PERKINS+WILL

Research Journal

2013 / VOL 05.01

www.perkinswill.com

SPECIAL ISSUE: NATIONAL SCIENCE FOUNDATION WORKSHOP

ARCHITECTURE AND ENGINEERING OF SUSTAINABLE BUILDINGS

PERKINS+WILL **RESEARCH JOURNAL** 2013 / VOL 05.01

Editors: **Ajla Aksamija, Ph.D., LEED AP BD+C, CDT** and **Kalpana Kuttaiah, Associate AIA, LEED AP BD+C (Perkins+Will)**

Guest Editor: **Abbas Aminmansour, Ph.D. (University of Illinois at Urbana-Champaign)**

Journal Design & Layout: **Kalpana Kuttaiah, Associate AIA, LEED AP BD+C**

Acknowledgements: **National Science Foundation for sponsoring the 2nd Workshop on Architecture and Engineering of Sustainable Buildings**
NSF funding was provided through the Engineering Directorate for a project with Dr. Angus Rockett as the Principal Investigator (PI) and Dr. Abbas Aminmansour as the Co-PI. Dr. Rockett is a professor in the Department of Material Science and Engineering and Dr. Aminmansour is an Associate Professor and Chair of the Structures Program in the School of Architecture, both at the University of Illinois at Urbana-Champaign. Dr. Ajla Aksamija is an Associate and Building Technology Researcher at Perkins+Will, and she co-organized the Workshop.

Perkins+Will is an interdisciplinary design practice offering services in the areas of Architecture, Interior Design, Branded Environments, Planning + Strategies and Urban Design.

PERKINS+WILL
Research Journal
+7 2013 / VOL 05.01

JOURNAL OVERVIEW

The Perkins+Will Research Journal documents research relating to architectural and design practice. Architectural design requires immense amounts of information for inspiration, creation and construction of buildings. Considerations for sustainability, innovation and high-performance designs lead the way of our practice where research is an integral part of the process.

The Perkins+Will Research Journal is a peer-reviewed research journal dedicated to documenting and presenting practice-related research associated with buildings and their environments. Original research articles, case studies and guidelines have been incorporated into this publication. The unique aspect of this journal is that it conveys practice-oriented research.

This is the ninth issue of the Perkins+Will Research Journal, specially dedicated to documenting the outcomes of the 2nd Workshop on Architecture and Engineering of Sustainable Buildings, sponsored by the National Science Foundation.

TABLE OF CONTENTS

JOURNAL OVERVIEW .... Page 2

EDITORIAL .... Page 4

01. CONSTITUTIONAL ECOLOGY:
The Case for Aligning Science and the Law in Urban Design
David Green, AIA, LEED AP BD+C .... Page 7

02. BUILDING SIMULATIONS AND HIGH-PERFORMANCE BUILDINGS RESEARCH:
Use of Building Information Modeling (BIM) for Integrated Design and Analysis
Ajla Aksamija, PhD, LEED AP BD+C, CDT .... Page 19

03. NORTH HOUSE:
Prototyping Climate Responsive Envelope and Control Systems
Geoffrey Thün, BES, OAA, MRAIC, LEED AP
Kathy Velikov, MUD, BES, MRAIC, LEED AP .... Page 39

04. CURRENT TRENDS IN LOW-ENERGY HVAC DESIGN
Robert L. Tazelaar, PE, LEED AP .... Page 55

NEXT STEPS .... Page 64

WORKSHOP PARTICIPANTS .... Page 66

PEER REVIEWERS .... Page 69

AUTHORS .... Page 70

EDITORIAL

Special Issue: 2nd NSF WORKSHOP ON ARCHITECTURE AND ENGINEERING OF SUSTAINABLE BUILDINGS

This special issue of Perkins+Will Research Journal is dedicated to capturing proceedings of the 2nd Workshop on Architecture and Engineering of Sustainable Buildings, sponsored by the National Science Foundation (NSF). This two-day workshop was organized by the University of Illinois at Urbana-Champaign and Perkins+Will, and was held at the Perkins+Will's Chicago office on July 26 and 27, 2012.

The event brought together invited participants from different universities, design/architectural and engineering firms, and national laboratories, representing multidisciplinary and multi-faceted perspectives on sustainability issues relating to buildings and urban design.

The main objectives of the workshop were to discuss cutting-edge research and development, as well as design methods for sustainable, high-performance communities and buildings, and to identify current research gaps that should be addressed in order to advance the state of knowledge. The workshop was organized around these main categories:

- Sustainable urban design and cities
- Role of technical research in the design of high-performance buildings
- Climate-responsive and energy-efficient buildings
- Passive design strategies
- Low-energy mechanical systems
- Role of integrated design in sustainable architecture and engineering.

The articles that are included in this special issue capture the essence of the workshop, and the state-of the-art research that was presented by the participants.

"Constitutional Ecology: The Case of Aligning Science and the Law in Urban Design" discusses current trends in research relating to the design of cities. It focuses on the relationships between regulations that are employed to control urban development, and the outcomes resulting from these regulations. This article suggests that regulations have a significant impact on health, safety and welfare of the population, and that there should be legal and scientific mechanisms in place to monitor the efficacy of the adopted regulations. The article suggests that there should also be a mechanism to modify the existing and adopted regulations, if they are not implementing sustainable urban development principles for cities.

"Building Simulations and High-Performance Buildings Research: Use of Building Information Modeling (BIM) for Integrated Design and Analysis" discusses relationships between building performance simulations and design, and the role of building performance research in architectural practice. The first part of the article discusses Perkins+Will Tech Lab, its research focus and research activities relating to the design of high-performance buildings. The second part of the article discusses the role of performance simulations in the design of high-performance buildings, methods for integrating analysis procedures with the design, as well as case studies that illustrate these processes.

"North House – Prototyping Climate Responsive Envelope and Control Systems" presents an interdisciplinary design research project, with the primary objective to develop a full-scale prototype of a net-positive energy solar powered residence, optimized for cold climates. The article describes the project's high performance objectives, design aspects, development of a specialized facade system with integrated photovoltaic panels, coordination of all building systems (passive and active), and control mechanisms that have been implemented to track and monitor energy usage, operation and engage building occupants in the operation of this high-performance residence. Conclusions suggest that there is a critical relationship between performance of building systems, energy demand reduction and occupant behaviors.

"Current Trends in Low-Energy HVAC Design" provides an insight how HVAC systems are changing to meet the necessity to design energy-efficient buildings. The article discusses different systems and methods, such as decoupling of ventilation and heating/cooling that either partially or completely separates the ventilation air from the cooling and heating. The article also discusses some of the emerging types of HVAC systems, such as chilled beams and radiant floor heating. Also, use of simulation tools for energy modeling or computational fluid dynamics (CFD) modeling are necessary for the design decision-making, and must be integrated with the design process. The last part of the article discusses a case study where CFD modeling was performed to verify the design approach using radiant floor heating.

During the workshop, each presentation was followed by discussions. The objectives were to respond to these following questions, and identify research gaps:

- What are the appropriate design strategies for minimizing environmental impact of cities and communities?
- What are the successful design strategies for minimizing energy usage of buildings?
- What is the role of technical research and building performance analyses in the design of high-performance buildings?
- How do different building systems and components (HVAC, lighting, building envelope) influence energy performance of buildings?
- What are the current challenges in designing high-performance buildings?
- What are the available tools and resources that can aid the decision-making process for the next generation of high performance buildings? What types of tools need to be developed?
- What are the strategies for successful integration of different disciplines (architecture, MEP, structural engineering) in the design of high-performance, energy-efficient buildings?
- What are the current challenges for integrated design of sustainable buildings and cities?

In this special issue of the Perkins+Will Research Journal, we have included summary of the responses to these questions, identified research gaps, and next steps that need to be addressed in order to advance the current state of knowledge, and promote design and construction of future sustainable, high-performance buildings and cities.

Ajla Aksamija, PhD, LEED AP BD+C, CDT
Abbas Aminmansour, PhD

01.
CONSTITUTIONAL ECOLOGY:
The Case for Aligning Science and the Law in Urban Design

David Green, AIA, LEED AP BD+C, *david.green@perkinswill.com*

ABSTRACT

This paper discusses current trends in research related to the design of cities, primarily focused on the relationship between regulations that are put in place to control development and the outcomes resulting from the regulations. Unlike other arenas of urban research, where the desired outcome is the health, safety and welfare of the general public, research into the impact of regulations on a population is almost nonexistent. There are few protocols for tying the performance of regulations to outcomes and little testing of the regulations to ensure the outcomes align with their intentions. This paper makes the case that regulations have a significant impact on health, safety and welfare, and that their implementation and adoption should be tied to basic research and testing, and further, that there should be legal and scientific mechanisms in place to monitor the efficacy of the adopted regulations and to modify the regulations based on alignment with stated intentions.

KEYWORDS: research in cities, development regulations, health, safety, welfare, zoning, public health

1.0 INTRODUCTION

Cities are critical to the efficient operation of society. Beyond just issues of quality of life, they are large consumers of natural resources. They consume energy, both through the end use (electricity and gas) and through automobile and mass transit, as well as water, coal, building materials, and myriad of other natural and fabricated resources. In addition, there is a growing concern that the form of cities may have a profound effect on public health: chronic diseases related to obesity, heart disease, and asthma, among many others. But cities are making decisions about their development in the absence of critical data and analysis that provides direction for these actions. There is a clear need to establish research that provides a scientific basis for rationalizing city planning and urban design.

We have, for the past eighty years or so, used a pseudo-scientific set of criteria to direct and regulate the design and construction of our cities, towns and suburbs. From the very beginning, social-scientific measures formed the foundation of the professional planning movement. In this process, however, the rigors of basic research and scientific methods have been remarkably absent in reflection on the efficacy of planning's impact on the built environment. Abstract planning principles are translated into operational regulations without a basic protocol for testing, evaluating, and modifying assumptions based on the results of evidence. The reticence of the profession to test and evaluate is further complicated by the fact that planning is ultimately implemented through a series of legal documents – regulations. Once adopted, regulations are notoriously difficult to change, both due to the precedential nature of the legal system itself and the seemingly inherent credibility bestowed upon regulation by virtue of its own adoption.

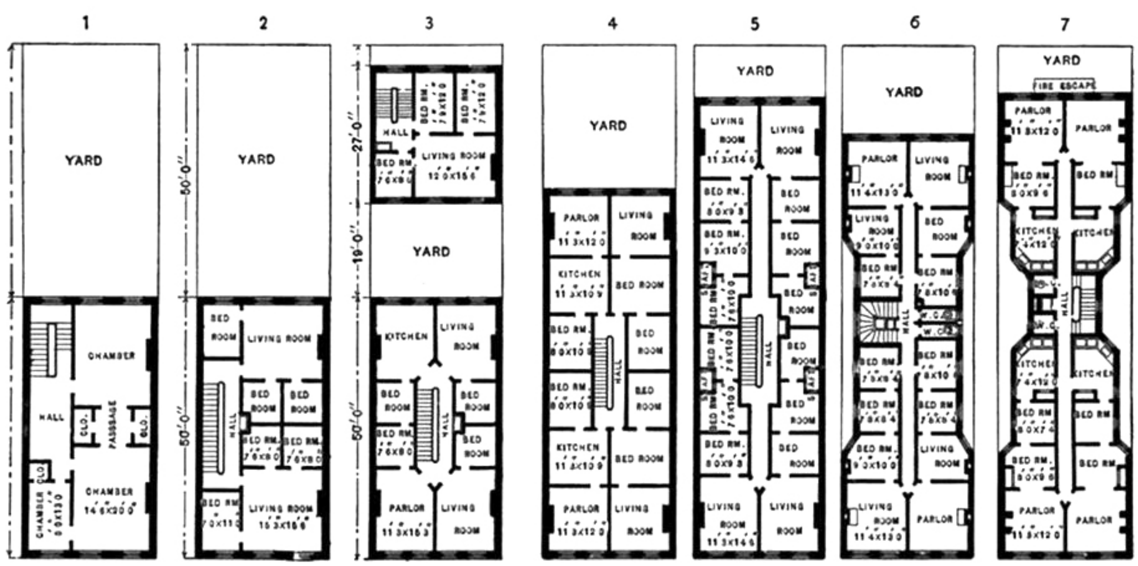
At its core, the planning profession is charged with creating rules and guidelines for the development of urban places through constitutional policy powers: to provide for the health, safety and welfare of the general public. Ultimately, effectiveness of planning means, such as zoning, can and should be measured. For example, Justice George Sutherland states that plans and their regulations must "expand or contract to meet the new and different conditions which are constantly coming within the field of their operation" in the seminal Supreme Court case, *Village of Euclid, Ohio v. Ambler Realty Co.* (Village of Euclid, Ohio v. Ambler Realty CO, 1926). He went on to say that, "in a changing world it is impossible that it should be otherwise."[1] What Sutherland knew as a fact, and the planning profession seems unwilling to address, is that planning is only as good as its ability to positively affect the health, safety and welfare of the people in places it impacts. And, if our impacts are not positive, we are obligated by the law to improve our regulations[1].

A nationally supported system of testing and evaluation protocols, both for proposed regulations and adopted regulations, is still absent from planning and urban design processes. Jurisdictions continue to rely on theory and precedents alone when adopting new regulations. Because of the significant impact that the built environment has on the health, safety and well-being of the general population, it seems logical that the profession would adopt scientific research protocols. To avoid doing this would be analogous to the pharmaceutical industry, in the absence of the Food and Drug Administration, releasing new drugs to the public without trials and then turning a blind eye to potentially negative outcomes.

This paper will examine several specific cases that articulate the issues outlined above and provide suggested methodologies for beginning to frame a scientific method for planning and urban design at a consistent, national level. It also makes the case that institutions, such as the National Science Foundation, should establish foundations for research in these areas. The answers to the questions posed above, if they are to be solved, must be considered scientifically and comprehensively.

2.0 THE BIRTH OF REGULATIONS

The impetus for regulating the built environment came from conditions that we can hardly imagine today. In the second half of the nineteenth century, people were living in conditions that were extremely unhealthy. For example, extreme population density grew in the Tenth Ward of lower Manhattan without infrastructural support – population densities were as high as 1000+ people per acre, or roughly 50 times the density of Manhattan today[2]. Most of this population lived in tenement houses with little natural light, open pit latrines and no



1. Old Knickerbocker dwelling.
2. The same made over into a tenement.
3. The rear tenement caves.
4. Packing-box tenement built for revenue only.
5. The limit; the air shaft — first concession to tenant.
6. The double-decker, where the civic conscience began to stir in 1879.
7. Evolution of double-decker up to date.

Figure 1: The evolution of the Knickerbocker tenement house type leading up to the 1901 Act and subsequent to the Act. The transformation from 5 to 6 demonstrates the direct, positive effect the Act had on the living conditions of the residents; in this case, the diagram illustrates shafts for natural light and air included on sidewalls between the buildings, which were lined up in rows. (Source: *The Battle with the Slum,* by Jacob A. Riis, New York, NY: The Macmillan Company, 1902).

air circulation. With the publication of books such as Jacob Riis's *How the Other Half Lives,* the public began demanding reform through regulation and local jurisdictions responded[2]. One of the most important steps forward was New York State's adoption of the 1901 Tenement House Act. Figure 1 illustrates the impact of regulations as demonstrated by the evolution of houses themselves. The Tenement House Act served to open living quarters to light and air, and set the conditions for healthier living environments.

While the 1901 Tenement House Act is representative of the changes that were affecting individual building form and execution, it was with the adoption of the 1916 Building Zone Resolution of the City of New York that the role of regulations addressed what is commonly understood as zoning. The catalyst for this action was the completion of the Equitable Building in the financial district of the city. The building was reputed to cast a seven-acre shadow across the district at certain times of the day and year, with significant detrimental effect upon those other buildings in the affected area, and upon the general health and welfare of residents and office workers in the district. As a response, the city of New York adopted the resolution. The resolution provided for a number of requirements, including the zoning of the city into areas for residential, commercial and unrestricted uses, the requirements of yards for light and air, and restrictions on the height and form of buildings to ensure natural light and air for the district in general, not solely for the individuals occupying the buildings. The regulation had a significant impact on the quality of the city as demonstrated in Figure 2, the height and setback requirements for buildings permitted under the new resolution. Further, the regulations were easily tested and evaluated to determine the efficacy of their providing more light and air into the city streets and parks[3].

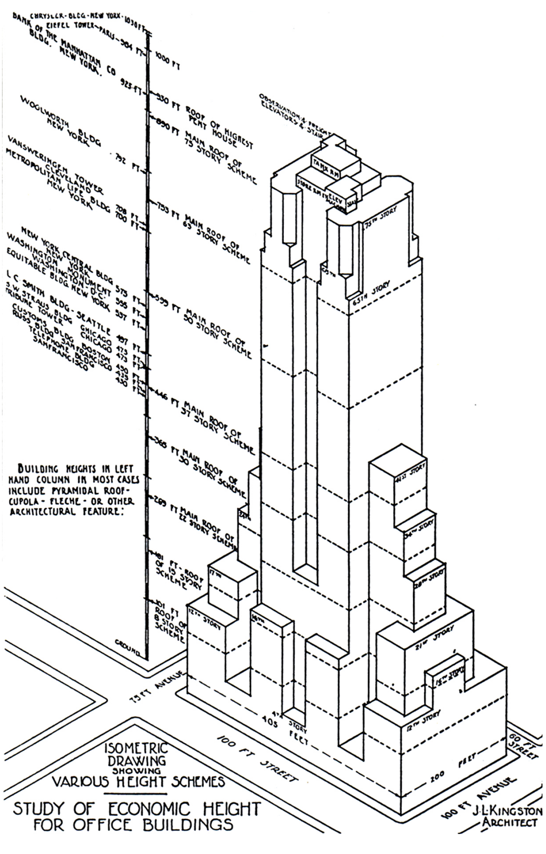


Figure 2: Diagram from the 1916 Building Zone Resolution describing the setback requirements for new buildings (Source: Building Zone Resolution, 1916).

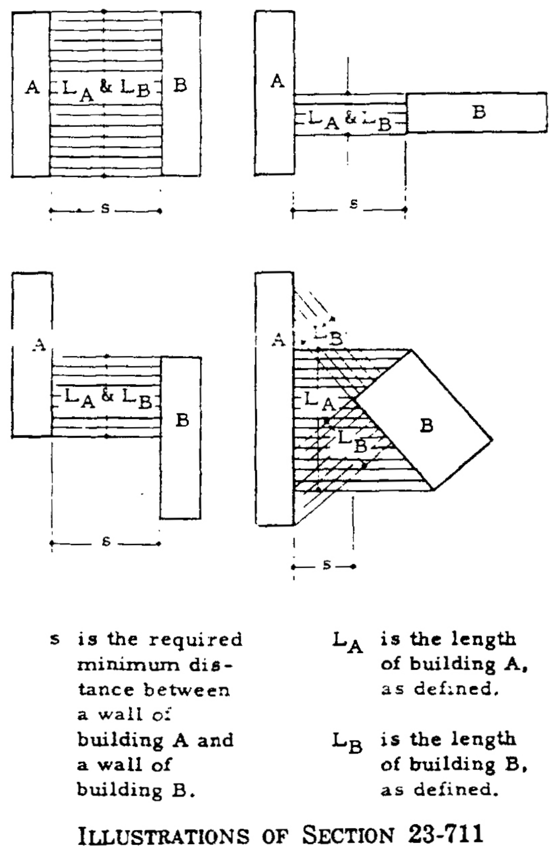


Figure 3: Diagram from the 1961 Zoning Resolution describing the calculations for meeting building spacing requirements (Source: 1961 Zoning Resolution, 1961).

This original ordinance was updated and modified many times over the course of 45 years until the 1961 Zoning Resolution superseded it. The adoption of this ordinance signalled the acceptance of a radically transformed understanding of the way regulations operated. Instead of relying on simple, straightforward guidelines that were easily tested, the newly adopted regulations were much more reliant on formula-driven criteria for development. This transformation created a scenario in which it was almost impossible to project the physical outcome resulting from the regulations because each project was easily manipulated based on local and site-specific conditions. This is demonstrated in Figure 3, a seemingly simple calculation to determine building massing and spacing that opened the process to infinite possible results, most of which led to unintended consequences. In addition, there was almost no incremental testing of the proposal to ensure that it would garner the desired results and that those results would meet the constitutional guarantees of health, safety and welfare. While the specifics of the 1961 Resolution were not copied verbatim into other ordinances across the country, the logic of regulating the development of cities and towns and suburbs was predicated on this resolution almost universally. The following two sections demonstrate two very specific regulations that were adopted, generally, throughout the country without testing and evaluation, and the impact they have had and continue to have on the built environment[4].

3.0 EXAMPLES OF REGULATIONS' EFFECT ON URBAN DEVELOPMENT

3.1 Example One: Local Streets

In the seminal zoning case, *Euclid v. Ambler*, the core issue before the court was the question of protection of single-family neighborhoods. The case was brought to the court in a time, the 1920s, when questions of appropriate uses in these neighborhoods was critical as it was not uncommon to find toxic uses, such as rendering plants, slaughterhouses and tanneries, among others, interspersed with people's dwellings. At the time of the case, there was a clear need to separate these extremely unhealthy operations from the districts where families lived[1]. Over the course of subsequent decades, however, the protection of single-family neighbourhoods expanded greatly. This can be demonstrated in a number of regulations adopted, especially through the 1950s, including minimum lot sizes for single-family homes, extremely restricted uses such as the restriction on corner groceries, neighborhood restaurants and other uses that had, historically, been a part of the rich mixture of a healthy neighborhood. While there are many examples of regulations that were adopted that have, and continue to have, negative impacts on the health, safety and welfare of the general public, there are some that stand out as clearly demonstrating the need for scientific study to determine the true impact they have. And further, they demonstrate the legal implication of the enactment of the regulations.

