Definition of a Home Automation System for Energy Management and Efficiency

Dr. Sergio Romero Hernández
Departamento de Ingeniería Industrial y Operaciones (IIO)
Instituto Tecnológico Autónomo de México (ITAM)
sromero@itam.mx,

MTIA Paulina Clares García
Maestría en Tecnologías de Información y Administración
Instituto Tecnológico Autónomo de México (ITAM)
paulina.clares@gmail.com

While there are no simple or immediate solutions for the warming up, the requirements in energy consumption are varying to achieve a sustainable evolution, mainly at the production of electricity. In Mexico the industrial sector registers the highest consumption, but at the residential sector —the second highest consumer of energy [1] *— more people might get to know the relevance of taking care of the planet. Now that different options might provide energy to Mexican homes, there is a tangible opportunity to develop residential energy management and efficiency models, as well as energy generation, transmission and consumption [mainly solar panels, societies of auto-generation, or buying power from the nearest generation-plant]. Home automation may provide a means to achieve this. A well-done planning is fundamental to create a clear concept of a solution; therefore, a reachable conceptual design of home automated solutions to energy conservation may emerge from this proposal* [2].

1. Introduction

The extent of this work is to define what can be achieved by a solution of Home Automation (HA) applied to Mexico so as to improve energy efficiency by allowing users to manage their energy consumption with real-time information. The kind of solution defined will focus on illumination and the capability to upgrade through many applications, with technologies for wired and wireless network sensors at homes. In a *generic product development process methodology* [3] (see Table 1) *planning* the solution will define the scope, while the concept development has been worked deeply to reach a conceptual design satisfying customers' needs and also establish target specifications as requirements to equal those to other solutions as competitive benchmarks. See Table 2.

Table 1 Generic product development process

Planning	Concept Development	System Level Design	Detail Design	Testing and Refinement	Production Ramp-Up

Table 2 The customer-needs activity in relation to other concept development activities

Planning	Concept Development	System Level Design	Detail Design	Testing and Refinement	Production Ramp-Up
Identify customers	Establish target	Generate, select, test concept		Select final specifications	Plan downstream development

The *generic product development process methodology* is useful to identify a set of customers' needs. In the proposal, this methodology will be developed to define HA scenarios with coverage of objects, actors, needs and services, using also the Quality Development Function (QDF) [4] technique. The objectives of the methodology are:

- Ensure that the product is focused on customer needs; identify latent or hidden needs as well as explicit needs; provide a factual base in order to justify the product specifications; create an archival record of the needs activity of the development process; ensure that no critical customer need is overlooked; develop a common understanding of customer needs among members of the development team.

The philosophy behind the methodology is to create a high-quality information channel that runs directly between the customers in the target market and the product developers.

The purpose of this document is to encourage energy management and efficiency at Mexican homes with a solution plan of home automation in scenarios, so a resilient, secure and reliable energy system could emerge. The main objective is to define a concept design on a home automated solution to achieve quality on electricity power inputs and uses at homes, with the faculty of decision-making among users and objects in the house.

1.2 Problem, background and opportunity

Human beings have found many forms of energy sources —renewable and non-renewable—, which are transformed into different kinds for energy consumption. The irrational use of most non-renewable sources contributes to the climate change. That is why many efforts are being made around the world to confront it. The primary effort is the Kyoto Protocol, which is an international agreement linked to the United Nations Framework Convention on Climate Change. As protocol, it commits 37

