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ARTICLE

Do Well to Dwell Well. Awareness as the Driver for the Behaviour of Tomorrow's Citizens

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ABSTRACT

Because of the impact of global warming, the Earth's ecosystems are currently at a critical stage. The European building sector, and the residential element in particular, is responsible for the largest portion of energy end-use. Although we know how to build a perfectly engineered house, it will not work properly if its inhabitants do not know how to run it. "Well-educated" dwellers can really improve energy use. The aim of this research is to optimize the users' role in the energy reduction process, analysing as a case study, Dwell!, the monitoring system designed for "RhOME for denCity", the housing prototype developed by Roma Tre University and winner of the "Solar Decathlon Europe" competition in 2014.

1. Introduction and research focus

Global warming is having significant and costly effects on our climate, our health and our communities. Unless we take immediate action to reduce emissions, these impacts will continue to intensify, to grow, to damage and to increasingly affect the ecosystems of the entire planet.

Because of 1°C of global warming, the Earth has had a lot of extreme climate change in recent years.

An important impact on energy consumption is the building stock and, in particular, the household sector, which is mostly inadequate in Europe in terms of envelope quality. Indeed, a large portion (41,69%) of global energy consumption, 27.16% (287.975 ktoe) and 14.53% (154.040,6 ktoe) of final energy use in Europe (1.060.037,3 ktoe), is due to the buildings sector (Figure 1)^[1]: it is one of the major contributors

to the increase in greenhouse gases because heating, lighting and powering our buildings require energy, mainly produced, still today, by fossil sources, thereby affecting European carbon dioxide (CO₂) emissions.

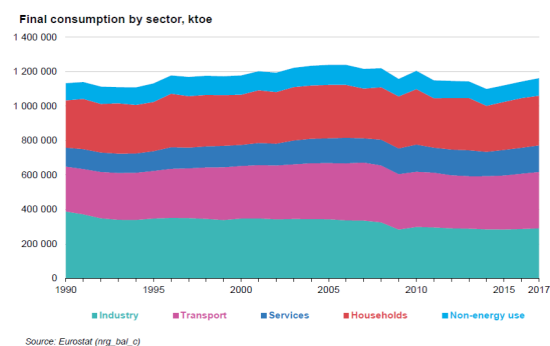


Figure 1. Final consumption by sector in the European Union (28 countries)

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Despite national measures aimed at saving energy, the last Annual Report on Energy Efficiency (RAEE) by ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), published in Italy in July 2019 and based on Eurostat source ^[2], shows that in 2017 the final energy use amounted to 121.1 Mtoe/year (with a 3.8% increase compared to 2016). In particular, in Italy, the residential sector consumed 32.6 Mtoe/year (which represents 26.9% of the total, with a 1.9% increase compared to 2016) and the non-residential sector (inclusive of buildings for commercial services and Public Administration buildings), consumed 18.2 Mtoe in 2017 (which represents 15% of the total).

Housing, despite laws and regulations, depends on dwellers' habits, education and attitude to energy use. For this reason, it is essential to deal with citizens' awareness in order to reduce energy consumption as part of a strategy to alleviate environmental stresses.

Therefore, encouraging citizens to adopt smart and healthy lifestyles has become a priority in urban development. Indeed, the user role in building energy performance, as demonstrated in the Post Occupancy Evaluation approach (POE), is central to building energy performance and, consequently, for energy waste reduction. POE, introduced in the United States to appraise the performance of buildings after they have been handed over and during occupation, has been described by Visser ^[3] as "... all activities that originate out of an interest in learning how a building performs once it is built, including whether and how well it has met expectations and how satisfied building users are with the environment that has been created ...".

The interesting link between building performance and user role is that, traditionally, POE has been used to establish user satisfaction, in addition to the other pre-set technical criteria related to buildings. Preiser ^[4] highlights that the evaluation of building performance may be undertaken quantitatively or qualitatively. Most of the performance indicators of a building are quantifiable, such as lighting, temperature, acoustics and humidity. So, while a building may show a set of excellent indicators in the quantifiable domain, its occupants may still not be entirely comfortable and satisfied when using it. Based on this focus, POE has developed a methodological approach that can be used to examine the performance of buildings by focusing on user satisfaction in order to improve building design from the perspective of the people who use them.