In 1957, a new subdivision ordinance was adopted in the City of Atlanta. It included, as did many other ordinances adopted throughout the country at the time, a seemingly simple, clear and intelligent requirement that cut-through traffic (traffic moving through a particular geographic area with no intention of stopping in that area) should be minimized, or if possible, eliminated from single-family developments. In the Atlanta Ordinance the statement, *"Local streets shall be so laid out that their use by through traffic will be discouraged,"* was a prominent element of the ordinance[5]. The requirement led, and continues to lead, to a very particular development pattern, as demonstrated in Figure 4. Individual suburbs are designed and developed in such a way that there is absolutely no connectivity between the subject development and other, contiguous or proximate developments (residential or commercial). This seemingly benign requirement has had enormous impact on the lives of the inhabitants of the communities developed under this requirement. The result is a community that disconnects neighbors from each other, where people are discouraged from walking and where the primary way to move through the system is in an automobile.

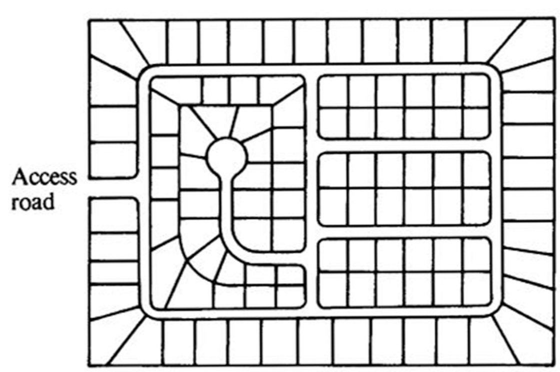


Figure 4: Typical land development pattern resulting from regulations prohibiting through traffic.

However, when this ordinance was originally adopted, it was not tested, evaluated and determined to operate effectively to actually provide a healthy and safe environment for its occupants. Further, in the face of mounting evidence that instead of being a healthy and safe development strategy, it is actually causing unhealthy and unsafe results for the inhabitants of the areas developed under the regulation. Certainly further investigation is warranted to expand and verify the initial research, but this expanded research is extremely slow in coming. And as with all regulations and laws, changing them is extremely difficult.

It is here, in the evaluation of regulations, that the benefit of following a scientifically dictated protocol for research would prove beneficial. If, for instance, basic research provided the data and interpretation of data to correlate the regulation with issues of Health Related Quality of Life (HRQOL), such as obesity, asthma, heart disease, pedestrian and vehicular deaths and injuries, crime rates, even long-term house values, an issue of welfare, the professionals charged with creating and adopting the regulations would have much greater certainty that they were adopting regulations that resulted in measurably healthier, safer and more economically vibrant developments, and they would be fulfilling their professional obligation to ensure the constitutional guarantees upon which Justice Sutherland based the ruling that made the regulations constitutional in the first place. Further, from a legal standpoint, it would be much easier to modify existing regulations if there was compelling scientific research to back up the proposed modifications.

3.2 Example Two: Walking

Current research suggests that walking provides health benefits; that areas of cities with more pedestrians are safer; and that areas of cities, particularly commercial, with more pedestrian traffic are more economically robust. As with most current information regarding cities, towns and suburbs, and the efficiency of their operation, more research is needed to understand correlations between walking and urban planning. As evidence-based research supports the premise that more people walking in cities promotes the health, safety and welfare of the general population, current regulations can be evaluated based on their efficiency in producing developments that are conducive to pedestrian activity.

Throughout the United States, the single most difficult element to incorporate into new developments, redevelopments and other forms of modifying a jurisdiction's form is the creation of new streets. This difficulty stems from several issues: maintenance costs borne by the jurisdiction, a pre-conceived notion that more streets are less environmentally beneficial, and, as demonstrated in previous section, a general belief that more streets lead to more traffic. Each of these issues demands additional research, but it is extremely difficult to replicate the highly connected street systems of cities and towns constructed in the pre-regulatory era. In this specific case, we are focusing on expanding pedestrian activity, and the effect the street system and the regulations that drive street locations have on the efficacy of providing pedestrian activity.

As a basis for researching this issue, the correlation between street layout and pedestrian activity, the first step is to identify areas that seem to promote pedestrian activity and those that seem to suppress it. An example of the former is New York, arguably one of the most highly pedestrian cities in the world. In New York, specifically Manhattan, the streets are highly connected, with resulting block sizes of 200 feet in the north-south direction, and block sizes generally between 500 and 800 feet in the east-west direction. In this system, there appears to be a correlation between the size of the block face and the level of comfort in walking similar distances. As demonstrated in Figure 5, a walk in the north-south direction of 10 blocks is perceptually different from a walk in the east-west direction of the same distance. This begins to identify the possibility that the physical distribution of streets has a direct effect on the pedestrian's comfort, and further on the efficacy of the system to produce the desired result, more pedestrian activity. It is generally perceived to be easier to walk the half-mile uptown than the same half-mile crosstown.

The research on block dimensions and its correlation to a supportive system for pedestrian activity is not the end, however. It is an analytical method to help cities create more energy-efficient and healthier overall systems. The increased number of people who walk, due to myriad factors, will have a direct impact, we hypothesize, on the reduced use of fossil fuels for automobiles. It should also create a more efficient overall system for distribution of utilities and a more resilient infrastructure layout, which minimizes rebuilding when single buildings are reconstructed or newly constructed. In addition, increased walking should correlate, again, we assume, to decrease numbers of health problems such as chronic disease and asthma. However, the basic research to prove or disprove these hypotheses is currently almost nonexistent. Cities are, in aggregate, among the largest users of energy, and home to the greatest number of people, yet the national planning community,

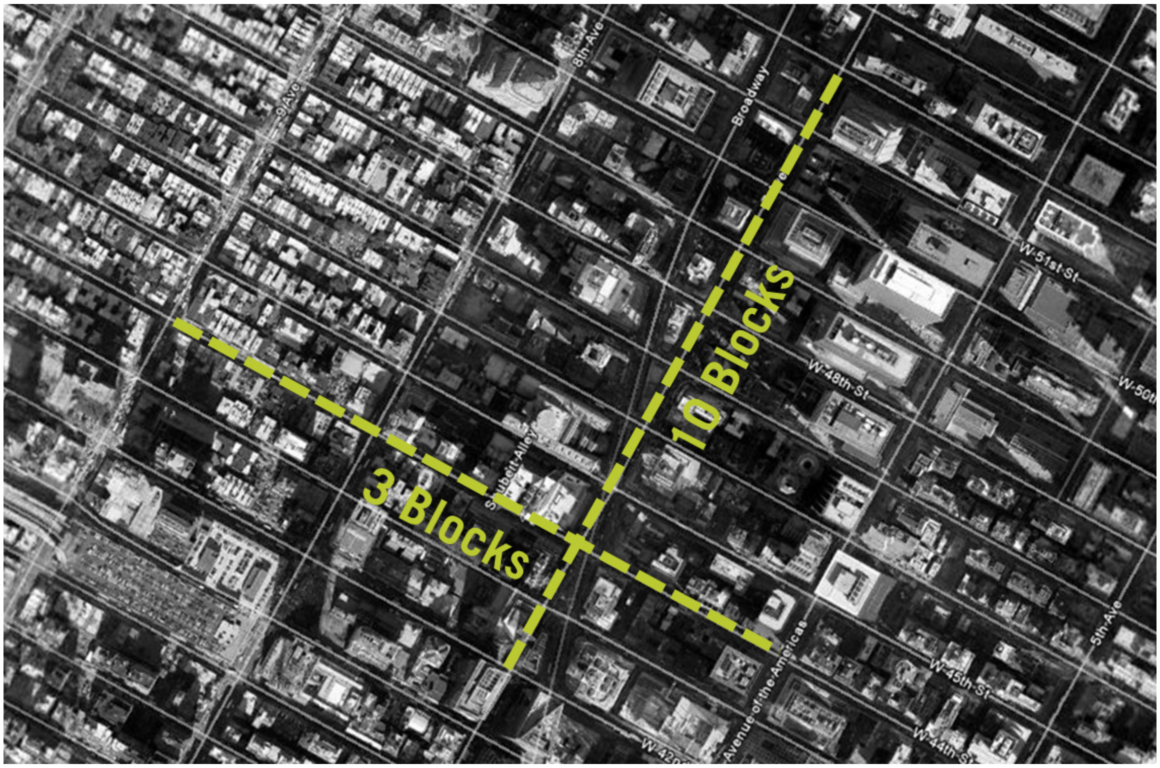


Figure 5: Demonstration of the physical difference in pedestrian experience; uptown versus crosstown.

and the funded research within which it is engaged, is minimal. There is a clear need for an increase in research in these areas, and to increase the connection between current health-related research and the planning profession.

The physical layout and the efficiency of the pedestrian system in this case is tied directly to the original regulation that dictated where and how streets would be laid out as Manhattan developed. In this case, it was the Commissioners' Plan of 1811, a survey and plan that identified the location of streets as the city grew. The power of the regulation in this case was the certainty of the outcome, and in retrospect, the value of the plan for producing (or allowing) significant pedestrian activity[6].

Throughout the twentieth century, however, the methodology for the design of street patterns changed radically. As indicated in Example 1, connected streets were discouraged or prohibited[5]. Further, streets were no longer identified in a specific plan, guaranteeing short block faces and highly connected system, but were placed project-by-project based on capacities of individual projects and the demands those projects would place on the vehicular efficiency of the system. The resulting pattern of development is indicated in Figure 6. It clearly shows the physical implications of the regulations, including limited intervening public streets, expanded parking requirements, significant building setbacks, among other requirements that led to the disappearance of the connected system of all pre-regulatory cities. The outcome of these regulations is the production of development patterns that deter inhabitants from walking. There appear to be direct correlations between the sizes of blocks (or the frequency of streets) and the level of pedestrian activity. This is further indication of the need for a rigorous research platform for the investigation of these issues.

Figure 6: A typical development pattern resulting directly from the regulations governing the jurisdiction..

4.0 WAY FORWARD

There is research underway that attempts to align the planning and urban design professions more closely with scientific research. These efforts are framed around two distinct trajectories. The first is identifying, through research, the correlation between regulations and physical development patterns historically. The second is the creation of research tools that allow for the testing, projection, and evaluation of proposed policies and regulations, as well as provide for analysis of implemented regulations and recommendation for modifications based on data analysis.

4.1 Correlation Between Regulations And Development Patterns

The first trajectory is exemplified through a simple analysis of the relationship between regulations in place and block sizes. Assuming Example two above is accurate, then what was the correlation between regulations in place and the resulting block sizes, and by extension frequency of streets? Table 1 below indicates the results of a cursory investigation into the relationship between the existence of subdivision regulations and the size of blocks. In this statistically limited sampling, the data suggests that there is potentially a significant correlation between the mere presence of a regulation and the efficacy of creating small, consistent block sizes.

Observation 2: the standard deviation of average block size in the following selected cities has increased from .79 to 6.14 from pre-1928 subdivision to post -1928 subdivision.

	Pre 1928 Block Size					Post 1928 Block Size		
		avg.	max				avg	max
		acres	acres				acres	acres
1	Atlanta, GA	3.70	8.26		1	Atlanta, GA	22.87	44.49
2	Boston, MA	3.09	4.13		2	Boston, MA	9.45	14.46
3	Baltimore, Md	3.29	5.78		3	Baltimore, Md	14.93	22.72
4	Charleston, S.C.	4.12	6.07		4	Charleston, S.C.	16.89	25.25
5	Chicago, Illinois	3.51	4.96		5	Chicago, Illinois	14.74	19.10
6	Los Angeles, CA	4.41	7.89		6	Los Angeles, CA	8.01	16.08
7	New York, N.Y. (Manhattan)	2.60	3.67		7	New York, N.Y. (Manhattan)	7.72	13.31
8	Omaha, Nebraska	4.34	8.26		8	Omaha, Nebraska	8.27	13.42
9	Portland, Oregon	1.92	3.72		9	Portland, Oregon	2.69	4.24
10	Philadelphia, Pennsylvania	3.07	6.33		10	Philadelphia, Pennsylvania	5.03	5.88
	Average	3.41	5.91				11.06	17.90
	Median	3.40	5.93				8.86	15.27
	Std. Dev	**0.79**	1.80				**6.14**	11.42

Figure 7: Statistical analysis provided by Douglas Allen, Georgia Institute of Technology[7].

The conclusion derived from this preliminary investigation is that there is an inverse correlation between the degree to which regulations are implemented and the efficiency of creating consistency; the stated goal of the regulation. If this is verified through further research, it implies that the regulations adopted to provide for health, safety and welfare are resulting in development patterns that are inconsistent with the goals of the regulations.

This early work supports the proposal that there should be regional, and even national, systems in place to track these issues. The computing power, and much of the data already exists, but the planning profession is slow in taking up the move to identify critical data that would form the foundation for a more rigorous and directed national research agenda[7].

4.2 Human Spatial Comfort

The second trajectory is exemplified through the research of John Peponis at the Georgia Institute of Technology[8,9,10,11,12,13]. This effort is predicated on the notion that existing development is measurable, both in terms of its physical characteristics (e.g. the connectedness of streets, the alignment of streets), as well as its operational characteristics (e.g. the amount of pedestrian activity, the level of retail development). Both of these aspects measure the efficacy of the system. The correlation between the physical and operational characteristics and the system itself is built on analysis and evaluation of existing conditions. The results of these analyses are then used to construct a model that interprets projected systems to evaluate their effectiveness prior to implementation, in an objective manner based on data and analysis. These tools can be used to test and evaluate proposed regulations prior to adoption and continue to evaluate as the regulations are implemented, and provide recommendations for modification reflecting a potentially higher level of efficacy of the system.

In a recent paper, Peponis et al. propose a specific strategy for implementing measures of street connectivity that is determined based on standard GIS computational platforms[8]. The innovation in the proposal is the specifics of measurements and their correlation to experienced outcomes, as well as the potential for more refined methods of projecting effects of regulations on urban development. The core objective of the research is to determine a method for measuring street connectivity and "setting the foundations for future research aimed at testing theoretical hypotheses."[8]

The metrics evolve from a specific desire to understand how much street length can be reached as one walks in a number of different directions. This is further framed, and limited, by utilizing specific distance thresholds to provide consistency and control in the research. The unit is defined as a *mean metric*, a method to measure potential pedestrian reach, as well as density of available streets. The system generally works as such:

> "[w]e have pursued the relationship between mean metric reach and other measures in two ways. First, we studied the relationship between block size and mean metric reach in theoretical infinite regular square grids... For such grids, the smaller the urban blocks, the higher the mean metric reach. Furthermore, the smaller the block size, the higher the rate at which the metric reach increases with an increase in threshold distance."[8]

Figure 8 below describes the general analytical process and outputs. The figure at the left indicates presence of retail land uses, which correlate to pedestrian activity, and the dispersal is further described on a larger scale in the middle figure. The figure on the right indicates the level of connectivity, based on the parameters input in the computational model. In this figure the intense red color indicates a higher level of connectivity, while the intense blue color indicates reduced connectivity. The statistical analysis below indicates the correlation between location of retail, pedestrian activity and the level of connectivity in the street pattern.

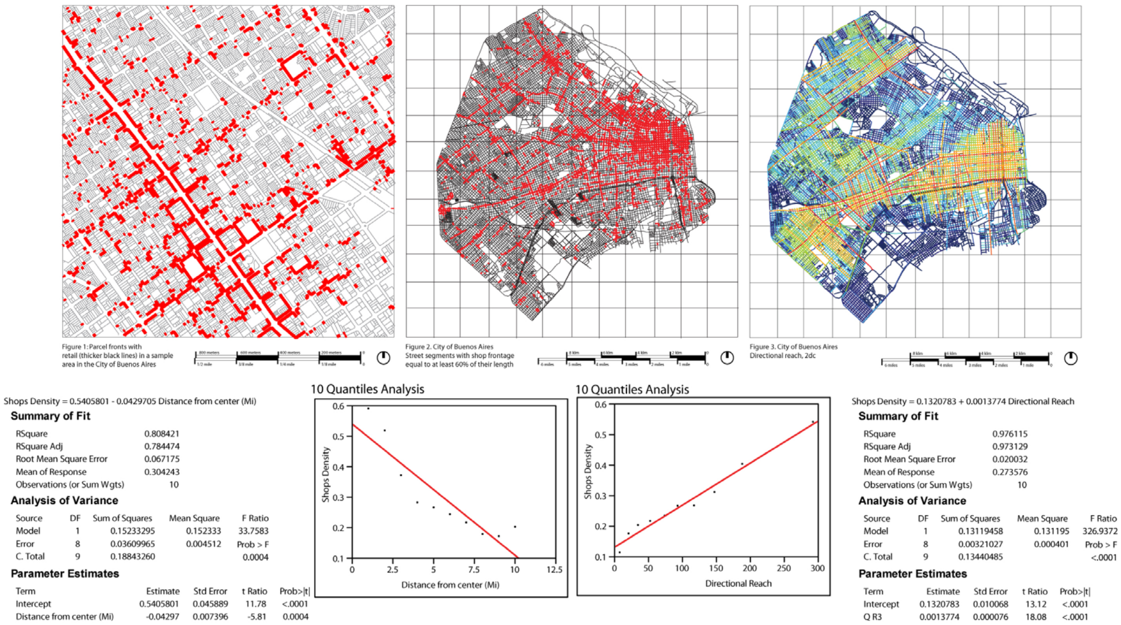


Figure 8: Modelling the effectiveness of certain elements of the city (Courtesy of John Peponis).

5.0 FUTURE RESEARCH PLAN

The future of research in the field of planning and urban design requires a directed strategy. In many instances policies are implemented that have little basis in analysis, and minimal correlation to other research that has bearing on planning policies. To implement this, these following aspects should be addressed and executed:

- Create a working organization that brings the various public health and planning organizations together to specifically focus on issues of planning and its relationship to city planning.
- Provide strong protocols for research and analysis in the planning process that are adopted by the profession.
- Revise statutory enabling legislation to require a higher level of objective analysis and research into policy and regulatory adoption processes.
- Support more inter-disciplinary funding for basic research into the issues of city planning and public health.
- Increase support from the Federal Government for basic research in these areas. This will require a concerted effort of those involved to change perceptions about the scientific nature of research in these areas.
- Provide funding for and a legal mechanism to track the efficacy of current and newly adopted regulations. This should be modeled on efficacy tracking protocols in the pharmaceutical industry.

These recommendations will require a cultural shift in the planning and urban design professions that foregrounds basic research as a model for planning. It will require the planning profession to objectively evaluate current planning practices and make modifications to ensure results, and to change when results are other than anticipated. It will also require a shift in the urban design field. Urban designers should allow reliable and objective research, and its results, to play a much larger role in the design process. Other fields that have significant levels of impact on public health already operate in this manner, relying on research to make decisions and implement policy. It is critical that the planning and urban design fields learn from these examples and adapt to these models.

6.0 CONCLUSION

This paper examined the current and future trends in research as it pertains to city planning and urban design. It is intended to demonstrate the need to reconsider the methodology used in planning cities, towns and suburbs. There is a significant lack of scientific rigor in the research protocols, and further a lack of research in general, in these arenas. The paper poses questions and identifies potential fundamental problems with the current system, and further identifies the need for support for these efforts.

Regulations drive the pattern of development almost to the exclusion of all other influences. They are legally binding and not easily susceptible to change. However, the method through which current and future regulations, and the environment in which they are created, can change is through the implementation of stringent protocols for basic research. The built environment affects our health, safety and welfare, and the rigor with which we investigate the effects on the public should be commensurate with those efforts.

Many of the questions that need to be addressed such as the relationship between urban form, pedestrian movement, and public health cannot be adequately addressed because we do not have a database of sufficient size and depth on the variables of urban configuration to adequately research the issues. Is there a relationship between energy consumption, public health, and the configuration of urban infrastructure? The same questions remain unanswered for energy consumption, and especially re-use of existing infrastructure in light of land use changes over time. What configurations offer the greatest accommodation of change? The aim of this paper is to propose that these efforts are in the best interests of the national citizenry, and that as we regulate the development of cities, we should align the laws that dictate our actions with scientific evidence.

ACKNOLWEDGEMENT

I would like to thank Douglas Allen and John Peponis for assistance with this paper, and providing supporting documentation and direction. I would like to thank Jeff Williams for editing support and advice.

REFERENCES

[1] Village of Euclid, Ohio v. Ambler Realty CO, 272 (U.S. Supreme Court November 22, 1926).

[2] Riis, J., (1970). *How the Other Half Lives: Studies Among the Tenements of New York,* Cambridge, MA: Belknap Press of Harvard University Press.

[3] Building Zone Resolution, (1916). *Appendix B City of New York Board of Estimate and Approtionment,* New York, NY: City of New York.

[4] 1961 Zoning Resolution, (1961). *The Zoning Resolution of the City of New York,* New York, NY: City of New York.

[5] Part 15 Subdivision Regulations, (1957). *City of Atlanta Code of Ordinances,* Atlanta, GA: City of Atlanta.

[6] Bridges, W., (1811). *Remarks of the Commissioners for Laying Out Streets and Roads in the City of New York, Under the Act of April 3, 1807,* Commissioners of Streets and Roads in the City of New York, New York, NY: City of New York.

[7] Allen, D., (2010). "The Standard City Planning Enabling Statute and the Regulation of Suburban Block Size", Rocky Mountain Land Use Institute - Sturm College of Law, Denver, CO: University of Denver.

[8] Peponis, J., Bafna, S., and Zhang, Z., (2008). "The Connectivity of Streets: Reach and Directional Distance", *Environment and Planning B: Planning and Design,* Vol. 35, pp. 881-901.

[9] Christova, P., Scoppa, M., Peponis, J., and Georgopoulos, A. P., (2012). "Exploring Small City Maps", *Experimental Brain Research,* Vol. 223, No. 2, pp. 207-217.

[10] Ozbil, A., Peponis, J., and Stone, B., (2011). "Understanding the Link Between Street Connectivity, Land Use and Pedestrian Flows", *Urban Design International,* Vol. 16, No. 2, pp. 125-141.

