the theoretical values. Calibration was then done by software.

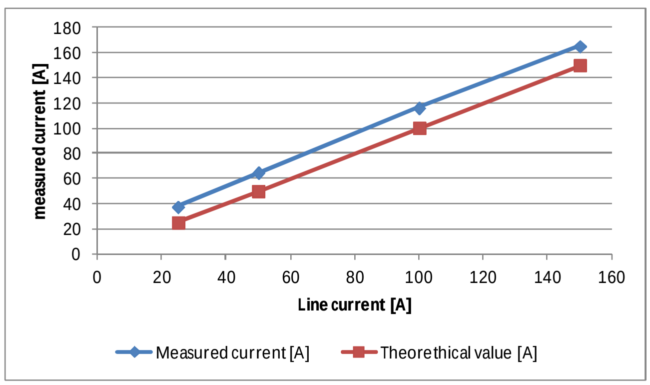

Fig. 5. Accuracy analysis for MV.

4.2 *In Situ* Accuracy Tests

For the current measurement tests, extra current was externally injected in the LV lines by the EDP technicians and the sensor reports were confronted against the known current injection values.

For the trip-coil, on-demand tests were performed while the trip-coil was operational. Then, the 110 V terminal was disconnected from the trip-coil to check whether the malfunction was automatically detected. The on-demand test was also repeated under this condition.

For the intrusion and hotspot detection tests, the respective situations were simulated by the EDP and INOV team. The tests entailed the transmission of images from the LV/MV power transformer to the primary substation. The corresponding SCADA screen is shown in Fig. 6. For the hotspot detection, a soldering iron was placed in front of the camera, while for intrusion detection, a member of the EDP team simulated intrusions in a secondary substation.

The measurement precision test results are listed in Table 1 and Table 2. It should be noted that these results already have sensor calibration into account. Regarding the temperature measurements, the precision is high, with an average error of 1% and maximum of 3%. For the power line current measurements, the average error was 4.58% with peaks of 10.83%. This precision is enough to detect breakdown spots in the power-lines as well as to provide coarse reports about the distribution of current consumption within the EDP network. The remaining components feature a high precision.

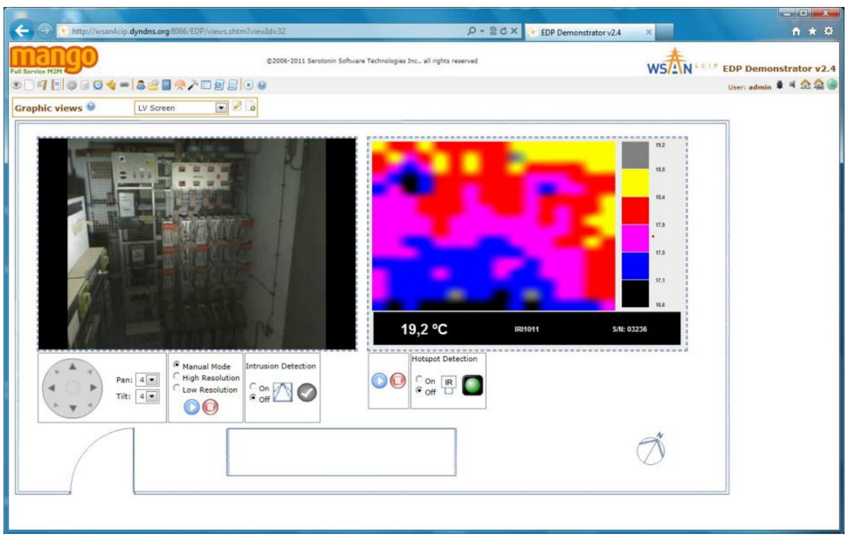

Fig. 6. SCADA screen.

5 Conclusions

This paper has presented the sensor node hardware that was developed and deployed in the demonstrator of FP7 project WSAN4CIP. Besides standalone tests, the sensors were also tested as nodes of the WSAN, both in-lab and in the deployed pilot system. Results of performed tests show that sensors performance is adequate. The energy harvesting mechanism implemented to recharge the WSAN node batteries demonstrated to be effective in powering sensors to measure MV power line activity.

Table 1. Temperature and Current Precision Evaluation.

Application	Number of Trials	Average Error	Maximum Error	Standard Deviation
Power Transformer Oil Temperature[6]	10	1.0%	3.0%	0.4%
Power Line Current	20	4.6%	10.9%	3.1%

Table 2. Event Precision Evaluation.

Application	Number of Trials	Measurement Errors	Success Rate
Trip Coil	24	0	100%
Intrusion Detection	11	0	100 %
Hotspot Detection	10	0	100 %

6 Acknowledgement

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[6] Temperature precision measurements were similar for the Neutral Reactance and Neutral Resistance components, since the sensor node is the same.

Decentralized Multiagent Planning for Balance Control in Smart Grids

Francisco S. Melo[1], Alberto Sardinha[1], Stefan Witwicki[1],
Laura M. Ramirez-Elizondo[2], and Matthijs T.J. Spaan[2]

[1] INESC-ID/Instituto Superior Técnico
2780-990 Porto Salvo, Portugal
{fmelo,witwicki}@inesc-id.pt, jose.alberto.sardinha@ist.utl.pt
[2] Delft University of Technology
2628 CD, Delft, The Netherlands
{l.m.ramirezelizondo,m.t.j.spaan}@tudelft.nl

Abstract. Integrating large-scale micro-generation in distribution grids is challenging for distribution grid operators, particularly when renewable energy sources (RES) and micro-cogeneration are involved. In this paper we contend that recent developments in multiagent decision making under uncertainty can positively contribute to safe, efficient and cost-effective operation of future distribution grids.

Keywords: Smart Distribution Grids, Decentralized Planning, Agents

1 Introduction

Electric power systems have been undergoing momentous changes over the last decade. In the past, power was supplied predominantly by a limited number of large power plants, mainly nuclear powered or fossil fueled, and then transmitted to the consumers [5]. In the near future, production will increasingly rely on a greater number of decentralized, mostly small-scale production sites [5] based on renewable energy sources (RES), such as solar or wind power, and micro-cogeneration units, such as stirling engines and fuel cells. These will be located closer to the final consumers than traditional power plants, even at the households themselves.

The inclusion of micro-generation enhances the overall system in terms of sustainability. However, we advocate that additional improvement may be achieved through intelligent agent-based decision making. Customers, or agents acting on their behalf, should play an active role in managing the energy produced by the controllable micro-generation units. Additionally, the balance between consumption and supply is required for a proper and stable operation. Thus, agents that control energy consumption can also support the distribution network by matching the timing of their demand to the dynamic availability of the energy supply. As a result, a more efficient operation can be obtained by reducing the peak load while maintaining the power balance.

The massive introduction of small-scale RES-based production and active consumption management introduces significant uncertainty in the normal operation of the distribution grid. Some of the sources behind such uncertainty are [4]: (i) *Operational uncertainty*, usually associated with the demand and the supply of energy (e.g., load pattern predictions, future energy supply of solar cells and windmills); (ii) *Structural uncertainty*, associated with changes in the physical infrastructure (e.g., switches in the power grid may have to be closed or opened to keep voltage and frequency within normal operational limits; a distribution line breaking due to bad weather).

With the introduction of decentralized generation, several important changes regarding the planning, operation and control of power systems have taken place, particularly because of the following differences: decentralized generation units are connected to the distribution network and not to the transmission network; several types of decentralized generation units are connected to the grid by means of power electronic interfaces (whereas large generation plants are coupled to the electricity grid directly); the power generated by micro-generation units is considerably less than power generated from traditional power plants (several orders of magnitude); and renewable energy generators depend on natural and uncontrollable sources, which adds a high level of uncertainty to the system. Given that distribution generation will play an important role at distribution level, power systems are forced to adapt in order to perform control actions at this operating level as well.

In the literature, a large number of the planning and control architectures designed for distribution network and micro-grid applications have two-level hierarchical configurations and only take into account electrical parameters and electrical interactions, even though heat outputs from micro-cogeneration units are also available. For example, in [11] a droop control method is applied on a system that contains renewable energy generators and storage. The control unit optimizes the power output of the generators by communicating new droop settings based on the information collected from the inverters, micro-generation units and battery banks. Another example can be found in [6], where control and power management strategies based on locally measured signals without communication were proposed under various micro-grid operating conditions. The real power of each decentralized generation unit is controlled based on a frequency droop characteristic and a frequency restoration strategy [6].

In contrast to these prior works, we propose addressing the electrical flows, but also the usable heat produced by the micro-generation units, as considered in [8]. Moreover, we defend the incorporation of three aspects of control using an integrated agent-based planning methodology, namely the active power control, voltage control and control with respect to economic considerations. An economic optimization based on forecasts will provide the set-points to the controllable components of the system in which the active power control and voltage control will be applied.

Hence, we envision a distribution grid that is able to self-regulate with little human supervision. We defend the use of new decentralized planning and control techniques for the distribution grid that take into account the dynamics and the topology of the grid and also handle the uncertainty inherent in the production and consumption of electricity. These techniques should allow the grid to preserve its properties as it scales in size and should also accommodate the possibility of massive micro-generation from renewable energy sources and from micro-cogeneration units. Finally, it should facilitate the inclusion of new technologies such as smart heating, ventilation, and air conditioning equipment.

2 Decentralized Planning and Optimization

Consider the distribution grid as a complex system composed of interconnected components, many of which need to be controlled in order to optimize system objectives. Decentralized planning accomplishes this optimization by distributing the control among a team of intelligent agents, each of which operates an individual component. For instance, an agent controlling a particular power substation decides where and when to route power. In planning its decisions, each agent should account for uncertainty in the consequences of its actions, reasoning over, for instance, the likelihoods of different volumes of future energy consumption. Agents may only be able to base their decisions on incomplete and local information, depending on sensory capabilities and on infrastructure supporting information exchange throughout the system. Nevertheless, because the actuation of one component may affect the state of another, the agents should work together to formulate coordinated plans that fulfill quantifiable global objectives.

In the literature, these characteristics serve as the basis for a formal model of multiagent decision-making called a *Decentralized Partially Observable Markov Decision Process* (Dec-POMDP) [1]. The Dec-POMDP model has been hailed as a rich, principled mathematical framework for optimization under uncertainty, and has spawned an increasingly active area of research referred to as multiagent sequential decision making (MSDM) under uncertainty. Power systems research has considered the effects of uncertainty in load predictions [2], the inherent uncertainty in wind forecasts [3] or uncertainty in unit commitment [9]. However, the decentralized optimization techniques for tackling uncertainty that we propose have not yet been exploited in Smart Grids.

3 Discussion

Framing the control problem as one of decentralized planning, one can address the problems of keeping the network under stable operation, performing balance control, and economically optimizing the system, in a single integrated solution, all while accounting for uncertainty. An appealing aspect of this application is the structure in the distribution grid control problem that we expect can be leveraged to improve the efficiency and scalability of decentralized planning [7]. Recent theoretical developments have established that multiagent systems in which the interactions between agents are *weakly coupled* allow for significant computational savings that can result from exploiting such weakly coupled interaction structure [10]. This has resulted in increasing research efforts in the development of better representations of the structure of multiagent systems and better techniques for exploiting it.

Although there is yet little application of MSDM techniques to real problems, control of smart distribution grids provides a well-motivated application domain, and with it a golden opportunity to break free of the status quo and to develop and validate MSDM research on realistic problems. It not only allows the testing of conventional assumptions of existing models and algorithms that have long been taken for granted, but it can also inspire the development of more useful models and methods whose assumptions are more realistic. This would constitute an important step forward in grounding recent MSDM work, and one that is essential for maturing the field.

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A Simulation Tool for Demand Response Programs Implementation

Pedro Faria, Zita Vale

GECAD – Knowledge Engineering and Decision-Support Research Group of the Electrical Engineering Institute of Porto – Polytechnic Institute of Porto (ISEP/IPP), Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal
{pnf, zav}@isep.ipp.pt

Abstract. The design and development of simulation models and tools for Demand Response (DR) programs are becoming more and more important for adequately taking the maximum advantages of DR programs use. Moreover, a more active consumers' participation in DR programs can help improving the system reliability and decrease or defer the required investments.
DemSi, a DR simulator, designed and implemented by the authors of this paper, allows studying DR actions and schemes in distribution networks. It undertakes the technical validation of the solution using realistic network simulation based on PSCAD. DemSi considers the players involved in DR actions, and the results can be analyzed from each specific player point of view.

Keywords: Demand response, decision support system, simulation

1 Introduction

Demand Response (DR) was expected to significantly grow in the scope of electricity markets, bringing economic and technical benefits to the whole system. However, DR is not being as successful as expected [1]. In this way, the positive impact of DR on power systems and on the involved players' business may be enhanced by adequate tools which are able to simulate DR programs and events, from the point of view of the relevant players. Several tools have been developed to support decision making and validation concerning demand response programs. A list of some tools can be found in [2]. Generally, the existing software aims to assess the cost savings opportunities based on building and load characterization.

DemSi, the DR simulator developed by the authors of this paper, presents several innovative features when compared with other existing tools [3]. One important point is that the other tools deal with specific installations (e.g. commercial or residential buildings) whereas DemSi is able to deal with the application of DR programs to a large set of consumers. Moreover, it uses realistic models that allow to simultaneously take into account contractual constraints and to undertake the technical validation.

DemSi considers the players involved in the DR actions and results can be analyzed from the point of view of each specific player. This includes five types of players, namely consumers, retailers (suppliers), Distribution Network operatos (DNOs), Curtailment service Providers (CSPs), and Virtual Power Players (VPPs). The analysis can also be done from the point of view of the retailer, of the consumers (both individually or in the scope of a load aggregator) or of the DNO.

Another advantage of DemSi is that it includes a diversity of DR programs. DemSi allows choosing among a large set of DR programs, each one modeled according to its specific characteristics.

2 Computational tools used in DemSi implementation

The development of DemSi has been based on three simulation tools. GAMS – General Algebraic Modeling System – is a computational tool developed to implement linear optimization problems, as well as non-linear and mixed-integer ones [4]. With GAMS the user is concerned only with the formulation of the problem / model. In this way, the difficulties around the modeling of the solving method are suppressed. It is simple to choose from several numeric methods and then comparing the results. The diverse solvers make possible to solve a large variety of problems.

MATLAB is a powerful software of numeric computation that was developed in 1978 by Cleve Moler and is nowadays a property of MathWorks. The main characteristic of MATLAB is the use of matrixes as the basic data structure [5]. As it is an interactive software of high performance, MATLAB is used in several applications in the industry, as well as in academic activities, and has been applied to several problems of science and engineering. MATLAB has toolboxes that allow obtaining the solution for several types of problems such as the ones related with numerical analysis, data analysis, matrix calculus, and signal processing. The user can use the available toolboxes or program functions and routines to solve the envisaged problem.

PSCAD/EMTDC is a simulation tool developed by the Manitoba-HVDC Corporation, dedicated to the system analysis and having electric power systems as the main application area. PSCAD is the graphical interface to the user, while EMTDC is the simulation software. The graphical interface of PSCAD considerably improves the EMTDC usability. It makes possible for the user to build the circuit schematically, to process the simulation, to analyze the results, and to manage the data in a completely integrated environment. An important advantage of PSCAD, which is crucial for DemSi, is the possibility of linking it with MATLAB software.

3 DemSi architecture and implementation

DemSi combines the use of GAMS optimization software and of MATLAB, which has been used to program some of the models. The other models have been programmed in GAMS. PSCAD is used for the electrical network simulation and is connected with the other two software tools.

DemSi is an important tool for DR programs and models analysis and validation, both in what concerns the business and economic aspects and the technical validation of their impacts in the network.

Consumers can be characterized individually or in an aggregated basis. The simulation requires knowledge about load data and about the contracts between clients and their electricity suppliers. These contracts may include flexibility clauses that allow the network operator to reduce or cut the load of specific clients and circuits. On the other hand, the response of each client to the used tariff scheme is also characterized, allowing the analysis of the impact of alternative DR schemes.

Figure 1 presents the DemSi functional diagram. The simulation of a scenario requires information concerning network characterization, consumers' profile, and DR programs models. The gray blocks in figure 1 are the ones that do not change when the conditions of simulation (models, network, etc.) change.

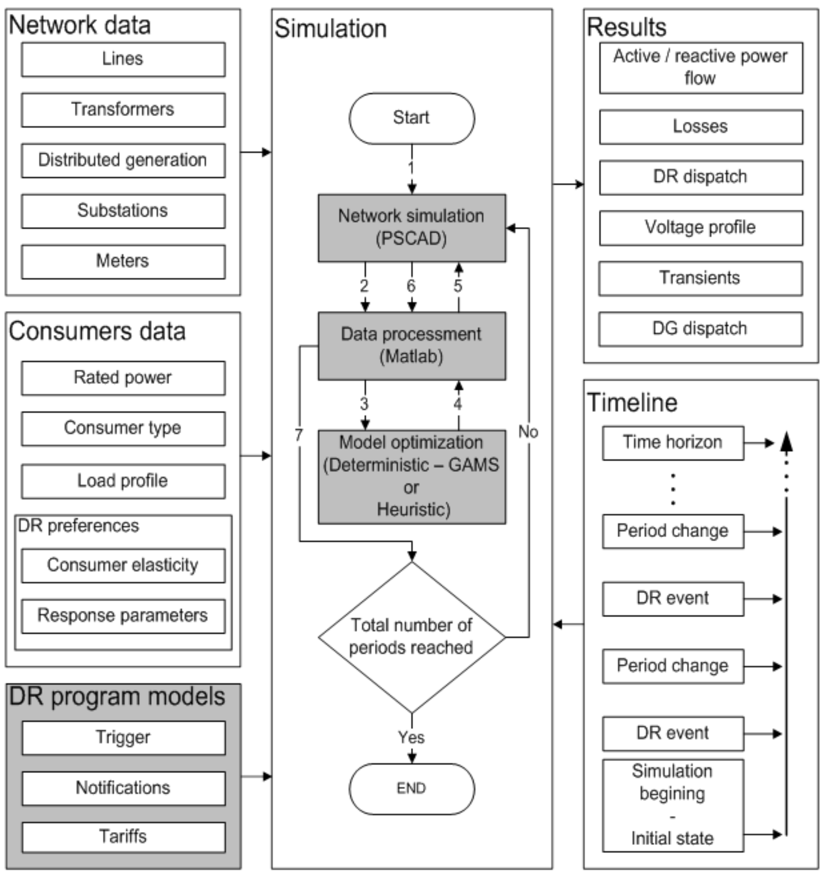

Fig. 1. DemSi functional diagram

PSCAD requires a large amount of parameters for the modeling of the network elements and for the resources connected to it. In this way, the network data (including DG and loads' electrical characteristics) are an important basis for the success of the simulations to be run. The data concerning load response characterization, as well as the event data, are necessary for the DR programs and models simulation.

The simulation timeline is composed by a sequence of periods with a single event or multiple events occurring over time. In the beginning of the simulation, all the variable parameters, including the system voltage, are defined according to the considered initial state. Every change in the system causes instability in the simulation, and therefore some simulation time is given for the system to be in a stable state. After this stabilization time, the network state is saved and the first DR event is simulated. A stabilization period succeeds the DR event trigger; after this, the new state of the system, seen as the results of the event, is saved. This sequence is repeated for the number of periods of the simulation. After saving the results of an event, the network state for the next period is charged.

During the simulation, the different software tools used communicate and transfer data among them. The simulation starts in PSCAD and every time a new network state needs to be charged and/or saved this is done using the MATLAB connection to save/use data to/from Microsoft Excel datasheets. The sequence of software data transferences is represented by numbers in the middle block of figure 1.

4 Conclusions

DemSi, the DR programs simulator presented in this paper, is of crucial importance to enable decision-support by the players acting in DR programs. DemSi presents characteristics that distinguish it from the already existing DR tools, what makes it a valuable contribution to the DR field. A very relevant feature is the realistic technical validation of DR solutions, based on PSCAD, which ensures DemSi applicability to real world problems. Moreover, DemSI provides the means for this analysis to be undertaken from different points of view of several players.

Acknowledgment

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Analyzing Residential Electricity Consumption Patterns Based on Consumer's Segmentation

Henrique Pombeiro[1], André Pina[1], Carlos Silva[1]

[1]*Center for Innovation, Technology and Policy Research – IN+,*
Instituto Superior Técnico, Technical University of Lisbon, TagusPark Campus,
Av. Professor Cavaco Silva, 2744-016 Porto Salvo, Portugal

henrique.pombeiro@ist.utl.pt

Abstract. The identification of energy consumption patterns contributes for the tailoring of energy efficiency solutions. This paper contributes to this issue by addressing the characterization of electricity consumption data with 15 min sampling of twenty two households, in Lisbon. The consumers have been segmented according to: social class, contracted power, number of rooms, family size and type of tariff (flat or dual prices). Social class has been estimated according to education and income. The results show that consumption behavior has a stronger association with inner values rather than the habitation characterization. In fact, families who have chosen non-flat tariff consume less electricity than remaining ones. Such a choice should be a consequence of a higher energy (and cost) consciousness associated to the choice of a dual-tariff and a consequent decrease of electricity consumption. Social class can be a reflection of income but, more than that, a reflection of education, knowledge (also energy-related knowledge), values and amount and performance of the existing appliances. For this reason, such factors should be analyzed more intensively by crossing consumption to occupancy and equipment efficiency, as well as socio-economic characterization, resourcing to social sciences expertize. With the proper consumers' characterization, the design of energy efficiency solutions should be more effective.

Keywords. Consumers' segmentation, energy efficiency, electricity consumption patterns, design of energy efficiency solutions.

1 Introduction

The search for energy efficiency is a priority for the achievement of a more sustainable society. The goals established by the European Union (EU-27) in the 20-20-20 targets by 2020 are an example of such a concern. [1]

Several references can be found in the literature which underline the importance of achieving energy efficiency in the buildings sector in particular, and that is reflected by the several ongoing works that are being undertaken in this concern, both regarding consumption behavior [2, 3] and equipment performance [4, 5]. For example, in

Portugal, the electricity consumption in the building sector accounts for 60% of the total share (29% concerning the residential sector and 31% concerning the service sector) [6]. However, to develop energy efficiency measures, it is important to understand the consumers and their consumption patterns.

This paper addresses the characterization of electricity consumption in the residential sector using the electricity consumption data from 22 households using electricity meters with a sampling time of 15 minutes, provided by the company ISA (Intelligent Sensing Anywhere). The goal is to characterize the electricity consumption patterns based on the segmentation of the households by features considered to be correlated to the consumption.

A proper consumers' segmentation contributes for the achievement of energy efficiency solutions since it allows the recognition of the influence of different factors in energy consumption. Though several factors can influence the energy consumption in a household (e.g. family dimension or income of the family) others can overcome, such as socio-economic ones (e.g. values, culture or education) [3]. After defining the influence of different factors in energy consumption for each household, the proper approach for the design of energy efficiency solutions can be undertaken. In fact, if technical factors are defined as the main ones that influence energy consumption, engineering solutions are required but if socio-economic factors are defined as the most important ones, social sciences are required for the design of energy efficiency solutions.

In [7], pattern recognition was achieved for the definition of consumption habits, based on working/weekend days and the respective temperature, concluding that such pattern recognition can be useful to improve small scale forecast and to enable tailor-made energy efficiency solutions. In [3], the energy-behavioral characterization is addressed and it is concluded that factors such as beliefs, motives and attitudes can define consumption patterns and, with that, the proper interventions for energy efficiency can be undertaken. In [8], occupancy and electricity consumption is predicted through the detection of internet usage in a university campus. The automation is again used with behavior prediction features in [9]. In fact, consumption behavior prediction is important for the development of a more efficient energy system, on which the balance between production and demand is better achieved and one can reduce energy losses and pollution generation [10-13].

The studied segmentation parameters considered in this paper are social class, contracted power, number of existing rooms, family dimension and type of tariff, given particular focus on social class due to the known impact that income can have on energy consumption [14-17]. The correlation between these parameters and the analyzed families' electricity consumption is assessed in this work.

2 Methodology

This experiment is part of a research project on energy efficiency that is being developed in the Vergílio Ferreira School in Lisbon (Lumiar and Telheiras area). Fifty households are being monitored, belonging to the students' families. However, for now, due to some technical issues, only twenty two have provided acceptable data.

During the electricity meters installation (during the first months of 2012), a survey was applied for the family social characterization, as well as to characterize some technical aspects of the household, such as the existing appliances. The data presented in this paper concerns from May 1st to June 30th, 2012.

From different possible characteristics, we chose to analyze the social class (A – high, B – Moderate, C – Low), contracted power, number of existing rooms, family dimension and the type of tariff (flat or dual-tariffs). The characterization of these parameters is depicted in Table 1, accordingly to the respective social class.

Table 1. – Different socio-economical parameters according to the social class, for the analyzed families.[1]

	Social class A	Social class B	Social class C
Contracted power [kVA]	8.5 (1.8)	8.7 (2.8)	5.4 (2.7)
Family dimension [#]	4.5 (0.9)	3.8 (0.9)	4 (1)
Number of rooms [#]	4.3 (0.5)	3.4 (0.8)	2.6 (0.8)
Simple tariff share [%]	50	30	90
Total consumption [kWh/day]	10.7 (2.7)	10.7 (3.1)	11.3 (5.1)

From the table, it is possible to conclude that the households with families of social class C tend to have less contracted power, a smaller number of rooms and a very high share of flat rate.

Regarding the families of class A, they present the highest family dimension and number of rooms, which is coherent with the current socio-economic profile of the Portuguese society.

Concerning the total electricity consumption, there is no significant differences, albeit families from social class C present a slightly higher average value (5.6% higher). However, the respective standard deviations show that the samples are disperse, mainly in social class C, followed by B and by A.

Besides the twenty two analyzed families, there were two families that were considered to be outliers, since the total consumption is 3.3 kWh/day (from a household of social class A) and 26.2 kWh/day (from a household of social class B) which correspond to 29% and 144% of the average consumption respectively (10.7 kWh/day for both social classes, with a standard deviation of 2.7 and 3.1 kWh, respectively).

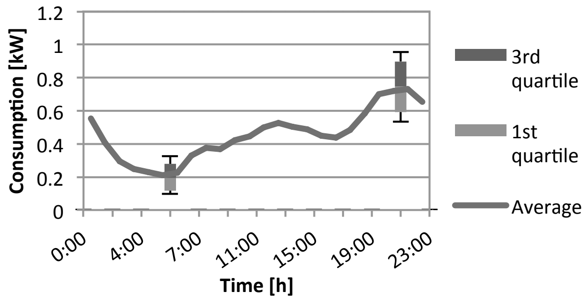
In the next section, we analyze the results in greater detail. The results' analysis is split in the average consumption in the different parameters.

1 Values represent the average. Standard deviations are represented in brackets.

3 Detailed analysis and discussion

3.1 Daily profile

Figure 1 displays the average electricity consumption profile for the 22 analyzed families, with a boxplot for the off-peak hour (5h15) and peak hour (22h15).



	5h15	22h15
average	0.20	0.74
max	0.48	1.13
3rd quartile	0.28	0.90
median	0.19	0.75
1st quartile	0.12	0.59
min	0.03	0.35

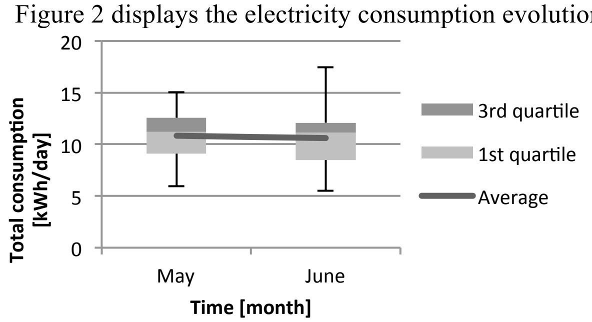
Fig. 1. – Average electricity consumption profile & statistical significance parameters, for the analyzed families.

The lowest consumption occurs at 5h15, with an average value of 0.20 kWh. The first and third quartiles of the sample are 0.08 kWh (40%) below and above the average value, respectively.

The highest consumption occurs at 22h15, with an average value of 0.74 kWh. The first and third quartiles are 0.15 (20%) and 0.16 kWh (22%), below and above the average value, respectively. In average, there are two other peak values: immedialty before 8h00 and another around 13h30.

Different consumption habits are integrated in this average profile, contributing to the identifyed variations. In fact, while some households have someone permanentely inhouse (family member or housecleaner), others have people only in the morning and evening time. Further, this profile does not distinguish weekdays from weekends.

Figure 2 displays the electricity consumption evolution in May and June 2012.



	May	June
average	10.8	10.6
max	15.1	17.4
3rd quartile	12.5	12.1
median	11.2	11.2
1st quartile	9.1	8.5
min	6.0	5.5

Fig. 2. – Average electricity consumption evolution & statistical significance parameters, between May and June.

The accumulated average consumption decreased slightly, from May to June (10.8 to 10.6 kWh, which is less than 2%). The values of the first and third quartiles, for the month of May, are 1.7 (16%) and 1.1 kWh (10%) below and above the average value, respectively. For the month of June, the values of the first and third quartiles are 2.5 (24%) and 1.5 kWh (14%) below and above the average value, respectively. Therefore, the sample dispersion has increased.

3.2 Social Class

Figures 3 to 6 analyze the consumption profile by social class in detail.

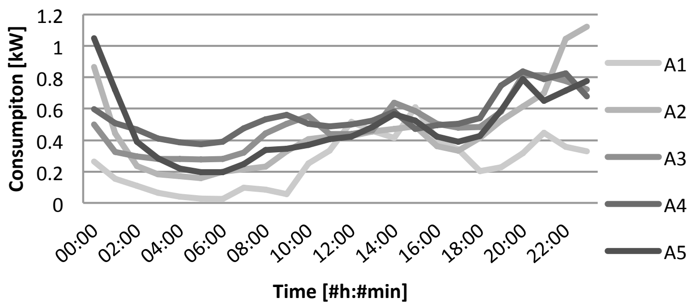


Fig. 3. – Average daily electricity consumption profile for social class A.

Regarding social class A, one can realize that the electricity consumption profiles are very similar, with the exception of the one associated to family A1, which is lower than the remaining and, therefore, contributes to lowering the average consumption.

