Tuning houses through building management systems

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Abstract
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Tuning Houses through Building Management Systems

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ABSTRACT

This paper departs from an analogy of sailing race instruments to demonstrate the potential of automation systems on the house performance and, more important, on impacting households for a more sustainable behavior. Sailing instruments have positively influenced the results on experienced sailors’ speed and ultimately have confirmed their observations on nature cycles. We have presented two research projects for the development of Building Management Systems for a house that relies mostly on natural ventilation and thermal mass and another one, based on a complex conditioning system with a solar assisted HVAC system, connected to a Phase Change Material thermal storage. Our argument is that if research on the sailing tournament America’s Cup instruments soon became available to other sailing boats, systems developed to the Solar Decathlon houses’ academic competition could, and should, be accessible to a great number of home owners. These two research projects give evidence that further research should be guided to more sustainable BMSs, which could significantly contribute to households’ behavior changes and ultimately support dwellers reconnection to natural cycles.

INTRODUCTION

Burry, Aranda-Mena, Alhadidi, Leon and Williams (2013) presented a challenging statement that “compared to architecture, performance is more transparent in a high-performance sport such as sailing where it is clear that ‘speed is good’.” Although their approach to sail racing and architecture focus towards a different perspective, we would like to use it as a starting point to elaborate our argument.

Sailors can teach us about having their boat perfectly regulated. A connection between sailing and buildings has been presented by different authors, with a broad range of approaches (Murcutt, 2008; Lynn and Gage, 2011; and Burry et al, 2013). We believe that a house could be tuned in a similar way as sailors trim their sails and plan their racing strategies. Experienced high-performance sailors’ success depends on their ability to understand the boat functioning and environmental changes and cycles. We would argue if it would be possible to stimulate in dwellers similar abilities found in these sailors.

“... And you work this house and you work most of my buildings like you sail a yacht. You have to work them so that you understand how to get the best out of the climate without having to aircondition.” (Murcutt, 2008) In this remark, offered in a TV interview, Murcutt does not present a revolutionary concept. Actually, he raises a primitive concept forgotten in most contemporary houses.

Contemporary homes are no longer able to communicate their operation systems. The systems’ complexity is usually hidden from the dwellers and does not support the latter engagement. Primitive communities’ homes, on the other side, clearly displayed their technologies that united them to their...
place. Primitive dwellers, as sailors, understood their technologies, building performance and the direct environmental influence.

High performance sailing boats have embedded a great variety of technologies. These technologies support sailors’ connection with the natural environment and boat performance awareness. Several of these technologies are brought by research for high-performance and high-cost competition enterprises, such as the most famous America’s Cup.

“All through the 1980’s the America’s Cup was contested in Twelve Meter Yachts, and significant advances were being made in hull construction, sailcloth and panel layout, and in sailing instruments systems. But, perhaps more than the others advances, sailing instruments were beginning to change how boats were sailed. The information regarding wind angles and speed were better than ever, but being able to make calculations which could indicate how efficiently the boat was being sailed was what was changing the game for the world’s best sailors.” (Ockam, 2013a)

Sailors use polars as predictions of the ideal boat speed across a range of wind angles and speeds. Several sailing instrument systems can compute and display, in real time, polar plots of the boat target speed in the given current conditions. They offer to the crew information that allows them to judge how they are performing against the boat’s speed potential. Their precision is quite important to the point that sailors such as Dennis Conner account for the polars’ precision to their success in races. (Ockam, 2013b)

A dwelling performance is quite different from race sailing boats. The latter has to reach the destination before the other competitors. Boat speed is not the only parameter to define the winner, but it is surely decisive and sailors have always to search for the best speed in the particular conditions or strategies. In a house, users should seek for a sustainable comfort. Home sustainable comfort presents different variables to distinct dwellers and to their various activities (de Dear and Brager, 2002). Thus, there is no ideal performance modelling that could apply to everyone. Following this line of thought, it is important that users identify their comfort zone that could be applied to control natural and mechanical conditioning methods and even lighting levels.

Cruising boats do not have to beat competitors, but are highly influenced by innovations developed by high performance sailing. These technologies afford cruisers with a combination of boat performance, weather data and location conditions. These instruments do not move away sailors from environmental awareness, as building technologies have done in the past. On the contrary, they facilitate an understanding of environmental data as an integrated natural network. Primitive dwellings have been developed as devices adapted and adaptable to environmental conditions. Dwellers could feel wind shifts, see changing colours and smells. Weather could be predicted and the house prepared for extreme conditions. Modern building technologies have supported comfortable homes, better protected from weather extreme conditions, less dependent to environmental cycles, as well as more energy dependent.