[11] Peponis, J., Allen, D., French, S., Scoppa, M., and Brown, J., (2007). "Street Connectivity and Urban Density: Spatial Measures and Their Correlationlation", *Proceedings of the 6th International Space Syntax Symposium,* Istanbul, Turkey.

[12] Peponis, J., Ross, C., and Rashid, M., (1997). "The Structure of Urban Space, Movement and Copresence: The Case of Atlanta", *Geoforum,* Vol. 28, No, 3-4, 341-358.

[13] Peponis, J., Wineman, J., Bafna, S., Rashid, M., and Kim, S. H., (1998). "On the Generation of Linear Representations of Spatial Configuration", *Environment and Planning B: Planning and Design,* Vol. 25, pp. 559-576.

THIS PAGE LEFT BLANK INTENTIONALLY

02.
BUILDING SIMULATIONS AND HIGH-PERFORMANCE BUILDINGS RESEARCH:
Use of Building Information Modeling (BIM) for Integrated Design and Analysis

Ajla Aksamija, PhD, LEED AP BD+C, CDT, *ajla.aksamija@perkinswill.com*

ABSTRACT
High-performance, energy-efficient buildings require a different design approach than conventional buildings. Building performance predictions, use of simulations and modeling, research-based and data-driven design process are the key elements in the design of high-performance buildings. This article discusses relationships between building performance simulations and design, as well as the role of building performance research in architectural practice. The first part of the article discusses Perkins+Will Tech Lab, its research focus and research activities relating to the design of high-performance buildings. The second part of the article focuses on the role of performance simulations, best methods for integrating analysis procedures with the design, as well as case studies.

KEYWORDS: high-performance buildings, simulations, modeling, decision-making, integrated design and analysis

1.0 INTRODUCTION
What are the appropriate strategies for designing extremely low-energy or net-zero energy buildings? Methods for high-performance buildings require use of passive design strategies, use of advanced building technologies and renewable energy systems. Passive design strategies include shading, response to building orientation and site, utilization of thermal storage and natural ventilation, and use of daylight. Active design strategies include use of energy-efficient building systems and advanced building technologies where appropriate, such as mixed-mode ventilation, radiant heating and cooling systems, dynamic windows (for example, using electrochromic glass), and combined heat and power systems. Passive strategies should be utilized to the fullest extent since their cost is minimal and their effect on energy efficiency is significant. Advanced building technologies should be used to increase energy efficiency measures when and where applicable. Lastly, renewable energy should be used to supplement energy demand with renewable sources, such as wind power, photovoltaic systems and geothermal energy.

Why do we need to use simulations and building performance analysis for the design of high-performance buildings? Building performance simulations are an integral part of the design process, since they help in investigating different options and simulation of design decisions[1]. Quantifiable predictions during the different stages of design process help establish metrics that can be used to measure improvements associated with these different types of strategies. It is important to note that improvements in building efficiency that are obtained through passive and active measures reduce the energy consumption, thus reducing the needs for renewable energy sources. Therefore, understanding effects of design decisions on building performance is crucial in achieving low and zero energy buildings.

The objectives of this article are to illustrate how performance predictions and simulations can assist in identifying strategies for reducing energy consumption and improving building performance by rigorous analysis process. The first part of the article discusses Perkins+Will Tech Lab, whose primary research objective is to advance the performance of project designs through dedicated research. Tech Lab's primary research methods include computational simulations and modeling, where different design scenarios are investigated, as well as their effects on building performance. The second part of the article discusses best methods for integrating performance simulations with the design, specifically addressing relationships between Building Information Modeling (BIM) and analysis software applications. Two specific case studies are discussed to illustrate these processes. The first case study discusses a specific architectural project and different types of studies that were performed during the design to improve building performance. The second case study discusses research on advanced computational design methods, and development of custom applications that allow parametric control of BIM elements based on environmental performance data.

2.0 TECH LAB RESEARCH

Tech Lab was initiated in 2008 as a research entity within Perkins+Will to enhance project designs through dedicated research. Tech Lab's research agenda focuses on advanced building technologies, materials, sustainability, high-performance buildings, renewable energy sources and computational design. Tech Lab monitors developments in building systems, materials, and information technology; reviews and analyzes emerging technologies that can have a direct impact on the course of architectural design, and investigates building systems and technologies that can significantly improve the value, quality and performance of architectural projects.

Examples of Tech Lab's research projects are:

- Performance and life cycle cost analysis for building integrated photovoltaics
- Performance of double skin walls
- Renewable energy systems optimization
- Advanced thermal comfort modeling
- Daylight analysis
- Parametric modeling
- Thermal analysis of exterior wall assemblies
- High-performance building envelopes
- Selection of renewable energy sources.

Primary research methods include simulations and computational modeling, which are used to investigate different design scenarios and strategies. Typical research process involves: 1) determination of research objectives and questions based on the needs of specific architectural/design projects; 2) identification of appropriate research methods; 3) identification of the timeline, schedule and research procedures; 4) execution of the study; and 5) dissemination and implementation of research results. Besides implementation of research results on architectural and design projects, sharing and dissemination of findings with the larger architectural and design community is a key aspect of Tech Lab's objectives. Publications of research data and methods, analysis processes and results benefits the entire field, therefore, research studies and results are shared through Tech Lab Annual Reports, shown in Figure 1.

For example, Tech Lab Annual Report 2009 includes studies such as building envelope performance analysis and daylight optimization, life-cycle cost analysis of building-integrated photovoltaic system, building envelope studies and daylight analysis, relationships between thermal comfort and outdoor design elements, study of facade options and building integrated photovoltaics, and a feasibility study for stand-alone self-powered exterior signage lighting system[2]. Tech Lab Annual Report 2010 includes facade energy studies, photovoltaic system energy performance and cost analysis studies, curtain wall heat transfer analysis, and exterior wall thermal transfer study[3]. Tech Lab Annual Report 2011 includes studies relating to high-performance building facade, dew point analysis of a typical exterior wall assembly, hygrothermal analysis of exterior walls, and facade energy performance and daylight analysis studies[4]. Tech Lab Annual Report 2012 includes thermal analysis studies for exterior wall assemblies[5]. These reports also include selected white papers that are written on building technology topics, as well as published research articles and research reports.

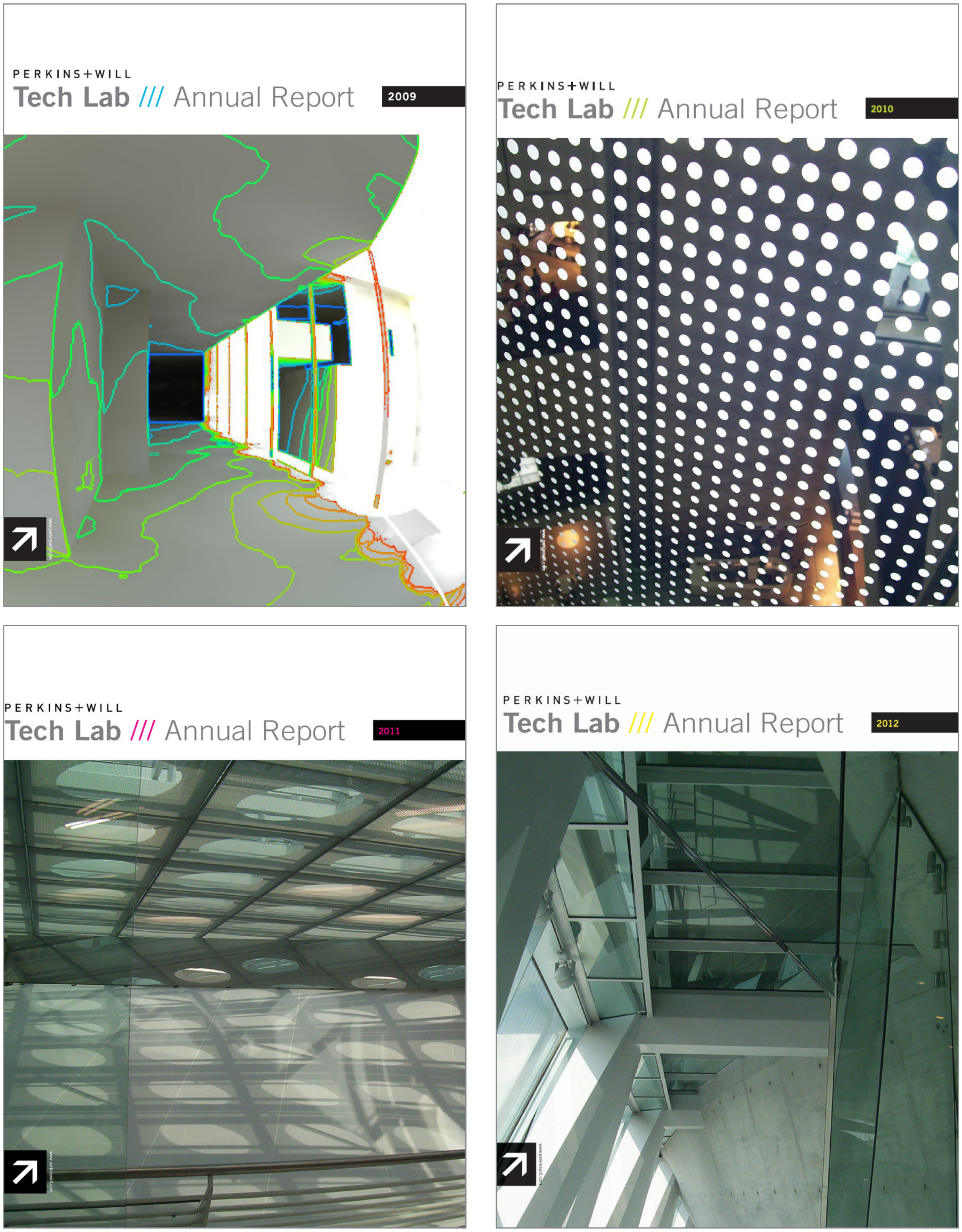


Figure 1: Dissemination of research results through Tech Lab Annual Reports.

3.0 BIM, BUILDING PERFORMANCE ANALYSIS AND DESIGN PROCESS

In order to evaluate and optimize the building performance, different analysis cycles supported by simulations should be part of an integrated design process. This is the basis for **performance-based design method.** However, this is challenging paradigm when compared to a traditional design method[6]:

1) **Traditional Method** has deficiencies because (1) it may include simplified assumptions based on rules-of-thumb which can be inaccurate; (2) it may force an aesthetic feature without considering performance impacts; and (3) it may not provide performance measurement/evaluation of a certain design solution.
2) **Building Performance-Based Design Method** has an ability to estimate the impact of a design solution since: (1) performance measures are investigated with actual quantifiable data and not rules-of-thumb; (2) it uses detailed building models to simulate, analyze and predict behavior of the system; (3) can produce an evaluation of multiple design alternatives.

Past research on utilization of simulation tools during architectural design process indicates that despite the increase in number of available tools in the last decade, some architects and designers are finding it difficult to use these tools, since they are not compatible with their working methods and needs, or the tools are judged as complex and cumbersome[7, 8]. To remain competitive, design professionals must weigh the value of information gained through simulation tools against the invested time, resources and against the value of comparable information that might be gained through the use of other or no tools[9]. So, why do we need to use simulations in the first place? Quantifiable predictions through simulations and modeling can help in identifying strategies and methods to improve building energy efficiency and building performance, and help in the decision-making process for sustainable design. They must be integrated with the design process from the earliest stages of the design.

Starting point for the schematic design is site analysis, where environmental factors must be systematically examined. Typical information about environmental conditions of the site includes topography, context, solar orientation, climatic characteristics, surrounding structures, and infrastructure[10]. Building orientation plays a significant role in providing access to daylight, as well as solar exposure. Solar radiation introduces passive solar heat gain, which can be advantageous in heating-dominated climates and unfavorable in cooling-dominated[11]. While passive solar gain can be harnessed to decrease heating demand in winter, gains during summer months create the need for cooling.

Building Information Models (BIM) can be used for energy and performance simulations, where the analysis process can be integrated with the design process. Figure 2 shows the basic types of performance analysis in relation to the project stages indicating what types of analysis should be performed when and how they relate to the BIM development process. The top part of the diagram shows the impact of decisions on actual building performance and relationships to project stages. As early as conceptual phase, the analysis should focus on the bigger design picture such as climate information, orientation, passive strategies and building massing. Then at the schematic stage, the analysis should explore the shading methods, solar access and building envelope options. For example, the iterative cycle of different design options of sun shades can be analyzed at this stage. During the design development stage, optimization of shading devices, daylight and glare studies, energy performance studies, thermal analysis and optimization should take place. However, BIM design authoring software programs and analysis applications are currently distinct and require exchange of data and building information. To successfully use BIM design models for environmental and performance analysis, it is important to consider the Level of Development (LOD) of BIM design models, what type of information is needed from them to develop BIM analysis models, and data exchange mechanisms and workflow between different software programs. LOD refers to the amount of information embedded in BIM design models, and widely accepted example is the American Institute of Architects (AIA) document E202[12].

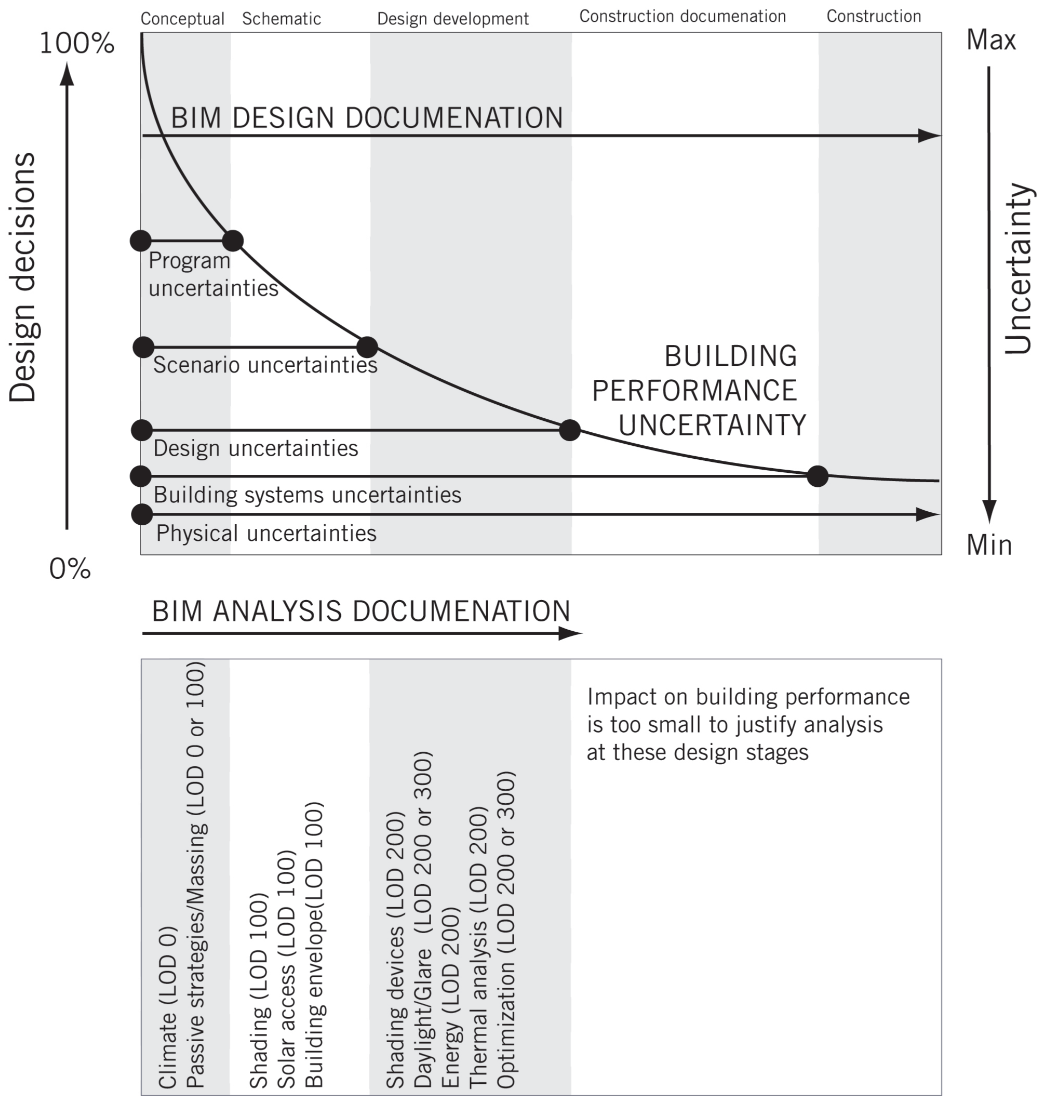


Figure 2: Design decisions and uncertainly for building performance. Relations between “BIM design” and “BIM analysis” process and documentation, indicating recommended level of development (LOD) to be embedded in the BIM models corresponding to each simulation type/analysis.

For example, LOD 100 should include overall building massing, area, height, volume; and can be used to analyze building orientation. LOD 200 includes model elements as generalized systems or assemblies, and may include non-geometric information, such as material properties. BIMs at this stage of development can be used for performance analysis of shading devices, daylight/glare analysis, basic energy analysis, as well as thermal studies. LOD 300 includes model elements that are accurate in terms of quantity, size, shape, location and orientation, and the amount of information embedded in the models is equivalent to construction documentation. BIMs at this stage of development can be used for detailed daylight/glare analysis, energy analysis, as well as optimization of systems. It is important to note that these types of studies have the greatest impact on the building performance if they are conducted early in the design process (conceptual, schematic and design development).

4.0 METHODS FOR INFORMATION EXCHANGE BETWEEN BIM AND ANALYSIS APPLICATIONS

Best practices for data exchange between BIM and environmental analysis software depend on the analysis objectives and what type of information/data is needed. For example, for determination of building massing that minimizes solar exposure or incident solar exposure on the facade, data exchange through DXF file format is adequate. For these types of studies, geometric properties of the building massing or component under analysis (for example, part of the facade with shading devices) are sufficient, as developed in LOD 100 model. Examples are shown in Figure 3, where the building massing and form are optimized based on incident solar radiation for different building orientations.

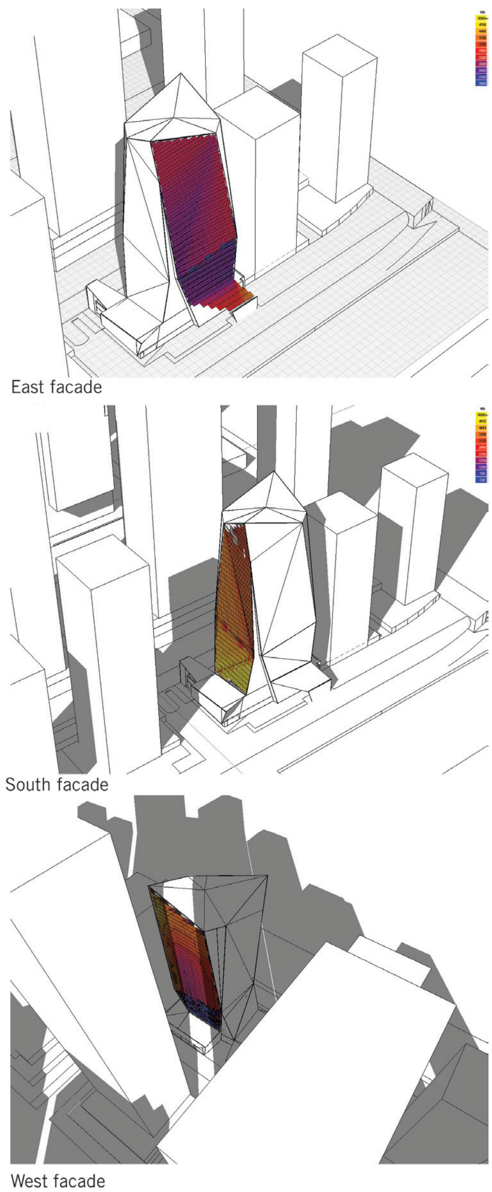


Figure 3: Optimization of building form based on incident solar radiation (LOD 100 model).

For other types of studies, such as daylight or thermal analysis, enriched information about interior spatial organization and zones, material properties and properties of shading surfaces is needed. Therefore, information stored in “design” BIM needs to be exported as “analysis” BIM. For example, Ecotect analysis software is designed to be used during the early stages of the design process and can be effectively used for variety of analysis functions such as shadow analysis, shading, and solar exposure studies. Data exchange between Revit and Ecotect can be performed through Green Building XML (gbXML) schema, a computer language specifically developed to facilitate transfer of building properties stored in BIM to analysis tools.

Basic structure of gbXML consists of elements such as rooms, walls, floors, ceilings, shading surfaces and windows, which inherit properties embedded in the model (actual numeric values) and transfer to analysis applications. The following model parameters are essential for data exchange and are useful in utilizing BIM models for environmental analysis:

1. **Rooms** are the basis of the gbXML file. The hosting structure, location and properties must be specified in the model since all the other data is associated with these elements. Only significant spaces, corresponding to thermal zones, should be defined as rooms. Smaller supportive spaces (elevator shafts, storage spaces, mechanical spaces, etc.) of minimal impact should be grouped. Rooms must be fully bounding, and setting up correct heights and dimensions is important.
2. **Analytical surfaces (Floors, Walls, Roofs):** Building elements must be bounding and connected.
3. **Openings:** Windows and skylights should be defined and their properties and technical details (such as material properties) can be modified in Ecotect (thicknesses, U-values, visual transmittance, solar heat gain coefficient).
4. **Shading surfaces:** Shading surfaces are treated as analytical surfaces (walls, floors or roofs) not bounding a room and are exported as simple surfaces.

These basic elements can be embedded in the model from the earliest stages of the design process (LOD 100), and developed in LOD 200 for studies of different design options and scenarios through environmental analysis. It must be noted that these elements must be properly defined and embedded in the BIM design models if this data exchange mechanism is to be used for translation of building information from design to analysis applications. Also, some modification of translated geometry or element properties may be required in the analysis software application.

