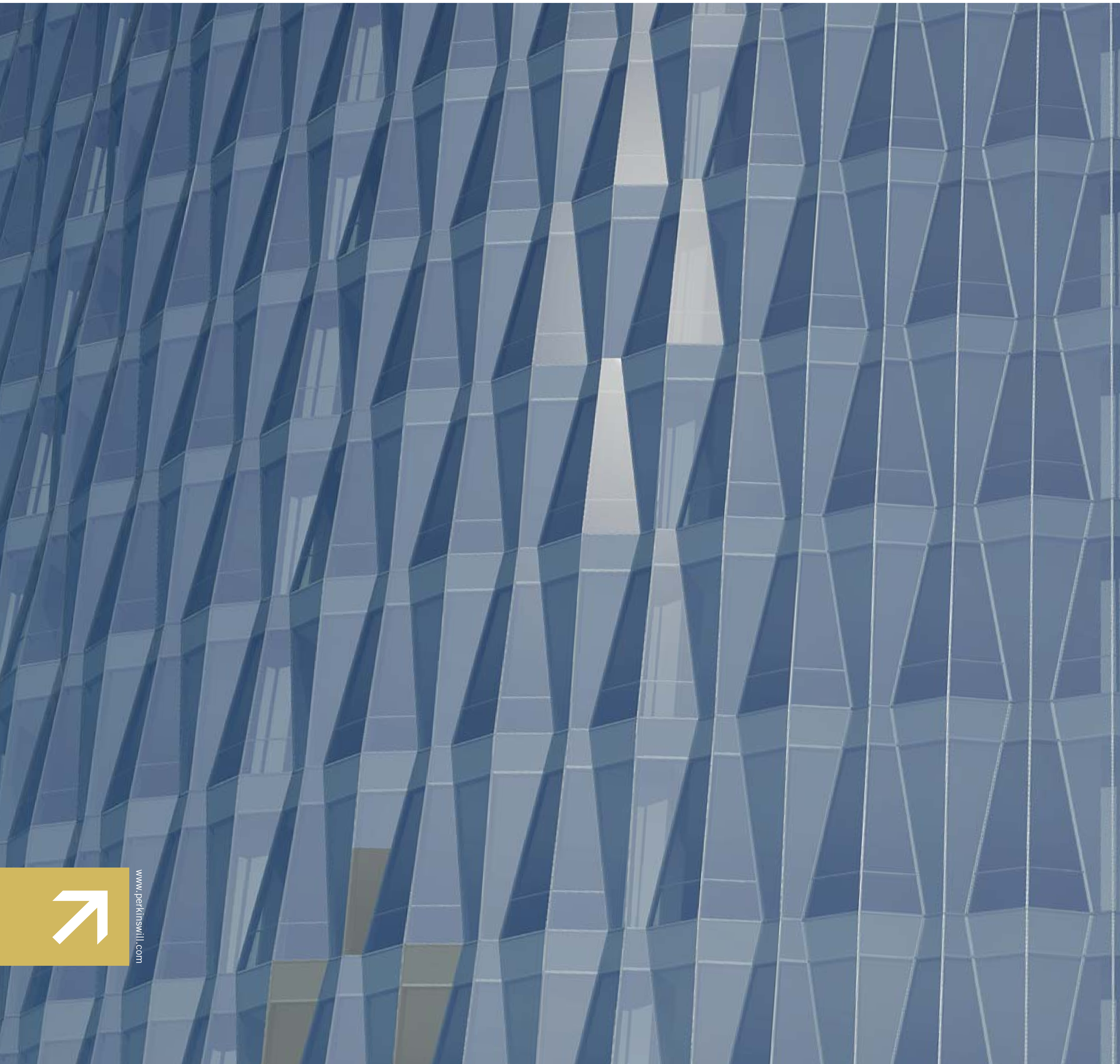
PERKINS+WILL

Research Journal

2010 / VOL 02.02



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Perkins+Will is an interdisciplinary design practice offering services in the areas of
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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 themes included in this journal illustrate types of projects and inquiries undertaken at Perkins+Will and capture research questions, methodologies and results of these inquiries.

The Perkins+Will Research Journal is a peer-reviewed research journal dedicated to documenting and presenting practice-related research associated with buildings and their environs. 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 projects aimed at supporting our teams.

This is the fourth issue of the Perkins+Will Research Journal. We welcome contributions for future issues.

RESEARCH AT PERKINS+WILL

Research is systematic investigation into existing knowledge in order to discover or revise facts or add to knowledge about a certain topic. In architectural design, we take an existing condition and improve upon it with our design solutions. During the design process we constantly gather and evaluate information from different sources and apply it in novel ways to solve our design problems, thus creating new information and knowledge.

An important part of the research process is documentation and communication. We are sharing combined efforts and findings of Perkins+Will researchers and project teams within this journal.

Perkins+Will engages in the following areas of research:

- Market-sector related knowledge management
- Sustainable design
- Strategies for operational efficiency
- Advanced building technology and building performance
- Design process benchmarking
- Carbon and energy analysis
- Organizational behavior.

EDITORIAL

This issue of Perkins+Will Research Journal includes five articles that focus on diverse topics, such as methods for improving design decision-making through simulations and modeling of building performance indicators, finding solutions for complex curtain wall systems, relationships between architectural planning of educational facilities and different learning styles, guidelines for integration of energy analysis into architectural design and lastly, design considerations for pool environments.

“Building Performance Predictions: How Simulations Can Improve Design Decisions” discusses relationships between simulations, modeling and design decisions. The article focuses on the methods that can be used to quantify building performance and predict various performance parameters. It presents relationships between BIM and analysis software applications, outlining best practices for the integrated analysis-design process.

“Finding Façade Solutions for Complex Curtain Wall Systems: Shanghai Fisherman’s Wharf Iconic Tower” explores different complex curtain wall systems that were investigated for this high-rise building. The article reviews different two-dimensional curtain wall options (consisting of flat rectilinear unitized modules) and three-dimensional (consisting of projected geometrical patterns). The article discusses visual design, technical complexity and code restrictions that had an effect of the design as well as constructability issues.

“Students of Today and Tomorrow: Discovering How They Learn” explores different learning styles and how organization of architectural spaces within educational facilities needs to adapt accordingly. The article reviews different styles of learning that have been recognized and how these need to relate to programming and spatial organization. It also includes an overview of the survey administered to high school students aiming to understand relationships between student engagement and physical space and the role of technology in today’s schools.

“Energy Modeling Guidance: Guidelines for Energy Analysis Integration into an Architectural Environment” outlines how and when an energy analysis can be conducted and reviews guidelines for streamlined integration into architectural design. It reviews what to expect in an energy modeling analysis as well as interpretation of results, typical software applications, scope and timing and modeling methodology and parameters than need to be considered.

“Design Considerations for Pool Environments: Cold Climates” discusses design elements and considerations for natatoriums in cold climates focusing on exterior and interior environmental conditions, air quality and movement, mechanical systems, building envelope design considerations and control of vapor migration. The article reviews important design decisions that need to occur during the design process in relation to treatment of the exterior building skin, management of internal environmental conditions, materials and selection of interior finishes.

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01.
BUILDING PERFORMANCE PREDICTIONS:
How Simulations Can Improve Design Decisions

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ABSTRACT
This article discusses relationships between building performance simulations and design decisions and how building performance predictions can improve the design outcomes. The first part of the article discusses why we need to quantify building performance and predict how a building as a whole or its components will function. Then, relationships between Building Information Modeling (BIM) and analysis software applications are discussed, where best practices for developing BIM models that are suitable for different types of simulations are discussed. Lastly, two case studies are used to illustrate this process. The first study reviews curtain wall energy performance for a healthcare facility located in a mixed humid climate and daylighting analysis. The second case study discusses comprehensive analysis for an academic research building focusing on site and orientation studies, solar exposure, investigation of performance of shading devices and daylighting analysis.

KEYWORDS: building envelope, energy efficiency, daylight, BIM, solar exposure

1.0 INTRODUCTION
Developments in information technology are providing methods to improve current design practices, where uncertainties about various design elements can be simulated and studied from the initial starting point of the design. Energy and thermal simulations, improved design representations and enhanced collaboration using digital media are currently being utilized. In terms of sustainable design practice, building performance simulations are an integral part of the process since they help in investigating design options[1]. Quantifiable predictions can help in identifying strategies and methods to improve building energy efficiency and overall building performance.

Methods for achieving extremely low-energy 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, under-floor air distribution, dynamic windows (electrochromic glass, suspended particle devices), radiant heating and cooling and combined heat and power systems. Figure 1 shows these design strategies in relation to the overall cost. Passive strategies should be utilized to its 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. Quantifiable predictions during the different stages of design process help establish metrics that can be used to measure improvements by using 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 thereby reducing the need for renewable energy systems.

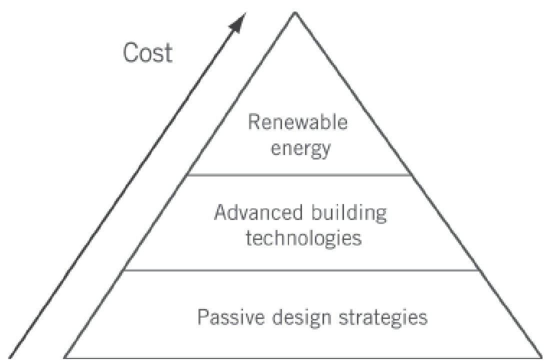

Figure 1: Design strategies for low and net zero energy buildings in relation to cost.

This strategy is applicable for the design of low energy buildings and currently is a viable approach for achieving net zero energy buildings, as it was found by a recent study[2]. The study considered buildings contained in the Commercial Buildings Energy Consumption Survey (CBECS) 2003 database, which includes energy consumption data, energy sources, costs and building characteristics for all US climate types[3]. Building types in the CBECS database include educational facilities, food sale and service facilities, healthcare, hotels, retail, office spaces, public assembly, public order and safety, religious buildings, service buildings and warehouses.

Research method included prediction of lowest energy usage for all of the building types in CBECS database by modeling energy requirements. The study considered currently available building technologies and projections of future improvements in building systems. Also, the study considered inclusion of photovoltaic systems, and the percentage of buildings that can meet zero energy goals. It was found that 62 percent of current commercial sector could reach net zero energy goals by 2025. Figure 2 presents results of the study, represented by the number of buildings and floor area. These following characteristics indicate scenarios that were investigated and energy-efficiency measures:

- Base and photovoltaic system: examined current commercial building stock by applying performance criteria complying to ASHRAE Standard 90.1-2004 and photovoltaic system covering 50 percent of roof area for every building.
- Low energy buildings: examined what can be achieved when current practices are applied (passive and advanced building technologies).
- Low energy buildings 2025: predicted energy savings of low energy buildings with higher component performances reflecting advancements in technology (increase in PV performance, improvements in HVAC systems, reductions in lighting power density).
- Low energy buildings 2025 and reduced lighting

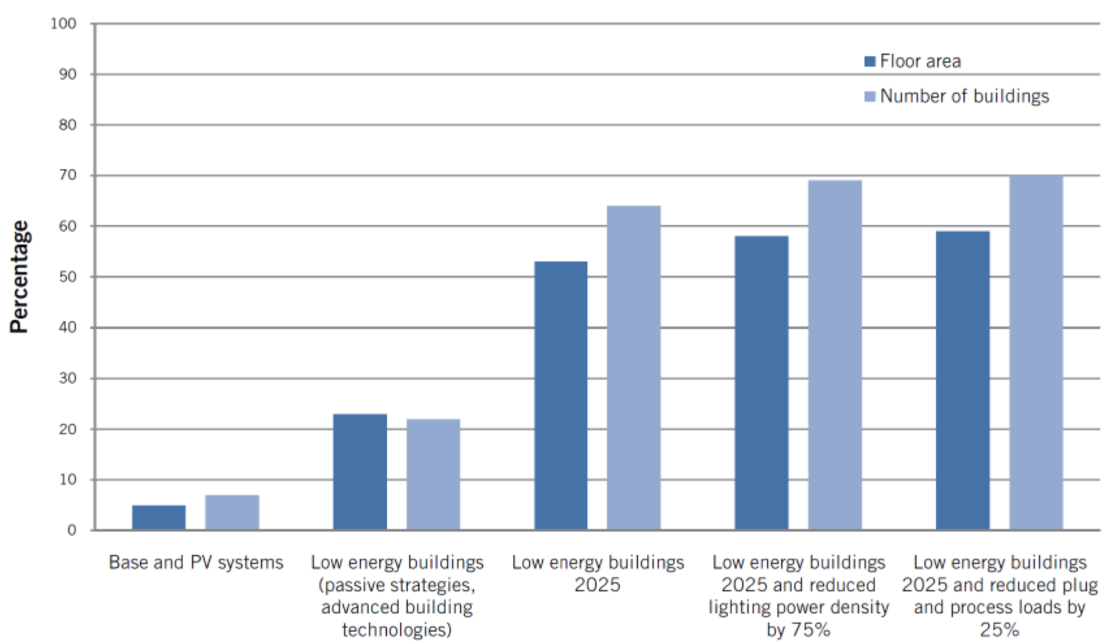

Figure 2: Percentage of US commercial sector that can reach zero energy goals.

- power density by 75 percent: similar to option above with increased reduction of lighting power density.
- Low energy buildings 2025 and reduced plug and process loads by 25 percent: examined reduction in energy use by appliances and electrical equipment compared to other models.

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 why we need quantifiable predictions, followed by the discussion of climate-driven design strategies. Then, relationships between Building Information Modeling and analysis software are discussed, particularly focusing on the best practices for developing models that are suitable for different types of simulations and workflow between BIM and analysis software applications. Lastly, two case studies are discussed to illustrate this process. The first study reviews curtain wall energy performance for a healthcare facility located in a mixed humid climate and daylighting analysis. The second case study discusses comprehensive analysis of an academic research building, focusing on solar exposure studies based on building orientation, investigation of performance of shading devices and daylighting analysis.

2.0 BACKGROUND AND LITERATURE ON BUILDING PERFORMANCE ANALYSIS

2.1 Why Do We Need to Quantify Our Design Decisions?

Past research on the utilization of simulation tools during the 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

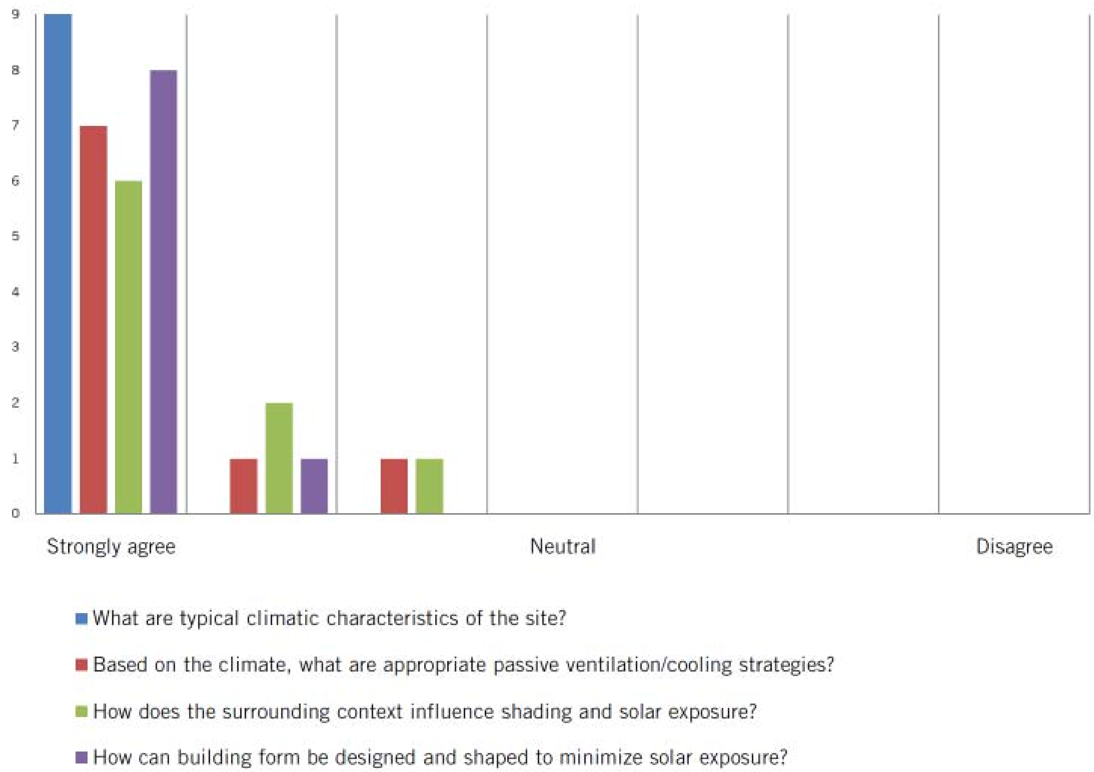

Figure 3a: Survey results rating importance of different questions during conceptual design phase.

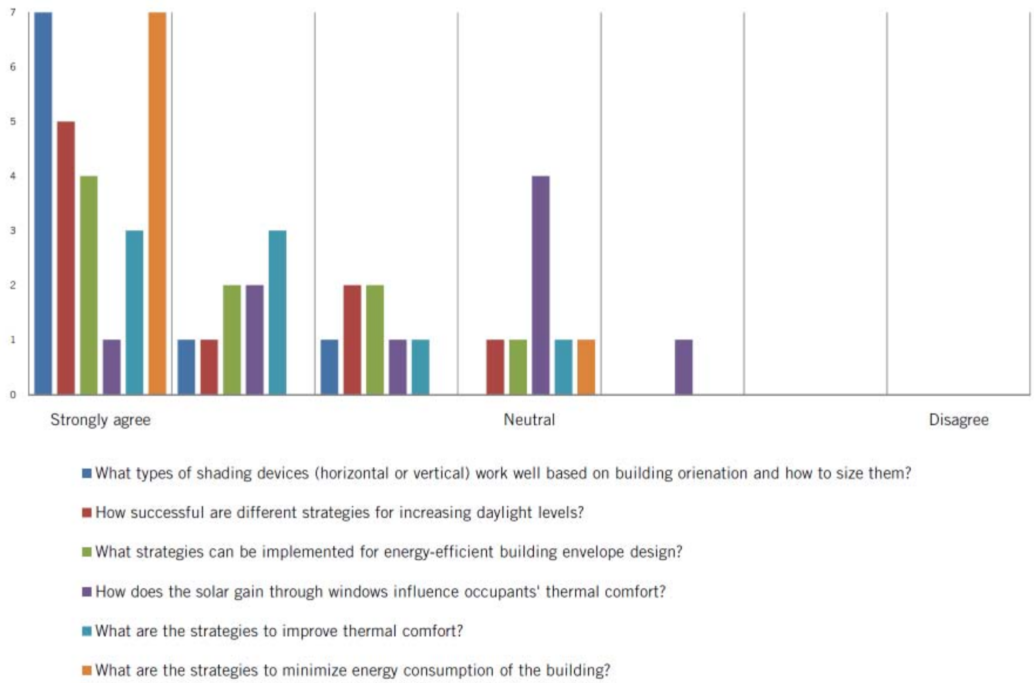

Figure 3b: Survey results rating importance of different questions during schematic design phase.

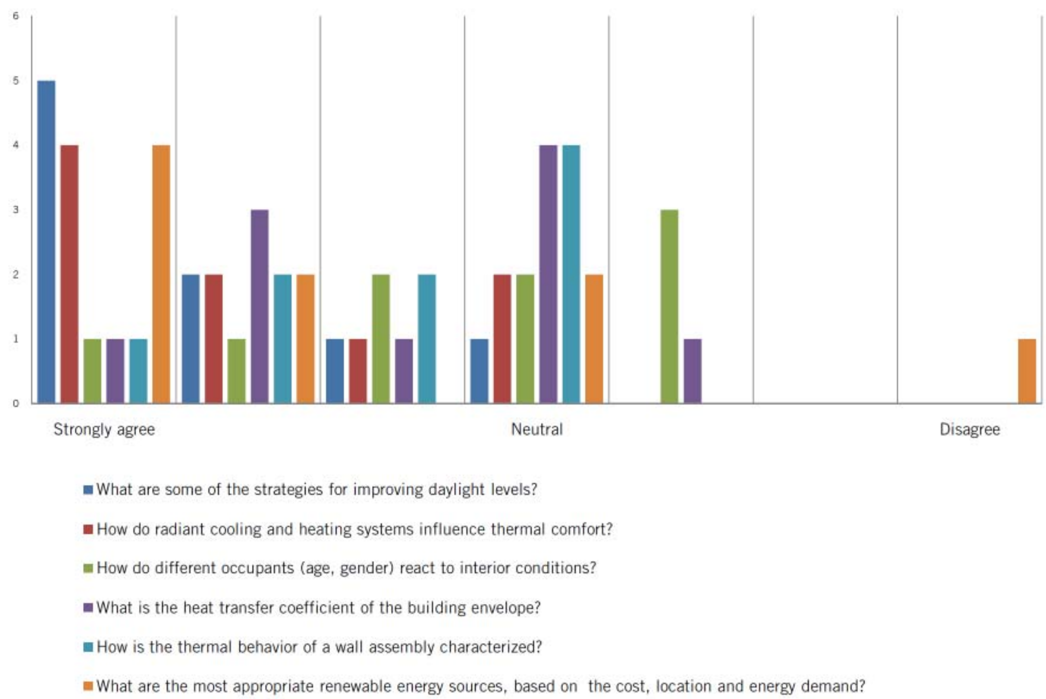

Figure 3c: Survey results rating importance of different questions during design development phase.

with the working methods and needs or the tools are judged as complex and cumbersome[4, 5]. To remain competitive, design professionals must weigh the value of information gained through simulation tools against the invested time, resources and the value of comparable information that might be gained through the use of other or no tools[6].

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. As it is shown in Figure 1, the objectives for attaining extremely low and zero energy buildings rely on several strategies including the use of passive methods, advanced building technologies and renewable energy sources. Therefore, we need to quantify the benefits of each individual methodology and relate them to a specific design problem, building, its climate and the context. Quantifiable predictions during the different stages of the design process help establish metrics that can be used to measure improvements by using these different strategies.

A survey has been conducted at two Perkins+Will offices to investigate relative importance of typical questions raised during the design process that can influence building performance. The objective of the questionnaire was to assess applicability of analysis tools and their relevance in helping address or answer these questions. The survey instructed respondents to rate the relative importance of each question on a 7-point Likert scale indicating whether they agree or disagree that this specific aspect is important during the specific design phase and whether analysis tools should be used to establish specific metrics.

Figure 3a shows questions associated with the conceptual design phase (influences of climatic characteristics, appropriate cooling strategies, surrounding context and solar exposure and derivation of the building form to minimize solar exposure). The majority of respondents agree that these aspects are important for the design and that analysis tools should be used to help during the design process.

Figure 3b shows questions that are associated with the schematic design phase (dimensioning and selection of shading devices, methods for improving daylight levels, strategies for designing energy efficient building envelopes, effects of solar heat gain and strategies to minimize overall building energy consumption). For these questions, the majority of the respondents have indicated that selection of shading devices and determination of their typology (vertical versus horizontal types and dimensions) and determination of strategies to minimize overall energy consumption of the building are very important. Strategies for designing energy efficient building envelopes and methods for improving daylight levels have also been identified as important parts of the design. These aspects require quantifiable predictions and simulations in order to have a significant impact on the design rather than relying on rules-of-thumb.

Figure 3c shows responses and questions that are associated with the design development phase. The types of questions focus on advanced methods for improving daylight levels, thermal comfort and influence of radiant cooling and heating systems, thermal behavior of exterior building envelopes and selection of renewable energy sources. Reponses show that the most important aspects are advanced methods for improving daylight, strategies for improving occupants' thermal comfort and selection of appropriate renewable energy systems. Again, all of these aspects require predictions through simulations, especially in this stage since more information about the design is available.

2.2 Climate-Driven Design and Impact of Simulations

The starting point for the schematic design is site analysis, where environmental factors are systematically examined. Typical information about environmental conditions of the site includes topography, context, solar orientation, climatic characteristics, surrounding structures and infrastructure[7]. 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. While passive solar gain can be harnessed to decrease heating demand in winter, gains during summer months create the need for cooling.

In a climate-sensitive design approach, it is necessary to account for local solar radiation, temperature, wind and other climatic conditions. Different design strategies are required for different climatic regions and basic concepts that are suited for a particular climate type are outlined in Table 1. Heating dominated climates can benefit from solar collection and passive heating, heat storage and conservation through improved insulation and use of daylight to reduce lighting demand. For cooling-dominated climates, opposite strategies can be applied, where protection from sun and direct solar

Table 1: Climate-dependent design strategies.

Climate type	Design strategies that can achieve reductions in energy demand
Heating-dominated climates	Solar collection and passive heating: Collection of solar heat through the building envelope Heat storage: Storage of heat in the mass of the walls and floors Heat conservation: Preservation of heat within the buildings through improved insulation Daylight: Utilization of natural light sources
Cooling-dominated climates	Solar control: Protection of the building from direct solar radiation Ventilation: Movement and replacement of air within occupied spaces Minimization of internal gains: Reduction of heat from occupants, equipment and artificial lighting Reduction of external gains: Protection from solar heat gain by infiltration (factor for building enclosure design), and conduction (factor for shading design) Cooling: Possible utilization of natural ventilation where climatic characteristics and building usage permit this method Daylight: Utilization of natural light sources while minimizing solar gain by utilization of shading devices and light-shelves
Mixed climates	Solar control: Protection of the building from direct solar radiation during warm seasons Solar collection and passive heating: Solar collection during cold seasons Daylight: Utilization of natural light sources

radiation is advantageous as well as reduction of internal and external heat gains, use of natural ventilation where permissible and use of daylight. In mixed climates, combined strategies need to be implemented balancing solar exposure and access to daylight.

Daylighting and shading are one of the aspects of façade design for high-performance building facades. Facades not only offer the aesthetic look and the building's architectural expression, but should be advantageously used to control the internal conditions of the building. Methods for design of high-performance building envelopes include:

- Enhanced sun protection and cooling load control while improving thermal comfort and providing most of the needed light with daylight.
- Enhanced air quality and reduced cooling loads using natural ventilation schemes employing the façade as an active air control element where permissible.
- Reduced operating costs by minimizing lighting, cooling and heating energy use by optimizing the daylighting and thermal trade-offs.

There are several key parameters that influence performance of building façades, but location and climate are prevailing considerations. Design strategies need to adapt according to the climatic conditions and take into account local characteristics in order to minimize loads and energy consumption. Perfection of a building envelope design depends on the appropriate solutions for the various parameters of visual, thermal and acoustical comfort[8].

Maximum advantage of daylight can be achieved by shaping the plan arrangement of a building to suit the activities within by properly sizing windows and by including light-shelves and selecting interior material finishes that reflect light. Spaces that utilize control systems for artificial lighting (occupancy sensors and photosensors) can significantly reduce lighting loads, accounting for 25 to 40 percent of energy savings for interior lighting[9]. Daylight simulations can help in selection of appropriate strategies, especially for mixed climates since provision of shading devices can negatively affect availability of natural light.

Reinhart and Fitz conducted a study on the utilization of daylight simulations and their impact on building design[10]. A survey was administered to architectural designers (31 percent), engineers (38 percent), researchers (23 percent) and other building professionals (8 percent) totaling 169 participants. Results show that utilization of simulation tools for assessment of daylight potentials was significantly higher during design development than during schematic design and that shading types and controls were the number one design aspects that were influenced by the daylighting analysis. Also, window size, glazing type and choice of lighting controls were identified as important aspects that can benefit from daylighting analysis, followed by building orientation, interior surface properties and room dimensions.

