North House:
Developing intelligent building technology and user interface in energy independent domestic environments

KATHY VELIKOV[1], LYN BARTRAM[2]

[1]School of Architecture, University of Waterloo, Cambridge, Ontario, Canada
[2]School of Interactive Arts and Technology, Simon Fraser University, Surrey, BC, Canada

ABSTRACT: This paper presents current research in the design of the domestic environment and "intelligent" user-control system for North House, a prototype solar-powered dwelling being developed for the 2009 Solar Decathlon. The residential occupant needs to operate as both user and manager of a green dwelling, and thus requires both specific information and access to help the building work more efficiently. The domestic environment requires a means of control, display and integration with user lifestyle that possesses different challenges than workplace-designed buildings. The Adaptive Living Interface System, being developed for North House, comprises of interactive technologies combined with ambient and haptic information cues, that help the residential occupant to both control the systems of the house while at the same time providing feedback on the operation of the house, in this way supporting behavioural transformation for energy saving living patterns.

Keywords: green building; human intelligence; occupant comfort; personal control; smart environments;

INTRODUCTION

North House is a prototype solar-powered dwelling being developed for the 2009 Solar Decathlon by the Canadian Team North: a collaboration of students and faculty at the University of Waterloo, Ryerson University and Simon Fraser University's School of Interactive Arts and Technology, led by UW Architecture Professor Geoffrey Thün. The Solar Decathlon is a bi-annual competition sponsored by the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) where twenty selected teams from accredited universities and colleges compete to design, build, and operate highly energy-efficient, completely solar-powered houses.

While these prototype houses have often employed innovative building technologies and systems, the question of energy independence and new technologies in relation to innovation and transformation within the domestic living environment warrants further exploration. One of the key questions that the North House project aims to address is the question of how intelligent design and automation can impact occupants' daily rituals and patterns of behaviour, using a combination of both passive design strategies as well as responsive and interactive technologies. This work is engaging students and faculty working together from several disciplines – architecture, engineering, computing and interactive arts and technology – and will ideally lead to further interdisciplinary transfer and resulting expansion of disciplinary concerns and perspectives, as well as more holistically designed and responsive green living solutions.

NORTH HOUSE

The North House prototype (Fig. 1) aims to develop a strategy for solar powered residential design that approaches the questions of how to build and live in the demanding northern context, how to design buildings that are resilient and adaptive to climate extremes, and how new technologies, alternative energies and pre-fabricated components can be optimized to create a viable and sustainable architecture. The prototype strives to develop a regionally, socially and environmentally responsive architecture within an increasingly globalized and mobile modern condition. North House is designed

Figure 1: North House exterior rendering.

to encourage a way of life that is intensely social, closely linked to the exterior, to the climate of a place and its specific seasonal and diurnal cycles, while at the same time embracing and optimizing contemporary technologies and building techniques.

Cole and Brown [2] point out that although the tendency for green buildings, especially in America, is persistently biased toward passive systems, human comfort and satisfaction is nonetheless linked to the amount of control that the user perceives to have over their internal environment, be it through passive or mechanical means. The recent rise of ubiquitous computing and smart environments [3], as well as the widespread acceptance of PDA devices by the current generation, offers an opportunity to enable occupants to dynamically interact with building technologies through haptic and digital media providing both feedback and control regarding performance and atmosphere while empowering the occupant as an agent of behavioural change. Our team is working with an approach that combines passive design with responsive and interactive technologies. The three principles guide the development of North House and focus on the impact and interaction of the occupant with the design, configuration, systems and technologies of the house are: Holistic Solar Living, Distributed Responsive System of Skins (DReSS) and the Adaptive Living Interface System (ALIS).

HOLISTIC SOLAR: THE SENTIENT HOUSE

Our team defines Holistic Solar Living as an approach to building and living that incorporates the energy and benefits of the sun in all ways possible. The consideration of day-lighting, passive systems, microclimate generation, maintenance, food production, solar phase-change materials, the use of natural materials produced with the sun's energy, and solar responsiveness are all part of the design approach. The idea that both the house and the occupant are sentient beings, aware and responsive to their environment, both inside and outside, runs through all of the decisions on space planning, design and technology.

North House is designed with an open concept plan wherein the interior and exterior living spaces are conceived of as a continuous experience, encouraging the occupant to live in a relationship with the exterior surroundings and landscape. The human psychological and health benefits of natural light, especially in northern climates where winter daylight hours are short, has been noted by environmental psychologists such as Judith Heerwagen, Howard Frumkin and Vivian Loftness [16, 4, 8]. The adjacency of the kitchen and interior dining space to the outdoor dining facilitate a shady outdoor supper in the summer months (Fig. 2). The open concept living, sleeping and dining within the fully glazed south-facing living space allow maximum day-lighting during all hours. High-performance glazing combined with dynamic solar shading and integrated solar power result in a house that is projected to be a net energy producer despite the demands of northern climates.

Holistic Solar Living also includes using the sun's energy to grow food in the raised bed garden outside, as well as inside along the east facing windows. The landscape design provides space for drying and canning to preserve garden produce and limit the need for refrigeration. Species selected for the landscape have been considered for food value, seasonal variation, as well as their potential for creating micro-ecologies, inviting birds and desirable insects to the site.

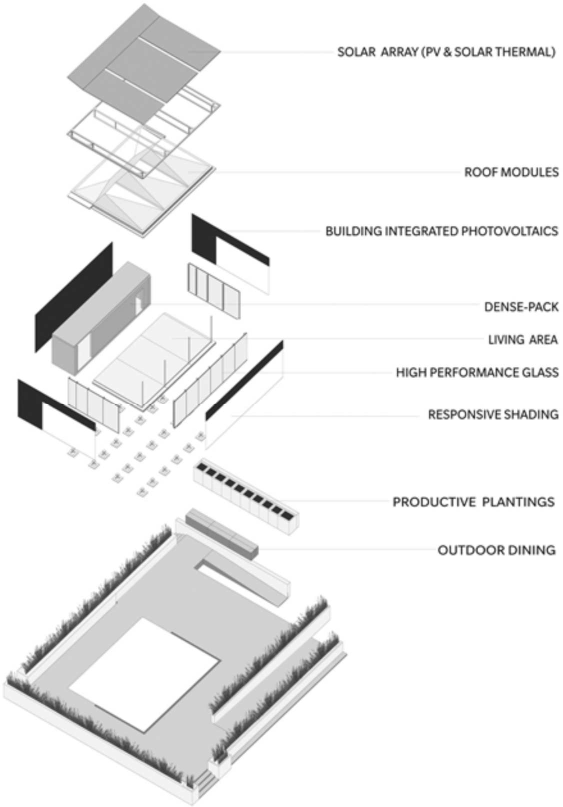

Figure 2: North House exploded axonometric.

PASSIVE & ACTIVE TECHNOLOGIES: ***DReSS***

In Canada, anyone who spends time in the outdoors camping, canoeing, or hiking, knows that the best way to prepare for unpredictable weather is to dress in layers. Similarly, the North House is structured and constructed in layers, with each layer performing a different task. Together the layers will provide passive solar gain when necessary, shading at other times, will open to the exterior when views are desired, will produce energy, and will be capable of mitigating extreme climatic shifts by closing down when the house is in conditioned mode or opening up to allow the house to breathe and expand during the temperate seasons. The idea behind this strategy is that each layer is able to be optimized for performance and can undergo future research, development and modification, independent of the other layers. We have termed this entire system of layers the Distributed Responsive System of Skins, or the DReSS.

The outermost layer integrates glass encapsulated photovoltaics on the walls, flat plate photovoltaics and solar hot water technology on the roof, with passive solar heat management in the dynamic shading system. These outer layers are free of the structure and thermal envelope of the house. The second layer is a high-performance, highly insulated glazing system with a high solar heat gain coefficient to maximize solar gain on the south, and an R60 solid envelope on the north. Operable units on the east and west allow for passive ventilation. Inboard of the glazing system, is an interior shade to moderate privacy and view. On the east wall, are suspended planters for growing herbs and seedlings.

An area in which major improvements on existing systems is urgently required is high performance glazing design to match the performance of highly insulated building envelopes [10, 5]. Team North graduate student and faculty members have undertaken significant glazing research, and have developed a custom wood curtain wall system that is estimated to achieve an assembly thermal resistance of R-8.6. The glazing unit is a quad glazed configuration featuring two sheets of glass sandwiching two layers of plastic films which have selective low-e coatings on surfaces 3, 5, and 7. Placing the low-e coatings in this configuration limits the amount of long-wave thermal radiation from indoors to outdoors while still allowing significant amounts of solar gains transmitted through the glazing. To achieve the high performance frame design the team has developed custom wood curtain wall window frames with warm edge spacers. THERM5 and EnergyPlus simulations are being performed to determine the optimal embedment depth of the window into the frame, optimal window sizes and the optimal edge spacer material.

Current energy modeling indicates that up to 30% of the winter heating load can be delivered by passive solar radiation entering through the high performance glazing (Fig. 3). However, solar radiation entering the building must be mediated by an active shading system in order to avoid overheating. Simulation modeling shows that dynamic shading, combined with phase change materials (PCM's) in the floor and ceiling, significantly decreases the cooling load, while taking maximum advantage of passive heating. A dynamic exterior shading system of customized exterior venetian blinds wraps the glazed volume of the house, managing the passive heating and cooling of the building by offering a range of modes and configurations, from full solar penetration to full shading, always allowing the occupant to choose to expose panoramic views of the landscape, or close the shades completely (Fig. 4).

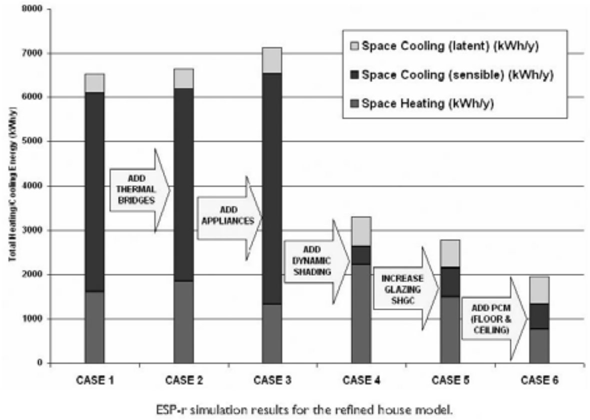

Figure 3: ESP-r simulation results illustrating effect of dynamic shading and PCM's to cooling and heating loads. (simulation climate: Toronto, Canada CWEC data)

Figure 4: Dynamic shading system: formal exploration.

EMPOWERING THE OCCUPANT: *ALIS*

An emerging area of research in the design of sustainable buildings is the extent to which the occupants of that building are engaged and involved with its operation [2, 7]. The motivation for the design of the North House Adaptive Living Interface System (ALIS) is rooted in the observation that intelligent buildings are not just automated but provide the occupants with the information and access to help the building work more efficiently (Fig. 5). Cole et. al. stress the need to add this concept of *occupant intelligence* to existing design concepts of intelligent buildings. Buildings that are designed around occupant intelligence will provide flexible, adaptive work environments, refined control zones and technologies that maximize occupants' access to adaptive opportunities [2]. A critical issue, then, in supporting occupant intelligence revolves around how the system is presented to its users and how appropriately the complexity is mapped to both the expertise and the involvement of the user. A common observed enemy of occupant satisfaction is when the building control system becomes too complex for its managers [7].

When we consider that the bulk of this research has been carried on large, usually work-related buildings, the nature of the questions expands. The occupant of North House is both *resident* (not worker or part-time visitor) and *manager*. People engage with their homes in very different ways than with the work environments studied in the research described above. Issues of comfort, identity, and repose are critical. Should one be expected to be an expert building manager? The trend in current systems (such as FatSpaniel[fs] or Domotica[ref]) seems to derive from a “resident as interested manager” model. In a study of 35 families committed to sustainable living in “green” residences, Woodruff et al. discovered that committed adopters of sustainable building technologies take pride in their expertise around these technologies but emphasize that knowledge and constant management become a way of life in these houses [11]. In fact, many participants described living in a sustainable house as “piloting a ship”, demanding constant, active monitoring; course corrections and reconfiguration; and strategies for understanding how occupant behaviour interacts with the desired outcomes (including reduced ecological footprint, comfort, and social outcomes such as influencing others’ actions). To quote one participant in the study: “There is no such thing as a passive house: the technology may be passive but the occupants have to be constantly active!” [11].

The people in this study, however, had already made substantial changes to their ways of life motivated by their strong social philosophies and were willing to embark on that ship. What about the “average” person? As part of our User-Centered Design [9] approach, we conducted a workshop with people who described themselves as “interested” in sustainable living environments but who had no experience with any such. Participants included students, professionals and blue and white-collar workers. While the motivating models differed (some were more interested in positive financial outcomes where others were more interested in their energy footprint and ecological impact), we found several common threads. The first was time: all of our “users” identified themselves as very busy people and were concerned about having to spend too much time and effort in managing the house. A related thread was place: people are very mobile, wanted appropriate information and controls accessible from wherever they were, and wanted localized and contextually appropriate access in the house itself. For example, none found the notion of a central control panel and dashboard for lights, shutters, etc. very useful, but liked the idea of information and controls in place. A third was related to complexity: whereas several indicated they would be interested in learning more about how the house actually worked, all wanted a simple interface with a low learning curve that would provide quick access to reasonable house configuration while allowing the more expert user to fine tune settings. Finally, participants really wanted to know “how they were doing” in the context of their particular goals (financial, energy use) and how this changed over time and events.

The Woodruff participants and our workshop interviewees represent different ends of a spectrum, and suggest we need to characterize our user base along several complementary dimensions:

- engagement: how actively involved they are and want to be in the process of how the house works
- commitment: how dedicated they are to particular outcomes (and implicitly how much and what they are prepared to commit in terms of time and learning curve)
- technological aptitude and inclination
- goals and motivations (e.g. financial, green, pragmatic, philosophical)

ALIS combines several different types of interface technologies to span these seemingly divergent needs. It is grounded in several design principles outlined below.

Supporting the right tasks. Rather than think of the tasks the user performs in terms of the house technology, we need to capture what the user wants to do. For example, the user doesn’t want to turn off all the lights and reduce heat when away; rather, she wants to conserve as much energy as possible while making sure the house will be comfortable when she returns. Indentifying tasks with respect to desired outcome as much as possible enables us to define modes and task sequences that reduce the user’s cognitive overhead and time to execute. Preparing the house for an “away” period, for example, may better be modeled as a *mode* with configurable settings rather than as a set of individual steps.

Ubiquity. Information and access to building configuration should be available wherever and whenever the user desires it. This means both from remote locations and on different devices. It also mandates a common information framework that maps coherently to the user’s model across widely different representations and types of control.

Contextually appropriate information and control. Information and feedback should be integrated into the house in contextually appropriate ways that present little overhead to the user but support relevant tasks. If the user wishes to know simply whether running the dishwasher will cause the house to pull from the grid, then a small ambient display such as a light on the dishwasher can effectively convey this information. If the user wants to know how much energy over the past month has been put back in the grid, then a standard UI supporting query and display is much more appropriate. From another perspective, organizing information about always-on appliances into "vampire power drain", or continuous tracking displays may be more effective than simply displaying consumption patterns around the entire house for suggesting behaviour changes to the user.

Integration with life. Rather than deliver a whole new set of tools and devices to the user to manage the house, we endeavour to integrate those functions where possible with familiar tools and systems. For example, scheduling functions for house operations and modes should be integrated into current calendaring and messaging applications that residents use, so that house information and control are seamlessly included in their personal information management tools.

Meaningful performance feedback. Information about how well the house is performing is most meaningful when it is related to the user's goals. The user should be able to set milestones and views with respect to these goals. For example, a user may want to set milestones and warnings around a particular level of energy consumption; alternately she may choose to monitor the cost of that consumption. Simple incentives, like a progress meter or "awards" notification, can serve to gently cue the user when choices result in achieving a milestone.

ALIS COMPONENTS

Three types of user interface components comprise the ALIS. First, we are developing a standard web-basesd graphical user interface (GUI) that can be accessed from anywhere connected to the Internet. This GUI includes traditional application-style tools that provide an overview of building state and performance and supply alerts according to user-specified events. Capabilities include full controls to configure the house settings, pull up histories of consumption and settings, and forecast energy and water use based on current and predicted weather conditions. We are extending the GUI to a set of mobile components for a smartPhone, further extending ubiquity. (Full forecasting and history analytical tools are not currently planned for the smartPhone, however). Users can monitor building performance and make decisions from remote locations allowing them, for example, to elect to sell excess energy to the grid while away from home. Relevant GUI functions will be integrated as well into common personal applications such as Google™ Calendar, email, social networking sites (e.g. Facebook) , and others.

Second, we are developing a set of small, peripheral, always-on information components that provide a continuous overview of the house, deliver appropriate alerts, and serve as a quick navigation button into remote controls. These peripheral information tools reside on a desktop or phone and run without requiring dedicated attention, similar to IM tools like MSN Messenger™. We anticipate that the provision of these tools will provide more effortless integration into occupants' daily routines, as they will not demand a dedicated focus to provide relevant updates.

Third, we are exploring ambient and subtle information systems that are "organically integrated" into the house itself, changing their behaviour as conditions change in small and non-intrusive ways. These subtly cue occupants to change and state in both general and contextually specific ways. For example, a dynamically illuminated surface called the "Ambient Dashboard" paints a pattern that changes colour according to house performance and efficiency and forms an aesthetic element in the house in its own right.

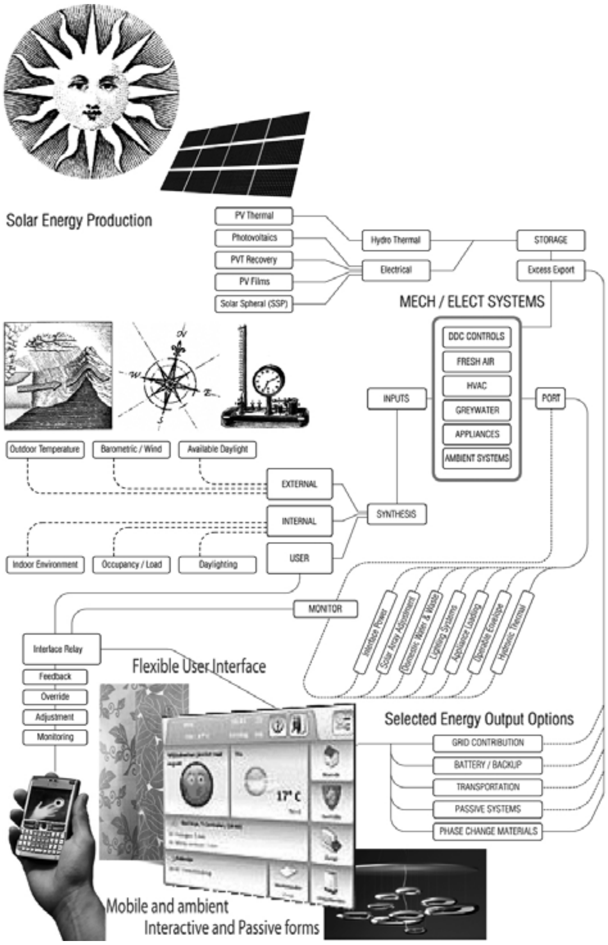

Figure 5: ALIS conceptual schematic diagram.

The artificial lighting of North House is based on the idea that light not only becomes a source of illumination necessary for tasks, but is also a way of communicating with the house. Lighting provides information about the energy use of the home, allows the occupants to set the ambient night mood of the house and is also strategically located to enhance the social and sensual parts of the house. The primary areas of light-based communication with the house are the underside of the suspended bed and the shower, which are also the main areas for sensual rituals within the home. Coloured light emitting diodes (LED's) are connected to the North House energy system. When the occupant turns those lights on, they glow with colors that are coded to reflect the energy status of the home (i.e. blue if the house is drawing heavily from the grid and gold if the house has an abundance of energy generated from the photovoltaics). The occupant than can override the colours to set their own mood and ambience, after the initial connection with the status of the house has been made. Other ambient devices are being developed by the team and include haptic feedback devices that respond to current energy consumption, or subtle audio indications of something changing in the house's performance according to user specified events. Additionally, indicator lights attached to appliances suggest whether power conditions are good for using the device in question.

This research is led by a team at SFU's Interactive Arts and Technology who are deeply engaged in the user-centred design of human-digital interface systems and pervasive computing interfaces. Current design prototypes are under active development for initial testing for efficacy, clarity and relevance. The impact of immediate performance feedback on building user habits and energy use patterns will be studied in the post occupancy monitoring phase of the project.

CONCLUSION

North House is a prototype solar home that deploys a simple, elemental design, and both built components (interior and exterior) as well as technologies are able to be personalized and modified to suit specific lifestyles, needs, and desires. With regard to occupant-focused design, the thesis of the design rests in the idea that by empowering the occupants with both knowledge and control, they are able to make intelligent choices and to transform their own habits and rituals to live more sustainably and intelligently. The North House will be reinstalled in Canada after competing in the Solar Decathlon and will undergo a minimum of two years of Post-Occupancy Evaluation (POE) and testing, gathering both quantitative data on energy performance, as well as qualitative data on user livability, comfort and user satisfaction. The post-occupancy results will be measured against performance simulations during the design phase and will be used to provide feedback on simulation software, develop further prototype iterations and to add a much-needed residential component within current research on how occupants interact with intelligent and automated green building environments, and the impact of building intelligence on behaviour and livability.

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