Figure 4 shows an example of a Revit file (upper right) with information needed for the analysis imbedded in the model (rooms, their dimensions and properties), which get transferred by gbXML file to analysis engine. The gbXML file containing exactly the same information, but showing a different, data-based view is shown on the left. The lower right image displays analysis model created in Ecotect from the gbXML file.

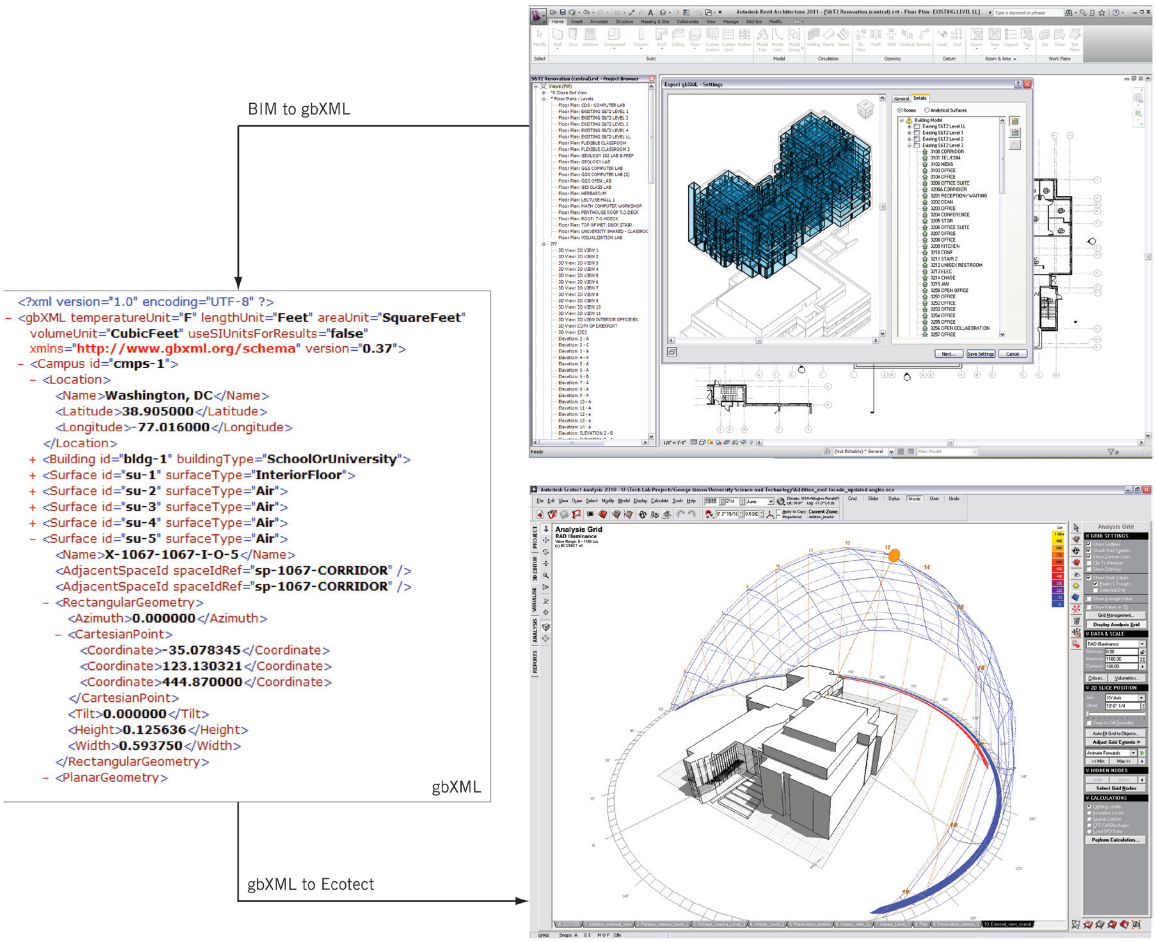


Figure 4: Revit "design" BIM with LOD 200 (upper right); gbXML file structure and data-centric view of the same properties (left); Ecotect "analysis" model generated from the gbXML file (lower right).

5.0 CASE STUDY 1: SIMULATIONS OF DESIGN OPTIONS AND BUILDING PERFORMANCE ANALYSIS

The first case study reviews results of a study that was conducted during the design of a commercial building located in Boston. Building performance analysis and simulations were used during the schematic design to investigate different facade design options, and their effects on energy performance and available daylight. BIM-based and non-BIM based simulation tools were used. For example, EnergyPlus was used for energy modeling, in order to assess the effects of different facade design options on energy consumption. Ecotect was used to study solar exposure for different facade options, and Radiance daylight simulation tool for daylight analysis. The study considered different facade orientations of the building, and different design strategies for improving energy performance and occupants' visual comfort.

5.1 Facade Design and Energy Modeling

The plan for a typical floor of the building is shown in Figure 5, indicating facade orientations that were investigated. Two different facade types are used along the east orientation (type 1 encloses a double-story atrium, and type 2 encloses single-story office space). South and west oriented facades enclose a double-story atrium space. Three different design options were investigated for each orientation, and specific characteristics are listed in Table 1. In summary, these following scenarios were investigated:

- **East orientation (type 1):**
  - Base case: curtain wall

  - Option 1: curtain wall with 50% of vision area glass covered with ceramic frit pattern
  - Option 2: similar to option 1, with added vertical fins to provide shading
- **East orientation (type 2):**
  - Base case: curtain wall with spandrel
  - Option 1: similar to base case, with 50% of vision area covered with ceramic frit pattern
  - Option 2: similar to base case, with vertical fins
- **South orientation:**
  - Base case: curtain wall (Figure 6)
  - Option 1: curtain wall with spandrel
  - Option 2: curtain wall with horizontal shading elements (Figure 7)
- **West orientation:**
  - Base case: curtain wall
  - Option 1: curtain wall with vertical fins
  - Option 2: curtain wall with horizontal shading elements, identical to option 2 for south orientation.

All scenarios considered thermally broken aluminum mullions for curtain wall framing, and the properties of the glazing units are listed in Table 2.

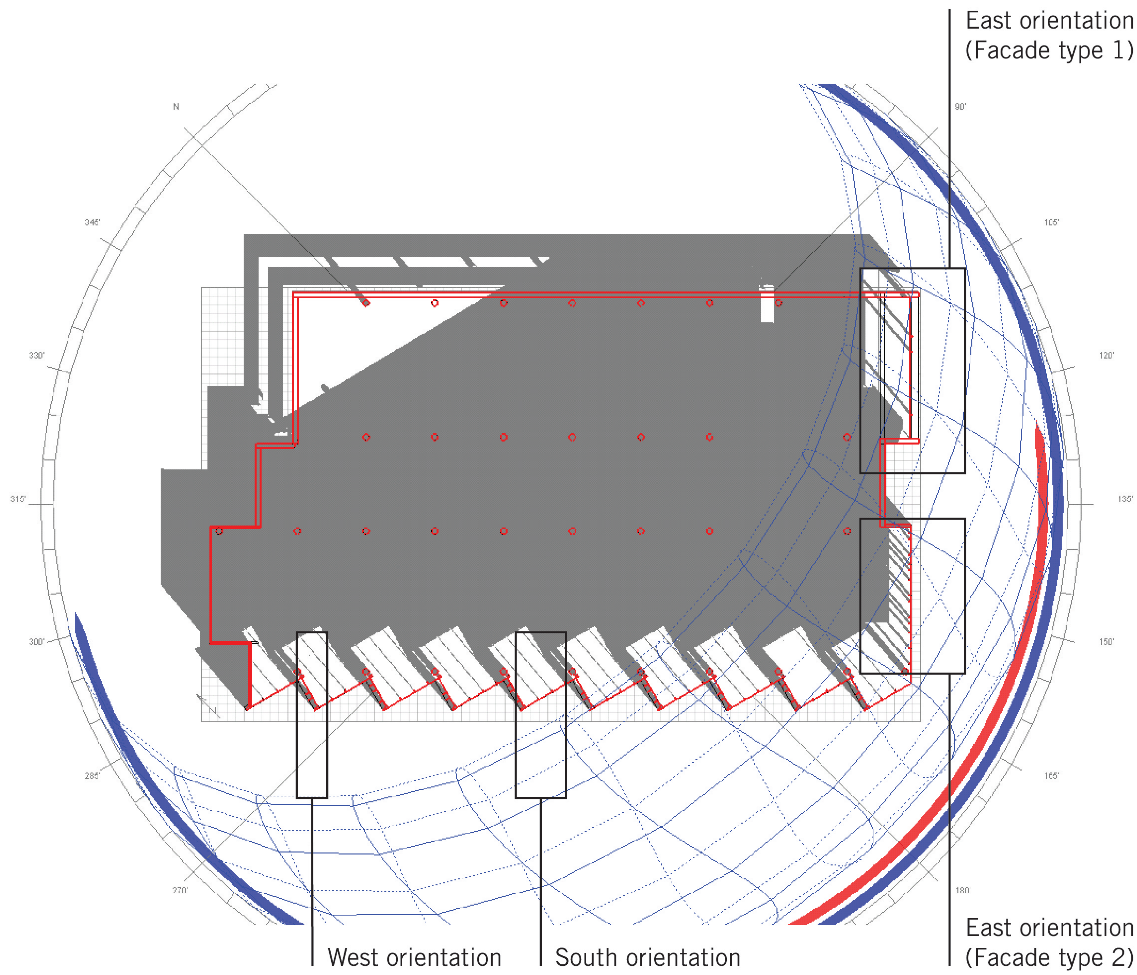


Figure 5: Building plan indicating different facade orientations.

Table 1: Different facade design options considered in the study and their characteristics.

Facade orientation	Design options	Characteristics
East facade type 1 (enclosing two story atrium)	Base case	Fully glazed curtain wall with low-e IGU
	Option 1	Fully glazed curtain wall with low-e fritted IGU (frit pattern covering 50 percent of the vision area)
	Option 2	Fully glazed curtain wall with low-e fritted IGU (frit pattern covering 50 percent of the vision area), and 1.5 ft deep exterior shading elements (vertical fins) spaced 2.5 ft apart
East facade type 2 (enclosing one-story interior space)	Base case	Curtain wall with low-e IGU and 2.5 ft high spandrel with R-17 h-ft^2-F/Btu (window-to-wall ratio 70 percent)
	Option 1	Similar to base case, with added 1.5 ft exterior vertical fins spaced 2.5 ft apart
	Option 2	Similar to base case, with frit pattern covering 50 percent of the vision area
South	Base case	Curtain wall with low-e air IGU (window-to-wall ratio 95 percent), as seen in Figure 6
	Option 1	Curtain wall with low-e IGU and 2.5 ft high spandrel with R-17 h-ft^2-F/Btu (window-to-wall ratio 85 percent)
	Option 2	Curtain wall with low-e IGU, horizontal overhang (3 ft deep) and an interior light-shelf, and horizontal shading elements (0.5 ft wide fins spaced 1 ft apart below the overhang, and 2 ft above the overhang), as seen in Figure 7
West	Base case	Curtain wall with low-e IGU (window-to-wall ratio 95 percent)
	Option 1	Curtain wall with low-e air IGU and 1.5 ft deep vertical fins spaced 2.5 ft apart
	Option 2	Curtain wall with low-e IGU, horizontal overhang (3 ft deep) and an interior light-shelf (also 3 ft deep), and horizontal shading elements (0.5 ft wide fins spaced 1 ft apart below the overhang, and 2 ft above the overhang), identical to south facade option 2

Table 2: Properties of the glazing units.

Glass properties	Base case	Options 1 and 2 (fritted glass)
U-value (Btu/h-ft^2-F)	0.29	0.29
SHGC	0.38	0.60
Visual transmittance	0.70	0.48

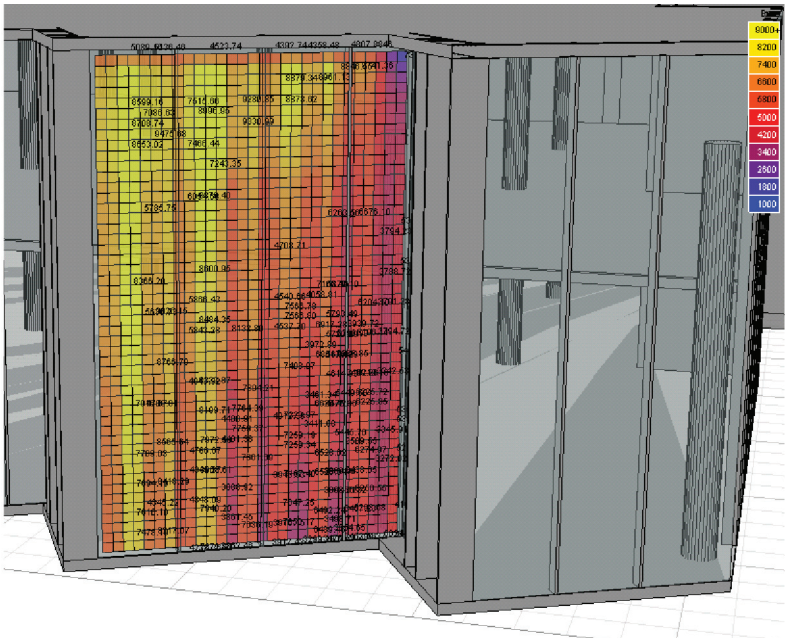


Figure 6: Incident solar radiation for south-oriented facade (Base case).

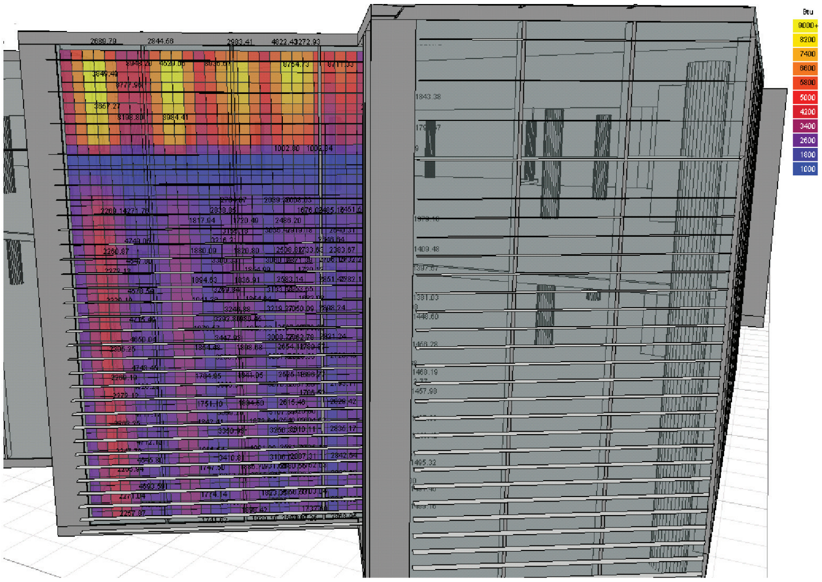


Figure 7: Incident solar radiation for south-oriented facade (Option 2).

Figures 6 and 7 show incident solar radiation for the south facade (base case and option 2 with horizontal shading elements). Ecotect simulation software was used to calculate incident solar radiation for these scenarios, and results indicate that horizontal shades work really well in reducing incident solar radiation for this facade. Figure 8 shows results for hourly solar heat gain (all three options for south facade).

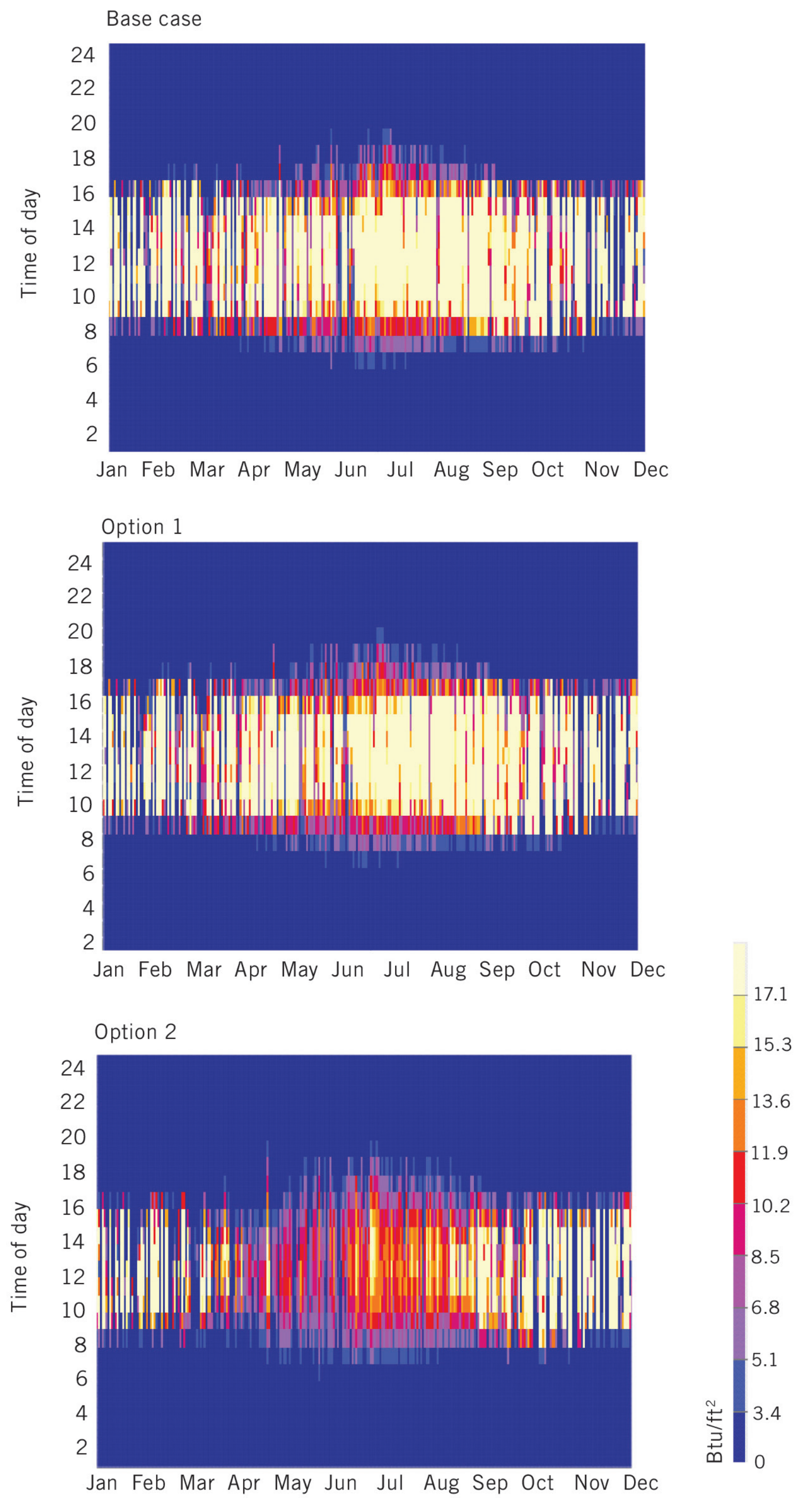


Figure 8: Comparison of hourly solar heat gain for south-oriented facade design options.

Figure 9 shows summary results for energy consumption for all building orientations and design options. These simulations were performed using EnergyPlus, which is non-BIM based energy modeling software. The results indicated that options 2 would be the best design scenarios (all four orientations) for improving energy performance.

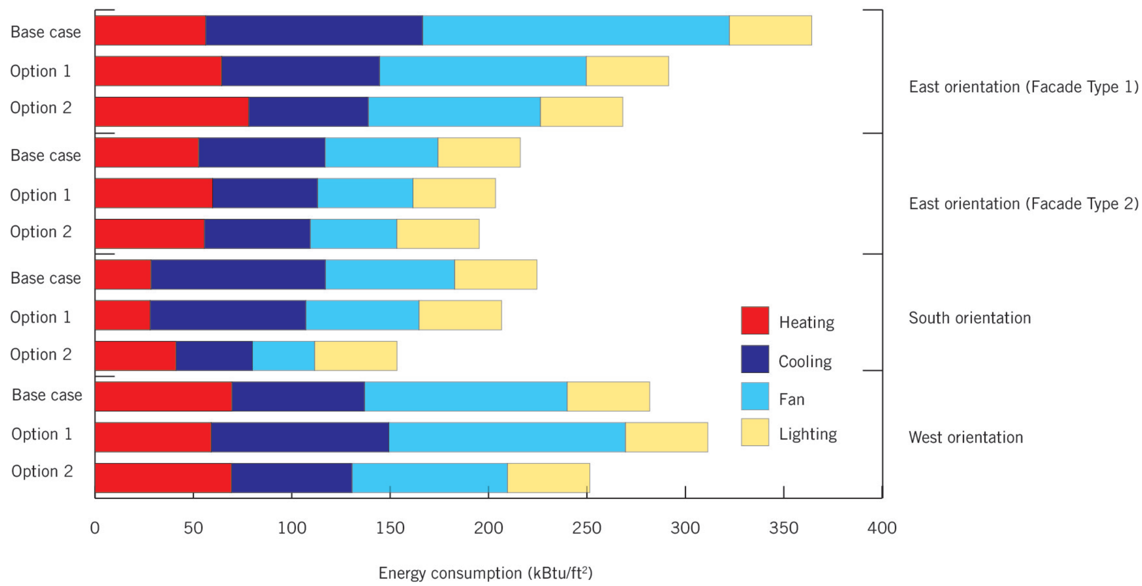


Figure 9: Comparison of energy consumption for all design scenarios.

5.2 Daylight Analysis

Daylight simulations were performed to investigate availability of natural light reaching the interior space. Since it was found that the best-performing design scenarios for the south and west orientations include horizontal overhang, horizontal shading elements and a light-shelf for reducing energy consumption, these design options have been used to study availability of natural light. They were compared to two other design options:

- **Base case:** flat south-west facade
- **Option 1:** serrated south-west facade without any shading elements or light-shelves
- **Option 2:** serrated south-west facade with a 3 ft deep horizontal overhang, horizontal shading elements (0.5 ft wide fins spaced 1 ft apart below the overhang, and 2 ft above the overhang) and 3 ft deep interior light-shelf.