2.3 The Need for Integrating Analysis into the Design Process

In order to evaluate and optimize building performance, different analysis cycles should be part of an integrated design process. Figure 4 shows the basic types of performance analysis in relation to the project stages, particularly focusing on building envelope design. The top part of the diagram shows the impact of decisions on actual building performance and relationships to project stages. As can be seen, as early as the programming

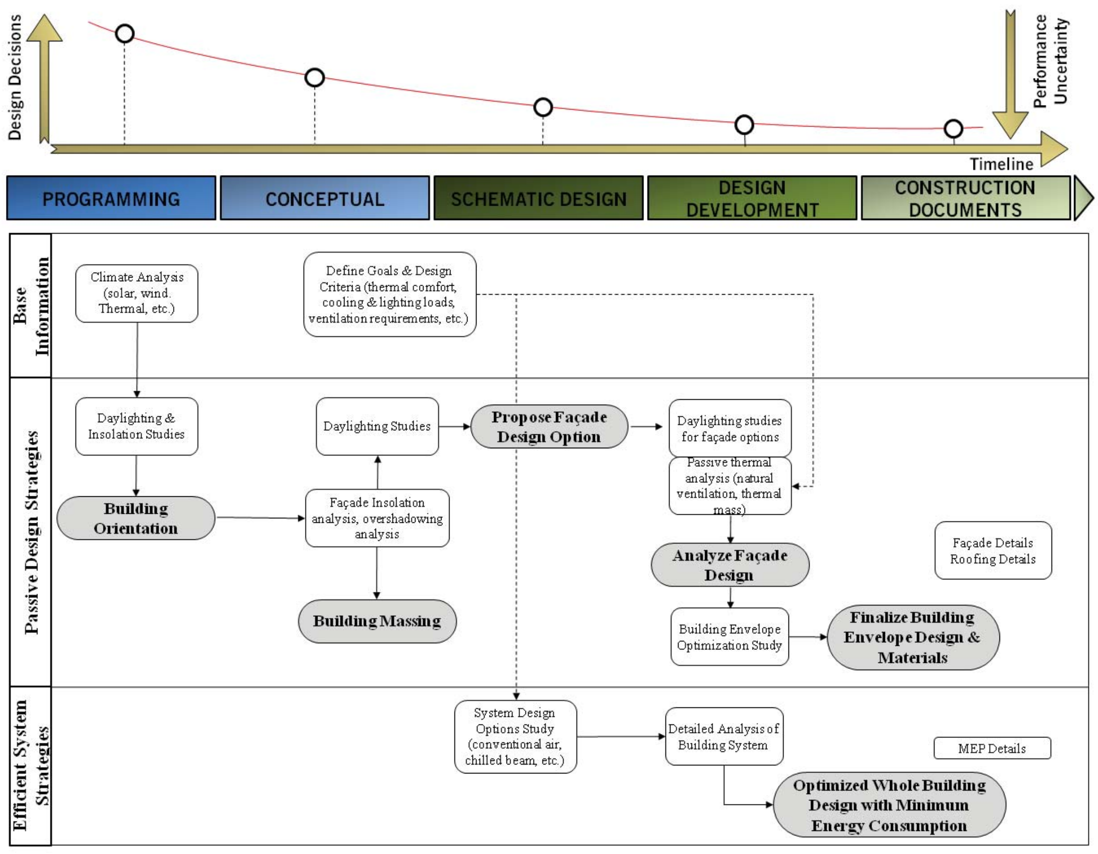

Figure 4: Design performance analysis flow with a focus on building envelope optimization (Adapted from Kohli, 2008)[11].

phase the analysis focuses on the bigger design picture such as climate information, orientation and building massing. Then, at conceptual and schematic phases the analysis observes the whole sun shading method proposed for the façade in alignment to overshadowing of surrounding buildings. Generally, an iterative cycle of different design options of sun shades are analyzed as well as daylighting studies. The decisions here are of high impact on the design because they influence the exterior design character of the project, potential energy use reduction and affect the comfort levels inside the spaces.

The design method that integrates energy and environmental analysis at early design stages suggests a procedure to follow in order to reach a particular solution to a design problem. This is a challenging paradigm when comparing between the traditional and building performance-based design methods:

1. *Traditional Method:* has some deficiencies because: (1) it includes simplified assumptions based on rules-of-thumb that can be inaccurate (e.g. forcing an aesthetic feature); and (2) not accurate in relation with performance measurement of design solution.
2. *Building Performance-Based Design Method:* has power in predicting a design solution because it: (1) uses performance measures with actual quantifiable data and not rules-of-thumb; (2) aims to develop a 'simplified' model of a complex physical system; (3) uses the model to analyze and predict behavior of the system; and (4) produces a more realistic evaluation of the design.

It is important to distinguish between different steps that are associated with performance-based design method, associated design phases and types of design decisions that can be influenced.

2.4 BIM-Based Building Performance Analysis Using Revit and Ecotect

Current design representations offer improved communication and interoperability between design documentation and analysis applications. Best practices for data exchange between BIM Revit® platform and Ecotect® analysis software are discussed to illustrate this process. Ecotect analysis is designed to be used during the early stages of the design process and can be effectively used for a variety of analysis functions such as shadow analysis, shading, solar exposure studies, lighting and daylighting studies[12]. Data exchange between Revit and Ecotect is performed through Green Building XML (gbXML) schema, a computer language specifically developed to facilitate the transfer of building properties stored in BIM to analysis tools. The basic structure of gbXML consists of elements such as rooms, walls, floors, ceilings, shading surfaces and windows. It inherits properties imbedded in the model (actual numeric values) and transfers to analysis applications. The following model parameters are essential for data exchange and are useful in utilizing BIM models for environmental analysis:

1. *Rooms:* Since rooms are the basis of the gbXML file and its structure (all the other data is associated with these elements), their location and properties must be specified in the model. Only significant spaces should be defined as rooms (corresponding to thermal zones) and smaller supportive spaces (elevator shafts, storage spaces, mechanical spaces, etc.) can be grouped. Rooms must be fully bounding, therefore, 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) that are not bounding a room and are exported as simple surfaces.

These basic parameters can be embedded in the model from the earliest stages of the design process and used for environmental analysis. Figure 5 shows an example of a Revit file with information needed for the analysis imbedded in the model (rooms, their dimensions and properties), which get transferred by gbXML file to analysis engine. Figure 5b shows an excerpt of the gbXML file containing exactly the same information, but showing a different, data-based view. Figure 6 shows the analysis model created in Ecotect from the gbXML file.

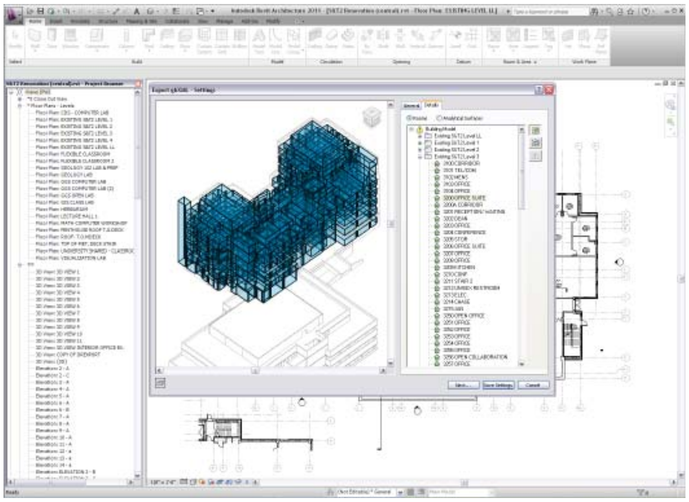


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Figure 5: a) Example of Room properties inside a Revit gbXML 3D model, b) gbXML data file structure.

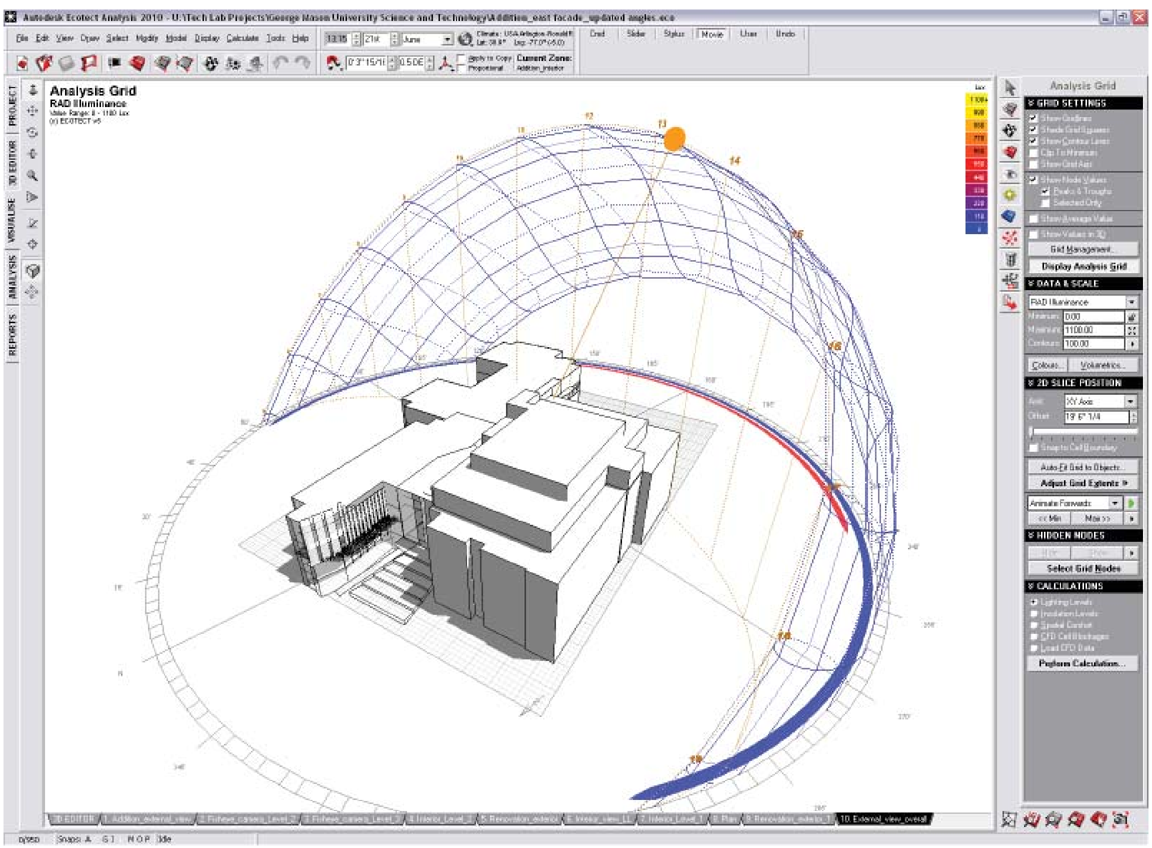


Figure 6: Ecotect model (based on the import of the gbXML file shown in Figure 5).

2.5 The Work Context for Building Performance Analysis

It has become important that designers evaluate building energy performance at early and schematic project phases before a detailed whole-building energy model is produced. This saves the project from drastic changes due to misguided energy goals. However, building performance analysis can be long, tedious process and the authors believe that it is important to demystify such process. This article proposes that building performance analysis can be performed in two primary stages, which can be parallel or complement each other. The first method is a lightweight energy analysis performed at early project phase. We refer to this method as a *Design-Performance Energy Analysis* whereby it could follow two stages and each is utilizing the appropriate tool. In some cases we have noticed that a whole building energy analysis is hard to accomplish at this early stage due to many operational and logistical reasons. Most importantly, certain energy attributes such as detailed information about building systems are not known and are needed for populating a whole-building energy model. This is why isolating components that are known (e.g. building envelope options, skylight options, etc.) work well. The two stages within the *Design-Performance Energy Analysis* method are[13]:

1. *Understanding some energy target goals and design scenarios:* the aim is to establish early in the project some meaningful energy performance targets in order to assess against the different design schemes. With this, early design characteristics and decisions are understood such as: the site, building orientation, climatic conditions, shadow ranges, basic solar exposure and its directionality and passive strategies based on the location. One of the tools that can be used is COMFEN tool, which allows analysis of key fenestration variables on energy consumption, peak energy demand and thermal and visual comfort. Other tools like Autodesk® Green Building Studio® can assist in calculating energy target goals.
2. *Design solutions and optimization:* occurs when the project progresses into design development phase. For example, the building envelope undergoes cycles of performance analysis based on the exterior skin configurations. In this approach different design options are tested utilizing a more detailed "3D prototype model". The analysis tool that can be used here is Ecotect Analysis, which aids the team in performing iterative analysis to assess:

- Façade solar exposure to determine total solar radiation: Understanding the total radiation assists in understanding insulation needs in the building, which is done by evaluating different wall construction materials' properties.
- Sunshade design and optimization: The tool helps us optimize the size of sunshades as well as understand the shaded area of exposed glass.
- Natural daylight levels, which are analyzed at various critical spaces of the building (for example, classrooms, patient rooms, public spaces and lightwells).

The *Energy Modeling* is the second method and it focuses primarily on sizing and selection of mechanical equipment and prediction of annual energy consumption through the "whole building" approach[13].

For the purpose of the work presented in this article, the authors are focusing on the *Design-Performance Energy Analysis* method and application to the two case studies.

3.0 CASE STUDY (1): DUKE MEDICINE PAVILION BUILDING ENVELOPE ANALYSIS

3.1 Project Overview and Analysis Objectives

The objectives of this study were to investigate building envelope design options and the effects on energy consumption, visual and thermal comfort and daylight strategies for Duke Medicine Pavilion, located in Durham, North Carolina. Durham is characterized by a mixed-humid climate. Climatic conditions indicate that high air temperatures and high humidity levels are predominant during the summer months while relatively low temperatures are predominant during the winter months.

As shown in Figure 7, the hospital building is part of a large campus (approximately 350,000 square feet floor area). The first two levels contain the imaging department and public access areas, the third floor is the surgery level, levels four and five contain mechanical open floors and roof garden with two patient towers above them.

Annual solar path, building orientation and shade provided by surrounding buildings were investigated to de-

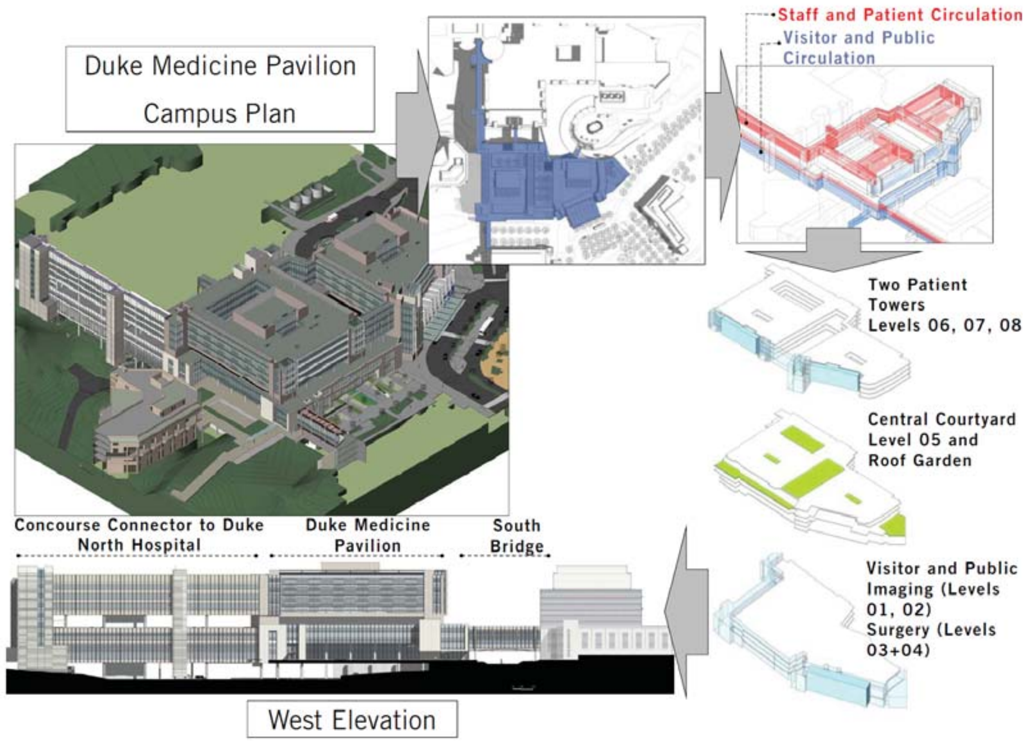


Figure 7: Duke Medicine Pavilion project within campus context and 3D Revit model.

termine critical areas where shading devices are needed as seen in Figure 8. East, south-east and south orientations are critical and require shading devices. West orientation is shaded by the adjacent existing building.

These following aspects were investigated:

1. Energy performance for south and south-east oriented curtain wall and the effects of glass properties (varying U-values, SHGC, visual transmittance), configuration and dimensions of shading devices and daylighting controls.
2. Design of shading devices and light-shelves and their effect on available daylight in the public waiting areas along the south and south east orientations.

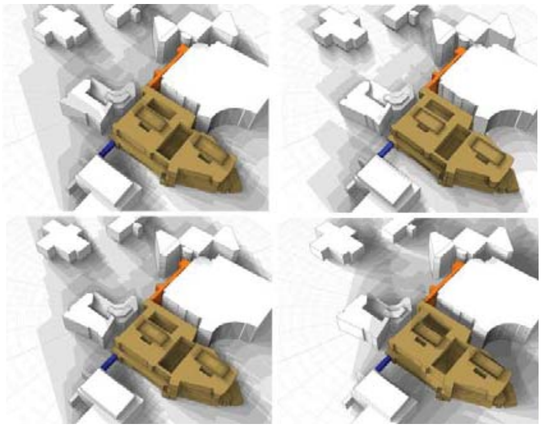


Figure 8: Projections of shadows from surrounding buildings on March 21, May 21, September 21 and December 21.

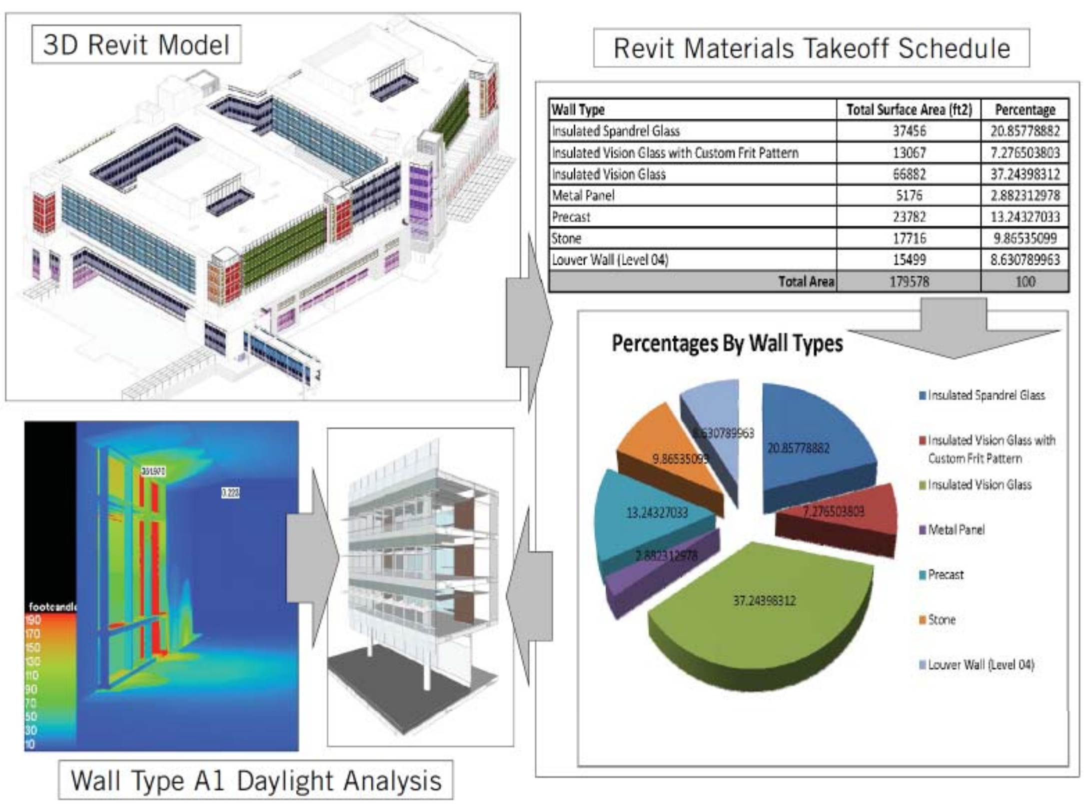
3.2 Building Envelope Design Elements and Effects on Energy Consumption

A number of curtain wall types have been used for this design, but only curtain wall Type A1 is discussed in this article, located on the south and south-east facades (Figure 9). The objective of the study was to analyze different design options (properties of glass and shading devices) that can be applied to minimize energy consumption. The elements of the curtain wall Type A1 are portrayed in Figure 9, where horizontal shading elements are used to block solar radiation and two different types of glass are used (low-e vision glass and insulated spandrel glass). The facade system delivers the greatest performance to the building owner and occupants when it becomes an essential element of a fully integrated building design in a manner that reduces operating costs for a building and increases comfort and productivity for occupants.

Basic guidelines for building envelope design located in a mixed-humid climate are as follows:

- Sun protection should be enhanced while providing most of the needed light using daylight.
- Operating costs should be reduced by minimizing artificial lighting, cooling and heating energy by optimizing the daylight.

For this particular climate, the reduction in cooling loads and provision of daylight are the most important strategies for the reduction of overall energy consumption. Therefore, glass that exhibits higher visual transmittance (Tv) and lower solar heat gain coefficient (SHGC) is preferable, but should be analyzed in order to understand the correlation between heat gain and provision of natural light. Table 2 shows properties of glass types, where GL 1 and GL 2 are low-e, double air-insulated glazing units studied for the vision-areas of the curtain wall. GL 3 and GL 4 are used for spandrel areas and the type of glass is identical, but GL 3 includes ceramic frit to reduce solar heat gain.



Wall Type	Total Surface Area (ft2)	Percentage
Insulated Spandrel Glass	37456	20.85778882
Insulated Vision Glass with Custom Frit Pattern	13067	7.276503803
Insulated Vision Glass	66882	37.24398312
Metal Panel	5176	2.882312978
Precast	23782	13.24327033
Stone	17716	9.86535099
Louver Wall (Level 04)	15499	8.630789963
Total Area	179578	100

Figure 9: Visualizing curtain wall types in Revit and showing material areas/percentage calculation in the model.

Table 2: Glass properties.

Glass type	Visual transmittance (Tv)	Solar Heat Gain Coefficient (SHGC)	U-value (Btu/hr-sf-°F)	U-value (W/hr-m²-°C)
GL 1	0.71	0.38	0.29	1.65
GL 2	0.62	0.29	0.28	1.59
GL 3 (40% white frit coverage)[9]	0.27	0.19	0.30	1.70
GL 4 (No frit)	0.38	0.25	0.30	1.70

One set of simulation scenarios focused on different cases for wall Type A1 (south orientation) and the properties are listed in Table 3. Types of glazing units and shading elements were varied to analyze the effects of their properties on energy consumption (heating, cooling, lighting loads), daylighting and thermal comfort. Moreover, comparison to wall types without shading devices and daylighting controls was performed. Simulation set for south-east orientation also included similar scenarios. Also, vertical shading elements were introduced for the south-east orientation. The study investigated a single bay per floor and a single zone, where associated annual energy demand for heating, cooling and lighting loads for these four cases were calculated.

Table 3: Characteristics of analyzed curtain wall options.

South orientation	South-east orientation
• Vision glass: GL 1 • Non vision glass: GL 3 (40% frit coverage) • Horizontal overhang 4’ depth (1.2m) • Mullion extensions 6” (0.15m)	• Vision glass: GL 1 • Non vision glass: GL 3 (40% frit coverage) • Horizontal overhang 4’ depth (1.2m) • Mullion extensions 6” (0.15m)
• Vision glass: GL 2 • Non vision glass: GL 3 (40% frit coverage) • Horizontal overhang 4’ depth (1.2m) • Mullion extensions 6” (0.15m)	• Vision glass: GL 2 • Non vision glass: GL 3 (40% frit coverage) • Horizontal overhang 4’ depth (1.2m) • Mullion extensions 6” (0.15m)
• Vision glass: GL 2 • Non vision glass: GL 3 (40% frit coverage) • Horizontal overhang 4’ depth (1.2m) • Mullion extensions 1’ (0.3m)	• Vision glass: GL 2 • Non vision glass: GL 3 (40% frit coverage) • Horizontal overhang 4’ depth (1.2m) • Mullion extensions 1’ (0.3m)
• Vision glass: GL 2 • Non-vision glass: GL 4 • Horizontal overhang 4’ depth (1.2m) • Mullion extensions 1’ (0.3m)	• Vision glass: GL 2 • Non vision glass: GL 4 (40% frit coverage) • Horizontal overhang 4’ depth (1.2m) • Mullion extensions 1’ (0.3m) • Vertical fins: height=9’ (2.7m), depth=1’ (0.3m), thickness=3” (0.08m)

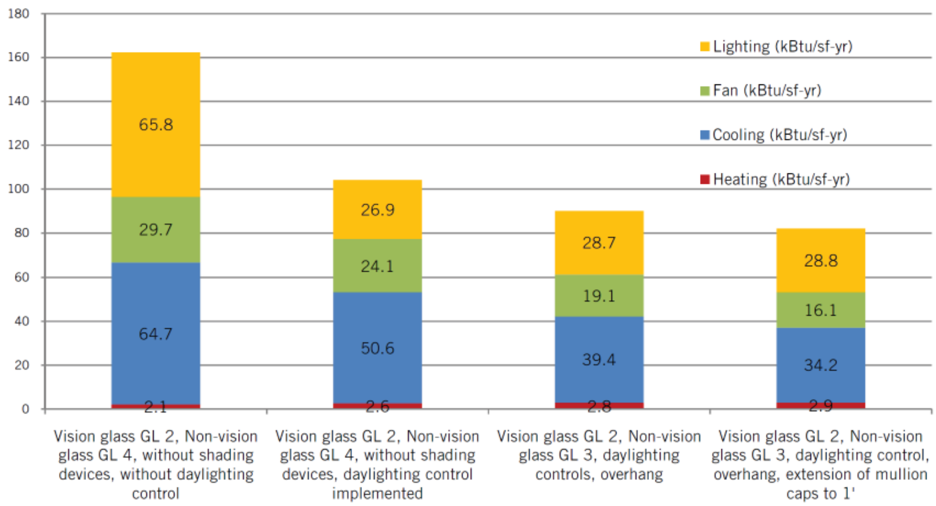


Figure 10: Calculated energy demand for different design options (south-oriented curtain wall).

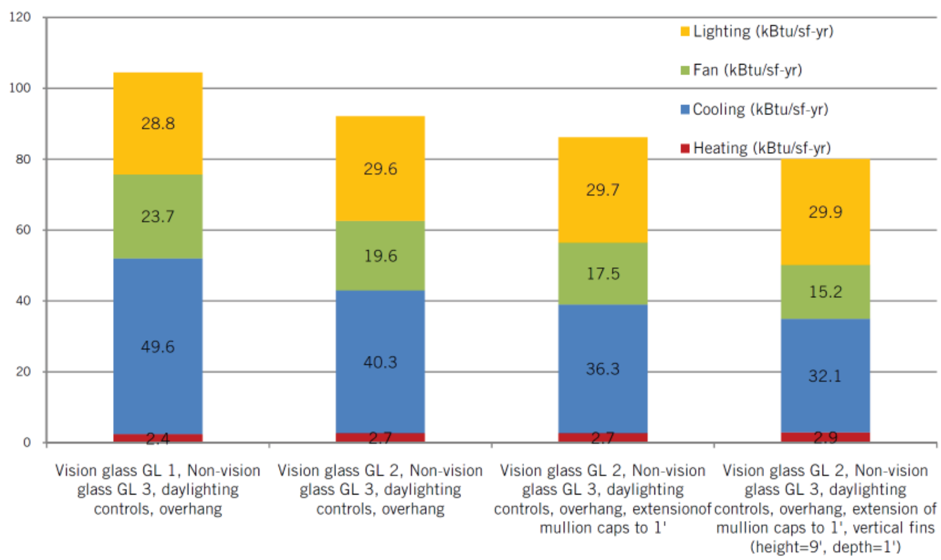


Figure 11: Calculated energy demand for different design options (south-east oriented curtain wall).

Figure 10 shows results for selected scenarios (south orientation), illustrating demand for south perimeter zones only. It was found that glass with lower visual transmittance and lower solar heat gain coefficient used for vision glass (GL 2) would results in reduced cooling loads, therefore, all the shown options show those scenarios. Implementation of lighting controls would significantly reduce lighting loads. Also, use of fritted glass for non-vision areas would reduce solar gains. The optimum design scenario utilizes GL 2 type for vision area, fritted glass for non-vision area, daylighting controls, horizontal overhang and extended horizontal mullion caps to provide additional shading. This scenario would result in 50 percent reduction in energy demand compared to a scenario that utilizes the same type of glass for vision area, but excludes fritted glass for non-vision area, shading devices and daylighting controls.

Figure 11 shows results for selected scenarios (south-east orientation). For this orientation, optimum design scenario also uses GL 2 for vision area, fritted glass for non-vision area and vertical fins are introduced to block early morning sun (besides horizontal overhang and extended mullion caps).