Smart cities are driven by science and technology but are meaningless without consideration for people and community and, above all, without considering the behaviour of the inhabitants. Design and practice are es-

sential in implementation, while education and training stimulate innovation and empower professionals and inhabitants.

Near-Zero-Energy-Buildings, although perfectly designed and engineered, show higher energy consumption than the ones simulated in the Post Occupancy Evaluation (POE): users behave and consume in the exact same way as in a non-efficient house ^[5].

As studied with POE methodology ^[6], many case study analysis results emphasize a substantial performance gap between predicted and measured energy use and underline how the user behaviour plays a crucial role in energy consumption in buildings because it can promote sustainable conditions, as well as improving energy saving.

The role of "well-educated" dwellers, who know and understand how to manage their own houses, can really improve the energy efficiency of their homes.

Starting from this reference scenario, and considering that a perfectly engineered house will not work properly if inhabitants do not know how to manage it, the aim of this research is to optimize the user role in the energy reduction process and address the human and building interaction issues analysing as a case study Dwell!, the informative system designed for "RhOME for denCity", the housing prototype developed by Roma Tre University and winner of Solar Decathlon Europe 2014 ^[7].

2. Methodology

2.1 The Solar Decathlon

The Solar Decathlon was held for the first time in Washington DC, where the United States Department of Energy ^[8] invited 14 universities to participate in the inaugural Solar Decathlon 2002 as a public showcase of cost-effective possibilities for renewable energy housing prototypes, powered by sun, and temporarily built on a shared site named "Solar Village".

From this ambitious beginning, the US Department of Energy has formalized the Solar Decathlon program as a recurring biennial competition beginning in 2005 and the competition has grown into the premier international competition for energy plus building design and sustainable architecture that involves 20 multidisciplinary teams selected globally among universities.

Named in part after the Olympic games event that inspired it, the Solar Decathlon competition is organized around ten contests where points are awarded on the basis of both subjective (decided by a jury) and objective (measured) evaluation criteria.

The competition addresses energy consumption, inspiring innovative solutions regarding the relationship

between buildings, energy and resources. This requires a balance between active systems and passive strategies, as well as a focus on affordable solutions with life cycle durability and behavioural awareness.

Based on daily assignments, like in a real home, every team has to simulate the house functioning, executing tasks planned in the Competition Calendar (such as cooking and making social dinners, dishwashing, clothes washing and drying, and so on). Students, as principal actors of the competition, have to decide how and when to combine these activities, taking into account the electrical energy balance and the comfort conditions. Sensors, installed in every competing prototype, connected to a centralized data-logger, that transmits the performance in real-time on the web, thereby helping students to run it properly. Therefore, user behaviour becomes one of the parameters influencing the result of the performance, and therefore of the competition. The prototypes become a model for the citizens of tomorrow that is able to benefit from heightened awareness.

2.2 Dwell!, Less Automation, More information

Roma Tre University, with the cooperation of the Architecture, Economics and Engineering Departments, was selected in the 2012 Solar Decathlon in Madrid, where it won the third prize, and in 2014 Solar Decathlon in Versailles, where the first prize was won.

In the 2012 edition, with “MED in Italy”, fast-assembly lightweight energy efficient housing tailored to the Mediterranean climate, in the second edition, with “RhOME for denCity. A home for Rome” (Figure 2), an apartment prototype of high-efficiency and affordable social housing.



Figure 2. South and North facades of RhOME for the denCity prototype in Versailles

During this innovative research project, the university team acquired interesting know-how.

Considering the central role of users in achieving a better energy saving strategy and that in building/technological systems synergy it is possible to have a better balance between comfort and consumption, the research team designed an informative system of data visualization named Dwell! (a play on words that, if extended, might sound like “do well to dwell well”), to encourage and stimulate user awareness and, thanks to this awareness, reduce ener-

gy consumption.