industrialized countries and the European Community to stabilize greenhouse gas (GHG) emissions, instead of just encouraging this effort [5]. There are two other relevant initiatives: Leadership in Energy and Environmental Design (LEED)[1] and Clinton Climate Initiative (CCI)[2]. These initiatives are designed for cities, the C40[3] Large Cities Climate Leadership Group, and buildings, but they may show best practices that could be taken into ("green") homes. Moreover, the Organisation for Economic Co-operation and Development (OECD) brings together the governments or countries committed to democracy and the market economy from around the world to achieve many goals, one of which is to support sustainable economic growth **[9]**. The main form of energy to support the everyday life of human beings is electricity. To generate it, the world requires large quantities of fuel, coal being the dominant source. It is expected that member countries of the OECD continue to decrease the usage of petroleum and derivatives for the generation of electricity. Nowadays, there are opportunities to change the way power is produced, distributed and consumed, where new roles or business processes may emerge for special functions. Therefore, the expansion of electricity structure in Mexico for example could lead to new business models in an *energy ecosystem*, so everyone must understand energy consumption to improve the way energy generation and supply are planned, built and operated. The final user has a type of function to perform, so those usages are classified into distinct sectors. This proposal works with the residential sector; therefore it seeks opportunities to improve energy management and efficiency in houses. Energy efficiency lies on the response time and the pertinence of its consumption, with the variety of devices at home that use this energy, while the energy management, as the ability to control kinds of consumption and times among renewals solutions —at home or in a condominium society— or along with different distributors, has plenty of potential usage in collaboration with producers and distributors. The main opportunity is to use Home Automation (HA) features, so that an integral development of best practices for energy care at administration and controls for energy efficiency may allow the final user to know his/her current situation (options and own ways for consumption). The main requirement is to obtain the knowledge of consumption management at home, thus innovating in consciousness and culture. See Figure 1.

Figure 1 Integral development for energy knowledge care

2. Related work on energy conservation in home automation

Home automation (also called *domotics*) applies information and communication technologies in private homes, from the manufacturing with specific automation requirements for comfort, security and convenience, in and around the home. HA enables a distributed and remote control for domestic applications. There are many domestic applications, but since a holistic sustainable solution is desired for this project, some of those applications are classified as *home ecosystems*. Furthermore, the definition of *green home* will be used as a strategy.

2.1 Green home

The Green Technology industry is growing, as many businesses recognize the benefits of using this kind of technology to reduce their carbon footprint and to minimize waste. In our work *green home* is a strategy that defines two main goals as the reduction of energy consumption, usage and cost at home through efficient applications that are functional. These applications should share the characteristics of existing infrastructures, as well as increase/optimise their capacities. To understand this approach, the home is considered as a community looking forward to sustainability and the existence of *ecosystems*. As there are a lot of domestic applications, these are segmented in primary ecosystems, so that their appearance and ways of interaction can be identified in order to fit all the pieces together and create a sustainable home. There are many definitions for sustainable development, but they have three major characteristics in common: living within the limits offered by nature; understanding of the interconnections among economy, society, and environment equitable distribution of resources and opportunities [4] **[12]**; and the definition for sustainable community and society that fits best to define the green or sustainable home that is

[1] The Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ encourages and accelerates global adoption of sustainable green building and development practices through the creation and implementation of universally understood and accepted tools and performance criteria. LEED provides building owners and operators with the tools they need to have an immediate and measurable impact on their building's performance **[6]**.

[2] President Clinton launched the Clinton Climate Initiative (CCI) in August 2006 to make a difference in the fight against climate change in practical, measurable and significant ways. **[7]**.

[3] C40 is a group of the world's largest cities committed to tackling climate change**[8]**.

[4] The original definition of sustainable development was made in the Bruntland Report, which defined it as: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Sustainable development is all about ensuring a better quality of life for everyone, now and for generations to come **[10][11]**.

the object of this project is taken from the Sustainable Community Roundtable Report (South Puget Sound) [13].

2.2 Home ecosystems

The home infrastructure has different segments or systems; those may have a life cycle as they can evolve into an ecosystem. The concept of interest in this proposal has a management focus, which considers multiple activities that may occur in specific areas and thus imply links among living and nonliving resources[5]. Some home ecosystems are listed: *Heating, Ventilating, and Air Conditioning (HVAC); Security; Access; Lighting; Entertainment; IT & Telecom; Garden; Integral control automated home; Renewable energy generation.* The evolution for those home ecosystems may have different stages, which may or not grow, but there might be a performance planning to illustrate how they can interoperate among each other, so a convergence area might emerge. This means that there are segments or ecosystems that interact. The stages to scale a home ecosystem up or down go from the equipment to its operation, and then this must be maintained. All this may be managed, and finally each change may incur in costs. See Figure 2. In particular a case or scenario that converges in HVAC, lighting and integral control home automated. As this one, there could be as many as necessary, but control, monitor and policies are strategic. Those interactions may achieve green development for homes hence allowing "smart grid" technologies to be employed for electricity efficient usage[6]. For instance, this proposal defines an integrated lighting control system for all the lamps/luminaries in the house at the management stage from Figure 2, assuming there is already an electricity infrastructure for lighting in operation at home.