3.3 Effects of Design Options on Occupants' Thermal Comfort and Glare

The effects of the above discussed design options on thermal comfort and glare has also been investigated using COMFEN/EnergyPlus. Controlling glare is necessary for occupants' visual comfort. Average discomfort glare index is based on a subjective response to brightness within one's field of view. In this analysis, the average annual glare index was computed for a person facing the south wall, sitting five feet from the window. A glare index of ten is the threshold for just perceptible glare while a glare index of 16 is the threshold where glare is just acceptable.

Thermal comfort analysis, following Predicted Mean Vote-Percentage of People Dissatisfied (PMV-PPD) method, was used to study the interior thermal comfort conditions for the design options. This method is based on human body energy balance and is combined with an empirical fit to thermal sensation. PMV is based on a seven-point, cold-to-hot sensation scale for a large population of people exposed to a certain environment. PPD is the "Percentage of People Dissatisfied" at each value (PPD indicates the probability that an average person will be dissatisfied with his/her thermal comfort).

PMV-PPD statistically indicates the number of individuals that would express satisfaction by comfort conditions and ASHRAE 55-2004 Standard (Thermal Environmental Conditions for Human Occupancy) recommends that PMV value should be between -0.5 and +0.5, which corresponds to PPD of ten (or ten percent of dissatisfied persons)[14]. It also defines acceptable thermal environment as one in which there is 80 percent overall acceptability, basing this on ten percent dissatisfaction criteria for general thermal comfort, plus an additional ten percent dissatisfaction that may occur from local thermal discomfort.

Comparison of average discomfort glare index and thermal comfort PPD index is listed in Table 4 for south and south-east orientations. Results show that design options that result in improved energy efficiency for both south and south-east orientations are also best candidates for minimizing glare. All design options meet the recommended 80 percent acceptability threshold, but options that improve energy efficiency are also preferable for improving thermal comfort.

Table 4: Glare index and thermal comfort.

	Option 1	Option 2	Option 3	Option 4
South orientation				
Average discomfort glare index	5.30	5.80	4.60	5.10
Thermal comfort (PPD index)	16.83	15.40	14.11	13.40
South-east orientation				
Average discomfort glare (glare index)	5.20	5.00	5.00	4.30
Thermal comfort (PPD index)	14.57	14.24	14.23	14.38

3.4 Daylighting Analysis and Results

Daylight is the best source of light for the public space. The analyzed curtain wall adjoins waiting areas of the hospital. In order to understand the effects of different design options on daylight levels, subsequent daylight analysis was performed. Ecotect and Radiance programs were used for the study. Sixteen different options were investigated (varying window to wall ratio, configuration of shading devices and ceiling geometry). These studies were limited to evaluation of natural light under overcast sky conditions.

Properties of glazed portions of the building envelope were constant as obtained from the best scenarios from energy analysis presented in the previous section. Figure 12 shows three different options and results for south and south-east orientations. The properties are as follows:

1. Base design: vision glass GL 2 (7'-10"), Shading device depth = 4', shading device elevation = 7'-10", flat ceiling at elevation = 12'
2. Option 1: vision glass GL 2 (7'-10"), shading device depth = 4', shading device elevation =

7'-10", interior light shelf, sloped ceiling (sloping down from the curtain wall from 12' elevation to 10'), and with 2' fritted glass band placed 2' above shading device.

3. Option 2: vision glass GL 2 (7'), shading device depth = 3', shading device elevation = 7', sloped ceiling (sloping up from the curtain wall from elevation 10' elevation to 12'), 2' of fritted glass at base.

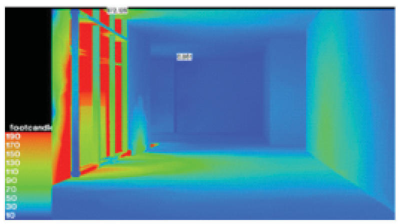
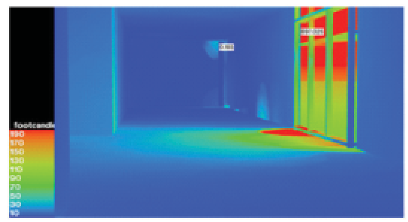
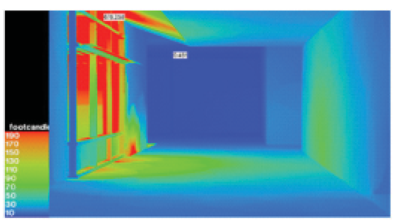
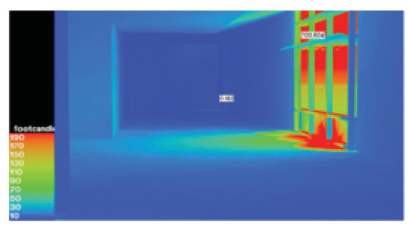
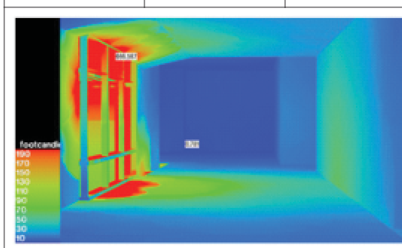
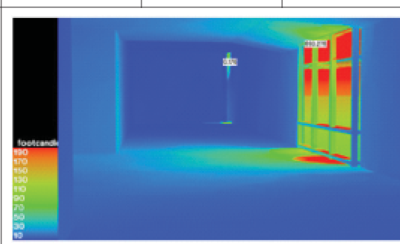
June 21 at 12:00 (South / South East)	At Window		At Middle Space		At Back Wall	
Measurement Distance	1'	1'	8'	10'	14'	17'
Base Design Option (fc)	130	115	70	45	35	10
						
Monthly Transmitted Solar Radiation (Btu/ft²)	41,834; No Shade = 288,249; Glass Area = 181 ft²			125,832; Glass Ares = 181 ft²		
Monthly Average Shade Percentage	75 No Shade = 64			69		
Option (1) (fc)	130	135	60	35	40	10
						
Monthly Transmitted Solar Radiation (Btu/ft²)	203,390 Glass Area = 151 ft²			256,932 Glass Ares = 151 ft²		
Monthly Average Shade Percentage	74			71		
Option (2) (fc)	160	130	70	50	35	10
						
Monthly Transmitted Solar Radiation (Btu/ft²)	27,550 Glass Area = 141 ft²			66,445 Glass Ares = 141 ft²		
Monthly Average Shade Percentage	79			79		

Figure 12: Comparison of daylight levels for three different scenarios (south and south-east orientation) and effects of ceiling geometry and light-shelf on daylight levels (June 21).

Results indicate that the last option would be the best option since uniform distribution of light would be present for summer and winter conditions. Other reasons include:

- It enhances the overall daylight quality within the space. This is visible from the heat-map renderings indicating better light distribution.
- The transmitted solar radiation is dramatically reduced from the original base design option, which allows a reduction in the cooling loads.
- The recommended design option results in using less glass area (141 ft^2) instead of (181 ft^2) from the base design option.

4.0 CASE STUDY (2): GEORGE MASON UNIVERSITY

4.1 Project Overview and Analysis Objectives

George Mason University Science and Technology Complex is located in Fairfax, Virginia. The building complex consists of an addition to an existing academic research center as seen in Figure 13. There is also an existing building bounding the complex on the west. Objectives of this study were to analyze shading strategies, daylight levels and solar exposure for various building orientations and components and methods to improve performance of building envelope. These following objectives were investigated:

- Site context and shadow ranges for winter and summer solstices.
- Addition building: shading devices on east facade; solar exposure, daylight levels and glare for selected laboratories.
- Addition building: shading devices on west facade, daylight levels and solar exposure; daylight levels and glare for corridor area.
- Addition building: solar exposure and daylight for north and south atrium facades.
- Renovation building: shading devices on west facade, solar exposure, daylight levels for selected computer laboratories and glare analysis.
- Properties of building envelope (specifically, glass selection) for improving energy efficiency.

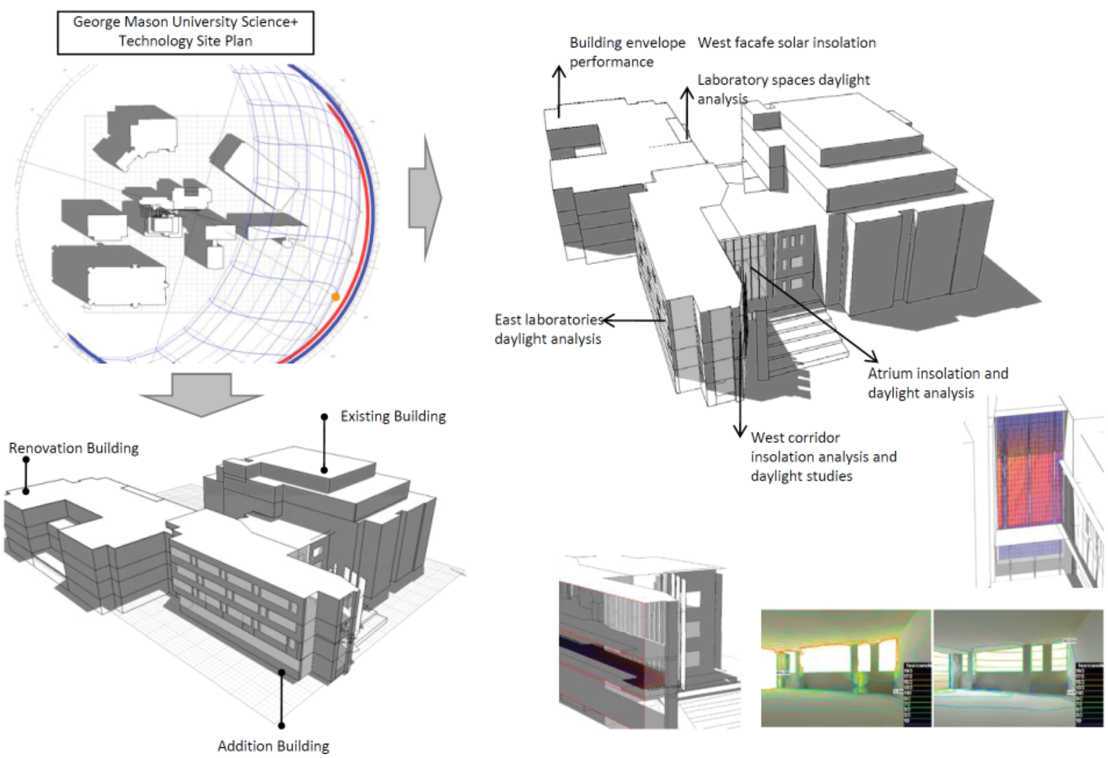


Figure 13: George Mason University Science and Technology complex and analysis objectives.

4.2 Environmental Conditions and Passive Strategies

Fairfax, Virginia is characterized by mild humid climate. Review of average monthly temperatures and humidity conditions revealed that mild conditions are present for the majority of the year (October through April: cool conditions; April through middle of June and middle of September through October: moderate conditions) and only during summer months warm and humid conditions are present (middle of June through middle of September). Passive solar heating is possible for the majority of the winter months for this location, but solar gain should be minimized for summer months, therefore, following sections discuss analysis of site context and orientation, performance of shading devices and relationships between solar exposure and daylight.

4.3 Shading Devices, Daylight and Glare: West Facade

Selection of shading devices depends on building orientation. Generally, horizontal devices should be used for south façades. Vertical devices, such as fins, should be used on east and west facades and be able to rotate depending on the daily sun path. Shading of south facades respond to seasonal changes while east and west façades should respond to daily changes. Since the buildings under consideration are oriented -73° from true north, relative orientation and solar position was taken into account. During the winter months, buildings' east facades do not have direct access to sun and during summer months only receive direct solar radiation for a few hours in the morning. Since there is an existing building directly bounding Addition and Renovation buildings on the west side (as well as other buildings in the near proximity) detailed shadow analysis was performed for the entire site to understand the effects of surrounding buildings. Overall site context, surrounding buildings and daily shadow ranges for selected dates (December 21, March 21, June 21 and September 21) are portrayed in Figure 14. Gradient intensity indicates the amount of time that the selected surfaces spend in shade (in one hour increments). Significant shading is provided by the building that bounds Addition and Renovation Science and Technology buildings on the west (during afternoon hours throughout the whole year, especially Renovation building).

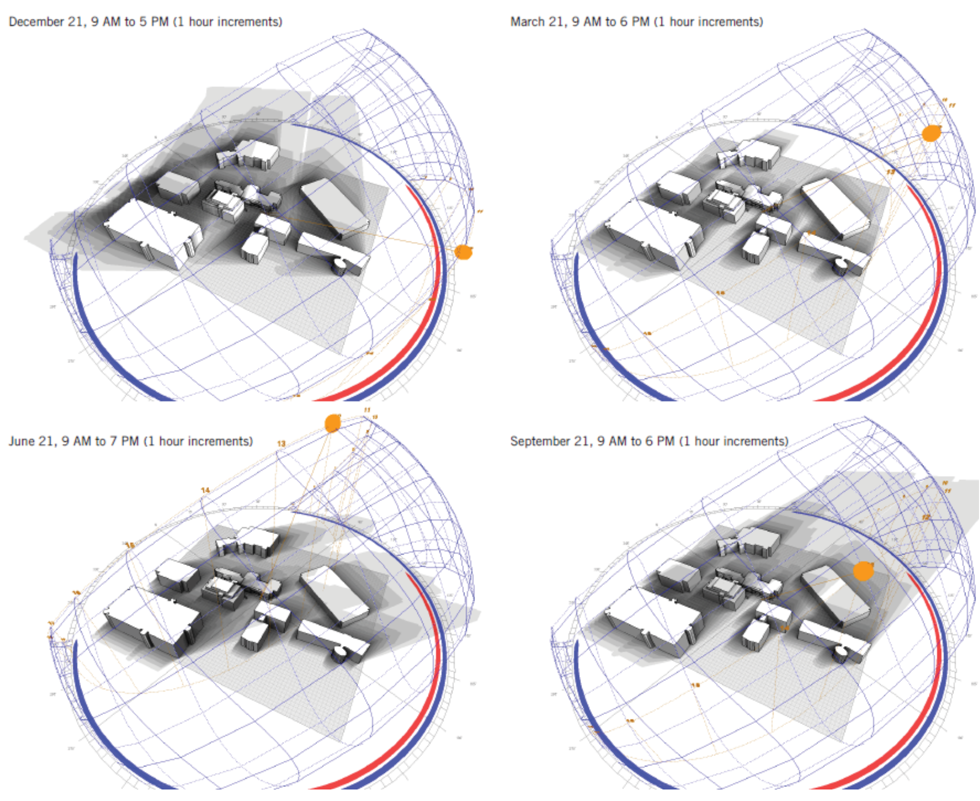


Figure 14: Site context and shadow ranges for selected dates.

Figure 15 shows hourly shadows for June 21. During this time, shading devices are needed during the whole day. Therefore, relative south and west facades are the most critical, especially in the afternoon hours.

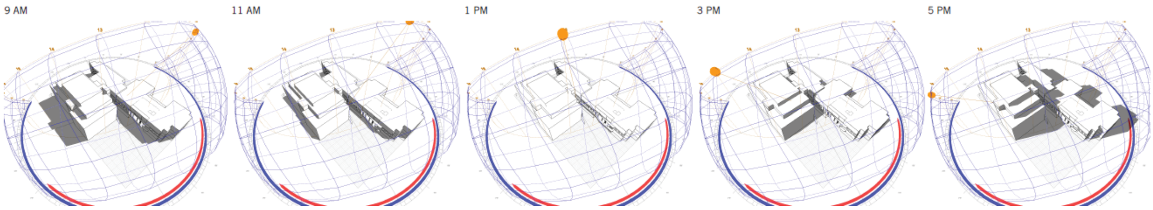


Figure 15: Hourly shadows (June 21).

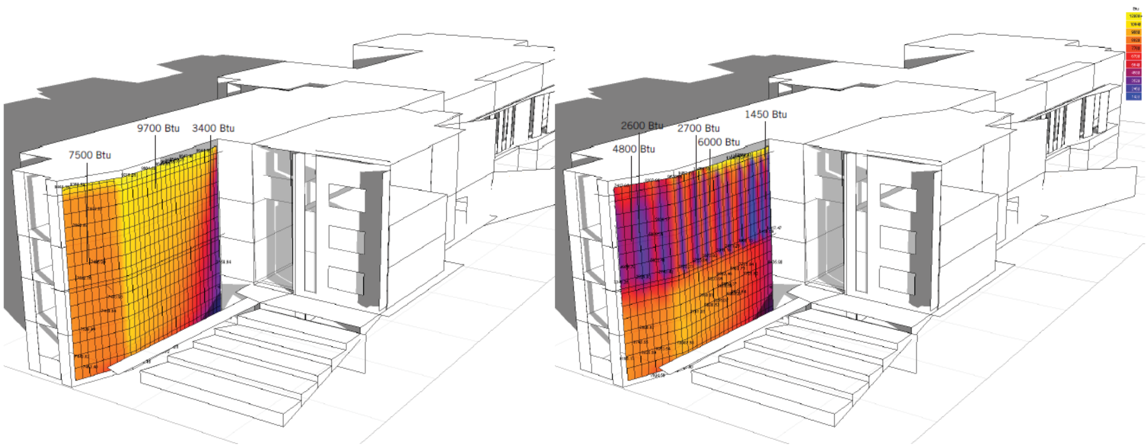


Figure 16: Comparison of average solar exposure for west façade without and with shading devices.

Figure 16 compares average solar exposure for west facade without and with shading devices for summer months. It is evident that shading devices (aluminum screen mesh used as vertical fins) significantly reduce solar heat gains. Moreover, reducing the angle of vertical fins would further reduce solar heat gains. Since shading devices can negatively affect access to natural light, daylight analysis was conducted to investigate the effects. Figure 17 shows daylighting levels in the corridor. It is evident that the vertical fins do not reduce amounts of natural light within the interior space.

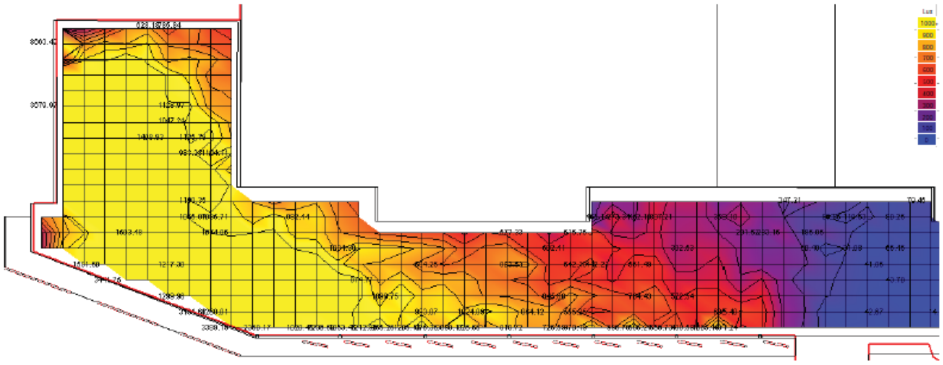
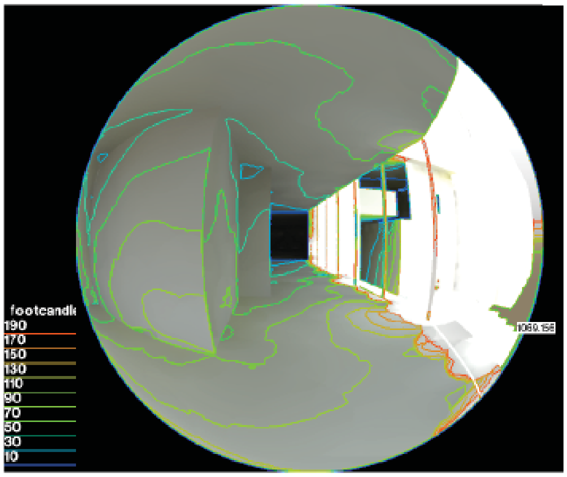


Figure 17: Daylight levels in the corridor and the effects of shading devices.



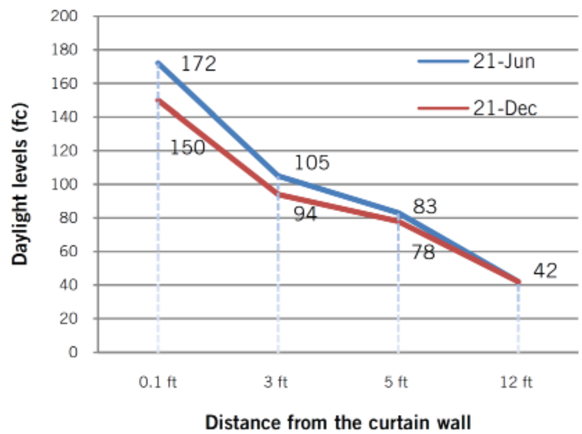


Figure 18: a) Interior view of the corridor and daylight levels; b) Daylight levels at measured distances from the curtain wall (simulated on June 21 and December 21).

Glare analysis has been performed for June 21 and December 21, where two different calculation methods have been used (Unified Glare Rating and Visual Comfort Probability). Figure 18 shows interior view of the corridor used for the analysis (fisheye camera is used to generate the image appropriate for the analysis). Detailed daylight levels at measured distances from the curtain wall are also shown for June 21 and December 21 conditions. Radiance was used to calculate two glare indices Unified Glare Rating (UGR) and Visual Comfort Probability (VCP). UGR indicates visual discomfort and is calculated by a formula that takes into account position and brightness of each potential glare source. Following values for acceptable ranges are recommended[15]:

- Discomfort zone
  - Intolerable: >28
  - Just intolerable: 28
  - Uncomfortable: 25
  - Just uncomfortable: 22
- Comfort zone
  - Acceptable: 19
  - Just acceptable: 16
  - Noticeable: 13
  - Just perceptible: 10

Results for June 21 and December 21 indicate that glare would not be present in this space, since calculated UGR index was 0 for both winter and summer conditions. Visual Comfort Probability index was also calculated. It is an estimate of how many people out of 100 would feel comfortable in the given visual environment, and results showed that VCP index would be 100 for both summer and winter conditions. Therefore, the vertical aluminum screen mesh vertical fins used on the west façade reduce unwanted solar heat gain, but do not negatively affect the amounts of natural light and provide protection against unwanted glare.

4.4 Shading Devices, Daylight and Glare: East Facade and Atrium

East facade of the Addition building is shadowed during most of the year, and receives only small percentage of incident solar radiation, as seen in Table 5. Shading devices on this facade are therefore redundant. Daylight levels for laboratories located on the second level are shown in Figure 19.

Table 5: Average solar radiation, incident solar radiation and average shade percentage for the east façade.

	Available solar radiation (Btu/ft²)	Incident solar radiation (Btu/ft²)	Average shade percentage
Jan	25,744	1,185	91%
Feb	27,208	1,534	88%
Mar	35,784	1,993	87%
Apr	46,550	2,857	86%
May	35,197	2,194	85%
Jun	43,175	2,719	83%
Jul	42,109	2,558	83%
Aug	41,275	2,374	84%
Sep	35,846	2,204	87%
Oct	43,697	2,738	86%
Nov	26,064	1,354	88%
Dec	25,219	1,120	90%
TOTAL	427,868	24,828	

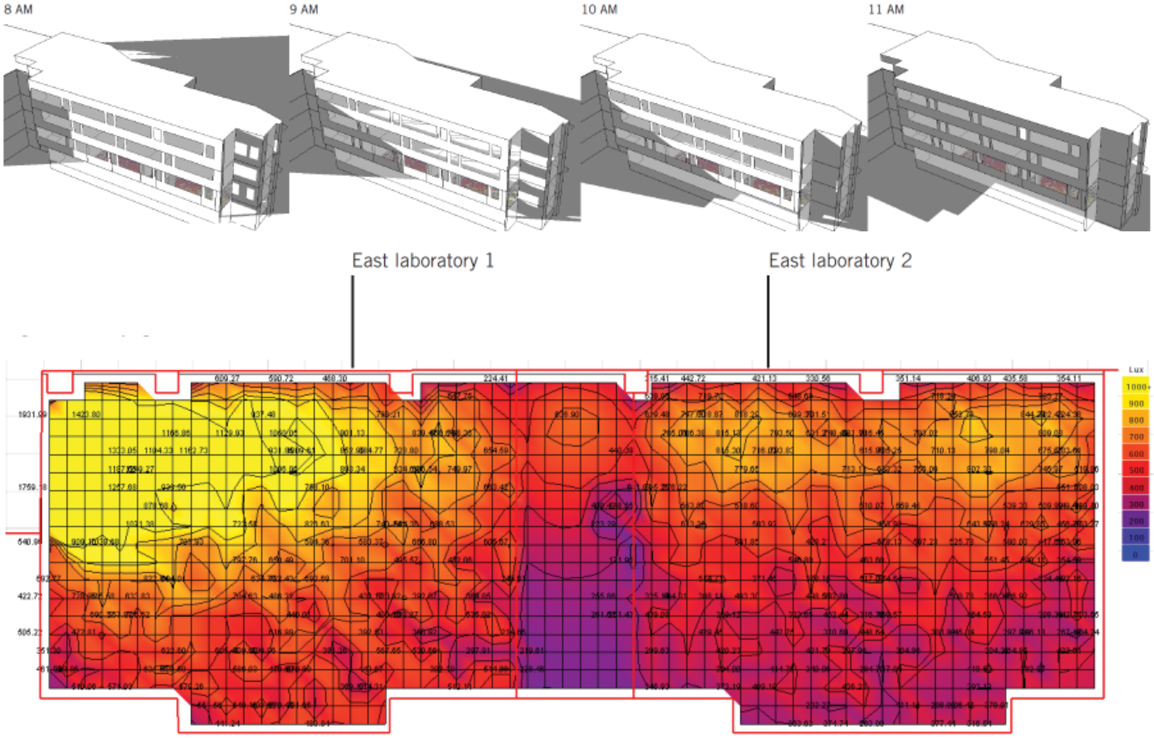
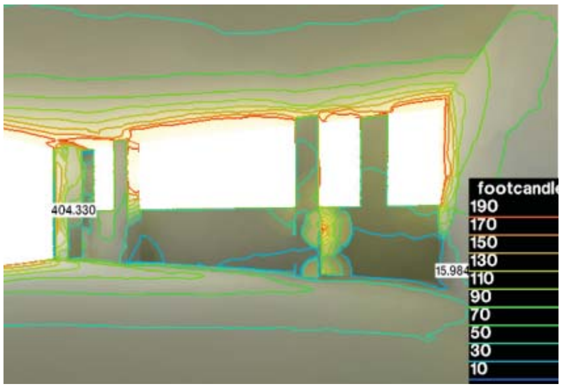


Figure 19: a) East façade and shadows (June 21), b) Daylight levels for laboratory spaces (plan).



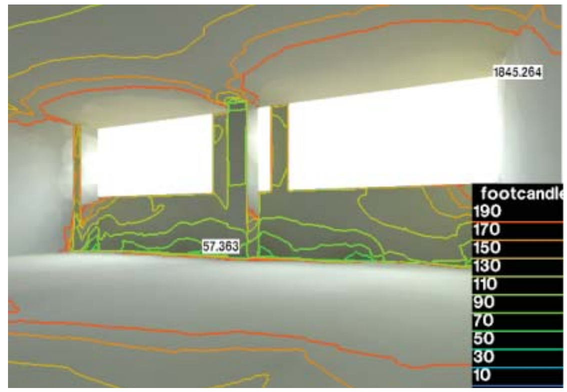
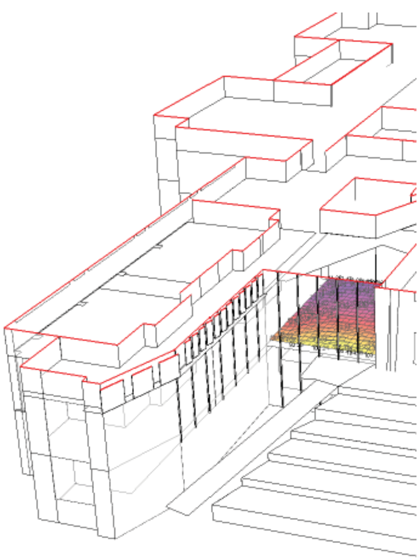


Figure 19c: Distribution of daylight within 3D models of laboratories.

Average incident daily solar radiation for atrium façade is relatively low due to the orientation and shading provided by the existing building. Also, it was found that this facade is shaded for majority of the year, except late afternoon hours during summer months. Therefore, shading devices (or other methods for controlling solar heat gain such as fritted glass) would be redundant. Daylight analysis indicated that sufficient daylight levels would be present in the atrium (Figure 20), where values are shown for measured distances from the curtain wall.