We are so disconnected from environmental cycles that it is a difficult task to engage users in more sustainable habits. Sailing technologies can teach us to better understand environmental data in order to recognise our place on earth and better adapt our habits to environmental cycles. Most of our home technologies have been developed in times when energy and environment were not a major concern. We do not need to get rid of technology, but develop more efficient systems able to better connect our buildings and users to natural environment. Sailing technologies have performed this movement mostly because they have always depended on nature’s cycles. Information has been a key issue. We have lost the use of our senses to acquire it, as primitive dwellers did once. Therefore, systems integrated to environmental data could support engaging residents to dwell with more sustainable habits.

This paper explores the development of two residential Building Management Systems and their user interface. The houses and their systems are quite different. They were designed for different continents (Australia and Brazil) but share some climatic similarities, as well as analogous relationships identified in high performance sailing systems and their potential impact on cruising boat technologies. Although the two management systems have broader applications, particularly related to energy generation and management, the discussions in this paper will focus on their thermal comfort systems. One of the houses relies on a hybrid and innovative HVAC system, while the other applies, with the exception of few days during the year, on passive conditioning and ventilation methods.

**BUILDING MANAGEMENT SYSTEMS**

Building Management Systems (BMS) applied to houses have become relatively cheap and
widespread. However, they are mostly limited to integrate few home controls usually related to lighting, thermal conditioning, media and security. These systems are able to incorporate powerful applications similar to those found in sailing instruments. These applications should be more explored to afford updated data about house performance, as well as weather data. They may also support understanding of the house functioning, which has been lost throughout history, as our houses became more technologically complex. In order to provide a meaningful environmental impact, the houses should not only be technologically holistic. They should appear holistic to their users. House performance depends heavily on users and their awareness. The reduction of energy consumption, for example, depends on technologies but also, and heavily, on choices taken by users (Schipper, 1989; Socolow, 1978).

Building design and its technologies have the potential to involve and educate. Orr (1997) placed the argument that our buildings miss their potential to reflect a hidden curriculum embedded in design choices. He asked if "[t]hrough better design is it possible to teach our students [users] that our problems are solvable and that we are connected to the larger community of life?" Following his advice, designers should care about how dwellers perceive and understand their homes. Houses, as any building, should be adaptable to different environmental conditions and residents should aspire to have them tuned.

Sensors, actuators and BMSs’ interfaces could act similarly to sailing technologies, in order to facilitate adjustments for tuning the house. They are able to provide updated data of the house performance and its systems, implementing automated functions towards dwellers awareness. If they become widespread, they could drive the development of affordable systems even for low-income housing. Although the experiments described below apply to relatively expensive houses, they demonstrate systems with a great potential for a relevant impact on more sustainable home behaviour.

THE ILLAWARRA FLAME HOUSE

The Illawarra Flame House is a small and high performance house developed for the academic competition Solar Decathlon (US Department of Energy, 2014), organized for the first time in Asia. Team UOW, lead by the Sustainable Building Research Center, University of Wollongong, designed, constructed, brought the house to Datong, China and won the Chinese Solar Decathlon, in 2013, attended by a total of 22 teams representing recognized universities around the world.

Team UOW has demonstrated a remodeling and retrofitting of a common and archetypal Australian house built approximately 50 years ago. The aim is to inspire national building industry and the general community that it is possible to transform the vast majority of Australian homes into stylish, affordable, and sustainable homes of the future. By upgrading an existing house, Team UOW took up the challenge set by the U.S. Department of Energy, China National Energy Administration, and Peking University’s goals to "accelerate the development and adoption of advanced building energy technology in new and existing homes". With less than two per cent of Australia’s housing replaced each year the Australian team believes that this retrofitting approach has the greatest practical potential to achieve significant economic and environmental gains across the country domestic built environment.

