Building Enclosure Performance Research—Applications in Professional Practice

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Examples of complex fenestration in projects by ZGF Architects.

Left—figures 1, 2: Interior roller shades at 12 | West, Portland office. Photo: ZGF
Center—figures 3, 4: Exterior venetian blinds at UCSD laboratory building. Photo: ZGF
Right—figure 5: Double skin facade with stainless steel vertical screen and roller shades in cavity at UO Jaqua Center. Photo: Eckert and Eckert

1. Abstract

As design professionals pursue aggressive energy goals in the creation of new and renovated buildings, the building enclosure plays a critical role. Conventional practice methods do not support the depth and types of analysis required to meet these goals. This paper explores the potential of building enclosure research and innovative consulting services to provide the analysis needed for achieving aggressive performance objectives. An overview and discussion

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of professional applications is provided for three research areas that are being covered in associated BEST3 papers: complex fenestration research at Lawrence Berkeley National Laboratory, daylighting analysis research by the University of Washington Integrated Design Lab, and human thermal comfort simulation research at the Center for the Built Environment at UC Berkeley.

Window systems have the potential to improve overall building performance, but require a design and analysis process that includes daylighting management and solar heat gain control to reduce energy use and support occupant comfort. Daylighting is an essential element in architectural design, but a more engaged process of simulation and analysis is needed to realize its performance potential. Analysis of complex glazing assemblies with diffusing and shading characteristics is important to accurately understand their daylighting and solar control implications. Evaluation of human thermal comfort in perimeter zones is complicated due to the impact of dynamic climate forces on window systems. The thermal comfort simulation method described here offers promise for more accurate assessments. By engaging with research and unique consulting services to address the complex issues raised by the pursuit of exceptional energy performance, optimal design solutions can be realized.

2. Introduction—Context and Significance

Increasingly, design professionals are striving to create new buildings and renovate existing buildings to meet aggressive energy reduction goals. The current target of the *2030 Challenge*[2] is 60% better than the regional average by building type. In 2015 the target will become 70%, and in 2030 the target will be "carbon neutral." To meet these goals, the building enclosure plays a critical role. Conventional practice methods, the structure of consultant teams, and design fees do not support the depth and types of analysis required to meet these objectives and avoid unforeseen yet interconnected compromises to building function, longevity, and occupant needs. This paper explores the potential of building enclosure research and innovative consulting services to provide the needed analysis. Although this approach offers promise for many performance categories, this paper will focus just the on three that are being covered in associated BEST3 papers: complex fenestration research at Lawrence Berkeley National Laboratory (LBNL), daylighting analysis research by the University of Washington Integrated Design Lab, and human thermal comfort simulation research at the Center for the Built Environment (CBE) at UC Berkeley.

In most existing buildings, windows are valued for view and light, but compromise enclosure and overall building performance. They lose heat due to poor U-values, are not optimized for daylighting, and admit too much solar heat gain.[4] Window systems have the potential to improve overall building performance, but typically project schedules and budgets do not support the necessary design and analysis to realize optimal solutions. At the same time that professionals need to push the potential of the building enclosure to support high performance,

[2] http://architecture2030.org/2030_challenge/the_2030_challenge
[4] Alex Wilson, "Rethinging the All-Glass Building" *Environmental Building News*, July 1, 2010.

design fees have been dropping,[5] which has made it even more challenging to engage the consulting expertise to fully support this effort while avoiding the pitfalls. Accurate analyses must take into account dynamic interior and exterior climate conditions, and the complexity of interrelated building enclosure, HVAC, and lighting systems. Due to the demands of schedules and fees for services, design teams rely primarily on experience and intuition for decision making. Although these are essential, they alone are not sufficient for the current and future performance demands. This paper explores the potential of building enclosure research, particularly related to window systems, and new models of consulting as an effective means of supporting performance demands.

Building enclosure performance research can help bridge the knowledge and analysis gap by providing valuable information regarding the characteristics and performance potential of currently available fenestration systems, new configurations of existing assemblies, and innovative new systems. Relevant published research can be applied broadly to projects and result in effective fenestration configurations that range from low-tech, off-the-shelf assemblies at moderate costs, to more expensive technically complex solutions.

A range of research and design support services currently exist outside of typical design and engineering consulting, including the following: building technology research at National Labs,[6] energy efficiency design assistance through utility-funded programs,[7] building scale renewable energy research,[8] as well as education and research programs at university schools of architecture and engineering. This is valuable work that needs to continue to focus on the pressing performance issues in practice. Outreach and engagement with design professionals is also essential to increase applications of the research findings to realize the needed performance improvements. Because these programs operate with public and utility funding, they are typically not allowed to compete with services offered in the private sector. A gray area exists, however, relative to specialized areas where private consulting services may be available nationally, but are not common or affordable for smaller-scale local and regional projects with modest budgets. Several recent programs, such as the ASHRAE Advanced Energy Design Guides[9] are seeking to meet this need.