Daylight analysis was performed for September 21 at noon, with sunny sky conditions, using Radiance simulation software. This date was selected in order to investigate representative conditions for fall equinox, and this specific time was selected based on the relative orientation of the analyzed space. Daylight simulations can also be performed for other times of the year (such as June 21 for summer, and December 21 for winter conditions).

Since this facade adjoins two-story interior space, the purpose of the analysis was to compare daylight levels on both levels. Specifically, light redirecting mechanisms for the office space located on the second floor were investigated, since this space is located approximately 20 ft from the facade, and is separated from the atrium by a glass partition wall. These different options are shown in Figure 10, as well as the daylight simulation results.

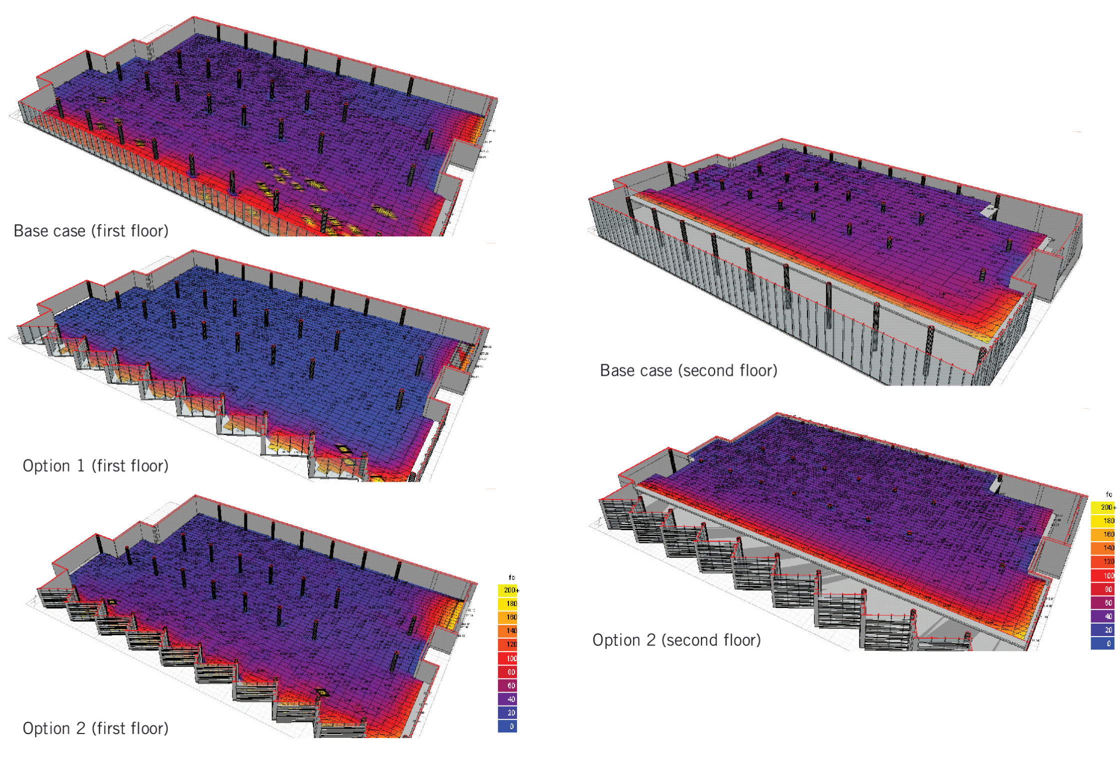


Figure 10: Design options and daylight levels.

Generally, the base case scenario has highest daylight levels along the first floor; however, this option is the worst from energy performance perspective. Comparison between options 1 and 2 shows that option 2 would provide more daylight, since the shading elements and a light-shelf would redirect light within the interior space. For the second floor, daylight levels are comparable for both options, although the actual values are higher for the base case scenario. Since option 2 is the best performing design scenario in terms of energy performance, the addition of light-shelves would balance the effects of shading elements on the availability of natural light. Figures 11 and 12 show detailed results of the daylight analysis.

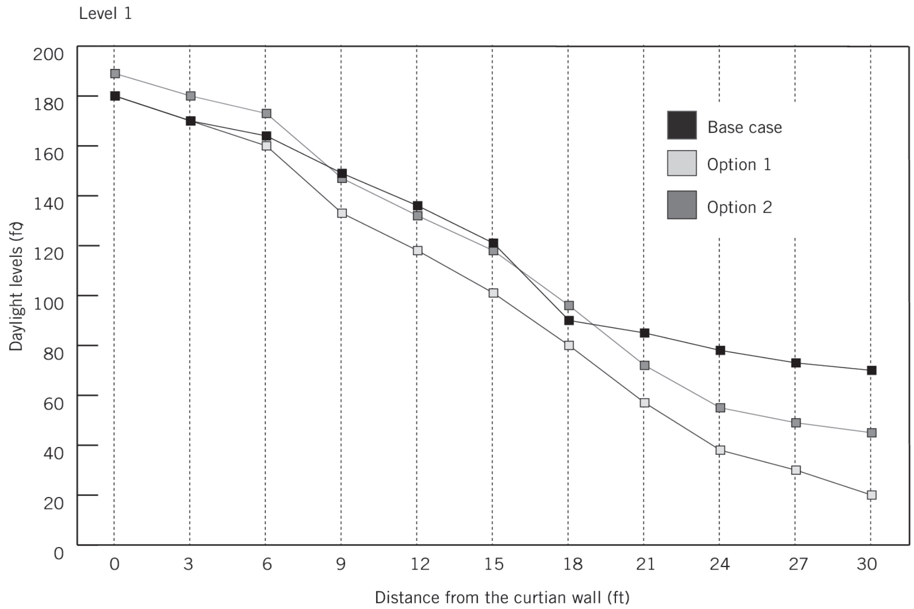


Figure 11: Daylight analysis results (first floor, September 21 at noon).

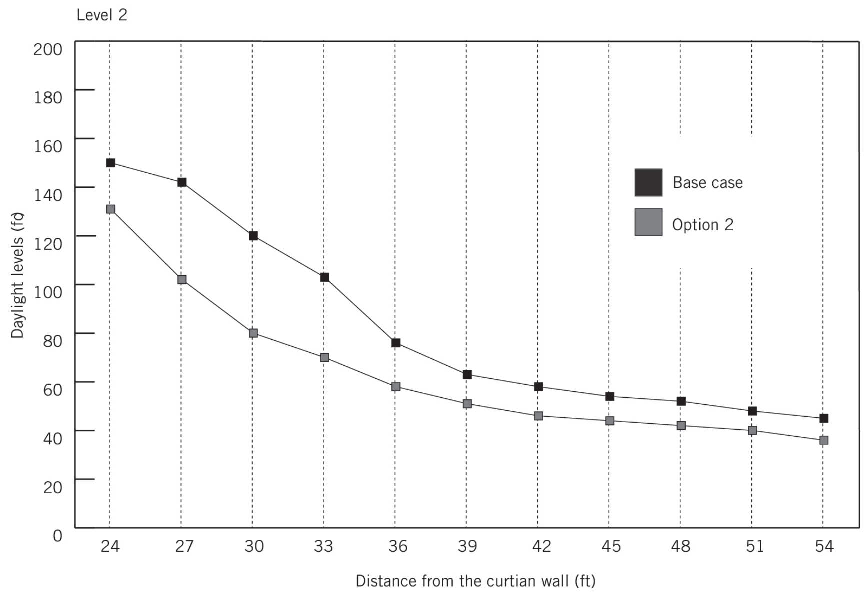


Figure 12: Daylight analysis results (second floor, September 21 at noon).

This case study illustrates how research process, as well as use of building performance analysis can be beneficial for design decision-making. Having these results and quantifiable data allowed the design team to make informed decisions regarding the facade treatment for this specific project, as well as daylight harvesting strategies. At the same time, documenting results and sharing research processes, objectives and results is beneficial for the design community at large since these results can also be applied to other similar projects or design problems.

The next case study reviews how advanced computational design approaches that use analytic data for parametric modeling can be beneficial. Currently, while data exchange between BIM and analytical software can be accomplished, importing the results of the analysis back into the BIM and controlling the geometry of its elements based on the results is extremely challenging. Therefore, custom applications, advanced computational design tools and methods that fully integrate BIM design and analysis software programs are necessary to accomplish this.

6.0 CASE STUDY 2: PARAMETRIC DESIGN, BIM AND PERFORMANCE ANALYSIS

Using analytic data as a driver to parametrically control the geometry of BIM elements is currently a promising method for modeling design elements, such as sun shades, that respond to environmental constraints, such as incident solar radiation or solar angles. This can be done qualitatively, but evaluating multiple options with many variables can be time consuming. A preferred method is to use analytical data, coming from applications such as Ecotect, to parametrically control BIM elements. A previously published article reviewed in detail customization of the Autodesk Revit BIM authoring software to allow for data exchange between BIM design and analytical applications (Revit and Ecotect), where analytic data is used to control the geometry of BIM families[13]. Major points and findings are summarized in this section, and a specific case study is discussed to illustrate innovative approach for parametric modeling and data-driven form optimization based on environmental analysis data.

A BIM provides a common database of information about a building, including its geometry and attributes. It is an integrated, comprehensive building model that stores the information contained in traditional building documents, such as drawings, specification, and construction details, as well as additional 3D information and metadata, in a centralized or distributed database. The goal of BIM is to provide a common structure for information sharing that can be used by all agents in the design process and construction. It virtually simulates design and construction, and provides groundwork for collaborative design, since all the relevant information, such as spatial organization, building components, building systems (mechanical, electrical, plumbing, HVAC) can be incorporated into building descriptions.

Typical workflow and data exchange between BIM and environmental analysis applications requires export of model geometry from BIM to analysis applications, as discussed in previous sections of this article. Appropriate methods for data exchange between BIM and environmental analysis software depend on the analysis objectives and what type of information/data is needed.

As stated above, data exchange between BIM and analytical software can be accomplished, but importing the results of the analysis back into the BIM and controlling the geometry of its elements based on the results is challenging. Therefore, a custom-built plug-in for the Revit platform was developed that allows import of analytical results, such as solar radiation, into BIM design model[13]. It enables importing of data via Excel spreadsheets and parametric control of Revit families based on the numeric values contained in the imported data. The process is shown in Figure 13.

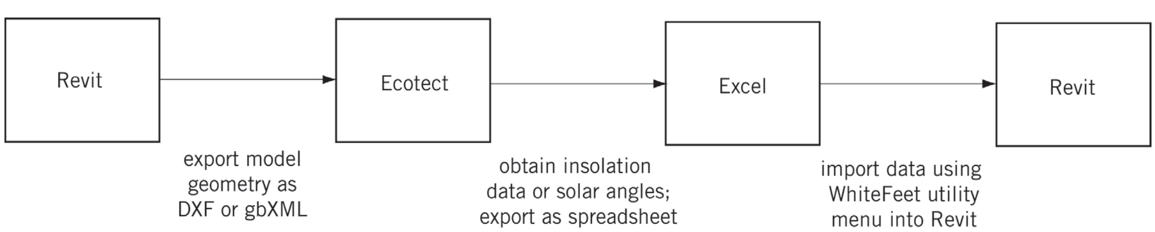
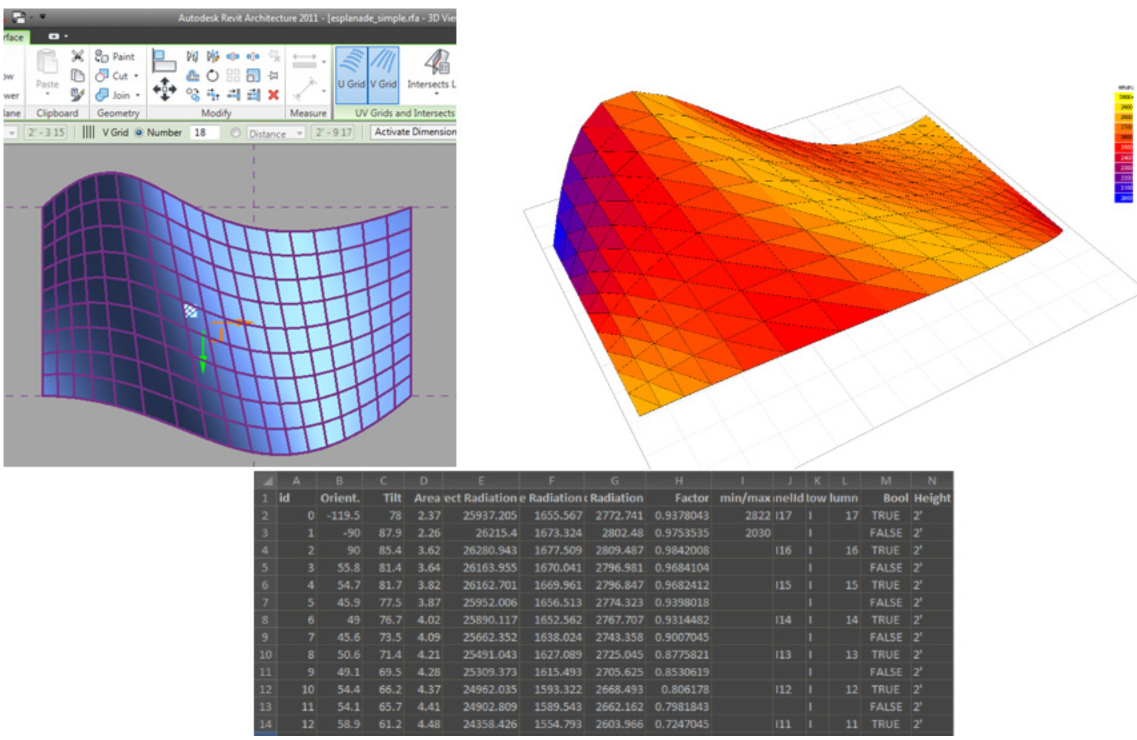


Figure 13: Process diagram showing data exchange between different applications for parametric control of BIM elements based on performance analysis data.

It was tested in relation to building envelope design, as seen in Figure 14, specifically focusing on optimizing design of shading devices along a complex surface based on solar radiation data obtained from Ecotect. In order to align the Ecotect data with individual instances of Revit panel families, several instance parameters can be created within the family. This allows the subdivision of families to be logically ordered in order to align them with Ecotect. After creating a surface in the conceptual design environment, the surface can be subdivided into a desired number of divisions, which can then be exported into a DXF file. This geometry can be imported into Ecotect to analyze incident solar radiation, and obtain solar radiation values based on building location and specific orientation of the panel. These values can be exported from Ecotect into an Excel spreadsheet, as seen in Figure 14. Once the solar radiation data is obtained and imported in Excel spreadsheet, it must be normalized based on minimum and maximum solar radiation values (in this case, it is normalized into values from 0 to 1). This normalized data is imported into Revit using WhiteFeet utility menu, and used to control the geometry of Revit panel families. This is achieved by matching the normalized values to the correct panel position on the complex curved surface, and using the normalized value from 0 to 1 to control the position and geometry of the shading element relative to the center-point of each panel. The resultant is shown in Figure 15, showing a surface where the shading elements for the curtain wall panels respond to solar radiation striking this surface.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	id	Orient.	Tilt	Area	ect Radiation	e Radiation	Radiation	Factor	min/max	nelId	tow	lumn	Bool	Height
2	0	-119.5	78	2.37	25937.205	1655.567	2772.741	0.9378043	2822	I17	I	17	TRUE	2'
3	1	-90	87.9	2.26	26215.4	1673.324	2802.48	0.9753535	2030		I		FALSE	2'
4	2	90	85.4	3.62	26280.943	1677.509	2809.487	0.9842008		I16	I	16	TRUE	2'
5	3	55.8	81.4	3.64	26163.955	1670.041	2796.981	0.9684104			I		FALSE	2'
6	4	54.7	81.7	3.82	26162.701	1669.961	2796.847	0.9682412		I15	I	15	TRUE	2'
7	5	45.9	77.5	3.87	25952.006	1656.513	2774.323	0.9398018			I		FALSE	2'
8	6	49	76.7	4.02	25890.117	1652.562	2767.707	0.9314482		I14	I	14	TRUE	2'
9	7	45.6	73.5	4.09	25662.352	1638.024	2743.358	0.9007045			I		FALSE	2'
10	8	50.6	71.4	4.21	25491.043	1627.089	2725.045	0.8775821		I13	I	13	TRUE	2'
11	9	49.1	69.5	4.28	25309.373	1615.493	2705.625	0.8530619			I		FALSE	2'
12	10	54.4	66.2	4.37	24962.035	1593.322	2668.493	0.806178		I12	I	12	TRUE	2'
13	11	54.1	65.7	4.41	24902.809	1589.543	2662.162	0.7981843			I		FALSE	2'
14	12	58.9	61.2	4.48	24358.426	1554.793	2603.966	0.7247045		I11	I	11	TRUE	2'

Figure 14: Example of curved surface in Revit and solar radiation analytic data from Ecotect, used to parametrically size and position shading devices along the curved surface.

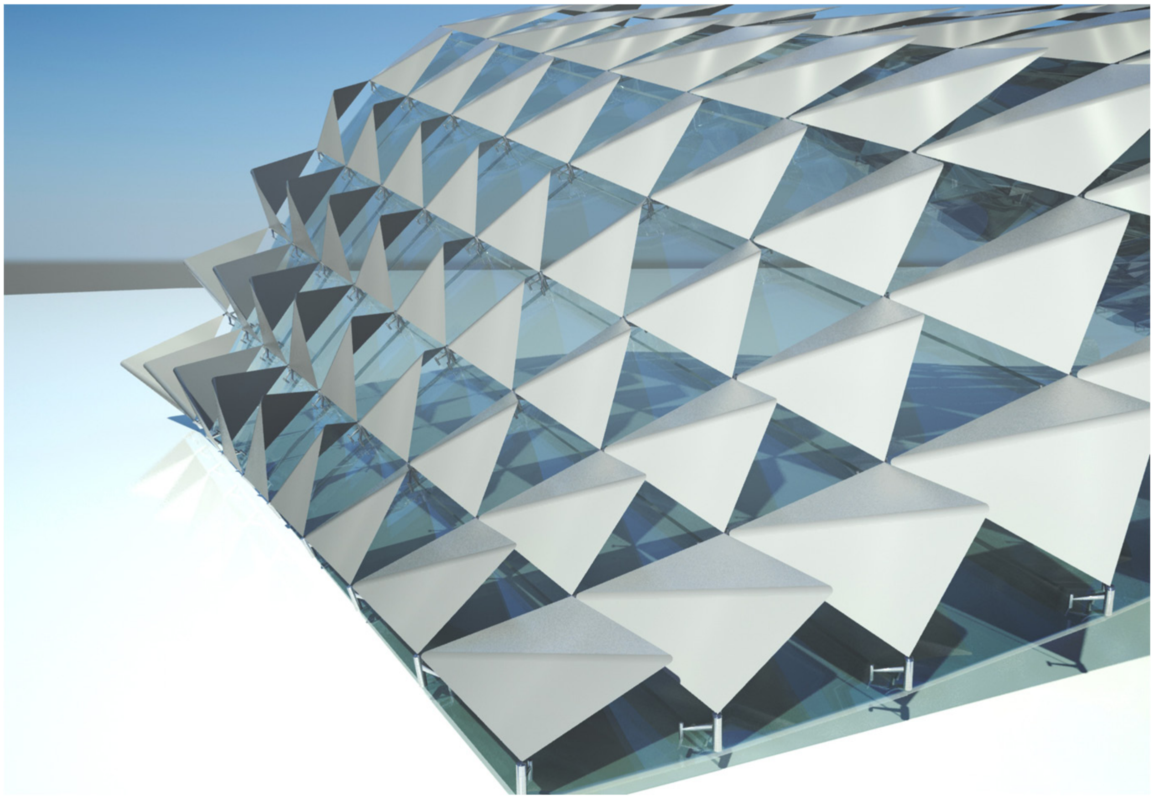


Figure 15: Example of parametric control of shading elements in Revit.

7.0 CONCLUSION

This article discussed relationships between building simulations and design process, and how performance predictions can assist in identifying strategies for reducing energy consumption and improving building performance. The first part of the article discussed why we need to "quantify" design decisions—in order to achieve extremely low and net-zero energy buildings, quantifiable predictions are needed at every step of the process, which evaluate the benefits of using passive strategies, advanced building technologies and renewable energy sources. We need to quantify the benefits of each individual methodology, and relate them to a specific design problem, building, its climate and the context. We also discussed objectives of Perkins+Will Tech Lab and its research projects. Tech Lab's primary research methods include computational simulations and modeling, where different design scenarios are investigated, as well as their effects on building performance.

We also reviewed methods for data exchange between BIM and environmental analysis software applications, emphasizing the importance of differentiating between "design" BIM models and "analysis" models. Interoperability between BIM-based design and simulation tools can improve the workflow between design documents and analysis applications, where information contained in the models can be used for analysis process as well. However, BIM-design model and the BIM-analysis model need to be managed and properly developed, considering the LOD and the required information necessary for performance analysis. It is important to track what type of information is needed for a particular analysis, and how effectively to use BIM to simulate design decisions. We also demonstrated this by reviewing two specific case studies. The first case study discussed building performance analysis that was performed during the design of a commercial building, methods and results. The second case study discussed advanced computational design methods for integration of environmental performance data with the design.

REFERENCES

[1] Aksamija, A., (2009). "Integration in Architectural Design: Methods and Implementations", *Design Principles and Practices: An International Journal,* Vol. 3, No. 6, pp. 151-160.

[2] Aksamija, A, (2010). Tech Lab Annual Report 2009, Perkins+Will, Available from http://www.perkinswill.com/research/tech-lab-annual-report-2009.html.

[3] Aksamija, A., (2011). Tech Lab Annual Report 2010, Perkins+Will, Available from http://www.perkinswill.com/research/tech-lab-annual-report-2010.html.