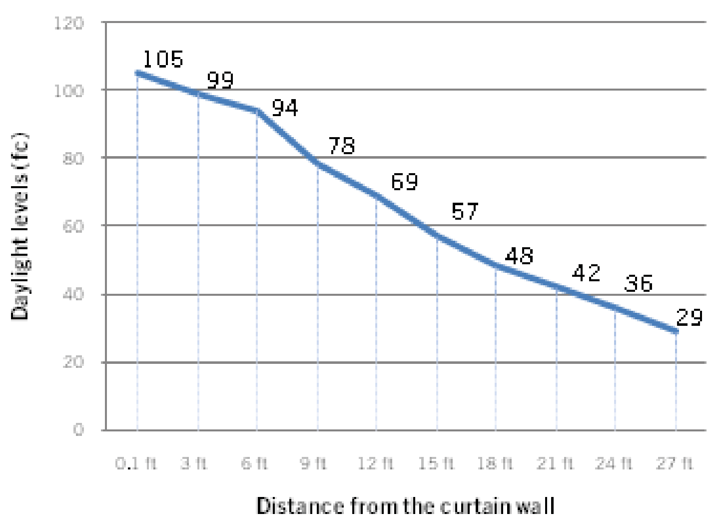


Figure 20: a) Atrium; b) Daylight levels at measured distances from the curtain wall.

4.5 Building Envelope Energy Performance

Solar heat gain plays a major role in determining thermal performance of a building façade. The factors that can influence energy conservation of windows and curtain walls are use of low-emissivity (low-e) coatings, balanced relationships between properties of glass (specifically, solar heat gain coefficient, thermal conductance, and visual transmittance), inert gases and frame materials. Improvements in the thermal performance of windows can be achieved by using spectrally low-e coatings that allow a high proportion of the visible light in the solar spectrum to be transmitted, but block much of the other wavelengths responsible for solar heat gains, thus improving thermal efficiency. Further improvements in thermal resistance can be achieved by replacing air with low conductivity gases such as argon or krypton. In order to investigate building envelope performance and to select glass according to building orientation and energy loads, several representative spaces were selected for areas of low and high solar exposure:

- Low solar exposure:
  - East laboratory (Addition building)
  - East office (Renovation building)
- High solar exposure:
  - Corridor (Addition building)
  - Atrium south entry (Addition building)
  - South office (Renovation building)
  - West computer laboratory (Renovation building)

For low solar exposure, selected glass options that were used in the study have low U-factor, relatively low solar heat gain coefficient (SHGC) and high visual transmission (Tv). For high solar exposure, options with low U-factor, lower SHGC and lower Tv were analyzed. One option with low SHGC and average visual transmittance was analyzed for both areas as well as system with higher visual transmittance (GL 4). Specific properties are listed in Table 6.

Table 6: Properties of glass used for analysis.

	Visual transmittance (Tv)	Solar Heat Gain Coefficient (SHGC)	U-value (Btu/hr-sf-°F)	U-value (W/hr-m²-°C)
Base Case				
Double insulated clear glazing unit (air infill)	0.79	0.70	0.48	2.73
Low solar exposure areas				
GL 1	0.62	0.28	0.30	1.71
GL 1 (argon infill)	0.62	0.28	0.25	1.42
GL 3	0.70	0.38	0.29	1.65
GL 4	0.48	0.28	0.30	1.71
High solar exposure areas				
GL 4	0.48	0.28	0.30	1.71
GL 5	0.36	0.28	0.31	1.76
GL 5 (argon fill)	0.36	0.27	0.26	1.48

Different scenarios were simulated for all cases (base case and options with different glass properties). All of the analyzed spaces were modeled as a single zone. Results showed that for low solar exposure spaces best results are obtained by using glass with low U-value and relatively high visual transmittance (such as GL 1), as seen in Table 7. Heating loads would be reduced by using argon-filled glazing unit, but since heating loads only constitute small percentage of the overall loads, the higher cost of the building façade would not benefit the overall energy/cost savings. For areas with high solar exposure (such as west corridor), results show that glass with low solar heat gain coefficient and visual transmittance (GL 5) would be the best choice (Table 8).

Table 7: Results for low solar exposure options (energy consumption).

LOW SOLAR EXPOSURE (East laboratory)	Base case	GL 1	% (Difference from Base case)	GL 3	% (Difference from Base case)	GL 4	% (Difference from Base case)	GL 1 (argon infill)
Heating (kBTu/sf-yr)	4.2	2.4	-41%	2.4	-42%	2.3	-44%	1.9
Cooling (kBTu/sf-yr)	22.7	18.8	-17%	18.6	-18%	20.3	-11%	19.4
Fan (kBTu/sf-yr)	12.9	8.9	-31%	8.8	-32%	9.6	-25%	8.7
Lighting (kBTu/sf-yr)	21.6	23.3	8%	25.4	17%	22.4	4%	23.3
Total energy (kBTu/sf-yr)	61.4	53.5	-13%	55.2	-10%	54.7	-11%	53.4

Table 8: Results for high solar exposure options (energy consumption).

HIGH SOLAR EXPOSURE (West corridor)	Base case	GL 1	% (Difference from Base case)	GL 4	% (Difference from Base case)	GL 5	% (Difference from Base case)
Heating (kBTu/sf-yr)	8.8	6.9	-22%	5.8	-35%	6.1	-31%
Cooling (kBTu/sf-yr)	134.8	62.4	-54%	69.8	-48%	61.3	-55
Fan (kBTu/sf-yr)	81.6	37.7	-54%	29.6	-51%	35.7	-56%
Lighting (kBTu/sf-yr)	41.9	41.9	0%	41.9	0%	41.9	0%
Total energy (kBTu/sf-yr)	267.2	148.9	-44%	157.1	-41%	145.0	-46%

5.0 FUTURE RECOMMENDATIONS

The authors would like to highlight issues and areas for improvements when it comes to building performance predictions:

- There is a general consensus for the need to develop and derive project designs based on rules-of-thumb in combination with the scientific/analytical approach for performance assessment.
- Coupling BIM-based energy analysis with BIM-based design production tools occurs when all design team members work collaboratively and while they are involved in the iterative process of design decision-making.
- There are both direct (gbXML) and indirect (DXF) routes when it comes to exchanging 3D-BIM models with energy analysis applications. We believe that most of the model-data interoperability is converted properly using gbXML. The challenge becomes the backward process when importing the energy analysis model/features back into BIM, which currently is not a feasible two-way mechanism between Revit and Ecotect.
- It is imperative to understand the underlying concepts and methodologies that a certain tool is applying in the analysis as well as its benefits and drawbacks.
- The final issue is that BIM-production model and the BIM-energy analysis model need to be managed and properly developed. In essence, BIM-production model has too many architectural/construction details and the second is a low level of detail simulation model. Users need not waste time in constructing or exchanging the whole project and details of the building that are not needed for the analysis, but rather focus on the zones under study and dependent on the objectives of the investigation.

6.0 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 assess 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. 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. 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. This article reviewed best practices for data exchange between Revit platform and Ecotect environmental analysis software through gbXML schema. Then, two case studies have been reviewed that illustrate this process in detail, analysis objectives, and results. The first case study reviewed curtain wall energy performance for a healthcare facility located in a mixed-humid climate and daylighting analysis. The second case study reviewed comprehensive analysis for an academic research building, such as site context and shadow analysis, solar exposure studies for different building orientations, daylighting and glare analysis. Finally, recommendations have been identified that suggest future areas of improvement for building performance predictions.

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] Griffit, B., Long, N., Torcellini, P., Judkoff, R., Crawley, D. and Ryan, J., (2007). Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector, Technical Report NREL/TP-550-41957, National Renewable Energy Laboratory and US Department of Energy.

[3] US Energy Information Administration, (2003). The Commercial Buildings Energy Consumption Survey, Retrieved from http://www.eia.doe.gov/emey/cbecs on 8/19/2010.

[4] 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.

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

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

[7] 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.

[8] Selkowitz, S. E., (2001). Integrating Advanced Facades into High Performance Buildings, Report LBNL-47948, Lawrence Berkley National Laboratory.

[9] Brambley, M. R., Hansen, D., Haves, P., Holmberg, D. R., McDonald, S. C., Roth, K. W. and Torcellini, P., (2005). "Advanced Sensors and Controls for Building Applications: Market Assessment and Potential R&D Pathways", Technical Report PNNL-15149, Pacific Northwest National Laboratory.

[10] Reinhart, C. and Fitz, A., (2006). "Findings from a Survey on the Current Use of Daylight Simulations in Building Design", *Energy and Buildings,* Vol. 38, No. 7, pp. 824-835.

[11] Kohli, V. (2008). "Form Follows the Sun: Hill County SEZ Office Complex", PLEA 2008 – 25th Conference on Passive and Low Energy Architecture, Dublin, Retrieved on 9/2010 from http://www.som.com/resources/content/5/0/4/4/0/7/5/7/documents/SOM.com_FormFollowstheSun1.pdf.

[12] Autodesk, (2010). "Using Autodesk Ecotect Analysis and Building Information Modeling", Retrieved on 9/2010 from http://images.autodesk.com/adsk/files/using_autodesk_ecotect_analysis_and_building_information_modeling_final.pdf.

[13] Haxton, B., (2010). "BIM and Energy Software Analysis: Net-Zero Energy Expert Roundtable II", Hucal, M., ed., Environmental Design+Construction, October, pp. 22-29, Retrieved on 11/2010 from http://digital.bnpmedia.com/publication/?i=48595.

[14] ASHRAE, (2004). Standard 55-2004: Thermal Environmental Conditions for Human Occupancy, Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

[15] CIE, (1995). Discomfort Glare in Interior Lighting, CIE 117 Technical Report, International Commission on Illumination.

02.
EXPLORATION OF COMPLEX CURTAIN WALL SOLUTIONS:
Shanghai Fisherman's Wharf Iconic Tower

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ABSTRACT
This article explores the various curtain wall façade system solutions as developed for the Shanghai Fisherman's Wharf project's iconic skyscraper. The high-rise tower comprises a curvilinear nautical shape, nicknamed "The Fish" and is the main iconic identity of the large-scale mixed-use project. Cladding this morphic building shape involved an intense exploration of 2D and 3D curtain wall façade systems in order to emphasize the overall nautical theme of the project and add visual complexity and unique identity to the project. Exploration relied on investigation of numerous options, aimed to achieve the desired visual impact and evaluated by our technical team and external industry experts.

Curtain wall explorations comprised from relatively simple flat rectilinear 2D solutions to complex 3D projected faceted patterns to form unitized modules arrayed over the curved façade of the high-rise tower. This article explores the visual design, technical complexity, cost implications and constructability issues over the different stages of the project. It covers the curtain wall design process from concept design through construction documents, as it became impacted by City Code constraints and client-driven building program changes.

KEYWORDS: curtain wall systems; 3D facades; faceted geometries; curvilinear facades; unitized curtain wall modules

1.0 INTRODUCTION
Curtain wall systems have evolved dramatically in the past years to more complex and customized solutions, driven in equal parts by design aspirations as well as technical aptitude. Complex building geometries together with market forces and the aesthetic desire for distinguished iconic architecture, merged with the growing technical ability of the construction industry to generate very unique solutions[1]. At the same time, Building Codes, City Ordinances and environmental constraints have become more stringent to address the growing energy use considerations in the performance of building facades, environmental awareness as well as the building's impact within its urban environment, such as light-reflectivity issues.

1.1 The Shanghai Fisherman's Wharf Project
The Shanghai Fisherman's Wharf project is a major new urban development aiming to revitalize a disused industrial portion of the HuangPu riverfront, once a heavily industrialized shipping, commercial and warehouse district. This is part of city wide efforts by the Shanghai municipality to reactivate the river shore, upgrading the flood-zone retaining-walls and providing interconnected public access shoreline developments by linking green-zones and park to the dilapidated industrial riverfront. As part of the winning master-plan competition awarded to us, a high-rise tower was envisioned as part of this development, to anchor the site visually on the riverfront, provide identity to the development and serve as a visual beacon on the skyline of Shanghai.

Figure 1: Perkins+Will winning master plan design.

This winning master plan led to a second stage design also awarded to us, for the first phase of the development. This consisted of a 48,680 square meters (524,000 square feet) site with a mixed-use program of retail, underground-parking, public amenities, public park, shoreline marina, hotel and office spaces. A curvilinear, abstract nautical design theme was set for the entire mixed-use complex anchored by a gracefully shaped skyscraper, 35-stories high and 160-meters (525 feet) tall. The program of the high-rise was set as a high-end office space for the lower half while the upper portion was set as a luxury boutique hotel.

The tower, a streamlined nautical shape, endearingly nicknamed "the Fish" quickly became the architectural challenge for our team. While from the initial competition stage of the design, it was approved and locked into its overall streamlined sculptural shape, finding a suitable curtain wall façade solution was a major challenge. It was important for the project that the tower have a unique skin to add marketing identity and to visually distinguish it from the regular rectilinear façade walls on the skyline. Maintaining the nautical emphasis of the overall shape and adding visual complexity led to multiple explorations of applicable 2D facades all the way to complex 3D faceted pattern systems.

Technical impacts on the curtain wall solutions included wind and earthquake lateral loads, constructability of façade units, patterns limited to unitized façade modules, assembly and installation restrictions, interstory drift as impacted by lateral building movement, integration of venting mechanical floors and mechanical louvers.

An added complexity to the façade was brought on by the client-driven program change of the tower occupancy very late in the design process and after construction started. The major shift in program involving the change of the top half of the building to luxury residential apartments forced dramatic changes to the permit-approved building documents and approved façade. Residential code restrictions and requirements for dedicated balconies, utility balconies, exterior utility pipe requirements and dedicated individual mechanical rooms and venting prompted major changes to the façade design.

On our Shanghai Fisherman's Wharf project, we pursued dozens of options, vetting them for aesthetic implications and technical challenges. The team relied on 3D Studio Max, Rhinoceros (building shape) and AutoCAD as well as physical scale models to study detailed curtain wall systems and their resultant visual impact on the overall skyscraper design.

1.2 Code Constraints

Shanghai's City Code impacts on the curtain wall solutions included city zoning restrictions, environmental building shadow implications over the neighboring residential zone, local ordinance reflectivity restrictions and envelope energy restrictions as relating to the façade glass and insulated wall ratios[2,3].

Local energy codes required incorporating efficient low-e (low emissivity) insulated glass with a stringent solar shading coefficient due to the hot southern climate of Shanghai. At the same time, new zoning restrictions limited the outbound reflectivity ratio of the glass to under 15 percent due to urban light-pollution concerns, thus limiting our range of low-e glass we could use. Fire Code required the façade to have a 800mm (31.5 inches) solid-wall separation between floors, which we could either accommodate by aluminum panel cladding or an insulated shadow-box spandrel. Shanghai Code restrictions of 70 percent vision glass to a 30 percent insulated solid wall ratio, interpreted as glass shadow-box spandrels in our case, had to be implemented. In the permit phase, additional zoning constraints of limiting the percentage of façade reflection (determined by surface ratio of glass area) towards the northern residential district forced inclusions of opaque aluminum panels onto the façade module. New code restrictions also required natural ventilation options to the office floors as well as ability to naturally flush out the entire floor-plates in case of air contamination.

1.3 Tower Geometry and Program

The streamline shape of the tower consists of a simple two dimensional extruded curve, trimmed in a gently curved dynamic oblong form. The shape is oriented north-south, with the flat side oriented south and the long sides facing east and west making use of the views up and down the HuangPu river and the dramatic new city skyline of the PuDong district. To the north is an older existing residential district tightly packed with low-rise and mid-rise apartment blocks. Zoning Code restricted the amount of shade that the tower could cast over the neighborhood, so as not to deprive the residential units of minimum sunlight requirements. The shape and height of the tower had to be adjusted numerous times as part of the zoning permit process as zoning impact and sun-shadow studies were developed, thus reducing the overall tower to its present 160m (525 feet) height. The south facing façade was densely screened for solar shading.

The tower was initially programmed to have 14 floors of office space, with a 4.3 meter (14.1 feet) floor-to-floor span. The upper portion of the building was to have 16 floors of luxury hotel, with a 3.6 meter (11.8 feet) floor-to-floor span. Auxiliary floors included hotel conference and meeting room floors, mechanical, hotel sky-lobby and a sky-bar restaurant level at the top. A large 16-story atrium organized the hotel rooms on the southern face, highlighting views to the south towards the river. In a later phase, with the concrete foundation already poured and extensive negotiations on building permits completed, the client revised the program to luxury residential apartments at the upper half and moved the hotel to the lower half. At publication of this article, permit documents for the new program and new façade are still being reviewed with the City Permit department, and pending re-approval.

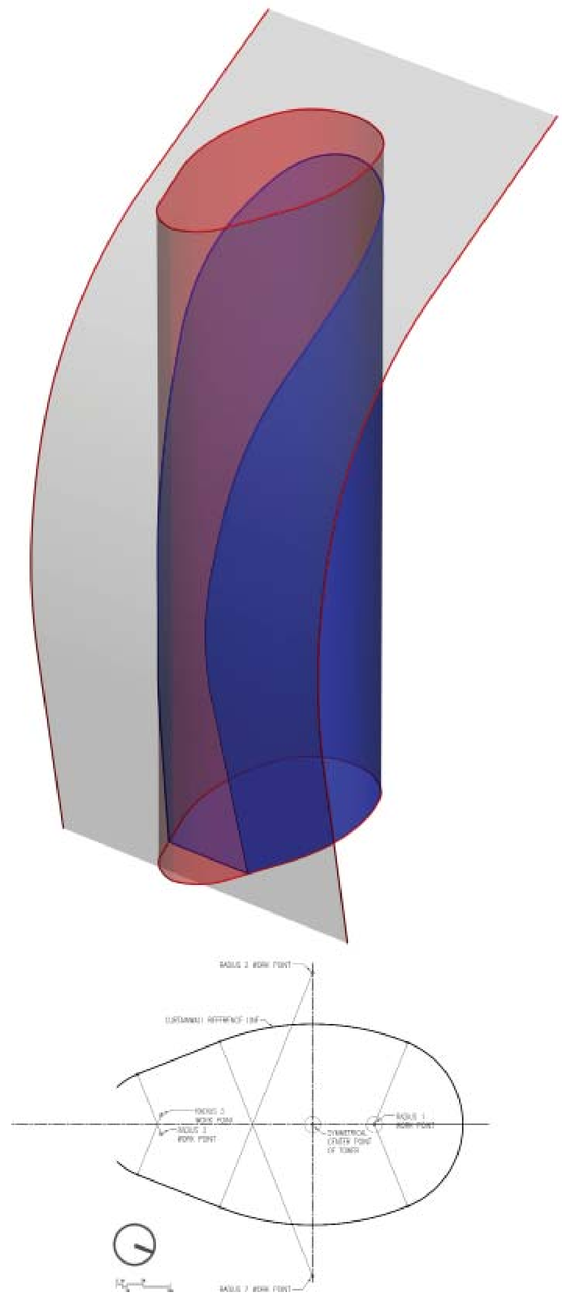

Figure 2: Tower geometry.

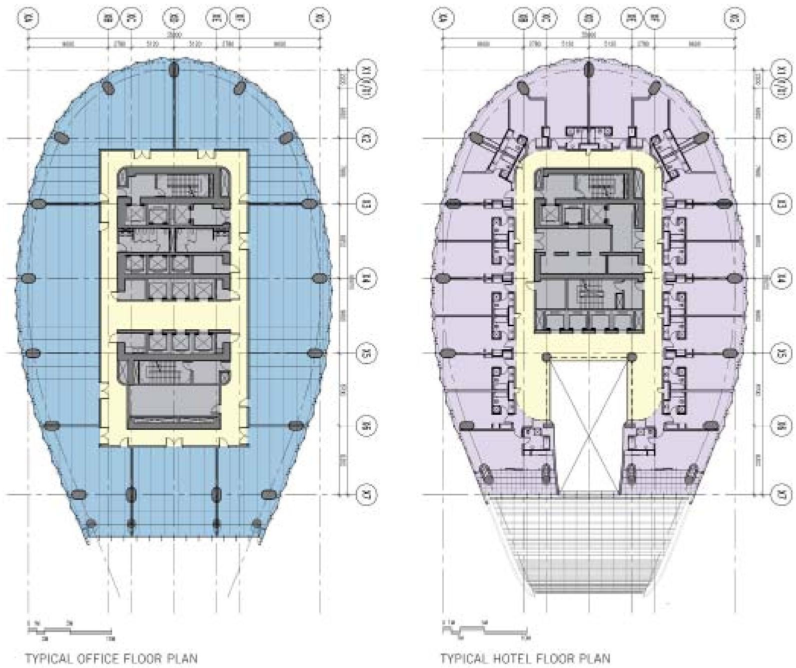

Figure 3: Tower floor-plans: a) Office b) Hotel.

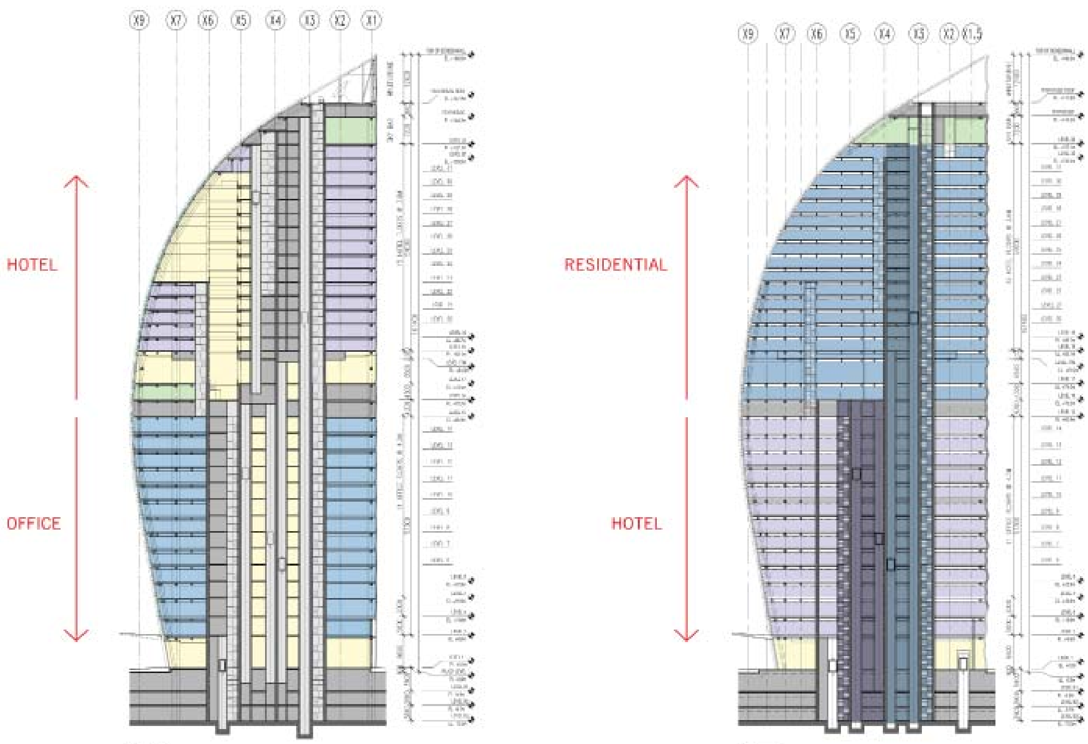

Figure 4: Building Section diagrams a) Original program; b) Revised program.

2.0 CURTAIN WALL SYSTEMS: FLAT 2D AND PROJECTED 3D SCENARIOS

From the competition phase, the tower was defined as glassy and modern with a strong unique pattern to add visual identity. A decision to stay with unitized curtain wall solutions was important to control construction quality and maintain a high-end appearance on the tower facades[4]. Double-façade systems were avoided from the onset as too expensive for the project scope as well as code restrictions on the amount of vision-glass allowed.

For manufacturing efficiency and to limit the variations in the unitized curtain wall modules, all solutions were limited to uniformly sized flat pieces of glass and straight aluminum mullions. The module was composed of 1500mm (5 foot) wide units that were equally spaced arrayed along the curved perimeter of the façade. The curvature of the façade was resolved by slightly splaying the unitized mullions at the vertical interlocking joints.

Our explorations of curtain wall façade possibilities can be broken down into two major groups, flat 2D and projected 3D modules. While flat 2D curtain wall modules are simple technical solutions, finding a visually complex pattern suitable for the building shape was a design challenge. However, projected 3D facades add a technical complexity when applied to a high-rise building, where performance issues become critical[5]. In addition, due to the folding curvilinear shape of the tower, the projected 3D forms of the curtain-wall would have to resolve themselves back to flat 2D profiles at the cantilevered building edges in progressive graduated steps.

Six different façade options are presented in this paper as broad examples of the numerous curtain wall options studied as iconic skins for the skyscraper. Three versions of flat 2D and three versions of projected 3D facades are shown. At the time of publication of this article, two separate options are pursued by the client and negotiated with the City Permitting department including one 2D façade and one 3D façade option.

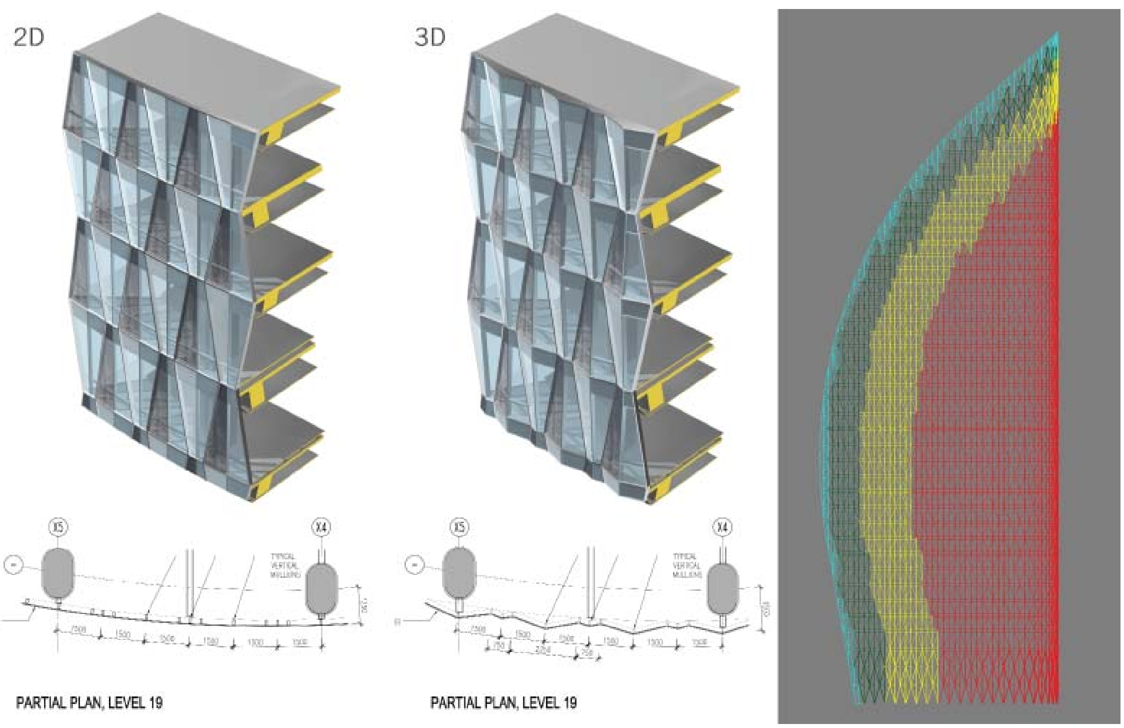

Figure 5: a) Flat 2D curtain wall; b) Projected 3D curtain wall; c) Gradated projection of 3D facade.

2.1 2D Curtain Wall: Rectangular Option

The most straight forward application of a flat 2D curtain wall module is in a typical rectangular arrangement of glass and aluminum profiles. Our "Rectangular Option" explored a very flat skin effect, stretched over the curvilinear form of the tower. Solid aluminum panels were used to create a visually random looking pattern on the façade, to add aesthetic interest and to resolve City Code requirements. This scheme was intended to work equally well in an office program as well as a hotel program. It also translated well into residential program requirements. A major drawback was the lack of grand panoramic views from inside the building due to the very fragmented mix of opaque and vision panels.