Significant differences exist between the worlds of education, research, and professional practice. The pace of new and in-progress research is usually not fast enough to provide data to support decision-making as required by project schedules. Explorations in the professional design and documentation process are typically directed at solving specific problems. “Literature reviews” and “research” methods are rarely documented beyond the solution

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5 Merlin Fulcher, “Architects’ fees plummet and hourly rates fall” *The Architects’ Journal*, November 2010. Kermit Baker, AIA Chief Economist, “Declines in Design Activity Suggest a Bumpier Road to Recovery” *AIArchitect,* July 8, 2011.

6 Lawrence Berkeley National Laboratory, Building Technologies, http://btech.lbl.gov/ Oak Ridge National Laboratory, Building Technologies Research and Integration Center. http://www.ornl.gov/sci/ees/etsd/btric/index.shtml

7 This exists across the U.S. Two examples from the west coast: Northwest Energy Efficiency Alliance (NEEA) in the Pacific Northwest and their BetterBricks programs, and the PG&E Pacific Energy Center in Northern California.

8 National Renewable Energy Laboratory (NREL), Buildings Research, http://www.nrel.gov/buildings/

9 ASHRAE Advanced Energy Design Guides are currently available for meeting 30% and 50% energy reduction targets for a number of building types. http://www.ashrae.org/technology/page/938

selected, and findings are retained within the professional organization if at all. Of course there are exceptions to this, including industry research advisory groups and consortiums of professional firms. These exceptions and other advanced research and collaboration with practice, such as those described in this paper and associated BEST3 papers, have the potential to support the realization of significant performance improvements.

3. Complex Fenestration Research

3.1 Definition

Complex fenestration is defined as glazing materials that have diffusing and/or light redirecting properties which may involve a single or multiple planes. Examples include fritted glass, woven roller shades, and venetian blinds. (See Figures 1-5.) The optical properties of complex fenestration—which include transmitted and reflected light energy—are dependent on the angle at which light hits the glazing assembly. This is in contrast to “simple glazing,” which can be clear or tinted, with or without a low-e or other spectrally-selective coatings. Because the optical performance of simple glazing is quite consistent for any solar angle that is 60 degree or less from the normal angle of incidence (combined azimuth and altitude), simple glazing is tested and characterized only by optical properties based on light at a normal incidence angle. LBNL tests the optical properties of simple glazing materials and maintains the International Glazing Database (IGDB) which currently contains data for over 3800 materials.[10] Although complex fenestration research is not new, LBNL has increased efforts over the last few years to establish methods for characterizing these materials and is working with the NFRC to explore rating or labeling methods. In the fall of 2011 they established a format for a complex glazing database which complements the IGDB. Complex fenestration research is addressed in greater detail in an associated BEST3 paper by LBNL researcher, Christian Kohler.[11] In this paper, the focus is on the application of complex fenestration research to professional practice.

3.2 Current Practice and the Potential of Complex Fenestration Research

Complex fenestration research can have a significant impact on the energy and comfort performance of window systems in buildings due to the implications of managing solar heat gain and optimizing daylighting through distribution and glare management. Assemblies that meet the definition of complex fenestration (including ceramic frit, roller shades, and venetian blinds) are commonly used in buildings, but in current practice are seldom analyzed for their potential to optimize daylighting and effectively manage solar heat gain. The design and engineering of most buildings is based on simple glazing data, since it is most readily available and recognized.[12] Solar heat gain management provided by interior elements such as shades and blinds would be somewhat underestimated by simple fenestration data. The impact of fixed exterior shading elements on windows can be fairly easily modeled by determining the annual

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10 http://windows.lbl.gov/materials/optics/
11 Christian Kohler, Building Technologies, Lawrence Berkeley National Laboratory.
12 International Glazing Database, LBNL http://windows.lbl.gov/materials/IGDB/IGDB_Knowledge_Base.htm#WhatIsIGDB

hours when direct sunlight reaches the glazing vs. the hours when it is shaded. The impact of diffusing and reflecting elements in managing solar heat gain is much more difficult to simulate and typically is simply ignored. Mechanical engineers are generally reluctant to reduce the size of mechanical equipment based on reducing envelope loads if they cannot reliably quantify the reduction. Significant solar heat load reductions can be realized for glazing assemblies with operable exterior shading such as venetian blinds, and for these assemblies the complex fenestration data is important for accurate projections.

Complex fenestration data can also improve the accuracy of daylight simulation and analysis, which is discussed in more detail in section 4, and is addressed in an associated BEST3 paper by Christopher Meek.[13]

3.4 Research overview, applications, and tools

Complex fenestration research involves measuring the surface properties of glazing, shading, and other daylighting materials using a scanning radiometer, digital modeling of the results as a system, and generating full bi-directional solar-optical data. The BSDF data (bidirectional scattering distribution function), is maintained by LBNL in a new database called the CGDB (complex glazing database.) This data can be used to compute window properties, daylighting performance, and whole building energy performance.