[4] Aksamija, A., (2012). Tech Lab Annual Report 2011, Perkins+Will, Available from http://www.perkinswill.com/research/tech-lab-annual-report-2011.html.

[5] Aksamija, A., (2013). Tech Lab Annual Report 2012, Perkins+Will, Available from http://www.perkinswill.com/research/tech-lab-annual-report-2012.html.

[6] Aksamija, A., and Mallasi, Z., (2010). "Building Performance Predictions: How Simulations Can Improve Design Decisions", *Perkins+Will Research Journal,* Vol. 2, No. 2, pp. 7-32.

[7] Gratia, E., and de Herde, A., (2002). "A Simple Design Tool for the Thermal Study of an Office Building", *Energy and Buildings,* Vol. 34, pp. 279-289.

[8] Punjabi, S., and Miranda, V., (2005). "Development of an Integrated Building Design Information Interface", *Proceedings of IBPSA '05 Buildings Simulation Conference,* Montreal, pp. 969-976.

[9] Attia S., Beltran L., de Herde A., and Hensen J., (2009). "Architect Friendly: A Comparison of Ten Different Building Performance Simulation Tools", *Proceedings of IBPSA '09 Buildings Simulation Conference,* Glasgow, 204-211.

[10] Aksamija, A., (2010). "Analysis and Computation: Sustainable Design in Practice", *Design Principles and Practices: An International Journal,* Vol. 4, No. 4, pp. 291-314.

[11] Zisko-Aksamija, A., (2008). "Information Modeling in Architectural Design: Collaborative Environment for Decision-Making Process", *Design Principles and Practices: An International Journal,* Vol. 2, No. 2, pp. 79-88.

[12] AIA, (2008). AIA Document E202: The American Institute of Architects Building Information Protocol Exhibit.

[13] Aksamija, A., Guttman, M., Rangarajan, H., and Meador, T., (2011). "Parametric Control of BIM Elements for Sustainable Design in Revit: Linking Design and Analytical Software Applications through Customization", *Perkins+Will Research Journal,* Vol. 3, No. 1, pp. 32-45.

THIS PAGE LEFT BLANK INTENTIONALLY

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.

pacity, 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 less[1].

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 depravation and seasonal affective disorder typical of higher latitudes[2].

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 technologies[3].

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 comprised 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.

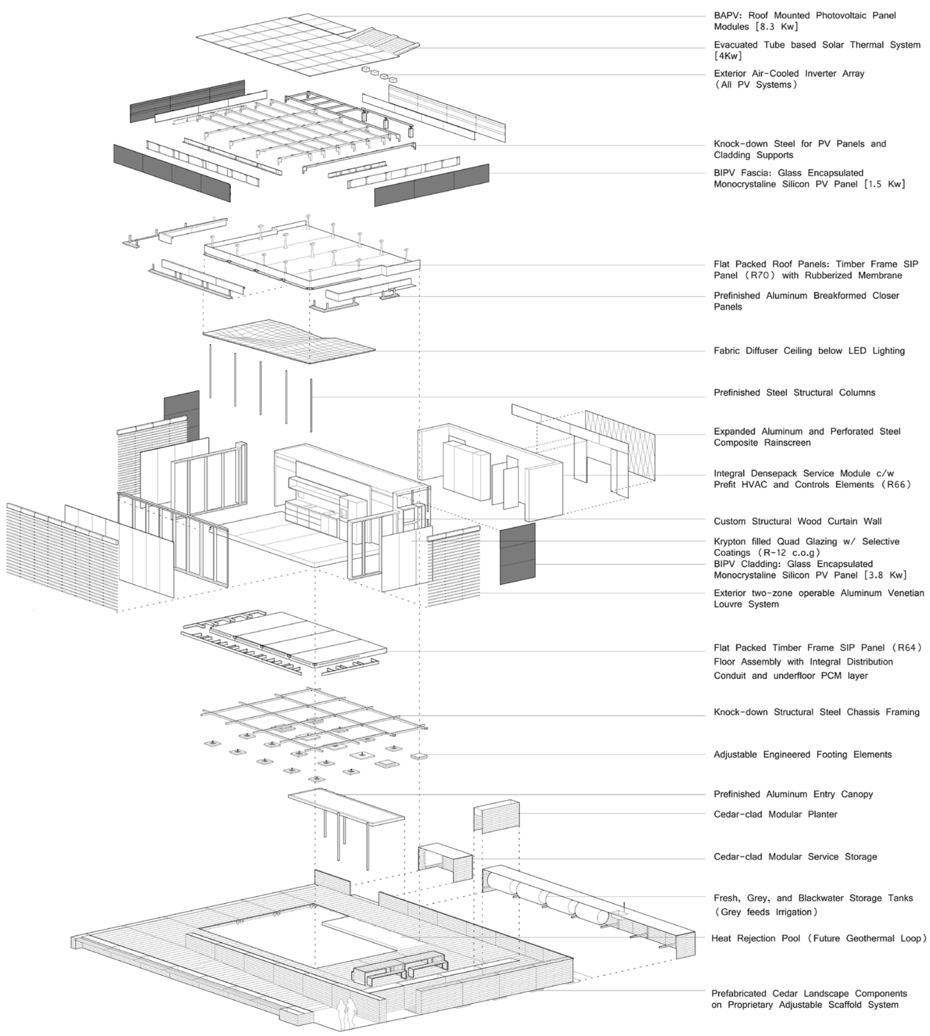


Figure 2: Exploded axonometric of North House building components.

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 floor[4]. 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 performance[5]. (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.

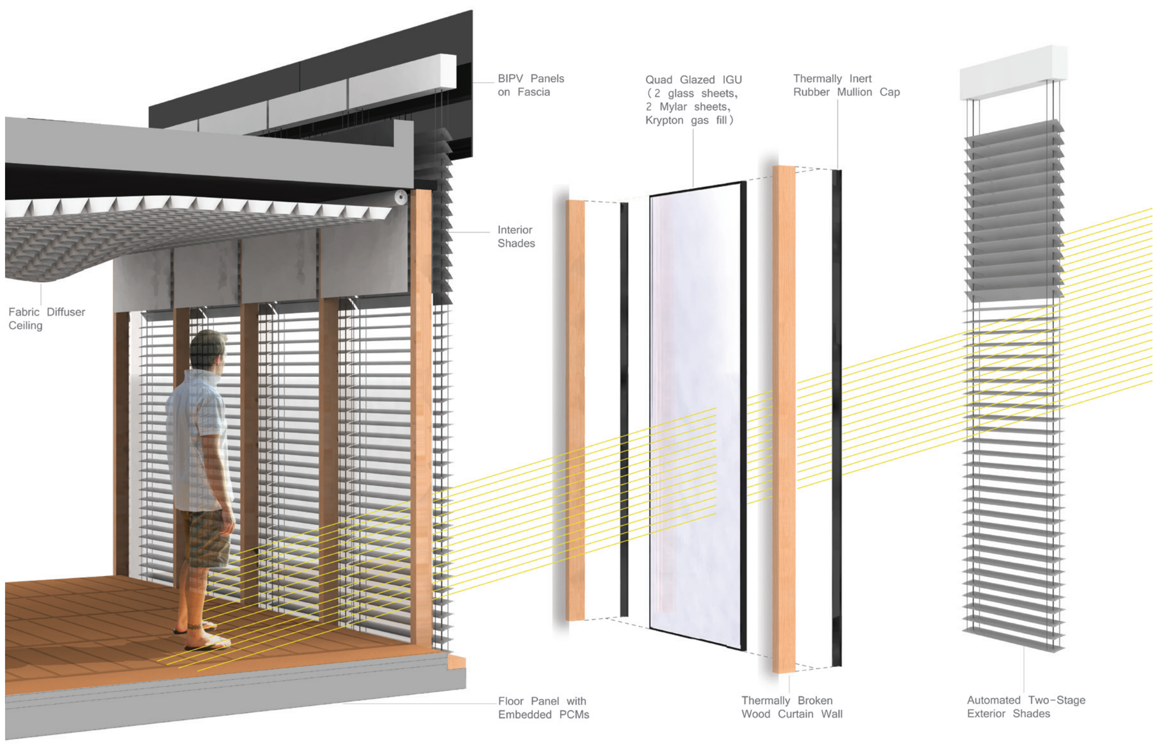


Figure 4: Components of Distributed Responsive System of Skins (DReSS).

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).

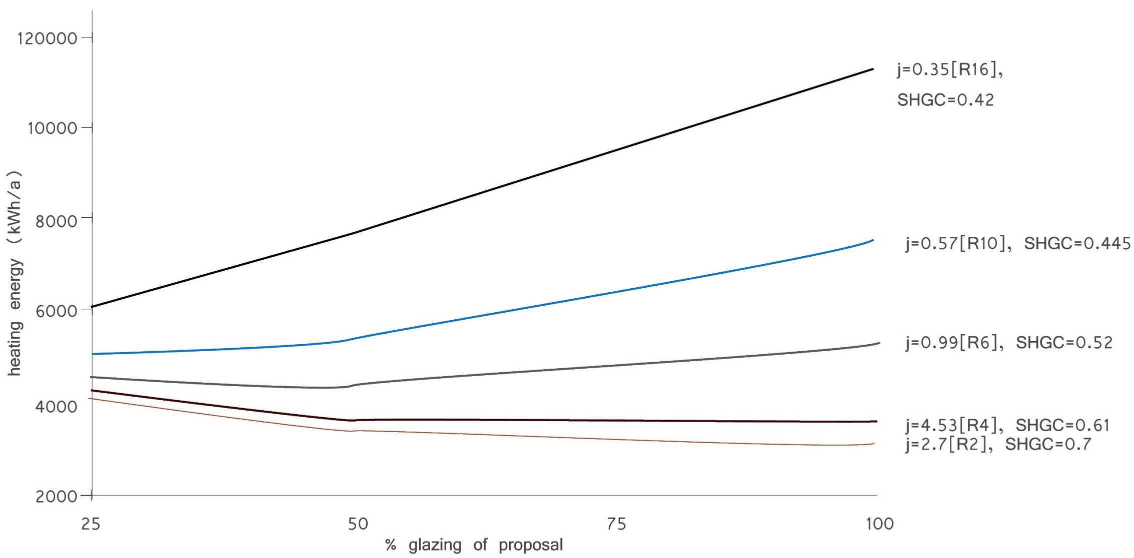


Figure 5: Predicted effect of various glazing property combinations and percentage glazing on annual heating energy.

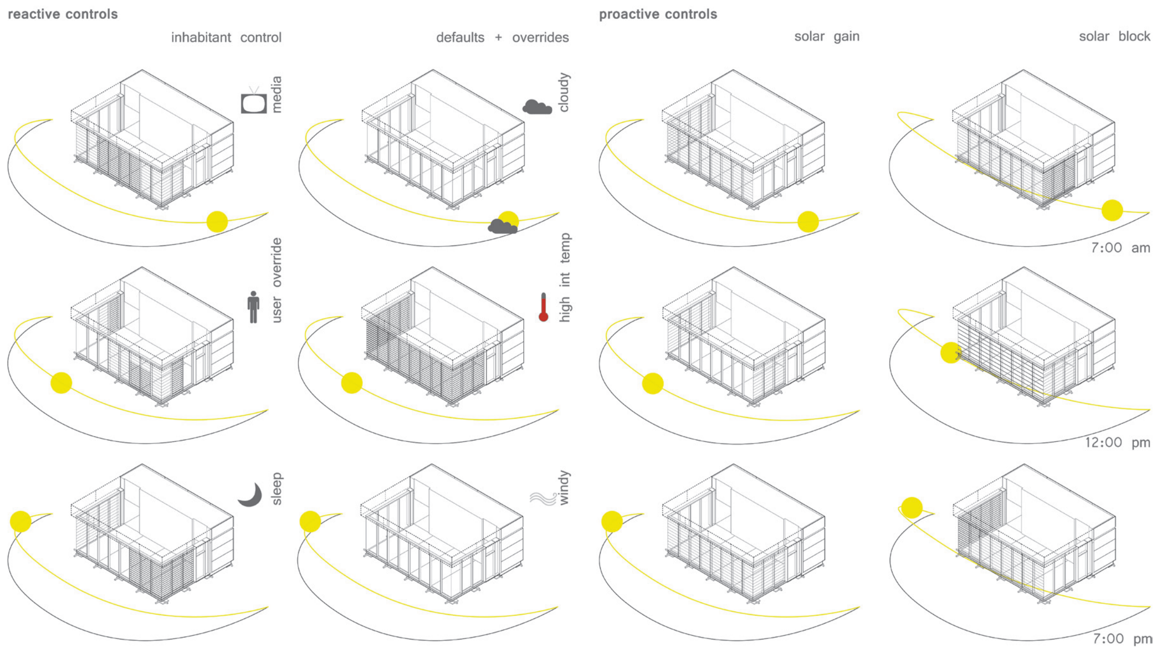


Figure 6: Exterior shade configuration scenarios based on relative exterior environmental conditions, and related responsive envelope reactions that formed an operational logistics framework for the development of the home automation system.

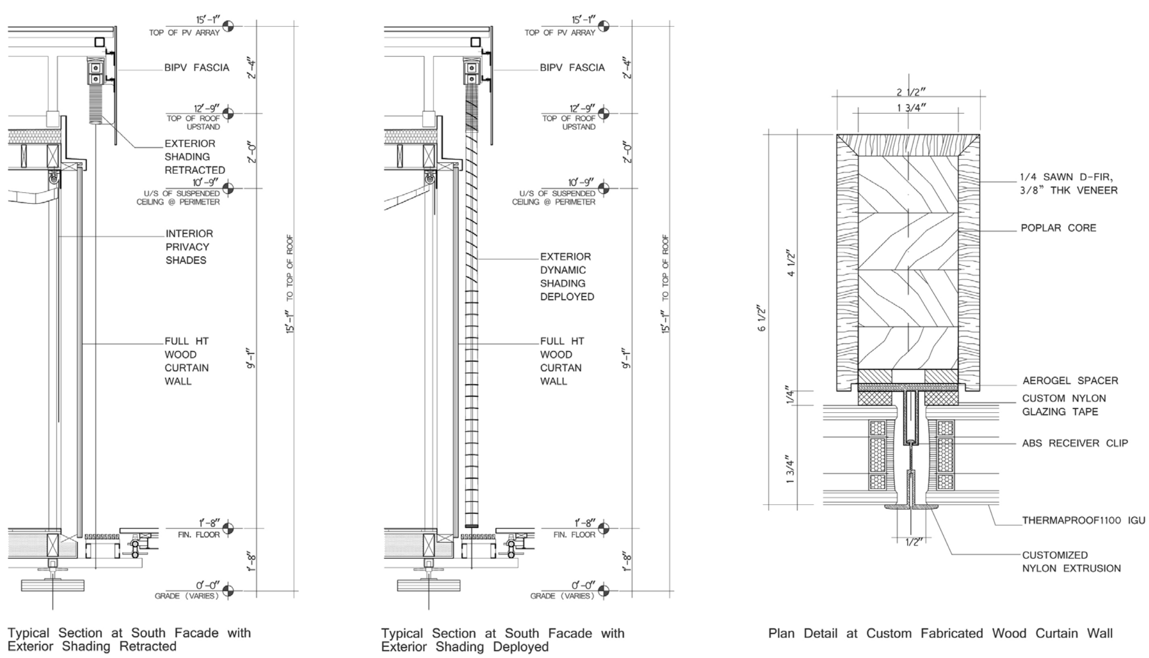


Figure 7: Technical details at wood curtain-wall envelope with automated shading.

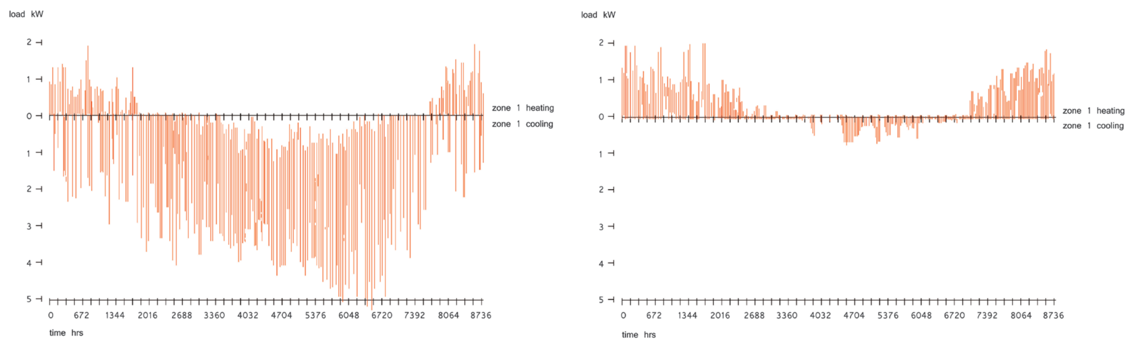


Figure 8: Modified ESP-r model of annual heating and cooling loads with no shading (left) and with dynamic shading (right).

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 assembly[6]. 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 IGUs[7]. 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 12.7mm[8]. The resulting IGU had a center of glass insulating value of R-12 (U-value of 0.474 W/m^{2}K), 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/m^{2}K) 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 61.32m^2 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 kWh[9]. 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)

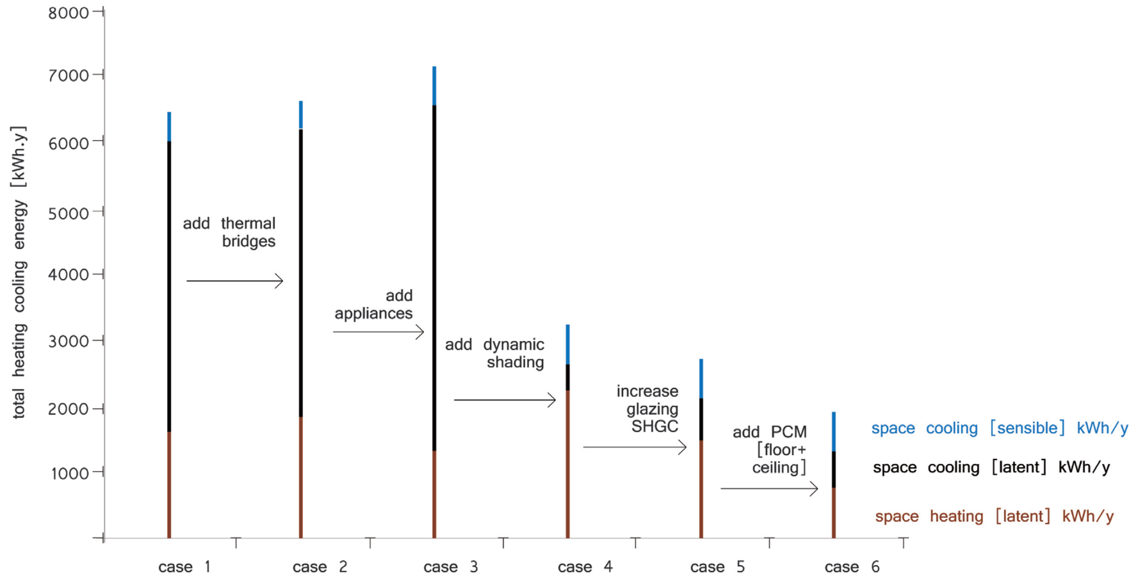


Figure 9: Predicted demand reduction effects of DReSS design strategies on annual space conditioning load.

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 weather[10]. (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.

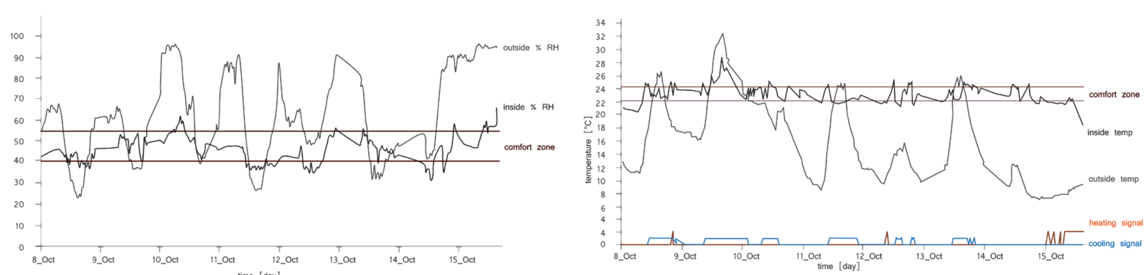


Figure 11: Performance data gathered during ten days of Solar Decathlon competition: relative humidity %RH (left), and interior temperature performance and logged system response to temperature fluctuations (right).

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 efficiency[11].

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

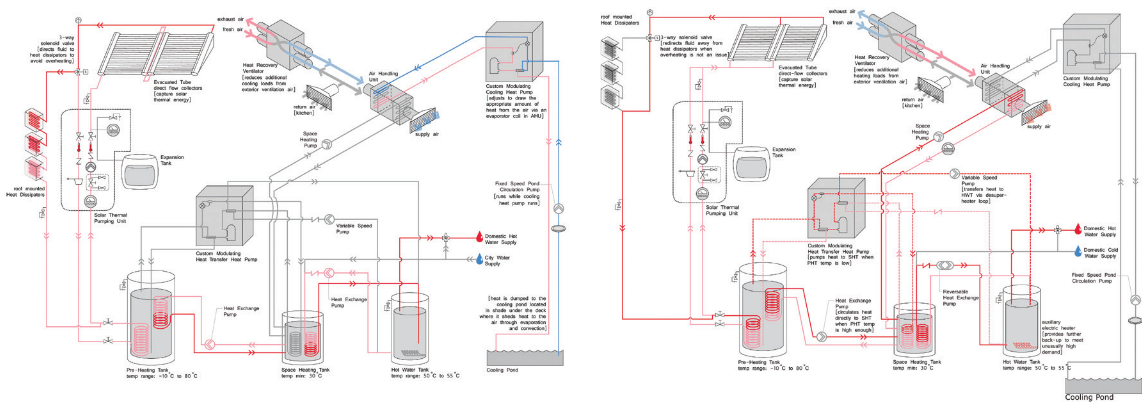


Figure 12: Diagrams of custom developed solar assisted heat pump system. Left, shows the system in cooling and dhw mode, where the space needs to be cooled, but hot water also needs to be produced. Right, shows the system in a heating mode where both space heating and water heating are required.