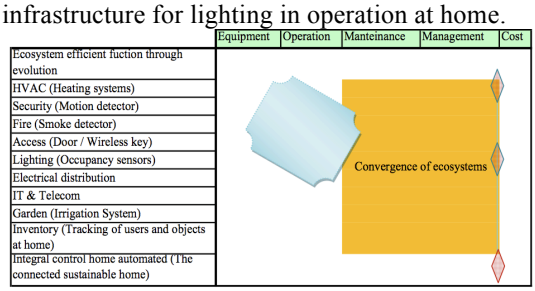

Figure 2 Ecosystem efficient function through evolution

[5] "As we understand for ecosystem: Ecosystem-based management is an environmental management approach that looks at all the links among living and nonliving resources within an ecosystem, rather than considering single issues in isolation..." **[14]**.

[6] "Smart grid technology: This could include developing devices that tell when it's most efficient to run the dishwasher or the dryer." **[15]**.

3. Methodology deployed for understanding the sustainability problem at home and the development of engineering specifications

For an example description of a scenario it is considered engineering specifications such as demand and supply. Demand supply for lighting and HVAC working, first with demand response, so smart energy usage can be performed; second, with load control, so manipulation of load profiles can be done. Knowledge of consumption for energy efficiency and management at home is a proposal, which will hopefully be developed through a quality product for home automation. For now, this work will use a standard methodology for *Product Development*, seeking to get the precise requirements for *Product Planning*, in order to build mission statement for the project. Subsequently, a *Concept Development* will be worked on, that will allow the quantification of customer needs, as well as the understanding of how these are transferred into engineering characteristics **[3]**. To ensure quality in the products, the *Concept Development* phase also involves work using the Quality Function Deployment (QFD) technique in the *House of Quality Matrix* to generate engineering specifications. The QFD method was developed in Japan in the mid-1970s and introduced in the United States in the late 1980s **[4]**. House of Quality is a graphic tool for defining the relationship between customer desires and the firm/product capabilities. It is a part of the Quality Function Deployment (QFD) and it utilizes a planning matrix to relate *what* the customer wants to *how* a firm (that produces the products) is going to meet those requirements **[16]**. Product Development involves six phases (see Table 1). This project focuses on the first two phases (*Planning* and *Concept Development*) to carefully develop the requirements as a key element for the future ("finding the 'right' problem to be solved").

3.1 Engineering design specifications

Engineering design specifications need to be well stated to ensure that requirements will be: discriminatory, measurable, orthogonal, universal and external. Furthermore, creeping specifications may change requirements during the design process. There are three factors that cause creeping specifications: First, as the design process develops, more is learnt about the product and many more features can be added. In this proposal, two main classifications were made: identifying modules and quality dimensions. This allowed more features and specifications to emerge or to become patent. Second, since design takes time, new technologies and competitive products become available during the design process. It is a difficult decision whether to ignore these, incorporate them, or start all over. By following the routing over low power and lossy networks (roll) working group at the IETF, this