Window 6, a computer program developed and maintained by LNBL, accesses both the IGDB for simple fenestration, and now the CGDB for complex fenestration, to calculate total window thermal performance properties including U-values, solar heat gain coefficients, shading coefficients, and visible transmittances.[14]

COMFEN, a software tool designed for analyzing and comparing the annual performance data (including energy and comfort) of a number of facade configurations, also allows Window 6 BSDF data to be applied. This is a tool that makes the research data most readily available in professional practice. Although less accessible to design teams, the whole-building energy simulation software, EnergyPlus[15] can also apply Window 6 data for whole-building energy simulations. Development of a user interface is underway to make EnergyPlus more available to the design and engineering community.

Window 6 complex fenestration data (BSDF) can also be used in Radiance[16] to more accurately simulate and analyze daylighting in these assemblies. Although Radiance is not accessible to the casual user, specialty consultants can use it to generate very detailed and accurate results.

13 Christopher Meek, University of Washington, Seattle, Washington.
14 http://windows.lbl.gov/software/window/window.html
15 http://apps1.eere.energy.gov/buildings/energyplus/
16 http://radsite.lbl.gov/radiance/framew.html

3.5 Discussion—short and long term implications

Using currently available tools from LBNL (Window 6 and COMFEN) design teams can include analysis of complex fenestration to support decision-making in the design process—including consideration of the daylighting and solar heat gain management offered by multi-layered diffusing and daylight redirecting assemblies. And with the support of specialist consultants, this data can also be incorporated into whole-building energy simulations (through EnergyPlus), accurate daylighting simulations (through Radiance), and comfort analysis as described in section 5. Through both the non-specialist (design team) and specialist use of the complex fenestration data and tools, teams can develop design and performance concepts to reduce energy use and support user comfort and productivity.

As complex fenestration research continues, including the testing and documentation of materials and development of simulation tools, teams will have greater access to accurate data and methods to support low-energy design. Manufacturers will also be able to develop and market shading and daylight redirecting products based on accurately defined performance potential for various applications. Design teams, from the earliest concept stages, will be able to work with complex fenestration data to create building geometries and enclosure strategies that optimize performance relative to building program demands. Working with this information over time, designers should be able to develop an intuitive sense for complex and multi-layered glazing systems that distribute and manage daylighting and control solar heat loads, similar to the way in which they have developed an intuitive sense for traditional construction materials including timber, steel, concrete, brick, and stone. And as with structural and other enclosure assemblies, calculations can be done with verified data to properly size and detail the assemblies.

4. Daylighting Analysis Research and Applications

4.1 Importance of daylight in buildings

Daylighting has a significant impact on buildings and occupants: it is essential to health and well-being, it is a fundamental design element, and it can offset a significant portion of a building's electricity use. William Lam's classic book on daylight and architecture, *Perception and Lighting as Formgivers for Architecture,* begins with the sentence, "Light has always been recognized as one of the most powerful formgivers available to the designer, and great architects have always understood its importance as the principal medium which puts man in touch with his environment."[17] Because daylight is dynamic, it needs to be managed to assure that a sufficient, but not excessive amount of light is provided. Glare must be adequately controlled for particular building uses. Daylighting typically also has a close relationship with views and management of solar heat gain.

[17] Lam, William M.C., *Perception and Lighting as Formgivers for Architecture,* McGraw-Hill Inc., 1977.

4.2 Daylighting research, metrics, and tools

The use of daylight in buildings has received a significant amount of attention in design education and research. The research has been in a number of areas including the psychological and physiological effects on occupants, aesthetic considerations in schools of architectural design, and energy performance including solar control as well as daylight distribution. The research methods include post-occupancy surveys of building occupants, human subject testing in controlled environments, measurements of daylight in existing buildings, mock-ups and chamber tests, materials testing, physical scale models, 3d computer modeling and analysis, and energy simulations to quantify energy savings potential.

The most common metrics in professional practice are the unit of illuminance, foot-candle (fc), and daylight factor (DF), the ratio of interior illuminance relative to outdoor illuminance, in part due to their use in USGBC's LEED criteria for daylighting.[18] However, other metrics have been developed which offer more nuanced information. The research report, "Dynamic daylight performance metrics for sustainable building design"[19] provides a very good discussion about the challenge of quantifying dynamic daylight conditions. It reviews several dynamic metrics including daylight autonomy (DA) and useful daylight illuminance (UDI). While more complicated than daylight factor and foot-candle, these metrics provide more useful data regarding the effectiveness of daylighting.

Radiance[20] is widely recognized as the most accurate daylight simulation tool, but because it lacks a graphic user interface, its direct use is limited to researchers and specialists. Ecotect[21] is a tool in common use in architectural practice, and offers an interface with Radiance. Although some concerns have been raised regarding the accuracy of Ecotect results, it has been one of the few accessible and flexible daylight analysis tools. Diva,[22] a recently developed plug-in application for the 3d software Rhinoceros also provides an interface for Radiance. Mental Ray, the native rendering engine in Autodesk's 3DStudio Max also offers daylight rendering and analysis capabilities. A 2009 study compared it and Radiance with field conditions and found generally favorable results.[23] An effective but underutilized approach in professional practice combines 3d modeling, rendering, and visualization with daylight simulations and analysis.