The Illawarra Flame showcases a radical, affordable and achievable blueprint and benchmark for retrofitting a typically Australian ‘fibro’ house. Fibro refers to cladding sheets constructed of asbestos fibre-reinforced cement. They are ubiquitous to Australian suburban streets. In addition to environmental concerns, recent increases in energy prices, the health implications of asbestos, and the poor thermal performance of these houses, have led to an urgent need for widespread upgrading. (Team UoW, 2013)

The Illawarra Flame features a Solar Assisted HVAC system that integrates an air based Photovoltaic-Thermal (PVT) system, a Phase Change Material (PCM) thermal energy storage and a standard reverse cycle air conditioning system. The house holds two types of Photovoltaic panels, a 1st Generation Polycrystalline 5kW array on a 5kW MPPT Inverter and a 4.6kW Thin Film CIGS array on a second 5 kW MPPT Inverter. The CGIS array constitutes the Illawarra Flame’s Photovoltaic-Thermal (PVT) system: a number of thin-film PV panels mounted on a steel sheet flashing that is fixed to the top of an existing sheet metal roof profile (Figure 1). This system creates a cavity underneath the steel flashing through which the working fluid, air, can flow and exchange heat with the PV panel. The
advantages of a PVT system rather than a PV system include an increase in the efficiency of the PV panels by reducing and regulating their temperature and the possibility to extract or release heat for heating or cooling purposes. This process increases the total energy extracted from the solar system, therefore improving the overall efficiency of the system.

The performance of the Illawarra Flame PVT system is enhanced by coupling it with a PCM thermal energy storage system. By using this thermal storage system it is possible to phase-shift the thermal generation so that thermal energy may be released at times when generation is not possible. The system can be used both for heating and cooling. Further cooling of the ambient air can be achieved in the PVT system, since during clear nights, it radiates heat to the sky.

The Illawarra Flame BMS is based on an off-the-shelf residential control system, Clipsal C-Bus. This control system manages different systems implemented on the building, including the solar assisted HVAC system, electrical generation and distribution and automated high level windows for natural ventilation. To achieve this goal, readings from a Davis Vantage Pro 2 weather station, integrated in the control system, support logic decisions and inform users through graphic interfaces.

Managing and displaying information are key features of BMS systems. One of the objectives of the Illawarra flame BMS is to let households be aware of the house performance, educating them on the different aspects of managing energy in the house. The user can easily access the consumption of each electrical subdistribution circuit and try to target a reduction of the most energy consuming appliances. One can see how much energy can be harvested by the solar assisted HVAC system and which working mode the HVAC is operating at each time to maximise its efficiency.

Integrating the readings from the weather station, the BMS displays outdoor conditions and indoor performance. Therefore, users can take the best decision to guarantee comfort with the use of natural ventilation or reducing the energy associated to conditioning with the different mechanical systems. The interface bottom part displays a gray strip that identifies the comfort zone or better conditions for each variable. The coloured bars indicate the variables interval in the previous 24 hours and a filled dot, inside these bars, expresses the current measurement, facilitating quick readings by lay people.
The BMS system controls on/off dampers, variable position dampers and variable speed fans, to set the system in the correct working mode. The system considers the generation and storage status with the house heating/cooling demands, optimising it to achieve the required thermal comfort with the maximum efficiency. The logic has been custom developed in Pascal language on the house C-Bus Pascal logic controller. A touch screen and a web supervisory engage the users in the systems performance displaying generation data of both arrays as well as thermal storage.

The Illawarra Flame house comfort conditions are maintained using the feedback reading from 5 independently calibrated temperature sensors. Due to the small size of the house, the average temperature of the conditioned space is used for decision-making. The individual temperatures are fed back to the user though the touchscreen, as well as the average one.

The comfort can be achieved using mechanical heating or cooling, using the different working modes of the Solar Assisted HVAC system or, every time outdoor conditions are favourable, using natural ventilation. In this case the BMS will open automatically the high level windows and advise the user to open the non-automated windows. Automatic opening of windows can be always be overridden by the user using the touchscreen or wall pushbuttons. Households can also define different temperature setpoints that overwrite the system Auto Mode. Predicted energy consumption is provided by each temperature user setpoint, who can compare with the prediction for the Auto Mode.

**THE FLORIANOPOLIS HOUSE**

The Florianopolis House is located in the south of Brazil, within an island, more than 50km long and around 20km wide. It is near a beach, which has few elevations and temperatures slightly lower than the interior of the island, ranging from 7.5°C and 31°C, with around 1600mm of annual rain precipitation, 85% of annual relative humidity and about 140 days of rain per year (Lamberts et. al, 2010). Rainwater is therefore an important resource to be highlighted. The rainwater falling into the pool, with bamboo trees on the background (Figure 3), is enjoyed in the living room and collected for water reuse. The pool amplifies changes on the cycles of nature, such as sunny or windy days.