As is fairly common in the contemporary market, each system has its own proprietary monitoring and automation system, optimized based on internal parameters using data from dedicated sensors, and relying on its own predefined logic. Inhabitants are not supposed to participate in how their house works. They are just clients of a fully automated and pre-engineered system.

The purpose of *Dwell!* is not to replace humans in house management, but to provide exhaustive information to provide dwellers with a graphic guide to performance results that are useful to “drive” their home. “To drive” has been chosen precisely in order to compare houses to cars, where, thanks to data on instant and cumulative fuel consumption shown on the dashboard, significant savings have been registered. Therefore, there has not been any automated reaction to these data.

The reference is to cars because 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 drivers about the impact of their driving behaviour. The simple evidence of immediate consumption and the prediction of their remaining distance have been proven to stimulate drivers to change their behaviour and adopt a more energy-efficient driving style. Some authors^[9,10] have also identified, in particular cases, a “game-effect” (“gamification”^[11]) whereby social rewarding is used in strategies to promote eco-driving behaviour.

Dwell!, developed with the support of the Italian Company Almagora, is based on sensors, located in every room of the house, to monitor comfort conditions and to provide energy and water production balance graphs.

As in cars, with the purpose of providing, in real-time, exhaustive information to help dwellers to be more aware of their environment, Dwell! is organised into three different levels of interaction with users, from the well-informed to the less aware ones: a WebGL based model (Dwell! Digital Mirror), a web app (Dwell! Dashboard), and an analytic database (Dwell! Discovery).

The Digital Mirror, a WebGL interface, is a user-friendly digital representation of the house, where intuitive dynamic graphics represent what is happening in the real world and let a non-expert user understand the variation of comfort parameters according to the factors that affect it. The user, with an intuitive solution of changing colours and point clouds, and with an interactive point-and-click model of the house, and through a fun animation, can visualize in real time what is going on in every point of the house. This interface has two web pages: one represents the urban area where the

house is located and the average real-time energy balance of each apartment, and the other one represents the single apartment (in the competition in Versailles) (Figure 3 and 4), users can walk around virtually and explore values in real time, as well as monthly, daily or hourly data collected by the sensors.

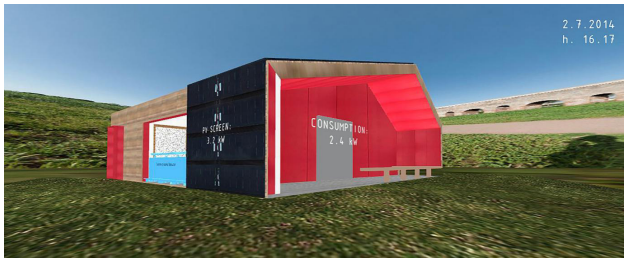


Figure 3. Dwell! Digital mirror: prototype model from outside

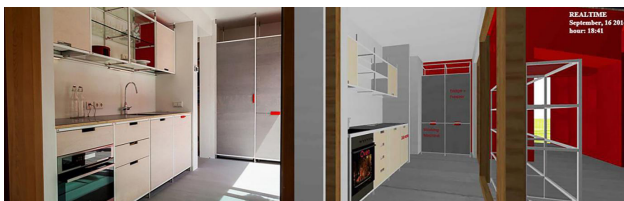


Figure 4. Dwell! Digital Mirror: prototype photo/prototype model from inside

The Dashboard (Figure 5) allows users to check, wherever they are, the current state of the house regarding energy balance. Specifically, the Dashboard shows the comfort conditions and the temperature and humidity values, the PV production value in Watt, the PV battery charge ratio, the balance of total consumption in Watt, the final energy balance and the PV consumption in Watt.

Using this app, from any device, the user can view the balance counters and the relevant relations among the data collected by sensors.