A significant component of the complex fenestration research described in section 3 of this paper and in an associated BEST3 paper by LBNL researcher, Christian Kohler, focuses on the daylighting implications of these glazing systems. The daylighting research and analysis of Christopher Meek and his colleagues at the University of Washington and the Integrated Design Lab (IDL) is also described in an associated BEST3 paper which discusses the simulation of dynamic systems for a net-zero building in Seattle. As the paper describes, dynamic systems offer the best performance, but are also the most complicated to analyze. To reach a broader

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18 LEED Reference Guide for Green Building Design and Construction, 2009 Edition, IEQ Credit 8.1.

19 Reinhart, Mardaljevic, & Rogers, "Dynamic daylight performance metrics for sustainable building design," *LEUKOS, Journal of the Illuminating Engineering Society*, 2006.

20 LBNL Radiance website: http://radsite.lbl.gov/radiance/

21 Autodesk Ecotect website: http://usa.autodesk.com/adsk/servlet/pc/index?id=12602821&siteID=123112

22 http://diva-for-rhino.com/

23 C. F. Reinhart,P-F Breton, "Experimental Validation of Autodesk 3ds Max Design 2009 and Daysim3.0", *contract report* for Autodesk, January 2009.

audience, they have also partnered with the New Buildings Institute (NBI) to develop a set of daylighting guidelines and resources.[24]

4.3 Current practice

Although consideration of daylighting plays a significant role in the design of buildings, particularly the way in which it interacts with space, form, and materials, and it is generally understood that it can play a major role in reducing the use of electric lighting, daylighting seldom receives deliberate attention in the form of analysis. The attention it does get is typically based on observations, experience, and intuition. In some cases, experienced architects pay close attention to daylighting during the design phases, and also carefully observe the results in their completed projects. In doing this, they can develop fairly good empirical knowledge and a good intuitive feel for daylighting. In most cases, however, interior shading systems and electric lighting are simply used to compensate for the lack of analysis. The USGBC rating program does bring additional attention, but the required method and metrics are a fairly rough approximation of proper daylighting design.

4.4 Discussion—short and long term implications

Despite the numerous research efforts, tools, and resources that are currently available, applications in professional practice lag considerably. Design teams could make significant improvements in energy use and occupant visual comfort with little or no increase to construction budgets if adequate design time and effort could be directed toward daylighting design and analysis.

No single approach is likely to make sweeping changes in the profession's approach to daylighting, but a combination of promising strategies could be effective. The first priority is education—raising the knowledge among architectural staff of fundamental aspects of daylighting design and exploring applications that are consistent with architectural firms' approach to design. A second approach is to expand 3d computer modeling efforts to support daylighting analysis. Most firms are now using various forms of 3d modeling and lean on young staff and recent graduates to do this work. With knowledgeable support, this staff could also engage many aspects of daylight modeling. To develop the most promising solutions, daylighting analysis expertise would be needed, as well as expertise regarding building detailing and construction. A third strategy is to commission studies of daylight solutions for building types that are common in professional practice. Examples of this approach include the IDL/NBI "Daylighting Pattern Guide" and also an earlier study on daylighting hospital rooms that was done by the Energy Studies in Buildings Lab in conjunction with ZGF Architects.[25]

In the long term, the goal is to evolve a more integrated and seamless daylighting design and analysis process with quick feedback loops via a number of tools and methods. Daylighting research, tools, and material databases will support this, but expertise within design firms and

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[24] "Daylighting Pattern Guide," http://patternguide.advancedbuildings.net/home

[25] *Daylighting Patient Rooms in Northwest Hospitals*, 2005. Energy Studies in Buildings Laboratory, Department of Architecture, University of Oregon and ZGF Architects. The study was funded by BetterBricks, the commercial buildings program of the Northwest Energy Efficiency Alliance (NEEA).

from specialist consultants will continue to be essential for significant advances. As daylighting design and analysis literacy becomes more widespread, a greater number of beautiful, innovative, daylit buildings with very small energy footprints will be realized.

5. Thermal Comfort Modeling and Applications

5.1 Fundamental building enclosure role

One of the fundamental roles of the building enclosure is to provide a comfortable interior environment. Due in part to technological advances over the last century, occupants of buildings in North America have come to expect that interior environments will be maintained within a narrow range of temperature and humidity. Although mechanical heating, cooling, and ventilation systems can support this, it requires that buildings use a significant amount of energy. Aggressive energy reduction goals (such as the *2030 Challenge, LEED, Living Building,* and other net zero programs) challenge the amount of energy used to condition interior spaces and consequently, comfort expectations. Low-energy conditioning systems, such as natural ventilation and radiant systems have a more limited capacity for heating and cooling and thus require a more complex understanding of occupant thermal comfort. Building enclosure elements, particularly window systems, are a major variable in perimeter zone comfort conditions and are critical to the related energy use.