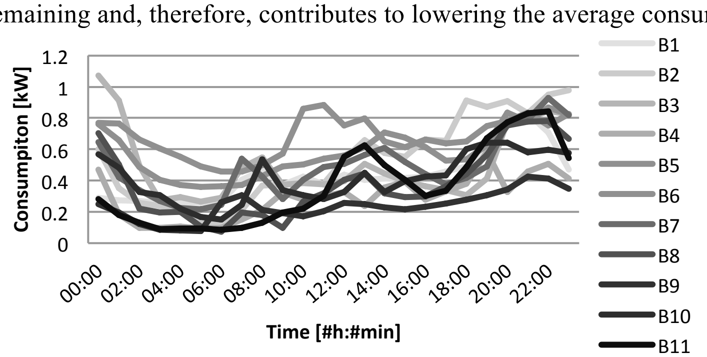


Fig. 4. – Average daily electricity consumption profile for social class B.

The consumption profile of the families of social class B is more disperse. Family B7 presents a higher consumption profile, especially during the day, which contributes to the increase of the average consumption profile.

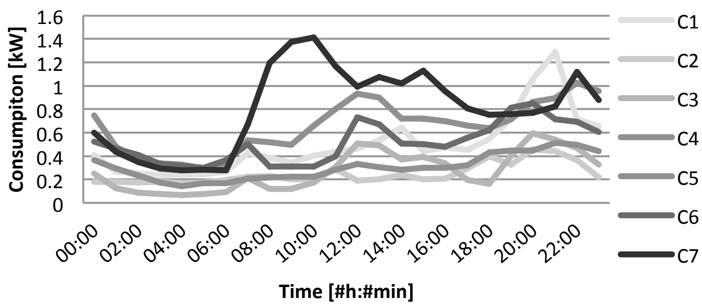


Fig. 5. – Average daily electricity consumption profile for social class C.

Social class C has the higher standard deviation value (5.1 kWh/day), reflecting a more disperse sample as can be seen in Figure 5. It can be also noticed that family C7 has a distinguished higher consumption profile from the remaining families, which increase the average consumption profile.

The total elelctricity consumption profiles, for the different social classes, is displayed in Figure 6.

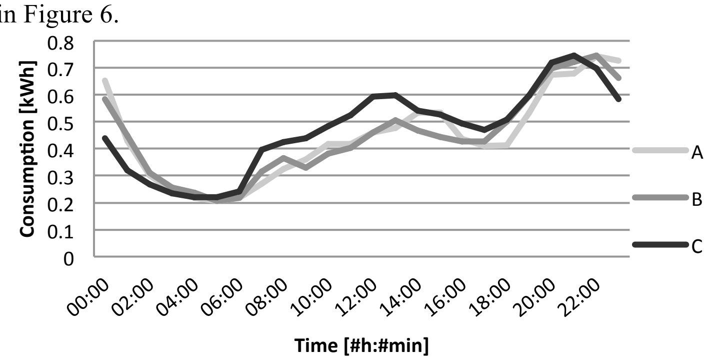


Fig. 6. – Average daily electricity consumption profile for the different social classes.

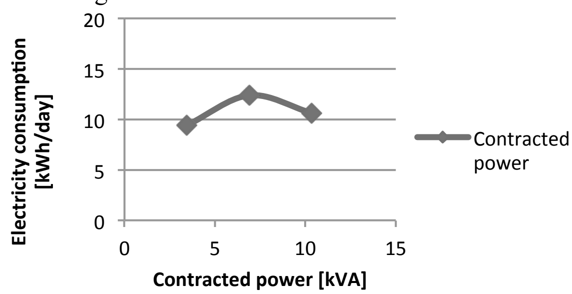
A higher consumption for social class C is displayed, while social classes A and B have close consumption profiles. Social class C has higher consumptions during the afternoon, which can reflect the presence of active people during the day (e.g. retired or unemployed people), more than in the remaining social classes.

Higher social class level can induce higher consumptions due to the fact that income is not a restriction and the number of existing appliances can be higher. However, other factors are probably more important, such as education, energy efficiency awareness and better performance of the existing equipment.

Concerning the houses occupancy; the following events were identifyed: family A1 was out of home for one day, family B6 was out of home for two days, family B10 was out of home for two days and family C1 was out of home for one day. In total, social class A has four vacation days, social class B has one vacation day and social class C has one vacation day, meaning that social class A has the presented consumption values lowered due to more vacation days than in the remainins social classes.

3.3 Contracted power

Concerning the contracted power with the utility, the electricity consumption is presented in Figure 7.



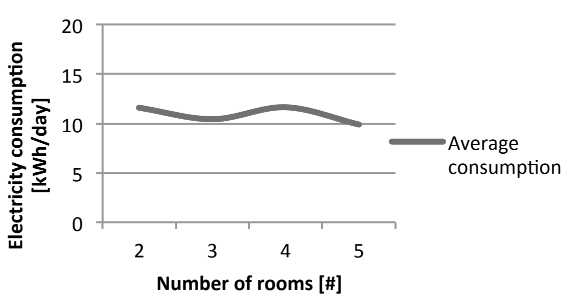
	3.45	6.9	10.35
n	6	8	8
max	13.9	16.3	19.4
min	6.0	7.0	5.7
average	9.4	12.4	10.6
standard deviation	3.3	2.9	4.4

Fig. 7. – Average daily electricity consumption & statistical sigificance parameters, by contracted power.

Electricity consumption is aperantly lower in families with contracted power of 3.45 kVA (9.4 kWh/day). However, to contracted power 10.35 kVA does not correspond to the highest consumption value - this corresponds to 12.4 kWh/dayat contracted power of 6.9 kVA. This fact shows that contracted power is not diretcly related to the total consumption, albeit it can be associated to other factors: either these households have higher peak consumptions or their contracted power is overdimensioned. It should be noted that this is in general the contracted power suggested by the utilities given the current set of appliances that exist in as typical household.

3.4 Number of rooms

Concerning the number of rooms in the houses, Figure 8 displays the electricity consumption variation with this parameter.



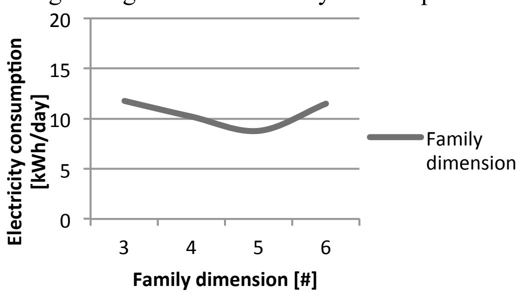
	2	3	4	5
n	5	10	5	3
max	19.4	16.3	15.6	12.7
min	5.9	7.0	5.7	6.1
average	11.6	10.4	11.6	9.9
standard deviation	5.6	2.7	3.7	3.4

Fig. 8. – Average daily electricity consumption & statistical significance parameters, by number of rooms.

A direct correlation between electricity consumption and number of rooms is not visible, as the lowest value (9.9 kWh/day) corresponds to the highest number of rooms (5 rooms) and the highest value (11.6 kWh/day) to both 2 and 4 rooms per house. The standard deviation values for number of rooms 2, 3, 4 and 5 is 5.6, 2.7 , 3.7 and 3.4 kWh respectively, which corresponds to a deviation of 48, 26, 32 and 34% from the average value.

Family dimension

Figure 9 gives the electricity consumption variation with the family dimension.



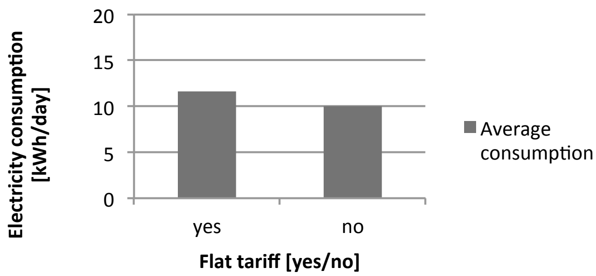
	3	4	5	6
n	7	12	1	3
max	19.4	16.3	8.8	15.6
min	5.7	5.9	8.8	6.1
average	12.2	10.2	8.8	11.5
Standard deviation	4.2	3.1	-	4.9

Fig. 9. – Average daily electricity consumption & statistical sigificance parameters, by family dimension.

The houses with 3 persons are the ones that have a higher average consumption (12.2 kWh/day), with a standard deviation value of 4.2 kWh (34% of the average value). The second highest are the houses with 6 family members, with an associated electricity consumption of 11.5 kWh and standard deviation of 4.9 kWh (43% of the average value). The houses with 4 persons have an electricity consumption of 10.2 kWh and a standard deviation of 3.1 kWh (30% of the average value). The 5 persons set is composed only by one sampleand an electricity consumption of 8.8 kWh/day. Once again, it is not visible a direct correlation between consumption and the number of persons in the household.

3.5 Type of tariff

Figure 10 displays the electricity consumption with the type of tariff. The decision to have a non-flat contracted tariff relates to a higher energy (and or cost) consciousness, since it requires to study the benefits from such a tariff and a capacity of changing consumption behaviors to obtain a higher economic benefit.



	Yes	No
n	12	11
max	19.4	16.3
min	5.9	5.7
average	11.6	10.0
Standard deviation	4.0	2.9

Fig. 10. – Average daily electricity consumption & statistical sigificance parameters, by tariff (if flat tariff is chosen or not).

The families with non-flat tariff have an average consumption 9% (10.0 kWh/day) lower than the ones with flat tariff (11.6 kWh).

4 Conclusions

This work fosters the discussion on energy efficiency concerning the identification of consumption patterns based on user´s segmentation. Proper energy consumers' segmentation is sought but its general applicability is questioned, as the presented results show.

The presented work still lacks on representativeness due to the limited sample population (twenty two households) and limited analysis period (two months). However, the electricity consumptions of the studied families will continue to be measured for a whole year, which should reveal more representative results.

The segmentation (social class, contracted power, number of existing rooms, family dimension and type of tariff) shows that the samples are dispersed and that none of the parameters displays strong correlations to electricity consumption. However, the non-flat tariff shows a correlation to smaller electricity consumption. This result can be interpreted as a reflection of a higher energy (and cost) consciousness associated to the choice of a dual-tariff and a consequent decrease of electricity consumption.

Social class can be a reflection of income but, more than that, a reflection of education, knowledge (also energy-related knowledge), values and amount and performance of the existing appliances. These factors can vary in the same social class and for this reason social class cannot be a general-applicable segmentation feature without being undertaken more intensive analyses, crossing consumption to occupancy and equipment efficiency, as well as socio-economic characterization resourcing social sciences. With more representative results and with a more intensive characterization of the households, one should be able to define consumption patterns according to defined characterization factors and, with that, the proper solutions could be designed. If those factors are considered as dependent on socio-economic factors, the help of social sciences for the definition of such solutions should be required.

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Airline Fuel Savings Estimation Based on Segmented Fuel Consumption Profiles

Bruno Marques[1], Nuno Leal[1]

TAP Portugal, Lisbon, Portugal
{bmarques, nleal}@tap.pt

Abstract. Fuel conservation programs are instruments used by airlines to improve operational efficiency and trim fuel related costs. Identifying fuel savings to accurately manage these programs has always been an issue due to the operation volatility and lack of reliable data. Advanced data management systems were developed to support these programs, but having means to identify fuel savings is still compelling. A new methodology based on segmented fuel consumption profiles is proposed as a tool to accurately identify fuel savings across periods. This approach allows for a detailed fuel consumption analysis with full operation coverage.

Keywords: airlines, fuel efficiency, fuel conservation, fuel consumption profiles

1 Introduction

Airlines today struggle to survive in a highly competitive market, facing high operating costs and being seriously affected by the global economic and financial crisis. Market deregulation and growth of low-cost carriers have since late 90's reinforced the need to improve and follow operational costs and finding means to reduce them. From the airlines' cash operating costs, fuel represents the highest block of direct operating costs, having had a dramatic increase in the latest years [1, 2]. Additionally, fuel prices constant fluctuation represents a challenge to the airlines.

Besides the high fuel costs, there are emerging global environmental concerns to reduce carbon emissions from the aviation industry. Despite the fact that aviation transport system energy intensity continues to decline due to more efficient aircraft, engines and general procedures, air travel continues to experience the fastest growth of all transport modes. Air transport industry was responsible in 2005 for approximately 2.5% of total anthropogenic carbon emissions [3]. However, aviation's relative contribution to climate change is presumably higher due to the fact that the majority of emissions are produced at high altitudes [4]. If no additional fuel efficiency measures are adopted, this contribution may grow up to 15% if this industry keeps the growth pace at around 5% per year.

Due to these environmental concerns and the need to reduce aviation carbon emissions, there were several commitments from different entities to approach the global warming issue and define strategies to reduce carbon footprint. IATA (International Air Transport Association) proposed a four-pillar strategy for carbon neutral growth from 2020 [5]. Despite the fact that today's aircraft are 70% more efficient than first jet-era aircraft [6], Technology, mainly related to aircraft and engine manufacturers new solution developments, as well as biofuels, has the best prospects for reducing aviation carbon emissions. Infrastructure, through improvements on air traffic management and airport infrastructure, is a major opportunity and may provide 4% emission reduction by 2020. A more efficient combination of air traffic management and airline procedures can reduce by 30% the typical descent fuel burn [7]. Economic Measures can prove to be another mechanism that can contribute to reduce aviation carbon emissions. The fourth and last pillar, Efficient Operations, mainly airline's responsibility, is potentially the one that can result in immediate carbon emissions reductions.

Airlines, aiming at mitigating fuel cost and carbon emissions have developed for several years extensive fuel conservation programs with numerous initiatives covering areas as flight and airport operations procedures, aircraft weight reduction or engine and aircraft washing [8]. These initiatives, all together, have already contributed to a general operational efficiency improvement. As some of these initiatives come at cost, it is critical to properly analyze the impact of such implementation. It is also vital to monitor across time the adherence to these initiatives, as well as perform periodic assessments of fuel burn reductions to continuously evaluate program's operational impact. Airlines soon realized that up-to-date, reliable operational data is imperative to complete these tasks.

2 Problem description

Fuel conservation programs developed by airlines typically integrate all key areas of operations that affect fuel usage having as main objectives trimming annual fuel costs and increasing operational efficiency. Many airlines' fuel conservation programs have failed because of the lack of automated data feeding fuel analysis and dashboards to cross-departmental stakeholders [9]. On cross-departmental programs like these it is fundamental to monitor the implemented initiatives' performances, as well as the overall performance.

In terms of fuel conservation, the lack of useful, readily available and reliable recorded data is a crucial issue. The airline operation, highly dependent on procedures and checklists, usually generates large amounts of data that is typically spread out through the departments. Therefore, data availability has always been one of the biggest issues in the fuel conservation programs.

To solve this data availability and quality issues, airlines, such as TAP Portugal, invested substantial effort in developing complex database systems that could concentrate information from different sources, and could provide means to perform smart fuel consumption analysis.

Despite the significant improvements in data availability, historically, the evaluation of fuel savings within the airlines has always been a tough task due to the constant changes in the airline's operation. Airline's operation is highly dynamical not only in terms of operated routes, but also in operated aircraft or aircraft types. Different aircraft within a fleet have different fuel consumption profiles due to distinct aerodynamic and weight characteristics, but also fuel performance degradation. Also, different aircraft operating in different routes have distinct fuel consumption profiles. As the operation constantly changes between periods, one needs to look at various aggregation levels to properly compare the fuel consumption between periods, ensuring that all the flights are being taken into account.

2.1 Fuel Efficiency parameter

To identify airlines' fuel consumption reductions, one needs to compare typical fuel consumption profiles between periods. As there isn't a single fuel efficiency parameter that is suitable to all applications, airlines need to identify the one that best suits its aircraft operations and available data. Aircraft fuel consumption varies significantly with flight time and aircraft performance degradation, but is also influenced by carried weight, en-route winds, flown route profiles or en-route and airport congestion. Generically commercial aviation fuel burn is function of two key factors: aircraft fuel efficiency – which stands for the amount of productivity delivered by the aircraft through the usage of fuel energy and; operational factors – that comprises mass load factors, airline and air traffic control inefficiencies [10]. While this could be translated as Fuel Burned per ASK (Available Seat Kilometer) or Fuel Burned per PKU (Passenger Kilometer Used) for passenger airlines, Fuel Burned per TK (Tonne Kilometer) may be most appropriate to cargo carriers. On aircraft design stage one of the most popular parameters if Fuel Burned per ATK (Available Tonne Kilometer) [11].

However, when the objective, more than representing an efficiency parameter, is to quantify the fuel savings obtained by the initiatives under the fuel conservation program, one needs to identify a variable or set of variables that corrects fuel burn from quantifiable effects that influence fuel consumption and that are not linked with fuel conservation program initiatives. The fuel efficiency parameters above mentioned depend on the great circle distance (GCD) between two airports that is constant throughout time. Therefore the effect of different routes flown by aircraft between two airports is not properly taken into account. To adequately evaluate the fuel savings between periods, instead of using GCD, it is recommended to use flown hours to normalize fuel consumption. Additionally, as a flag carrier's typical operation is not only carrying passengers but also cargo, and as carried weight also plays an important role in the aircraft's fuel consumption, it is necessary to correct fuel burn from differences on carried weight between periods. Therefore, on top of normalizing the fuel consumed by flown hours, one can use the payload variable to additionally correct fuel burn.

In order to adequately compare consumed fuel differences between periods it is required to identify the quantifiable parameters that can be used to define a fuel efficiency profile illustrative of the operation.

2.2 Information architecture

The data analyzed in the fuel consumption analysis has the granularity of a single flight. For every single flight, numerous parameters are recorded and collected, each having its own source. Flight duration can be reported automatically by the aircraft systems or by airport ground handling agents but can be also reported by flight crews in their debriefing procedure. Additional flight information, as carried passengers or payload are reported by crew or ground handling agents in different formats and timings. Fuel figures are logged by the flight crew members in the debriefing procedure. All these figures may be reported by a totally different process when the flights are operated in a wet-lease basis from another operator.

The diversity of data sources available (associated with a multiplicity of processes to obtain the same data) can cause gaps in each individual measure, making that flight unusable (despite the fact that several other measures associated with that same flight can be available). This means that it is understandable and acceptable that the information produced from this data uses a sample size usually above 90%, but away from the complete set.

The operational systems are the core data source, where all processes, being automatic or manual, end up providing values. Some values are critical for the operational system (precise weight estimates are crucial to feed the flight plan generator) and others are just statistical (fuel consumption).

An important part of transforming data into information is related to the building of a standard data warehouse (DW), where data from several sources is collected and made available as a single record, like schematically described in Fig. 1.

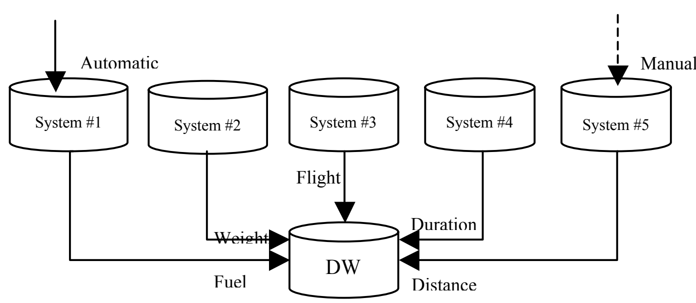

Fig. 1. Data flow, from users and systems to corporative data warehouse

The diversity of processes also implies that information will be produced based on data with different quality levels. Automatic processes are usually more reliable than manual ones, since manually recording (in a paper document) and further reading might more likely lead to insertion errors (when no feedback is given to the user about the correctness of the value) or interpretation errors (namely calligraphy issues or unclear values). Data quality can be checked while loading data into the DW, searching physically impossible values, or values that fail expected correlations between several measures (for instance, fuel consumption per flown hour on a single flight should be coherent with the used aircraft average value). These checks can lead to two distinct consequences: the identification of flights that need to be further examined, or identified as having “no good” information that are rejected on the analysis process.

The data quality process should mainly focus on the data input processes of the operational systems, both in manual and automated scenarios. This continuous evolution, involves migrating manual processes into automatic ones, providing users immediate feedback on entered values, creating simple boundaries for data input and providing systems or forms that are clear and less error prone.

These systems continuous improvement is mandatory to proficiently analyze fuel consumption, identify improvements on fuel savings and pinpoint areas that require additional work.

3 Fuel savings model

As previously stated, quantifying fuel savings within airline’s operations has historically been a demanding task, not only due to the dynamic airlines’ operations, but also to the lack of required data, both in quantity and quality. While this latter hurdle has been addressed by investments in capable information systems, the comparison of operation and fuel consumption profiles still represents a challenge. The proposed solution attempts to minimize the potentially misleading effects of computing fuel savings between two periods that have distinct sets of flights.

The proposed model is based on the identification of fuel consumption profiles that are representative of consumed fuel in distinct periods. These period-characteristic profiles are the basis to recognize equivalent fuel consumption amongst periods. When pinpointing the fuel savings for a period compared with a reference, pre-computed reference period profiles are used to extrapolate what would be the fuel consumption if the operational reference period characteristics would still rule.

In a nutshell, the solution explores the process described here briefly. **Error! Reference source not found.** provides an example of operation data, for two consecutive years. The different values obtained in the variation of each parameters shows distinct change rates, meaning that changes from one year to the other are not linear.

Table 1. Basic example data, set with two years for comparison

Year	# Flights	Distance Flown (km)	Avg Flight Distance (km)	Fuel Burned (ton)	Fuel Burned per Distance (kg/km)
N – 1	100	350,000	3,500	1,100	3.14
N	150	585,000	3,900	1,500	2.56
Variation(%)	*+50%*	*+67%*	*+11%*	*+36%*	*-18%*

In a simplified approach, as an example, if the fuel profile function is defined as fuel burned per distance, it would produce the values presented in the last column of **Error! Reference source not found.**. When the year N fuel profile is applied to the Year N flown miles, as expected, the result is 1,500 ton. If the year N – 1 fuel profile is applied to the Year N operation flown miles, the value 1,838.5 ton is obtained. This value can be read as the Year N fuel consumption, if the consumption profile had not change from year N – 1. The delta between both values (+338.5 Kg) represents the additionally spent fuel from one year to the other. This methodology enables the comparison of equivalent fuel consumption profiles characteristic of different periods and by using this, allows the identification of differences in fuel efficiency. This example tries to set the path for the two major improvements that this process can benefit from:

- **Fuel Profile Function** – In the example, the distance was used, but other flight information can be used to define a profiling function that reflects the fuel consumption behavior in the compared periods.
- **Flight Segmentation –** In the example, an overall profile was used, applied to both periods. But knowing for instance, that long haul flights have different fuel consumption behavior when compared with medium haul flights, can lead to flight segmentation, originating two segments with distinct fuel profile functions.

The fuel consumption calculation using the generated fuel profile functions is a two-step process: firstly identify for each flight the applicable segment and fuel profile function for the considered periods; secondly, with flight information as flight time, carried weight, aircraft performance, compute fuel consumptions for each period using the applicable fuel profile functions. The difference between the extrapolated reference period fuel consumption and the actual period calculated fuel consumption represents the amount saved or additionally burned compared to the reference period. A schematic representation of the process is found on Figure 2.

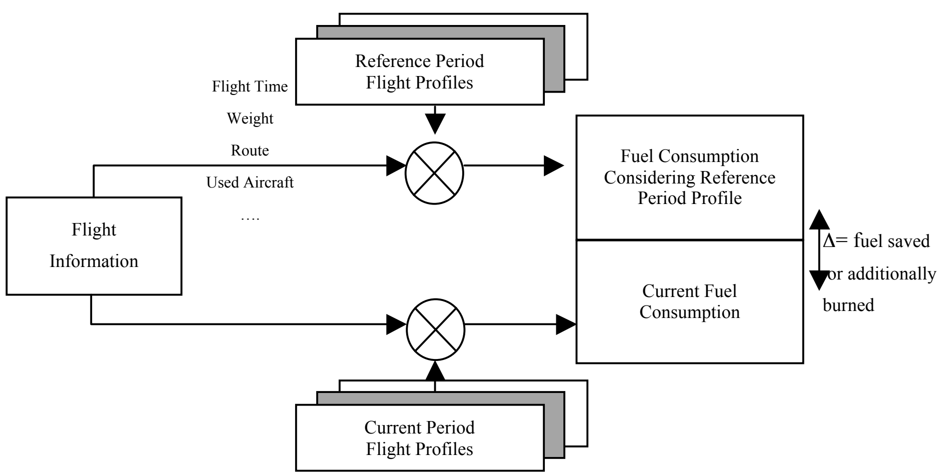

Fig. 2. Fuel savings calculation process

3.1 Fuel Profile Function

Flight fuel consumption varies with the aircraft used, but also depends on physical variables like flight duration, carried weight, wind speed and direction, and other daily features like weather, used routes and both airport and en-route congestion. Although all these variables have an impact on the aircraft fuel consumption, their contribution to the final figures is different. Flight duration, for instance, has a much larger contribution than aircraft performance. On top of this there are variables that are harder to estimate and to quantify their impact on fuel consumption.

In order to properly evaluate the fuel consumption savings, it is mandatory to identify a fuel efficiency parameter that can best represent the operation. The selection of variables used in this parameter should be the ones that have larger impact on fuel consumption and have available data.

Considering the profile function as the ratio between fuel consumed on a flight and a variable, or a set of variables, the accuracy of several different considered alternatives is presented on Table 2. In this table the absolute error is the difference between the real fuel consumption and the estimated fuel consumption, calculated on a flight-by-flight basis, using the calculated fuel profile functions.

Table 2. Average absolute error using several possible parameters

Variables Used	% Absolute Error (Average Flight Fuel)
Carried Weight	22.34%
Airport Distance	7.17%
Flown Hours	5.47%
Flown Hours × Carried Weight	3.49%
Flown Hours × Carried Weight × Aircraft Performance	3.35%

As expected, when considering using one variable profile function, the smallest error is obtained when using flown hours, since it is the parameter with larger impact on fuel consumption. The combination of flown hours and carried weight reduces further the error, as the weight also has also a significant impact on fuel consumption. On top of this, when considering aircraft performance, the error is minimized, as the actual aircraft and engine performance is taken into account.

When quality data is available, the selected fuel profile function should be the one that provides the minimum error in estimating aircraft fuel consumption. Although the model is flexible to use these, or any other parameters, as on the current model there is reliable data available to calculate the fuel burned per flown hours per carried weight per aircraft performance, this will be the fuel profile function used since it is the one with minimum error. This fuel profile function will be then computed for each considered flight segments representative of the period’s operation.

Flight Segmentation

The amount of segments to be used is a difficult decision. When the number of segments used is increased, the profile calculation quality is also enhanced, as it describes a more specific type of flights. On the other hand, a higher number of segments mean a smaller sample of flights used for each profile calculation, leading to a greater impact caused by outlier flights. Table 3 provides a comparative analysis for several segmentation approaches taking into consideration one year of operation.

Table 3. Comparative analysis of flight segmentation

	All	**Haul**	**Model**	**Aircraft**	**Model Route**	**Aircraft Route**	**Aircraft Route Quarter**
# Segments	1	2	12	90	900	6,000	17,000
# Elements /Segments	100,000	53,000	9,000	1,200	120	20	6
Outlier Weight	3%	3.6%	3.9%	4.1%	4.7%	4.9%	6.3%

On segments with a lower sample size, outlier's weight can be more misleading, so defining a minimum required sample size can help to exclude segments that may cause distortion on the final figures. On the current model a minimum of 10 elements per segment is required.

One of the biggest issues concerning this subject is the fact that there are many variables, as aircraft or routes changing from one period to another. When lower aggregation levels are used, finding common segments in the analyzed period can be challenging. For instance, when an aircraft-route aggregation level is selected, if a route is operated in one period, but not on the other, a comparison at the same level is not feasible. In such circumstance a higher aggregation level that enables a comparison between the two periods must be used. Table 4 provides a comparative analysis of the flight coverage rate between two distinct periods. For example, when using a model segmentation approach, a flight is considered uncovered when the aircraft model used in one period was not operated in the other one.

Table 4. Flight segmentation comparative coverage rate

	All	**Haul**	**Model**	**Aircraft**	**Model Route**	**Aircraft Route**	**Aircraft Route Quarter**
Profile Coverage	100%	100%	99.7%	97%	93%	89%	85%

Since the solution should provide a comparison between all the operated flights (and not only the ones that share a similar profile with the reference period being used), an extra qualifying step is needed on the segment selection. This extra step requires the computation of more profiles, not only on the considered detail level, but also on upper aggregation levels. This way, when a profile is missing on a more detailed level, a less detailed profile can be used to ensure that all the flights are covered, like shown on Figure 3.

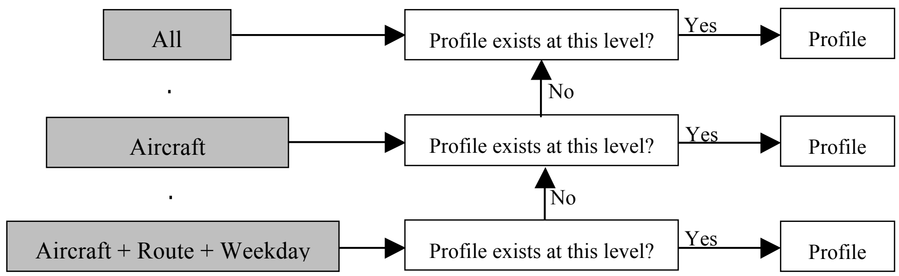

Fig. 3. Flowchart for profile match

On the current model, the lowest segmentation used is obtained by splitting the set of flights by aircraft and route.

4 Information Analysis and Visualization

One of the main purposes of this fuel savings calculation method is to be able to calculate fuel savings on a per-flight basis. This means that, at the bottom line, it is possible to identify how much fuel would have been consumed on the same flight if reference period's conditions were still valid, being the difference between actual and estimated reference period values, the amount of fuel saved or additionally burned. Having information at this level, provides the ability to give a greater insight on how, when and why fuel consumption changes are happening. Table shows some of the potential analysis that can be performed from the generated information.