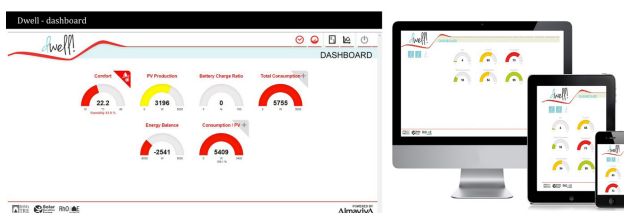


Figure 5. Dwell! Dashboard: a multidevice web app

Discovery, a database of the house's data collected over time (Figure 6 and Figure 7), is displayed in an analytical way that can improve environmental awareness, responsibility and comprehension of the connections between different physical events and energy cost. Specifically, Discovery shows the energy balance between the PV energy production in kWh and Total Consumption in kWh and

also allows planning of the appliances program start time based on PV energy production.

As shown in Figure 6, the users actually planned the start time for the washing machine, oven and hob, scheduling the start time via touch screen according to the PV production curve.

The graphic shows the comfort-consumption and production-consumption charts and allows users to put together the single measurement and calculated values in order to analyse the details of the events and provide dwellers with the possibility of understanding the consequences of their actions^[12].

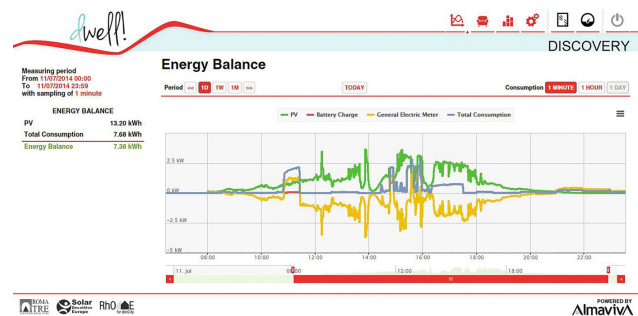


Figure 6. Dwell! Discovery: energy balance graph

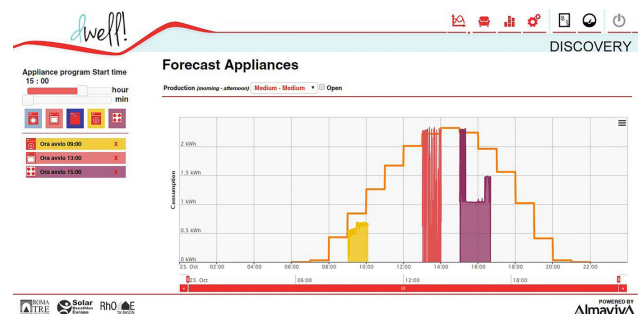


Figure 7. Dwell! Discovery: prediction graph

3. Results and Discussion

The RhOME team made an evaluation of energy strategies using TRNSYS as a simulation software and Dwell! as an informative monitoring system, with the aim of validating the digital simulation through measurements taken in July 2014 during the Solar Decathlon competition in Versailles, France.

Indeed, as mentioned above, the house was fully functional during the two weeks of the competition and each team was required to perform tasks simulating daily life, according to the Competition Calendar.

It's particularly important to underline that the data on energy consumption and comfort conditions were available through official measurements, taken by the organization, and also by the monitoring system Dwell! which, for each competition day, shows daily energy balance, com-

fort conditions and a consumption chart from the internal monitoring system for every single activity performed, therefore showing how good user behaviour was and its influence on results.

This allowed evaluations regarding energy strategy after the competition, according to energy simulation results and based on the validity of the monitoring system in guiding the inhabitants towards the conscious use of energy.

We decided to show in the chart (Figure 8) the hardest competition day for the function of the house: the “Passive Day” (8th and 9th July), a competition task whereby the house had to work passively, without any HVAC (Heating, Ventilation, and Air Conditioning), except for Mechanical Ventilation.