5.2 Current practice

Although thermal comfort is generally considered in professional practice, it receives little direct attention in the architectural design process. The common expectation is that the HVAC engineer will address it with mechanical systems. As teams work more closely with engineers and other consultants to make large reductions in energy use, it becomes apparent that there are significant trade-offs between energy use, enclosure design, and occupant comfort. And it also becomes clear that conventional methods of addressing these issues through experience, intuition, rules-of-thumb, and prescriptive-path codes, are insufficient. The Berkeley Comfort Model,[34] developed by CBE, is one of the few tools available to simulate occupant comfort.

5.3 Definition

As described at the CBE website, the Berkeley Comfort Model is a "computer model of the human body that is sensitive to detailed thermal complexities around the body. [It] include[s] the capability to model the indoor environment in detail, allowing for prediction of comfort and thermal perception, for the body overall, and for specific body parts."[35]

[34] http://www.cbe.berkeley.edu/research/briefs-thermmodel.htm
[35] Ibid.

The model has a user interface in which a room with windows can be created. A manikin representing an occupant, can be placed anywhere within the room. The model can "calculate heat transfer between the occupant and the environment by convection, conduction, and radiation. The model is capable of evaluating the effects of solar gain through windows by calculating how much radiation is hitting the body and where. Based on the description of the environment, the model can generate graphic results such as skin temperature distributions, equivalent homogenous temperatures, and overall comfort indices."[36]

CBE and LBNL have studied the thermal comfort implications of glazing and window systems and have explored possibilities for developing a new standard for use by the design and construction industry. They are also looking into making thermal comfort analysis accessible to a broader audience through integration into COMFEN.

5.4 Applications—tools and process

The window assemblies that can be modeled in the current CBE tool are limited to simple glazing assemblies (transparent or tinted) which can include fixed shading elements. Operable interior or exterior shading elements can only be modeled through a succession of individual simulations of the complete glazing assembly in each open or closed position. But in most actual applications, multi-layered facade assemblies are used including shades or blinds. Interior venetian blinds and roller shades are the most common in North America, but a small number of buildings have recently incorporated exterior venetian blinds, double skin facades with automated shading in the cavity, and operable louvers. Several of these projects have been recognized with AIA COTE Top 10 awards (Terry Thomas,[38] Manitoba Hydro,[39] LOTT Clean Water Alliance.[40]) To simulate thermal comfort in projects such as these with multi-layered shading and diffusing facade configurations, Sabine Hoffmann[41] has developed "SoloCalc," a new approach that takes advantage of complex fenestration data from LBNL's Window 6.2 to more accurately simulate three-dimensional solar angles. Her method utilizes a 65 node model of the human body and the equations for the comfort evaluation as implemented in the Berkeley Comfort Model. Hoffmann's study is described in an associated BEST3 paper.

5.5 Case study

A recent collaboration between Sabine Hoffmann, CBE, and ZGF illustrates the need and potential for thermal comfort analysis. Hospital patient rooms require a comfortable environment for the patient as well as visitors. While the daylight and view provided by windows play an important role for patient healing, windows also introduce a significant thermal asymmetry to the space due to heat loss during cold weather and excessive thermal heat gain during hot weather.

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[36] Ibid.
[38] http://www.aiatopten.org/hpb/overview.cfm?ProjectID=1292
[39] http://www.aiatopten.org/hpb/overview.cfm?ProjectID=1712
[40] http://www.aiatopten.org/hpb/grid2011.cfm?project_id=1954&section=1
[41] Sabine Hoffmann, PhD, Center for the Built Environment, University of California at Berkeley

For a large Denver hospital project, 24-inch deep fixed horizontal sun shades were designed for the south, east, and west building elevations. Analysis by the energy modeler indicated that the exterior shades would not significantly reduce energy use beyond the shading provided by high-performance glazing. Based on experience with similar facilities, the design team expected that the exterior sun shades in the extremely sunny Denver climate would play a significant role in occupant comfort in perimeter areas, but had limited tools or methods to quantify the impact. The team turned to CBE and Hoffmann to analyze thermal comfort.

Hoffmann analyzed the guest area of south-facing and west-facing patient rooms for an August day. For the south, the results showed that the exterior shades reduce the solar radiation striking a manikin in the space by approximately 75 watts during mid-day peak hours. For the west during late afternoon peak hours, the exterior shades were shown to provide approximately a 100 watt reduction. Reducing solar radiation would help avoid shifting the occupant comfort due to heat sensation, and would help manage thermal asymmetry in the space. (See Figures 7 and 8.) The implications of these results are shown on Figure 9 which combines two graphs—thermal sensation with solid lines, and thermal comfort with dashed lines. The thermal sensation scale runs from -4 for very cold to 4 for very hot with neutral at 0. The thermal comfort scale also ranges from -4 for very uncomfortable to 4 for very comfortable. Although the thermal sensation and comfort follow the general pattern of the solar radiation on the manikin, the relationship is not linear. The thermal sensation of solar radiation intensives discomfort, and thus blocking it with high-performance glazing and fixed exterior elements significantly improves comfort.

