Energy and Buildings 83 (2014) 173–180

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

# Digital mirror: A method to shape smart citizenship

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ARTICLE INFO

*Article history:*
Received 4 January 2014
Received in revised form 14 March 2014
Accepted 8 April 2014
Available online 14 May 2014

*Keywords:*
Home automation
Energy monitoring
Comfort conditions
Passive behavior
WebGL

ABSTRACT

The introduction of digital technology into home management is historically connected with home automation: systems are built to serve the user, who is considered satisfied if he does not have to worry about them.

This paper will explore a different path whereby the user is highly involved in home management and uses a careful strategy based on highly efficient passive building behavior developed in the context of the Solar Decathlon competition, within the MED in Italy prototype.

This strategy relies on a web-based "Dwelling Black Box", in which all data on house behavior are sent to and saved on a database, building a timeline of houseliving aimed at raising the inhabitants' awareness and consequences of their actions. The interface was developed with two focuses in particular: a 3D web interface, based on WebGL open standard, and integration into a content management framework, allowing multiple houses to be investigated as nodes of a social network of homes, so that behavior and performance data can be compared and exchanged. The whole is aimed at returning to the contemporary context the awareness and know-how of our grandmothers, who knew very well how to operate their homes: from "domotics" to "grandmothics".



## 1. Introduction: users as energy saving drivers

One of the most important topics in the scientific investigation of building energy efficiency is the user's role in providing, great savings and improvements. A perfectly designed and engineered housing prototype will likely not work properly if its inhabitants do not know how to use and live in it. It has been studied that in some cases, there are "near-zero-energy buildings" in which users behave and consume in the exact same way as they would in non-efficient homes [1], as if they do not recognize the direct relationship between their behavior and the performance of the house.

The active role of users has proven its effectiveness in several recent successful experiences. One of the most documented is the Empire State Building energy retrofit, in which a number of measures to increase the passive and active behavior of the building itself (i.e., new windows, more efficient systems) saved a yearly amount of $4,393,796 and user awareness reduced 8% of consumption costs, $386,709 [Data Source: 2]. In residential use, this number would evidently increase, but its exact determination is an open scientific problem; the issue is under investigation at many levels [3] because the ratio that is attributable to user behavior can vary according to context strategies.

The impact of human awareness on reducing energy consumption is particularly evident with cars. Currently, cars are equipped with increasingly complex information systems that continuously tell the driver the impact of his driving behavior. The simple evidence of immediate consumption and the projection of the remaining distance have proven to stimulate drivers to change their behavior and adopt a less energy-consuming driving style. Some authors [4,5] also identified in particular cases a "game-effect" (also called "gamification" [6]) whereby social rewarding is used in strategies to promote eco-driving: interfaces have been developed in this direction in vehicles by manufacturers such as Ford's "Ecoguide", Honda's "Insight", and Nissan's "Leaf". In the former, leaves appear on the screen and increase in number as driver behavior becomes greener, in the latter, there is a network of drivers that compares driving styles and offers "high-scores" for the most performative ones.

This relationship between different players in a competitive environment, based on shared monitoring, is already present in the Solar Decathlon competition, in which 20 homes are connected into a smart grid that transmits data to a shared system that is available over the web. Thus, each competitor can see in near real time the performance of others and observe the differences in how his house is performing.

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http://dx.doi.org/10.1016/j.enbuild.2014.04.032
0378-7788/

**Fig. 1.** MED in Italy house during the competition in Madrid.

The only missing point, in the comparison with cars, is the "drive-effect": how can we encourage people to "play" with the house to modify and optimize its performance? The MED in Italy team worked exactly on this topic.

## 2. Mediterranean tradition and passive behavior

MED in Italy is an advanced housing prototype (Fig. 1), developed for the 2012 edition of the Solar Decathlon Europe competition, that aims at addressing the issue of energy efficiency in hot climates, in particular in the Mediterranean area. The strategy adopted by the team puts great emphasis on passive behavior: home design is based on introducing the traditional features of a Mediterranean building into a lightweight, entirely prefabricated, highly insulated wooden structure. The team worked on the traditional typology of the patio house, providing a useful microclimate in the immediate environment of the house; they introduced in the building envelope a layer of mass that provides thermal inertia [7] combined with careful management of shading devices and natural ventilation.