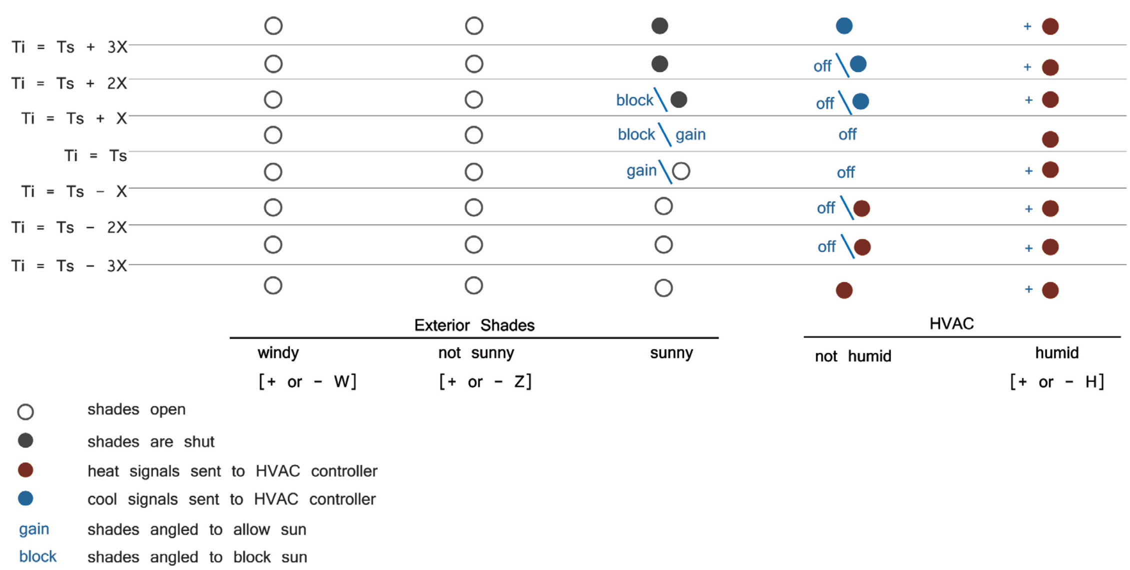


Figure 13: Logic diagrams for external shade and HVAC states, where Ts is the setpoint of thermostat, Ti is internal temperature, X is internal temperature hysteresis factor, Z is solar radiation hysteresis, W is wind speed hysteresis and H is humidity hysteresis.

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-

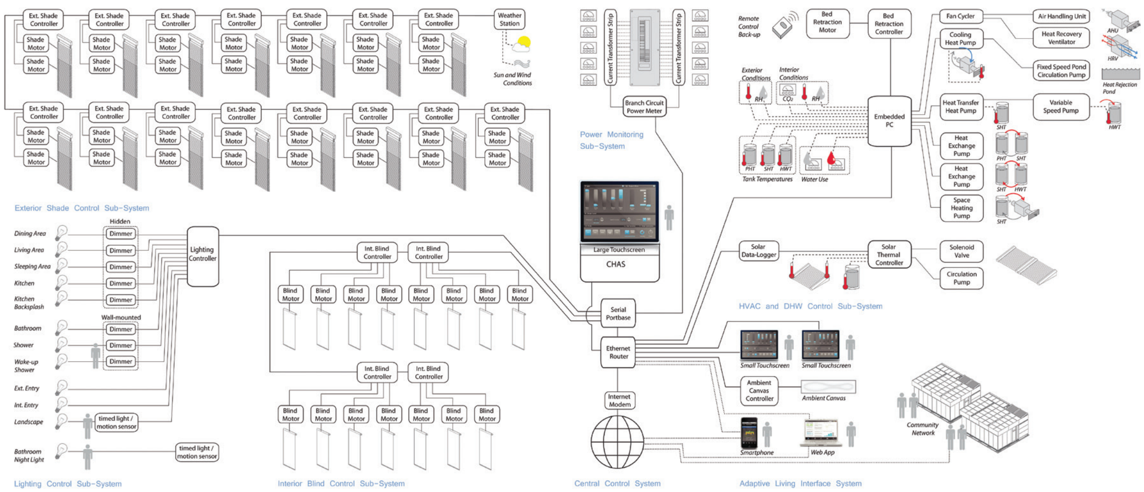


Figure 14: Overview control architecture of the Central Home Automation Server (CHAS), Adaptive Living Interface System (ALIS), and their integration with North House DReSS and mechanical sub-systems.

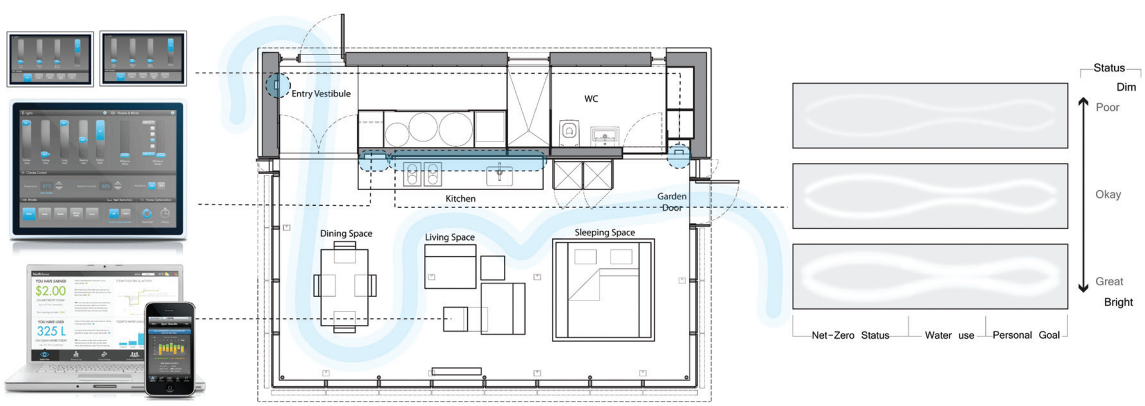


Figure 15: ALIS components and locations in plan (left) and Ambient Canvas operations indicating zoned areas of LED illumination (right).

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 compliments 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 Touschscreen 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 | 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.

04.
CURRENT TRENDS IN LOW-ENERGY HVAC DESIGN

Robert L. Tazelaar, PE, LEED AP, *robert.tazelaar@arup.com*

ABSTRACT
The objective of this paper is to provide some insight into how HVAC systems are changing to meet the drive towards lower energy usage. The paper is primarily focusing on trends, observed by the author in designs which have been highlighted in research journals and project work. A case study is provided which highlights how some of the trends have been implemented on a current design.

KEYWORDS: Heating, Ventilation and Air Conditioning (HVAC), Dedicated Outside Air Systems (DOAS), Ventilation decoupling, Variable Air Volume (VAV)

1.0 INTRODUCTION

Throughout the 20th century, trends in HVAC design have been determined largely by technological advances and energy costs. Engineers have always sought to find new ways to ensure occupant comfort, but the level of attention devoted to finding innovative ways to reduce energy use has fluctuated over the last few decades. When energy costs have risen, energy efficiency has become a priority; when they have been low, it has been less of a design driver.

This article identifies several trends which are being used to reduce energy use in commercial buildings. The trends to be considered include decoupling of ventilation and heating/cooling, designing systems for optimal efficiency, increased analysis in system design, and total building integration. This article is not intended to be a technical argument or justification for selection of one system against another. Many technical articles are available for more complete handling of each of the trends.

2.0 DESIGN TRENDS

2.1 Decoupling of Ventilation and Heating/Cooling

The current movement in HVAC design toward the decoupling of ventilation and heating is in some ways a return to the past. Prior to the widespread use of cooling for buildings, perimeter radiation of some form was typically used for heating, with operable windows providing ventilation.

Following World War II, use of air conditioning became more common, mainly driven by prosperity and the manufacturing boom. Early air conditioning systems combined heating, ventilation, and air conditioning into a single system, delivered by the building's central fan and air distribution network. This fan system typically delivered a mixture of outdoor air for ventilation along with warm or cool air to meet the building's temperature requirements. Larger buildings would have separate systems or zones for interior and perimeter spaces. In more extreme climates, a perimeter heating system may also have been installed or reheat coils provided on ducts serving perimeter spaces.

As prices soared during the energy crisis of the 1970s, engineers looked for a way to reduce costs and improve space comfort conditions. One solution, dual duct systems, provided warm air through one duct and cool air through another. The air would then be mixed at the zone level to provide appropriate temperature supply air for the zone's needs, typically at constant volume. Dual duct systems allowed buildings to be divided into many more zones while using a larger central fan system. Dual duct systems also eliminated the need to re-heat air at the zone level resulting in less re-heat energy and reducing the piping network throughout the building.

The next major innovation to emerge included variable air volume (VAV) systems which eliminated the warm air duct and kept airflow from the system at a constant temperature of approximately 55° to 58°F. VAV systems reduced energy consumption by reducing the quantity of air delivered to the space, matching the quantity of air delivered with the cooling needs of the building. Depending on the ratio of interior to perimeter space and the facade loads of the building, a VAV system could reduce the air quantity delivered to the space by 50% or more, which reduced the amount of fan energy consumed. Another benefit inherent to the VAV system was a reduction of the total system capacity since the system is based on a diversified "block" load which compensates for load variations within the space due to occupancy and solar loads.

Current industry trends are moving HVAC design away from VAV systems, which provide both ventilation and heating and cooling, to decoupled systems which either partially or completely separate the ventilation air from the cooling and heating functions. The primary cost savings associated with decoupled systems is the result of a reduction in fan energy. In one common example, a dedicated outside air system (DOAS), the airflow provided by the fan system is limited to the code-required ventilation component. The DOAS air handling unit provides heated and de-humidified air for ventilation and is frequently provided with some form of heat recovery component such as enthalpy transfer wheels, "run around" coils or heat pipes to further reduce energy consumption by utilizing building exhaust air to pre-condition the ventilation air. A DOAS system typically provides 20% or less airflow than what would be provided at peak cooling periods utilizing a VAV system. With a DOAS system, the heating and cooling requirements for the space are met through a water-based system. Since water has a much higher capacity for energy transfer than air, the amount of energy required to deliver the heating and cooling is greatly reduced, while pump energy is somewhat increased. A side benefit of the reduced air quantity is smaller ductwork, which decreases the cost of the ventilation system and, potentially, the building's required floor-to-floor height. DOAS systems are typically paired with passive chilled beams, radiant heating/cooling, or fan coils.

When applying DOAS and chilled beam systems (shown in Figure 1), the designer must be careful to pay attention to how the air is distributed to the space and how heating is accomplished. In buildings with low heating needs, the ventilation air may be able to provide adequate heating. In buildings with higher heating requirements, supplemental heating systems such as perimeter baseboard may be required. It is critical that the ventilation air reach the occupied breathing zone. For this reason, DOAS systems are frequently configured to deliver the air with a displacement strategy at low level.

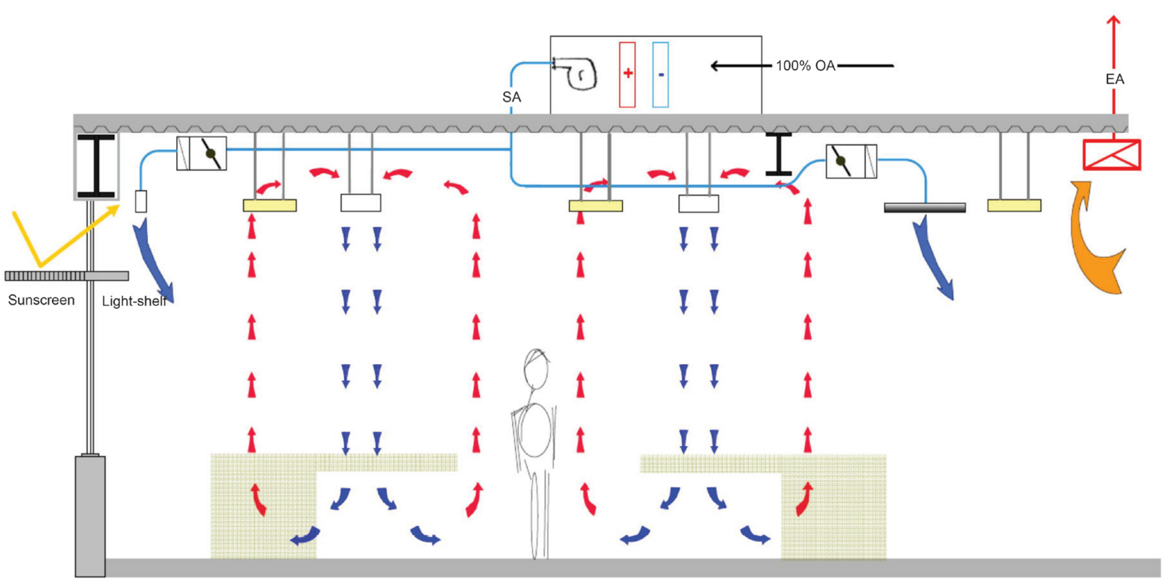


Figure 1: Passive chilled beam system diagram.

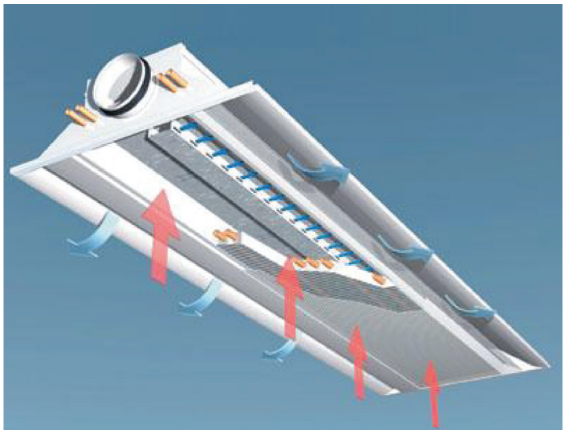


Figure 2: Active chilled beam diagram.

A second type of decoupled system could be considered a hybrid model. Active chilled beams (shown in Figure 2) deliver both ventilation and heating/cooling services, but induced air at the chilled beam delivers most of the heating and cooling while the air handling unit provides only a portion of the requirements. A primary air duct system provides either 100% ventilation air or a mixture of return and ventilation air, depending on the system configuration. The primary airflow for an active chilled beam system is more than that of a DOAS/passive chilled beam system because the active chilled beam utilizes the primary air to induce room air across the coil in the beam. The static pressure in the primary air system may also be higher than that of a DOAS system. Similar to the DOAS/passive chilled beam system, the active chilled beam system delivers pre-heated and dehumidified air to the space through use of an air handling unit which frequently is provided with a means of heat recovery.

We analyzed a simple 20-story building to compare the DOAS/passive chilled beam system and the active chilled beam system to an ASHRAE standard 90.1 baseline VAV system. The results of the study are reflected in Figure 3.

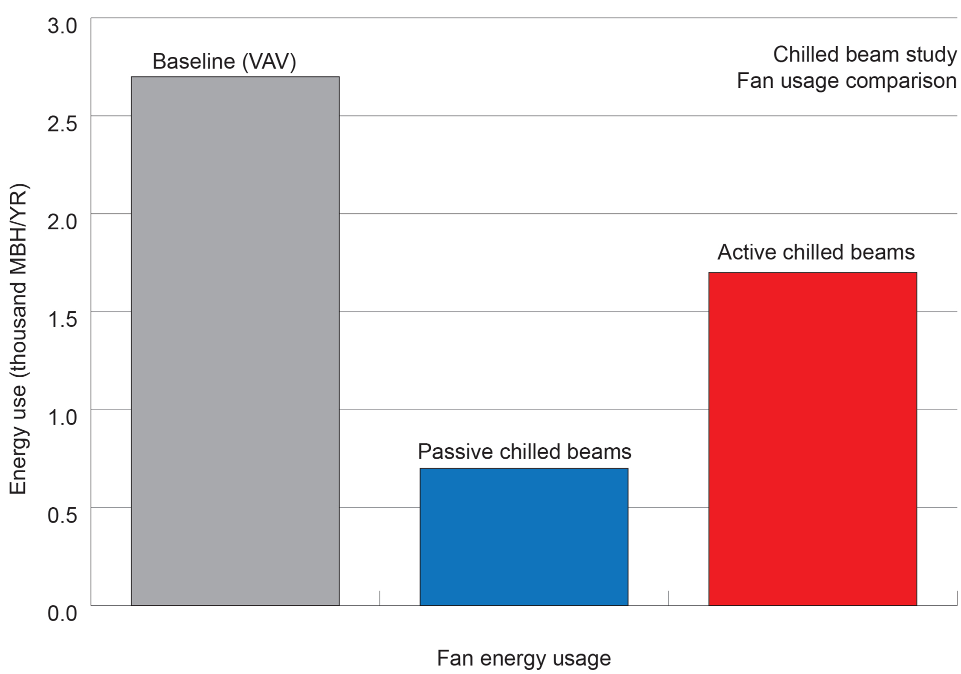


Figure 3: Fan energy comparison.

2.2 System Design for Equipment Efficiency

To take full advantage of new high-efficiency equipment, it is necessary to design the overall system to operate at parameters which correlate to the equipment's best efficiency. While this may seem obvious, too often high-efficiency equipment is specified and applied in systems whose operating parameters do not allow the equipment to realize its best possible efficiency.

One example of this occurs when condensing boilers are applied to systems in which the temperatures are maintained above the point at which condensing occurs, thereby reducing the actual operational efficiency. As seen in Figure 4, boiler efficiency decreases with return water temperature and increased firing rate. While the 87.6% efficiency of the boiler with return water at 160°F exceeds the ASHRAE requirement of 82% for boilers, the equipment is capable of much higher efficiency if the system can be configured for lower return water temperatures. Installing higher capacity equipment which allows for lower operational firing rates also increases efficiency.

System design approaches such as including radiant floor heating, selecting air handling unit coils for lower inlet temperatures and higher differences in temperatures, and arranging heating devices in series can reduce the return water temperature and substantially increase the overall system efficiency. In this manner, it is possible to achieve operational boiler efficiencies in excess of 95%.

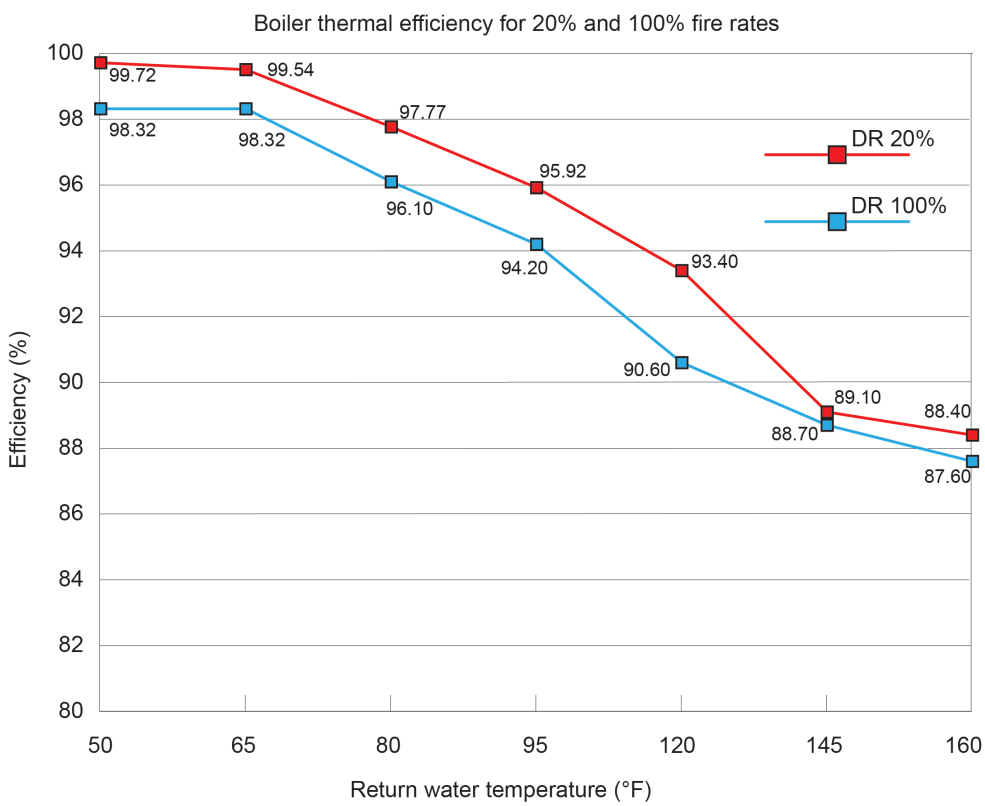


Figure 4: Condensing boiler efficiency diagram (Source: Camus Hydronics).

A similar approach can be applied to the chilled water system. Utilizing systems such as chilled beams allows the designer to use higher chilled water temperatures to provide cooling which allow for equipment selection at improved efficiency.

The use of modular equipment can also improve system efficiency. Selecting and applying equipment such as modular chillers helps each module operate at or near its peak efficiency. The modular chiller can also be more easily applied to allow for variable chilled and condenser water flow through the use of isolation valves and multi-cell cooling towers.

2.3 Design Analysis

Applying new system types and altering design parameters requires the design team to conduct additional analyses to ensure the desired results. Designing for maximum efficiency requires the engineer to go beyond basic load calculations — adequate for ensuring building comfort — and take the next step: modeling hourly system loads to determine overall efficiency and optimize equipment and operational parameters.

Energy modeling programs such as EnergyPlus, Trane Trace, Carrier HAP, and IES provide detailed hourly information about system load requirements which enable the engineer to compare different system types and equipment configurations. In the past, these programs were typically used only with complex, large-scale buildings or projects seeking LEED certification. Today, however, more projects are being analyzed and optimized.