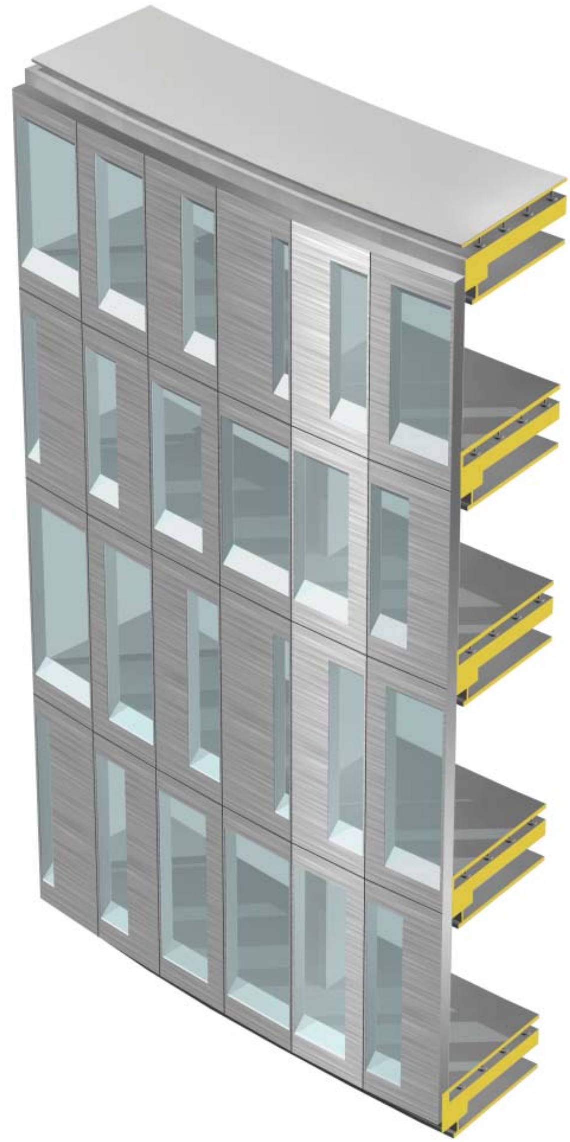

Figure 6: Flat 2D façade; Rectangular curtain wall option.

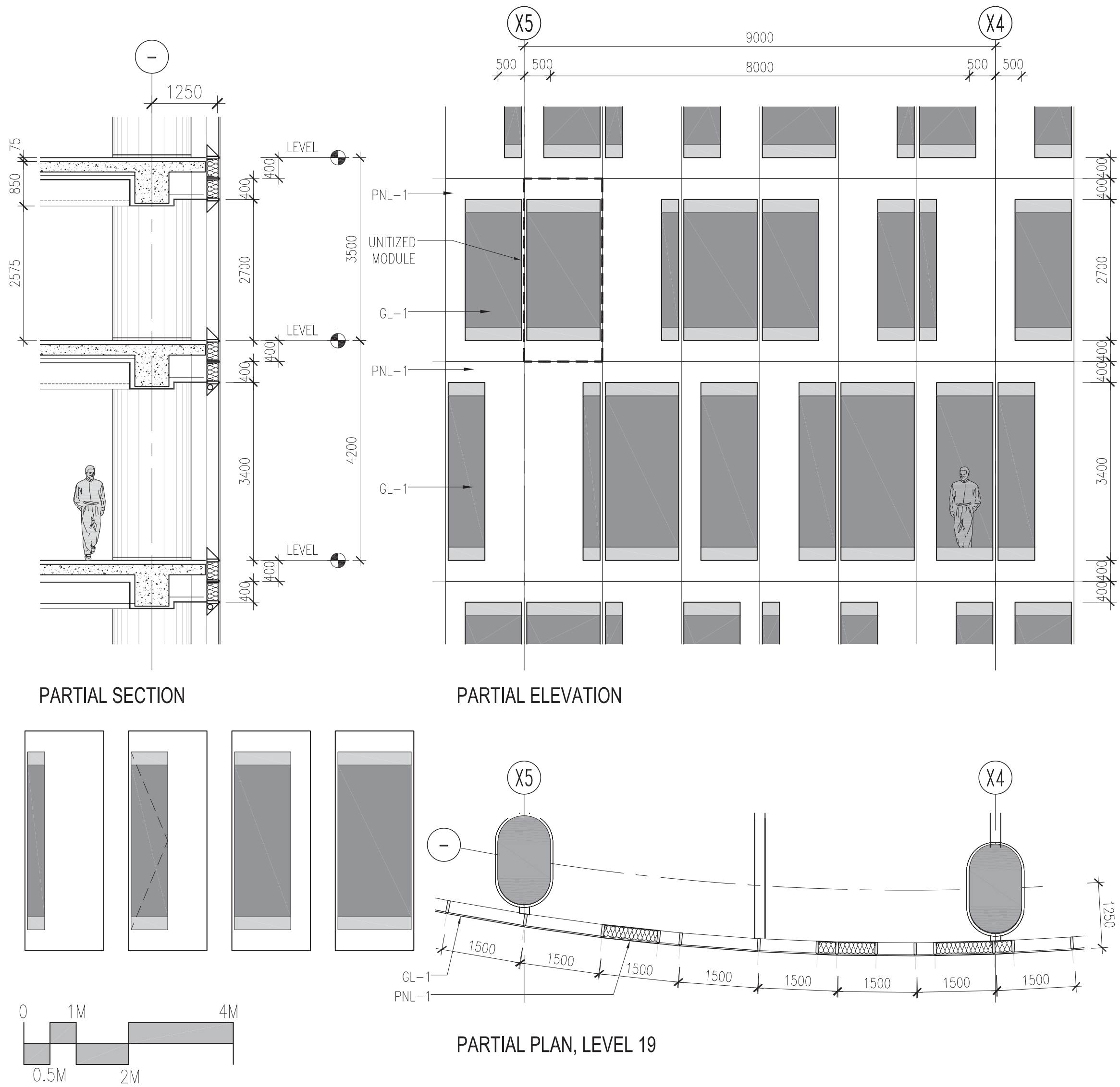

Figure 7: Flat 2D façade; Rectangular curtain wall option.

2.2 2D Curtain Wall: Oval Option

One way to express the individual units that make up the hotel and residential programs of the tower was through emphasizing the repeating nine meter (29.5 feet) structural bay module. In this option, we chose an oval pill-shaped, punched-window pattern within the aluminum panel skin to express the modularity of the program and maintain an abstract nautical expression for the tower. Incorporating recessed balconies and mechanical louvers were also easy to achieve in this scheme due to the powerful visual pattern. The city code requirements for the façade performance were also easily resolved in this scheme.

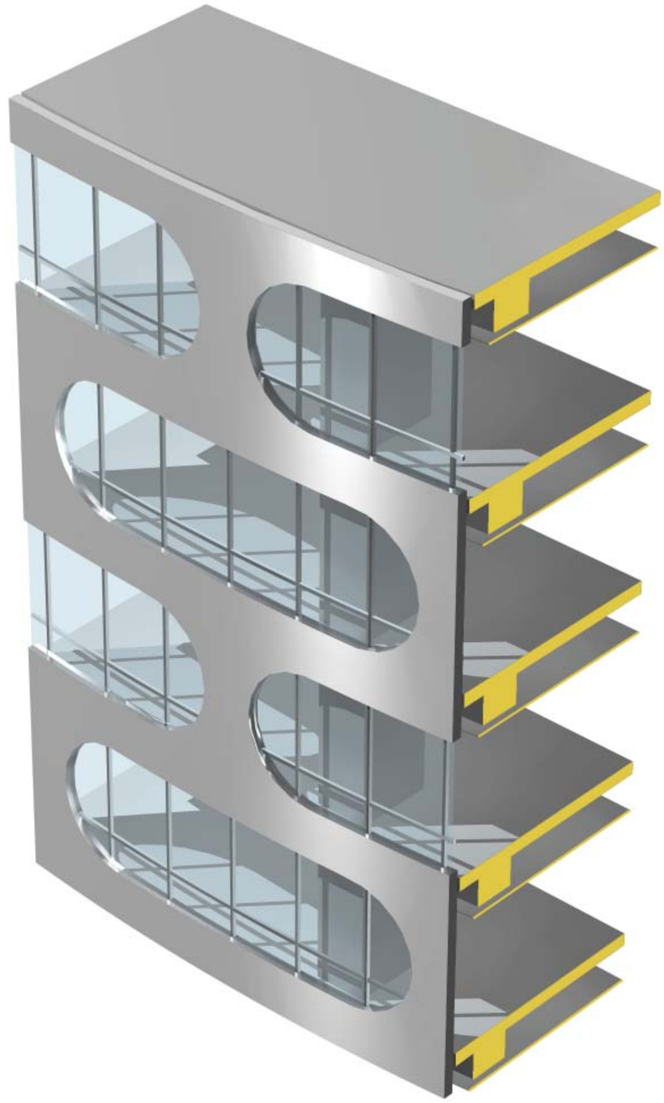

Figure 8: Flat 2D façade; Oval curtain wall option.

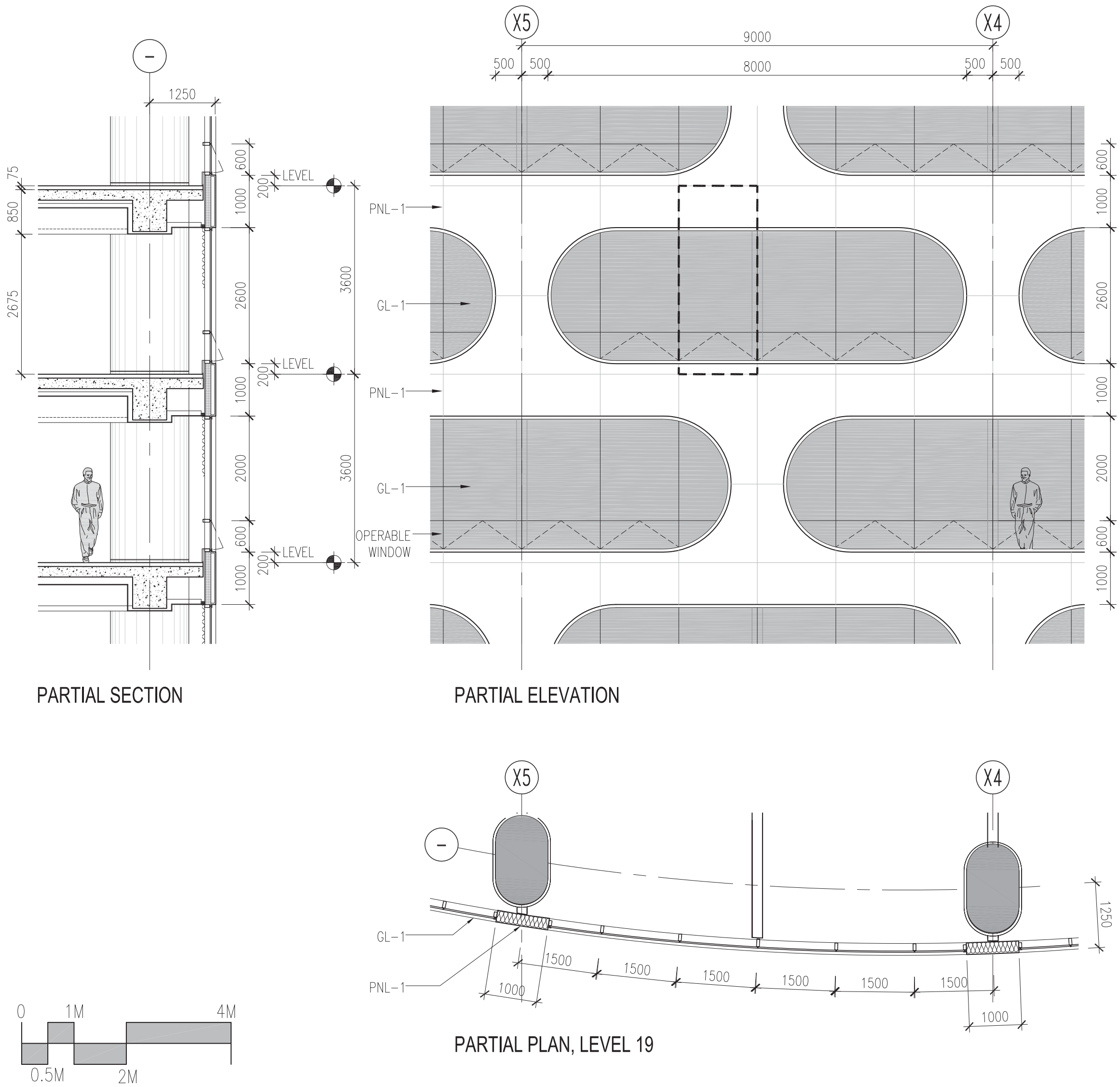

Figure 9: Flat 2D façade; Oval curtain wall option.

2.3 2D Curtain Wall: Linear Ribbon

Incorporating strong linear patterns through the use of ribbon windows within the aluminum panel skin worked very well with the curvilinear shape of the tower to accentuate its form. It added a dynamic and abstract nautical expression with minimal technical complexity. Window sizes of the stripes were varied to comply with Shanghai zoning code by reducing building glass reflectivity to the northside residential neighborhood as well as to add variety to the façade. This option also allowed easy inclusion of recessed balconies and mechanical louvers without taking away from the overall streamline shape of the tower. While this facade could be built in a simple stick-system, to maintain quality, our team and external curtain wall experts agreed that this should be looked at as a unitized curtain wall system. For technical simplicity, lower cost basis, building-program flexibility and visual aesthetics this curtain wall option was a favorite with the Client and is one of two schemes to make it to city permitting and contractor bidding phase.

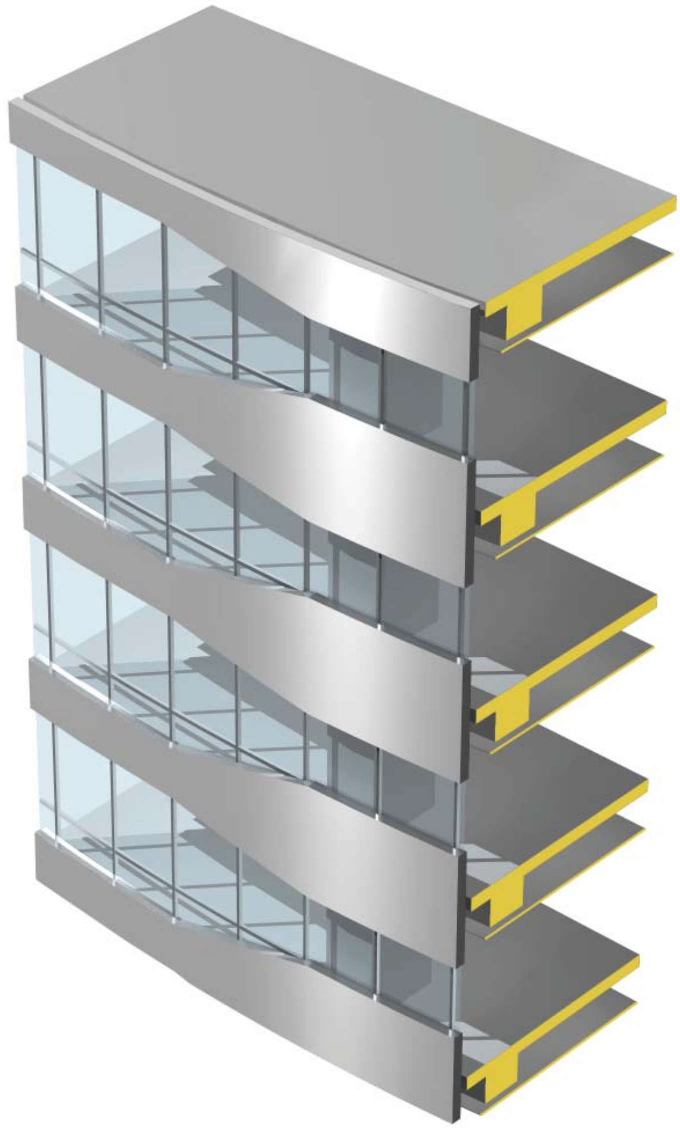

Figure 10: Flat 2D façade; Linear ribbon window option.

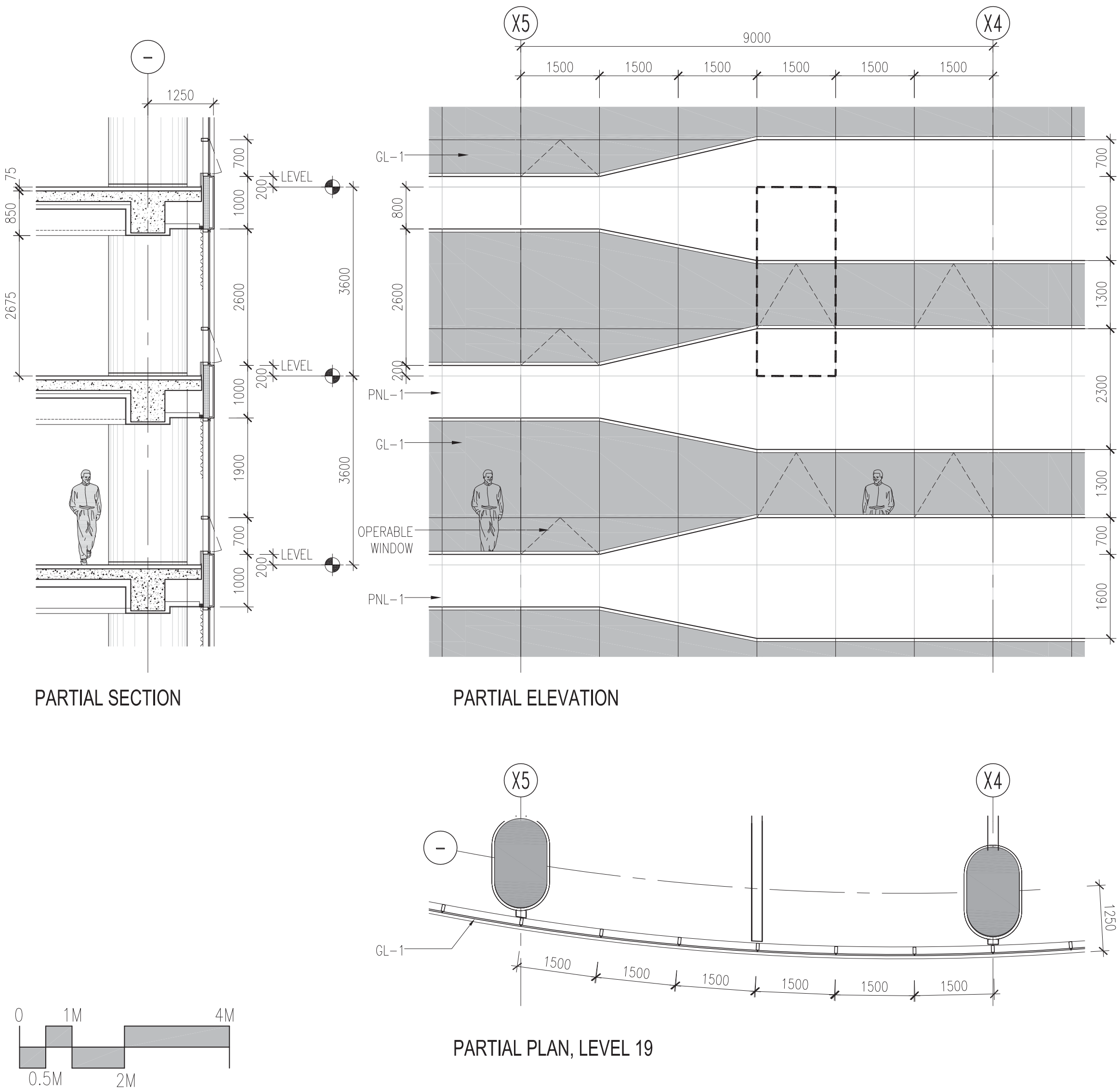

Figure 11: Flat 2D façade; Linear ribbon window option.

2.4 3D Curtain Wall: Shingles Option

Numerous 3D projected curtain wall options were explored to add visual complexity to the façade. A simple rectilinear glass and aluminum curtain wall system was used to explore 3D options by tilting and slightly overlapping the units. Operable louvers were incorporated in the concealed nested overlap to provide code-required natural ventilation. However, getting this glassy scheme to comply with Shanghai code requirements for opaque walls and limitations on glass area would have required substantial changes. Additions of solid panels and shadow-box spandrels would easily compromise the skin appearance.

Figure 12: Projected 3D curtain wall; Shingles option.

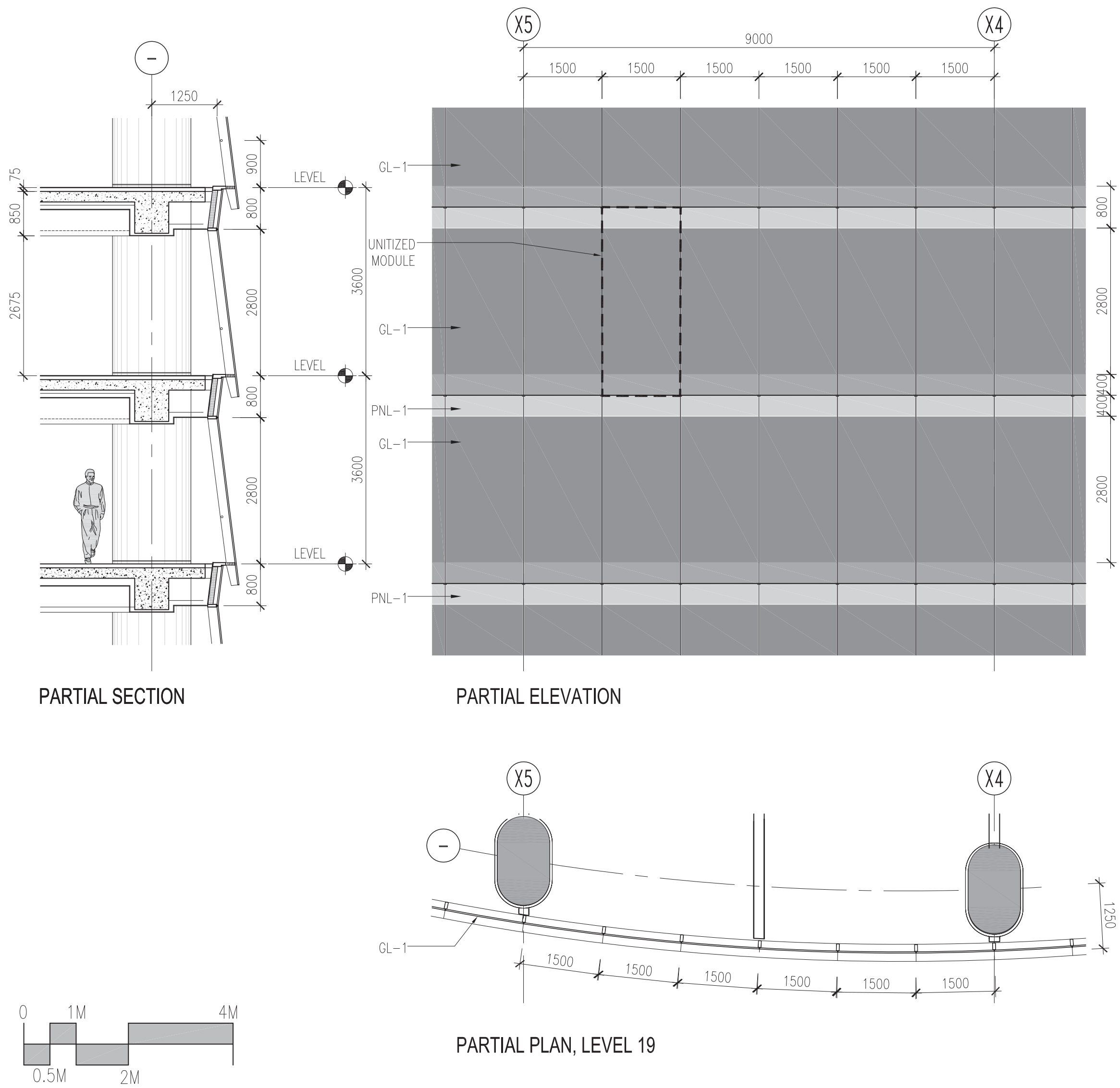

Figure 13: Projected 3D curtain wall; Shingles option.

2.5 3D Curtain Wall: Fish Scales Option

A much more complex curtain wall was to triangularize the façade and stagger the 3D projections so as to achieve a fish scale pattern. Solid panels and translucent fritted glass were intermixed with clear vision panels to further accentuate the shimmering pattern and comply with code restrictions. To resolve this façade required unitized curtain wall module solutions. Obvious technical difficulties in trying to resolve this option included the fabrication of the sharp triangular shapes of glass and structural mullions connecting at very acute angles. Structural curtain wall complications were also emphasized by the resulting staggered saw-tooth profile at the slab-edge, thus incurring lateral inter-story drift stresses. In high wind and earthquake conditions, as the building sways sideways, the floor-plates would drift slightly from vertical taking the curtain wall with it[6,7,8]. The saw-tooth plan-profile at the slab-edge would make the curtain wall resist such linear side movement (lateral drift), thus causing the curtain wall to fail. Special mullion detail connection at the sill would be required to allow for this lateral-drift movement.

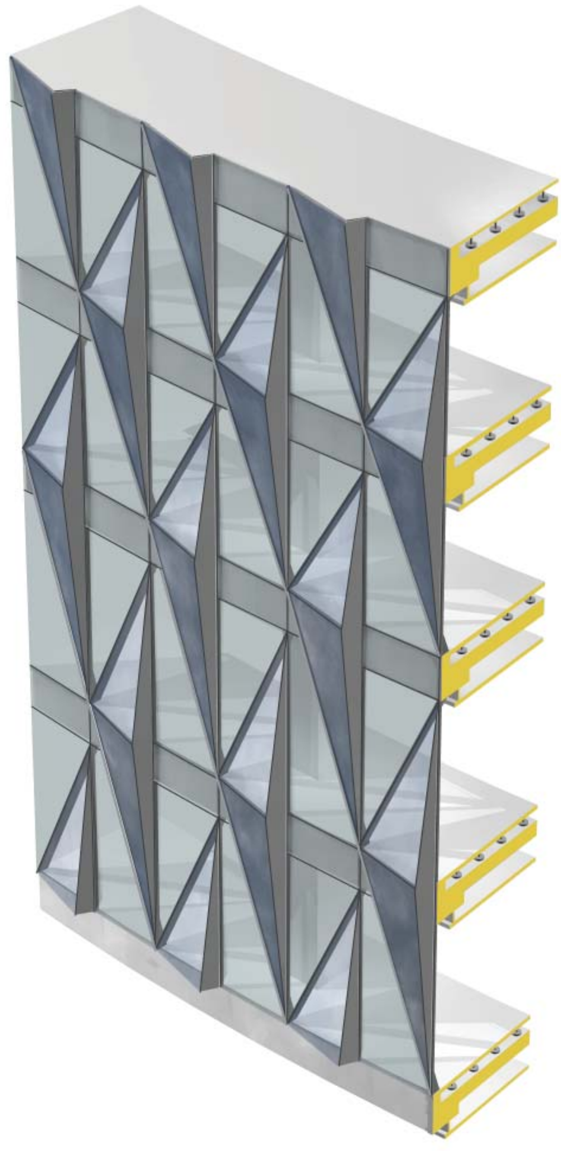

Figure 14: Projected 3D curtain wall: Fish scales option.