proposal is supported on two distinct versions for home automated applications requirements' set [17] [18]. Third, since design requires decision-making, any specification change causes a readdressing of all the decisions dependent on that specification. The design was better defined with the specification that allows consumptions while power is cheap, which helped to achieve some main customers' needs. In this case, any decision with this specification would be correlated with the ability to control strart/stop decision on household appliance. At the same time, this last specification has other relations, which means that any decision on it would affect them as well. Even a seemingly simple specification change can cause the redesign of virtually the whole product. The point is that when specification changes become necessary, they should be done in a controlled and informed manner. This is how a good design of specifications ensures what the requirements must be: the requirements are *discriminatory*, as they need to reveal the differences between alternatives to help distinguish one from the other during an evaluation that should be clear, meaningful to outcome, and reasonably acceptable; *measurable*, as all identified requirements are ideally measurable, a good practise is to prepare the measurement methods when writing the requirement; *orthogonal*, which means that each requirement should identify a unique feature of the alternative: there should be no overlapping of requirements; *universal*, so each requirement characterizes an important attribute of all the proposed alternatives, and also in order to eliminate features that are not consistent with the issue being addressed. Finally, the requirements are *external*, as every system or object considered has a boundary; users of the product are outside this boundary, that is, external to the system or object. Thus, the only purpose of the performance of the system or object is what decision-makers discern within its boundaries. Everything that happens inside the boundary, the internal workings of the system or object, is not observable: specifying *what* is to be met is external, while specifying *how* it is to be met is internal.

3.1.1. Planning. Planning a product aims at ensuring that the right product development projects are pursued; therefore, it is necessary to identify opportunities as a first step. So far, this document has identified ecosystems at home that may be optimized relying on energy efficiency and management use in home automation. Additionally, to evaluate and give priority to ecosystems, this project will focus on lighting and the *integral home automated control*, as the connected sustainable household. Also, it is clear that convergence drives the development of more ecosystems at home, as a mix of new products, platforms, and derivatives to develop with the selected technologies. About resources and times of development, the main elements are: services in scenarios, which are defined upon engineering specifications for the solution, and objects and their communications in wired and wireless sensor networks. Consequently, the concept to develop is the best practices involving resources and times for developing those scenarios as a reaction to certain events. This can be growing for this proposal on lighting and integral home automated control, but also in sequence and timing of new product or ecosystem developments. The planning stage has two main outputs: an aggregate product plan and a mission statement for each development project. Aggregate product plan ensures that selected projects have proper resources for a successful ending. Therefore, this proposal will focus on lighting and suggest energy efficiency and management at home. Thus, the mission statement for an integrated lighting control system for luminaries at home which enhances energy conservation and optimizes energy consumption was developed for this project [3]. The product description is the name for the solution proposed in this document, which is *integrated lighting control system for luminaries at home*. There are three key business goals: i. *Encourage energy management and efficiency at Mexican homes in Home Automation applications, so a resilient, secure and reliable energy system could emerge*. ii. *Reduce energy consumption by 30%*[7]*, on lighting at home through efficient applications*. iii. *Utilize applications that are adaptable to the functional characteristics of existing infrastructures.* The primary market is *Home and their inhabitants,* and the secondary markets are: i. *Installer personnel*. ii. *Sales staff* or *Organizations for improvements in sustainability solutions at homes*. As assumptions and constraints there are three: i. *Innovation available in the National Electricity Commission*. ii. *Interoperability among services: demand response and load control*. iii. *Home Automation with PLC and ZigBee*. The stakeholders are: i. *Users*. ii. *NGOs*[8]. iii. *Mexican Government*. iv. *Educational Institutions*. v. *Citizens.*

3.1.2. Concept development. At this point, the fist step is to identify customer's needs as the main features of the proposal. The ideas of any potential user or target market had to be collected. With the list of ideas resulting from the QFD technique, customers' needs will be integrated in subsequent sections. Therefore, to improve this task, the Quality Function Development technique was implemented. An overview of the steps for QDF technique is listed below. Step 1: Identify the customers; Step 2: Identify what it is they want the product to do; Step 3: Determine to whom the product function is important—*who* versus *what*; Step 4: Identify how the problem is solved now, in other words, define the competition for the product being designed; Step 5: Determine how to measure the product's ability to satisfy the customers' requirements; Step 6: The *hows* consist of the engineering specifications; their correlation to the

[7] 30% is estimated for energy safe at home, saving on lighting [19].
[8] Non-Governmental Organizations.

customers' requirements is given by *whats* versus *hows*; Step 7: Target information—how much; Step8: Determine the interrelationship between the engineering specifications —*how* versus *how*.