Another analysis method which is becoming increasingly used is computational fluid dynamics (CFD) analysis. CFD modeling uses differential equations to predict temperature and airflow patterns throughout a space, allowing the engineer to study alternative approaches to system design without relying as extensively on past experience or conventions. For instance, Arup used CFD analysis at the University of Chicago's Early Childhood Center to verify that radiant floor heating could be applied adjacent to a tall glass wall without leading to significant downdrafts, which could cause occupant discomfort. Diagrams shown in Figures 5 and 6 indicate the temperature and velocity contours. Without the CFD analysis, a more conventional system with baseboard heat or radiant ceiling panels would have been used for the project. In addition to providing a warm floor for comfort, the radiant floor system enabled the use of lower heating water temperatures, increasing system efficiency by lowering return water temperature and improving boiler efficiency.

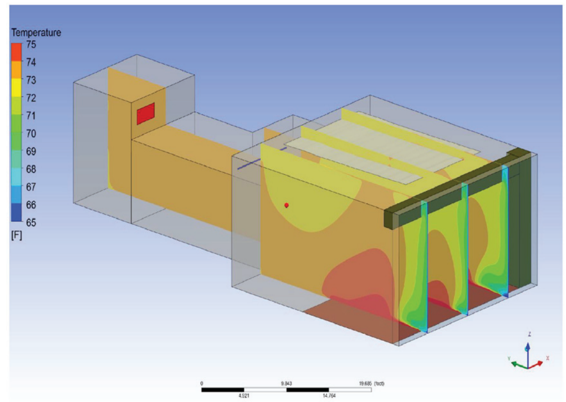


Figure 5: CFD temperature plot.

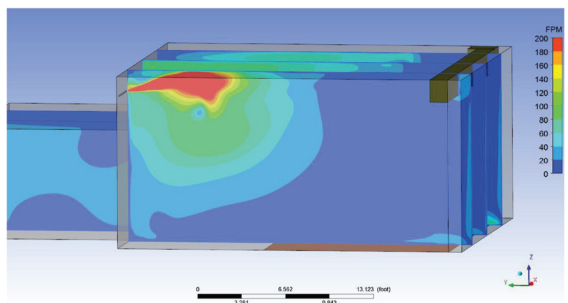


Figure 6: CFD air velocity plot.

2.4 Total System Integration

Another current trend is total system integration, or smart building technology. To maximize energy efficiency in high-performance buildings, everything must work together. Lights, shades, usage scheduling, ventilation, video displays, even desktop telephones — performance of these systems must be integrated, constantly monitored and adjusted in order to maximize energy efficiency.

Linking formerly discrete building elements through wiring and software allows systems to work together. This can reduce not only the energy required to operate a building, but also the overall amount of space required in the building. As an example, a scheduling system that links to conference room occupancy sensors can recognize that a scheduled meeting has been cancelled if occupants are not present within a given time. The scheduling system can then identify the room as available for another meeting. In large conference centers, this has the potential to reduce the total number of rooms required.

Realizing the design of a smart building is a process which requires the integration of the entire design and construction team and close collaboration.

3.0 CASE STUDY: UNIVERSITY OF CHICAGO, LABORATORY SCHOOL – EARLY CHILDHOOD CENTER

Earl Shapiro Hall at the Early Childhood Campus (ECC) is a new 125,000 ft^2 early education center associated with the University of Chicago in Chicago, IL (Figure 7). The building is targeting LEED Gold certification and consists of classrooms, offices, library, and a gymnasium as well as outdoor play space adjacent to the building and on the roof.

The building is expected to achieve a 32% energy cost savings and 39% energy savings over ASHRAE 90.1-2004 baseline (Figure 8). The annual energy savings are primarily obtained through reductions in energy used for heating, cooling, and lighting.

Energy conservation strategies include:

- Low temperature condensing boilers/radiant floor heating
- Modular chillers
- Demand controlled ventilation
- High-performance glazing/curtain wall.

CFD modeling was performed to verify if the design approach utilizing radiant floor heating would result in acceptable temperature and airflow conditions in the finished space (Figures 9 and 10).

Figure 7: Earl Shapiro Early Childhood Campus[1] at the University of Chicago (Courtesy of VDTA/FGM/Visualized Concepts).

[1]Client: University of Chicago Laboratory School
Design Architect: Valerio Dewalt Train Assoc.
Architect of Record: FGM Architects
Engineer: Arup

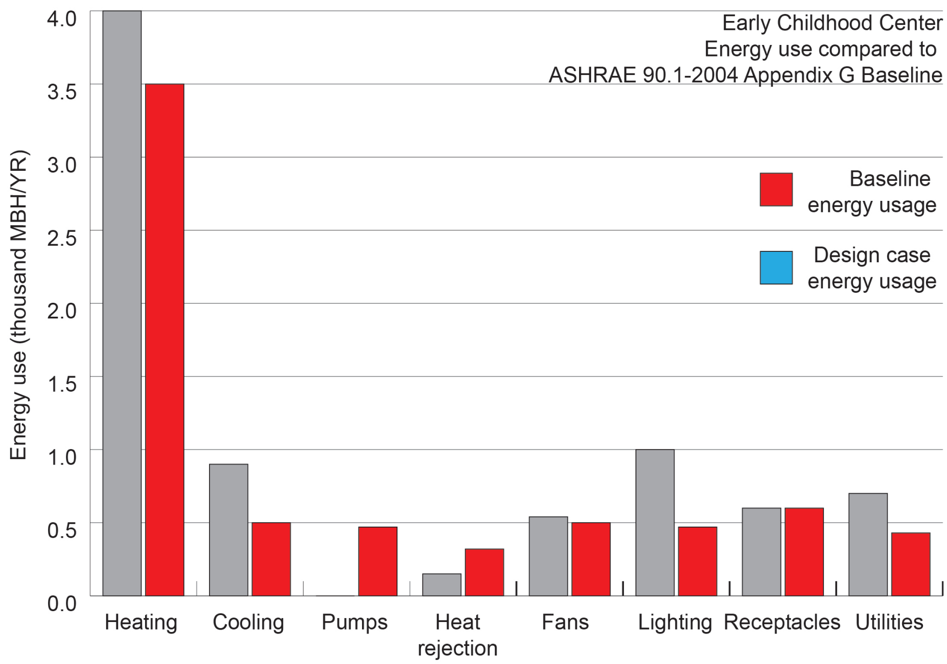


Figure 8: Comparison of modeled energy usage against the ASHRAE 90.1-2004 baseline.

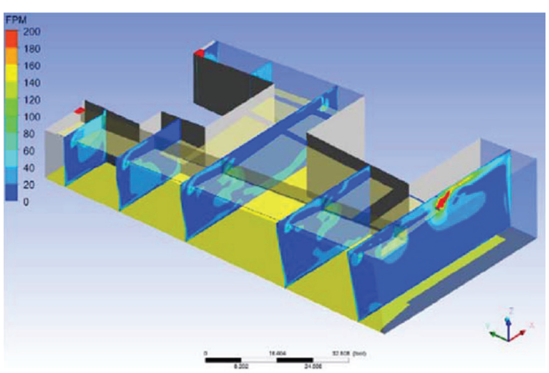


Figure 9: Velocity contours.

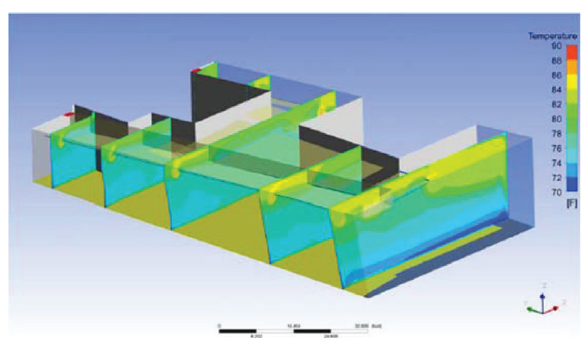


Figure 10: Temperature contours.

4.0 CONCLUSION AND LOOKING TO THE FUTURE

Like all efforts to reduce building system energy consumption, designing a high-performance, smart building requires close cooperation between a number of parties: engineers, architects, contractors, equipment manufacturers, and end users. Due to the highly integrated nature of the process, it is important that all parties share a common vision for the project.

From an HVAC perspective, one of the many unfortunate effects of the recent economic recession has been, counter-intuitively, a relative drop in energy costs in North America. Because consumers and businesses have had less cash on hand for discretionary products and services, energy use has fallen. Because of the way the energy economy is structured, this drop in usage has had the result of keeping prices relatively affordable. While this is obviously beneficial for consumers in the short term, because it has deferred conversations about energy efficiency in the built environment, it has the potential to be damaging to both the environment and the bottom line in the long term. It is therefore even more important for designers to play a key role in educating the public — and one another — about energy efficiency.

NEXT STEPS

A Path Forward: WORKSHOP OUTCOMES, IDENTIFIED RESEARCH GAPS AND PLAN FOR THE FUTURE

This section summarizes the outcomes of the 2nd Workshop on Architecture and Engineering of Sustainable Buildings, sponsored by the National Science Foundation (NSF) and organized by the University of Illinois at Urbana-Champaign and Perkins+Will. The final session during the Workshop focused on the identification of current research gaps, as well as the next steps that should be addressed in order to advance the current state of knowledge, and promote design and construction of next-generation of sustainable, high-performance buildings and cities.

These following aspects were identified as current research gaps and appropriate actions to address these gaps:

- Investment in research and development of digital tools / software applications to facilitate integrated design and analysis of sustainable buildings and cities
- Prioritization of permanence and design quality, and consideration of building performance over a 30-year building's lifecycle during design process
- Improvement of the link between economic aspects and design; identification of cost-effective design strategies for extremely low and net-zero energy buildings
- Documentation of lessons learned in practice; publications of case studies
- Identification, normalization, and quantification of the variables used to assess sustainability (considering both building and urban scale)
- Creation of a digital forum for sustainability research relating to buildings and urban design
- Establishment of metrics related to the sustainable use of materials and associated costs
- Exploration of financial regulations, financial opportunities and lending trends, related to design and construction of sustainable buildings
- Comparison of energy simulations with verified as-built buildings' energy use data, and distribution of results
- Improvement of the link between practice and the academy in respect to sustainability
- Development of guidelines for integrating sustainable design principles into building aesthetics
- Advocating sustainable principles to the public; improvement of knowledge dissemination to clients and into the public domain
    - Apply lessons learned from the fields of politics and advertising
    - Be persuasive, and improve communication skills in order to relay that the sustainable value can be worth more than either cost or time
    - Remedy the "language barrier" of technical terms related to sustainability so they are more accessible to the public and design professionals
- Escalating research into sustainable principles that can be applied to the retrofit / renovation of existing buildings, which comprise a significant portion of the market
- Development of design guidelines for water conservation and use in buildings.

Short terms objectives were identified as the first line of action that can take place to address the research gaps and improve knowledge dissemination:

- Document and disseminate topics discussed in the Workshop
- Repeat the workshop (possibly on an annual basis) using all available resources, such as:
  - Chicago Committee on High-Rise Buildings or similar local groups and organizations
  - Continue industry partnerships with Perkins+Will and others
  - Seek other partnerships between academic institutions, industry representatives, national laboratories, and software development companies
- Continue momentum from the Workshop, including:
  - Formation of a task-force
  - Presentations at conferences
- Utilize Advanced Energy Design Guides, published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
- Collect data and information about simulated and actual energy use for different buildings, and create a building performance database.

Long term objectives were identified as follows:

- Submit collaborative and multi-faceted research proposals to the National Science Foundation, Department of Energy and other federal agencies to address the need for transformational research relating to sustainable, energy-efficient buildings and the built environment
- Create an online "hub" for sustainability research and building technologies
- Research, store and share sustainable research and case studies from practice, and invest into collaborative research projects between academic institutions and industry organizations
- Research sustainable retrofit solutions for existing buildings and document design guidelines for improving the efficiency of existing building stock.

With these concluding remarks, we would like to establish a strategy for future research and development focusing on sustainable buildings and cities. Multidisciplinary research and direct implementation of generated knowledge for the design of next generation of sustainable buildings and cities should be the key objective; therefore collaboration between academic institutions, research organizations and design firms is essential. These types of multidisciplinary, multi-faceted collaborations would support our overarching goal of creating a more responsive, sustainable and lasting built environment.

WORKSHOP PARTICIPANTS

Dr. Ajla Aksamija, LEED AP BD+C, CDT (Presenter)
Associate, Building Technology Researcher
Tech Lab, Perkins+Will
Specialty: Building technology research, high-performance buildings, building science, sustainable building facade design, simulations and modeling, computational design
Presentation title: "Perkins+Will Tech Lab/High Performance Buildings Research"

Dr. Abbas Aminmansour
Associate Professor
Structures Program, School of Architecture University of Illinois at Urbana-Champaign
Specialty: Sustainability impact of tall buildings, integrated design and construction of buildings

John Andary, PE, LEED AP (Presenter)
Principal, Bioclimatic Design Leader
Integral Group
Specialty: Integration of passive design and climate-based engineering, carbon-neutral and low energy buildings and communities, integrated design
Presentation title: "Democracy of the Sun: Lessons Learned from the Design and Operation of the NREL Research Support Facility (RSF)"

Sarah Beardsley, AIA
Senior Architect
Adrian Smith + Gordon Gill Architecture
Specialty: Facades, renewable energy, high-rise building design

Raymond Clark, AIA, LEED AP
Specialty: Design management, building systems integration, engineering coordination and quality assurance of large scale, high rise technically complex multi-use projects

Yolanda Maria Baez Batista
Student
School of Architecture, University of Illinois at Urbana-Champaign

Theresa Daytner
Daytner Construction Group

Dr. Christopher Drew, LCIWM (Presenter)
Director of Sustainability
Adrian Smith + Gordon Gill Architecture
Presentation title: "Understanding and Using Climate Data for Performative Passive Design"

Taneisha Gordon
Student
Tuskagee University

Arathi Gowda, LEED AP BD+C
Sustainability Specialist
Skidmore, Owings & Merrill (SOM)
Specialty: Sustainable architecture, building performance

David Green, AIA, LEED AP BD+C (Presenter)
Principal, Urban Designer
Perkins+Will
Specialty: Urban design
Presentation title: "Constitutional Ecology: Nature and Law Working Together for Sustainable Cities"

Taylor Guinn
Student
Tuskagee University

Nicholas Jackson
Student
Tuskagee University

Dr. Ramesh Krishnamurti
Professor, Carnegie Mellon University
Specialty: Computer-aided design, BIM

Ingrida Martinkus
Architect/Sustainable Design Specialist
Specialty: Smart building and interior, market segment research and assessment, sustainability guidelines for corporate real estate

Rachel Michelin, R.A., LEED AP BD+C
Project Director
Thornton Tomasetti
Specialty: Architectural and structural repairs of existing buildings, renovations, facade examinations

Dr. Kyoung Sun Moon, AIA
Assistant Professor, Yale University School of Architecture
Specialty: Sustainable design of tall buildings

Dr. Ralph Muehleisen, PE, LEED AP, INCE Board Certified, FASA
Principal Building Scientist
Argonne National Laboratory
Specialty: Basic building science, building enclosure design, building energy modeling, acoustics of green buildings, building sensors and control, smart building/smart grid interaction, indoor environmental quality

Mary O'Malley
Architectural Researcher
University of Michigan Taubman College of Architecture and Urban Planning, Ann-Arbor
Specialty: Energy-efficient lighting and daylighting design, building performance metrics, sustainable building guidelines

Edward Peck, AIA, LEED AP
Vice President – Building Skin Practice
Thornton Tomasetti
Specialty: Building skin technologies, sustainable facades, environmental analysis of building skins

Susan M. Reynolds, PE, RA, LEED AP
Assistant Professor
University of Colorado
Specialty: Structural engineering, architecture

Dr. Varun Singh
Vice President of Engineering
Sefaira, Inc.
Specialty: Energy modeling, building optimization, software development, product development, HVAC systems

Ming Tang, LEED AP BD+C
Assistant Professor
University of Cincinnati
Specialty: Parametric design, digital computation, performance driven design, simulation, data visualization

Robert Tazelaar, PE, LEED AP (Presenter)
Associate Principal
Arup
Specialty: Design of mechanical systems, renewable energy, ground source heat pumps, high-performance facades
Presentation title: "Current Trends in Low Energy HVAC Design"

WORKSHOP PARTICIPANTS

Geoffrey Thun, BES, OAA, MRAIC, LEED AP (Presenter)
Associate Professor
University of Michigan Taubman College of Architecture and Urban Planning, Ann-Arbor
Specialty: High-performance building assemblies, responsive building envelopes, occupant control and interface, sustainable community design, renewable energy-based mobility and urban design
Presentation title: "Ecological Paradigms & Responsive Envelopes"

Bruce Toman, AIA, LEED AP
Principal, Technical Director
Perkins+Will
Specialty: Enclosure (roofs, waterproofing and facade) design, documentation for construction, construction contract administration

Kathy Velikov, MUD, BES, MRAIC, LEED AP (Presenter)
Assistant Professor, Registered Architect
University of Michigan Taubman College of Architecture and Urban Planning, Ann-Arbor
Specialty: high-performance building assemblies, responsive building envelopes, occupant control and interface, building integrated energy technologies, sustainable community design
Presentation title: "Ecological Paradigms & Responsive Envelopes"

Peter Weismantle, FAIA, RIBA
Director of Supertall Building Technology
Adrian Smith + Gordon Gill Architecture
Specialty: High density/high rise technical systems design and optimization, urban redevelopment of brownfield sites, urban/mixed use projects

PEER REVIEWERS

DR. WILLIAM BRAHAM
University of Pennsylvania

ALAN JACKSON
Case

ALEXIS KAROLIDES
Rocky Mountain Institute

BLAIR McCARRY
Perkins+Will

ADAM McMILLEN
Energy Center of Wisconsin

DIANA NICHOLAS
Drexel University

STEVE SANDERSON
Case

SPYROS STRAVORAVDIS
Institute of Advanced Architecture of Catalunya

MING TANG
University of Cincinnati

AUTHORS

01.

DAVID GREEN

David Green focuses on large-scale urban design and planning projects for Perkins+Will. He is a Professor of the Practice of Architecture at the Georgia Institute of Technology. David has been involved in the execution of hundreds of projects in the past twenty years ranging from the adaptive re-use of multiple historic structures to multi-thousand acre urban design and planning projects. His work and research focus on issues of development, particularly within an urban framework and the creation of a strategy for sustainable cities, which include aspects of public policy implementation, criteria for implementation of development controls, design guidelines, as well as strategic infrastructure implementation.

02.

AJLA AKSAMIJA

Dr. Ajla Aksamija leads Perkins+Will Tech Lab, center for research of building technologies. Her research expertise includes building science and sustainability, emerging technologies, digital design and representations, information modeling, and knowledge management. She received PhD in Architecture from the University of Illinois at Urbana-Champaign, with an emphasis on technology and environment. She has worked on developing building analysis and modeling applications, implementation of novel materials in architectural design, development of computational models, and has collaborated with researchers from material science, civil and environmental engineering and computational design. Dr. Aksamija has contributed to several books, and is the author of the recently published book *Sustainable Facades: Design Methods for High-Performance Building Envelopes* (published by John Wiley & Sons). She has published more than forty research articles and invited papers. She is currently teaching advanced environmental building design at the University of Pennsylvania.

GEOFFREY THÜN

03.

Geoffrey Thün is an Associate Professor of Architecture at Taubman College at the University of Michigan. He also holds an Adjunct Professor position at Ryerson University and Dalhousie University in Canada. Thün's research pursues the integration of complex systems in design practice and ranges across scales, from examination of regional ecologies and infrastructures to the development of high-performance prefabricated building systems and interactive responsive architectures. His work has received support from the U.S. Department of Energy (DOE) / National Renewable Energy Laboratory (NREL), The US Department of Transportation (DOT), NRCan, the Social Sciences and Humanities Research Council of Canada (SSHRC) and the Ontario Power Authority (OPA), the Research Through Making Program, The University of Michigan Office of the Vice President for Research, and the Graham Environmental Sustainability Institute. He is a founding partner of RVTR Inc., a research-based practice with studios both in Toronto and Ann Arbor.

KATHY VELIKOV

03.

Kathy Velikov is an Assistant Professor of Architecture at the Taubman College of Architecture and Urban Planning at the University of Michigan, holds an adjunct position at Ryerson University, is a licensed architect in Ontario, Canada, and a founding partner in the research-based practice RVTR Inc. Her work and research focuses on built environments and landscapes that are shaped and mediated by advanced materials, technologies and energies, within the context of complex ecological, economic, and social systems. Current research includes: The Stratus Project, a kinetic interior envelope which aims to attune one's attention to the immediate air-based environment and to the physical conditions that produce it; research in responsive building envelopes and occupant control systems; as well as a project on energy- and mobility-based urbanism in the Great Lakes Mega-region.

ROBERT TAZELAAR

04.

Robert Tazelaar leads Arup Chicago's MEP group. He has more than 26 years of experience in the design and project management of varied building and project types encompassing office, performing arts, residential, commercial, retail, mission critical, institutional, and sustainability projects. His primary expertise is in design of HVAC systems, and he has supervised and participated in the design of several LEED certified buildings. Robert is a member of the Chicago Committee on High Rise Buildings and is LEED certified. Robert focuses his efforts on meeting the owner's criteria for building operation and cost while championing sustainable design practices and energy efficiency.

MOHAWK windpower

This piece is printed on Mohawk sustainable paper which is manufactured entirely with Green-e certificate wind-generated electricity.

Through its "Green Initiative" Program, Phase 3 Media offers recycled and windpowered paper stocks, recycles all of its own post-production waste, emails all client invoices, and uses environmentally friendly, non-toxic cleaning supplies, additionally Phase 3 Media donates 5% of all sales from its recycled product lines to Trees Atlanta.

PERKINS
+WILL

ISBN 978-0-9815436-5-9

For more information, please send an email to **pwresearch@perkinswill.com**