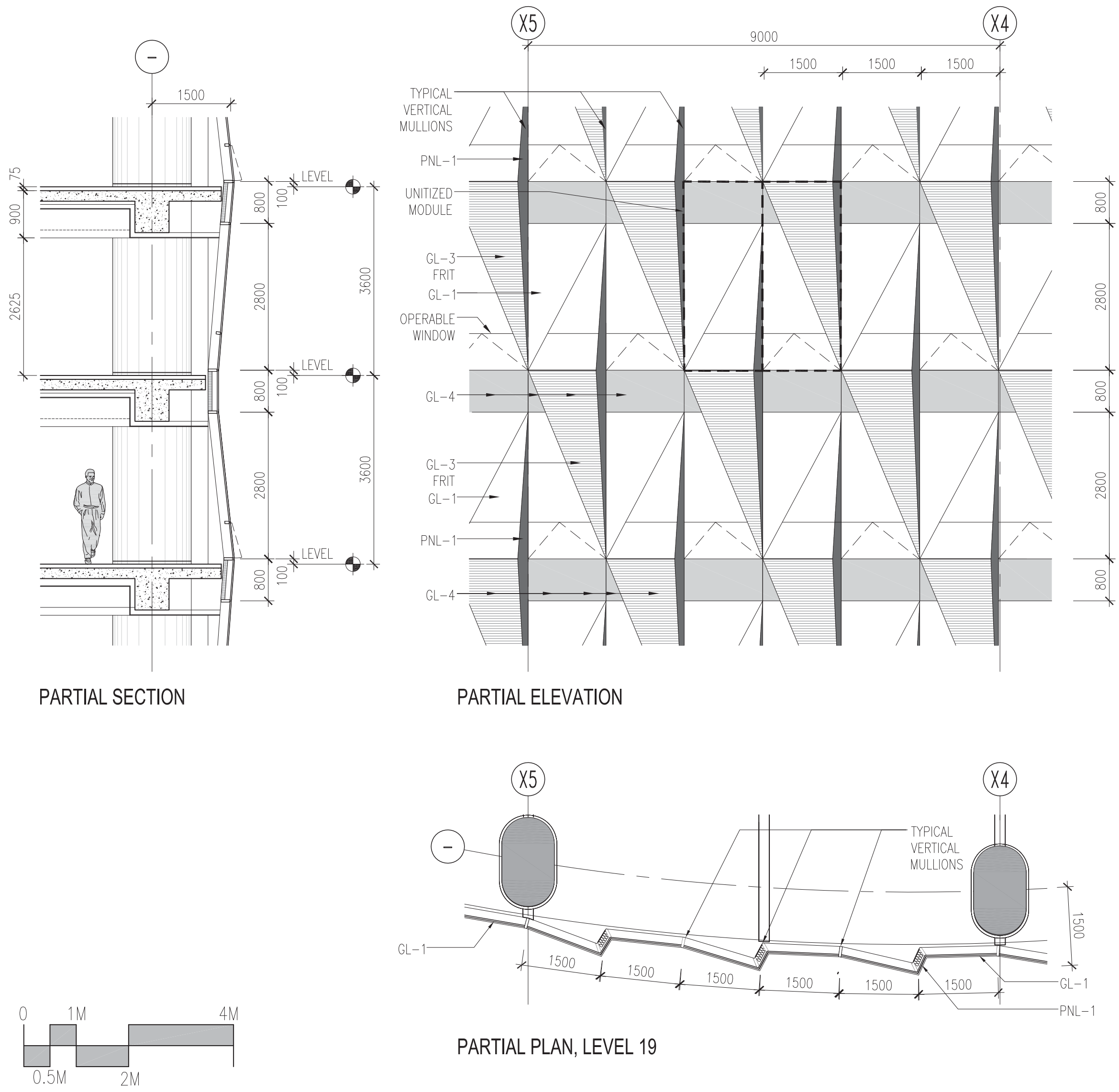

Figure 15: Projected 3D curtain wall: Fish scales option.

2.6 3D Curtain Wall: Faceted Diamond

A natural evolution of the “Fish Scale” façade option was to simplify the geometry and eliminate the sharp corners in the glass modules. To keep the flat faceted glass pieces from needing to warp, the sides of the triangular plan profiles had to be parallel. Three glass types were envisioned to accentuate the triangularized shimmer façade, one with translucent ceramic frit pattern and one with a low-e coating having a high outer reflectivity ratio to the typical tower low-e glass. In the city permitting stage of approval, the fritted glass pane had to be replaced by a solid insulated aluminum panel to pass local zoning requirements restricting outer façade reflectivity. While the saw-tooth plan layout of the sill-mullion would incur lateral inter-story drift stresses, the curtain wall engineers felt confident that they could resolve this in customizing profile details of the sill mullions.

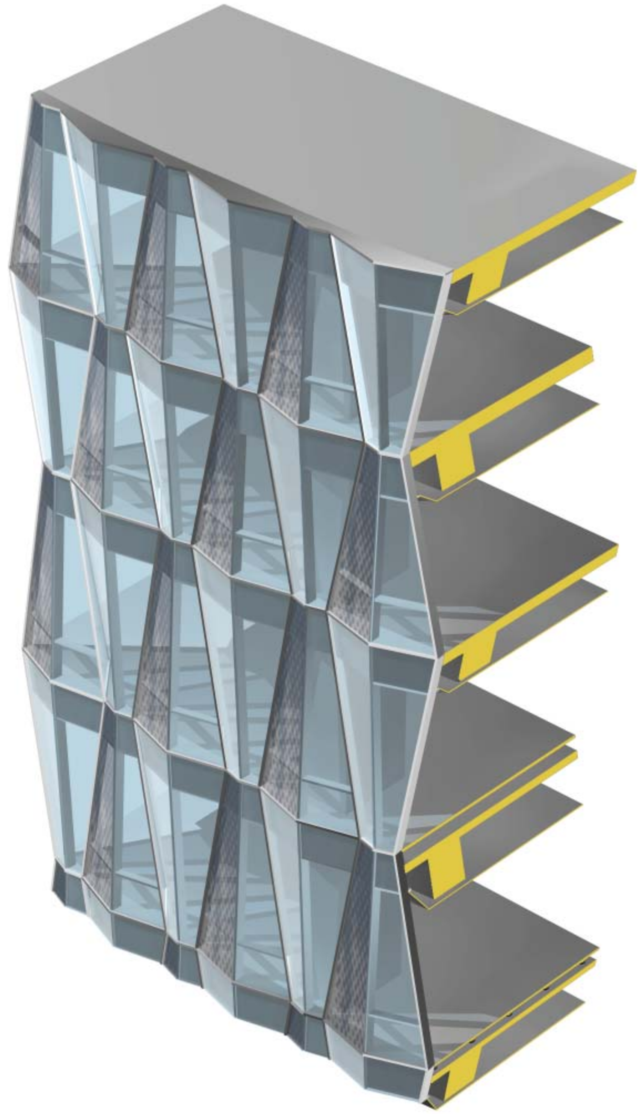

Figure 16: Projected 3D curtain wall: Faceted diamond option.

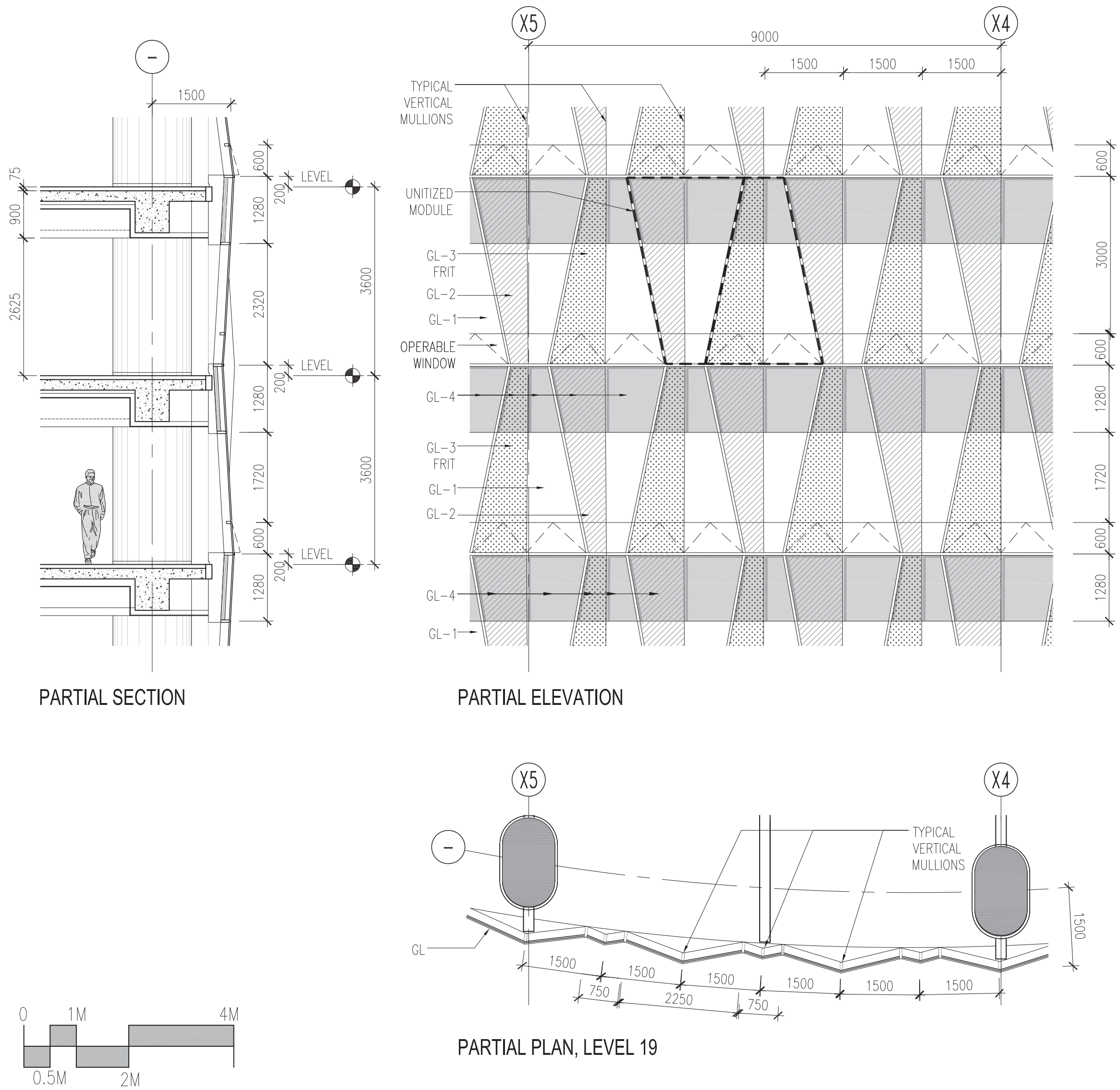

Figure 17: Projected 3D curtain wall: Faceted diamond option.

This scheme was the preferred curtain wall option by our client, infusing a visual complexity and uniqueness to the façade that would distinguish the tower on the Shanghai skyline while technically feasible in the local Chinese curtain wall construction market. Sustained dialogue with local curtain wall fabricators made this option realistically buildable for the client and their construction consultants. The cost implications of this curtain wall option, while not shared with our architectural team, was within acceptable range for the client.

However, changing the building program from office/hotel to a hotel/residential mix made this particular curtain wall option difficult to resolve and expensive to justify. A flattened 2D version of this scheme, which was previously explored but abandoned, quickly became much more financially desirable. As a residential façade, inclusions of recessed balconies and mechanical louvers were fairly easy to incorporate due to the faceted nature of the façade.

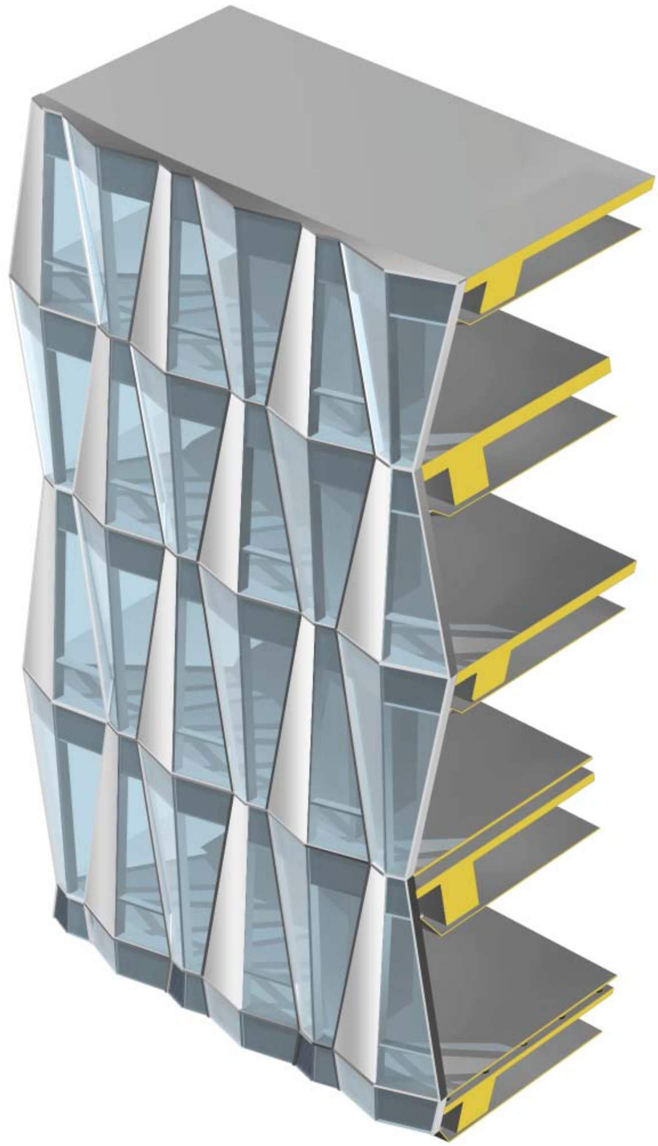

Figure 18: Inclusion of aluminum panels in building facade.

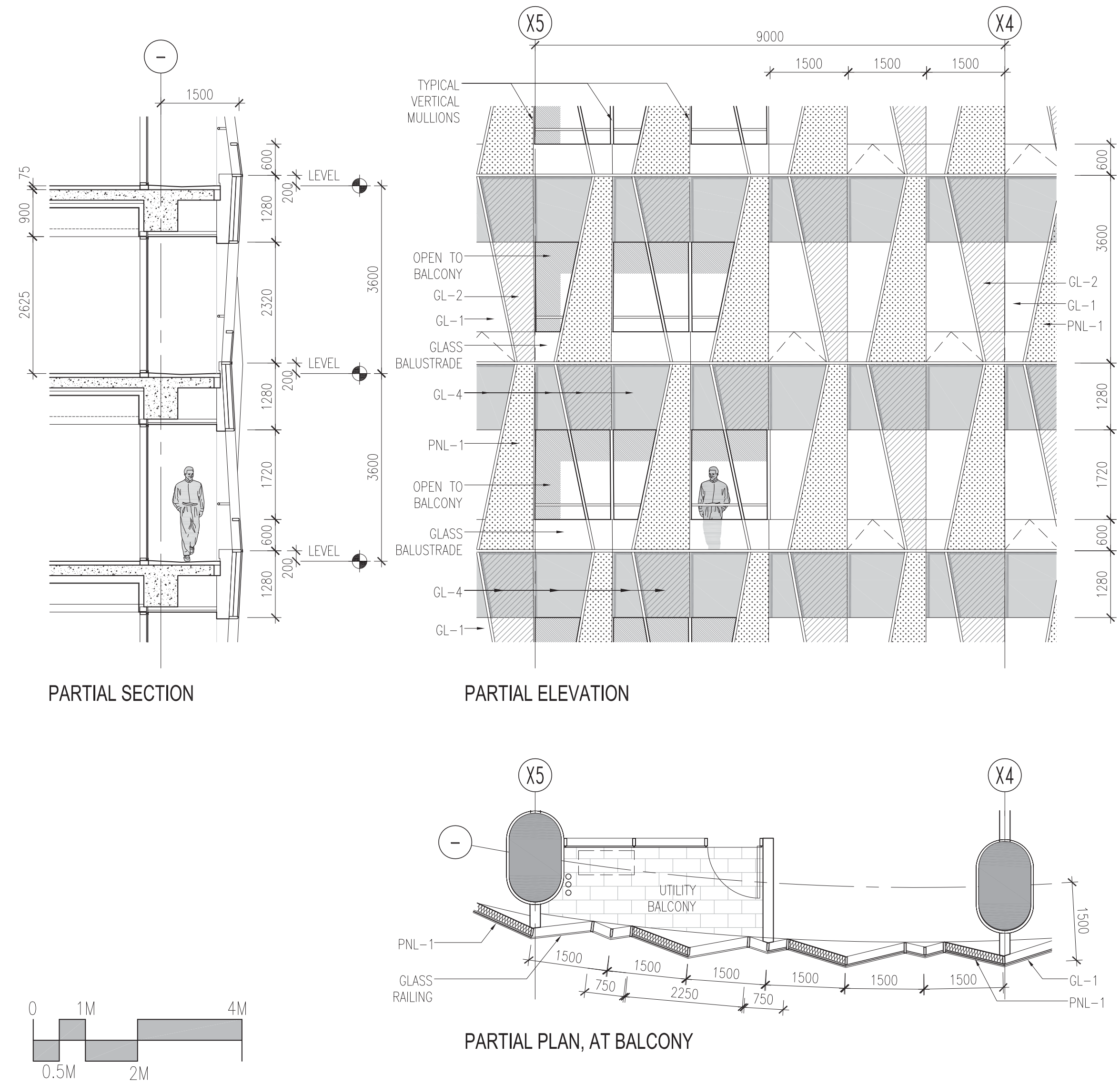

Figure 19: Inclusion of recessed balconies into facade.

2.6.1 Flattened 2D Diamond Pattern

As a fall-back to the client's preferred 3D projected faceted diamond curtain wall, we also had to develop a flattened 2D version of it. Overall, the visual impact could be similar, though without the 3D angled layout of the glass planes, the shimmering effect of the façade would not be achievable. Still, the much simplified technical resolution and detailing of this scheme was an attractive backup solution to the 3D façade option. This option became even more desirable once the tower program was revised to include residential apartments. Façade materials stayed the same as in the 3D version, relying on the faceted geometry of glass and aluminum panel layout to form the desired pattern. The unitized curtain wall module gets simplified to a regular rectangular unit. Without the projected 3D geometry, the sill and head "tongue and groove" nesting of the unitized modules was vastly simplified both structurally as well as in performance requirements. Inclusions of recessed balconies and mechanical louvers in this scheme would be the same as in the 3D option.

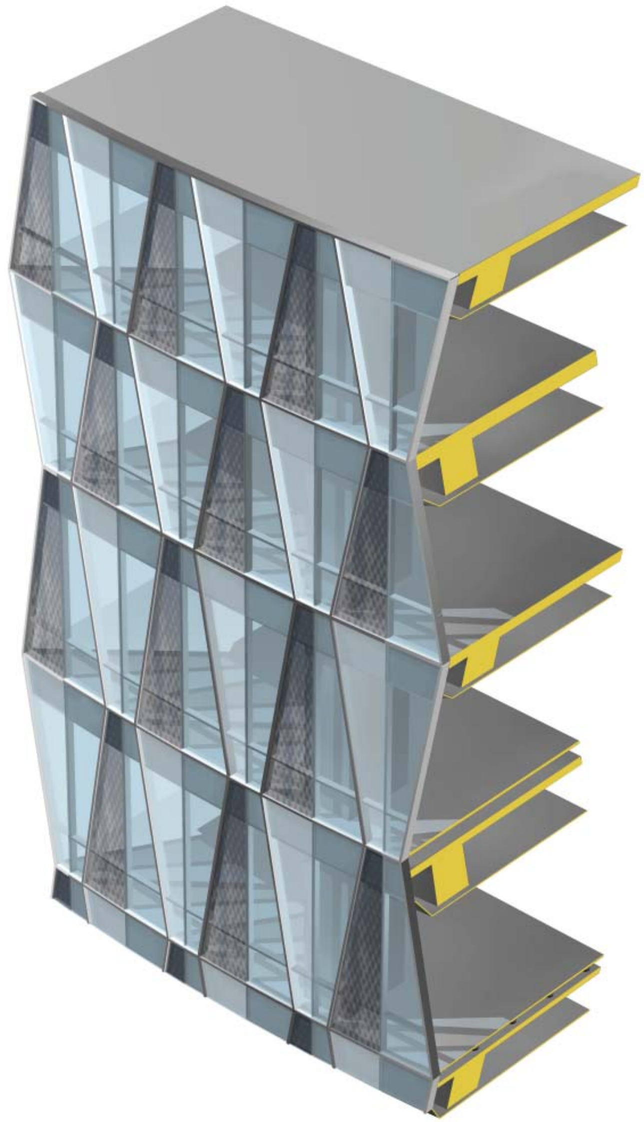

Figure 20: Flattened 2D curtain wall version of the faceted diamond option.

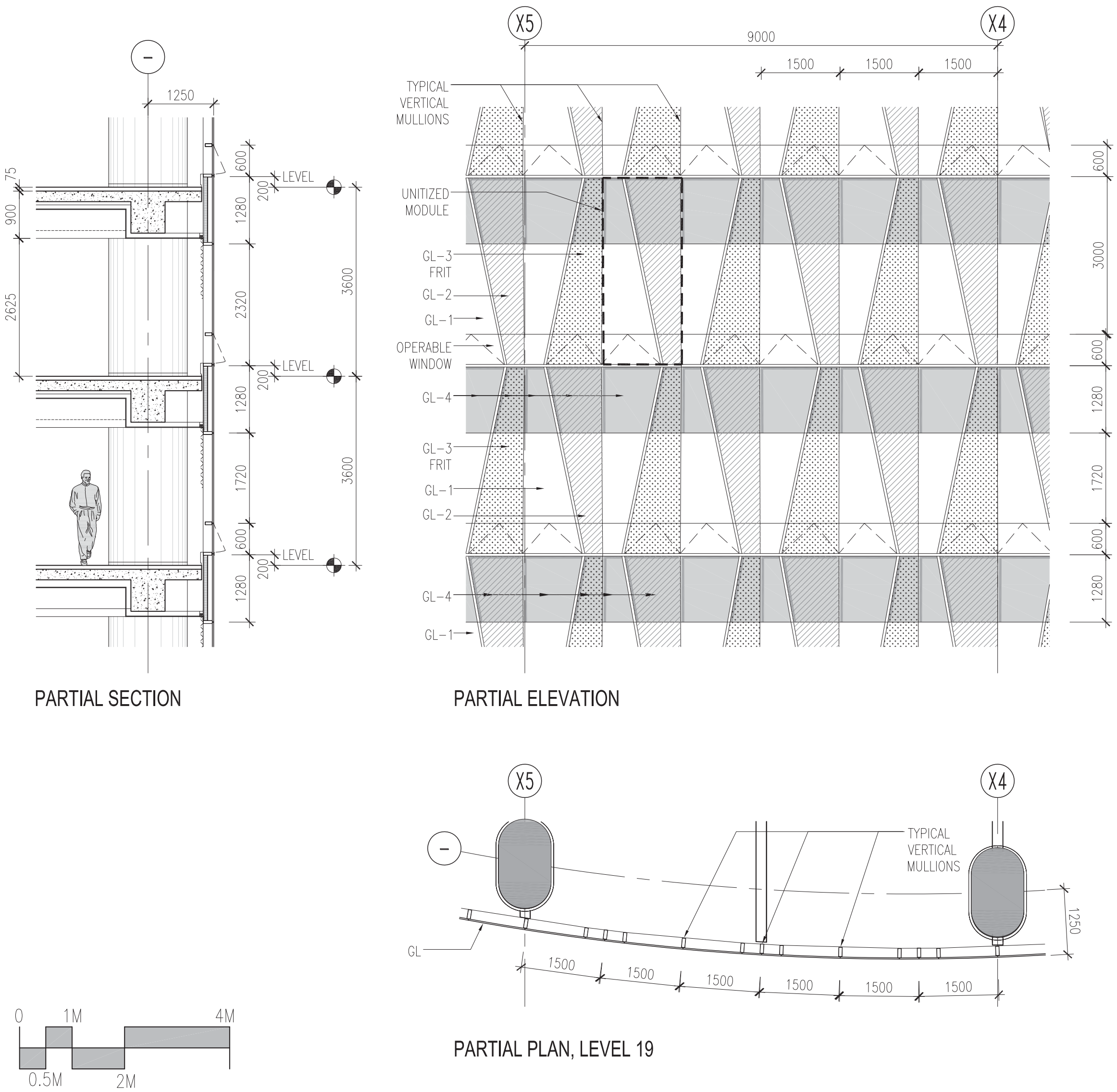

Figure 21: Flattened 2D curtain wall version of the faceted diamond option.

Figure 22: Developed first-phase design; Mixed-use site.

3.0 CONCLUSION

Creating unique curtain wall facades on a high-rise building requires constant dialogue between design aesthetics and technical solutions with heavy reliance on feedback from the curtain wall fabricators and engineers. In addition, solid and timely feedback on code interpretations is crucial, especially when designing in foreign countries and in sensitive urban environments such as the Shanghai Fisherman's Wharf site. Explorations of 3D projected facades need to be grounded in solid technical solutions particularly when dealing with the stringent envelope performance and structural requirements in tall buildings.

There are reasons why high-rise curtain walls tend to be built the way they are, thus any innovations need to look at the resulting technical and fabrication implications. Intricacies in the envelope system module, that seem easy to overcome on low-rise buildings, quickly become major issues on a skyscraper and even more so when the tower is already a complex 3D shape. Fabrication methods and ease of standardizing the façade module can have a serious impact on construction time and costs.

On our particular project, the most difficult and time consuming portion was in making alterations that would address particular code, zoning and ordinance restrictions. Permit approvals was a very drawn out process with constant options and sub-options needing quick architectural studies. Navigating complex codes written to address environmental impacts of previous generations of buildings needed constant negotiations to understand how they would impact our particular unique project. Major obstacles in our case were overcoming solar sun-shadow studies, glass reflectivity issues and resulting building reflectivity onto the residential neighborhood.

ACKNOWLEDGMENTS

Tower curtain wall team: Ralph Johnson, Carl Knutson, Marius Ronnett, Joachim Schuessler, Abul Abdullah, Ian Bush, Hemant Thombre, Jason Flores, Max Adams and Brad Lightner.

REFERENCES

[1] Murray, S., (2009). *Contemporary Curtain Wall Architecture*, New York, NY: Princeton Architectural Press.

[2] (2007). *National Code: Curtain Wall for Building*, Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD).

[3] (2003). *National Code: Technical Code for Glass Curtain Wall Engineering*, Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD).

[4] Vigener, N., and Brown, M., (2010). "Building Envelope Design Guide: Curtain Walls", Whole Building Design Guide, Retrieved on 09/2010 from http://www.wbdg.org/design/env_fenestration_cw.php.

[5] AAMA, (2005). Curtain Wall Design Guide Manual, AAMA CW-DG-1-96, Springfield, IL: American Architectural Manufacturers Association.

[6] AAMA, (2009). Recommended Static Test Method for Evaluating Curtain Wall and Storefront Systems Subjected to Seismic and Wind Induced Interstory Drifts, AAMA 501.4, Springfield, IL: American Architectural Manufacturers Association.

[7] Brenden, K., (2006). "Dynamic Issues Drive Curtain Wall Design", *STRUCTURE*, August, pp. 50-52.

[8] Kazmierczak, K., (2010). "Review of Curtain Walls, Focusing on Design Problems and Solutions", *BEST2 Conference,* Portland.

03.
STUDENTS OF TODAY AND TOMORROW:
Discovering How and Where They Learn Best

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ABSTRACT
This article explores various educational theories, research and factors that can be correlated to or have an impact on the physical spaces in which learning takes place. As school design and planning becomes more in tune with the influences that affect education, the connection between physical space and the learning process becomes more relevant. Drawing from sources such as recognized research on student learning habits and styles as well as our own research regarding student social behavior and engagement we can begin to propose concepts and design solutions that may help achieve the goals of education and most importantly, the goals of the student.

KEYWORDS: engagement, relevancy, involvement, technology, transferable

1.0 INTRODUCTION
"Schools cling more and more stubbornly to their mistaken idea that education and teaching are industrial processes, to be designed and planned from above… and then imposed on passive teachers and their even more passive students."

John Holt[1].

Holt's statement above summarizes the educational delivery model for American schools over the past fifty years. Education was distributed and measured in the same manner of our industrial economy in the post World War II era. Educational theory and practice has since evolved and there are numerous approaches to student learning that were not part of the educational discussion fifty years ago. Is it possible to make correlations between the new educational models and the spaces in which learning is taking place? For architects and school designers, it is important to make this correlation. By highlighting a select number of educational principles and examining the goals of these principles, we can begin to propose designs that are responsive and informed by the educational process.

Holt commented on relationships between education and architectural spaces, "*When we better understand the ways, conditions and spirit in which children do their best learning and are able to make school into a place where they can use and improve the style of thinking and learning natural to them, we may be able to prevent much of the failure… that takes place in school*"[1].

This article discusses a comparative analysis of learning styles and learning spaces. Perkins+Will embarked upon a survey-based research project entitled "The High School Project", which was intended to gather feedback and comments from high school students across the country. It was decided that a focused study of student life would potentially provide evidence about how schools function and how students function within them. One of the primary goals of the High School Project is to determine, through various survey questions, which environments students find most engaging and why. The preliminary results of this survey have proven to be very valuable. The content of the student responses reflected many or our predictions about how the physical environment affects the student experience and provided insight into the specifics of how students are using technology in today's learning environment. This research project sought to measure student engagement, which is one of the most important aspects in education. Many of the questions sought to reveal something definitive about physical spaces that foster engagement. How can we, as architects, take this information and plan our new schools around these engaging spaces?

2.0 MULTIPLE INTELLIGENCES: AN OVERVIEW
There are libraries filled with books and studies on child psychology, educational trends and other topics related to education and learning. Each author or group of re-

searchers have their own perspective on the issues and propose a solution to a problem, an analysis or a new concept. Among all of these publications, there exists a shared fundamental idea that children are naturally very good learners. Whether it is children's limitless curiosity, innate resilience or inexhaustible resourcefulness, children's natural ability to learn and learn in many ways should be the dominant factor in education.