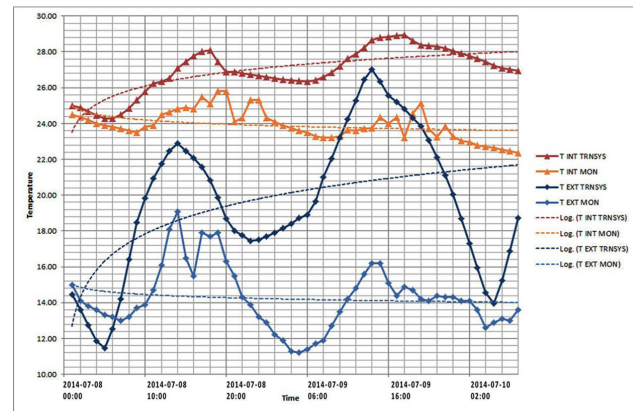
The assumptions we made in the TRNSYS simulation are shown in the chart below: Initial value: 25°C temp, with 50% RH; Set point for the heat recovery system: 25°; 1.5 ach from 8:00 PM to 7:00 AM; 5 W/m² appliance internal gains; Two people “seated at rest” for 24 hours.

Thanks to both the monitoring and the software simulated data it was possible to calibrate the simulation model using temperature profiles and user behaviour as input, both extrapolated by Dwell! monitoring results during the competition.

It is important to underline that a series of events occurred during the competition (i.e. public visits or jury visits) thus causing large peaks in temperature monitoring, although these events are not typical of everyday residential use. For example, on July 8th at 8:00 PM all windows were opened to let some fresh air in and on July 9th at 4:00 PM a competition jury wanted to see the house with all the windows open.

The interesting result that can be seen in the graph, in addition to the temperature reduction, the phase shift and the damping of the thermal wave, due to the efficient envelope, is that the graph seems to not show a large difference between monitoring of the real user behaviour graph and the simulated model. This evidence underlines that the virtuous and desirable behaviour of the users, “designed” as a user profile in the energy simulation model thanks to the user-friendly energy management system, was not so different from the conscious and wise behaviour adopted by the users during the real use of the house.

It is important to specify that the graph of monitored temperatures shows some peaks, obviously not present in the simulation model, caused by particular events inside the house during the competition, such as doors opening, there being no people inside, a jury visit.



“Passive days” (0-24 July 8th and 9th): Difference between simulation and monitored data in interior temperatures (top curves: red TRNSYS, orange monitored) and exterior temperatures (dark blue TRNSYS, light blue monitored). The diagram shows a similar time shift of interior temperatures, despite a difference in exterior temperatures.

Figure 8. “Passive days” (0-24 July 8th and 9th)

Note: Difference between simulation and monitored data in interior temperatures (top curves: red TRNSYS, orange monitored) and exterior temperatures (dark blue TRNSYS, light blue monitored). The diagram shows a similar time shift of interior temperatures, despite a difference in exterior temperatures.

4. Future Work

Dwell! aims to promote further information on consumption as opposed to automation. The result is a data viewer that allows the user to know how much energy has been consumed in the past or is being consumed in the moment. We are working on a new system that enables users to foresee and plan future scenarios and to calculate much more than just energy consumption. This research seeks to exploit the possibilities offered by artificial intelligence applied to the IoT (Internet of Things) to calculate the entire ecological footprint of buildings, while also allowing users to predict and plan their overall consumption.

The application of artificial intelligence in IoT, known as Cognitive IoT (CIoT), uses Cognitive Computing to merge IoT with machine learning. Machine learning allows the IoT to interact dynamically with connected objects and automatically learn and solve future problems based on past event data. CIoT recognizes, filters and assimilates information through a continuous learning environment, turning it into useful knowledge and meaningful patterns^[13]. CIoT adds to IoT a cognitive ability similar to human cognition, allowing it to overcome its current functioning limitations based on fixed and pre-programmed models^[13, 14].

The team from the Roma Tre University Department of Architecture will once again be competing in the Solar Decathlon for the Dubai edition of 2020 with the project “Moon”. The new system will be tested as a prototype. The main purposes are: to measure and monitor in real time the ecological footprint of the house on the basis of the environmental data and the behaviour of people living

in the house; to predict future scenarios and effects by using data on user behaviour together with external data.