Table 5. Possible analysis for data visualization

Aircraft	• Changes in airline fleet configuration • Aircraft / engine performance degradation
Route	• Changes in airline network configuration • Flight planning routing (planned and flown) • En-route and airport congestion
Calendar	• Low season / High season operation • Operational fuel saving measures (before and after) • Operational unexpected events (namely, weather condition, volcanic eruption, strikes)

5 Conclusions and Future Work

Quantifying fuel savings has been a challenge that airlines face as they seek new ways to improve fuel efficiency. The proposed methodology ensures that an adequate comparison between periods is achievable through the usage of a multi-stage aggregation levels approach. Defining a suitable fuel efficiency profile varies from airline to airline and greatly depends on the available data. This methodology provides total flexibility on the fuel efficiency profiles used as well as the aggregation levels considered in the calculation. Obtained results demonstrate that full coverage of operation is feasible, allowing a complete fuel efficiency comparison across periods with distinct operation. The generation of fuel savings data on an aircraft, or aircraft-route basis provides a step change in the typical fuel savings analysis, giving room to identifying trends and spotting changes in the airline's operations.

The described solution is generic enough to be easily adapted to other domains where the problem of comparing performance needs to be calculated over changing operational scenarios.

The solution is sensible to data volume and quality. As described, when segmentation goes to a more detailed level the average size of each of the segments drops, making outlier records more relevant in the profile function definition, causing larger deviations. All the improvements that benefit data quality will also benefit the quality of the fuel savings estimates.

A systematic and reusable analysis process still needs to be defined over the obtained set of information, in order to increase the visibility of emerging problems and provide correct savings for specific measures decided by the company.

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Background of Portuguese Domestic Energy Consumption at European Level

Joana Sousa[1]

[1] Faculdade de Engenharia da Universidade do Porto, Porto, Portugal
j.bastos.sousa@gmail.com

Abstract. The energy consumptions in households and the energy resources used for fulfilling the energy needs have been changing in a quite short period of time. The present study aims to provide a background of the energy consumptions in Portugal in a European context. A significant part of the energy consumptions is related to buildings. It is estimated that buildings use about 40% of all the energy needs in Europe. In that way, buildings, including households, play a major role in the energy consumptions in Europe. In Portugal the energy consumption of buildings represents about 30% of the final energy consumption of the country and actually electricity plays a major role in the households energy needs. In European households as well as in Portuguese households the energy required is mainly for cooking, for electrical equipment, for heating and cooling the houses, for domestic hot waters (DHW), and for artificial lighting.

Keywords. Domestic Energy Consumption, Energy Resources, Households.

1 Introduction

During the last decades the consumption of energy for heating has been reducing due to the introduction of more restrictive European regulations that pretended to reduce the consumption of energy in buildings [1, 2].

However, a decreasing tendency on global energy consumptions has been interrupted in the past 20 years [2] due to the introduction of new electrical equipment with the purpose of improving people's quality of life.

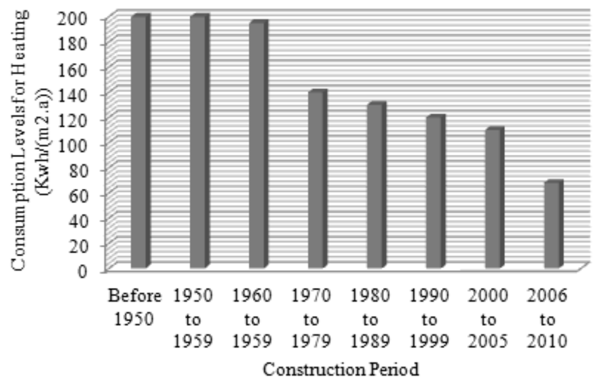

Fig. 1. Average Final Consumption Levels for Heating (kWh/(m^2.a)) by Construction Period in Portugal [2].

In European Union the residential sector represents about 40% of the total amount of energy used, which make it responsible for a significant part of greenhouse emissions at European level. It is expected that about a quarter of housing needs are still to build, and for that reason it is estimated that energy consumption in Europe will continue to increase until 2050 [3]. The majority of the energy is used in buildings built in the period between 1950 and 1975 (Figure 1). These buildings are the ones with bigger energy saving potential and simultaneously with higher needs of retrofitting. It is then necessary to develop new buildings more efficient using energy and make improvements in existing in order to substantially improve their energy performance.

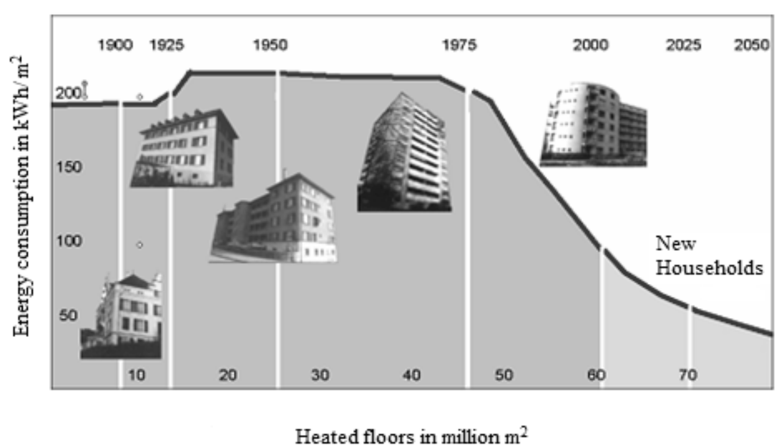

Fig. 2. Energy Consumed by the Buildings Constructed between 1900 and 2050 (forecast) [3].

In Portugal, the consumption of buildings represents about 30% of the final energy consumption. In 2010, about 17,7% was for household needs and about 12% was for energy needs in services buildings [4].

In the Portuguese household sector the consumption of electricity has been growing in the last decades due to the new consumption habits of the population. The residential sector depends mainly on electricity for satisfying people's needs and it is produced through hydropower plants, fossil fuel thermal power plants and lately through renewable sources like the wind energy (Figure 3).

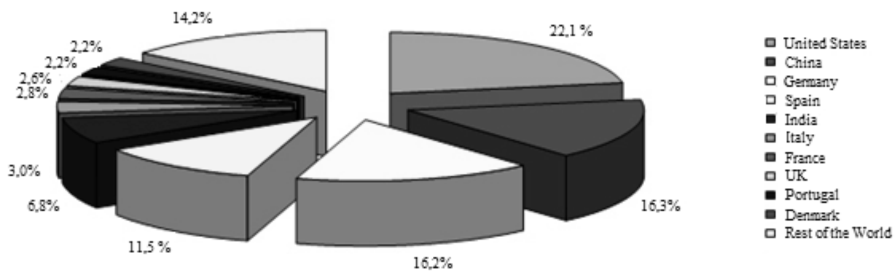

Fig. 3. Top Ten World Installed Capacity of Wind Energy in Percentage (%), 2009 [5].

2 Portuguese Building Stock Energy Characterization

2.1 Main sources of energy used in Portuguese Households

The Portuguese building stock is the third largest energy consumer (Figure 4). Nevertheless, in the last decades there has been a growing tendency on housing energy needs due to the introduction of several new equipments using electricity, which reflect a raise of people's quality of life due to the improvement on economic conditions.

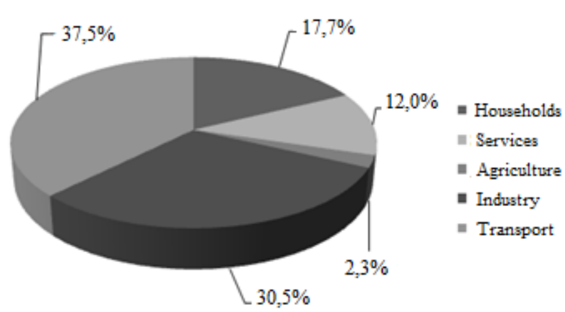

Fig. 4. Energy Consumptions in Percentage (%) of Portuguese main Economical Activities [4].

As mentioned before in the last decades there has been a profound changing on energy consumption habits in Portuguese families due to an economical favorable environment. With the increasing in economic power and the improvement of living conditions, people fit to have better comfort conditions which increased significantly the energy consumption in residential buildings.

In the Portuguese households the current main source of energy is electricity, representing about 42,6% of the total energy consumption [4]. Firewood is the second main source of energy, representing about 24,2% of the energy used in Portuguese households (Figure 5) [4].

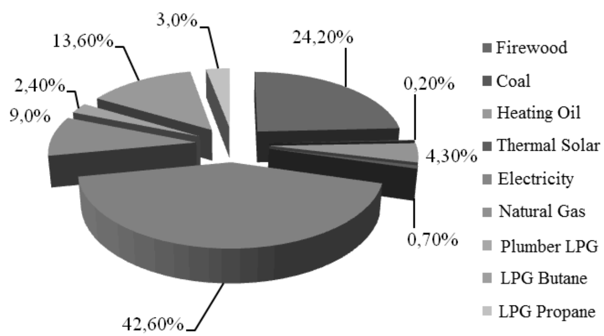

Fig. 5. Sources of Energy in Percentage (%) consumed in Portuguese Households [4].

The continuous growing of electricity consumption in Portuguese residential buildings leads to a major role of this energy source in the domestic sector, which is directly related with the increasing use of equipments using this type of energy but also with the use of electricity for heating. That can explain why electricity registered the greatest consumption evolution when compared with all other energy sources. In 1989 the electricity consumption represented 15,8% of the total energy consumption, while in 1996 it already represented about 41,9% of the total energy consumption in households.

2.2 Energy Consumed in Portuguese Households According with Utilization

Considering the different uses of energy in households, energy used in the kitchen has the highest weight, accounting for over one third (39%), followed by water heating with 23% (Figure 6).

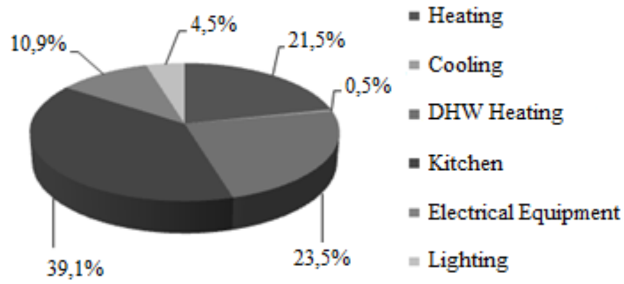

Fig. 6. Energy Consumes in Percentage (%) by Type of Utilization [4].

However, depending on the type of use, the dominant source of energy is different: in the kitchen dominates the use of electricity, while in water heating is predominant the use of bottled LPG (Liquefied Petroleum Gas).
Considering the final use of electricity, it becomes clear that consumptions in the kitchen and in electrical appliances were the highest, being respectively responsible for 41% and 33% of the overall electricity consumption in the reference period.
The energy used for heating and cooling of indoor spaces accounted for nearly one quarter (22%) of total energy consumption of housing in 2010.

3 European Domestics Energy Consumptions

In Europe the sum of energy consumption in the Residential Buildings (27% of all the European final energy consumption) and Services Buildings (13% of all the European final energy consumption) represents about 40% of the total final energy required in Europe and more than the transport sector, which had needed 33% of the total (Figure 7).

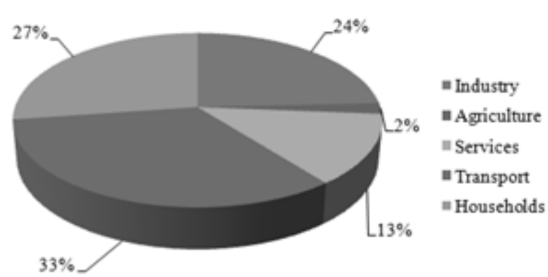

Fig. 7. Energy Consumes in Percentage (%) of European main Economical Activities [2].

Comparably with the energy consumption in households in Europe (independently if it is North & West, Central & East and South Europe), Portugal spends in households a much higher quantity of electricity (42,60%).

The sources of energy used in the South of Europe coincide with the major energy sources used in Portugal (Figure 8). However the implantation rate of renewable energy sources (RES) is not very significant in this region despite the good geographical conditions to explore some of the like, i.e. the solar energy.

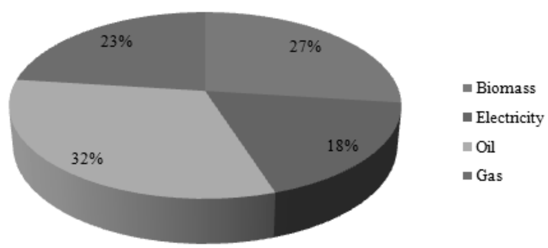

Fig. 8. Sources of Energy used in the South of Europe [2].

In Central and East Europe the Coal (41%) and the District Heat (29%) represent two of the major energy sources while in North and West Europe Gas (39%), Biomass (21%) and RES, District Heat (DH) and Liquefied Petroleum Gas (LPG) (21%) represent the main sources of energy. To note that in general the South region of Europe is more dependent on oil (32%) than Central & East Europe (3%) and North &West (20%) even being a region without oil resources.

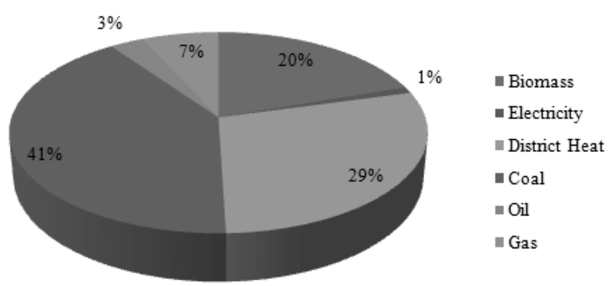

Fig. 9. Sources of Energy used in Central and East Europe [2].

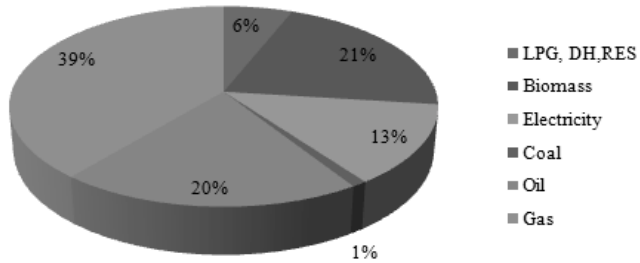

Fig. 10. Sources of Energy used in North Europe [2].

Once these countries haven't got fossil energy resources, a big amount of energy resources has to be imported, particularly oil, which is one of the most expensive energy resources. This fact it's not only harmful for the economy of these countries but also for the environment. Renewable energy resources represent 21%, 12% and 9%, respectively for Central & Eastern, South and North & West European regions.

4 Conclusions

The present study revealed that depending on the region the energy resources used could be very different and quantities can also show many variations.

One of the major conclusions is that, in Portugal, energy needs for any use in households are mainly supplied by electricity. Furthermore it is known that it is in the kitchen that the energy consumptions are higher due to the introduction of several electrical equipments, which have become essential in current days.

Besides the energy consumptions of kitchen equipments, there is also a significant amount of energy used for DHW heating and for heating and cooling spaces. In the future, energy needs for heating spaces will be reduced due to the introduction of constructive solutions that improve the quality of buildings envelope. However there are still a significant number of buildings in Portugal and in Europe built in a period of time in which thermal regulations were not in force. It means those buildings were not subject to a retrofit intervention and need more energy than buildings built according to thermal regulations.

These buildings represent a vast amount of energy that could be saved. In order to decide which should be the main actions and interventions to improve the situation, it is absolutely necessary to know the current reality. In the future energy saving in buildings will be a priority to control the importation of energy resources in countries as Portugal, which is strongly dependent on external energy resources.

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Energy Simulation Software for Buildings: Review and Comparison

Joana Sousa[1]

[1] Faculdade de Engenharia da Universidade do Porto, Porto, Portugal
j.bastos.sousa@gmail.com

Abstract. Energy simulation software tools are an important support used for building designers to reduce the cost of energy in buildings. The energy simulation software allow to determinate with accuracy some variables that can support designers to take decisions about the best measures to apply for any building to built or already existent. There are several energy simulation software tools in the market. The present study aims to identify some of the most important due to their capacity of calculating a significant number of variables and to compare them in order to establish their differences.

Keywords. Simulation Software Tools, Energy Consumption, Buildings.

1 The Energy Simulation Software Tools

1.1 Introduction

The energy simulation software tools can be important for reducing the cost of energy in buildings [1]. About one third of the energy consumption in buildings is used to increase thermal conditions of the dwellings and for lighting. Thermal simulation software tools for buildings allow to:

- Determine the appropriate size of HVAC systems;
- Analyze the energy consumption;
- Calculate the cost of the energy used.

1.2 Advantages of Energy Simulation Software tools

The rules concerning the requirements on building envelope's thermal behavior have become increasingly restrictive. For instance, in Portugal there are three regulations which requirements should be meet by designers regarding thermal comfort, namely, the RCCTE (Regulamento das Caracteristicas Térmicas dos Edifícios - Regulation of Thermal Performance Characteristics of Buildings) [2], the RSECE (Regulamento dos Sistemas Energéticos e de Climatização nos Edifícios - Regulation of Energy Systems and Climate in Buildings) [3] and the SCE (Sistema Nacional de Certificação Energética e da Qualidade do Ar Interior nos Edifícios – National Energy Certification System and Indoor Air Quality in Buildings) [4].

Nowadays, designers need tools that answer to very specific questions even during the initial design phase. Through the use of energy simulation software designers can consider specific choices, (e.g., heating and cooling). Designers can also predict the thermal behavior of buildings prior to their construction and simulate the costs of energy in existent buildings in their current conditions, establishing the best thermal retrofitting measures to adopt in the buildings under analysis. Besides the energy consumption, simulation software tools can also be used calculate to the following variables:

- Indoor temperatures;
- Needs for heating and cooling;
- Consumption needs of HVAC systems;
- Natural lighting needs of the occupants;
- Interior comfort of the inhabitants;
- Levels of ventilation.

The calculation of energy consumptions spent in dwellings still to build or to retrofit allow a more accurate determination of design charges and help to decide with highest accuracy the possible devices to be used in a room (limited zone) or dwelling.

Energy simulation software tools can also allow considering all the regulations in force and simultaneously provide a sense of comfort to its inhabitants through a correct design of heating and cooling systems. Such software have also available tools to improve constructive solutions through simulating the incorporation of passive solar systems in buildings, such as horizontally and vertically shading systems and a more accurate study of the HVAC system loads to use.

2 Steps to Perform in a Building Energy Simulation

There is an increasingly range of energy simulation software tools available, with the ability to calculate increasingly complex energy requirements, with more variables and a more rigorous approach. Generally speaking in all energy simulation software tools there are three steps that have to be performed in a building simulation.

2.1 First Step - Creation of a Building

The creation of the building is the earlier stage of an energy simulation. This process can be done for example by inserting the coordinates in the software tool such as in Energy Plus simulation software (Figure 1) or by uploading files from other software, such as AutoCAD or Google Sketch Up. The introduction of coordinates is performed according to a certain reference (which is located in a pre-determined position).

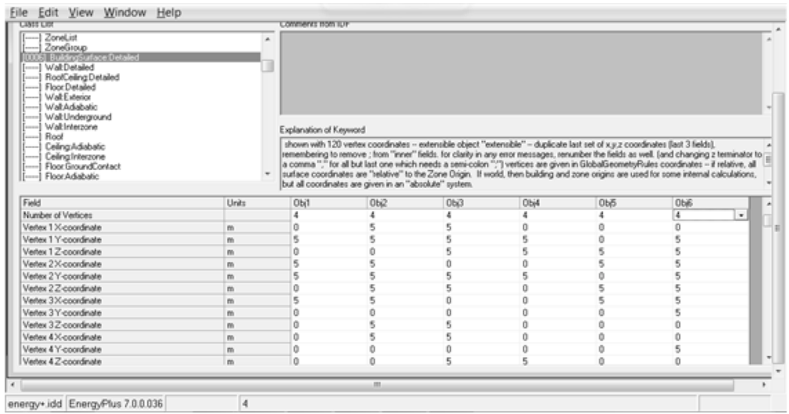

Fig. 1. Introduction of coordinates of a cube in the option "Detailed Surface Building" of EnergyPlus

After this procedure, it is possible to see the figure introduced in the software tool through the DXF button (Figure 2) that connects to AutoCad and which allows to view it in this format (Figure 3).

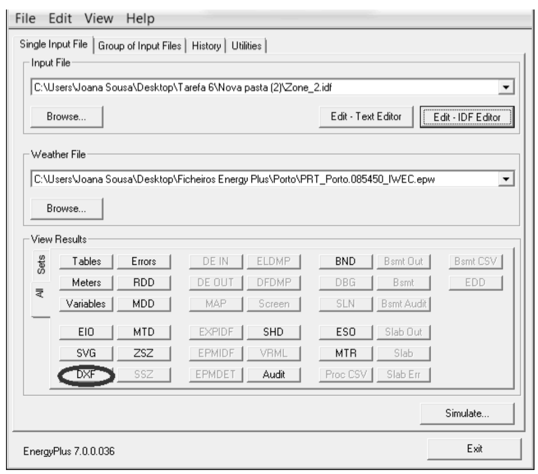

Fig. 2. DXF button in the EnergyPlus.

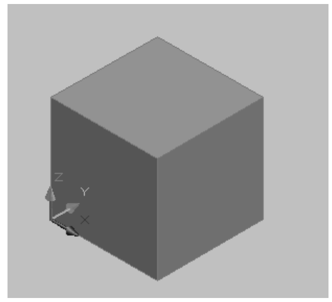

Fig. 3. Results of Coordinate Insertion in EnergyPlus.

Concerning the structure of the building and its construction, it is essential to specify the dimensions of the organizational structure, geometry and materials used in the components of the building architecture (Figure 4). The development of the model based on the characteristics mentioned above represent the building itself ready to be computed.

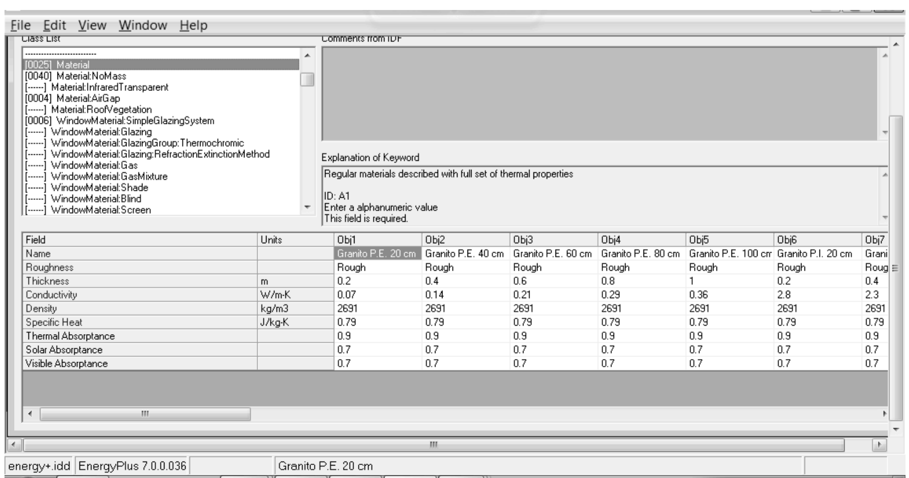

Fig. 4. View of the Interface to the Introduction of the Materials in Energy Plus.

2.2 Second Step - Building Simulation

In this step, it is established which variables are to consider in the simulation of the building and make the software tool run.

The thermal performance of the building can vary according to its use. Therefore it is important to specify the type of building (office, housing, etc.), the human activities carried out, the existing equipment (lighting, refrigeration, air conditioning systems, furnaces, etc.), and their daily schedules (Figure 5). The description of these parameters allows establishing the internal heat load and ventilation (Figure 6).

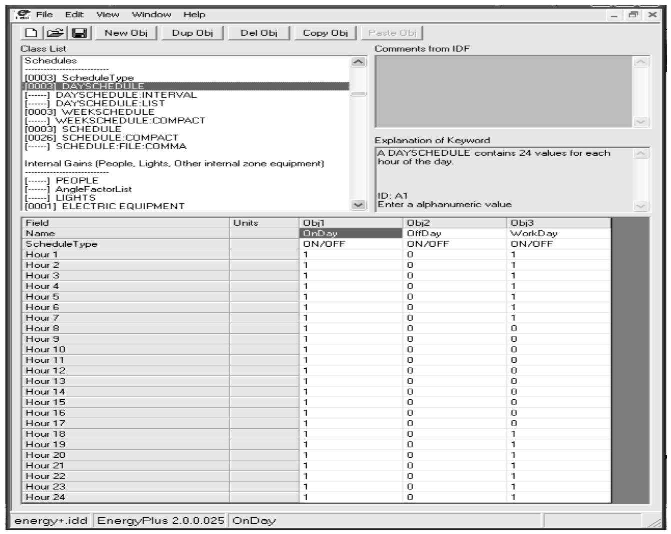

Fig. 5. View of the Interface to the Introduction of Schedules in Energy Plus.

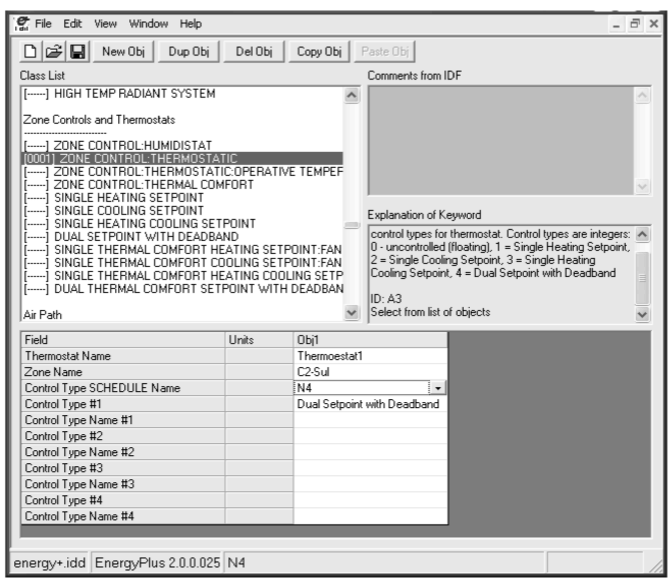

Fig. 6. View of the Interface to the Introduction of Thermostat Definitions in Energy Plus.

2.3 Third Step - Analysis of Results

After running the software tool, it should be checked if there are any error or severe mismatch introduced in the variables set. In some cases the simulation software tool issues its own warnings in a final report containing the results from which should be retained all the relevant conclusions.

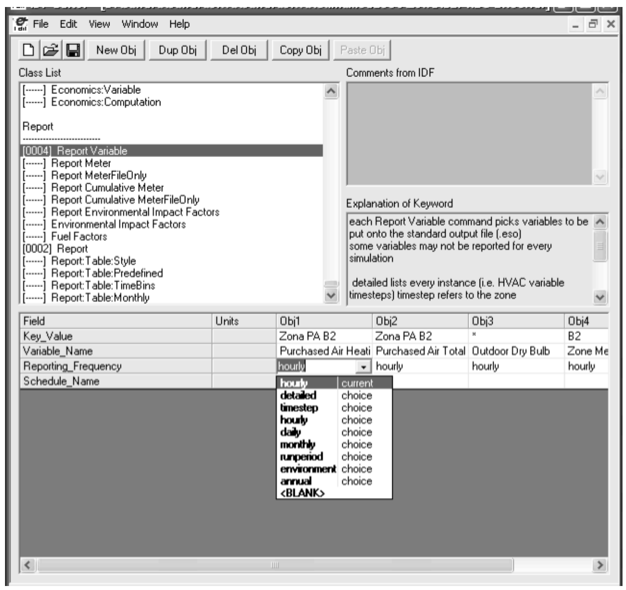

Fig. 7. View of the Report Variable Definitions in Energy Plus.

Depending upon the simulation software tool of energy it is used, the following aspects should be considered:

- Physical Phenomena: Hygrothermal behavior, artificial/natural illumination, acoustics, ventilation and air distribution;
- Energy Systems: Modeling energy in a building, heating and cooling, thermal mass, cogeneration and renewable energy;
- HVAC Systems: Thermal loads and its forecast for optimizing control of components and modeling systems, dynamic behavior and control systems, environmental quality and energy consumption;
- Human Factors: Comfort, visual modeling and indoor air quality;
- Urban Simulation: Sunlight and shadow effects.

In each building simulation there are four fundamental aspects that must be taken into account:
- Structure of the building and its organization;
- Physical phenomena involved in the simulation;
- Weather conditions;

- Use of the building.

In relation to physical phenomena, the model seeks to describe the physical behavior of building materials and their components, and their performance on the transfer of heat by conduction, convection and radiation.

3 Presentation of Some Energy Simulation Software tools

3.1 Energy Plus

Energy Plus is one of the most known energy simulation software tools. Its development began in 1996, sponsored by the Department of Energy (DOE) from United States of America (USA) [5]. Initially, the U.S. government was developing two different software tools, BLAST and DOE-2, which were abandoned after many discussions and represented a first step and the working basis of the Energy Plus. The Energy Plus has the features and capabilities of BLAST and DOE-2, however is an entirely new software tool that combines the heat balance of BLAST with a generic HVAC system. The Energy Plus aims to develop and organize software tools in modules that can easily work together or separately. It is important to outline that in Energy Plus does not exist a visual interface that allow users to see and concept the building. In this case third-party software tools, i.e., Design Builder need to be used. Energy Plus is a thermal simulation software tool that allows the analysis of energy throughout the building and the thermal load and it is used by engineers, architects and researchers to model the energy use and water use in buildings. The software tool simulates models for heating, cooling, lighting, ventilation, other flows of energy and water use. The simulation of a building is divided into two stages [5, 6, 7, 8]:

- Construction of the building;
- Introduction of data, such as environmental aspects, effects of shading, cooling system, internal gains, etc.

3.2 ESP-r (Energy Simulation Software tool)

The software tool ESP-r (Energy Simulation Software tool) is intended to support the construction project with regard to energy and environmental performance, in a realistic and accurate way. The software tool is a mathematical software for a project manager that coordinates the data, simulation, CAD applications, different tools for evaluating performance, display and report generators, etc.. The ESP-r uses several complex equations to deal with all aspects at the same time (geometry, construction, operation, distribution, heat dissipation, etc.). These equations are integrated in successive time steps in response to the influences of the occupants, and climate control systems. The geometry of the building can be set in CAD software tools or other similar tools to allow the specification of the geometry of buildings. The models created in this software can be exported to Energy Plus [9, 10].

The operating conditions are determined through database support. Shading, insulation, HVAC systems, areas of computational fluid dynamics (CFD), electricity, renewable energy embedded systems, lighting, natural ventilation, combined heat and power generation, facades photovoltaic systems for control of indoor air quality can also be included in the models pre-determined. The time simulation of the building with ESP-r simulation tool can vary in a range from one minute to one hour. The outputs of the simulations can be viewed by the interactions between the domains of assessment or exported to other graphics software. The ESP-r is extremely useful and is a powerful tool to simulate many innovative technologies. However, the program requires a great knowledge and expertise from its users, and requires a long learning process.

3.3 IDA ICE

The thermal simulation software tool IDA Indoor Climate Energy is based on a general system simulation platform with a modular system. The multi-domain physical systems are described in the IDA using symbolic equations starting with a simulation language Neutral Model Format (NMF - Neutral Model Format). The user defines the tolerances which control the accuracy of the solution, thus allowing the isolation of numerical modeling approaches [. End-user has the following advantages:

- Extensions can be added to the initial model;
- The mathematical model can be inspected to investigate the variables, parameters and equations;
- The research models are easily performed.

3.4 IES VE (Integrated Environmental Solutions - Virtual Environment)

The simulation software tool IES provides the design professionals with a variety of variables in simulation analysis of buildings. The model works on the geometric representation that represents the building. The software tool allows interaction with other energy simulation software tools. The simulation software tool incorporates a tool for dynamic thermal simulation of heat transfer processes of buildings, which is the ApacheSim. The simulation software tool was tested using the IES ASHRAE 140 and is qualified as a dynamic model in CIBSE system of classification. The software tool provides an environment for the detailing of the building systems, allowing their optimization taking into account criteria such as comfort and energy. The dynamic tool ApacheSim can be dynamically linked to the Macro FLO dynamic tool for natural ventilation and HVAC Apache dynamic tool to perform analysis of air leaks and for analysis of natural lighting and shading. The results should be automatically exported.

3.5 TRNSYS

TRNSYS is a transient system simulation software tool with a modular structure that has been specially designed to develop complex systems related to energy, outlining the problem in a number of smaller components [11]. The components ("Types") may range from simple heat pump to a multi-zone of a building complex. The components are configured through the graphical user interface known as TRNSYS Simulation Studio. In the simulation software tool energy TRNSYS the construction of the building can be achieved by the introduction of data on dedicated visual interface, known for TRNBuild [5].

The software tool sets the time intervals which may vary from 15 minutes to an hour, but may be able to perform simulations in the time interval of 0.1 seconds. The library software tool in addition to a multi zone, allows the use of many commonly used components, including: solar panels, photovoltaic systems, HVAC systems, cogeneration systems, hydrogen, among others. It also allows the creation of routines to manipulate weather data and other data by changing the simulation results. The modular nature of this software tool facilitates the addition of mathematical models to the software tool. The components can be shared among multiple users without having to recompile the software tool due to the use of DLL technology. In addition, this energy simulation software tool allows the user to incorporate other components developed in software tools such as Matlab, Excel, VBA, etc.. Moreover, the software tool includes the possibility of adding HTML views through a software tool called TRNSED, which enable non-users to view and do parametric studies of TRNSYS files, in a simplified representation of a web page.

4 Comparison of Energy Simulation Software tools

Each software tool of the mentioned energy simulation software tools has certain characteristics, and specific applications [12]. In order to better understand specific features of each one, Table 1 presents a summary table of the features of each of the software tools mentioned above, in particular: Solution of Simulation; Duration Calculus; Geometric Description; Renewable Energy Systems; Electrical Systems and Equipment; HVAC systems.

5 Conclusion

Along with materials and construction techniques also energy simulation software tools of buildings have had developments over the years. Currently there are several energy simulation software tools with different levels of complexity and response to different variables. Among the most complete simulation software tools are the Energy Plus, the ESP-r (Energy Simulation Software tool), the IDA ICE (Indoor Climate Energy), IES-VE (Integrated Environmental Solutions - Virtual Environment) and TRNSYS. Being the most complete software tools, these are also the most complex and therefore require greater expertise.

From the analyzed energy simulation software tools, TRNSYS is the most complete, but depending on the user perspective and final purpose the other software tools could be more appropriated. The major limitation of TRNSYS is to not being able to connect with AutoCad Software tool for importation and exportation of files. In this aspect Energy Plus, ESP-r and IDA ICE are more appropriate.

Table 1. Comparison of Features of Various Simulation Software tools [5].

	Energy Plus	ESP-r	IDA ICE	IES	TRNSYS
Simulation Solution					
Simulation of loads, systems and solutions	X	X	X	X	X
Iterative solution of nonlinear systems	X	X	X	X	X
Duration of Time Calculation					
Variable time intervals per zone for interaction of the HVAC system	X	X			
Simultaneous selection of building systems and user		X	X	X	X
Dynamic variables based in transient solutions	X	X	X		
Complete Geometric Description					
Walls, roofs and floors	X	X	X	X	X
Windows, skylights, doors and external coatings	X	X	X	X	X
Polygons with many faces	X	X	X	X	
Imports of building from CAD programs	X	X	X	X	X
Export Geometry of Buildings for CAD software	X	X	X		
Import / Export of simulation models of programs	X	X	X	X	
Calculation of thermal balance	X	X	X	X	X
Absorption / release of moisture from the building materials	X		X	X	X
Internal thermal mass	X	X	X	X	X
Human thermal comfort	X	X	X	X	X
Solar Analysis	X				X
Analysis of Isolation	X	X	X	X	X
Advanced fenestration	X	X	X	X	X
Calculations of the building in general	X	X		X	X
Surface temperatures of zones	X	X	X	X	X
Airflow through the windows	X	X		X	X
Driving surfaces	X	X	X	X	X
Heat transfer from the soil	X	X	X	X	X
Thermophysical variable			X		
Daylighting and lighting controls	X	X	X	X	
Infiltration of a zone	X	X	X	X	X
Automatic calculation of coefficients of wind pressure				X	
Natural Ventilation	X	X	X		X
Natural and mechanical ventilation				X	X
Control open of windows for natural ventilation	X	X	X		X
Air leaks in multiple zones	X	X	X		X
Renewable Energy Systems					
Solar Energy	X	X		X	X
Trombe Wall	X	X	X	X	X
Photovoltaic panels	X	X		X	X
Hydrogen Systems		X			X
Wind Energy		X			X
Electrical Systems and Equipment					
Energy Production through R.E.	X	X			X
Distribution and management of electric power loads	X	X			X
Electricity generators	X				X
Network connection	X	X			X
HVAC Systems					
HVAC idealized	X	X	X	X	X
Possible configuration of HVAC systems	X	X	X	X	X
Repetitions cycle air	X	X	X	X	X
distribution systems	X	X	X	X	X
Modeling CO_2			X	X	X
Each distribution of air per area	X	X	X	X	X
Forced air unit per zone	X	X	X	X	X
Equipment Unit	X	X		X	X

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TIMES_PT: Integrated Energy System Modeling

João Pedro Gouveia*, Luís Dias*, Patrícia Fortes*, Júlia Seixas*

jplg@fct.unl.pt; luisdias@fct.unl.pt; p.fs@fct.unl.pt; mjs@fct.unl.pt

* CENSE - Center for Environmental and Sustainability Research, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa 2829-516, Caparica. Portugal

Abstract. The complexity of energy systems operation and the necessity to design secure and reliable systems, compatible with greenhouse gas (GHG) mitigation goals, have justified the development of energy models. They are capable of representing detailed energy systems (technical and economic characteristics) and the interconnections between supply and consumer sectors, assessing energy consumption and production pathways. Energy modeling tools have been widely used to help energy planners to assess energy systems; from different approaches as the impacts of alternative energy and environmental policies, or the competitiveness of different energy technologies. This paper provides an overview of the energy-environmental-economic modeling tool TIMES_PT, the last generation of the IEA/ETSAP integrated technological energy models, with a focus on its structure, functioning, and calibration for the case of the Portuguese energy system. Applications cases of TIMES_PT, namely for the design of low carbon scenarios for the long-term, are presented. Innovative developments on linking TIMES_PT with a macro-economic model (GEM-E3_PT) and the assessment of non-technological variables are also described.

Keywords: TIMES_PT, Energy modeling, Low carbon scenarios, Energy system, Portugal.

1 Introduction

Since the 70's energy models have been widely used to support energy planning. In that time, models were used to understand the implications of an oil embargo in energy supply security. More recently, climate change and the need to reduce GHG emissions has become one of the main issues in energy planning [1]. Energy models outline how the transition to a more secure and decarbonized energy system can be achieved, identifying the competiveness of energy technologies and giving insights about the most cost-effective energy and environmental policies.

One of the major energy optimization tools used are the bottom-up technology MARKAL (MARKet ALlocation) and TIMES (The Integrated MARKAL-EFOM System) models. These models are used by more than 100 institutions and countries and supported under the ETSAP/IEA.

TIMES_PT [2] is a dynamic linear optimization peer-reviewed model corresponding to the implementation for Portugal (PT) of the technological based model generator TIMES [3]. TIMES_PT represents, in detail, the entire chain of the Portuguese energy system from energy supply, including energy imports and production, to transformation, distribution, as well as end-uses consumption and energy trade, considering different energy carriers.

The objective of the TIMES model is the satisfaction of an exogenous energy service demand at the minimum total system cost over the entire planning horizon (*i.e.* the optimal energy-technology pathways). Thus, supported by a database of more than 2000 technologies, the model determines the optimal mix of technologies and fuels at each period, the associated emissions and trading activities.

The TIMES_PT model has been extensively used in several national and international studies and its technological database has been continuously updated and validated by national stakeholders and international literature. TIMES_PT, as other TIMES models, is written in General Algebraic Modeling System (GAMS) language [4].

This paper aims to provide an overview of the energy-environmental-economic modeling tool TIMES_PT, focused on its general features and main components (Section 2), and applications cases (Section 3). Section 4 of the paper concludes and presents innovative features under development.

2 General characteristics of TIMES_PT

As abovementioned, TIMES_PT is a peer-reviewed linear programming optimization bottom-up technology model. This section describes the main features of the model as well as its specific characteristics that have been improved or updated in the last years. The TIMES_PT model formulates a single, overall mathematical programming (optimization) problem that covers the energy supply system, according to equation 1 [3]:

$$NPV = \sum_{r=1}^{R} \sum_{y=TEARS} \left(1 + d_{r,y}\right)^{REFYR-y} * ANNCOST(r,y) \qquad (1)$$

Where the *NPV* is the net present value of the total costs, *ANNCOST* is the total annual cost, *d* is the general discount rate, *r* is the region, *y* is the years, *REFYR* is the reference year for discounting and *YEARS* is the set of years for which there are costs.

TIMES_PT model uses the partial equilibrium version of TIMES, where the demand for energy services depends endogenously on own price elasticity. The model is usually run to deliver information on 5-year periods.

TIMES_PT represents the energy system of PT and its possible long-term developments. The actual system encompasses all the steps from primary resources in place to the supply of the energy services demanded by energy consumers, through the chain of processes which transform, transport, distribute and convert energy into services [5]. Figure 1 presents an overall view of the structure of the energy system modeled in TIMES_PT.

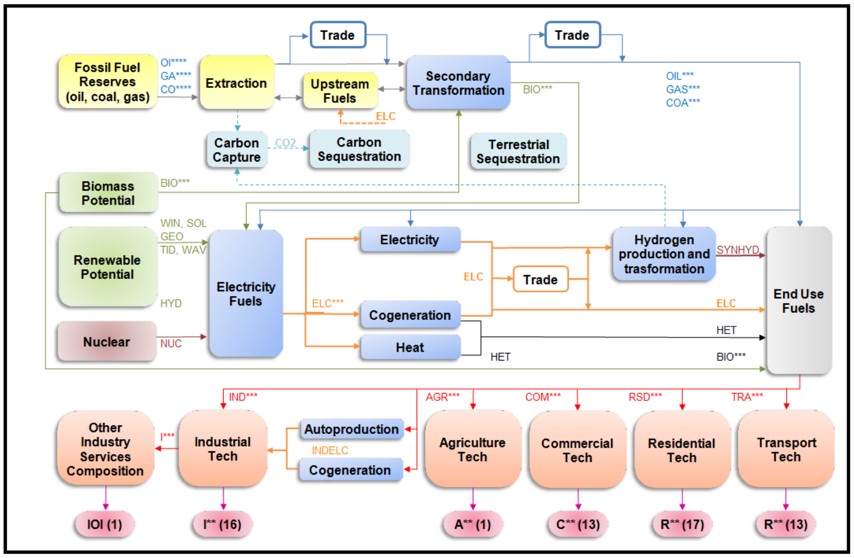

Fig. 1. High-level Reference Energy System of a single region model [5].

Each element in the network is characterized by several input parameters. The TIMES_PT technological database has more than two thousands of existing and future energy related technologies. Technologies are described by means of technical data (*e.g*. capacity, efficiency), environmental emission coefficients (e.*g*. CO_2, SO_x, NO_x), and economic values (*e.g*. capital cost, date of commercialization). Possible future developments of the system are driven by reference demands for energy services (*e.g*. commercial lighting, residential space heating, air conditioning, mobility and many others), and the supply curves of the resources (*e.g*. amount available at each price level) [6].

Several assets distinguish TIMES_PT from European aggregated models like PET (Pan European TIMES [5]): 1) the information on the majority of technological database is validated by national energy and industry related stakeholders reflecting specific national characteristics; 2) the Portuguese energy system and current policies and expectations are fully detailed; making TIMES_PT a well-established tool for Portugal. There are also a few general differences for other European national models (*e.g*. [7]) like 1) the inclusion of air pollutants like nitrogen oxides, sulfur dioxides and particulate matter and 2) the disaggregation of the national emissions as included/not included in the EU-ETS.

2.1 Time horizon and Time slices

TIMES_PT is a long-term model designed to explore the development of the PT energy system till 2050 through the computation of projections for the period 2005-2050. While in its original version, developed within NEEDS project [8], the model was calibrated to 2000 data, the current version is fully recalibrated to 2005 data. For the year 2010 the model results are partly validated to national statistics [9-10] and taking into account national short-term expectations (*e.g.* installed capacity).

Annual flows of energy consumption and production are split by season - spring, summer, fall, winter; and daily load profiles - night, day and peak, considering the Portuguese electricity demand profile.

2.2 Representation of the primary supply sectors

The supply side of the TIMES_PT model represents the primary energy sector: resource extraction or imports, processing and transport to transformation – plants and refineries, coke ovens and bio-conversion, etc. – followed by transport and distribution of the final energy products.

Each primary resource is modeled independently, and represented by a linearized stepwise supply function. The number of steps approximating each curve depends on the resource and on the country reserves. The energy commodities are disaggregated to the level of detail of the extended national energy balances reported by [9].

2.3 Representation of the demand sectors

TIMES_PT model includes five main end-use sectors: Agriculture (AGR), Industry (IND), Services (SERV), Residential (RSD) and Transport (TRA).

The AGR sector is represented in a simplified way, and future energy demand is driven by the projection of the sectorial economic activity.

Regarding IND, TIMES_PT model breaks-out the national industrial sector in eleven sub-sectors: hollow and flat glass, high and lower quality paper, chemistry, cement, iron & steel, lime, other non-ferrous metals, other non-metallic minerals and other chemical. Each of them includes diverse manufacturing processes and is modeled according to its mass and energy balance.

The SERV sector represents several different economic sub sectors like offices, banks, hospitals, etc. However, due to the lack of data for PT on specific sub sectors energy consumption and equipment, this sector is modeled in an aggregated way, considering two types of SERV - large (>1000m^2) and small (<1000m^2). The SERV sector energy demand includes: space heating and cooling, water heating, cooking, lighting, refrigeration and other electric equipment.

RSD sector includes the same categories as the SERV, but improved disaggregation on electric equipment including cloth washing and drying machines and cloth washing, among others. The devices that supply warm water, space heating and cooling are broken out by building type as its need vary significantly – namely multi apartment building, single house in urban areas and single house in rural areas.

The TRA sector corresponds to the economic sector “transport services” and private mobility. The demand for TRA is first broken out by: road, rail, navigation and aviation. Road and rail transport are split between passenger and freight. The demand for road passengers’ transportation is further divided to short and long distance private car transport, urban busses, intercity busses and motorcycles. Passenger’s rail transport is further divided into urban metro transport and intercity train transport.

Freight transport is disaggregated into road transport by heavy and light trucks and intercity rail transport [11].

2.4 Energy Services Demand

Energy end-use demand is an exogenous model input, commonly generated according to the methodology presented in [12]. This energy services demand generation is supported by a top-down method for industry, services and agriculture and bottom-up calculation for buildings [13] and transport. The top-down method is mainly sustained by the sector value added growth, while the bottom-up method is more complex and depends on several drivers, namely the number and characteristics of the dwellings, occupancy rate and building area, transport typology, population, average travel km, among other parameters.

2.5 Renewable Energy Potential

For Portugal, the endogenous primary energy potential solely relates to renewable energy sources (RES) once there are not known endogenous fossil resources. For most resources the potential is given not only having in mind the technical potential but also possible deployment of technologies in the near future.

These technical economical potentials restrict the use and future deployment of each technology, limiting its capacity. Generally speaking, the 2020 figures are in line with the expectation presented in National Renewable Energy Action Plan [14], after that the potentials are a result of national stakeholders best guess and analysis (see [10]).

2.6 Primary Energy Prices

Primary energy prices definition is crucial for setting the boundaries of an energy system future development. Average primary energy import prices projections are annually updated based on the scenarios from [15]. The import costs until 2050 for the different types of liquid biofuels (*e.g.* bioethanol) and due to no best available information are linked to the oil energy price. Extraction costs for municipal solid wastes; biogas and sludge are originated from [16] The import costs for wood biomass are from [17] and endogenous forestry and wood waste biomass production from [18].

2.7 Technology costs and characteristics

The evolution of the costs of supply and demand technologies between 2010 and 2050, are dependent on the actual expectation in terms of development and implementation, and are crucial to evaluate the competitiveness of the technologies. The model combines the technical economic data with energy prices to dynamically calculate supply cost curves for year and energy demand category. The combination between supply cost curves defines the competitiveness of the technologies. Fig. 2 presents an example of a supply curve for cooling services buildings.

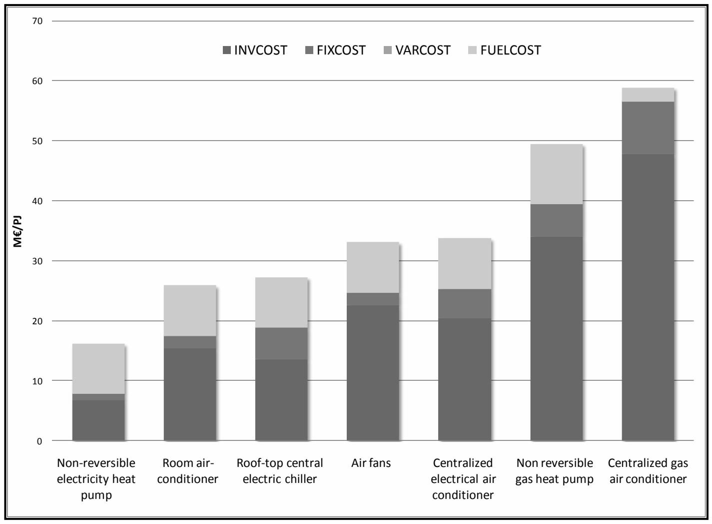

Fig. 2. Example of a supply curve for Services space cooling for 2030 ([11])

TIMES_PT technological database is frequently updated in order to reflect recent technological developments and national specificities. Table 1 presents, an example investment costs expectations for different RES and combined cycle natural gas power plants for Portugal.

Table 1. Wind, solar and combined cycle gas power plant investment cost perspectives

Years	Wind Onshore	Wind Offshore	PV Solar (Roof panel)	PV Solar (plant technology)	Combined cycle power
	Investment costs (M€$_{2000}$/GW)				
2010	1012	3140	2202	1966	385
2015	910	3140	1849	1793	381
2020	860	2747	1636	1587	377
2025	835	2551	1488	1443	377
2030	810	2355	1339	1299	377
2035	772	2159	1255	1217	370
2050	658	1570	1087	1054	363

Availability factors are also an important characteristic of a technology, especially for RES, influencing its future uses. For wind turbines and solar technologies the availability was defined based on the data from the production of the existing plants and parks in Portugal and Spain and national stakeholder's. The availability factors for hydro power plants are updated to an average Portuguese hydraulicity year.

3 Application cases

TIMES_PT model can be used for a wide set of policy and technological analysis associated with GHG and air pollutants emissions and energy related activities (*e.g.* Fig. 3). This section presents a sample of international and national projects where TIMES_PT has been used for different purposes.

- *COMET - Integrated infrastructure for CO_2 transport and storage in the west Mediterranean* - is a EU research project aiming at identifying and assessing the most cost effective infrastructure of CO_2 transport and geologic storage, that will be able to serve the West Mediterranean area (Spain, Portugal and Morocco), as well as the location, capacity and availability of potential CO_2 storage in geological formations.
- *$HybCO_2$ - Hybrid approaches to assess economic, environmental and technological impacts of long term low carbon scenarios: the Portuguese case* - is a national research project aiming to develop and implement two hybrid modeling tools to improve the cost-effectiveness assessment of energy/climate policy instruments.
- *Low Carbon RoadMap: Portugal 2050* - outlines how the transition to a low carbon economy in Portugal can be achieved, focusing on changes in the national energy system and evaluating its economic impact. The model was used to outline a -60% and -70% GHG decarbonization pathways (face to 1990) [10].
- *RoadMap for New Energy Technologies: Portugal 2010-2050* - Policy support project for assessing the competitiveness of national energy technologies, namely RES electricity generation and electric mobility technologies and its long-term impact in the PT energy system [12].

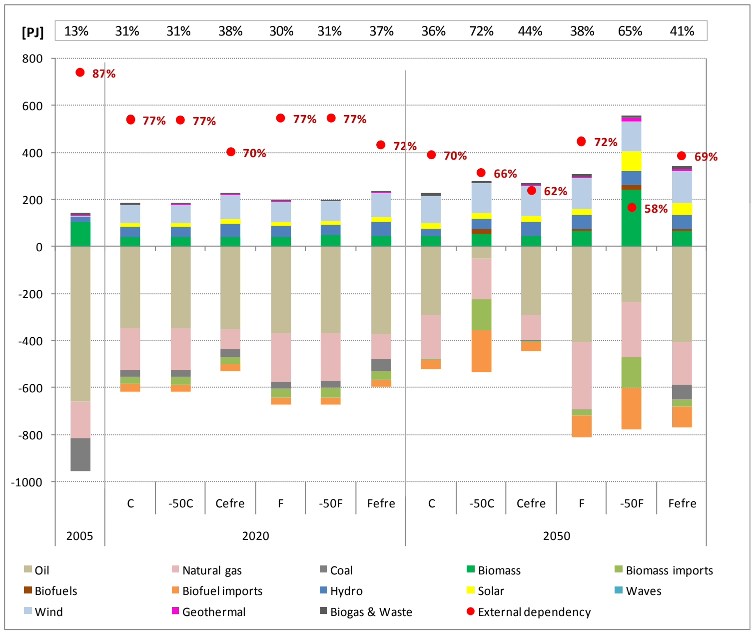

Fig. 3. Policy and technological analysis results from TIMES_PT (Primary energy consumption in Portugal in different emissions scenarios - % of RES (in the top rectangle)) [12]

4 Conclusion

The complexity of energy systems operation and the necessity to design secure and reliable systems, compatible with GHG mitigation goals, have justified the development of energy models. In this paper we describe the linear optimization model TIMES_PT that has been improved and updated to reflect the PT energy system and policies, and selected projects supported by it. Although technological based models have been useful to design future scenarios of energy systems, they present limitations that have been identified and researched.

Future work will advance energy modeling in two areas: a) by integrating non-technological features as the case of consumer behavior in residential sector, based on the knowledge behind energy consumption drivers; b) by linking with an economic computable general equilibrium (GEM-E3_PT) constituting a hybrid technology-economic platform (HybTEP), which overcome the state of the art absence of macro-economic feedbacks of different energy system pathways, namely the impact on gross domestic product or industry production, underestimating the costs of mitigation policies. These advancements will improve greatly the ability to model energy systems and reduce uncertainty for the medium to long term.

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Integrating Energy Data with ETL

Luís Luciano and Paulo Carreira

Instituto Superior Técnico, IST Taguspark, Av. Prof. Cavaco Silva, Tagus Park, 2780-990, Porto-Salvo, Portugal,
{luis.luciano,paulo.carreira}@ist.utl.pt

Abstract. In spite of the huge amount of energy information that is shared by cross-functional areas of companies, they aren't taking better decisions towards energy saving. Based on the existing literature, energy management systems and data warehouse architectures for energy management, a research model identifies several problems that affect intelligent building data integration. The aim of this article is to point several complexity factors that affect energy and building data integration and present a solution that could ease the integration process and applied in different environments to conform with different business requirements. To achieve it, is defined a generic prototype, which can help to define Extract-Transform-Load processes in building and energy management contexts. The prototype is intended to ease the process of extracting and transforming building and energy data by integrating specific ETL modules to an existent ETL tool.

Keywords: Data Warehouse, Energy Management Systems, Extract-Transform-Load, Intelligent Buildings.

1 Introduction

Business data analytics is becoming a key tool for managing nearly any kind of business enabling for instance analysing customer profitability, asset optimization and operation analysis to identify cost-reduction opportunities [1].

Data integration assumes an important role in business data analytics because it is responsible for combining multiple and heterogeneous sources of data (which may reside in different locations) and store them under a global schema, giving a unified view over that data. The main goal of this process is to help extracting knowledge that is scattered in different data sources [2]. Nowadays, data integration has been successfully applied in several domains, helping health professionals to extract valuable information from different medical records, managing personal information or even easing the data migration process in telecom providers [3,4,5].

Given the exponential growth of Intelligent Building we think that business analytics should be applied to building management as well. Therefore, building data should also be integrated, to ease the process of decision making and identify optimization opportunities among which, energy saving is chief. To achieve that, building data must be collected and consolidated, analysed and aggregated in proper formats (such as reports) allowing the drilling and mining of building data. Combining data in this way is crucial for example to understand the energetic behaviour of a building and to clarify the relation of each device and appliance to energy consumption.

This paper addresses the urgent need of integrating Intelligent Building data to identify possible energy savings and improvements in the energetic behaviour of a building. Monitoring and analysis of building performance is a key mechanism to profile consumption patterns, to detect abnormal energy use and to reduce energy consumption. This document is organized into five sections. After the introductory section, Section 2 explores the different types of Intelligent Building data and the underlying complexity of integration this type of data. Section 3 details the Extract, Transform and Load (ETL) process which is responsible for integrating data in a global unified schema and also the pros and cons of applying ETL methodologies in a energy and building domain. Section 4 presents a prototype that integrates an ETL tool with protocols and standards of Intelligent Buildings and the advantages of this synergy, Section 5 presents some conclusions about this work.

2 Intelligent Buildings Data

The concept of Intelligent Buildings (IB) is related with the usage of Information Technology in building operations to face the progressive demand of comfort environment, the requirements for occupant control of the environment and the reduction of energy usage [6]. Furthermore, IB are also concerned with preserving the surroundings of the facilities and enhancing building operations to reduce energy consumption and environmental impact [7].

2.1 Sources of Intelligent Buildings Data

An IB encompasses several site-specific systems that control well defined areas and aspects of a building. An Energy Management Systems (EMS) aims at identifying energy-savings opportunities through continuous monitoring of energy consumption and equipments. Building Management System (BMS) which has to control and monitor mechanical and electrical equipments of a building [7]. The integration of multiples data sources is crucial for energy and building management, which give accurate information about the location and time of energy usage [8,9]. It is possible to categorize the types of information that are needed to perform an energy analysis, a detailed list of each data source is depicted in Table 1.

- Building Structure, refers to the type of building, the internal infrastructure and the physical layout details. To understand the energy consumption in the building we have to break up different areas physically (i.e., space breakdown and functionality) to profile the energy for each location.

External Sources	Type of information	Data Source Format
Energy Management System (EMS)	Continuous monitoring of energy consumption.	EMS specific software
Automated Meter Reading (AMR), Advanced Metering Infrastructure (AMI)	Read, tranport and store meter energy data.	AMR, AMI specific software
Building Management Systems (BMS), Building Automation System (BAS)	Control and monitor building equipments(e.g. HVAC, Lighting System, Fire protection system).	Standard Protocol (e.g. BacNet, LonWorks). Proprietary Software (e.g. TAC Vista, Metasis).
Computer-aided Facility Management (CAFM)	Supports operational management and activities related with Facility Management (FM). Provides functional space information.	CAFM specific software
Building Information Model (BIM)	Provides information about building envelope.	gbXML, ifcXML
Organizational Information	Information about the organization and the way it is structured to perform the core activities.	Database Management System (DBMS)
Energy Pricing Data	Information about tariffs from different energy service providers.	Paper form (non-structured data)
Billing Information	Keep record of information about energy expenditures (i.e. energy cost, taxes, billing date)	Paper form, Billing Information System (BIS)
Weather Data	Provides information about climatic conditions in the facilities and surroundings.	Provided by weather stations connect to the BMS or from external sources.

Table 1. Set of External Sources which include several Intelligent Building Systems that must be aggregated into a global schema. The provided information will ease the process of Intelligent Building data analysis by exploring data according to different dimensions.

- Operational Data, refers to data that has a direct relation with the business process, with the space, the occupant and how they perform their core activities. This is important so that energy use can be traced to activities.
- Commissioning data provides details about the operation of IB data systems, showing temperature, pressure levels and setpoints, helping to determine the cause off peak-demands and abnormal situations.
- Sensor data captures environmental and occupancy data related with the information that can be measured using sensors (luminance sensors, occupancy sensors).
- Equipment status data is essential to fully understand the energetic behaviour of a building. Equipments may be grouped as a stand-alone device

or operate as a system (e.g. HVAC). Each device as a specific electric-load, an associate activity (e.g. air conditioning, lighting) and a working period.

Accordingly IB data integration is an activity that gives support to Energy Management (EM) and Facility Management (FM). A building should be understood as a whole system and the interaction of each system to energy consumption and building maintenance must be defined. Then, building data must be correlated, aggregated according to different dimensions and hierarchies in order to process and analyse information.

2.2 Complexity of Intelligent Buildings Data

There are intricate factors that affect the integration of IB data making it harder to provide an homogeneous and unified view. The data integration in this context is hindered mainly due to:

- Heterogeneity of data sources. As explained before, the information required in IB comes from different sources. The buildings, devices, occupants, external factors such as weather conditions have to be brought together. This variety of sources requires the communication with several external sources in order to extract useful knowledge. IB data sources present data in different data structures (structured, semi-structured, non structured), with different sampling periods (data that is constantly being updated such as energy information provided by meters and data that is most likely not to change like building information).
- Data storage. IB data is stored in databases of proprietary systems known as "informational silos", which makes it harder to extract and access information.
- The amount of data produced by external sources systems is often very large, since energy meters are constantly performing readings of energy consumption.
- Mapping problems. Due to the heterogeneity of data sources more efforts are need for schema matching (to identify that different schemas share similar semantics) and for schema mapping (performing transformations to integrate different schemas).
- Data Quality. In the IB context the quality of the information provided relies heavily in the accuracy of systems and devices (e.g. accuracy of data acquisition meters, sensors) and also to his fault tolerance capacity (e.g. communication losses with meters causes the storage of incorrect energy values).
- Large Data Models. The source data models are frequently very large due to the number of entities and instances requiring an additional effort to integrate these sources. Moreover, the documentation is often poor or absent.
- Organization-dependent data. In this context some information is hard to infer because is not explicitly stored in any system. This knowledge is

stored and shared by the people that compose that organization and is not stored in any physical format.

Nevertheless, collecting, archiving and analysing energy and building data requires significant computational resources with the ability of processing and analysis, making this a costly and cumbersome task and usually the information provided to the end-user is very difficult to interpret [10]. For that reason the IB data integration and data analysis is currently an handcraft process carried out by energy and building managers. Moreover, energy and building management systems are populated with inaccurate and outdated information leading to a distorted perception of the system's performance and to incorrect decisions [11].

3 Extract, Transform and Load

Building and energy data must be stored and integrated with a global unified schema enabling an easy access to information to specific users. This data can be integrated into a Data Warehouse (DW) which is a repository of information collected from multiple sources and integrated [12]. The main goal of a DW is supporting data analysis and decision-making, making information easily accessible and present information in a way that is consistent with the business requirements while being flexible and resilient to changes [13,14]. A DW is populated by integrating data from different sources which has to be cleaned, converted and conformed to fit in the DW schema [12]. Extraction, Transformation and Loading (ETL) processes play an important role, populating and assuring the data quality of the DW. ETL processes are responsible for: extracting data from operational source systems, transforming data which includes integrating it, checking for inconsistencies and assuring the data accuracy to meet business requirements and finally for the loading stage, which is accountable for delivering information to the data presentation area [15,16], as depicted in Fig. 1. They control the loading and refreshment of the new data [15].

Nevertheless, ETL is more than loading data from the operational source systems to the data presentation area. ETL processes are responsible for enforcing data quality and consistency, conforming and for mapping data from different data sources.

3.1 Challenges of ETL

To design ETL processes it is important to define the system requirements, to identify the data sources and the DW schema and determine the set of transformations that are needed for the project. The complexity factors of developing ETL process for building operations are due to difficult access to data sources, data source characteristics and lack of a reference model. Difficult access to data sources is related with the lack of drivers for IB protocols and with the existence of undocumented energy data models. Heterogeneous data sources have different characteristics, there are real-time data sources (that require real-time ETL)

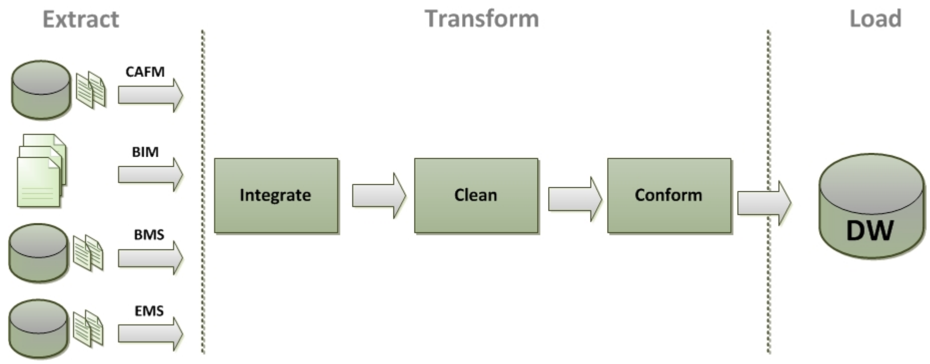

Fig. 1. Overview of an ETL system to populate a DW. The extraction from structured, semi-structured and unstructured data sources, the transformation and the loading step to a centralized model (adapted from [16]).

and data quality issues due to intermittent data sources (meters and equipments that disconnect). The lack of a reference integrated model, means that data has to be integrated against a model that no one knows how to build it (no such model has been proposed until now). Moreover, autonomous and heterogeneous data should be integrated in an uniform way and consolidated through the data cleaning activity to assure data quality. Poor data quality as a strong impact in enterprise strategies, because the foundations of his success and of the process of decision-making relies heavily on this data [17]. Therefore, several authors consider that energy and building data quality must be evaluated in terms of validity, accuracy, completeness and timeliness [18,17].

The ETL activity is crucial for designing a DW for Energy Management. This activity replaces the manual task of analysing and correlating energy data, which is very difficult and error prone since the amount of information is large and heterogeneous.

3.2 Advantages of using ETL to integrate intelligent building data

There are several reasons for using an ETL tool to integrate heterogeneous energy data sources.

Data Source abstraction, eases the process of creating an ETL transformation because data can be handled and accessed in a uniform way. There are several factors that depict the advantages of using an ETL tool to effectively integrate energy data:

- Logic access to data is location-independent and implementation independent. The abstraction level hides the complexity of extracting data and the location of the data source, the developer just needs to focus in the transformation process.

- Since the architecture is source-independent, raw data can be handled in a generic way because it is independent of the extraction process. Provides a uniform access to data sources in a common representation.
- Connectivity, provides connection with a wide range of source systems (from relational databases, XML files among other formats). This feature is important because it transforms heterogeneous data into primary data, which is easier to manipulate.

Declarative transformations, with this paradigm it is only required to express the logic of the transformation without describing the entire execution flow.

- Algorithms are chosen based in the context conditions that can be modified, allowing the solution to evolve to face new demands.
- The strategy to implement a transformation is defined through the specific context. For each transformation it is necessary to evaluate the best algorithm to face the context characteristics.
- Improve scalability, it is possible to use computing techniques to improve the transformation process, for instance using parallelism, partitioning or clustering.

Re-usability, since ETL process can be disaggregated into loosely-coupled components it is possible to modify and reuse ETL components to fit in new solutions.

- Domain specificity is low, which means that ETL transformations can evolve to solve other problems in different domains. Eases the process of reproducing a new ETL solution.
- Modularity, allows the separation and recombination of ETL components. Reduces complexity and increases the flexibility of creating an ETL transformation.
- Extensibility, allows the extension and creation of new functionalities. Since ETL is a wide explored area and several ETL tools are open-source solutions it is natural to take into consideration future growth.

Explicit knowledge, fruitful information about ETL process is easily stored and transmitted. It is focused on the "essential" data.

- Easy to understand and control ETL transformations, the user doesn't need to concern with implementation tasks.
- Business-oriented, it is possible to evaluate only the business logic, to identify transformation rules and constraints, determine the execution flow and necessary steps to complete a transformation.

4 Prototype

To validate our ideas we implemented an ETL data flow using an open-source ETL tool (Pentaho Data Integration - Kettle[1]) to create a set of extra-features

[1] http://kettle.pentaho.com/

that allows the communication with standards and protocols of intelligent buildings. Keetle consists of an ETL engine and GUI applications that allows the developer to define data integration process using jobs and transformations.

To extract data from building management and energy management systems there are two possible solutions: (1) build a specific data extraction software that must interact with each data source, (2) create data source adapters for an ETL tool that share some features (such as similar API, similar metadata format, among others) allowing the developer to focus only in the extraction process. The first option present several drawbacks, which makes this solutions infeasible to integrate building data. With specific extraction software there is no abstraction level between the transformation and the data source in that way the extraction driver must be embedded in the software, on the other hand the missing extensibility affects the flexibility since is not possible to add or modify a component to address a specific business need [19].

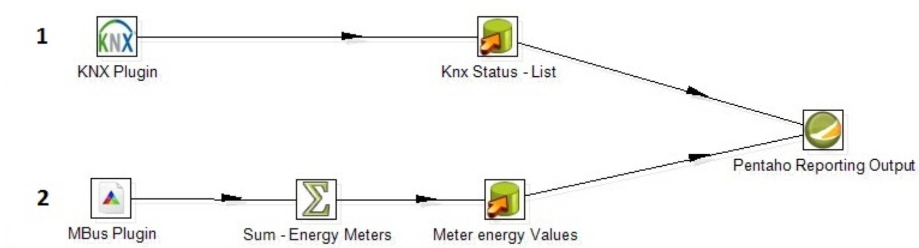

Fig. 2. Example of a Kettle transformation step. (1) Presents the input step: KNX Plugin which is responsible for connecting with KNX devices and read their status. After this step data is saved in a Database that stores the status of each KNX device. (2) Depicts a transformation that reads the values of several energy meters (running Mbus protocol) and performs the sum of all energy meters.

We propose to implement a module with drivers for extracting data from energy and building data sources. The prototype already has a connection with an Automated Meter Reading (AMR) system which is responsible for collecting, transporting and storing energy meter data from different types of meters (electricity, gas, heat) and with building control standards (e.g. KNX[2]) to verify the status of sensors and actuators to evaluate the operation of building management equipments, such as lighting, shutters, HVAC systems [20]. Using this two drivers it is possible to correlate energy consumption in a specific period with the weather conditions, which can reveal abnormal energy consumption (e.g. to study how energy consumption behaves with high temperatures and high illuminance values). The transformation scenario depicted in Fig.2 can be disaggregate

[2] http://www.knx.org

into two transformations, the first connects a KNX weather station to read the lux, temperature and humidity levels and stores this information in a database with a timestamp. The second transformation connects a Mbus[3] data concentrator to read the values of each energy meter, later the energy values are combined to calculate the energy consumption in that period (using an aggregator step) and finally stored in a database. This information will be provided in reports so that end-users could understand how weather influence energy behaviours.

By integrating this components of building management we are able to directly extracted data from devices, sensors, meters and actuators located in any point of the building. This direct extraction decreases latency time, since energy and building data can be faster modified and loaded to the final schema and increases the flexibility because data can be cleaned and conformed using the available steps of the Kettle framework.

5 Conclusion

Energy management is a fast growing area along with smart grids, smart metering infrastructures and intelligent buildings. Energy managers and building owners have realized the potential of this area but they are not totally aware of the fact they are not taking the most of these systems: they have a lot of information but little knowledge about their energy consumption. Thus, integration of energy data is of utmost importance.

Nowadays data warehousing and ETL are very popular tools in business analytics to effectively integrate data residing in different data sources. However these tools have not yet been adopted to energy management and more specifically to integrate energy-related data.

The aim of this article has been to discuss the superiority of using ETL tools to integrate energy data. We presented a prototype ETL implementation that extracts data directly from building management and energy management systems. The solution is highly modular and isolates the data transformation logic from the process of communicating with meters, sensors and actuators since it reduces the number of steps in the communication and allows the interaction of other steps in the extracted data because the steps are loosely-coupled.

The advantages of this solutions compared to build up a specific software from scratch are: flexibility to create different steps based in minor modifications with minor effort, re-usability to reuse existing components to create new components and connectivity to interact with a multiplicity of source systems. We expect the results of this work to contribute to streamline the engineering practice concerning data warehouse projects in energy contexts and integrating energy-related data sources.

[3] http://www.m-bus.com/

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Overview on Energy Data Reporting

Tiago Cardoso and Paulo Carreira
{tiago.cardoso, paulo.carreira}@ist.utl.pt

Instituto Superior Técnico

Abstract. Energy Management Systems (EMSs) are tools that monitor building energy consumption enabling more informed decisions towards rational usage of energy to be made. Current EMS applications provide high report diversity, allowing their users to gain significant insight to understand how their building is performing. However, to the best of our knowledge, there is no literature available on the different reports and visualizations types available. Report usability towards the user may vary depending on the type of data displayed and how it is displayed. This article tries to define and classify existing visualizations and reports. A reference data model together with an architecture is presented, both avoid having either lack of energy reports and also rigid reporting options, by enabling the generation of new reports.

1 Introduction

Energy Management Systems are tools able to monitor facility operations through the gathering of building data related to environment and equipment operations. Gathered data is used to generate reports that will help increase user awareness on how building operations are performing. Through reports, EMS aims at guaranteeing maximum operation efficiency, reducing energy usage, without adversely affecting the building occupants comfort. Adequate data presentations enable EMS to: *Improve the level of building management*, acting as centralized management system; *Provide a pattern of energy consumption*, through the captured energy data, allowing unexpected consumptions to be identified; *Identify peak electrical demand*, that might be responsible for additional costs.

In order to achieve its purpose, an EMS performs three fundamental operations, *(i)* gathering all energy related data , *(ii)* interpretation of collected data, *(iii)* data presentation to the users in the form of reports [11]. Currently there is not an agreed architecture describing an EMS, actually, most of the systems follow a monolithic approach, unsuited with the idea of having an extensible and flexible system. Allied to the fact that most of the current systems are vendor specific developed as close projects, current EMS systems have a narrow scope on reports, providing only a set of rigid reports. This inability cripples current solutions ability to maintain users informed through the use of reports that transmit raw data instead of knowledge.

The remaining of this document is organized as follows: Section 2 describes the main energy data reporting dimensions. Section 3 overviews which operations are desirable to perform according to dimensions described in previous section. Section 4 presents the report visualizations types. Section 5 describes the required data sources necessary to support the report generation with focus on a reference architecture, data model presented which design was oriented towards flexibility and extensibility and an EMS implementation based on them. Finally Section 6 will summarize this article and present the conclusions.

2 Energy Data Reporting

Reporting is the process of presenting collected data to the user. It is crucial that information is transmitted effectively from the EMS to the user in order to support his decisions [8, 13]. Report effectiveness and quality can be measured in terms of: *Interactivity* with the user; *Time window* needed for user read and understand the report; the *Usability* the report might have to the user and energy manager tasks; *Data exportation* capability allowing data to be captured and transformed freely by the user. In order to better understand report usage, we must study which **report dimensions** are available:

Time dimension allows the system to identify, through the use of a time-stamp, when the data was acquired.

Device and device type dimension is required to identify where the data is being collected from. It is through the device and device type that location dimensions and properties being measured are obtained.

Location dimension enables the user to known which locations are associated to the acquired data.

Organizational data dimension allows the system to relate which locations are associated to which department or individual.

Measured property dimension enables the user to select which properties/ measurement type should be presented in the report.

Energy tariff dimensions enable the system to correlated measurements from energy meters to the tariff in practice at the time of the measurement.

3 Reporting Operations

3.1 Filtering and aggregation

Report information must be filtered, otherwise the user could be overwhelmed with information presented towards him. Filtering is achieved through the manipulation of the data on report dimensions:

Time dimension allow users to select which time period will be analysed. EMSs gather data since the moment they are turned on, so reports need a time dimension filtering option otherwise report data could not be analysed in adequate time. Report data can also be aggregated by time, allowing users to compare energy consumption on different time periods (days, weeks, years).

Device and device type dimension is needed to identify where the data is being collected from, allowing to select only the information gathered by specific devices. This option enhances system capability to debug a problem when the building is not performing accordingly to expectations [8].

Location is a dimension obtained from the devices installation location or monitoring range. Location can act either as a filtering and aggregation dimension enabling the user to select which data devices should be presented.

Departmental organization is a dimension obtained from the relation between locations and departments. This dimension can be seen as a degenerated dimension from location, clustering locations through *"belongs to"* relationships and offering filtering and aggregation operations.

Measured property dimension enables the user to select which properties being monitored should be presented in the report. Some static data properties such as production line schedules might be available to selection due to their relevance to energy consumption.

3.2 Energy Profiling

Energy profiling consists on tracing an energy consumption pattern based on past consumptions or behaviours. Consumption is highly related to time, usually buildings have patterns that reflect daily scheduled operations or occupants routines. Nevertheless some significant deviations on energy consumption when analyzing collected data shall be found. Finding the sources of those deviations and how they influence energy consumption, will improve forecast effectiveness [10]. Those deviations can be found in data being extracted from equipment across the building. Determine those sources is a process denominated *data normalization* and in energy its main drivers are [2, 17]:

Weekdays influence building operations and building occupancy. Due to their influence on building energy consumption, information must be correlated according to the week day when the consumption occurred [16].

Temperature influence energy consumption due to its impact on HVAC systems, buildings major energy consumers. Systems use two set point temperatures, one to start cooling the building and other warm it up. Data normalization is usually performed according to *cooling degrees* and *heating degrees*.

Lighting equipment are the second largest energy consumer in our buildings [5]. Some buildings try to conserve energy by setting lights according to time schedules. In this case such event will be capture with consumption pattern according to time. However more advanced systems perform according with outside brightness. In those systems brightness levels need to be captured.

Humidity affects HVAC efficiency to cool and warm the buildings environment having direct impact on consumption.

Building occupation has an impact in the usage of most systems on the building [14]. The number of people have an direct influence on the effectiveness of HVAC system, because air needs to be recycled more often to reduce the amount of CO_2 and body heat production. Furthermore, the increase of building occupation might relate to the use of additional electrical equipment such as computers.

Production schedules might have a huge impact on energy consumption. In some cases, due to the heavy machinery being used during those periods, this factor overshadows other factors regarding energy consumption.

Equipment status gathers the mode on which systems are operating. For instance, on HVAC systems lowering the set-point might bring energy savings, in spite of affecting occupants comfort [8]. Some energy policies are defined according to the settings on which equipment operate.

3.3 Energy Forecast

Energy forecasting is the process of predict energy consumption based on past events. After data normalization process takes place, is possible to make accurate consumptions forecast according to the expected conditions. Through the forecast process energy peaks can be estimated and actions to avoid them can be deployed, allowing to save associated costs to be saved.

3.4 Cross Operations

A complete solution must offer the possibility to cross the previously stated operations. The raw energy consumption data does not provide any insight on how our building is performing, we need comparative views. By comparing expected consumptions against the real consumption, performance indicators can be found [7]. These will offer an better insight on how current energy policies are affecting the energy consumption. Due to the fact that forecasting the energy consumption results directly from assigning values to the measures used in the profiling operation, forecasting shares profiling dimensions.

4 Report data visualization types

EMS solutions must generate visualizations according to user needs. While performing his tasks, the user is interested to either analyse acquired consumption data or observe data regarding current building state. According to user needs and requirements, three different visualization types can be identified.

4.1 Historical Data Analysis

This approach is used when the user requires access to information regarding gathered data. However, a single query might return hundreds of thousands of points to be evaluated [12]. A data table presenting all gathering points could not be evaluated in adequate time. Charts and dashboards allow EMSs to display all several information data at once. EMS might use charts such as line charts or stream charts to perform analysis over time [13]. Dashboard can be used showing performance indicators, informing the user how energy was consumed during a time period, relative to expected consumption or past consumptions.

4.2 Real Time Monitoring

Real Time Monitoring enables users to see information about energy usage, equipment status and environment conditions on real time. Presenting the last read values from the devices across the building captured provides the current building state. However, metering data presents only values accumulated over time. This information alone unable to tell the user how the building is performing without information about the previous reading, therefore, some data has to be manipulated before being presented to the user.

4.3 Hybrid view

Hybrid view combine the best properties of both real time monitoring and historical data analysis. The user is looking for a correlation between gathered measures with the expected ones. The gathered values from environment sensors can feed the forecasting model (discussed in 3.3) to provide a prevision on real time consumption. A visual indication on how current consumption relates to the expected consumption can be presented, providing an insight on how the building is performing at a glimpse increasing system usability [13].

5 Energy Data Integration

5.1 Data Acquisition

Data gathering is the process responsible for acquiring data that might concern energy consumption. Gathered data might come from three different source types: energy meters, environment sensors, equipment status sensors [11]. Data retrieved from meters enable the EMS to gain insight on building energy consumption. Environment data will allow the EMS to correlate energy consumption to monitored conditions. Collecting data regarding equipment status enables correlations between consumption and operational status to be found.

Energy Metering Meters are cumulative reading devices, designed to measure the amount of consumed energy [1]. Their installation location might dictate the insight possible to be obtained.

In order to achieve a better resolution regarding energy consumption, some solutions might install meters on locations that were already monitored by other meters, this approach is named **sub-metering** [6]. Bigger insight on energy consumption can be achieved following this approach, allowing unexpected consumptions to be diagnosed and its root to be found.

Environment conditioning monitoring Energy consumption is highly related with external factors such as weather and building occupation, so they must be monitored and acquired in order to be correlated with energy consumption. Environment can be monitored through sensors, which provide an instant reading over the measure being monitored. These relations between environment and energy consumption enable EMS to profile consumption and forecast consumption based on the expected conditions.

Equipment status monitoring Equipment status data enables the EMS to obtain information about which devices were operating and under which conditions when a consumption pattern occurred. Therefore, collecting these data enable the EMS to establish a relation between energy consumption and device operation status. Usually energy policies are equipment settings definitions, such as HVAC set points, collecting this data will allow to identify which measures provided better savings.

With this knowledge the energy manager might decide the best path to achieve a desirable condition, e.g. lowering building temperature using the less amount of energy.

5.2 Data Quality

To ensure that reports are precise and accurate, faulty data must be identified and its integration into the repository avoided. Faulty data can be identified as incorrect, inconsistent or noisy. These type of data are determined through a data quality process, in which several quality dimensions must be evaluated [3]:

Accuracy dimension relates to the precision of the data being captured. All equipment have a known precision, however due to equipment malfunction or lack of maintenance its precision can be affected, leading to incorrect data.

Timeliness dimension reflects data quality according to how long is it valid. For instance, on real time monitoring data must be updated constantly.

Volatility dimension reflects data *expiration date*. Meters and sensors do not store data. EMS needs to keep acquiring devices to obtain their value, otherwise the time gap between reading intervals will have to be interpreted has missing data and be estimated leading to incorrect results.

Consistency measure evaluates if the equipment readings are non-conflicting. For instance, in a room with two temperature sensors, if they measurements are inconsistent it is impossible to say what the real temperature was.

Completeness dimension evaluates if all required information is available. Collecting data from a meter which monitoring range is unknown is an example of incomplete data. In this example sub-metering operations could not be tracked.

Duplicate dimension evaluates if gathered data was already acquired and added to the system repository. Acquiring duplicate values can lead to misleading information being presented on reports (energy peaks that didn't occur).

Acquired data that does not meet those measures must be identified as faulty data and the system must correct them. On EMS the mostly common issues are related to network failure, duplicate data, misread information and human error while inserting data manually. Having identification, EMSs have to either discard them or by correct faulty data. On EMS where data quality analysis is performed, error rate is expected to be in order of approximately 1-5%, although error rate can go up to 30% where the process is non-existent [15]. After extracted data is analysed and corrected, it might need transformations to fit system data model. [9]. The entire process of data extraction, cleaning and transformation is also known as the process of Extract Transform and Load (ETL) [12].

Data Mining Data mining is the process of data exploration aiming to find patterns in data in order to "extract" knowledge. [9] These patterns can aid determine if data is being retrieved correctly, measuring data quality. If some retrieved data is outside the range of expectable value according to other measurements, data can be seen as an "outlier" and be discarded or being simply market as having highly inaccurate. Furthermore, this process can be particularly useful for retrieving consumption patterns, identifying what are the most frequent causes of consumption peak responsible for high price tariffs and high billings. After retrieving an energy consumption pattern, the energy manager might prevent those peaks by managing the energy load. Is through Data Mining process that energy consumptions variables are found, allowing energy consumption and energy profiling to be made [4].

5.3 Centralized Model

The EMS architecture solution proposed is designed oriented towards flexibility and extensibility. This solution aims to gather data from several heterogeneous sources that might be added or removed from the system, while implementing a platform to develop new reports.

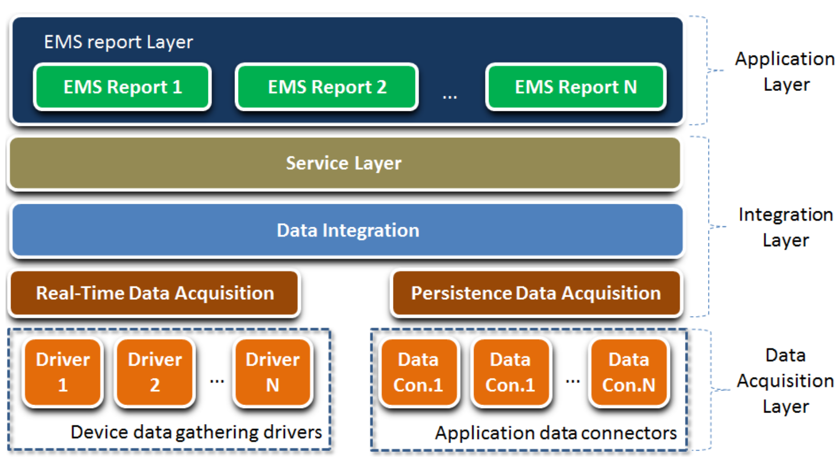

Fig. 1. Proposed architecture.

The proposed solution is a three layered architecture presented in Figure 1. *Data Acquisition Layer* oversees data acquisition from meters and sensors, *Integration Layer* is responsible for collecting, storing and granting access to the gathered data and *Application Layer* is responsible for the data visualization. *Real-Time Data Acquisition* module allows the addition of new devices through the implementation of a new *Device Data Gathering Driver*. These drivers are responsible for implementing the communication protocol, enabling them to collect data from the devices they are designed to. They are connected to the real-time data acquisition module through its exposed interface. For instance, if data from *deviceA* is required, the solution only needs to *know* that the *deviceA* is reachable through *driverX*. If a new device is created, to use it we simple develop a new driver and add it to the solution by linking the device to the driver.Data will be integrated in the solution data repository by the *Data Integration* module. This module is also responsible for dealing with data quality issues, identifying data errors and correcting them. Unexpected data, that is, data that is not coherent with the energy profile or forecast, will be marked as being inaccurate for further analysis. The frequency on which it occurs might trigger a warning about a required maintenance check. A *Service Layer* will be placed over the remaining solution providing access to gathered data through services exposure. This module serves as an abstraction layer between the data model and the applications demanding its data. Third party applications, represented as *EMS Reports* can be deployed using Service Layer exposed services. The underneath architecture serves as framework to the EMS applications deployed on top. They will be responsible for showing data and information to the user. This conception allows new data visualizations to be added to the deployed solution, offering another expansion capability without impacting the remaining solution.

5.4 Data Model

The data model is the conceptual design of a data warehouse where information collected from multiple data sources is stored into a coherent repository [9]. Having all information stored in a DW, makes information available even when is collected on different locations, enabling data analysis and data mining to be performed at a single point. All collected data will be stored in it supporting system reports generation. The schema model is represented in the Figure 2.

In this model there are three data gathered types needed to be modelled: (i) meter data, (i) environment data and (iii) equipment maintenance. Each measurement will be identified according to the time in which the measurement was performed, the device that performed the reading and which measurement (property) is being captured. Measurements performed by energy meters might have a tariff model associated to it, enabling energy costs to be obtained from a set of readings. Each measurement will have a data quality dimension associated, indicating if the measurement appears to be correct, doubtful according to expected results, or has been programmatically estimated to overcome missing data. Through the device dimension, we can access information regarding the device measurements range, an important aspect once a single device might be monitoring several locations. A location in this model can be seen as a tree, where each node is a distinct location. This hierarchical view allows sub-metering to be performed and tracked by the system. The tariff model relates to the meter data fact table, through the *TariffModel* dimensional table which might present several values.

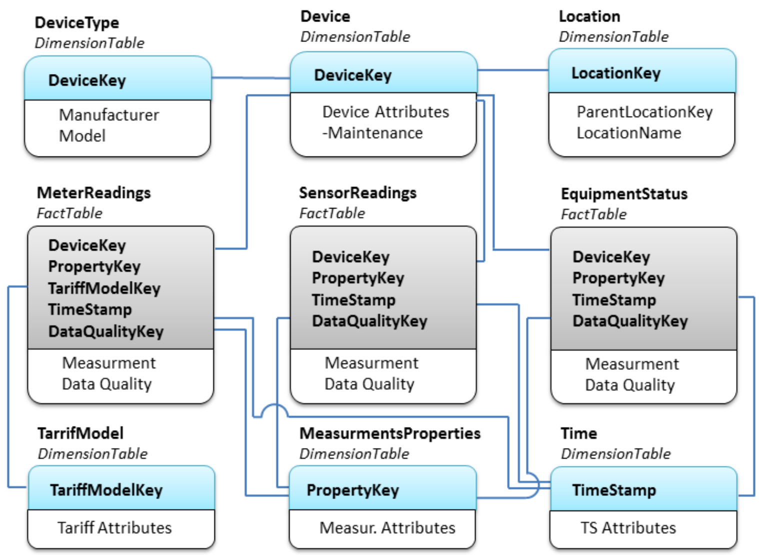

Fig. 2. Conceptual view of the data model.

5.5 Prototype Deployment

The final prototype will be deployed on Tagus Park installations using Tagus Park monitoring equipment and energy meters provided by QEnergia. QEnergia energy meters will be the S-Energy Manager [1] controller that can be connected to several devices collecting their readings. A driver will be implemented to collect data from QEnergia devices, as well as other available sensors and meters available at the laboratory. The real time data acquisition module will periodically retrieve information from the assigned drivers. Before being stored into the system data model, collected data will be analysed and its quality evaluated. Collected data must meet all quality measures (discussed in the Section 5.2), so data must be compared against data retrieved from other devices to check its veracity and only then can be stored into the system. Gathering data from several sources allows more interesting data correlation to be found allowing data analysis and energy forecast to be performed and evaluated more accurately.

[1] http://www.saia-energy.com/14-0-Energiemanager.html

Static data referring to Tagus Park class rooms and other areas as well as locations assigned to each department (organization data), will be loaded into the system. The energy cost plan in use at Tagus Park will be modelled into the system.