As described in the previous section, the schools and educational concepts during the 1950's and 1960's were designed, built and functioned in ways that ran counter to the notion that children learn naturally and each in their different ways. A school comprised of floors of identical corridors that lead to blocks of identical classrooms does not foster or support the varied learning styles of children.

The ways in which children learn has been well documented and serves as a critical component to the school design and planning process. A fresh idea in educational theory appeared in the mid 1980's with Gardner's publication of his book, *Frames of Mind*[2]. In this book Gardner identified eight multiple intelligences that unlike traditional educational theory, places a value on the numerous ways in which students learn. Each student sees the world in a different way and educational methods must respond to these various intelligences if they are to be successful. "The capacity to think intelligently is very different from knowing lots of information. ... And here at last is where our multiple intelligences can make their contribution ... Instead we can learn about it in many different ways using our multiple intelligences and that concept or topic is much more likely to remain with us … and to be usable in flexible and innovative ways"[2]. This book and the core ideas behind Multiple Intelligence (MI) theory began the movement towards student-centered education.

A common misconception about MI theory is that certain people only possess some of the intelligences and not others or that every person has a dominant intelligence. Gardner is clear to point out that this is not the case. Most people often display some level of aptitude in all of the intelligences and a strong aptitude in a single intelligence type may never develop.

The list of Gardner's multiple intelligences is as follows:

1. Linguistic
2. Logical-Mathematical
3. Spatial
4. Intrapersonal
5. Interpersonal
6. Bodily-Kinesthetic
7. Musical
8. Naturalistic (added in the mid-1990's).

2.1 Learning Styles: Ways and Means of Interacting

Gardner's multiple intelligences have also been defined as learning styles, referring to the way someone acquires knowledge. It is not focused solely on what is learned, but how something is learned. Learning styles are as much about interacting with the world as they are the content of the interaction. Although we may be capable of using all of the learning styles, most of us rely on only one or two. As a result, we develop a specific approach to learning based on our preferred learning styles. The list is as follows:

1. *Linguistic Learners* have a unique relationship to language, either in written or spoken form. Their ideal vehicle for learning is reading, storytelling, abstract thinking, etc.
2. *Logical-Mathematical Learners* perform best when logic and reason are used to interact with the educational process. Making observations, analysis, hypothesizing and making judgments based on information is their strength.
3. *Spatial Learners* prefer visual clues and imagery to handle information. Painting, drawing and sculpture are various means of acquiring knowledge and providing an expression for the spatial learner.
4. *Intrapersonal Learners* thrive in situations and conditions where they are required to self-reflect. Well developed reasoning skills and a heightened awareness of emotions are the strength of this learning style.
5. *Interpersonal Learners* are the opposite of the intrapersonal. These learners thrive in groups and when communicating with others. They have a well defined sense of others' feelings and perspectives and therefore thrive in the open group environment.
6. *Bodily-Kinesthetic Learners* find learning through physical movement as the most natural way to acquire knowledge. The movement of the body and exercise allows these learners to understand situations and their responses are most clearly expressed through their own movement.
7. *Musical Learners* have the inherit ability to recognize rhythm and tone, patterns in speech, music and other acoustic sources. Their preference is to interact and respond in music, sound and tone.

8. *Naturalistic Learners* use their surroundings, namely the environment and nature to learn best. Their connection to nature allows them to best recognize, categorize and deal with information.

2.2 Multiple Intelligences: Putting the Theory to the Test

Once MI theory became a widely distributed idea, hundreds of teachers and educators began to implement the theory in practice in various ways. There are countless examples of schools that applied the thinking to their educational approach, but the one school that stands out is the Key Learning Community in Indianapolis, Indiana. The Key Learning Community began in 1987 with their mission statement reading "research and develop innovative practices in teaching to celebrate diversity in our population and our communities and to personalize education by building upon each student's strengths in the following intellectual areas: Linguistic, Musical, Logical-Mathematical, Spatial, Bodily-Kinesthetic, Naturalistic, Interpersonal and Intrapersonal"[3]. The school establishes MI theory for the basis of their educational approach and the schedule is organized so that each day each student is able to study all of the intelligences. At this time there is no specific research on the educational performance of students at the Key Learning Community.

There have, however, been many research articles written on the impact of MI theory on education with two studies of importance in particular. Project Spectrum conducted a study from 1984 to 1993 that focused on effects of MI-based curriculum on academically at-risk first graders. A report released in 1993 by Chen stated the following, "At-risk students although they perform poorly in traditional academic areas, are not necessarily low performers in all areas of learning"[4]. The author continues to point out that identifying and nurturing the strengths at an early age led to increases in student motivation, productive social behavior and overall engagement.

The second study [(Project on Schools Using Multiple Intelligences (SUMIT)] was a national survey conducted from 1997 to 2000 that consisted of 41 schools that applied MI theory to its educational approach. A report on this study indicated some promising statistics as follows[5]:

- 81 percent of schools reported improved student discipline.
- 78 percent of schools reported improved academic performance by students with learning difficulties.
- 78 percent of schools reported improved standardized test scores.

2.3 Principles of Learning

Reinforcing the importance of the learning styles identified above, educators and school planners have begun to emphasize student-centered learning versus teacher-centered educational models. This trend focuses on connecting events and learning in the school to real life situations that students can easily relate to and identify with. One of the goals of student-centered learning is to be adaptive to various learning styles and, in doing so, focus on comprehension and thinking versus memorization and drills. Student-centered learning has significant implications regarding the design of the physical environment. In a student-centered classroom, the teacher is no longer the focus of the room, but based on the content of the curriculum, the students arrange themselves accordingly. This translates into countless learning environments that promote numerous learning styles.

Student-centered learning relies on some key principles. The International Academy of Education has established a list of twelve Principles of Learning that are widely referenced on the topic[6]. The principles are intended to work in concert with one another, each supportive of the next. They are as follows:

1. *Active Involvement*
   Learning requires the active, constructive involvement of the learner.
2. *Social Participation*
   Learning is primarily a social activity and participation in the social life of the school is central for learning to occur.
3. *Meaningful Activities*
   People learn best when they participate in activities that are perceived to be useful in real life and culturally relevant.
4. *Relate New Information to Prior Knowledge*
   New knowledge is constructed on the basis of what is already understood and believed
5. *Being Strategic*
   People learn by employing effective and flexible strategies that help them to understand, reason, memorize and solve problems.
6. *Engaging in Self-Regulation and Being Reflective*
   Learners must know how to plan and monitor

their learning, how to set their own learning goals and how to correct errors.

7. *Restructuring Prior Knowledge*
   Sometimes prior knowledge can stand in the way of learning something new. Students must learn how to solve internal inconsistencies and restructure existing conceptions when necessary.
8. *Aiming Towards Understanding Rather Than Memorization*
   Learning is better when material is organized around general principles and explanations, rather than when it is based on the memorizations of isolated facts and procedures.
9. *Helping Students Learn to Transfer*
   Learning becomes more meaningful when the lessons are applied to real-life situations.
10. *Taking Time to Practice*
    Learning is a complex cognitive activity that cannot be rushed. It requires considerable time and periods of practice to start building expertise in an area.
11. *Developmental and Individual Differences*
    Children learn best when their individual differences are taken into consideration.
12. *Creating Motivated Learners*
    Learning is critically influenced by learner motivation. Teachers can help students become more motivated learners by their behavior and the statements they make.

The principles of learning described above are based on a culmination of theories, observations and research. The intent of the research was to gain a greater understanding of student learning. As architects responsible for the design of learning environments, we looked to expand this type of research and begin exploring connections between learning styles and learning spaces.

3.0 THE HIGH SCHOOL PROJECT: STUDENT-CENTERED SCHOOLS: SURVEY AND EVIDENCE-BASED DESIGN

We began the High School Project by first meeting with a focus group of high school students. In our discussion, we addressed the issues and topics that we intended to cover with the survey. At that time it was unclear how the research and survey would be administered, whether it would be conducted school-by-school or district wide. The students in the focus group quickly identified the means to reach the broadest audience would be by establishing a web-based survey and creating a presence on a social networking site such as Facebook. The clear advantage to this method of distributing the survey was the organic manner in which news about the survey could be spread. This allowed the survey to take on a life of its own beyond the students and schools we had access to. The next phase of the research was to determine what questions the survey would include placing a priority on student engagement and physical space and the role of technology in the students' school life.

There is precedent for this research, however, the focus of the existing research is on teaching techniques and methodology. The most well published research is what is known as HSSE, High School Survey on Student Engagement, which was developed at Indiana University's College of Education[7]. One of the taglines for this research is "Charting the Path from Engagement to Achievement".

HSSE is a student research study that, as of 2005, had surveyed 90,000 high school students in 26 states. The findings of the survey indicate that the primary issue with students and education today is engagement. A 2005 USA Today article on HSSE had the following information to report:

- 56 percent of students surveyed said they put a great deal of effort into schoolwork.
- 55 percent of students surveyed devote no more than 3 hours a week to class participation, but 65 percent of these students report getting A's or B's in their classes.
- 37 percent of college bound students reported spending more than 7 hours a week on schoolwork.
- 18 percent of college bound students did not take a math course their senior year.

Another precedent of note is the 2002 21st Century School Fund's Building Educational Success Together collaborative work, which commissioned the research of the affect of school facilities on educational achievement. The research, in cooperation with the Council on Educational Facility Planners International, sought to review facility design and conditions with teacher and student feedback. The report was issued in October 2009. The schools represented are from public school districts all across the United States and share the common theme of better designed and better functioning facilities have a positive impact on educational success in many different forms.

Table 1: Examples of research highlights.

Data set	Information gathered
Sample: Data Source: Variables: Results:	South Carolina School Principals Facility condition score Significant relationship between building condition and test scores. At least 75 percent of principals indicated that adequacy of school facility impacted teacher attitudes, student behavior and parent and community attitudes and support.
Sample: Data Source: Variables: Results:	National sample of public school principals School Principals Facility condition rating Approximately 1/3 of schools indicated that there was at least one factor that interfered with their ability to deliver instruction to a moderate extent.
Sample: Data Source: Variables: Results:	Rural and Suburban Georgia schools Researcher observation Design Elements (movement/circulation, daylighting, views) Significant effects found between high scores on all three design elements and test score results.

Our High School Project survey developed into thirty five questions. The questions are divided into several categories such as demographic information regarding school size, community type, student academic performance, etc. These questions begin to identify possible similarities and differences between various student populations. The remaining questions are divided among four categories: Engagement, Facilities, Study Habits and Trends.

The breakdown of questions as a percentage of the total survey and sample of each is indicated below.

Demographics 26 percent
What type of community is your school located in:
- a. Urban
- b. Suburban
- c. Rural

Engagement 17 percent
In a typical class do you find that you pay more attention during:
- a. AV presentations
- b. Lecture/marker board discussion
- c. Group work
- d. All types are equal

Facilities 43 percent
In a typical class do you prefer to sit:
- a. Near the front of the room
- b. Near the middle of the room
- c. Near the back of the room
- d. Near the window

Study Habits 9 percent
In conducting research for school projects how much of the information you gather is via the school's library:
- a. 10 percent
- b. 25 percent
- c. 50 percent
- d. 75 percent
- e. 100 percent

Trends 6 percent
Do you post content (blog) on the web:
- a. Yes
- b. No

Because the primary goal of the research is to influence school planning and design, the majority of the survey consists of facilities-based questions. These questions inquire as to how and why students prefer specific spaces within a school versus others, which areas they spend most of their time, which classes do they find most interesting and what about those spaces stands out.

Table 2: Some information from preliminary responses.

States Represented:	**7 GA,FL,TX,MO,WA,MN,OH**	
High Schools Represented:	**32**	
Public 86 percent	44 percent respondents attend school with an enrollment of 500-1000	
Private 6 percent	34 percent respondents attend school with an enrollment of 1000-1500	
Charter 8 percent	12 percent respondents attend school with an enrollment of 1500-2000	
Question 15: What Influences have lead you to your decision about a potential career path?	- A particular inspiring teacher - A particular inspiring class - Exposure to career-based learning at school - A work-study program - An experience outside of school	31 percent of students responded that they have an interest in a career path because of a non-school related activity or organization.
Question 23: The media center/library should be open the entire day and the students should be able to access it during any free period they might have.	- Agree - Disagree	98 percent of students responded that they would use the media center if it were open to students throughout the day.
Question 27: How much of your work in the school's media center/ library is using the library books:	- 10 percent - 25 percent - 50 percent - More than 50 percent	The majority of the students polled (57 percent) responded that only 10 percent of their time in the media center is spent using the books.
Question 29: In a typical class do you find that you are more engaged during:	- AV presentations by teacher - AV presentations by fellow students - Lecture/Marker board discussion by teacher - Group projects/discussion with fellow students - Indepedent work time	40 percent of students responded that they feel most engaged during group projects with fellow students.
Question 30: If the resources of the media center/library were spread out throughout your school in student lounges would you use the books, computers, peridicals:	- More - Less - No change	68 percent of students responded that they would use the media center resources more if they were distrib-uted throughout the school.

4.0 TRANSLATING LEARNING INTO DESIGN: CASE STUDIES

The twelve principles of learning are an excellent road map to designing schools that promote students to engage and interact with their peers, their teachers, their surroundings and foster learning at the highest levels. In many ways each principle acts as a design requirement above and beyond the basic function of a school building. Examining the goals of the principles of learning and designing environments that respond to them is the aim of student-centered design.

Active, social, engaging, transfer, individual, motivated; are some of the essential characteristics from the list of twelve principles of learning. Not surprising, many of these words are action words and are associated with doing something. They inherently describe creative hands-on environments. Evidence from research is clear that learning involves many dimensions and senses including thinking, moving, speaking, listening and feeling.

Goal: Active Involvement
Affiliated Learning Style(s): All learning styles
Methods: Foster cognitive activities, engage the learner and create opportunities for exploration.

Response: More than any other goal, keeping students actively involved is the most critical principle to successful learning. The best means for achieving this goal is to provide a variety of spaces for learning to occur starting within a single classroom and extending throughout the entire school. Classrooms can be many learning spaces in one. As illustrated in the diagram below (Figure 1), classrooms provide spaces for lectures, group work, lab experiments, resource area and outdoor exploration. Each of these spaces is interconnected to the activities occurring in the adjacent spaces.

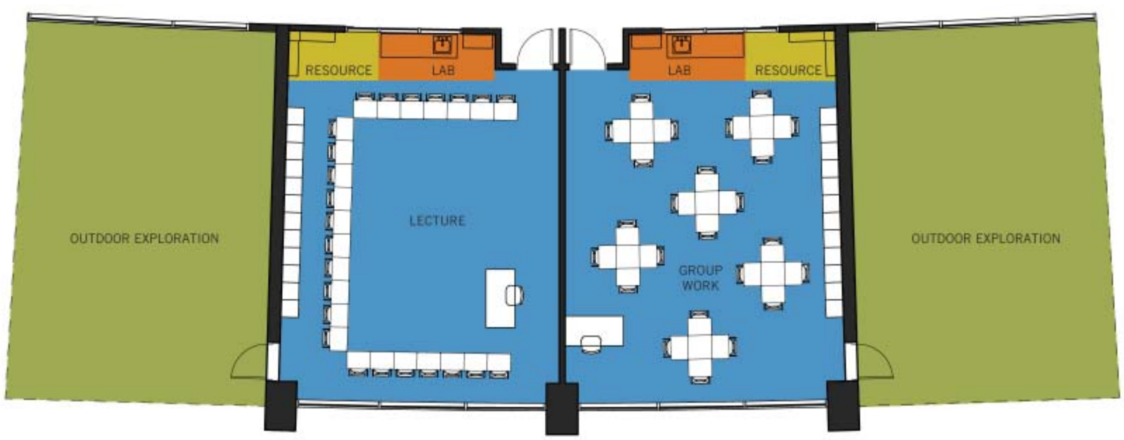

Figure 1: Mattie Lively Elementary, Statesboro, GA, 2009.

Goal: Social Participation
Affiliated Learning Style(s): Interpersonal, Logical-Mathematical, Bodily-Kinesthetic
Methods: Provide space and opportunity for group work and projects

Response: Learning is primarily a social activity. Interaction and collaboration are a part of every student's life and, therefore, should be a part of their education. The underlying success of social learning is that it is interesting and exciting. If students enjoy the activities they are engaged in they will get the most out of the lessons being taught. Design that not only allows for group work and collaboration, but celebrates the process and the results, has tremendous effects on learning. In the example below (Figure 2), a shared commons area is embedded within each classroom cluster. The commons becomes an extension of the classroom, it can function as computer labs for one group, study area for another or a meeting room for students from several classes.

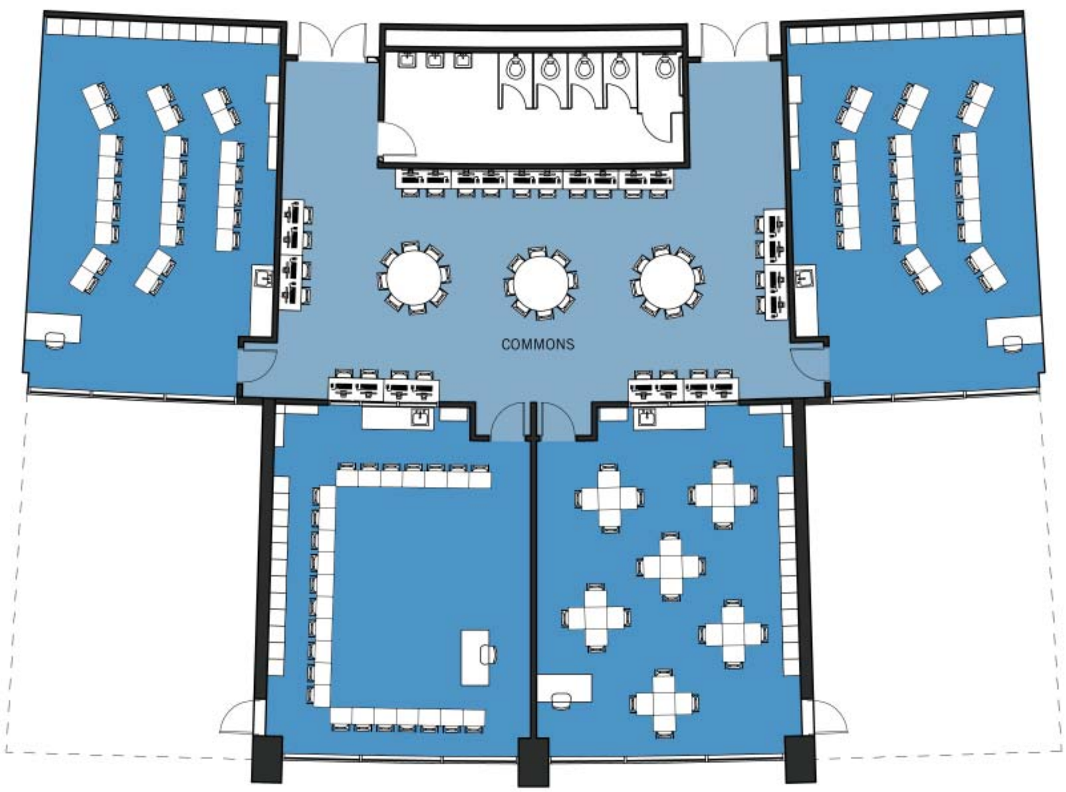

Figure 2: Mattie Lively Elementary, Statesboro, GA, 2009.

Goal: Helping Students Learn to Transfer
Affiliated Learning Style(s): Intrapersonal, Linguistic, Spatial
Methods: Bring subjects from out of the classroom into the classroom and vice versa

Response: Learning becomes more meaningful to students when they can relate personally to the lessons being taught. Connecting one subject to another through themes and experiences outside of the classroom begins to develop an atmosphere of continual learning. Not everything taught comes from the textbook and not everything learned happens in the classroom. In the example below (Figure 3), at specific locations within the school, walls of the cluster commons are designated with themes that may be related to coursework, student projects, school wide activities, etc. The integration of common space with educational topics through a graphically charged surface, such as theme walls, illustrates the power of transferred learning.

Figure 3: Mattie Lively Elementary, Statesboro, GA, 2009.

Goal: Developmental and Individual Differences
Affiliated Learning Style(s): Interpersonal, Spatial
Methods: Create various environments suited for specific student types and groups.

Response: Designing a school that meets the needs for every individual learning type is challenging since schools must be flexible and adaptable and meet the needs of the specific program and curriculum. The challenge of K-12 design is to create schools that meet curriculum needs, provide specific types of spaces for various learners, create opportunities for social engagement and handle the increasing enrollment sizes. Many of these challenges are met by the "School within a School" model that breaks down the scale of large schools into smaller learning communities. Within the smaller communities, individual program and student requirements can be addressed with an attention to detail not possible at a school wide scale. This design model is most successful with large high schools serving a large student body with a wide range of academic performance and goals. In the example below (Figure 5), a high school for 1850 students is divided among two floors with four separate academic wings or houses. These smaller learning communities include a 9th grade academy that houses all the 9th grade students, faculty and administration offices and a commons exclusively for those students. The idea behind the design is to provide a place that allows for nearly all academic and social activities of the 9th grade within a smaller community, thereby establishing strong engagement among peers, faculty and administration. The other three wings for the school may be programmed in various ways, either continuing the academy structure with 10th, 11th and 12th or dividing the wings by department and curriculum such as humanities, sciences and math.

Figure 4: Charles Drew High School, Riverdale, GA, 2009.

4.1 Technology in Schools: The Equalizer

As mentioned in the introduction, technology has dramatically transformed this generation of students just as it has the rest of our society. School-aged children are among the most skilled users of new technology; they are born into a life of technology.

This article does not intend to present a comprehensive history of technology in education, nor does it attempt to begin to analyze all the elements of education that have been and will continue to be greatly influenced by technology. One reason for this disclaimer is that although computing and internet availability has been widely used in classrooms in the US for nearly 15 years, the volume of information being disseminated by technology is very difficult to grasp, let alone record and analyze.

What can be said of technology in education is that it has undoubtedly opened up a world full of potential and possibilities to all who have access. For many students around the country and indeed around the world, the internet in the classroom has become the most powerful tool for learning, second only to the student's mind. In a pre-internet society, if one was to evaluate opportunities afforded to all students in all schools across the US and the world, it would be very clear to see that two cultures existed, "the haves and the have nots". Internet technology in the classroom has become, in many respects, the equalizer.

From the standpoint of school planning and design, current technology in education has created a need for additional spaces that are dedicated to technology and its distribution. Certainly every instructional space benefits from technology whether it be desktops for student use, projectors connected to cable television or access to the internet. The task of integrating technology into education is primarily a curriculum and pedagogical challenge more so than it is a facilities challenge. How teachers and students use technology to communicate within the classroom and beyond is something that remains to be seen.

Below are statistics on the use and accessibility of technology, specifically personal computers in the United States in a six year period prior to the new millennium[8].

In 1993:
32 percent of school age children had access to a computer at home
61 percent of school age children reported using a computer at school.

In 1997:
50 percent of school age children had access to a computer at home
71 percent of school age children reported using a computer at school.

In 1998:
89 percent of US public schools had internet connectivity
51 percent of classrooms had internet connections.

In 1999:
The US President's State of the Union Address calls for 100 percent connectivity.

4.2 Teachers/Students: A Learning Environment for Both

All of the educational theories and approaches discussed in this article have a common goal in that they all work toward improving the quality of education and the overall experience of the students. One of the notable effects of establishing student-centered education is that it inherently redefines the role of the teacher. As evidenced in many of the student survey responses and research literature, student engagement is perhaps the most critical aspect of successful learning environments. As seen in the case studies, student engagement can be fostered, to a large extent, by the spaces in which students spend their time. The same can be said for teachers who teach in those spaces. Part of a successful transition from teacher-centered to student-centered education is the decentralization of the teacher as the focal point of the classroom, the "sage on the stage model". This transition signifies a potential paradigm shift in how education can be delivered. Even when the physical environment does not change, there is a fundamental difference in how students and teachers interact, how students and students interact and how teachers interact with one another. The following diagrams illustrate how this shift could occur within a facility that remains unchanged.

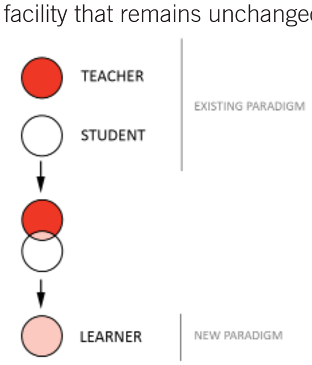

Figure 5: Adopting the mentality of both teacher and student as learner creates new opportunities for a truly collaborative educational experience.

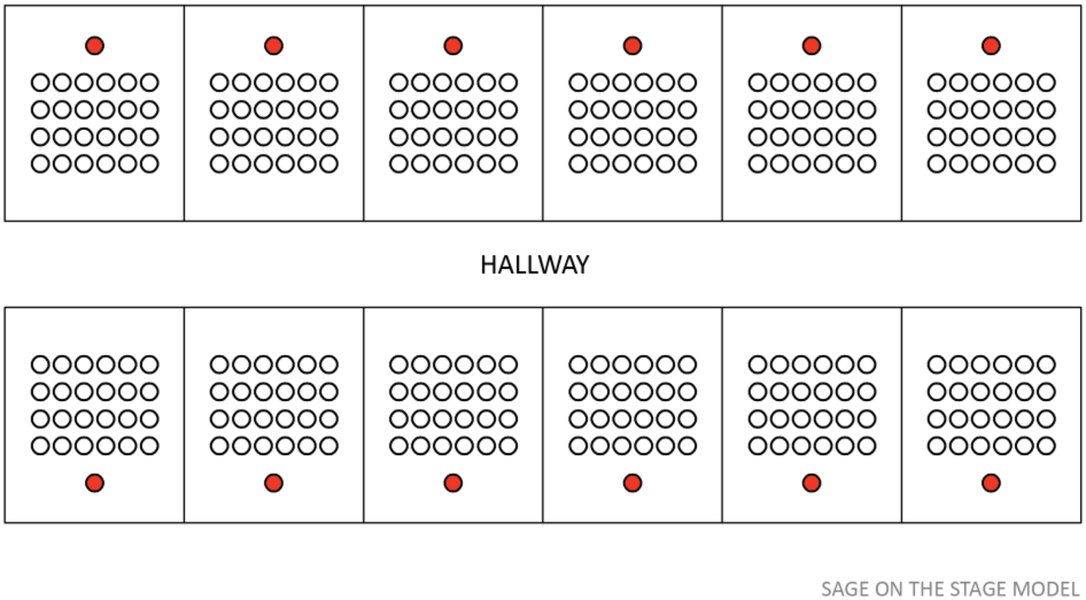

Figure 6: Teacher-centered education.

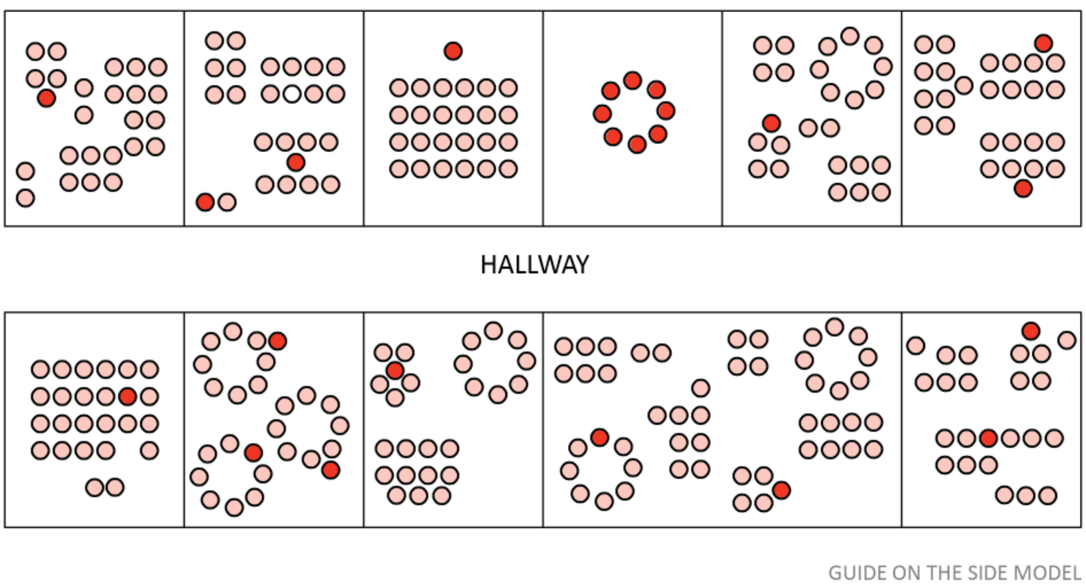

Figure 7: Student-centered education.