3.2. Quality Function Development (QFD)

There are many techniques to generate engineering specifications. In this project, QFD will be used for concept development. The QFD method is organized to develop the major pieces of information to understand the problem: 1. The specifications or goals for the product; 2. How the competition meets the goals; 3. What is important from the customers' viewpoints; 4. Numerical targets to meet

The QFD method is best for collecting and refining functional requirements. From Hathaway we have this point of view for the sequence to work [20]: 1. Customer Requirements (CR). 2. Shows how top competitive products rank compared to CR's. 3. Importance to customer. 4. Engineering Characteristics (EC). 5. Degree of interdependence of EC's. 6. Correlation between EC's and CR's. 7. Multiply values in 6 by values in 3 then sum column. 8. Total all in 7 and divide in individual values in 7. 9. Benchmarks your company performance against top competitors. 10. Tech Diff = ease of achieving each of EC's. 11. Setting your companies target values in each of the EC's.

3.2.1. Further for lighting solution design. The QFD technique ensures that the problem is well understood. It is useful with all types of design problems and results in a clear set of customers' requirements and associated engineering measures. It may appear to slow down the design process, but in reality it does not, as time spent developing information is returned in time saved later in the process. See Figure 3.

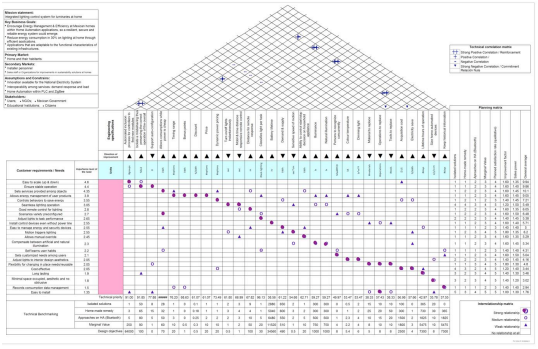

Figure 3 House of quality matrix for lighting solution design

Although this technique is presented as a method for understanding the design requirements, it forces such in-depth thinking about the problem that many good design solutions develop from it. Ideas recorded as brief notes or sketches during the *problem understanding phase* may be useful later; however, it is important not to lose sight of the goals of the technique and drift off to one favourite design idea. So far we can see that work has much iteration as needed to refine it. At this point product development methodology works on the reflection on results. To present the engineering specifications, they were arranged by basic dimensions of quality. Customers' needs were broken into primary and secondary types. What, for Market Quality Requirements, should always assure adherence to the customers' intent. How, as Quality Objective Item, could be broken into Product Quality Features: parts, processes or features of the design which either make-up the design or have an influence on the Market Quality Items. Those engineering specifications list the attribute or parameter to be measured for each one, with its unit and its direction of improvement [more is better (▲) or less is better (▼)]. Finally, the technical priority is presented. It is evaluated by the interrelationships in the matrix. The most technical priority is to allow consumption while power is cheap, followed by the engineering specification that classifies light per task. In this case, both are related to preconfigured variety scenarios, which might be the "killer application" to energy conservation. See Table 3.

Table 3 Engineering specifications among basic dimensions of quality, with units, improvement direction and technical priority