To test EMS extensibility, two applications will use the solution service layer. One application will use real time monitoring visualization, testing application capability to send events back to the applications connected the it. The second application will implement an interface that will allow to set energy price tariffs, and extract summarized reports regarding energy costs.

In the end the prototype development will result in a tool able to monitor the building operations, helping reducing the energy costs associated to them. Notice that although the final result will consist on an ordinary EMS application, this will be able to be expanded. New drivers can be developed in order to support new devices or even retrieve data from other sources such as available online web services to gather weather data. Due to the developed data model, the system will be able to support data from several types of devices relating energy, building data, organizational data and even equipment operations. On top, new visualizations can be developed and added to the existed solution, offering an expansion possibility to add new reports, visualizations and mechanism that will inform and aid both energy managers and building occupants.

6 Conclusion

In this paper we discussed the main features presented by current EMS systems, as well as their limitations. Energy Managers are fully aware on the potential offered by these systems towards energy savings. Nevertheless they are unaware on the fact that most of these systems only offer a narrow view over the available data. Most developed solutions are able to present a lot of data, but with little knowledge over the collected data. The system must be able to provide, effectively, an insight on energy consumption. A related issue relies on the fact that few systems are able to perform data analysis and detect problems with data. Faulty data must be handled by these systems, warning users about a potential lack of accuracy when presented.

Through the presented proposal, we believe those problems can be overcomed. Presented data model enables gathered data from multiple sources to be stored under the same repository, enabling the system to collect data regarding energy consumption, equipment condition and environment status. To enhance system's flexibility, new data sources can be added to the system through the implementation of data gathering drivers. Data quality issues can be found with data analysis and a quality measurement can be presented on the report. The solution service layer allows third-party software to use the underneath solution as a framework, enabling it to retrieve gathered data by the solution. New data reports can be added easily with minimal impact to the remaining solution. Prototype evaluation will be performed by system deployment, testing the solution capability to add new data sources and expandability. We expect to assist dissemination of EMS systems in buildings, through the developing of a state of the art system that will bring together features that will help to monitor and predict the cost of energy consumption in a single tool, enabling energy managers to make informed decisions to save energy.

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Intelligent Management of End Consumers Loads Including Electric Vehicles through a SCADA System

Filipe Fernandes, Pedro Faria, Zita Vale, Hugo Morais, Carlos Ramos

GECAD – Knowledge Engineering and Decision-Support Research Group of the Electrical Engineering Institute of Porto – Polytechnic Institute of Porto (ISEP/IPP), Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal
{fjgf, pnf, zav, hgvm, csr}@isep.ipp.pt

Abstract. The large penetration of intermittent resources, such as solar and wind generation, involves the use of storage systems in order to improve power system operation. Electric Vehicles (EVs) with gridable capability (V2G) can operate as a means for storing energy. This paper proposes an algorithm to be included in a SCADA (Supervisory Control and Data Acquisition) system, which performs an intelligent management of three types of consumers: domestic, commercial and industrial, that includes the joint management of loads and the charge / discharge of EVs batteries. The proposed methodology has been implemented in a SCADA system developed by the authors of this paper – the SCADA House Intelligent Management (SHIM). Any event in the system, such as a Demand Response (DR) event, triggers the use of an optimization algorithm that performs the optimal energy resources scheduling (including loads and EVs), taking into account the priorities of each load defined by the installation users. A case study considering a specific consumer with several loads and EVs is presented in this paper.

Keywords: End consumers, demand response, intelligent management, electric vehicles, SCADA

1 Introduction

The main goal of power systems is to guarantee that the generation meets the consumers demand, including the domestic, commercial, rural and industrial types of consumers. The power system should remain in a stable state, matching generation and demand values. The consideration of consumers' behavior (participating in Demand Response events) is one of the distributed energy resources, which have been of increasing importance [1]. In certain periods of the day, mainly when the generation is lower than the demand or the marginal cost of increasing generation is high, the use of Demand Response (DR) programs is interesting for reducing the demand level as an alternative to increase the generation. The demand level reduction in a real time horizon is one of the most common events of DR. In the opposite situation (when the generation is higher than demand), it is possible to store the excess energy in a storage system by optimizing the use of energy resources. The increase of small resources use at lower voltage levels of distribution networks leads to the context of Smart Grid (SG) operation [2, 3].

In this context, the Electric Vehicles (EVs) with gridable capability (V2G) can be used as a storage unit, storing energy when there is an excess of generation and, discharging energy when the load is higher than the generation [4]. Only one V2G has no impact on the grid; however, the large integration of V2Gs can have non-negligible positive or negative impacts. The different V2Gs user profiles, which consider the daily necessities of people, will cause changes in consumption daily diagrams [5].

The optimization of load consumption and V2Gs use is able to improve the energy use efficiency, while allowing the system operator to control some loads of installation. This makes possible the increase of energy resources management flexibility [6, 7]. A consumer endowed with an intelligent energy resources management system allows the interaction with the grid operator, improving the effectiveness of the consumer‘s participation in a DR event, by receiving and sending event-related information [8, 9]. A SCADA system must support a decentralized structure to control, monitor, supervise and optimize all consumer energy resources, even in a real time horizon [10].

The paper deals with the intelligent management of a Domestic Consumer (DC) that adds two V2Gs to the system beyond the normal consumption loads. As these V2Gs are used by house users to travel to their respective workplaces, the effects of V2Gs on the intelligent management of a Commercial Consumer (CC) and an Industrial Consumer (IC) are analyzed. In this way, an optimization methodology is proposed and implemented in a SCADA system considering each type of consumer. This SCADA system considers all loads and V2Gs to perform an intelligent management.

Given the differences between the load curves for each type of consumer, it is important to analyze how the management systems will consider the V2G connection when applied to the three types of consumers at different times of the day.

After the introductory section, Section 2 presents the proposed methodology and Section 3 describes the energy resources considered by the SCADA system developed by the authors of the paper. A case study is presented in Section 4. The final section includes some conclusions.

2 Methodology applied in SCADA management

The intelligent management systems used by different consumers have the same basic structure, being some differences related to the characteristics of each consumer. Considering the context of participating in DR programs, any of the systems used aims to optimize the total consumption of the installation, keeping it lower than the established limit consumption or cutting power indicated by the system operator or by the installation user [11]. The optimization is directly affected by the users’ consumption patterns and by the context of the day, which depends on several factors, such as the season, the temperature, the day of week, the time and the electricity price [12].

The SCADA House Intelligent Management (SHIM) has been described in previous works, and it was only applied to the DC [13]. In the present work, the integration of V2Gs is also considered. The same SHIM methodology is used to implement intelligent management systems for the CC and the IC. These systems include the following features, management of the power consumption in an installation, while maintaining user comfort and loads operation continuity; adaptability of the system to several daily factors that may influence the consumption; and ability to interact with DR events in the SG context.

The base algorithm, presented in [13], is able to manage the installation consumption whenever there are changes in the system operation conditions. The same algorithm has been improved in order to consider the CC and the IC. As mentioned before, this algorithm considers the consumers' loads and V2Gs, associated with a usage priority defined by the installation user. In the presence of a new event, the algorithm evaluates the current state of all installation equipment and, in accordance with the priority of each resource. It performs an optimal scheduling regarding the methodology presented in Figure 1. The Mixed Integer Non-Linear Programming (MINLP) optimization algorithm has been implemented in General Algebraic Modelling System (GAMS).

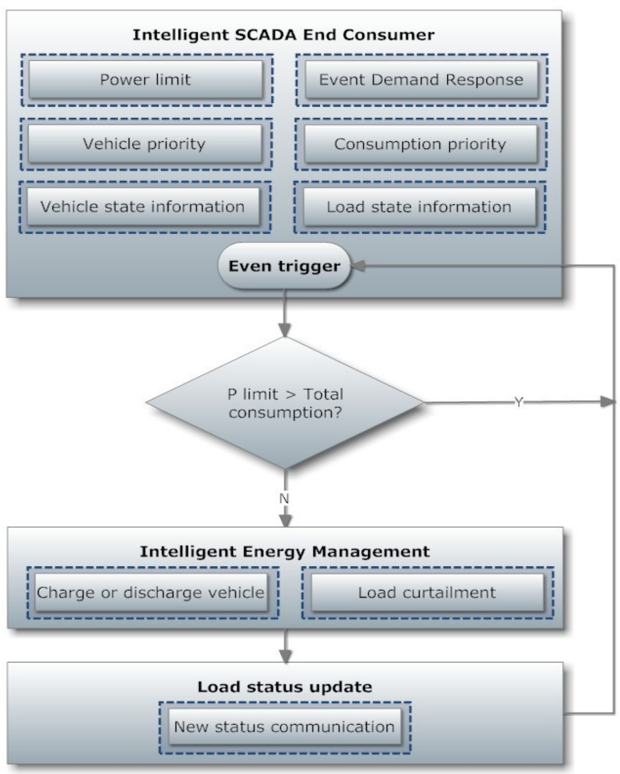

Fig. 1. SCADA End Consumer methodology

3 Energy Resources Description

3.1 End consumers with V2G

Each consumer installation has its load. Otherwise, V2Gs are common resources for the three considered installations of the SCADA system (see Figure 2), i.e., these resources have different connection points (installations) in different periods of the day as V2Gs travels between them. The current state/position of each V2G depends on the period of the day. For example, on Monday at 9 a.m. (peak consumption in the IC), the V2Gs are connected to the IC network and the charge / discharge periods could be managed by the SCADA system focusing on the IC installation resources use optimization. On the other hand, at 8 p.m. (peak consumption for DC and CC) V2Gs are connected to the housing network. The SCADA system is able to manage two V2Gs at the same period in a house (DC). In the case of the CC or the IC, it is prepared to receive one of the V2Gs that belongs to a DC. This is due to house users who give different functions to each V2G presented in Figure 2:

1. Move one user from the house to the industry (30 km) and return (30 km);
2. Move one user from the house to the commerce (15 km) and return (15 km).

The charge/discharge rate considered for both vehicles is 2.3 kW/h and a V2G battery at full charge has 16 kWh. The V2G have 160 km autonomy [14]. In this way, the V2G consumes 1500 Wh to travel 15 km (go to CC) and 3000 Wh to travel 30 km (go to IC).

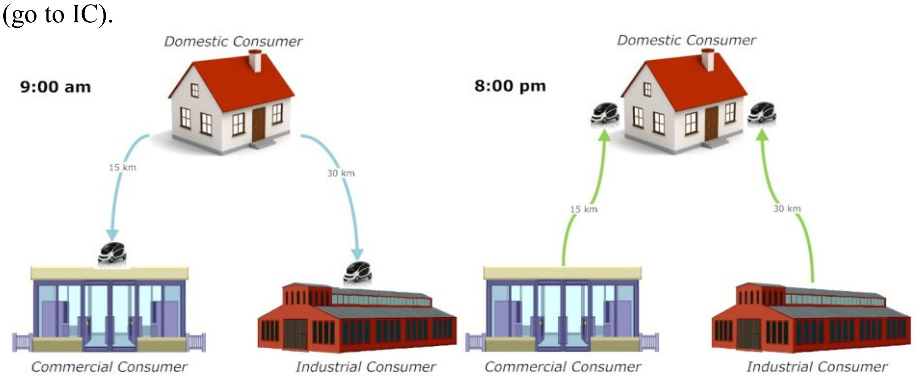

Fig. 2. End consumers with V2G at different times of the day

3.2 Description of End Consumers Loads

It has been considered different loads to perform the developed SCADA system, regarding the three consumers of different types. The GECAD's Intelligent Energy Systems Laboratory (LASIE) [11-13] loads were considered to represent the DC. The LASIE loads considered for the CC (coffee shop type) and for the IC (textile factory type) are presented in Table 1.

Table 1. Loads characteristics of end consumers

Type*	Domestic Consumer		Commercial Consumer		Industrial Consumer	
	Load	**Max Power (W)**	**Load**	**Max Power (W)**	**Load**	**Max Power (W)**
V_1	Induction Motor 1	90	Induction Motor 1	180	Induction Motor 1	450
V_2	Induction Motor 2	200	Induction Motor 2	400	Induction Motor 2	1 450
V_3	Induction Motor 3	300	Induction Motor 3	600	Induction Motor 3	1 700
V_4	Fluorescent Lamp	70	Fluorescent Lamp	700	Fluorescent Lamp	2 800
F_1	Incandescent Lamp 1	30	Incandescent Lamp 1	300	Incandescent Lamp 1	300
F_2	Incandescent Lamp 2	30	Incandescent Lamp 2	300	Incandescent Lamp 2	300
F_3	Heat Accumulator 1	1 600	Coffee Maker	1 500	Heat Accumulator 1	1 800
F_4	Heat Accumulator 2	1 000	Heat Accumulator 1	3 200	Heat Accumulator 2	1 800
F_5	Halogen Lamp	500	Dishwasher	1 500	Halogen Lamp	2 500
F_6	Exhauster	138	Plasma TV 1	276	Sewing Machine 1	690
F_7	Refrigerator 1	300	Desktop Computer	600	Iron 1	3 000
F_8	Washing Machine	550	Refrigerator 1	1 100	Clothes Dryer	5 500
F_9	Television 1	138	Security System	138	Sewing Machine 2	690
F_{10}	Refrigerator 2	300	Dehumidifier	600	Iron 2	1 500
F_{11}	Microwave	550	Plasma TV 2	300	Clothes Washer	2 750
F_{12}	Television 2	138	Sound System	138	Vacuum upright 1	690
F_{13}	Kettle	300	Refrigerator 2	300	Vacuum upright 2	1 500
F_{14}	Dishwasher	550	Air Conditioner	2 750	Cutting Machine	2 750
Total	**Maximum Power**	**6 784**	**Maximum Power**	**14 882**	**Maximum Power**	**32 170**

4 Case Study

In the case study, the SCADA system is applied for each type of end consumers (domestic, commercial and industrial) to perform an intelligent management of their energy resources (loads and V2Gs). The optimal energy resource scheduling is solved by the methodology presented in Section 2. Some scenarios are simulated in order to analyze the scheduling results for both consumers in different periods of the day.

All end consumers presented in this work have a database that contains a load priority, and the minimum and maximum power of each load and each V2G, depending on the context of the day. The SCADA system optimization analyzes the database and, according to the context, performs an optimal scheduling. The first development in previous work is the inclusion of two V2Gs in the optimization of the DC installation. After that, the methodology was improved in order to consider the CC and the IC, regarding the different characteristics of these consumers. The IC is the building with higher consumption. In this way, only one V2G should have low impact in the optimization process.

The present case study considers a Monday in the winter season, with an external temperature of 10ºC. At 9 a.m. and 8 p.m. the three consumers receive the simulated DR event respectively, according to the results presented in Table 2.

4.1 Timeline Results of the V2G State

In order to validate the case study, the results were analyzed. At 9 a.m. and 8 p.m. all end consumers receive the information regarding the DR event to cut or reduce loads consumption or to sell the energy stored in the V2G. The optimization of each end consumer installation depends on the availability of the V2G to be considered by the SCADA system. The timeline of the V2G state is presented in Table 2 according the DR event. The blue color means that the V2G is connected to the SCADA system respective, the red color means that the V2G is travelling and the green color represents the DR event participation at 9 a.m. (100 W to DC, 1450 W to CC and 5235 W to IC) and 8 p.m. (400 W to DC, 600 W to CC and 850 W to IC).

Table 2. V2G state and participation in a DR event

Hour	V2G	Domestic Consumer			Commercial Consumer			Industrial Consumer		
		State	Energy (Wh)	Charge/ Discharge Rate (W)	State	Energy (Wh)	Charge/ Discharge Rate (W)	State	Energy (Wh)	Charge/ Discharge Rate (W)
7 a.m.	1	Connected	16 000	0	Out	None	None	Out	None	None
	2	Connected	16 000	0	Out	None	None	Out	None	None
8 a.m.	1	Travel	None	1 500	Out	None	None	Out	None	None
	2	Travel	None	3 000	Out	None	None	Out	None	None
9 a.m.	1	Out	None	None	Connected	14 500	1 450	Out	None	None
	2	Out	None	None	Out	None	None	Connected	13 000	2 300
10 a.m.	1	Out	None	None	Connected	13 050	0	Out	None	None
	2	Out	None	None	Out	None	None	Connected	10 700	0
6 p.m.	1	Out	None	None	Travel	None	1 500	Out	None	None
	2	Out	None	None	Out	None	None	Travel	None	3 000
8 p.m.	1	Connected	11 550	400	Out	None	None	Out	None	None
	2	Connected	7 700	0	Out	None	None	Out	None	None
9 p.m.	1	Connected	11 150	0	Out	None	None	Out	None	None
	2	Connected	7 700	0	Out	None	None	Out	None	None

At 7 a.m. both V2Gs are connected to the DC SCADA system (with 16000 Wh of energy stored) but consumers do not receive any DR event. At 8 a.m., DC users begin the journey to their workplaces and at 9 a.m. a DR event is announced. At this time, $V2G_1$ is connected to the CC and $V2G_2$ is connected to the IC. This means that the DC will only be able to meet the DR event by cutting or reducing the loads consumption. Other end consumers can also use the discharge capacity of the V2G in the optimization process, according to the priority of the SCADA database.

At 9 a.m. all consumers receive the DR event order to reduce 100W, 1450W and 5235W corresponding to the DC, CC and IC respectively. The $V2G_1$ have 14500 Wh of energy due to the journey of 15 km to the CC and $V2G_2$ have 13000 Wh due to the journey of 30 km to the IC. At 10 a.m. one can verify that the $V2G_1$ storage energy is of 13050 Wh. This means that $V2G_1$ discharges 1450 W over one hour after the DR event announcement. The discharge value corresponds to the reduce power of the DR event and the loads that were being used by the CC were not changed, ensuring consumers' priorities. Regarding the $V2G_2$, the storage energy is of 10700 Wh. This means that $V2G_2$ discharges 2300W over one hour after the DR event announcement. The discharge value corresponds to a portion of the total reduce power of the DR event (5235 W). In this case, the IC SCADA system also needed to reduce the consumption in the lower loads' priority in order to fully meet the DR event requirements.

At 6 p.m. one can verify that any consumer of the SCADA system have V2Gs connected, because the V2G users begin the return journey, from the workplace to their houses, which will reduce 1500 Wh in $V2G_1$, and 3000 Wh in $V2G_2$. At 8 p.m. all consumers receive the DR event order to reduce 400W, 600W and 850W corresponding to the DC, CC and IC respectively. $V2G_1$ has 11550 Wh of energy and $V2G_2$ has 7700 Wh of energy.

At 9 p.m. one can verify that $V2G_1$ energy is of 11150 Wh. Thus, $V2G_1$ discharges 400W over one hour after the DR event announcement. The discharge value corresponds to the reduce power of DR event and the loads that were used by DC were not changed, ensuring consumers' priorities. Regarding $V2G_2$, the energy is 7700 Wh, maintaining therefore the initial energy. In this case, the CC and IC see the consumption reduced in the lower loads' priorities in order to fully meet the DR event, 600W and 850W respectively.

4.2 Energy Resources Scheduling Results

Tables 3 and 4 present the results of the optimization process to validate the methodology proposed in Section 2. Table 3 shows the priority of each load and of each V2G to charge (Ch) or discharge (Dch), when end consumers meet the first DR event at 9 a.m.. Table 4 summarizes the optimization results at 8 p.m. (second DR event). The coloured cells represent the resources which were subjected to changes.

The SCADA management system selects the loads or V2G mode (charge or discharge) according each priority. For example in first DR event to CC, the resource with low priority is 20 ($V2G_1$ discharge) and the resource with higher priority is 1 (Induction motor #2). The priorities are predefined by the installation users.

Table 3. Optimization results at 9 a.m. to end consumers

Type	Domestic Consumer			Commercial Consumer			Industrial Consumer		
	Priority	Power before (W)	Power after (W)	Priority	Power before (W)	Power after (W)	Priority	Power before (W)	Power after (W)
V_1	12	0	0	9	180	180	12	450	450
V_2	17	200	130	1	400	400	17	1 450	615
V_3	11	0	0	2	600	600	11	1 700	1 700
V_4	10	0	0	10	700	700	10	2 800	2 800
F_1	9	0	0	14	0	0	19	300	0
F_2	18	30	0	15	0	0	5	300	300
F_3	15	1 600	1 600	3	1 500	1 500	3	1 800	1 800
F_4	16	1 000	1 000	7	3 200	3 200	18	1 800	0
F_5	8	0	0	6	1 500	1 500	2	2 500	2 500
F_6	6	0	0	8	276	276	9	690	690
F_7	14	300	300	11	600	600	4	3 000	3 000
F_8	7	0	0	4	1 100	1 100	15	5 500	5 500
F_9	5	0	0	17	138	138	8	690	690
F_{10}	13	300	300	16	0	0	16	1 500	1 500
F_{11}	1	0	0	12	300	300	1	2 750	2 750
F_{12}	3	0	0	13	138	138	13	690	690
F_{13}	4	0	0	5	300	300	7	1 500	1 500
F_{14}	2	0	0	18	0	0	6	2 750	2 750
Total Power		**3 430**	**3 330**	**-**	**10 932**	**10 932**	**-**	**32 170**	**29 235**
$V2G_1$	None	None	None	Ch – 19 Dch – 20	14 500	13 050	None	None	None
$V2G_2$	None	None	None	None	None	None	Ch – 14 Dch – 20	13 000	10 700
Reduce Power		**100**		**1 450**			**5 235**		

Table 4. Optimization results at 8 p.m. to end consumers

Type	Domestic Consumer		Commercial Consumer		Industrial Consumer	
	Power Before (W)	Power After (W)	Power Before (W)	Power After (W)	Power Before (W)	Power After (W)
Loads Power	6 784	6 784	12 132	11 532	15 140	14 290
$V2G_1$	11 550	11 150	None	None	None	None
$V2G_2$	7 700	7 700	None	None	None	None
Reduce Power	**400**		**600**		**850**	

In the first DR event, at 9 a.m., the DC fulfilled the reduce power (100W) by turning off the incandescent lamp #2 and reducing the consumption of the induction motor #2 (loads with lower priority). The CC fulfilled the DR event requirement (1450W) through the $V2G_1$ discharge, keeping the same load consumption. The IC beyond the $V2G_2$ discharge, also turned off the incandescent lamp#1 and the heat accumulator #2, and reduced the consumption of the induction motor #2 to guarantee the required reduced power of DR event (5235W). In the second DR event at 8 p.m., the DC fulfilled the reduce power (400W) with $V2G_1$ discharge, keeping the same load consumption. The CC fulfilled the DR event requirement (600W) through the loads with lower priority; the same happened in the IC (850W).

5 Conclusions

This paper presents a case study considering a SCADA system to manage and optimize the consumption of all energy resources of the DC, CC and IC consumers. The case study is discussed and analyzed applying the methodology to the CC and IC in a particular context, and verifying the usefulness of V2Gs in their management systems. The results of using the proposed methodology regarding working days or weekends specificities, which require some distinct characteristics, have been addressed and will be reported in near future work.

In the present work, one can verify that V2G has direct participation and impact in the consumption optimization. The SCADA system of any consumer is provided with the priorities defined by the installation users to each load and each V2G according to the operation context. The SCADA database allows to know the user's needs in real time in order to guarantee the fulfilment of the DR event requirements.

One V2G may have more influence in the DC optimization than in the IC optimization, as the IC is a consumer with higher energy requirements. In this way, one V2G may have little impact in IC resources use optimization, but if we are dealing with a considerable number of V2Gs, this impact must be adequately analyzed. This means that the optimization decisions depend directly on the consumers' energy needs, on the number of V2Gs considered and on the type of end consumer. The benefits of using the proposed SCADA system can be summarized as follows:

- Creation of a system with its own capacity for decision in real time to support the grid operator with energy management capability;
- The methodology development can be adapted for any type of end consumer and amount of energy resources;
- Each SCADA system is able to be adapted to the current system conditions over the day with or without of V2G;
- The inclusion of V2G in the SCADA system makes possible to ensure the end consumer comfort through the V2G batteries energy discharge.

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Unplugg: A Cloud-based Home Energy Management Platform

Rafael Jegundo[1], Nuno Martins[2], and Jorge Landeck[1]

[1] University of Coimbra - rafael.jegundo@gmail.com, jlandeck@fis.uc.pt
[2] Intelligent Sensing Anywhere - nmartins@isa.pt

Abstract. The residential market represents an important part of the global energy consumption. However it is one of the hardest places to improve our energy efficiency. Several solutions exist with different approaches, however their adoption and results are suboptimal. We believe that this occurs due to the fragmentation of the solutions, up-front costs and a some lack of focus on the user experience. In this paper, we present a consumer centric, cloud-based Home Energy Management platform. Its aims are: to build the foundations of a hardware agnostic solution, supporting the main open data sources available and enlarging the potential interested consumer base; provide actionable metrics and consumption simulations that give insight to the user and help understand the impact of habits and choices; explore the potential of Internet of Things and cloud based energy management; and finally, to achieve in a market-ready solution that can be sustainable and effectively drive change.

Keywords: Home Energy Management, Cloud, Internet, Internet of Things, Open Data

1 Introduction

The residential market is responsible for an important part of the global energy consumption, representing 26,65% [1] in Europe, where 20% [2] of all energy is wasted. Being a fragmented market [3], and highly dependent on individuals convictions and circumstances, it presents a great challenge for energy efficiency increase. There is a crucial effort of promotion and innovation to be made, in order to effectively execute current energy policies [4, 5] and achieve concrete results.

Many concepts and market solutions have been developed in the Home Energy Management (HEM) field. Yet the market reality has failed to comply with expectations [3]. An important issue is the reasonably high cost of energy 'management systems, which creates a natural entry barrier for the consumer adoption. Most of these systems deliver a home-based solution where the intelligence of the systems is located in-site. This has its advantages from a technological stand point, providing a quicker and more effective response. However it has its drawbacks from a efficiency and business point of view. The up front cost is high, and quickly loses its novelty for smarter solutions due to its limited upgradability. The updates are irregular and the technology loses its novelty quickly due to the difficulty of upgrading hardware.

An interesting alternative is to move the intelligence to the cloud where it can be iterated and updated quickly, while leaving just the sensors and actuators in home. This enables lighter business models with lower costs for the customers up front. In this way the user can take advantage from the state of the art of HEM technology and pay by what is effectively used. This results in a more efficient solution from a data processing point of view; but also from a business point of view, since the since the cloud based management enables relevant economies of scale [6].

2 The Unplugg Platform

The cloud potential as base for innovation through open data and communication has been until now reasonably overlooked where the possible exceptions are the deprecated Google Power Meter[3] and the HITS concept [7]. Herein we explore a consumer oriented vision of this while making a market-ready solution. The developed platform is designated as "unplugg".

The ultimate goal of this platform is to enable an Internet of Things focused on energy management, building upon the many interesting concepts on this field [9]. In order to achieve that, beyond data sources which are already present, it is necessary to enable innovation in simple and global control solutions and explore its integration potential through an open platform [3].

2.1 Architecture

The effectiveness of such platform depends on its capability of integrating most of the main sensoring and actuation solutions. This presents a challenge to support a broad set of communication protocols. Looking into the power monitoring systems today, which is more a mature market than the control and actuation, one can understand that most data can be acquired simply through HTTP which simplifies its implementation. The exception are the smart meters that use standards like DLMS [8] which are a lot more powerfull, but also much more complex to interact with.

In this case, HTTP was selected as a priority in order to support immediately the market represented by power meters such as Current Cost[4] and The Energy Detective[5]. Another key element that make this selection obvious is that the integration with these systems through HTTP is based on open APIs, unlike the use of DLMS by utilities which is naturally closed to their infrastructure. The communication with these systems can also be made through brokers such

[3] http://www.google.com/powermeter/about/
[4] http://www.currentcost.com/
[5] http://www.theenergydetective.com/

as Cosm[6], or in the future the middleware solutions from utilities for which Tendril[7] can be seen as a possible example. A simplified vision of the integration architecture can be seen in Figure 2.1. This platform is currently deployed in heroku[8], a Platform as a Service (PaaS) hosting solution built upon Amazon EC2[9] that simplifies the administration while keeping the advantages of the cloud.

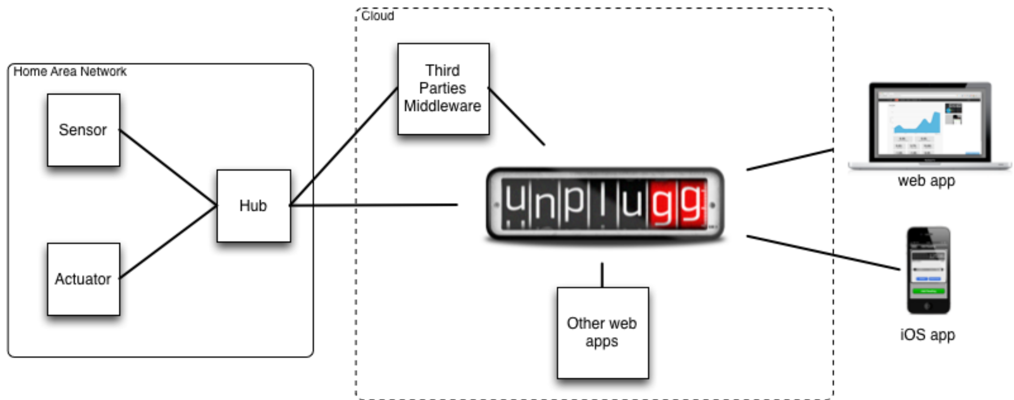

Fig. 1. Unplugg Platform architecture

Present systems integrated to the platform are: Cloogy[10], Current Cost Envi, The Energy Detective and the Tendril API[11]. These systems act generally as energy consumption data sources.

2.2 Internet of Things

Control solutions at low price points start to appear in the market. Examples of this are Cloogy which offers smart plugs that can be remotely controlled through an API, and through the just launched Wemo[12] from Belkin, which provides control and movement sensing. This type of integrations are already present in more early adopter segments where the IFTTT[13] association with Wemo stands out. In this field exciting times are coming with the arrival of the

[6] http://cosm.com
[7] http://tendrilinc.com/
[8] http://heroku.com
[9] http://aws.amazon.com/pt/ec2/
[10] http://cloogy.com
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Internet of Things and the growing awereness for energy issues, and cloud based solutions are a natural enabler due to its ubiquity and quick evolution potential.