![Figure 3](Views of Florianopolis House from inside the lot and from the back.)

Comfort inside the house is ensured by two main strategies: significant amount of thermal mass protected by insulation and shading devices as well as cross-ventilation in the direction of the region prevailing winds (North, Northeast and South). These strategies should be managed by the residents, to avoid opening the house in hours of extreme heat. On warmer days, upper windows are opened at night and, on cold days, closed windows let the warm sun in. The main facade, facing the pool is oriented N/NE, with large windows and doors that ensure ample lighting and sunlight in the colder months. Wooden panels on the upper balcony guarantee shading the rooms, providing more privacy to the bedrooms, when superimposed. The upper balcony provides protection to the hot sun during the summer, allowing it in to warm the colder days.

The BMS developed for the Florianopolis House is integrated with a Davis 6250 Vantage Vue weather station and an Internet weather forecast provider. Connected to different home sensors, it
supports dweller awareness and their decisions. Some tasks are automated, however, the system most significant contribution is to provide a holistic comprehension of the house systems and the environment, building up users’ concern to perfect house usage towards a more sustainable living.

Temperature sensors located in the living room on the lower floor, the top of the stairs, and the master suite show the temperature difference in these rooms and allow for comparison with the external temperature. (Figure 4) Different colours display the relationship between these four temperatures from dark blue (cooler) to red (warmer). The green circle displays humidity. A graph of the variation of the four temperatures (living room, roof, suite, and outdoors) allows checking of the performance of the house in the last 24 hours, confirming the adequacy of adopted strategies and data from the local weather station, associated with progressive variation of colours facilitates reading and comparison.

![Figure 4](image)

Figure 4  Screen for temperature and upper window control and bar graph.

With the association of temperature data from these sensors with information from the local weather station, such as speed and wind direction, one can plan a strategy for the next hours or days, with the support of the weather forecast. Three upper windows open above the roof, helping to extract the interior hot air. Those windows are motorized and controlled by the BMS. Therefore, it is possible to remotely open them. They close automatically on days with rain and strong southerly winds, to avoid water entering into the house. Combined with the other windows, they ensure cross-ventilation, which is particularly effective in such humid climate.

The three-floor height central volume, formally emphasized by the use of solid brick, facilitates the extraction of hot air from the ground floor. In warmer weather, ceiling fans in bedrooms alleviate the thermal sensation, without mechanical air conditioning devices. A house with a significant amount of thermal mass requires some strategy for managing its openings. They are not a direct response to the current conditions, similar to sailing boat that often take a lower speed direction that would prove to be more effective in a longer term. Therefore, the decision is not only based on the difference between interior and exterior temperature, but also a prediction of extreme higher or lower temperatures. Local information is associated with a three day weather forecast, allowing dwellers to plan strategies to ensure internal comfort within the house in the following hours or days. Data displayed through the graphic interface information would suggest the choice of windows to be opened or closed or the use of additional systems, such as the roof evaporative cooling or, in extreme conditions, the air-conditioning.

The bar graphs are aimed to support residents to learn with and about their house. The house systems become more transparent once the users find their location and performance, leading to more sustainable procedures and habits. The BMS and particularly the supervisory graphic interface are critical for this aim. The interface integrates numeric information, such as air temperature, with scalable vector graphics (svg). Therefore, one easily and quickly distinguishes temperature variation, translated into colour, in different areas of the house as well as outside temperature. The interface is optimally visualized on an iPad or a computer screen, although it can also be controlled through a smart phone. Data is organized in four main groups: energy, water, weather and security and background image changes also according to the menu item. Managing water and energy resources are also important
aspects of the system, but will not be detailed in this paper.

The open source supervisory control and data acquisition (SCADA) system is a critical component for the Florianopolis House BMS. The open supervisory (SCADABR) has been developed at the Federal University of Santa Catarina for a broad range of uses. Choosing an open source tool was one of the research goals. A relevant objective of the BMS research project is to test sustainable management solutions for low-income housing. Reading information is critical to maximize house performance, adapted to the residents’ needs and sensors’ data increasingly adds complexity to the interface. Thus, data has to be organized by hierarchy importance relating to different dwellers understandings.