#	Basic Dimensions of Quality	Engineering specification	Units	Improvement direction	Technical priority
1	Performance	Ability to control start/stop decision on household appliance	kWh	▲	62.712
2		Colour temperature	kK	▲	53.469
3		Dimming light	lx*m*°	▲	53.469
4		Distance for remote response	m	▲	67.815
5		Illuminance	lx	▲	59.274
6		Mobil & time distance responsive remote control	sec	▼	66.987
7		Natural illumination	lx	▲	59.274
8		Sensitive speed of motion	sec*cm	▼	54.675
9	Features	Allows consumptions while power is cheap	kWh	▲	127.233
10		Bonus points	kWh	▲	68.634
11		Demand & supply	kWh	▼	61.218
12		Discount	%/kWh	▲	61.074
13		Dynamic power pricing	#options	▲	73.494
14		Keep historical information	#days	▲	37.548
15		Persons to recognize concurrently	Max#RFID	▲	49.968
16		Price	#options	▲	61.074
17		Timing range	#options	▲	76.203
18	Reliability	Automated inclusion process for controllers to find new modules	#Logical groups	▲	90.999
19		Isolate a misbehaving thus preserving the correct operation of the overall system	%SLA	▲	91.848
20		Support auto-configuration	0	▼	77.877
21	Durability	Battery lifetime	hr	▲	38.556
22		Lifetime hours of operation	#days	▲	42.972
23	Serviceability	Material to replace	#materials	▼	38.331
24		Operations to replace	#operations	▼	57.429
25		Tools to replace	#tools	▼	38.331
26	Conformance	Acquisition cost	$ US	▲	56.979
27		Electricity save	%/kWh	▲	57.66
28	Aesthetics	Size home automated devices	x/y/z cm	▼	35.784
29	Perceived quality	Classifies light per task	#task-lighting	▲	96.129
30		Turn on/off lights instantaneously	sec	▼	61.803

4. General discussion and conclusions

Everyone at their homes might improve energy conservation and optimizing energy consumption, for it can provide comfort, security and convenience with the use of home automated information and communication technologies. Home automation enables distributed and remote control of domestic applications. The opportunities to come with it may be improved by scenarios for best practices through the knowledge of energy consumption. In this proposal, it is considered at the *offers lighting application in action* module as major type customers'

requirement for the *good remote control for lighting*, which would be scalable as the solution *allows an integral solution*. This proposal involved many refinements to achieve the generic *concept design*. Finally, it is presented through the methodology for product development, mainly at the planning and concept development stages, by using the QFD technique. Through the design, it was possible to propose that the solution may improve energy consumption, contributing to other kinds of programs that are being done by the Mexican government, as well as best practices anyone may have or adopt at home. A future line on this proposal is to analyse opportunities on the Return On Investment (ROI) with combined solutions, as it may get more expensive and improve energy management and efficiency. For example, it may be considered maturity curves across quality and number of modules. Those curves would show different level of benefits over the solution: starting, with quite quality; a significant improvement with more modules, but at some point it wont get better. At that moment in the future, there could be improvements in technology to scale up the frontier of possibilities. It was better to organize the specifications by major type customers' requirements, thus getting to know the different achievements in diverse home ecosystems.

Finally, all those refinements could lead into different importance levels for understanding a solution through HA; however, on the left-hand-side of the house of quality matrix are the main customers' needs, including their essential engineering specifications to ensure the best way for getting any HA solution. Next, it is important to identify how all the engineering specifications are correlated in order to understand the impacts during the development of the project. Through all that work, and knowing the competitors well, it was possible to outline possible opportunities in order to promote that a best product-service-solution is achieved. All this may be seen more closely at the opportunities among competitors. In order to harmonize with an energy ecosystem, it is important to go deeper into our own knowledge of energy consumption behaviour, and consequently become aware of the best practices to attain sustainable development. End-users want technology to be invisible; therefore, the better it operates, the better the improvements may be set.

Green homes are a great opportunity to maintain life quality, and they also harmonize with the environment. This might generate new business models, since the technologies needed to achieve any customer's needs or desires are now available. New ways to generate energy may be improved, so smart grids may function properly and new technologies may squeeze efficiency from the electrical transmission system.

Also, an opportunity is to offer education programmes to develop the necessary skills to encouragement of clean technologies under policies as green-power businesses— in order to attend the worlds' climate change as an organized responsive society. The impact on energy saving suggested in this proposal would not only benefit the climate, but also our minds, for it would spawn new ways of thinking as well of living. As a rhizome, an "image of thought" (Deleuze, 1977) to allow multiple, non-hierarchical entry and exit points in data representation an interpretation, which drive humanity to think, live, work, create or any across several dimensions. All this may converge at knowledge, but care on ethics is a main challenge.

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