However this trend will only evolve organically when the more tech enabled consumers start experimenting and creating mashups between the Internet of Things, HEM solutions and even other web applications. This makes the offer of an open, powerful and well documented API a crucial step for the effectiveness of a platform in this context.

2.3 Data Analysis and Presentation

Web and mobile apps are also a driver for smart energy solutions adoption, by enabling rich, frequently real-time energy management through already omnipresent devices. But these apps require access to actionable, meaningful data that can be easily crunched in the cloud. For unplugg, an iOS app was developed that provide actionable metrics which allow users to track progress, and complements the view offered by the main platform interface.

3 Conclusion

Cloud based energy management presents several advantages comparing with home based control systems, such as efficiency, low entry barrier, increased ease of adoption, global and ubiquitous potential of integration. It can hence be a technological solution to tackle the slow adoption of HEM systems. In this paper a global platform named unplugg was presented. It stands out by enabling the support of multiple data sources and empower the innovation through the Internet of Things while keeping a user-centric vision. It is currently in beta at http://unplu.gg.

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The iDom®Framework: A Novel Tool to Achieve Energy Efficiency

Gonçalo Bernardes

DOMATICA, Global Solutions, S.A. Rua Belo Horizonte Edifício 25C, 2640-027 Ribamar - Mafra, Portugal

www.domaticasolutions.com
goncalo.bernardes@domatica.pt

Abstract. Herein, we present an innovative and practical platform named iDom® Framework that enables non-specialist developers to create automated applications to monitor and control any physical device that relies on measurable physical units. A case study of our product Rulergy®, a solution for energy efficiency, that was built using the iDom® Framework is presented.

Keywords: Framework; Software; Hardware; Home Automation; Building Automation; Energy Efficiency; Sustainability; Energy Management System.

1 Introduction

There is a growing interest in innovative solutions for connecting the physical and the logical world. Most systems however fail in making such a connection. At DOMATICA, we set ourselves to create a platform that can be used by non-specialist developers and that facilitates bridging software and real world by enabling monitoring and controlled manipulation of physical devices. We aim to contribute to a better world by endowing these devices with intelligence, in an interconnected global network, interacting with humans in real time, facilitating their operations, business and cost control in a centralized platform. In this manner, we believe we can be part of the development of societies with a direct impact in keys areas including industry automation, process and energy efficiency or health management.

2 The iDom® Framework

DOMATICA has created the iDom® Framework,[1] an innovative technological solution that narrows the distance between the physical and the logical world. Skilled programmers often develop applications for software platforms using high level programming codes and databases. However, a significant barrier is found when trying to get out of the computing environment and to connect such applications with physical devices. The iDom® Framework is a practical platform that enables non-specialists developers to create automated applications to monitor and control any physical device that rely on measurable physical units.

The physical world is complex. There exist an almost infinite number of sensors available to measure the same logic unit and that can also act as actuators. The iDom® Framework makes it simple for developers to quickly build applications that can access real world physical devices. Complex systems are in this way built at a glance, without the need of special knowledge of the physical devices themselves, electrical signals or even communication protocols. Additionally, sensors, actuators and hardware blocks may be manipulated without changing a single code line at the application level.

The iDom® Framework consists of the Collector, Gateway, Project and SDK and is depicted in the Figure 1.

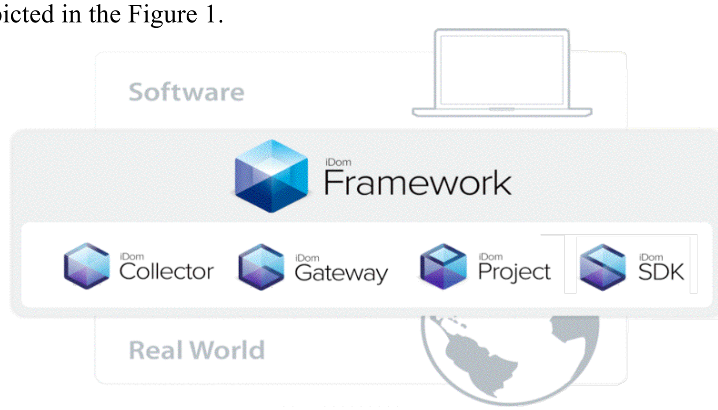

Figure 1 – Overview of the iDom® framework components.

The iDom® Collector as part of the iDom® Framework, works in a distributed intelligence architecture, where each module has its own program memory, object data memory (devices, timers, variables) as well as high processing power. When a module is added to a network, it adds power and resources to that network, instead of consuming resources from other modules. Peripheral devices receive and emit electric signals. The iDom® Collector handles these signals and supports almost all types of physical devices.

The iDom® Gateway is a communication concentrator, functioning as the bridge between the control devices and the SDK. Additionally, it also handles communications with several peripheral and sub-system protocols, bringing them to the iDom® Framework in a transparent way.

The iDom® Project provides drivers for many known devices. Nevertheless, new drivers can be easily created for new devices, at anytime, using driver builder. Once those drivers are applied, virtual devices are created and became available to the upper layer, for any custom application.

The iDom® SDK is the piece of the iDom® Framework that delivers the equalized objects to high level applications. iDom® SDK empowers applications to the physical world. iDom's SDK manages socket connections and communication frames, freeing the software engineer from this tasks. The iDom® SDK is available for all major platforms including Windows, Linux, Apple iOS and Android with a multitude of applications, such as OS Applications, Web Applications, Web services, SQL Databases connection and others.

3 A case study: Rulergy® - Solution for Energy Efficiency

Global energy consumption is growing at high pace.[2] The energy consumption of homes and buildings accounts for a great part of this energy and is expected to grow by 45% between until 2025. This creates a challenge for sustainable energy consumption and for the creation of tools that help reducing energy consumption of homes and buildings. Home and Building Automation Systems (BAS) provides a possible solution as an energy efficiency indicator, which shows consumption patterns and consumer behaviours, and allows consumers to take consumption choices in order to achieve energy efficiency. At DOMATICA, we used our iDom® Framework to create Rulergy®, a powerful and cost-effective tool to achieve energy efficiency and sustainability. This case study is now presented.

The Rulergy is an innovative Energy Management System for energy efficiency that was built using the iDom® Framework. It is a Plug&Play solution with data access in iDom® Live web platform that enables to monitor energy consumption in real-time, to know in detail energy usage, to control circuits and devices in real-time, to establish rules for automated control of devices, to create custom made performance alerts and reports. This is all accessible at anytime anywhere.

The Rulergy® system can be used in the context of many sectors including corporate, industrial and residential allowing immediate and significant energy savings. The main features of Rulergy® are the following:

- Energy consumption measurement
- Evaluation and control rules
- Monitoring the fulfilment of objectives
- Control devices and circuits
- Energy Quality
- Create consumption historical registers and reports
- System Condition and event notifications
- Easy to install (Plug & Play)
- Total mobility

3.1 Rulergy® based in iDom® Framework

The Rulergy solution is based in the iDom® Framework. Rulergy has its online access in iDom® Live platform that was built using the iDom® SDK, it structures the virtual devices into units and/or actions delivering this information to a higher level. Receive triggers from sensors such as buttons, energy meters and motion detectors, among others.

3.2 Rulergy® installation process

The Rulergy is a Plug&Play solution. The installation is performed at the electrical board level. For each circuit to be measured, a clamp must be added while each circuit to be controlled, a relay must be added. The Rulergy gateway connects data from circuit devices and also from Power Quality module. This data is deployed into the Rulergy web platform in real-time.

3.3 Constant Monitoring

On the web interface it is possible to access the different devices that are integrated into the system. The system display circuits and each individual device is organized by type, zone and/or group and is directly managed by the user. With the web interface, it is possible to have real-time information about the instant and the accumulated energy consumption of the selected device. Rulergy enables real-time reading and monitoring of energy usage, cost analysis, power quality, trends and the carbon footprint of the buildings. Rulergy monitors and logs values including voltage (single or 3 phases), current, watts, effective power, reactive power, apparent power, harmonics and power factor. Monitoring and controlling these elements is the cornerstone for sustainable energy consumption.

3.4 Devices Control

Each device has a dedicated control panel where it possible to monitor consumption readings while also controlling its state condition. Device control happens in two circumstances, by direct instruction (On /Off) from the user or by system automation.

3.5 Reports

Rulergy enables to monitor and to reduce consumptions and energy costs in the multi-functional reports. The used is able to choose the information at any given time, hourly, daily, weakly, monthly, yearly or on a specific date and to create activity reports for each device individually or by combination of various circuits and criteria and to export capability of the data analytics. These creates layers of monitoring and controlling that enables easy reduction of energy waste and therefore costs.

3.6 Rules

With the Rulergy one can establish the Rules and the system will monitor itself. It will be able to make the energy systems react to specific events, or even schedule the events:

- Time-based: Set a date and periodicity and automate the control of the devices.
- Event-based: Establish rules for the evaluation of events that translate into actions of notification or instructions for your devices.

4 Conclusions

There is a great demand for systems that enable the easy and systematic monitoring and control of physical devices. The iDom® Framework virtualises the physical world in a practical and unique manner. This framework can virtually be used with any physical devices in areas such as industry automation, process and energy efficiency or health management. We demonstrated the power of this framework by creating a tool for energy efficiency, Rulergy®, to face the world´s challenge of an immediate and sustainable reduction in energy consumption of homes and buildings.

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Towards a Taxonomy of Energy-Efficient Control Techniques

João Sequeira and Paulo Carreira

INESC-ID and Instituto Superior Técnico, Avenida Prof. Cavaco Silva, Tagus Park, 2780-990 Porto Salvo, Portugal
{joao.sequeira, paulo.carreira}@ist.utl.pt

Abstract. Energy usage in buildings can be reduced by coordinating devices to achieve higher energetic efficiency. Even conceptually simple techniques such as daylighting, occupancy based control or scheduling are known to achieve reductions on energy costs in the order of 20-30%. In fact, multiple techniques have been proposed over the years and, to date, there is no reference text giving them a systematic treatment. In this article we reviewing and categorizing existing techniques applicable the problem of energy-efficient control into an appropriate taxonomy.

1 Introduction

Efficient energy usage in buildings is determined primarily by the building's envelope, by behavioural patterns of occupants and increasingly by the available technology to coordinate devices to reduce energy consumption, while delivering the same level of service.

Building Automation Systems (BAS) increasingly feature digital networks of electronic devices, equipment and appliances that communicate with each other to achieve greater occupant comfort while operating more efficiently. A building controlled by a BAS is commonly referred as a Smart Building (SB). SB are becoming popular and associated with the idea of leveraging the BAS to reduce energy consumption, e.g., by intelligently switching loads based on occupancy information.

Energy usage in buildings can be understood in terms of *energy consumption reduction* and *energy conservation*. The first aspect has to do with a rational use of appliances avoiding turning them on or turning them on partially or even with lower level of service, reducing the quality service. The second aspect refers to the efforts made for reducing energy consumption in buildings and environmental pollution [10]. It can be achieved through efficient energy use (when energy use is decreased while achieving a similar outcome), or by reduced consumption of energy services. Through appropriate control strategies, devices and equipment can be coordinated to help both energy consumption reduction and energy conservation. These are called *energy-efficient control techniques*.

This paper reviews and analyzes the existing energy-efficient control techniques into a taxonomy. This work is of utmost importance to develop models supporting the selection of alternative control techniques automatically. We foresee such models will be required to develop a new breath of tools to assist facility managers in appropriately commissioning their BASs with toward energy-efficient control.

Our text is organized as follows. In the next section the fundamentals concepts of automated control are presented. Then, in sections 3 to 7 we overview the different control techniques, their variants and how they influence energy usage and conservation. Finally, section 8 presents the taxonomy and section 9 concludes.

2 Concepts

A useful abstraction when analysing energy usage is to consider that a facility, a SB for the case, offers services that support activities that take place therein. Illumination, air renovation and temperature can be considered as services. Services are implemented by equipment in given spaces, or parts of the space called zones. Controlling in which part of the space a service is offered is called zoning. Equipments can also operate during designated periods of time to meet a certain level of service. The level of service offered by equipment can be operated among other aspects by varying its output intensity. Greater level of service usually means greater energy consumption. Therefore, it can be said that equipments can be controlled according to the dimensions of *space*, *time* and *intensity*.

Conceptually, the most energy-efficient control system is one that delivers the required level of service for the task in hand in the area (space) where the activity is taking place and for the duration (time) of the activity. In practice, however, and due to limitations of the equipment installation or the built environments, it is only feasible to offer the level of service required for a given activity on a larger zone, for longer period, and at excess level of service, therefore leading to energy waste.

To achieve energy efficiency many techniques or standard behaviours can be applied, those are called energy-efficient control techniques. Combining this techniques, office buildings can achieve huge reductions on energy wastes. Some energy-efficient control techniques offer better gains than others, depending on the buildings location or based on human presence rates inside the building. Some of those techniques will be described further ahead.

Ideally, a very efficient system should have a fine grain of control. The finer the grain of control, the more efficient the system can be. This efficiency is only realized if the system is perfectly adjusted to deliver the required level of service, at the location and for the duration of each activity. Performing these adjustments has a cost which is not negligible. The only way out is for such control to be automated.

Consider a meeting room where a manager stays behind to follow up on a meeting. Let us assume that an energy-efficient task lighting scenario is activated, where only the luminary over the zone of the space where the manager is sitting is at full intensity while the rest are dimmed down. Consider, furthermore, that all luminaries go fully off as soon as the manager leaves This scenario depicts a very adequate control of the illumination service in terms of space, time and output.

3 Individualized control

The finer the grain of the control of the equipment in terms of space, time and output, the more efficient a system can be in delivering the service required by the activities that take place. The fundamental dimensions of equipment control, zoning, flow control and duration have important implications in energy efficiency.

3.1 Zoning

Zoning mainly consists of circumscribing the actuation of equipment or offer services within a space where it is most needed. For example instead of illuminating a whole room to perform a certain a task, which is undertaken in a small area within a room, only the area where the activity is taking place needs to be lit. Surrounding areas could be lit with a lower level of illumination, providing for user comfort still achieving energy consumption.

We distinguish three granularity levels for Zoning which are “All”, “Groups” and “Individualized”, being the last one where the granularity is finer. On the ”All” level one control command applies to all equipments and there are no divisions. For example, consider that light intensity is available but that it applies simultaneously to all units in the space. The energy waste can still be high if, for example, certain zones in the space could be at full off. On the Groups level, devices are grouped into that sets that may accept different commands. For example, they can be switched independently therefore decreasing energy consumption. The Individualised level is where the energy consumption is lower, due to the higher granularity.

3.2 Flow control

Flow control is a control technique that refers to the capability of controlling the amount of output flow on a device. The fundamental principle of flow control is that greater output requires more energy. Therefore, the amount of output should be minimized by adjusting it to the requirements of the tasks being performed in a certain space. For example, different level of service levels can be used in offices and in passageways.

Depending on the type of device, we distinguish three common types of flow control: binary discrete, multilevel discrete and continuous. The simplest type of discrete flow control, is a simple on/off control. This first level only allows two states usually meaning that either the service is being offered at full power or is not being offered at all. This is used for example to turn on/off HVAC systems, luminaries or a group of luminaries. Multilevel allows to choose from a small amount of predefined levels of intensities, for example bi-level discrete flow control, such as off-medium-full strategy which obtains energy savings by interleaving luminaries on and off. Other multilevel discrete controls allow multiple levels of service, common on luminaries and thermostats.

Continuous flow control is capable of delivering a continuous variation of the output of devices. Continuous flow control can be more efficient than discrete flow control. This type of control is achieved through the use of a specific electronic dimming ballast for lighting, variable motor speed drives or even damper valve controls, often applied in HVAC systems. Below, it will be detailed further.

3.3 Duration control

The capability of precisely controlling the time window along which a certain service can be delivered also results in energy savings. Once the activity is over the service can be switched off. Two basic types of limitations exist to implement such precise control. The first one is that the control system does not know when the activities requiring a certain service are taking place and the second one is that control may actually be limited. Certain types of equipment display hysteresis delays, and require a certain safety interval to be observed before being switched back.

4 Activity-based control

Activity based control tries to optimize the control towards the activities that are taking place in the space. Activities are performed for given periods of time, require certain levels of service to be available. Since no system is actually capable of knowing exactly the characteristics of the activity, the control is often based on time and space occupancy prediction.

4.1 Schedule-based control

Scheduling is understood as appointing commands to be executed by devices or group of devices at defined points in time, achieving a certain degree of independent action. Scheduling is frequently to turn on or off lights on determined schedules to meet the requirements of the activities that take place during those same periods of time.

However, scheduling is not limited to commanding devices at certain hours on given dates. Schedules can be also activated or interrupted upon the occurrence of an event or condition. Moreover, a schedule start time can be specified as an offset to the event or condition. For example, consider changing the morning switch-off time scheduling based on the season of the year. Another application would be turning off the lights when people leave rooms. A floating schedule can be used to solve to implement auto power on/off to solve this problem.

4.2 Occupancy-based control

Occupancy control sensors are commonly used in indoor spaces using infra-red or ultrasonic sensors to detect motion. When no motion is detected in a certain space, it is assumed that the space is empty, and thus does not need to be lit. There are two major types of actuation based on occupation detection: movement detection switching and movement detection dimming. In motion detect switching the occupancy sensor switch on/off devices (usually luminaries) according to the motion detected in a room, in motion detect dimming the sensor dims the light to a defined level in the absence of motion. Both types of actuation based on occupancy control to turn on/off or to dim the lights can result in saving substantial amounts of energy [9].

5 Environmental harvesting

Environmental Harvesting aims at taking advantage of external environment conditions to save energy. In literature it is possible to see that there are three major techniques, one applied to lighting systems and two applied to HVAC systems. Daylight harvesting is applied to lighting systems and makes profit of solar light to dim or even to switch off lighting during the day time. Heat gain is applied to HVAC systems and uses solar heat to reduce the use of energy on HVAC systems. Free cooling is used with HVAC systems but in this case it uses the outside cold air to reduce the use of HVAC systems during the night or during the early hours of the morning.

5.1 Daylighting

Daylight is a non-uniform and dynamic form of illumination which, varies in intensity, both spatially and temporally. Therefore, day lighting systems in order to properly work, should be capable of dimming small sectors of interior spaces independently. Using daylighting its possible to reduce in some cases 40% of energy consumption in a commercial building [7]. To achieve daylighting some basic principles have to be fulfilled. Buildings orientation should be such that most of it is within the daylight zone, or even bring the light ballast higher, so it can cover more area. Applying this technique in a proper way gives the occupant the comfort and satisfaction it needs to work, and due to that his work will improve [7].

Using daylight harvesting with the proper orientation and symmetry of a building it is possible to provide over 70% of the required ambient illumination in a building during a year. If an electric lighting control system responds properly to daylight harvesting, the electric consumption will be significantly reduced [11]. The main limitations of daylighting is that photo-sensors are not precise enough—their performance depends mostly on their placement [3].

Another important aspect of daylighting is the interaction with blind controls. Automated blind controls will help control light intensity in the room.

With more natural light the system will turn off or dim the luminaries, causing a reduction of energy consumption. To prevent excessive glare, the system can also automatically close the blinds to avoid glare. An installation of a dimming system with automatic blind control proved to be very efficient, creating a 27% reduction in lighting energy use [4].

5.2 Heat gain

Heat gain is the increase of temperature in a certain space from solar radiation. As the daylighting technique, it also consists of controlling blinds or curtains in order to maximize the environmental temperature in a building, also temperature measurements are needed in order to understand the need of closing or opening the blinds. The amount of heat gain varies depending on the sun strength and the exposure of the window, it also depends on the material of which the building is made of [6]. The position and orientation of a building is crucial to maximize the buildings heat gain. Heat gain technique can also use heat dissipation from other devices, such as from lighting systems to increase the environmental temperature.

5.3 Free cooling

One way to reduce HVAC energy consumption consists of circulating cold fresh air during the night that will cool the building avoiding the need of using HVAC systems during the day. Another advantage if free cooling is that it is done in off-peak hour benefiting from lower electricity tariffs.

6 Intelligent Load Control

Buildings control load and Load management is the process of balancing energy supply and consumption on a network or building by controlling the energetic loads. There are two main ways of doing this, know as Load shedding and Load shifting.

6.1 Load shedding

Load shedding is a deliberate switching off of electrical supply to some parts of an electricity network. So basically, the available electrical power is rationalized, by limiting the energy use or even cutting the energy supply on certain zones. Sometimes there is a need to reduce energy demand very quickly to an acceptable level, if not there might be a risk of turning the entire electricity network unstable or even a completely shut down may occur.

During the hot season, buildings normally have all their HVAC systems working during the day which represents a huge energy consumption that can even exceed, in some cases, the contracted energy power for the building, representing an extra cost. Load Shedding can also be implemented to reduce energy consumption in buildings in different ways. First, building areas may be limited during the peak hours to a certain level of energy consumption which they cannot be exceed even if consumers try to. Load shedding can be implemented by turning off non-critical loads when a facility is being charged to a maximum for power, in order to avoid exceeding the maximum contracted power supply.

Load shedding technique can also be implemented by performing the dimming of lights in the building to reduce the energy consumption avoiding exceeding the contracted energy power.

6.2 Load shifting

Load shifting is a way to manage energy loads, by advancing or delaying consumption into periods of lower energy prices. The limitation is that in some cases the consumer may actually need to perform the task at an appoint time. In this way the consumer still accomplish the task while being at a lower energy price when doing it [5].

7 Occupant buy-in

User buy-in control techniques are techniques that take advantage based on occupant characteristics in order to achieve an energy consumption reduction.

7.1 Adaptive compensation

Adaptive Compensation is a control technique that takes advantage of the human adaptation to the surrounding environment to save energy. For example, to take advantage of the fact that people need and prefer less light at night than they do during the day [2]. Therefore, lighting can be slightly dimmed at night due to the fact that it is dark outside. Similarly in winter when people wear warmer clothing and the air condition is not required to be so hot. It has been found as well that users may tolerate a progressive regression of set points during a period of time, for example the lowering of luminaries intensity to 70% over the course of 20 minutes.

A study performed in an office laboratory where participants had personal dimming control over lighting, and were then exposed to a simulated load shed involving dimming lighting by 2% per minute refers that only 20% of the participants intervened in the lighting control when the luminance level declined 35%, this shows that load shedding might be a valid option for energy costs reduction, since users might tolerate a considerable light dimming [8].

7.2 Set-point relaxation

Set point relaxation is a term that describes the technique of increasing or decreasing a determined set point to save energy. For example if a HVAC system is adjusted to 22 degrees the set point ”relaxation” can be between 21 and 23 which varies according to the season, in the winter the set point can be adjusted to 21 degrees and in the summer it can be adjusted to 23. This ”relaxation” will be hardly perceivable by the user if done gradually and if the variation between set-points does not exceed more than 2 or 3 degrees. This minor change in the set-point when applied to an entire building can help reducing energy consumption while keeping users comfort [5]. This technique can also be applied to lighting systems: if a user sets the lights intensity level to 80%, the relaxation can be 10% establishing the intensity level at 70% without any noticeable difference.

7.3 Set-point constraining

Maximum level of service set-point constraining basically limits users from setting a level of service above a predefined maximum. Suppose, for example that during the daylight it can pre-defined that no lamp in the corridors can be set to more that 80% and if the user tries to exceed that limit the system will gradually reduces the level of service to the specified level. In some situations, this technique may have a marginal impact in users comfort, which in face of the energy savings obtained can be tolerable.

7.4 Demand Limiting

Demand Limiting consists of reducing power loads during periods where power prices are at a premium cost. Demand limiting is different from load shedding because it reduces the current amount of power versus turning equipment off used on load shedding. For example, demand limiting would be dimming lights for a certain period of time where prices are high or decreasing cooling set points in non-critical areas during peak demand periods. Demand limiting will reduce energy bills as load shedding does but at the same time it will keep consumers comfort level higher [5].

7.5 Ubiquitous control

A more adequate interface allows the occupant to achieve a better control over the surrounding environment. Creating more frequent and more precise adjusted conditions for the task being performed. Consider the case of an occupant that does not leave the seat to turn off a lamp that is no longer needed. Therefore, the ubiquitiousness of control also leads to energy savings.

When energy-efficient control techniques are applied in buildings peoples comfort may be compromised and eventually consumers will stop using energy-efficient control techniques in favour to their personal comfort. Often people use more light intensity than what they actually need. The occupant is less likely to over illuminate if enabled to personalize their own ambiance, selecting their ideal light level for working. It has been demonstrated by a number of studies that personal dimming also results in higher productivity [1].

8 Discussion

A taxonomy of energy-efficient control techniques implemented by SB is presented in Figure 1. The taxonomy is organized into a tree hierarchy. The topmost nodes aggregate energy-efficient techniques based on their main characteristics. Individualized control refers to techniques that are capable of circumscribing control with varying granularity. The Automatic control node has two sub-nodes, the activity based sub-node where energy-efficient control techniques base their actuation on space occupation and Environmental Harvesting that tries to use the environmental condition to achieve energy consumption reductions. Load Control techniques try to manage energy loads in order to achieve energy cost reductions. Finally, User Buy-in gathers techniques that take advantage based on occupant characteristics in order to achieve an energy consumption reduction.

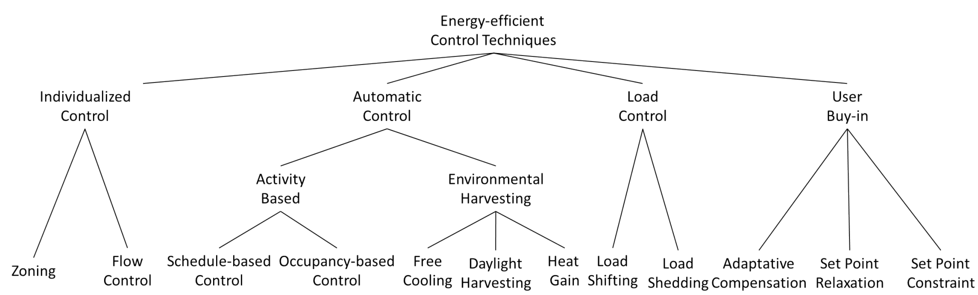

Fig. 1. Taxonomy of energy-efficient control techniques

9 Conclusions and future work

Although a plethora of techniques have been proposed over the years which, if combined, could result in a relevant energy savings, to the best of our knowledge existing systems apply these techniques in isolation. Herein we review and categorize existing control techniques aiming at an abstract model upon which new control can be based.

From literature review we organize the main energy-efficient control techniques into the appropriate taxonomy based on their techniques based on their main characteristics. While doing the literature survey we also identified the expected gains for all the main control techniques.

As future work we intend to model energy-efficient control operations. We believe that such model will be useful as *(i)* an abstraction enabling to separate techniques from specific implementations and *(ii)* understand how to compose the different operations. Another possibility is for different techniques to be modeled according to their energy requirements and the quality of service they deliver. Therefore, the modeling that we envision could also be used to select the most appropriate technique under certain energy constraints. This can be used to implement automated demand-response.

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Context-Based Reasoning in Smart Buildings

Pedro Fazenda[1], Paulo Carreira[2], and Pedro Lima[1]

[1] Institute for Systems and Robotics, IST, Portugal
[2] The Data Management and Information Retrieval group, INESC-ID, Portugal

Abstract. Smart buildings integrate various systems to effectively manage resources in a coordinated manner in order to maximize technical performance, operating cost savings and tenant comfort. These buildings are expected to extend beyond simple automation to include advanced user interfaces, and automatic building management capable of interacting in real-time. It is not yet clear, however, how to design and implement applications with the entire building structure, services and processes. We discuss the importance of considering *context* in the operation of smart buildings, and present context-based reasoning as a modeling paradigm to create a general purpose applications.

1 Introduction

Indicators show that there is a high cost-effective potential for energy savings in buildings [1], responsible for approximately 40% of the global energy usage [2]. Smart Buildings (SB) have been waved as a solution to increase energy efficiency in buildings. In contrast to the definition of Artificial Intelligence [3], in buildings the term "smart", synonymous with "intelligent", has a functional definition: "intelligent" is typically associated with the integration and automation of systems and functions which operate in ways that provide a responsive, effective and supportive environment, within which organizations can meet their performance objectives [4].

SBs are supported by a number of technologies, included in the automated building management system (BMS), that aim at the well being of occupants, promoting a comfortable environment while ensuring an efficient use of building resources.

The ideas described for SBs fall into a wider concept defined as Ambient Intelligence (AmI) [5], a term widely used to signify a vision in which environments support the people who inhabit them by incorporating data acquisition, computation, intelligence and behavior to everyday objects in an interconnected and unobtrusive way. One important part of AmI is that environments should be capable of anticipating the needs of its inhabitants and respond in a timely and user-friendly way. Advances in technology are opening doors for entire new concepts and applications and, in the limit, buildings may even be able to recognize and respond to user emotion.

1.1 Building systems

The deployment of AmI in buildings has been hindered, not only by the lack of a well defined and globally accepted standard to interconnect building systems, but also by the absence of a common platform that organizes all these different systems with associated knowledge, control strategies, services, variables, models, *etc.* A SB is a very complex system [6]. It can have multiple spaces, tenants, human-machine interfaces, distributed systems, sensors, and a set of observed variables with a significant size that require controlling and monitoring (*e.g.* temperature and humidity in each room). Many variables and models are correlated (*e.g.* the thermal behavior of adjacent spaces) and may depend on context (*e.g.* the temperature variation inside a room depends on a context defined by a set of variables like door/window open/closed). To make things harder, we have to consider that new components can be added at any time (*e.g.* a new energy meter or meteorological station).

Most software architectures for SBs are programmed in a modular way. This modularity deals with the complexity of the BMS's domain by dividing its operation into a number of interdependent services that are able to control building systems and functions such as: lighting, HVAC, access control, room-operations, floor-operations, *etc.* These modules, responsible for each control logic, are largely deployed in isolation and do not take into account a great deal of contextual information that could be useful for their operation. For example, an elevator group scheduler could balance between energy efficiency and quality of service (associated with the expected waiting times), depending *e.g.*, on a holiday or a normal working day.

In this paper we discusses another type of modularity: the operation of each service depends on a set of active *contexts*. These contexts organize knowledge and the necessary reasoning mechanisms to act on the buildings in order to accomplish greater energy savings than the ones we would accomplish with simple automation rules.