The entire design is a translation with contemporary technologies of the healthy principles inherited from our past, with a particular emphasis on the sustainability of materials and processes. The design is focused on achieving great efficiency with building shape: overhangs are carefully designed on southern glazed surfaces and on the northern skylight in order to provide the maximum thermal gain in winter and avoid it nearly entirely in summer, and the east and west façades are kept opaque. Because of the overhangs, the quantity of natural lighting is guaranteed at all times of the day. Natural cross ventilation is guaranteed by northern openings activated by remote control at the user's request.

In addition to this low-tech efficiency, the house also features very simple systems concentrated in an entirely prefabricated core element that hosts all systems, kitchen and bathroom (see Fig. 2). An air-to-water heat pump is connected to radiant systems located in the ceiling to optimize their cooling performance and combined with a mechanical ventilation unit featuring heat recovery. The roof is entirely occupied by the photovoltaic field at 10 kWp, shading the south glazed surfaces of windows on top of the watertight layer and micro-ventilated (see Fig. 1).

## 3. The involvement of people: more documentation, less automation

The "decathletes" of the Solar Decathlon competition are students from different degree programs, from bachelor's to PhD, who contribute to the design, engineering, fabrication and assembly of each house, and they are also asked to compete in home management during the two weeks of the "race". The home automation strategy of the MED in Italy house made students aware of the behavior of the house: they were able to adjust and tune all of the requested daily tasks by manually performing operations, as an alternative to full automation controlled by predefined algorithms. We introduced an in-between layer by allowing students to act on the system components of the windows and appliances.

To educate the inhabitants, we defined the building automation system (BAS) of the MED in Italy prototype as a **documented house**: energy production and energy consumption from systems and from white and brown appliances are shown in real time and archived in a "black box" that becomes continuously available. The house transmits much of the understanding of what is happening and what has happened.

Graphs show the exact behavior of each appliance, which during the competition allowed for the careful calibration of their use during the day based on the expected and instant electrical production. In Fig. 3, the top purple curve shows the difference in the energy production of the photovoltaic roof on a cloudy (image on the left side) and a sunny day (image on the right side).

In this strategy then, the black box becomes "green": systems and energy management are no longer hidden aspects of everyday life. Typically, systems are the exclusive domain of technicians; they leave little control to users, they are made as simple as possible, and in best practices, they may be available in a mobile configuration with few buttons.

In contrast, in this model, the house's behavior is shown in its richness, and people become active [8]: they can operate the house and change the configuration of their space, learning their past usage from a **timeline**. Users benefit from this model through the synthesis of 3D that relies on the experimental protocol WebGL, adopted among others by Google, that built on top of it one of the first large experimental applications, called "MapsGL". The fields using the WebGL protocol to exchange and show 3D data over the web include very different domains such as chemistry, medical science [9], and engineering [10].

The 3D model is the hub of a complex set of data that are collected and integrated through a series of software programs that were developed expressly for the project by a network of people within the team and the partners. The team had to directly develop code and build new software to define the integrated system.

### 3.1. Software structure of an "energy awareness machine"

The home automation strategy of the MED in Italy prototype relies on a web-based "dwelling green box" in which all data on the behavior of the house are saved over time and sent to a remote database located on a web server [11]. The full system thus relies on web technology. It locates in the house a "kit" of components:

- a local server (the power control board, with a Linux OS on an ARM server) able to control lighting and opening windows for night ventilation but configured mainly to collect data from different sources;
- a network of wireless sensors monitoring illuminance (lux), temperature (celsius), relative humidity (%), $CO_2$ (ppm), and position (*xyz*), manufactured ad hoc for the project and controlled through a sensor gateway;
- the electrical cabinet, which detects the power consumption of all of the different lines: the white and brown appliances, plugs, lighting sources, and window opening engines.

The kit is aligned a dedicated web space, and it establishes a "data stream" based on these operations: