

PERKINS+WILL

Research Journal



2013 / VOL 05.01



www.perkinswill.com

SPECIAL ISSUE: NATIONAL SCIENCE FOUNDATION WORKSHOP
ARCHITECTURE AND ENGINEERING OF SUSTAINABLE BUILDINGS

03.

NORTH HOUSE:

Prototyping Climate Responsive Envelope and Control Systems

Geoffrey Thün, BES, OAA, MRAIC, LEED AP, gthun@umich.edu

Kathy Velikov, MUD, BES, MRAIC, LEED AP, kvelikov@umich.edu

ABSTRACT

This article presents North House, an interdisciplinary, inter-institutional design research project to develop a full-scale prototype of a net-positive energy solar powered residence optimized for cold climate applications and describes the project's performance objectives that privileged environmentally responsive envelope design, the use of hybrid passive and active energy systems and inhabitant participation in managing the home's energy profile. These design principles and their respective performance measures were developed and evaluated by way of a tripartite suite of interdependent systems and technologies, each of which were used in building and operating the North House prototype: (i) DReSS: Distributed Responsive System of Skins, (ii) CHAS: Central Home Automation Server, and (iii) ALIS: Adaptive Living Interface System. The work presented here formed part of a broader presentation outlining ongoing research by the authors in the area of responsive envelopes as presented at an NSF sponsored workshop in July 2012 at the offices of Perkins+Will in Chicago. For more information on ongoing research by the authors, see <http://rvtr.com/research/catalogue/>.

KEYWORDS: responsive envelopes, net energy positive housing, residential building controls, building envelope design, solar facade systems

1.0 INTRODUCTION

The North House project was developed by a collaborative interdisciplinary team (Team North) of researchers and students at the University of Waterloo, Ryerson University and Simon Fraser University in concert with industry and professional partners between 2008 and 2010. The project was one of 20 selected for the US Department of Energy's 2009 Solar Decathlon, placing fourth in the competition. Subsequently the home has been re-assembled on the grounds of the RARE Charitable Research Reserve in Cambridge, Ontario, where it will become a permanent living lab and testbed. Central to the team's approach to research and project development was a perspective that privileged the pursuit of responsive systems, that is, systems that are capable of dynamic response to dynamic environmental, energetic and occupant demands. Architectural systems were designed with capabilities for second order cybernetics, co-evolution and learning. This concept, increasingly of interest to architectural researchers, is explored here in

the design and prototype development of a high performance residential model for mass-customized housing tailored to cold climate applications. The design and production of a full scale prototype discussed here, aims to test the plausibility and impacts that such a set of priorities might yield, and to explore the implications of such a perspective with respect to material systems, building controls and user interface models and their interrelations for future work.

2.0 PERFORMANCE PARADIGMS AND CHALLENGES

North House participates within the field of high-performance housing by embracing advanced integrated technologies that not only help manage building energy, resources and comfort but also make it possible for building inhabitants to actively redefine their role in how the home and its surroundings achieve their sustainability goals (Figure 1). The house was designed to perform beyond net-zero by operating as a net-positive energy dwelling. Equipped with energy generation ca-



Figure 1: North House as installed on the Mall in Washington DC, Fall 2009.

capacity, North House produces annually more energy than it consumes. The dwelling's Building Integrated and Building Applied Photovoltaics (BIPV and BAPV) were designed to be grid-tied, contributing to a distributed energy infrastructure and rendering its homeowner an energy producer.

North House featured design strategies tailored specifically to near northern climates (42° – 55° Latitude), where heating loads are significant relative to annual energy demand. These climates are characterized by wide annual extremes in temperature and humidity, and during much of the annual cycle periods of available daylight are short. This places special emphasis on maximizing available daylight to the interior and on constraints faced when wishing to generate on-site solar power. Hence, a research goal central to North House was challenging dominant "best practice" paradigms, which assume that buildings with high window-wall ratios are energy inefficient. Typically, buildings in northern climates are designed with minimally glazed areas because commercially available windows possess lower insulation values and higher air leakage coefficients than the opaque insulated assemblies in which they are located. Recognizing the energy related problems associated with large expanses of glass, prescriptive energy codes often restrict the window-wall ratio to 40% or less¹.

In stark contrast to this position, North House takes advantage of recent advances in glazing technology, active shading systems, thermal mass, and control systems to develop a high performance house with a highly-glazed facade (75% window-wall ratio), which, when combined with on-site solar power generation, was calculated to reach net-energy production of 6600 kW annually. The configuration and proportions of the home, consisting of a south-facing open concept living space and north-facing highly insulated service zone, optimize perimeter envelope ratios for minimizing heat losses while maximizing winter passive solar gains. This also facilitates the transmission of ample daylighting; a strategy which addresses winter daylight deprivation and seasonal affective disorder typical of higher latitudes².

A definition of "high performance" is herein examined which considers the performance of environmentally responsive envelopes, of hybrid passive and active energy systems, and of the role of informed inhabitants in managing the energy profile of a building. To this end, the following building case study discusses the tripartite suite of interdependent systems and technologies; (i) DReSS: Distributed Responsive System of Skins, (ii) CHAS: Central Home Automation Server, and (iii) ALIS: Adaptive Living Interface System. In this detailed discussion of the building's envelope, its controls and its interactive user interface, it will be argued that North

House radically revisits the ambitions of transparency and systems design which underscored early modernist housing, yet seriously addresses contemporary questions of environmental performance and construction technologies³.

3.0 DRESS: DISTRIBUTED RESPONSIVE SYSTEM OF SKINS: CLIMATE-ADAPTIVE ENVELOPE PERFORMANCE

In order to respond to the wide range of seasonal climate extremes characteristic of near northern climates, and to achieve environmentally responsive envelope performance, the design of the building envelope com-

prised both opaque and transparent assemblies (Figure 2). Where appropriate, opaque assemblies were integrated with active energy generating components, while transparent assemblies combined passive strategies with active energy systems and comfort management. The design was based on an ecological systems approach, wherein the building skin was composed of performative and interdependent layers that, like the body's epidermis, were designed to serve individual as well as cumulative environmental functions. The layers were capable of automated modifications in response to external conditions and/or internal demands and the larger system is referred to as the Distributed Responsive System of Skins, or the DReSS.

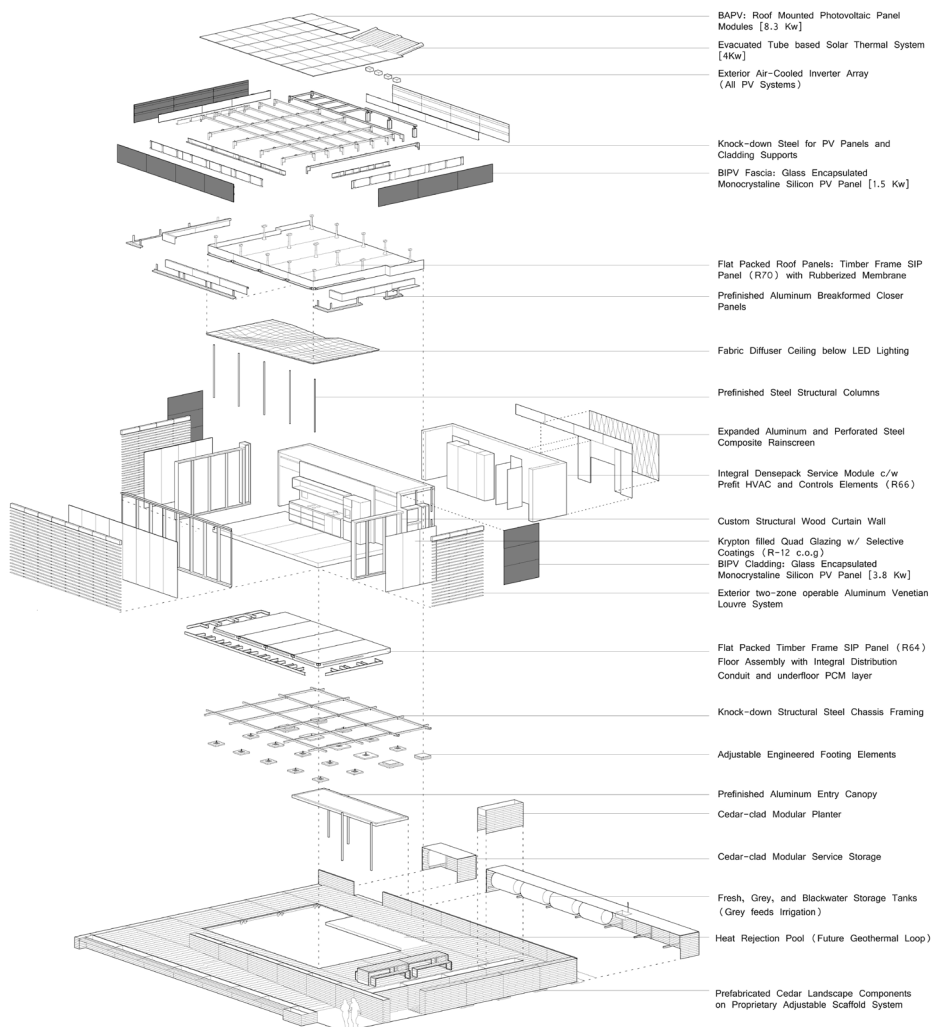


Figure 2: Exploded axonometric of North House building components.

3.1 Opaque Assemblies

During the schematic design phase, energy demand simulations were used to determine design targets for the opaque assemblies of the roof, floor, north facade and portions of the east and west facades. These building envelopes were designed with high thermal resistance values, typical of cold-climate, low-energy design. For designing the vertical faces of the assembly, the team used WUFI® modeling software to predict the heat and moisture transport (hygrothermal analysis) through various types of assemblies. Based on analysis results, the team designed structural panel assemblies of engineered wood, for use both horizontally and vertically, with offset framing to create a consistently thick assembly with no through-and-through thermal bridges. The cavities were filled with R-7.2/inch soy-based polyisocyanurate foam insulation to produce an airtight enclosure with insulation values of R-70 for the roof, R-64 for walls and R-51 for the floor⁴. Exterior and interior 16mm Medium Density Overlay (MDO) panel skins were used to manage shear and face-related forces while providing continuous anchorage support. These were finished on the exterior face with a liquid applied air barrier system

over which rain screen assemblies were added. Active energy-producing photovoltaic layers were integrated within opaque assemblies oriented for solar exposure.

3.2 Energy Generating Assemblies

On the roof of the project, an 8.3 kWp BAPV array captured the high summer sun while also integrating solar thermal evacuated tube collectors (4 kWp) for domestic hot water and supplementary space heating. A 600mm airspace between the roofing membrane and the underside of the PV modules assisted in mediating heat gain beneath the panels, ensuring optimum performance during periods of intensive solar exposure. Vertical exterior walls on the northeast and northwest, as well as the southern facing fascia, were clad with a glass encapsulated 5.3 kWp BIPV rainscreen. (Figure 3) This dry-jointed facade system, anchored to extruded aluminum face-mounted rails, integrated electrical power generation within the building envelope. The active vertical BIPV facades extended the period of daytime electrical power generation, capturing low incidence solar energy typical of winter months, as well as early mornings and late afternoons.



Figure 3: Detail of BIPV fascia at southeast corner with exterior shades open (Photo by Terri Boake).

3.3 Transparent Assemblies

The remaining east, south and west facades were built using transparent assembly components comprised of a number of distinct layers, each designed to manage overall energy performance⁵. (Figure 4) The primary glazed assemblies were made of large floor-to-ceiling panels of a custom-designed wood frame curtain-wall system that utilized quadruple-layered insulated glazing units (IGUs) with a very high thermal resistance, albeit engineered to maximize passive solar gains. Unwanted heating loads were managed by an automated active

exterior shading system made of motorized horizontal aluminum blinds attached by vertical tension members to the structure of the facade. Inboard of the primary glass envelope, motorized interior blinds delivered daylight diffusion on demand and a custom fabricated interior soffit transmitted light deep into the space. The final performance layer of the system was made possible by Phase Change Materials (PCMs) embedded within the floor's wood frame assembly to chemically simulate thermal mass.

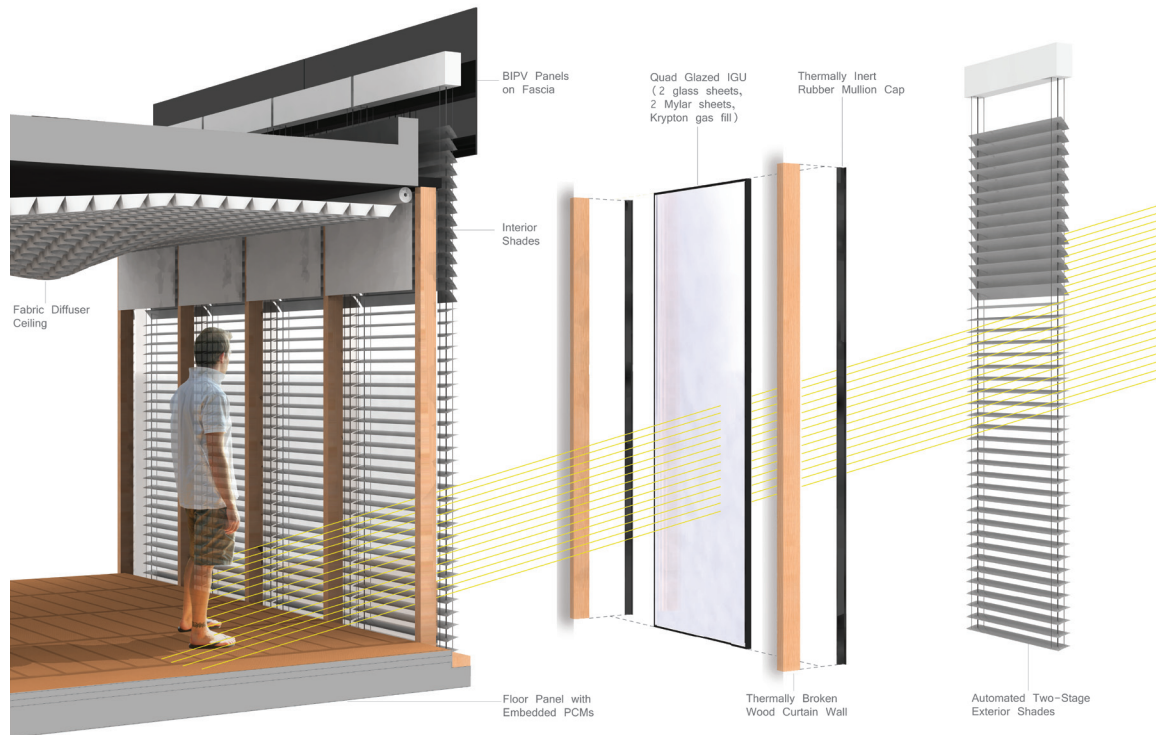


Figure 4: Components of Distributed Responsive System of Skins (DReSS).

3.4 Active Exterior Shading

Early energy models, produced using customized ESP-r and TRNSYS software, determined that exterior shading could significantly lower the cooling load, while allowing the glazed areas to take full advantage of passive solar radiation during heating months. (Figure 5) The location of the shading on the exterior of the envelope was critical to the overall performance of the system as it blocked solar energy outboard of the building envelope, eliminating heat buildup within the glazed assembly. The design team evaluated a wide range of custom external operable, mesh and curtain louver systems, ultimately selecting a proprietary system of Venetian blind type exterior shades. The system offered two important benefits: (i) the shades could easily and automatically be fully retracted from the face of the building behind its fascia to admit maximum solar penetration, daylight,

and views; and (ii) the individual slats were capable of a rotational range of almost 180° allowing for a high degree of precision in the control of solar shading, suitable for a variety of conditions and occupancy modes. (Figure 6) The 3048mm high shading panels were divided into two shading zones with individual rotation capacity for each zone; the 915mm high upper clerestory could be opened to allow natural light to enter the space while the lower zone was optimally rotated for blocking solar radiation. (Figure 7, left) Roof mounted daylight and wind sensors provided primary data measuring the availability of solar radiation and the blinds were programmed to retract below 100 lux and at wind speeds of over 12 m/s. The use of this active shading system is expected to reduce the cooling load by as much as 46% (Figure 8).

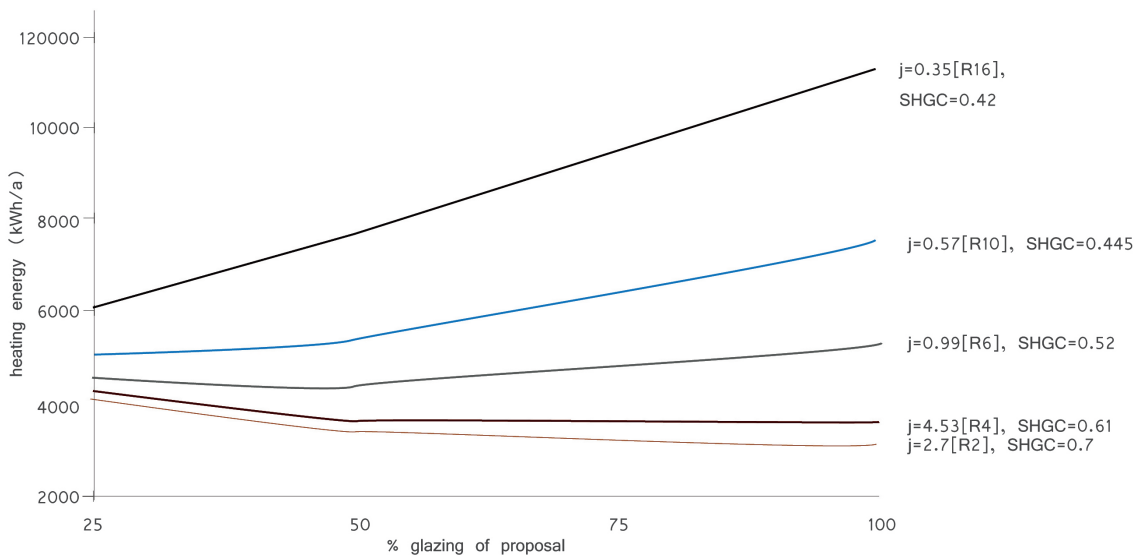


Figure 5: Predicted effect of various glazing property combinations and percentage glazing on annual heating energy.

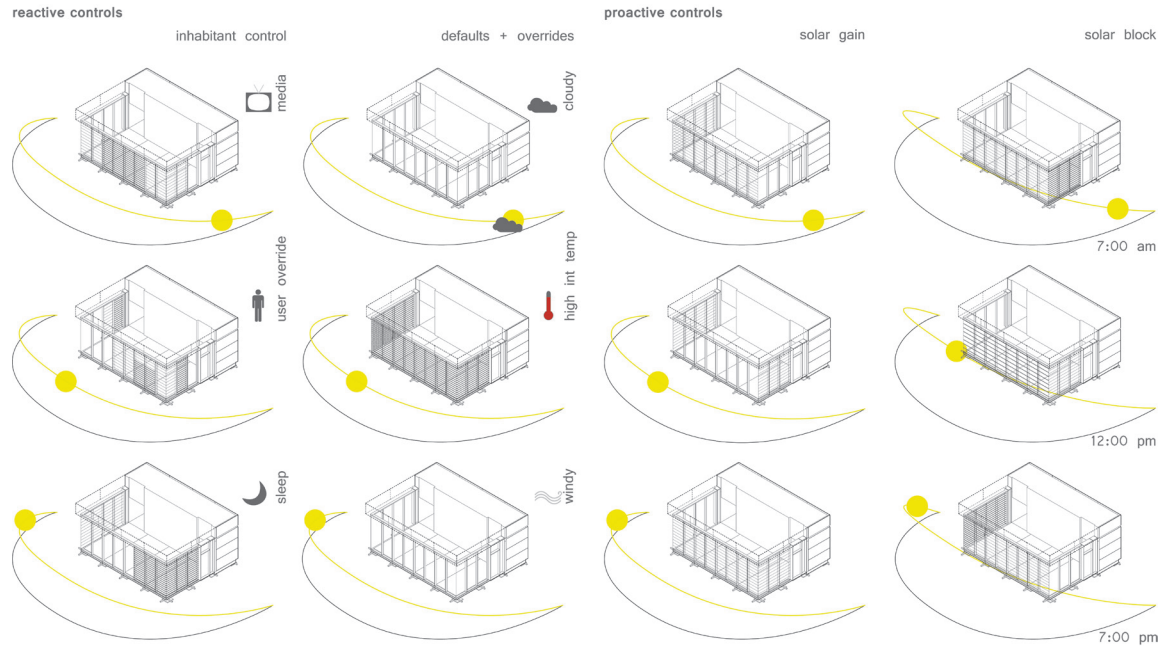


Figure 6: Exterior shade configuration scenarios based on relative exterior environmental conditions, and related responsive envelope reactions that formed an operational logistics framework for the development of the home automation system.

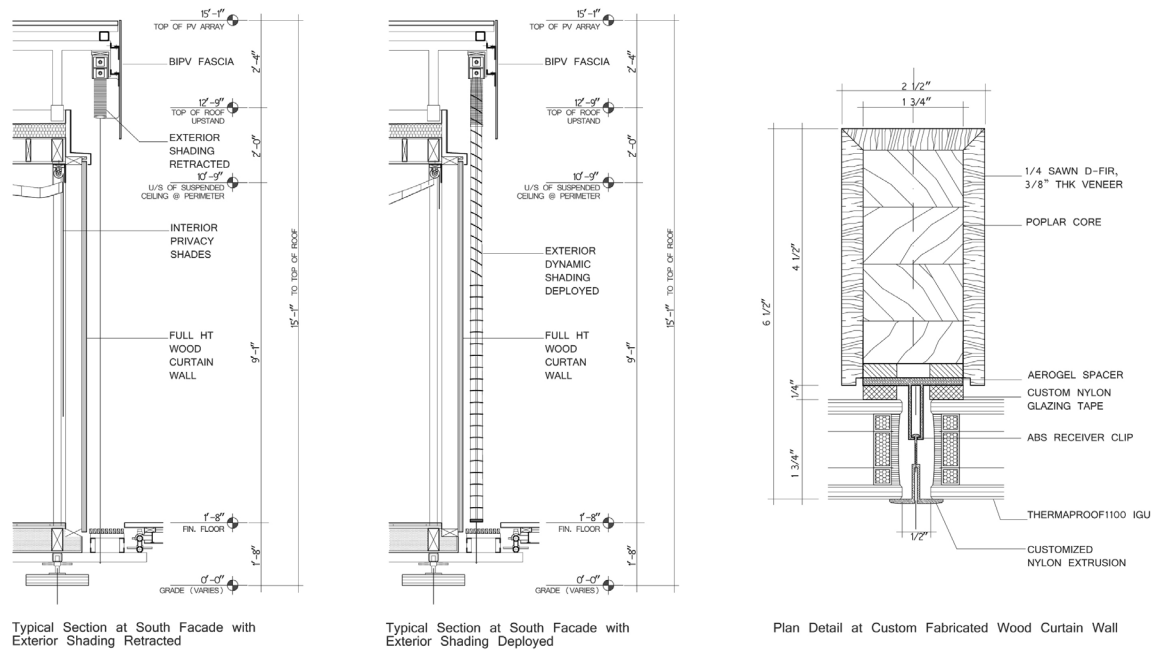


Figure 7: Technical details at wood curtain-wall envelope with automated shading.

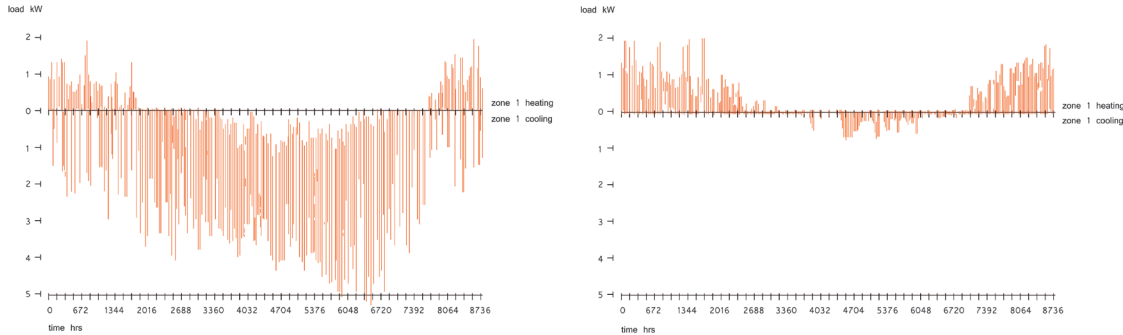


Figure 8: Modified ESP-r model of annual heating and cooling loads with no shading (left) and with dynamic shading (right).

3.5 Custom Wood Frame + Insulated Glazing System

Given that summer cooling is largely managed by the exterior shades, the glazing system was designed to provide maximum thermal resistance combined with optimized passive solar heat gain during the winter. Based on extensive energy modeling as well as considerations related to product availability and constructability, the chosen insulated glazing unit (IGU) was a Quad-Glazed Krypton filled unit comprised of two 6.5 mm sheets of clear low-iron glass sandwiching two sheets of Heat Mirror 88 (HM-88) mylar films. Low emissivity (low-E) coatings were placed on glazing surfaces 3, 5, and 7, with selective transmittance values engineered to maintain a moderate Solar Heat Gain Coefficient (SHGC) across the four layered assembly⁶. Low-E coatings minimize long-wave thermal radiation transfer across the glass cavity; a factor which typically accounts for nearly 60% of the thermal transmission in most IGUs⁷. The air cavity was filled with Krypton, a denser noble gas with lower convective heat transfer properties than air, further contributing to the reduction of heat transfer across the IGU. The use of Krypton also enabled a thinner frame and cavity with an optimal width of 9mm, instead of the standard 12.7mm⁸. The resulting IGU had a center of glass insulating value of R-12 (U-value of 0.474 W/m²K), a Solar Heat Gain Coefficient of 0.404, and a Visual Transmittance of 0.5434. The overall design of the glazing system first minimized locations of edge and mullion incidence by developing an uninterrupted floor to ceiling frame with large areas of individual IGU panels (nominal 1117mm x 2895mm). This reduced the ratio of center of glass (highest resistance) to frame (lowest resistance), and resulted in a performance of R-8 (U-value of 0.71 W/m²K) across the whole assembly. This particular IGU is typically manufactured with

a highly conductive steel spacer to hold the mylar films taut, but in order to improve the thermal resistance of the spacer, the team worked directly with the manufacturer to substitute a proprietary low conductance material for all perimeter spacer locations, reducing thermal bridging at the IGU edge.

The wood frame curtain-wall system in which the IGUs were positioned, was backed with custom designed quarter-sawn faced Douglas Fir mullions with a built-up Poplar core to provide the unit with dimensional stability. (Figure 6, right) The framing system utilized a mechanically fastened Fiberglass pressure plate to fix the top and bottom edges of the IGU, with compressive foam gaskets at 80% compression to provide a vapor and air seal without permanent sealants. In order to ensure a continuous exterior appearance of the system and to minimize thermal bridging impacts relative to vertical mullion placement, the team developed a milled nylon “T” and rubber snap-in face-gasketed cap. Finally, the function of natural ventilation was separated from the primary glazing system and achieved on the east and west facades through manually operated full-height insulated opaque casement units.

3.6 Integrated Phase Change Materials

Solar heat gained throughout the day was not only used to passively heat North house but was also stored for use as latent heat throughout the night. This was achieved using 61.32m² of Phase Change Materials (PCMs) installed directly underneath 16mm engineered hardwood flooring. In this position these highly engineered materials absorbed thermal energy from the sunlight which fell directly on the floor. PCMs are based on the principle that when matter changes phase, as when solids become liquids or liquids become solids, a great

deal of energy is absorbed and/or released from the environment, without a change in temperature. PCMs are light, flexible, and compact, yet their large heat storage capacity and specifiable temperature helps to reduce both total heating and cooling loads. They store heat when there is excess; release heat when there is a deficit. In doing so, they reduce peak heating and cooling loads by mitigating the daily variations in interior temperatures. The PCM used at North House was a proprietary salt-hydrate solution contained in 15 mm thick polypropylene panels and engineered to melt at 24°C (76°F) and solidify at 22°C (72°F). With a latent heat capacity of 158 kJ/kg, the panels had an approximate heat storage capacity of 62.6 kWh⁹. Because the PCM material was not directly exposed to the interior space, the resulting assembly experienced a 15-minute delay in the absorption and release of heat. This material contributed significantly to the overall energy performance of the home, and ESP-r simulations predicted the overall space-conditioning load of the home was reduced from approximately 2800 kWh/yr to less than 2000 kWh/yr when active. (Figure 9)

3.7 Interior Layers: Roller Blinds and Ceiling Panels

With such highly glazed facades, the control of glare and privacy was critical for the comfort of inhabitants. The DReSS included an interior motorized roller blind system controlled by the user through a digital interface that moved the shades either individually or by facade group (east, south, or west). With both the exterior shades and interior blinds working in concert, daylight and view can be orchestrated to suit any activity or preference. Moreover, the suspended translucent fabric ceiling softened the visual and acoustic properties of the space. Parametrically modeled using Rhino 3d and the Paneling Tools plug-in, the three-dimensional surface of varying thickness and opacity (to spatially correspond with zones of activity and repose) mediated the LED downlights and worked with the clerestory tilt-zone of the exterior shades to distribute and diffuse daylight deep into the living space. (Figure 10)

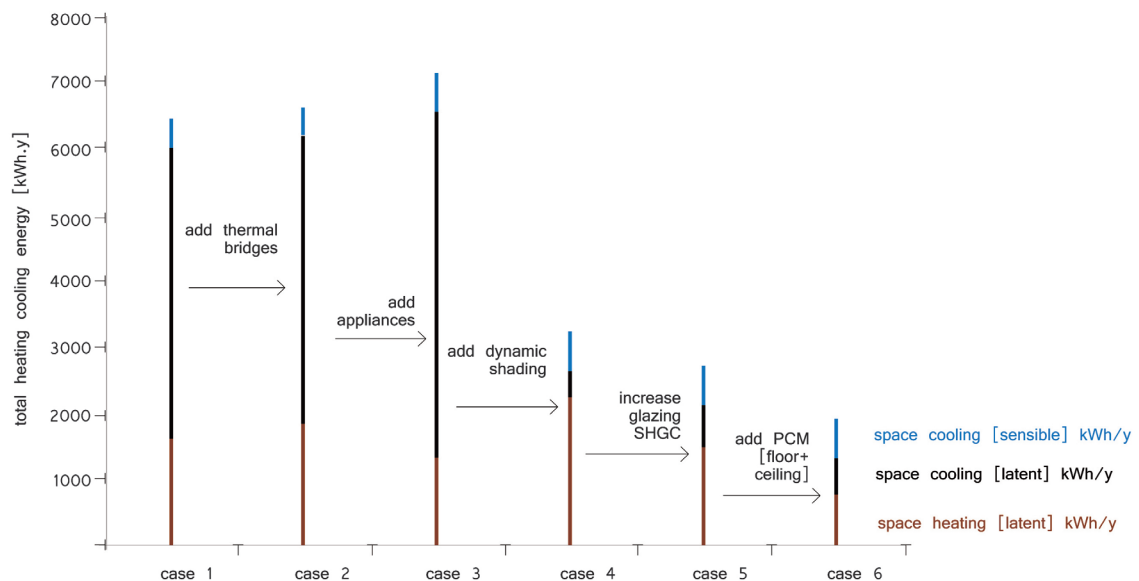


Figure 9: Predicted demand reduction effects of DReSS design strategies on annual space conditioning load.



Figure 10: Interior of main living space with internal and external shades deployed and light diffusing soffit above. Ambient canvas delivers haptic information at kitchen backsplash.

Hence, the DReSS was an integrated assembly of highly engineered components that each served a specific environmental function. Optimized for a broad range of climate variations characteristic of the near north – from high heat and humidity in summer months to prolonged periods below freezing in winter months – this layered multivalent system enabled multiple configurations as defined by program needs. The construction details of this component-based system are anticipated to allow for the various layers to be serviced, upgraded or replaced independent of each other, insuring flexibility and resilience over time. During the test conditions of

the Solar Decathlon competition, North House generated more electricity from the photovoltaic array than it consumed and consistently maintained interior conditions within the comfort zone, while exterior temperatures and humidity varied greatly in the October weather¹⁰. (Figure 11) However, it must also be noted that the unique use requirements of the Solar Decathlon do not map on typical home use patterns, rendering the verification of the simulated performance inconclusive. A comprehensive program of occupancy testing is expected to commence in late 2013.

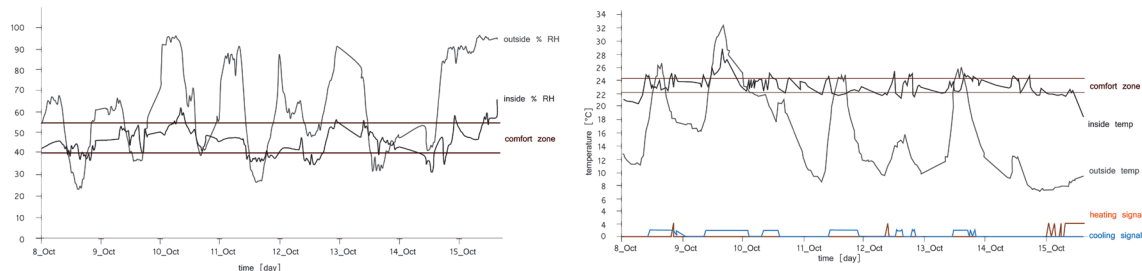


Figure 11: Performance data gathered during ten days of Solar Decathlon competition: relative humidity %RH (left), and interior temperature performance and logged system response to temperature fluctuations (right).

4.0 CHAS: CENTRAL HOME AUTOMATION SERVER - INTEGRATED SYSTEMS PERFORMANCE OPTIMIZATION

In order to manage the building's high degree of adaptability, a customized Central Home Automation Server (CHAS) was developed for North House. CHAS is a computerized controls architecture developed to manage all of the home's systems and subsystems, and designed to make high-level decisions enhancing energy performance. It continually optimizes available energy flows as, for example, when CHAS determines the operation of the external shading system is a function of the internal and external air temperatures, the amount of available solar irradiation, exterior wind speeds, and the detected position of the sun. Based on sensor readings, the system determines if the house should go into solar heat harvest mode to save on heating energy or solar heat rejection mode to save on cooling energy. Similarly, CHAS controls the HVAC system in conjunction with the operation of the exterior shades to ensure thermal comfort while maximizing energy efficiency¹¹.

During most of the year the house's heating and cooling needs are met by the exterior shades and the passive building envelope assembly. Being the most energy efficient strategy, CHAS privileges this passive method of thermal management whenever possible, reserving the HVAC system as backup. This integrated approach offers significant savings in operational energy as well as capital costs, since the majority of the HVAC equipment can be significantly downsized. The team developed a customized solar domestic hot water and HVAC system comprised of a three-tank solar thermal system combined with two variable capacity heat pumps. (Figure 12) It is estimated that this unique system will provide, on average, 65% of the required hot water for space heating, cooling and domestic uses, with collected solar thermal energy alone.

Embedded sensors above the interior fabric ceiling and exterior sensors located on a rooftop weather station provide continuous real time data to the CHAS system. A hysteresis control algorithm allows CHAS to make intelligent decisions based on real-time inputs and previous system states, ensuring smooth transitions between states and avoiding frequent "chattering" between different settings. (Figure 13) In total, CHAS interfaces with and coordinates seven systems, including the HVAC, domestic hot water, exterior shades, interior blinds, lighting, bed retraction, energy monitoring, and the ALIS. Two computers are central to CHAS, the touch-screen panel PC (for high level presets and user

commands) and an embedded PC (for controlling all of the automatic processes). The HVAC system is controlled by the embedded PC, which collects data from sensors and co-ordinates the heat pumps, circulation pumps, and fans, to deliver the required conditions for thermal comfort. Occupants set the conditions using the Graphic User Interface (GUI) that is hosted on the touchscreen panel PC. A Branch Circuit Power Meter (BCPM) performs energy monitoring, which installed with the main electrical load center, measures the current, voltage and energy consumption of each circuit. The BCPM measures both the power consumption as well as power produced by the PV system, and while typically used for industrial (3-phase) applications, it required some adaptation for residential use.

While the hysteresis control algorithm developed for CHAS was based on design logics prioritizing energy performance, system logistics were pre-determined relative to a range of anticipated scenarios. A future development of the system would include the capacity for CHAS to evaluate various response scenarios relative to both performance data and user preferences over time. This would enable the system to "learn" by refining the initial design modeling with respect to response automation and particular inhabitant practices.

5.0 ALIS: ADAPTIVE LIVING INTERFACE SYSTEM - INHABITANT PERFORMANCE ENABLER

Whereas the building envelope and engineering systems for North House were automated through CHAS, the Adaptive Living Interface System (ALIS)¹² offered building inhabitants the ability to set predefined modes, to override the system and to operate the home as met their needs and lifestyles through an intuitive graphical touch screen interface. (Figure 14) ALIS functions beyond automated controls by providing an easy-to-use interface and a series of applications that help the inhabitant monitor the home's performance. It delivered meaningful feedback across a range of didactic, haptic and ambient formats and was integrated within the design of the house to be reflective of the lifestyle of those who inhabit it. As such, it supports long term behavioral transformations by identifying and supporting living patterns that save energy and resources.

The ALIS was designed to facilitate owner engagement in the home's operation without requiring expert knowledge of any one of the specific components. A building's energy consumption is typically comprised of heating, cooling, ventilation, humidity control, and

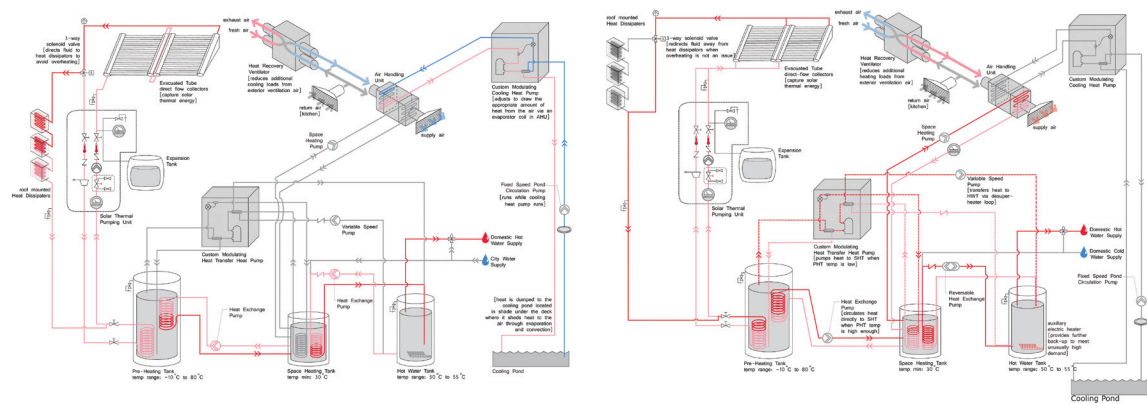


Figure 12: Diagrams of custom developed solar assisted heat pump system. Left, shows the system in cooling and dhw mode, where the space needs to be cooled, but hot water also needs to be produced. Right, shows the system in a heating mode where both space heating and water heating are required.

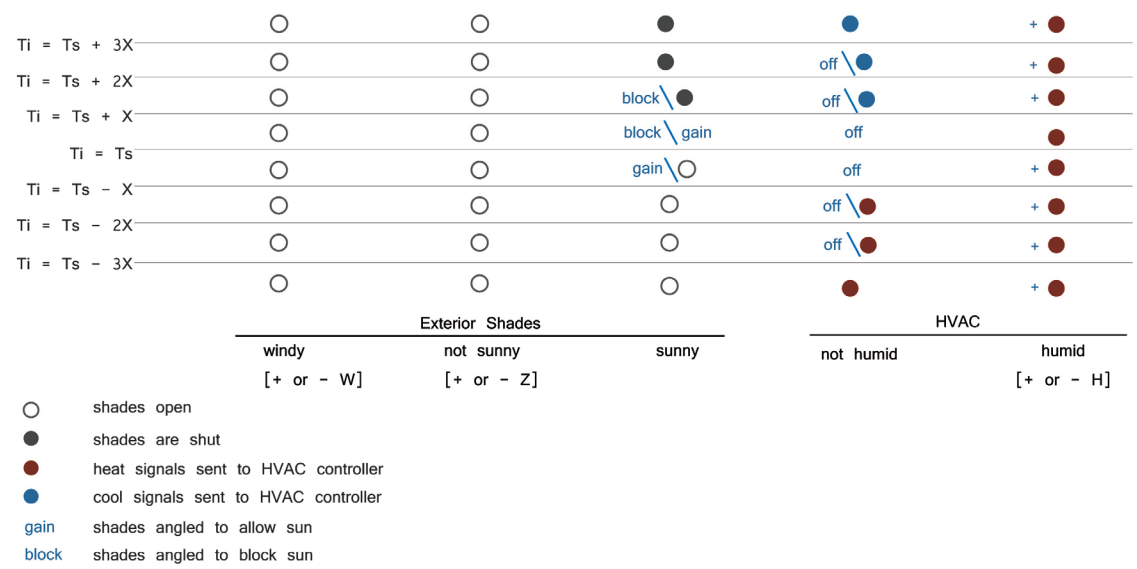


Figure 13: Logic diagrams for external shade and HVAC states, where Ts is the setpoint of thermostat, Ti is internal temperature, X is internal temperature hysteresis factor, Z is solar radiation hysteresis, W is wind speed hysteresis and H is humidity hysteresis.

lighting loads. While efficient equipment and advanced building envelopes can reduce this energy load, further energy conservation can only be achieved by involving the inhabitant directly in the control of comfort provisioning^{13, 14}. To this end, ALIS comprises three types of user interfaces: (i) active touch-screen panels distributed throughout the house; (ii) a web application, extended to a smartphone application for providing detailed graphic information feedback and advanced control options; and (iii) an embedded display that provides feedback in subtle, ambient formats. (Figure 15)

The touch-screen control panels are located at convenient and easily accessible locations, encouraging the inhabitant to sustain energy conscious living practices. (Figure 16) A large panel PC located in the kitchen makes possible the detailed control of all home systems, while a smaller screen positioned at each entrance manages local lighting. The preconfigured “modes” of whole home settings can be accessed via the kitchen touch-screen or any computer with an Internet connection. A similar smartphone application allows ubiquitous access to home monitoring and con-

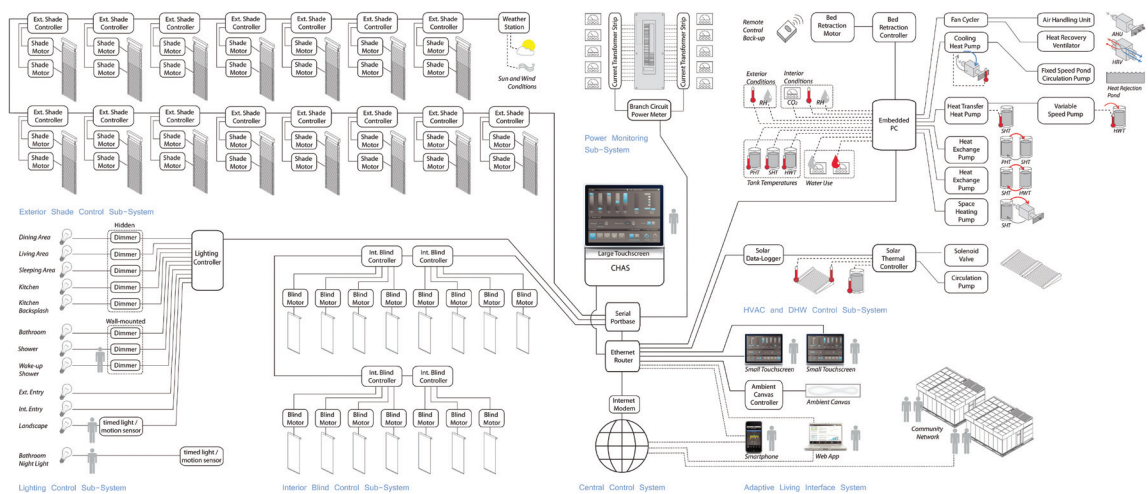


Figure 14: Overview control architecture of the Central Home Automation Server (CHAS), Adaptive Living Interface System (ALIS), and their integration with North House DReSS and mechanical sub-systems.

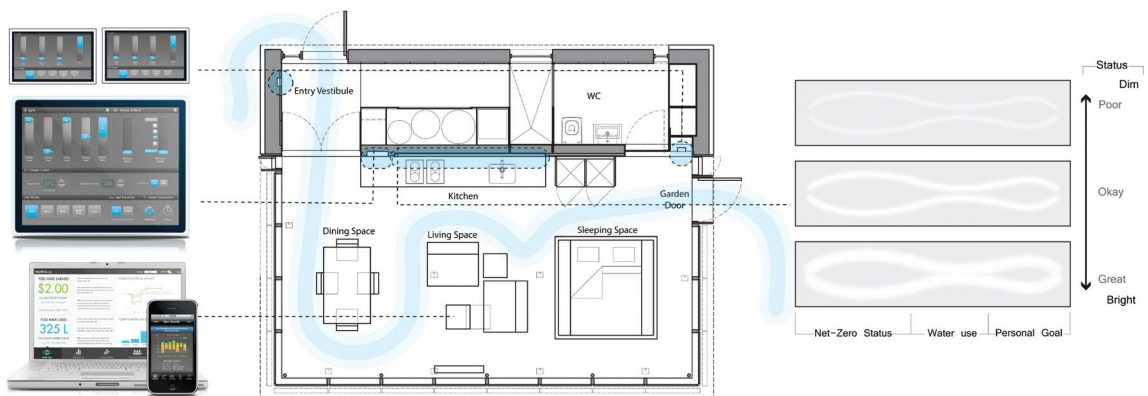


Figure 15: ALIS components and locations in plan (left) and Ambient Canvas operations indicating zoned areas of LED illumination (right).

trol, providing inhabitants with an array of features, including visualization of resource usage, management of house settings according to “modes” and schedules, and access to community networks. The “Resource Usage” feature graphically portrays detailed measurements of energy production, energy consumption by individual appliance, total water consumption, and hot water production and consumption. Inhabitants can choose to graph measurements on a daily, weekly, monthly, or yearly timescale, and compare them to historical records or weather patterns. Added features, such as annotating and bookmarking graphs, as well as calendar integration, allow the user to accumulate a nuanced understanding of energy use patterns over time. The “House Settings” feature has the ability to create and edit “modes” for system presets that correspond to recurring domestic activities. When inhabitant overrides compromise energy use optimization, the system informs them of the opportunity to choose a setting that does not compromise energy usage. The “Community Network” is a platform that recognizes the potential agency of online communities toward education and motivation for energy and resource use reduction, encouraging personal and communal goal setting, friendly

competition, and community information and resource sharing.

Additionally, the “Ambient Canvas”, located centrally along the kitchen backsplash (Figure 15, right), delivers continuous non-quantitative real-time ambient feedback on the home’s performance via visual cues. This complements the other forms of didactic feedback in the ALIS system while also acting as an aesthetic element in its own right. It is made of a series of LED rope lights, mounted behind a translucent Corian® surface, which glow with varying intensity in different zones according to net-energy consumption/ production and water consumption.

The intent of the ALIS system is to address the social and human element of sustainable buildings, to educate inhabitants about energy efficient practices and to support intelligent home use through design. It introduces a “learning” environment within the home, working towards a responsive system where both building and inhabitant functions co-evolve through continual feedback loops.



Figure 16: ALIS Home Systems Settings Touchscreen Panel and shade control user override operability and feedback (upper); ALIS GUI Web Application Resource Usage displays and Community Challenge Application display (lower).

6.0 CONCLUSION

The North House project advanced a number of pressing issues of interest to designers of high performance homes for cold climate applications. The development of specialized glazing systems paired with external shading has offered a unique opportunity for achieving the design of a net-energy positive system. Coordination of all building systems, through highly integrated and adaptive automation servers such as CHAS, made possible the hierarchical management of operational priorities of heating and cooling for occupant comfort, as well as enabled the use of hybrid active and passive systems for optimizing energy performance. Lastly, the development of increasingly intuitive feedback-based systems of inhabitant interface transformed the home into an enabling and learning tool that informed users of their habits and behavior. All of these innovations in the design and construction of the home can be leveraged for attaining “high performance”.

At the time of this publication, the North House project has recently been reconstructed on the RARE Research Reserve in Cambridge Ontario, where it will be utilized as a living lab and undergo long-term post-occupancy testing. The design of the project has been physically detailed to enable future research to be undertaken on both the system as constructed, while also allowing for component modification to occur as new and improved building component technologies become available. Of particular interest in this ongoing and future work is the assessment of the effect that the combination of the CHAS and ALIS has on the operation of the home. While designers are able to anticipate construction technology and control system performance through the utilization of simulation software and a range of quantified performance metrics drawn from built precedents in advance of project execution, the question of how humans interface with a new class of responsive envelopes remains difficult to evaluate through simulation. Given the critical relationships between system performance, energy demand reduction and human use of energy-focused system design, there is significant research to be done in the development of responsive systems that are linked to interface systems, sensing platforms and predictive controls that not only engage occupants directly in the management of complex systems, but inform and shape behavioral patterns in order to realize the potential of system-wide impacts. Post-occupancy evaluations of such systems will provide valuable insight into their efficacy, and will inform the ways in which such systems are designed – with a balanced prioritization of potential physical impact and an anticipation of human engagement in figuring response.

ACKNOWLEDGMENTS

A version of this text has been previously published in: Thün, Geoffrey and Velikov, Kathy “North House: Climate Responsive Envelope and Controls Systems” in Trubiano, Franca. (ed) *Design and Construction of High Performance Homes: Building Envelopes, Renewable Energies and Integrated Practice* (2012: Routledge, London UK): 265-282.

The North House Project was funded in part through grant support through the US Department of Energy / NREL, The Ontario Power Authority (OPA), NRCAN, MITACS Ontario, MITACS BC, The University of Waterloo, Simon Fraser University, and Ryerson University.

For a comprehensive list of project team members and credits, see: http://www.rvtr.com/files/TEAM_NORTH_CREDITS_NC_20110805.pdf

REFERENCES

- [1] Thomas, W., Dec, M., Troy, D., and Thornton, B., (2008). “Effective Early Collaboration Between Engineers And Architects for Successful Energy-Efficient Design”, *Proceedings of the Third National Conference of IBPSA-USA*, Berkeley, CA, July 30 – August 1, Retrieved on 1/2011 from http://www.ibpsa.us/simbuild2008/technical_sessions/SB08-DOC-TS09-3-White.pdf.
- [2] Baker, N., (2000). “We are all Outdoor Animals”, *Architecture City Environment, Proceedings of PLEA 2000*, Koen Steemers and Simos Yannas, eds., London, UK: James & James, pp. 553-555.
- [3] Beesley, P., Thün, G., Velikov, K., and Woodbury, R., (2008). *NORTH HOUSE: Team North Entry to the 2009 Solar Decathlon*, Cambridge, ON: Riverside Architectural Press.
- [4] For details on the envelope assembly construction, see Lee, I. Y. T. et al., (2010), “High Performance Facades for Heating and Cooling in Northern Climates”, *International High Performance Buildings Conference*, West Lafayette, IN, July 12-15, and Saeid, T. et al., (2010), “Compact Integrated HVAC System for a Net-Positive Energy House for a Northern Climate”, *International High Performance Buildings Conference*, West Lafayette, IN: July 12-15.
- [5] See Thun, G., (2009), “Latitude Housing I North House Prototype: Prefabricating Building Integrated Photovoltaic Envelopes for Energy Positive Housing

Design in Northern Climates”, *Solar Architecture and Urban Planning, Conference Proceedings of the 4th Energy Forum*, Munich, Germany: Economic Forum LTD, pp. 76-72.

[6] For envelope modeling glazing design, see Lee, I.Y.T. et al., (2010). “High Performance Facades for Heating and Cooling in Northern Climates”, *International High Performance Buildings Conference*, West Lafayette, IN, July 12-15.

[7] Hollands, T. K. G., Wright, J. L., and Granqvist, C. G., (2001). “Glazing and Coatings, Solar Energy The State of the Art”, *ISES Position Papers*, London, UK: James & James, pp. 29-107.

[8] Lee, I. Y. T. et al., (2010), “High Performance Facades for Heating and Cooling in Northern Climates”, *International High Performance Buildings Conference*, West Lafayette, IN, July 12-15, pp. 5.

[9] “Delta PCM Smart Temperature Management”, Cosella Dorkin Products online database, Retrieved on 1/2011 from <http://www.cosella-dorken.com/bvf-ca-en/products/pcm/index.php>.

[10] Saeid, T. et al., (2010), “Compact Integrated HVAC System for a Net-Positive Energy House for a Northern Climate”, *International High Performance Buildings Conference*, West Lafayette, IN: July 12-15, pp. 5-8.

[11] Barhydt, L., (2010). “The North House as Responsive Architecture: Designing for Interaction between Building, Inhabitant, and Environment”, Unpublished M.Arch Thesis, University of Waterloo, pp. 59-71.

[12] The ALIS system, designed specifically for the North House remains under development by academic and industry partners of Team North at Simon Fraser University’s School of Interactive Arts + Technology led by Profs. L. Bartram and R. Woodbury.

[13] Velikov K., et al., (2013). “Empowering the Inhabitant: Communication Technologies, Responsive Interfaces and Living in Sustainable Buildings”, in *Constructing Green: Sustainability and the Places We Inhabit*, R. Henn and A. Hoffman, eds., Cambridge, MA: MIT Press, pp. 171-195.

[14] Bartram L., et al., (2010). “Chasing the Negawatt: Visualization for Sustainable Living”, *IEEE Computer Graphics and Applications*, Vol. 30, No. 3, pp. 6-12.