By quantifying their thermal comfort impact, the findings supported the client's decision-making process regarding the exterior sun shades.

Figure 6: Denver hospital patient room, with analysis area.

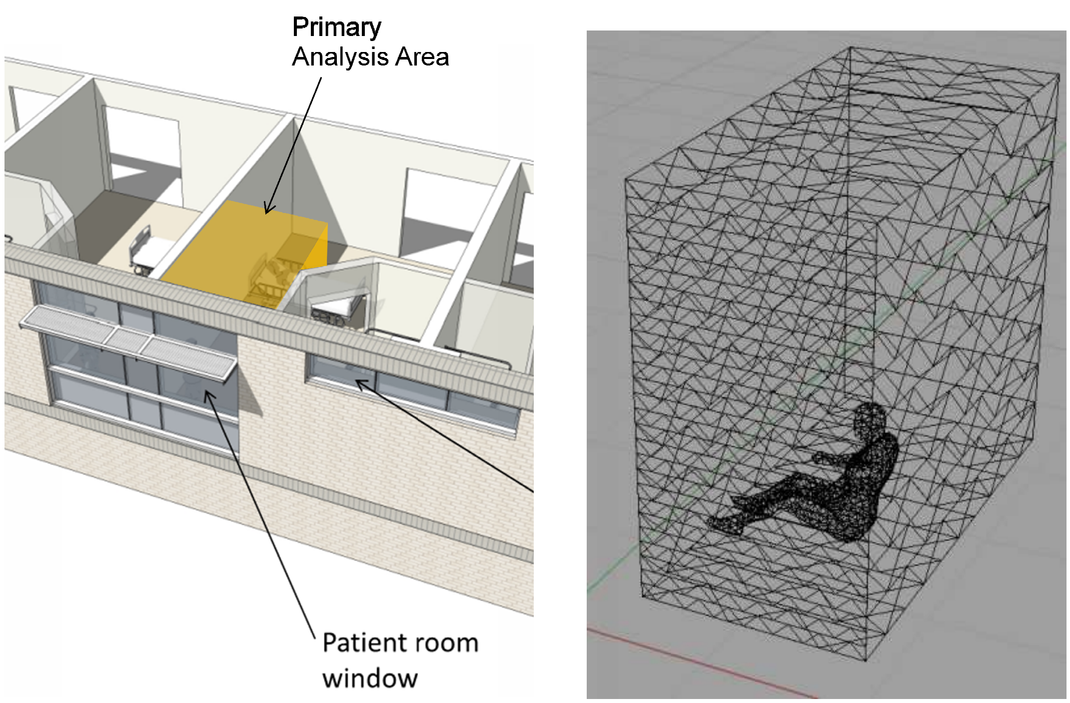
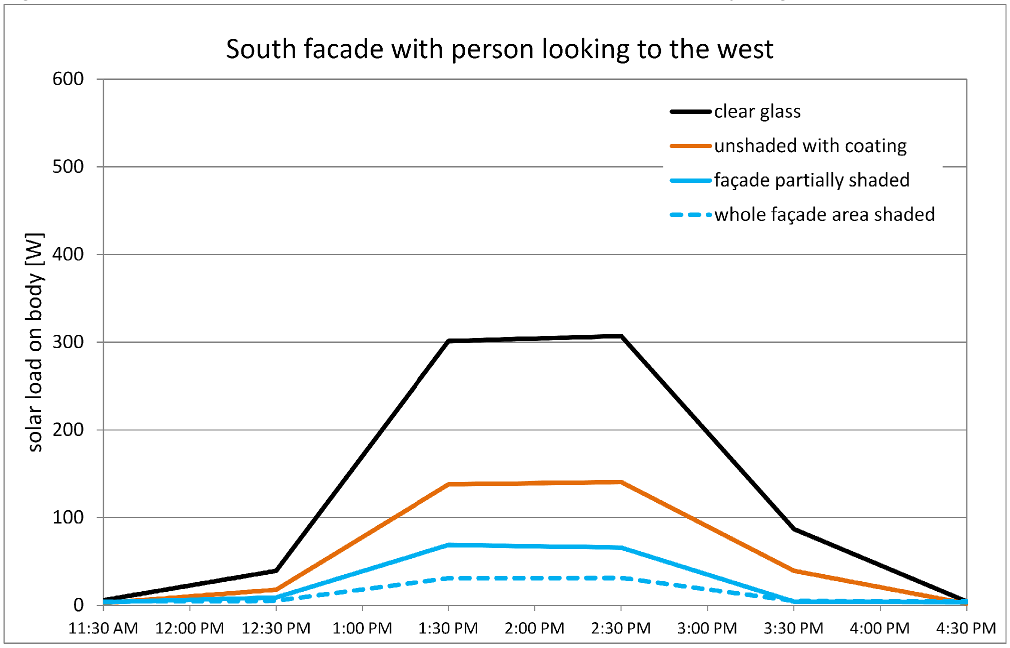
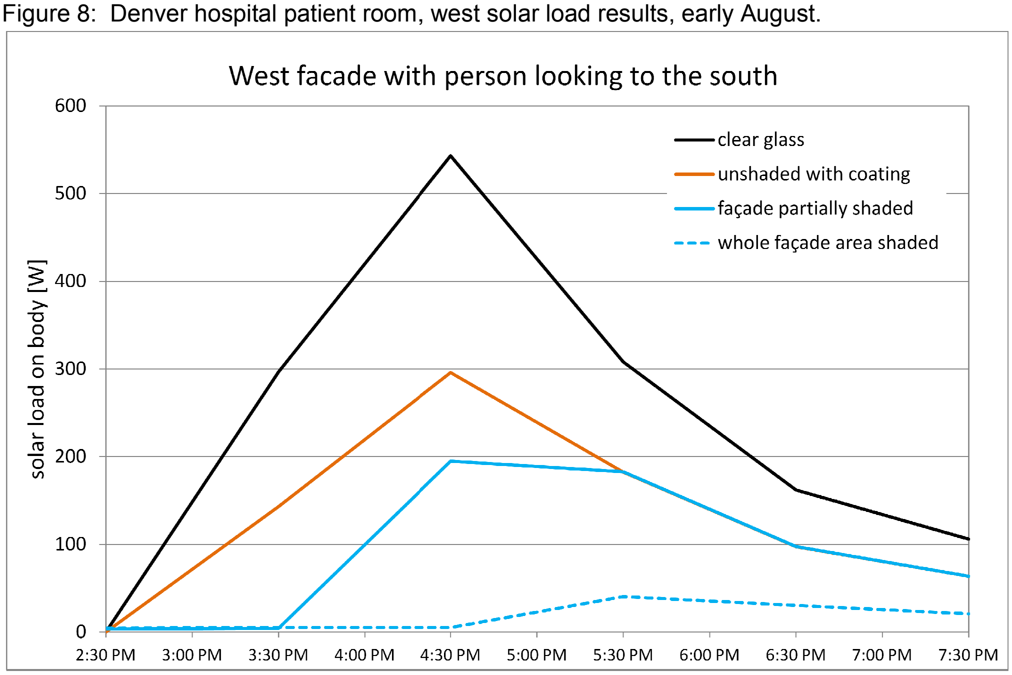