CONCLUSION

This paper does not aim to provide a result of the two systems’ impact evaluation on households or on energy use. One of the reasons is that the systems presented have just been implemented. In addition to that, the two houses are not targeted for regular families. The Illawarra Flame House was erected at the Wollongong University campus. The house will most probably be used by different guests. The other one is the home of one of the researchers, who cannot represent a regular use of a house. Therefore, the authors depart from an analogy of sailing race instruments to demonstrate the potential of automation systems on the house performance and, more important, on households’ behavior. Similarly to the most important sailing races, such as the America’s Cup, the Solar Decathlon competition has provided relevant and innovative experiments on home automation oriented to sustainable house performance. Our argument is that if research on America’s Cup instruments soon became available to other sailing boats, the systems developed to the Solar Decathlon houses could, and should, be accessible to a great number of home owners. The two systems illustrated in this paper convey a further development of Solar Decathlon research. The system accomplished for the Chinese Solar Decathlon continued to be improved after the competition and is presented in its current stage. The system for the Florianopolis House departed from the system of the Brazilian Solar Decathlon 2012 house, embodying its concept and some of its features. Instead of hiding the complexities of all the houses’ systems, both of them attempt to present and understanding of the house functioning, engaging and challenging the users for a better performance. We argue that home automation systems have a relevant potential that is not explored by the market. In addition to reduce the effort to perform some of the daily dwellers’ tasks, these systems are noteworthy tools for more sustainable home behavior.

Although the BMS design of the two houses followed similar principles, they highlight their houses specificities and display both their houses and BMSs’ sustainable features. The complexity of the Solar Decathlon house has offered increased possibilities for testing more innovative approaches. On the other side, the main contribution of the Florianopolis house BMS to engage users is through history graphs, data translated to colors and the 3D section renderings. Apprehending the impact of habit changes in the house performance is not an easy task and is critical to engage users. Sailors can check their instruments in order to evaluate a different sail regulation. Our houses have a much slower response and instant data from energy consumption, for example, does not directly translate the impact of changing an activity. Overall daily energy consumption, as well, displays several different circuits that may considerably vary during the day. Thus, history graphs with hourly consumption of two different days may facilitate the identification of the impact of an activity’s change, comparing data from the current and the previous days. Different patterns of opening windows during two similar and consecutive days can present contrasting temperature results in the rooms. Similar history graphs with hourly temperature bars of different rooms are very educative about the house performance. Users can benefit from learning to better use their houses with a much more pleasant comfort outcome, reducing environmental impact. A good design has also a unity. A sustainable house requires sustainable households. Connecting the latter with the house unity should be a critical aim of BMSs.

The Solar Decathlon house’s BMS presents some additional contributions. The comfort zone bar facilitates the readings of the house performance and climatic conditions. Usually, households do not directly identify comfort zones in their daily use of the house. Air conditioning temperatures, for
example, are many times set up after climbing stairs when arriving home. The comfort bar is not effective for all variables, for some, it may be decisive. Temperature, humidity, wind direction and speed, and even luminosity should be influential. They are often ignored and can be quite misleading even for more sustainable contemporary households. The possibility to identify if these variables are within the comfort zone supports more sustainable dwellers’ behaviour, as well as a confirmation of their observation of the influence of natural cycles in the house performance.

The Illawarra Flame House BMS introduces also an analogous tool of the target speed celebrated by high performance sailors. The system calculates the energy consumption in the next 24 hours for the Auto Mode, as well as set point changes for heating and cooling. Therefore, the Manual mode is not only based on the assumption that the user has of a comfortable condition. The system actually provides a benchmark of an optimal Automatic Mode condition using every house resource to reduce consumption. Therefore, changes provided by the users could be predicted and compared against the ideal Auto Mode. They have ultimately all information for reducing consumption changing temperature set points.

Sailing instruments do not reduce the connections between good sailors and natural environment. On the contrary, they support experienced sailors with a confirmation of their empirical observations of nature. Contemporary urban dwellers have diminished their connections to natural environment. Technologies developed over the last centuries have reduced the need to adapt their lives to natural cycles. Building standardization has also contributed to this tendency. Studies from primitive communities highlight these remarks. They have developed their homes and the way they inhabit them based on empirical observations. Their habits are directly associated to the building performance, particularly in cases of extreme climate conditions. Experienced sailors have not lost, throughout history, their ability to understand natural cycles. We have aimed, through this paper, to advocate that these systems have added precision and confirmation to sailors’ observations and they could support similar connections that urban dwellers lack.

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