The data collected by the sensors are processed through machine learning, providing a global assessment of the state of the house (a simple numeric index), from which the detailed assessment to provide a thorough understanding and suggested best practices can be extracted. The system's output is a dashboard connected to users' devices (smartphones, tablets, PCs, etc.). The overall ecological footprint of the house is assessed with a number from 0 to 10 and is measured by means of five "cycles": Energy cycle, Health cycle (air quality), Water consumption, Waste production, Food consumption. From the global evaluation, users can extract partial assessments of individual cycles (Energy, Health, Water, Waste, Food), (Figure 9) for a thorough understanding and suggestions of virtuous behaviours. Each cycle is also evaluated on a scale between 0 and 10.



Figure 9. The user-friendly interface

These measurements are relative to the single units but loaded in a data network, they contribute to the construction of a global urban database. The collection of data on an urban scale, together with data related to traffic conditions, weather and outdoor pollution, constitutes the dataset processed by the machine learning engine together with the indoor data of the single unit.

The new system differs from Dwell! in the following ways:

- (1) Addition of more measure quantities compared to the energy measures;
- (2) Processing of this information to calculate the actual ecological footprint of the house;
- (3) Estimation of the long and short-term consequences of the behaviour of the inhabitants in terms of consumption and environmental impact;
- (4) Suggestion of best practices for improving the ecological footprint;
- (5) Planning actions to achieve personal goals (less

consumption, less waste, etc.).

Since the main purpose of CIoT is "to make people's life smarter and chilled out by taking us way beyond the unadorned and artless automation" ^[14], its application in the public sector is desirable. The smart city is increasingly a reality. 60% of scientific articles that deal with IoT are focused on how to make cities more and more intelligent through its application ^[15].

With this purpose, the research group is now working on SoS research - *Sustainability of Schools. Definition of technologies, methodologies and protocols of use for health, well-being and energy saving in training places*, investigating and upgrading the results including in public buildings and especially schools, trying to create models of energy efficiency prediction, considering risk factors for human health, such as the presence of mould, bacteria, ionizing radiation and electromagnetic fields, and drafting a protocol of use to promote models of behaviour that encourage awareness in the citizens of tomorrow.

5. Conclusions

According to a report from the United Nations (UN), more than 55% of the world's population live in cities, consuming 75% of the planet's energy and producing 80% of CO₂-related emissions ^[16]. Besides, it is expected that the global urban population will continue to rise.

So, the user's involvement in housing management, as a crucial actor for home energy use, is one of the more important aspects of the Solar Decathlon Competition. In addition to the above mentioned issue concerning inhabitants' awareness and consequent lower consumption, social involvement represents another aspect of this approach. Indeed, a part of the data collected in the houses can be shared in a local network that is accessible by housing dwellers so that the comparison between comfort/consumption data of the single units might encourage energy saving thanks to a virtuous game engaged in by the housing community.

Aside from energy costs, it is also helpful to consider energy availability, which is not always, and in every situation, limitless. In Solar Decathlon 2014, for example, the solar houses had to manage daily tasks using a 5 kWp photovoltaic field: the scarcity of energy forces the user to learn how to better manage the available supply, teaching the importance of a single watt.

Precisely considering the reduced availability of energy, the main purpose of a house management system like Dwell! was to educate the inhabitant not only about how to manage energy consciously and intelligently, but above all not to waste it.

This is a precious feature of the Solar Decathlon initiative, because it builds a detailed profile of users' real be-

haviour in the house with the main purpose of educating the inhabitants as future sustainable dwellers.

The RhOME prototype of the house was inhabited only for the two weeks of the competition and then disassembled and transported to Italy for a permanent exhibition for educational and research purposes.

However, the research and development of tools to understand, plan and manage urban space at different scales is of fundamental importance. It is precisely in this direction that our department is setting future work, investigating and upgrading the results also in public buildings and testing this innovative monitoring system in the “Moon” prototype for Solar Decathlon 2020 in Dubai.

The future hope, through the help of these upgraded informative systems, is to learn how to “drive” the houses, taking into account energy as a precious but limited benefit, and considering the user as a central element in house management.

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