1.2 Context-awareness

The awareness of context about the environment, discussion, or problem in hand, allows many important aspects of human interaction to remain implicit. Contexts act like adjustable filters creating a knowledge frame that enables the correct semantics to be assigned to terms therefore enabling a minimal amount of information exchange towards effective communication. This means defining, at each step, which knowledge pieces must be taken into account explicitly (contextualized knowledge) and which pieces are not directly necessary or already shared (contextual knowledge). Human communication uses linguistic expressions that are rather highly contextualized and many misunderstandings, in human discourse, take place when communicants are not in a common context. A context inherently contains much knowledge about a situation and environment of a problem. For example, an area in a supermarket, where temperature values are abnormally different from the rest of the building, correspond, with high probability, to the cold section. In another type of service building, a similar situation may correspond to a datacenter.

In the next section we present some of the related work on applications for SBs. In section 3 we discuss the organization of knowledge and strategies and in section 4, how context-based reasoning (CxBR) can be used to organize such knowledge. Section 5 clarifies the concept of context and how it can be applied in different building services. Section 6 concludes.

2 Related Work

Creating applications for SBs is a current topic of research. Most approaches have used decentralized control solutions based on multi-agent systems (MAS) see, *e.g.* [7, 8, 9, 10, 11]. Their solutions consist of using collections of software agents that monitor and control different parts, as well as different aspects of the environmental conditions of the building. They operate and manage particular entities in the building, *e.g.*, offices, meeting rooms, corridors or electrical devices. Tianfield [12] presents a study on the MAS approach to large complex systems. Agent systems have been widely accepted as an effective coarse-granularity metaphors for perception, modeling and decision-making, particularly in systems where humans are integrated mostly because system modeling becomes greatly alleviated. Developing the infrastructure of a MAS includes developing an agent platform, the agents, and agent communication language, the agent-task association and the social communication. With and agreement on language and communication, agents can be reused, taking their behavior and functionality to other MAS. In this work we want include context-based reasoning [13, 14, 15] in a multi-agent architecture for SBs. The idea can also be extended to multi-service architectures, where different services, each with their own execution-context, manage particular parts of a BMS much like a MAS architecture. The term emergent is frequently used to describe behaviors that arise from the interaction of subsystems and are not evident from the analysis of each subsystem. We believe that a notion of context can bring a new organization to these systems that can help avoid some of the most common problems like avoiding and detecting emergent behaviors. Consider the following example: an agent, programmed to optimize the use of natural lighting in a room, will open the window blinds and turn of the lights. This action may inadvertently increase the temperature inside the space due to solar gains. The agent that manages the HVAC will notice this increase and will try to cool down the room, thus spending more energy. Without a link between lighting, energy and temperature, two agents designed to save energy by managing each of their isolated domains, may end up spending even more energy, when working together in the MAS. With strategies organized according to context, a user may easily detect the increase in energy spending in the situation where the blinds are open, because this may be explicitly verified within that context.

Even though a lot of research has been conducted within context-aware systems, the core term context is not yet a well defined concept [16]. In a general idea, context is a structure or a frame of reference. It permits to define which knowledge should be considered, what are the conditions of activation and limits of validity and when to use it at a given time. It is what constrains a problem solving without intervening in it explicitly. Brezillon et al. [13] state the lack of consensus on this work and present some of the definitions that are given in the literature. In section 5 we explain and redefine the definition of context given by Gonzalez et al. [17], and extended it to multi-agent/multi-service systems [3].

3 Knowledge and strategies in Buildings

The organization of knowledge (*e.g.* how energy is used in a certain room), and planning strategies based on that knowledge (that fulfil some expectations like *e.g.*, saving energy) is not an easy task. It should be accomplished in a modular way and should be available where it is needed *i.e.*, global knowledge (type of building, season o the year, *etc*), and knowledge associated with events in a certain area (*e.g.* the schedule of a tenant), should be available for decision making in that area. In this organization we have to consider:

- **Pre-acquired knowledge**. Of a static nature associated with a building and its operation that needs to be known before deploying a BMS. This includes knowledge about:
  - architectural aspects like the buildings' location and a plan of its structure including doors, rooms, materials, glazing, furniture, electrical layout, pipes, *etc*;
  - building systems (with information on service providers) such as elevators, HVAC (including subsystems, ducts and vents), power storage and generation, sensors and actuators, *etc*;
  - the building's function (supermarket, pool, school, *etc*) and associated information like schedules (*e.g.* holidays, working days), description of spaces (amphitheater, classroom, kitchen, *etc*), and other information like: a company or a department occupies a specific part of the building;
  - occupant's activities, and the association of these activities with specific spaces inside the building (sleeping, working, eating, entertaining, *etc*);
  - electric and gas utility rates.
- **Acquired knowledge**. Accomplished through a process of gathering information from the environment to improve the efficiency of a system in achieving certain goals. This includes creating models that can be used to predict and anticipate the behaviour of tenants and explain variables like indoor temperature, power, lighting, humidity, thermal-behavior of spaces, *etc*. There are many types of algorithms and techniques that can be used for this purpose. The learning process is performed throughout the operation

[3] Throughout this paper we will use the term multi-service.

of the building, with the models being continuously adapted and fitted to the observations. A well-defined organization of knowledge must take into consideration the context (*e.g.* holidays, working-days, winter, summer) that help explain these variables (*e.g.* the total amount of energy used over those periods).

- **Operation strategies** (including optimization). Technical difficulties in creating SBs also include the fact that the set of all possible behaviors, given all possible inputs, is significantly large. It can also be from dealing with several different types of data (discrete/real valued, complex-structured, states, transitions, *etc*) and multiple goals (*e.g.* energy efficiency and comfort) depending on context (working hours, holidays, emergency, *etc*). Operation strategies can also be partitioned into a hierarchy of levels and contexts. For example, at the highest operation level of a BMS, a building manager can be informed that energy is being lost because the building is not sufficiently air-tight (with detailed information); or some operational parameters of a chiller can be adjusted. At a lower (or local) level, a window can be closed because the HVAC is *on*. Some local decisions may depend on higher level strategies: *e.g.* a smart thermostat in a room will not turn the cooling/heating *on*/*off*, if the HVAC system is powered down, after a certain hour, in certain weather conditions.

To avoid ending up with a data rich but information limited environment, conceptual modeling of information must be part of the engineering process, to describe the general knowledge of each domain (HVAC, elevator, room, company located on the 5th floor, *etc*). Conceptual models serve to organize information in a way that can also help e.g., system operators understand the full context of some type of event that is occurring in some part of a network or process. This organization is necessary to support the ability to provide the right information at the right moment to the right decision maker. For example, if something is wrong with the HVAC system, then a message can be sent to an entity responsible for managing this system with detailed information. High-level contextualized information services are often needed along with supportive sensor data or trends to provide context e.g., a malfunction X in the HVAC happened due to a situation Y, as shown by some sensor values Z. The goal is also to facilitate data mining, information publishing, and the application of automatic learning and decision support tools to facilitate system management. For example, a room management service can learn that energy is being wasted when a window opened, while the HVAC is *on*. If such a situation happens frequently, the service may point out that fact by emailing the tenant with detailed information about how much energy is being wasted. At the building level, a building manager can be informed on how much energy is lost in the entire building due to to opened windows, including the corresponding economical costs.

4 Context-Based in Smart Buildings

The concept of context can provide a model to partition the operation of a complex system into "scenarios", where knowledge, strategies, parameters and objectives, are organized. To clarify the concept, lets consider the use of context in the following applications:

- **Problem diagnosis**. In problem diagnosis, context can be used, for example, to reduce the search-space when trying to detect the source of an identified problem. Gonzalez et al. [17] give the following example: a dead battery in a car that has been parked overnight has entirely different diagnostic implications than one that discharges while the car is in operation. This idea can be generalized to buildings. If a certain condition is being verified like *e.g.*, an unusual amount of energy is being used in a certain area, understanding the context in which this condition happens can be fundamental to identify the problem and take corrective measures.
- **Comparing performance**. Taking context into consideration can be very important when comparing entities according to certain performance metrics. In buildings, for instance, when comparing and analyzing the performance in terms of energy use between two different schools, a lot can be gained if context is taken into consideration. Facts like: level of education (primary/secondary school, university), type of school (*e.g.*, economics, dance, military), division of an academic year, *etc*, are important to extract more reliable conclusions.
- **Organizing knowledge**. Previous known expert knowledge about the operation of a particular building can be encoded in a context-based model. Context can be used to explain observed variables and organize models that predict the behavior of those variables. For example in a school, the energy used may depend on the division of the academic year (Christmas break, vacations, exams, holidays, exams, instructional days, *etc*); on the season, location, and other facts that can be previously known. Creating models within each specific context (from, *e.g.*, a time series obtained form an energy meter) can gain a lot from these divisions by minimizing the need of explanatory variables. This is a natural way of including previous known knowledge in the process of modeling variables from the observed environment, creating more reliable models. Following an hierarchy of contexts (*e.g.* building-operation, floor-operation, room-operation), information can also be organized according to locality and resolution (energy used by the entire building, floor or room).
- **Organizing strategies and behaviors**. Multi-context systems support the development of modular architectures. Following some of the arguments used for organizing knowledge, strategies and behaviors can also be organized according to context. Contextual information can help an agent focus attention on appropriate goals to achieve in certain situations. For example, at night a building strategy can be storing thermal energy and shifting energy demand to off-peak time periods, when utility rates are lower; in a

normal working hour, a room-behavior can be regulating natural light with shading devices; in the advent of an emergency situation like, *e.g.*, a fire, the building will assume a totally different set of behaviors and objectives.

- **Sensing and Perception**. To understand how context is important for this item, consider the example on how humans focus their attention. A magician or a pickpocket can take a wallet/watch away from the person's pocket/hand by manipulating this focus and attention. By showing something interesting with one hand, or by pushing the person, they can avoid being detected by distracting the person's attention away from the item that they want to obtain. People sense the environment depending on the surrounding context - giving more attention to certain details and relaxing on others. In buildings, we can imagine a situation like, for example, a fire, where all the focus of sensing is towards satisfying objectives within that context (*e.g.* check if there are locked spaces with people inside and notify the fireman of this situation).
- **Human-machine interfaces**. When considering, for example, the ability to recognize human emotions. This user-centric contextualized information can be used for decision support: *e.g.*, if at a certain moment the user is angry and stressed, then he is probably not very receptive to any notifications about efficiency performance inside the building. The concept is called Affective computing and it concerns enabling systems recognize human emotion and act accordingly. Emotionally intelligent buildings may have a clear advantage when it comes to human-computer interaction.

5 Context-based Reasoning

Part of the architectural design of a building service (*e.g.*, a service that manages the operation of a room by controlling the HVAC and lighting) is designing the CxBR model, *i.e.*, identifying the context set(s), transition rules, dependencies and relations between contexts. The classical frame problem [18] is closely related to this issue. The design process has to include the experience of human experts to model the necessary knowledge associated with the operation of particular types of buildings, equipments, systems, *etc.* Context-encapsulated knowledge appears as a chunk of reasoning that can be re-used in several designs and implementations. A context is a 3-tuple (Ak, Tk, Dk) composed of the following elements:

- Ak **- Action knowledge**. Required for the agent to carry out the behavior encapsulated within the context. It represents the agent's functional intelligence within its given environment for a specific situation. This knowledge can be previously coded with logic rules, or learned using reinforcement learning, neural networks, evolutionary algorithms, *etc.*
- Tk **- Transitional knowledge**. That indicates when a transition to another context is warranted. It can be expressed as IF(**conditions**) then(**activation**) transition rules or any other type of triggering mechanism using, *e.g.*, neural networks.

– *Dk* **- Declarative knowledge**: Describing some aspects of the context. For buildings, this can be used, *e.g.*, to include some of the pre-acquired knowledge, suited for the context.

5.1 Context Hierarchy

A CxBR model can include a context hierarchy as shown in Figure 1. The model can be used to partition knowledge into sub-levels, making it available in the context where it "makes sense". A multi-level hierarchy represents a *vertical* relationship between groups in a set $G = \{g_1, \ldots, g_n\}$. A group $g_i \in G$ contains a set of mutually exclusive contexts $C_i = \{c_0^i, \ldots, c_n^i\}$ and, an active context c_a^i in g_i, is active within the context of its parents *i.e.* it will inherit active, transitional and declarative knowledge from selected contexts in groups that are hierarchically above g_i. c_a^i can redefine or specialize behaviors and/or contain the functionality required to perform specific sub-tasks.

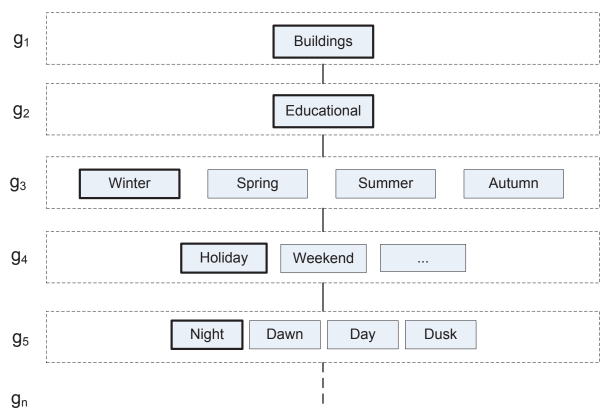

Figure 1: Part of a context hierarchy for an educational building. Highlights show an example of the active contexts at a certain time instance.

5.2 Operational Semantics

Exercising the CxBR model is the process of activating the set of contexts that best suits the situation in hand. This activation allows the active contexts to take over and control the execution a process, defining behaviors, constraints, and other context-dependent characteristics. The process must survey the environment as well as its internal state (including transition knowledge) to determine the conditions where the current context is deactivated and a new context is activated. In Figure 1, if context "Night" is activated then, following an hypothetical scenario, contexts "Holiday", "Winter", "Educational" and "Building" are also activated *i.e.*, the entire path up to the root of the hierarchy tree. A context can override behaviors, add behaviors, redefine attribute values and add knowledge to what it inherits from its parent contexts. Activating the correct context within some processes can be a hard problem. A process that manages the operation of an office room, *e.g.*, may be directly associated with an observable or partially observable state composed by the set of variables that are important for the operation of that room: (door/window opened/closed, temperature, humidity, ocuppied/empty, *etc*). The temperature inside the room behaves differently if a door/window is opend/closed or if the room is empty or occupied. In such a situation, context can be defined *e.g.*, by a set of explanatory variables that can somehow be used to explain or to predict changes in the values of other variables of the state.

G exists within the domain of a service s. At certain instance t, there is a set $C^t_{active} = (c^1_a, \ldots, c^n_a)$ that contains all the active contexts that exist in G. This set is continuously updated, as the following example shows:

$$C^t_{active} = \{Buildings, Educational, Spring, Holiday, Dusk\}$$
$$\downarrow$$
$$C^{t+1}_{active} = \{Buildings, Educational, Spring, WorkingDay, Night\}$$

Service s_i has its own execution thread(s) and its control is a function of C^t_{active}:

$$\texttt{Control of } s_i = \mathit{\Gamma}(C^t_{active})$$

where $\mathit{\Gamma}$ is the CxBR framework operating within s_i. Figure 2 shows a representation of the framework, including inputs and outputs.

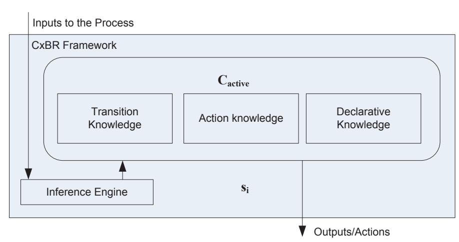

Figure 2: CxBR framework operating within a service s_i.

Distributed applications for a BMS can be composed by multi-distributed context-aware services. The interaction/inter-dependency between these services can be represented by a directed graph. The elements of the graph belong to the set of services $S = \{s_1, \ldots, s_n\}$ that operate with the BMS and the edges represent some type of context or action dependency. Figure 3 shows an example that includes services to manage a building-central (*e.g.*, one that contains the set of contexts represented in Figure 1), a floor, a department and two rooms.

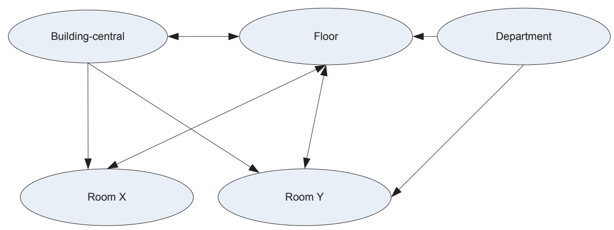

Figure 3: A service dependency graph.

Most actions assumed at the highest level (in the graph, probably the most connected vertex) affect the operation of all services: if the HVAC is turned *off*, then there can be no room-level HVAC strategies in operation within any other service. Most information and knowledge that exists within this service, can also used by several others: season of the year, building characteristics, *etc.*

Behaviors of a room-service can depend on a floor-level strategy or on other information like *e.g.*, information specific to a certain department of a company that is located at that building. For example, it may make sense to turn the HVAC *off* if a department meeting is scheduled to happen on another room. The operation of a floor-service can depend on the current context of each room on that floor. To model, *e.g.*, the thermal-behavior of all spaces, within that floor, it will need to know if windows or doors are opened/closed and the temperature/pressure difference between those spaces.

6 Conclusions and future work

We need the necessary foundations to acquire and organize knowledge and create the necessary reasoning mechanisms to act on the building and accomplish greater energy savings than the ones we could accomplish with simple automation rules. A building is a large complex system and there has been no common platform that organizes all these different systems with associated knowledge, control strategies, services, information, variables, models, *etc.*

In the last few years frameworks like the Robot Operating System [4] have been introduced to the robotics community as a common development platform for robots that provides hardware abstraction, low-level device control, implementation of commonly-used functionality message-passing between processes, *etc.* A similar platform is necessary for smart buildings. Such a software framework, for smart building software development, would enable programmers to reuse drivers and create optimization algorithms with an abstraction over the underlying hardware. We need a framework that is specific for buildings (that can use infrastructure/communication protocols like BACnet, Zigbee, *etc*) and to create such a platform, we have to know how to cope with the dimension of the system and consider the heterogeneity and complexity of a building environment.

[4] http://www.ros.org/wiki/

In this paper we discussed the importance of using a context-based architecture to support some of the aforementioned requirements that are necessary to create smart buildings. We proposed a modeling paradigm that needs to be elaborated and tested. Our vision includes working on a framework similar to the robot operating system, but for buildings. A clear strategy on how to structure such a operating system to fit a building environment and building management requirements is needed. We believe that this vision of creating a building operation system has a lot to gain with previous work on software architectures for context-aware applications.

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Home users as a Facility Managers

How is automation helping?

Cristina Caramelo Gomes[1] and Paulo Carreira[2]

[1]Department of Architecture and Arts, Lusíada University of Lisbon
[2]Department of Computer Science and Engineering, Technical University of Lisbon

Abstract. In the current economic setting companies are required to the operation of their facilities therefore making a growing use of technology supported Facilities Management and Energy Management activities. The same holds true for home owners. In fact we assist to an increasing adoption of Building Management technologies, most notably Energy Management by households. Therefore, it is expectable that other aspects of facilities management will end up being adapted to homes in the near future. In this paper we briefly discuss into what extend FM activities can be applied to homes and what is the technological support that can be found for them.

Keywords. Facilities Management, Building Automation, Dwelling Environment, Sustainability

1 Introduction

The main challenge that the built environment faces today is that of improving its effectiveness toward efficient usage of resources, among which energy comes first, while meeting crucial flexibility requirements of living environments towards contemporaneous dynamics of functionalities, occupancies and users' expectations.

The monthly budget expenditure with home facility is one of the major expenses to the traditional familiar core. The inhabitant, as the one who experiences the built environment continuously is best positioned to manage it. For organizations alike, facilities are among the major fixed costs [1], therefore prompting for professional management. In this context Facilities Management is gaining increasing acceptance worldwide as discipline and grounding upon a range of specialized tools and techniques. If this is true for the facility supporting the operation of a company, an interesting question is whether it is also significant for the facility that supports the home environment owned by the individual that inhabits it. Can the Facilities Management concept be applied to home environment to optimize the functionality of the spaces and equipment while increasing the user quality of life? Rational choices of areas to develop activities, due to the available space, light features, electric outlets to plug in different apparatus, and equipment usage are ways to optimize the usage of a facility. The human life style and the use of buildings do not remain static, users' requirements and expectations change, technology change, the way we perform daily routines change, the facility manager has to monitor and apply the corrective actions to balance human and building demands [2]. The sustainability of the built environment is based on its location, geographic orientation, conceptual planning and construction process. Overlooking these premises will stimulate uncomfortable environments and the need of correcting technology to minimize, to the extent possible, the inherent energy costs.

The contemporaneous social and economic context motivates new approaches to home environment based on users' needs and expectancies. The modern lifestyle demands comfort and the possibility of new functions within home environment considerably supported by technology.

2 FM in the Home

In order to balance individual and/or familiar budgets it is important to manage the equipment that supports human routine activities and the sense of comfort. The monitoring and management of the equipment such as appliances, computers and multimedia apparatus can be helped by technology development such as basic home automation. To promote facility management for housing demands to understand the type of occupant – tender or owner or social housing – the type of the building, flat, detached house, different sizes, locations, and access to different facilities [3]. This paper's discussion is focused on dwelling environment occupied by the owners, particularly to existing buildings which require more attention to their sustainable performance. As an owner the occupant wants to minimize costs without compromising the value of the building as a profitable asset, or its personal sense of comfort. This reality depends on owners' voluntary work, competencies and budget. However, once dwelling environments belong to buildings with different storeys, some transformations require the validation of the condominium administrative core, which by different factors can interfere in the desired and proposed initiatives.

2.1 Energy management

The parameters that contribute to the levels of energy demand in residential buildings, are related with behavioural determinants (concerning occupancy patterns, use of domestic appliances and users sense of comfort) and physical determinants (dependent on the type of building, flat, semidetached house, size, formal configuration, constructive process, etc…) [4]. The regular parameter of successful energy management is occupants' commitment. The daily routines must be planned to achieve continuous improvement. It is important to define the objectives to attain and observe behaviours to comprehend and establish the best practices [5]. This observation will help to gather data which must be detailed to permit an accurate analyses to understand objectives' accomplishment or by antithesis the need of objectives redefinition to ensure a successful solution. A system for tracking facility performance can range from a notepad, a simple spreadsheet to a detailed database and IT systems; in all the available solutions is important to define a method that is possible to continue and define the type of data to be gathered and analysed. The data can be based upon periods of time, and equipment usage.

2.2 Policy enforcement

Some considerations can be raised to improve home energy performance to a sustainable solution. Windows and doors must be insulated to minimize thermal exchanges, as well as chimneys; old appliances, lighting and HAVAC systems should be upgraded by new high-efficiency ones that are more environmental friendly, without questioning their functionality and the sense of comfort. Green electric outlets and different hours' rates can contribute to the difference. Furthermore, to increase the home's efficiency the inhabitant can decide for adding renewable energy systems such as solar electric (photovoltaic) or solar hot water, to increase the reduction of the bills and the ecological footprint.

Household routines. Home routines concern individual and familiar activities plus professional and leisure ones [6]. Home gained new activities to be performed within; if individual and familiar activities demand appliances technologies and functional environments the professional and leisure activities motivated the spreading of technology aiming for different ambiences, where lighting – which intensity, chromatic reproduction index, and distribution [7]are crucial to guaranty visual acuity [8] and functionality of the spaces – and temperature promote interiors quality of life. The dependence from technologic apparatus demands more devices such as electric outlets and electric power.

Automated control. The majority of today's home automation solutions present the same set of ranging from security control to the possibility to create different scenarios based on luminic contrast where the intensity and the CRI of the light are the major issues to manage.

The possible scenarios created based on artificial light, intensity and CRI can perform scenarios oriented to work and to relax. For example, it has been demonstrated that intensity and CRI can contribute to balance the circadian cycles, can ameliorate the visual acuity, and promote warm and relaxing interior environments or by opposite more cold and concentrative working environments. The intensity of the artificial light can be related with the intensity of the natural light and then contribute to the rationalization of the energy use and costs. These scenarios can strongly improve human quality of life. Beyond the quality of life is important to manage the energetic resources towards lower consumption and smaller ecological footprint. The automatic harvesting of natural light to minimize artificial light a way of doing it. Another use of automation is in green sockets, which are programmable schedule switches. The control of different devices like luminaires can be performed by remote control and from a central digital panel where the information can be presented in different modes such as daily control, equipment control. Ubiquity of control helps occupants to make more adjustments leading to higher comfort levels and lower energy consumption. The integration of data in the same device can be interesting to understand the functioning of the facility and enable the creation of interfaces with higher usability therefore being comprehensible by a major number of individuals. The control of equipment audio-visual can improve the different scenarios; moreover, the equipment remote itself may control other devices. A unique remote control can minimize a set of required remote control contributing to the usability of the system and the inclusion of individuals' with some technologic difficulties and people with special requirements.

Security solutions deal with the control of the main entrance as well as the windows. The quality of the equipment can present video surveillance where the quality of the image, the capacity of the buttons and the connection with security entities may contribute to the sense of security. On the safety side the prevention of flood or smoke detection with automatic cut of electric energy is another interesting feature.

In a new construction, these items can motivate the choice of the future owner. The inherent costs related with the equipment and the employment of domotics can be recovered by the energy savings and an increase in the comfort for the inhabitant. This equipment can be dissimulated within constructive process, guarantying the sense of home and comfort for the inhabitant. However current wireless technologies are becoming mature enough to install these solutions in every environment without any cables and/or constructive work, thus without compromising the existing interior layout.

2.3 Maintenance

The maintenance of the building is responsibility of the owner and/or landlord. The objective of maintenance is to avoid any kind of facility's obsolescence and promote occupants quality of life. There are different types of maintenance ranging from the reactive to the planned one. Both attitudes require knowledge and financial resources. Dwelling environment is sustained mainly by reactive maintenance, the immediate solution to emerged problems, mostly the ones related with infrastructures and constructive process diagnosis, neglecting repeatedly the ones related with the update of the facility to user's requirements and expectancies.

Equipment and plant installed within a building or dwelling environment require regular servicing and the replacement of consumables to keep them in working order. Usually, they have particular servicing and maintenance requirements, which are provided through a service contract, usually with the supplier. Planning maintenance requires the understanding of the problems and the schedule of the required actions to achieve their resolution. Planned maintenance is better as it can anticipate diagnosis and resolution, thus minimising costs. Providing maintenance is a way to ensure the functionality, the perceived image and the value of the facility. Planned maintenance can also minimise subjective decisions due to required emergency decision making. Facility performance by systematic monitoring and assessment can also be performed to some extent by current home and building automation systems. These automation solutions already are capable of counting the number of operating hours and to track the number of starts of several types of devices.

3 Discussion and open issues

Facilities management is not a common resource applied to home environment; however, each occupant aims to ensure its best performance, being unconsciously a facility manager.

A sustainable solution has economic and social responsibility; the rationalization of the inherent costs associated to home while supporting human occupancy patterns cannot question the feeling of functionality, security, safety and comfort.

Besides all the technology apparatus that contribute to daily routines, home automation is a new paradigm to handle the home environment, particularly in energy management, security and the possible scenarios to respond to user preferences. At the limit these technologies can be complemented by renewable energy systems to optimise energy consumptions. These technologies can be implemented upon new and existing buildings. However, the total costs required by these technical solutions are prohibitive for most homes' owner, and if chosen based on a condominium decisions positive decision is hard, sometimes impossible, to be reached. A paradox emerges because if these technologic systems can be useful and required to promote an effective and efficient dwelling management, their costs of acquisition and maintenance are too high to be spent by an individual or even by the association of owners, such as condominium. Yet, the dwelling environment ought to be managed to maximise its performance by answering to the user's occupancy patterns, and to achieve sustainable goals minimising ecological footprint.

Reality illustrates the need to modernise the habitat's built environment by the functional, social and economic obsolescence presented by apartments, buildings and neighbourhoods. Dwelling environment as a real estate asset definitely requires its management. Otherwise, dwelling environment will be the investment / property of the poor, once everyone wants/ expects to become an owner but do not have the financial resources and competencies to manage it, depreciating its value continuously.

4 Conclusions

An attentive survey of the dwelling environment shows that it is a piece of built environment that presents significant levels of functional, economic and social obsolescence. Dwelling built environment, like industrial and tertiary built environment needs to be managed to dignify and enhance its life cycle without undermining the users' needs and expectancies. Dwelling built environment is an asset (the biggest investment and expenditure of its owner) that requires its evaluation.

Considering traditional functions at the home environment, comfort emerges as the main issue regularly neglected by conceptual models and constructive processes; beyond the traditional activities performed, attached to individual and familiar requirements, home environment gained, along the recent decades, new functions comprehending professional and leisure performances, which by their nature depend significantly from technologic developments. Facing this reality, technology is an answer to promote comfort, throughout appliances that help to perform household tasks;

systems to guarantee the desired level of temperature and humidity; devices to promote security and equipment to develop work and leisure activities. The addition to technology, spatial environment implies significant costs on its acquisition, implementation and operation. The present-day status regarding different levels of obsolescence is due to the fact that dwelling environment do not benefit from maintenance and update policies, once there is no administrative motivation and obligation. Most apartments are occupied by their owners, who can't afford refurbishing to adapt them to contemporaneous life styles.

The sustainable awareness developed to minimize ecologic footprint motivates a rationalized use of energy resources along with the optimization of dwelling functional and comfortable performance. To achieve such goal the user needs to act as a facility manager to avoid and/or minimize any kind of home environment obsolescence and optimize the costs of its performance. Building automation appears as a trend to answer to users' needs and mostly to users' expectations. However, the solutions available are very expensive to individual investment; the inexistence of municipal, fiscal or administrative advantages implies that the time to reimburse such systems is not compatible with their life cycle.

From the reality experienced and its technical optimization, some actions can be implemented. From maintenance policies based on planning actions and not just reactive attitudes; communitarian solutions that can be applied in all the storey's of the building; individual behaviours more attached to sustainable principles; energy suppliers policies to motivate different uses and schedules rates; technical systems, equipment and devices suppliers to a rationalization of energy resources and inherent costs, can be the first step to achieve a more sustainable dwelling environment and a better human quality of life.

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