Figure 7: Denver hospital patient room, south solar load results, early August.



Thermal Comfort—South Facade

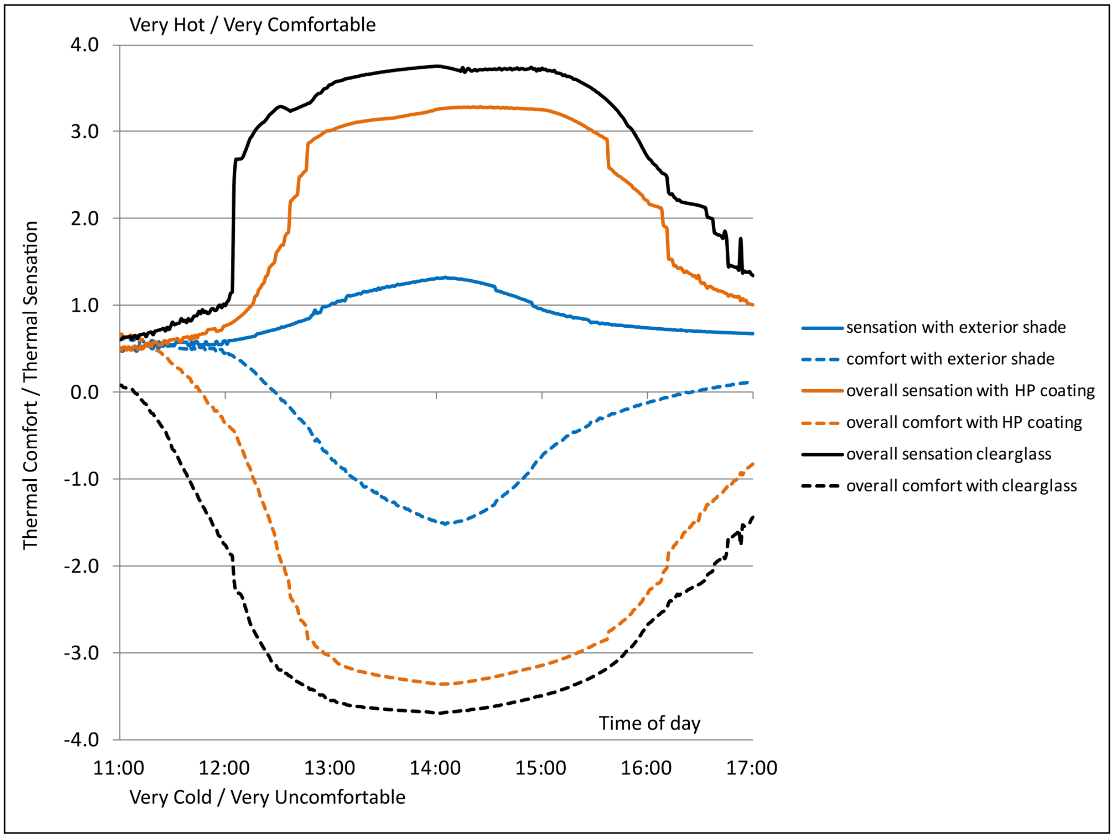
Figure 8: Denver hospital patient room, west solar load results, early August.



Early August

Thermal Comfort—West Facade

Figure 9: Denver hospital patient room, south thermal sensation and comfort results, early August.



5.6 Discussion—short and long term implications

Through the use of thermal comfort models in combination with complex fenestration data (e.g: Berkeley Comfort Model, SoloCalc, Window 6), the question of providing thermal comfort in perimeter zones with minimal heating and cooling, can be addressed by more accurately modeling solar influx from windows. Iterations of shading configurations, control algorithms, and multiple insulated glazing assemblies can be explored to find the best performing solutions. Unfortunately, the tools, data, and methods are currently accessible only to building science researchers and specialty consultants. As LBNL, CBE, Hoffmann, and others develop tools and user interfaces, design teams will be able to use them to directly apply the latest material testing and research data so that thermal comfort and usability of perimeter space can play a more prominent role in decision-making. There is potential for design teams to engage this input to play a generative role in creating building form and the development of building enclosure systems. The resulting information can also be shared with engineers and consultants for a more informed interaction to support the design of high quality buildings that fully meet occupant thermal comfort with the minimum possible energy use.

6. Conclusions—Research Applications in Professional Practice

Because building design—including massing, form, orientation, window-to-wall ratio, and development of opaque wall and fenestration configurations—is a significant driver of performance, it is critical to develop resources and methods that link design decisions with performance implications. In the early design phases it is especially important to have a quick feedback cycle. HVAC engineers and energy modeling consultants can provide valuable feedback to design teams, but typical project budgets limit the scope and frequency of services that can be provided. A number of climate and environmental analysis tools have been developed for use by design teams including Climate Consultant from UCSD,[43] and Ecotect from Autodesk. Through the Schematic Design and Design Development Wizards, design teams can also get early energy simulation feedback from eQUEST.[44] A number of new tools are under development to connect BIM to energy analysis (Vasari is an early version from Autodesk[45]) and to provide an interface to EnergyPlus (including Design Builder.[46]) And as noted earlier, the results from the testing of simple and complex glazing materials by the Building Technology Department at LBNL, can be accessed through a suite of tools including Window, Therm, Optics, RESFEN, and COMFEN.[47] Continued development of these and other new tools will further enrich the information which can be harnessed in the design process. One challenge will be for design teams, their consultants, and clients to keep pace so that the information can support intelligent decision-making.

The significant energy reductions that are being sought in buildings bring demands on design teams that exceed typical current capabilities. Applications of new research and innovative consulting services can help meet these demands. Three examples are given in this paper and associated BEST3 papers, but important needs exist in a number of other areas as well. These include: hygrothermal analysis of highly insulated wall assemblies using tools such as WUFI,[48] the energy and thermal comfort performance potential of natural ventilation in a range of climates and project types, the performance implications of infiltration and exfiltration, post-occupancy studies and benchmarking of building energy, thermal environment, and occupant satisfaction. These are just a few of the numerous important topics which have received far less attention than they require.

Although many challenges exist in bridging between the realms of research and professional practice—including funding and concerns about sharing intellectual property—collaboration, research applications, and innovative consulting services have the potential to support the realization of dramatic improvements in building enclosure and overall building performance.

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43 http://www.aud.ucla.edu/energy-design-tools
44 http://doe2.com/equest/
45 http://labs.autodesk.com/utilities/vasari/
46 http://www.designbuilderusa.com/
47 http://windows.lbl.gov/software/
48 http://www.ornl.gov/sci/btc/apps/moisture/

Acknowledgements
This paper has been written and will be presented in conjunction with three others in a BEST3 session moderated by building enclosure consultant, Rob Kistler of The Facade Group. As noted, the other papers present building enclosure research methods: Complex glazing research by LBNL researcher, Christian Kohler; daylighting analysis research by University of Washington Research Assistant Professor, Christopher Meek; and human thermal comfort simulation by CBE researcher, Sabine Hoffmann. I have appreciated the dialogue, input, and collaboration of my colleagues.