The diagrams above represent an exciting potential for what could be a powerful shift in educational delivery and the structuring of learning environments. The static relationship between teacher and student transforms into a fluid and dynamic setting where students can teach one another, teachers can learn from other teachers and a true learning environment is created. Although few schools have adopted this arrangement, there are examples of spaces such as this that schools can draw from as a resource. One such example is a retail chain of technology stores.

4.3 Student-Centered Learning: Using Technology as a Clue from the Everyday

As discussed in the previous section, the current generation of students are techno-natives. The millennial generation has grown up in an environment where technology is ubiquitous and, therefore, information is limitless. By combining the tenets of student-centered education and the familiarity of technology-driven environments, school facility design can begin to connect with students in an entirely new way and likely engage students who previously may have slipped through the cracks. Project-based learning is a collaborative educational model where students learn through group and individual work, theme-based projects, cross disciplinary subjects and on projects that are relevant to them.

The advancements in technology over the past twenty years has greatly expanded how project-based learning can be realized. There may be no better example of project-based learning than the modern day Apple store. On many levels these retail stores represent what today's learners are looking for: flexible and open spaces, the ability to access web-based resources, the opportunity to work independently, and access to the metaphorical brain of the Apple store the "Genius Bar" where experts in all fields of Apple technologies await eager customers who need assistance. What is described above is the operational model for how the Apple store functions, which is very relevant to today's students. The planning model for the Apple store is also very relevant to the architect designing schools.

Revisiting the concepts discussed in the previous section about fluid and dynamic environments where everyone involved is a learner in some capacity, the Apple store offers a glimpse of how this relationship might work. There are designated teachers in the form of the experts at the "Genius Bar". These staff members and their relationship to customers is similar to a traditional classroom where a teacher imparts knowledge to a group of students. There are training areas that provide a location for customers to receive one-on-one support with an employee, not unlike a teacher working with a student in a tutorial role. There are several open areas for display and browsing. It is in these areas that customers are free to explore the products and inherent technology that they provide. These areas represent the closest example of collaborative project-based labs, where students work independently or in groups and, only if requested, does a teacher step in to answer questions or provide guidance.

Below are plan diagrams, photos and renderings that illustrate how the model of the Apple store can be translated to tomorrow's learning environments.

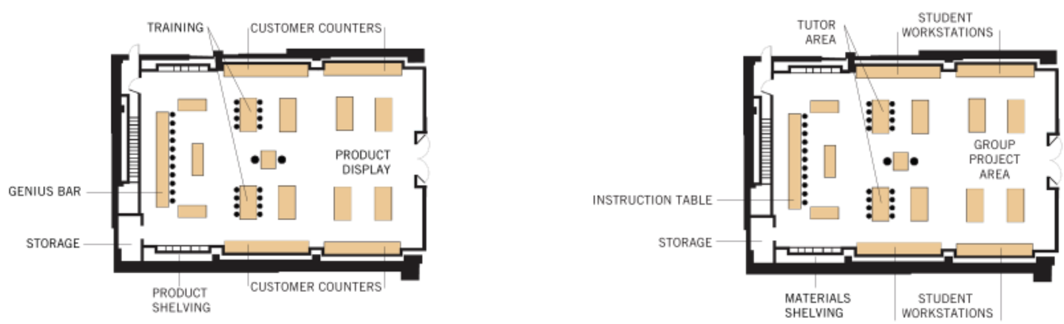

Figure 8: Apple store floor plan as reference for project-based learning lab (Case Study 1).

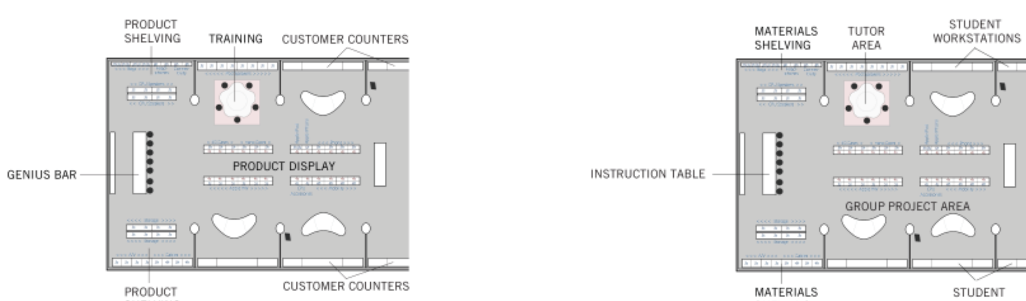

Figure 9: Apple store floor plan as reference for project-based learning lab (Case Study 2).

Figure 10: Photos from various Apple stores.

Figure 11: Rendering of project-based learning lab.

Figure 12: Diagram of project-based learning labs distributed school wide.

5.0 CONCLUSION

Collaborative, student-centered and project-based learning has significant implications regarding the design of the physical environment. In a school that is organized around these principles, the teacher is no longer the focus of a room, but an active participant with the students in a dynamic and fluid educational setting. By creating engaging environments, schools can support multiple types of learning styles to take place in spaces that are best suited for the learners.

Common to all ideas and topics discussed above is the fact that students learn in ways that often appear incongruous to a school environment. They observe, experiment, practice and, in doing so, they bend and break things, make mistakes and confuse things, complicate and misinterpret things. In all of these actions, children are open, receptive, bold, confident, excited and patient. Kids learn with an incredible collection of skills and talents. If schools can be designed to provide the time, the place, the opportunity and the reward for these remarkable events of learning, then they will make significant steps toward great education.

Acknowledgments

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REFERENCES

[1] Holt, J., (1983). *How Children Learn,* 2nd ed., New York, NY: Da Capo Press.

[2] Gardner, H., (1983). *Frames of Mind,* New York, NY: Basic Books.

[3] (2010), Key Learning Community, Retrieved 10/2010 from http://www.616.ips.k12.in.us.

[4] Chen, J., (1993). “Building on Children’s Strengths: Project Spectrum intervention Program for Students At Risk for School Failure”, *Biennial Meeting of the Society of Research in Child Development,* New Orleans, LA.

[5] Kornhaber, M. L., Fierros, E., and Veenema, S., (2003). *Multiple Intelligences: Best Ideas From Research and Practice.* Boston, MA: Allyn and Bacon.

[6] Vosniadou, S. (2001). “How Children Learn”, Report, UNESCO/International Academy of Education, Retrieved on 8/2009 from http://unesdoc.unesco.org/images/0012/001254/125456e.pdf.

[7] Yazzie-Mintz, E., (2007). “Voices of Students on Engagement: A Report on the 2006 High School Survey of Student Engagement”, Report, Retrieved on 6/2009 from http://www.indiana.edu/~ceep/hssse/images/HSSSE%20Overview%20Report%20-%202006.pdf

[8] Kinzer, C. K., and Leander, K., (2003). “Technology and the Language Arts: Implications of an Expanded Definition of Literacy”, in *Handbook of Research and Teaching the English Language Arts,* J. Flood, D. Lapp, J. R. Squire, and J. M. Jensen, eds., pp. 546-566, Mahwah, NJ: Lawrence Erlbaum Associates.

04.
ENERGY MODELING GUIDANCE:
Guidelines for Energy Analysis Integration into an Architectural Environment

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ABSTRACT
Designing energy efficient buildings requires an understanding of the energy impact of design features and how they interact with each other during the design process. This article outlines how and when an energy analysis can be conducted including guidelines for what to expect in an energy modeling analysis and how to interpret and understand the results. Guidance is provided in how to measure building systems and operations to align actual building performance with expected results from an energy modeling analysis. This article also describes several quick methods to do energy analysis at early design stages of the project. Resources are also provided to assist design teams in understanding the relative performance of proposed building designs compared to other similar building types in the industry.

KEYWORDS: energy, simulation, benchmark, design assistance, ASHRAE, GHG emissions

1.0 INTRODUCTION
Energy efficient and low impact building design continues to be a challenge as teams strive to predict actual building performance for each hour of the day and for all weather scenarios and operational schemes. Projecting how sequenced and demand-controlled mechanical systems react to complicated geometry is required to optimize how design features interact with each other. For architects to be the most successful at energy-efficient building design, an understanding of the basic principles of energy analysis is critical. This can decrease some of the reliance on external consultants, decrease time to analyze design options and facilitate higher levels of quality assurance in efficient building designs.

This article will examine the broad questions of when and why energy analysis should be done, how the analysis is conducted, what results are expected from the analysis, what opportunities are available for aligning actual building performance with simulated and resources on how to benchmark a building design.

The final area to be presented in this article is the outline of a quick energy modeling process. The process is not software dependent and urges the designer to develop an understanding of energy interplay and design impacts.

2.0 ENERGY MODELING SCOPE AND TIMING
It is important to first understand why an energy model needs to be done, what results are wanted and then craft the proposal call for the modeler to meet the project needs. Some of the reasons to use an energy model include:

1. Code compliance and/or estimating project energy use.
2. Early-stage model informing design or providing design assistance.
3. Progress models during design to ensure the project remains on track for energy or emission targets.
4. Model submission for LEED or equivalent.

A general rule of thumb for energy modeling is the more ambitious the project goals, the more extensive the energy modeling process. This tends to be because as the project gains ambitious goals for energy efficiency, energy conservation measures are designed to interact with each other and associated calculations increase.

To understand scope of the analysis, the energy model results should include information on the input data, the annual energy used, breakdown of the energy used by energy use type and per floor area, energy cost for LEED point calculations and GHG emissions (overall tons and per floor area).

2.1 Code Compliance or Project Energy Use

This is the basic level of energy modeling and it may be required to demonstrate code compliance for permits and/or to estimate the projected energy needs for a project. A single energy model done at or near the completion of design could be provided to demonstrate compliance or estimated energy use for the project.

2.2 Design Assistance

Energy modeling can be used to inform the design process and can include either a quick model at project initiation, a concept-stage design assistance model or iterative models analyzing energy conservation measures.

A quick model at the start of the project can provide the order of magnitude project energy needs and review basic design options. This can be done in several days if the project is a simpler design or a couple of weeks for a complicated project. The energy modeling input requirements at this stage include a starting point for the building envelope and basic system parameters. The ASHRAE Advanced Energy Design Guides (http://www.engineeringforsustainability.org/aedg.html) can provide a starting point for the building parameters, as noted in the "Energy Modeling Methodology" section. If detailed modeling is required at a later date, it is likely necessary to start a new model due to the general assumptions made in the preliminary model.

Design assistance at the concept design stage can use the initial building design model to evaluate design and system options and can include:

- Building orientation and shape.
- Envelope performance including insulation levels, window-to-wall ratio (glazing percentage), glazing performance and exterior shading devices on various façades.
- Mechanical system and lighting options.
- Various energy conservation measures (ECMs), which can be reviewed and preferred groupings assembled for an energy simulation to incorporate the interactions between the options. This would form the basis of design and performance for that phase of the project.

Typically, simulators will model the building systems exactly as instructed by the designers, although examining envelope and system options is possible. If the engineers and designers are not innovative, the project will be designed as usual. An advantage of using energy models is that they can be used to consider building and system alternatives and then to inform the design.

2.3 Progress Models and Model Updates

Model updates during design can be carried out if desired. If no significant changes are made during the design process, the need for updates is reduced. Model updates can be made at the end of each of the design phases like schematic design, design development and contract documents (CD). It may be advantageous to have the model updated toward the end of the CD phase to verify that the project is still meeting energy targets with time remaining for adjustment if necessary. Sometimes project design intentions go astray as designers fall back to old practices. Without some intermediary updates, the LEED submission model results may be a surprise.

2.4 Compliance Modeling for LEED Submission or Equivalent

The energy model for submission to LEED or equivalent must include information on the components, equipment and systems installed. For example, the installed glazing performance, the number of installed light fixtures and the horsepower of the fans installed are all required. This detailed model will be reviewed by the GBCI (Green Building Certification Institute) for accuracy. Early design assumptions are now verified. For example, lighting at 1 W/ft^2 would be verified by fixture counts. Therefore, estimates for the initial design assumptions must be realistic and should be verified earlier in the design process.

2.5 Proposal Call for Energy Modeling

The request for proposal for energy modeling services should outline the scope required of the model(s), the time frame for model results (i.e. at the end of schematic design) and list the required reports and results. The goals for the project should be outlined. Payment for energy modeling services should be tied to the completion of the various stages of the model. If the energy model is done by, for example, the mechanical engineering consultant and a model is required for schematic design, the payment for schematic design services should not be fully paid out until the model for that phase is completed appropriately.

The size and complexity of the project design are key factors that can affect the length and effort of the modeling process. For example, if all the floor plates are different sizes, this will generally require the modeler to trace each floor plate separately, compared to a singular floor plate that can be copied within the energy model.

3.0 ENERGY MODELING METHODOLOGY

Energy models are created to demonstrate compliance with a code or standard, to consider the performance of design options and to estimate the potential energy use of a building. Energy codes and LEED use standards such as ASHRAE 90.1 (Energy Standard for Buildings Except Low-Rise Residential Buildings), IECC (International Energy Conservation Code) and California's Title 24 to establish the minimum performance baseline, generally by specifying the minimum performance of components or equipment. A building performing equal to the standard is referred to as the *base case* (or baseline case or reference case).

The relationship between the various ASHRAE 90.1 standards is quite confusing. LEED V2.2 refers to the 2004 standard and LEED 2009 refers to the 2007 standard. The IRS Section 179D Code for Energy Efficient Building Tax Deduction refers to a baseline built to the 2001 standard. The proposed 2010 standard is said to be 30 percent less energy than the 2004 standard. The following graph, Figure 1, from the March 2010 ASHRAE Journal may assist in understanding the changes in the ASHRAE 90.1 standard.

Figure 2, indicates the ASHRAE Board's plans for future development of the energy related standards. The targets for the Advanced Energy Design Guides (AEDG) and the new Standard 189.1 are net zero energy. The clear trend is towards new buildings that use significantly less energy. It is good practice to consider the building's energy performance on opening day rather than just meeting the current minimum energy code performance.

A building design often uses a combination of elements that are not as outlined in the design standard, such as using 50 percent glazing when only 40 percent glazing is called for in the design standard. The energy model of the building design, called the *proposed case*, is created to demonstrate equal or improved performance compared to the base case. The calculations for the number of LEED energy points, obtained in Energy and Atmosphere credit 1 (EAc1), will require a percentage energy COST reduction compared to the base case. The energy model is used to demonstrate the potential performance of the proposed building.

The energy model can provide the following information for various uses:

- Energy Use - for energy benchmarking (kBTU/ft^2 or kWh/m^2).

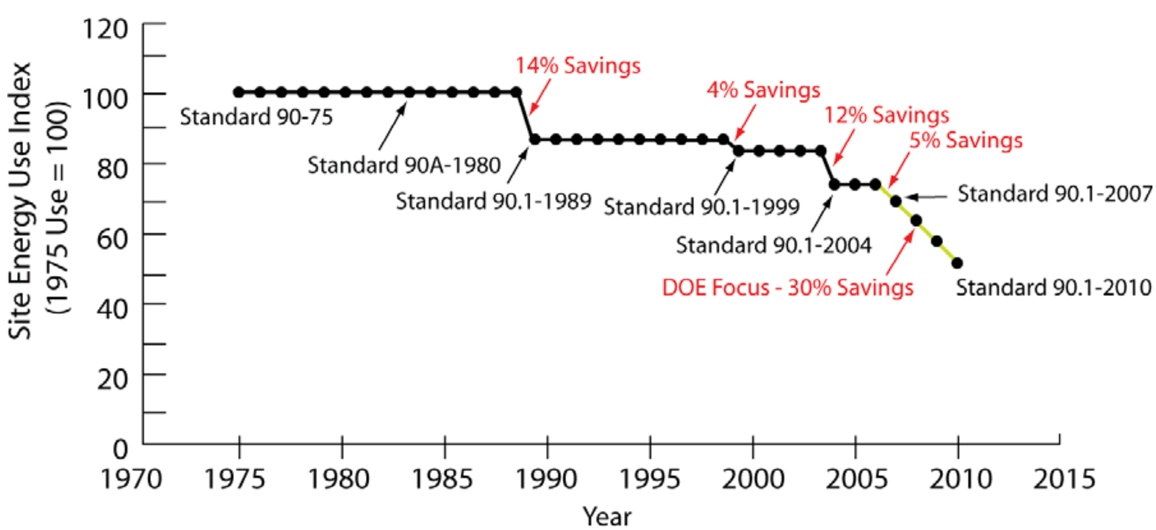


Figure 1: Improvements in the ASHRAE 90.1 code over time. ©2010, ASHRAE (www.ashrae.org). Used with permission from ASHRAE[1].

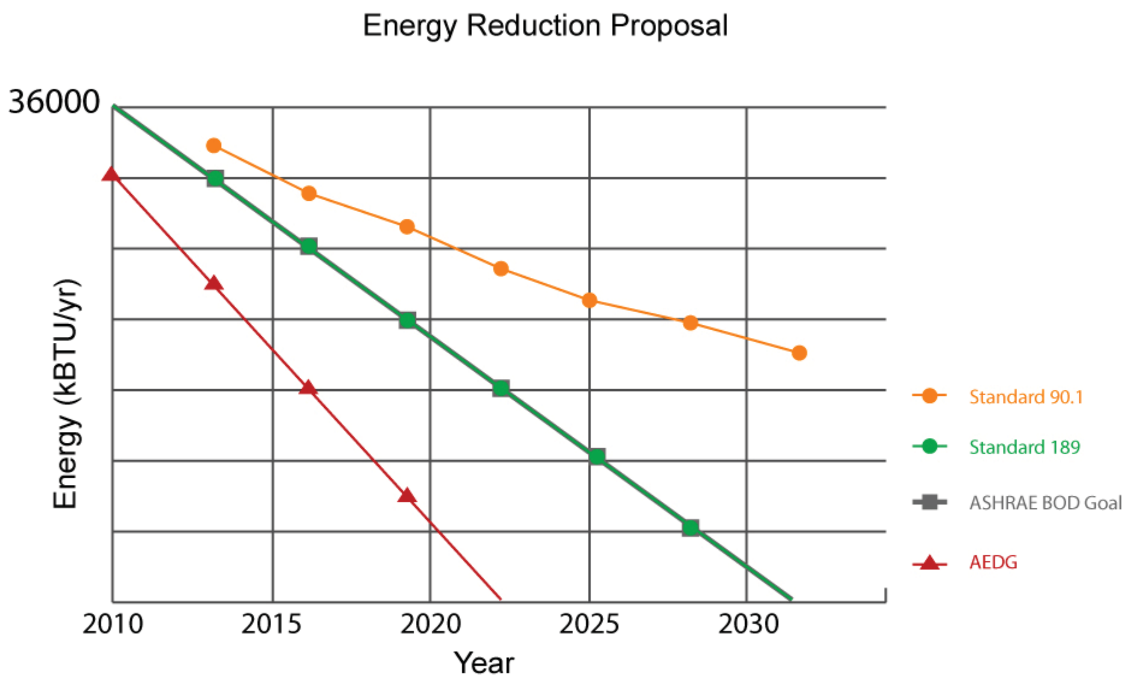


Figure 2: Improvements in Standards, Advanced Energy Design Guides, and the ASHRAE Board of Directors Goals. Used with permission from ASHRAE[2].

- Energy Cost - for LEED EAc1 point evaluation.
- GHG Emissions - for 2030 Challenge and emission calculations (tons/yr or lbs/ft^2/yr).

In preparation for energy modeling, the goals for the model should be clearly understood. Goals could be either LEED Energy points with energy cost, 2030 Challenge, Energy Benchmarking in kBTU/ft^2 or a combination of these. The building and system design options that are considered may not target all three of these issues equally.

Typically, an energy model will be created for both the *base case* and the *proposed design case* and the results will be compared. The "game" in energy modeling is to make the base case perform as badly as possibly while making the proposed case as good as possible for the best percentage energy cost improvement while abiding by the rules and guidelines for energy modeling.

3.1 Project Location and Weather

Weather station information in the form of a TMY (Typical Metrological Year) or similar file has weather information for all 8,760 hours in a year. Each hour has, for instance, dry bulb and wet bulb temperatures, humidity, solar loads and cloud cover. The hottest and coldest hours are not included so the simulation is not a design load tool. The building operation is simulated for each hour of the year. If a weather file is not available for the exact project location, a representative weather file should be used based on temperatures and heating/cooling degree days.

Energy utility rate schedules are input so that the energy cost can be determined. (That energy cost is used for LEED point calculation and not energy quantity.)

3.2 Geometry and Envelope Performance

Both the baseline and proposed cases will use the same building shape so any benefit of building shape will not be realized when the results are compared. Energy saving benefits associated with building orientation are available when comparing to the ASHRAE 90.1 baseline case.

The building is divided up into zones that will act differently from an energy perspective. Zones for a simple office building might include the north, south, east and west perimeter zones (perhaps 15ft deep), corner offices and the office interior. Zones in a school might include the classrooms. The zoning of the building avoids the sun on the south side of a building directly offsetting a heat loss on the north side and creates more realistic building loads.

The insulation values of the walls, roof and floor for each zone are input with the construction factors such as thermal mass. Glazing performance with insulation, framing, solar transmission and visible light factors are input with the orientation. Shading devices can be added. Often the energy codes have a maximum glazing allowance of 40 percent of wall area. If the proposed building has 50 percent glazing, the base building would have only 40 percent glazing and the difference is made up using wall construction elements. Therefore, the additional glazing area may make an energy target more difficult to achieve.

The glazing, wall, roof and floor performance for the base building is dictated by the energy code or reference standard. The performance factors for the proposed building originate with the design team. Energy models done at concept and schematic design might use estimated envelope performance factors. Models done later in the design period should use the actual calculated performance from the architectural details.

Changes in the design at later stages of the project can result in a considerable amount of work for the energy modeler as a lot of data in a large number of zones has to be changed and inputs are not generally grouped for easy alteration.

3.3 Internal Loads

Internal loads include the number of people, lighting loads, equipment loads and the associated schedules of usage/operation. Often design levels of ft²/person, lighting W/ft² and plug load allowances in W/ft² are input for the various uses in the building. Profiles or the schedules of how these loads vary over the 24 hour day for weekdays and weekends for the various building uses are entered. A project may have office, retail and residential uses. Each of these different uses would have different occupancy densities, lighting power densities, load allowances and profiles. Whether the lights in an area are on for 12 hours/day or 18 hours/day will obviously use different amounts of energy. While the number of people and plug loads would be the same for both the base and proposed cases, the lighting power for the base case is dictated by the energy standard and the design informs the proposed case. Standard profiles can be used for office, schools or other building types and these may be acceptable for LEED and other purposes. If actual kBTU/ft²/yr energy use is to be modeled, more detail on actual usage profiles is required. A typical office space occupancy profile and lighting profile are shown below in Figure 3.

The profiles, or schedules of operation, are used to apply the internal loads in a building. For instance, in the office occupancy profile above, it can be seen that occupants arrive between 8AM and 10AM, some occupants leave the office around lunch-time and then occupants leave gradually from 5PM onwards. In contrast, the lighting profile shows that the lights, once turned on, remain on for the course of the work day. Using schedules to apply the internal loads helps to produce realistic annual energy use numbers during simulation.

3.4 Mechanical Systems

The proposed mechanical systems for the building zones are simulated in varying levels of detail. System types such as VAV with reheat, fan coil or roof top units

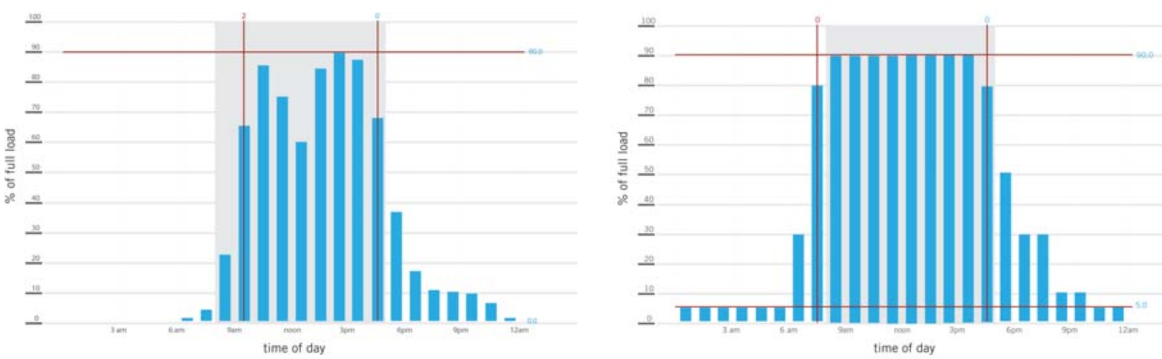


Figure 3: Typical office space occupancy profile and lighting profile for a certain day shown in the eQUEST interface.

may be used. Heating may be provided by gas, electric or other sources. Cooling may be provided by a group of chillers, direct expansion rooftop units or other systems. The equivalent base building systems are determined in the energy codes and standards by the type of proposed system, energy sources and the project size in the proposed case.

The performance parameters of the various systems are input including horsepower rating of fans and pumps, efficiencies of equipment and operating parameters. Requirements for heat recovery and operating strategies are also included.

Control strategies such as daylight control of lighting, occupancy control of lighting and ventilation and others can be considered initially or in individual studies.

3.5 Work-Arounds

Each of the energy simulation programs has standard approaches to equipment types and operations. For some innovative design approaches, simulation work-arounds are necessary. For example, if a chilled beam system were used it may need to be modeled as a fan coil system with no fan energy. Each of these work-arounds should be identified by the energy modeler. Work-around approaches may require considerable time and effort from the energy modeler, possibly with feedback from the designers.

3.6 Quick Inputs

For initial quick energy models or starting points for more efficient building designs, a summary or table of the building and system input parameters should be provided to the modeler. The team may consider using the performance tables in the ASHRAE Advanced Energy Design Guides as a starting point. There are six building type guides that are free and target a reduction of 30 percent energy cost compared to ASHRAE 90.1-1999.

3.7 Energy Conservation Measures (ECM's)

Once the base and proposed case energy models are built, a number of alternatives can be considered individually and assembled into different combinations. This analysis can inform the early design so that decisions can be made based on energy, comfort and cost considerations. ECM's might consist of:

- Different glazing performances or glazing areas,
- Different wall and roof insulation levels.
- Exterior shading options with or without daylighting.
- Mechanical system types and efficiencies.
- Different energy sources, boiler efficiencies, and chiller efficiencies.
- Different lighting levels and control strategies.
- Heat and coolth recovery options.

The ECM's can be reviewed and combined in different ways to evaluate the interactions between the ECM's. For example, a lower lighting power level may cause an increase in the heating load.

3.8 Model Review

The review of the energy model by the architect will probably not be a detailed review, but a few issues should be considered:

- Do the results make sense? For example, the lighting system did not change much from the base case, but the lighting power is significantly down – Why?
- Does the breakdown of energy per end use make sense?
- Are the schedules used correct? Is the building intended to be open 24 hours/day, but only modeled as a typical 9AM – 5PM schedule?
- Are the project goals of LEED energy points, energy use target and/or 2030 Challenge target being achieved? If not, what improvements can be made and at what cost?

3.9 Simulated Versus Actual Building Performance

Energy modeling is a useful comparison tool for building envelope and system options. To have the energy model produce a reasonable estimate of the actual building performance, a number of areas require more detailed information than is typically used. These include:

- Detailed building occupancy loading and schedules of occupancy including, for example, when the janitors are working.
- Actual lighting loads, including task lighting and incorporating in controls, if they exist. The accompanying schedules of usage for the lighting are also needed.
- Actual equipment loading and schedules of how they operate at night and on weekends. Plug-in equipment like personal heaters, fans and additional computer equipment needs to be included with schedules of use.
- Actual mechanical system operation such as temperature set-points or control strategies.

ASHRAE 90.1 (and other) energy modeling rules prior to the ASHRAE 90.1-2007 Standard excluded process loads (like a data room and similar loads) as well as exterior lighting, elevators and similar. These loads could increase the electrical energy use by 25 percent. In the 2007 Standard, these loads are to be included in the energy model. The trend is moving towards energy model results getting closer to actual operating results.

The actual energy use in a building is influenced by the building design, the building occupants, the building operation and commissioning. Designers have control over only some of these factors.

Energy codes using actual energy performance and building operation labeling are becoming more common. Actual building energy use is becoming a major consideration in the design and operation of buildings.

3.10 Overview of Selected Typical Energy Simulation Software

Each energy modeling program has capabilities and limitations. The following information provides a brief outline of the capabilities of commonly used energy modeling programs.

Trane Trace 700 and Carrier HAP: These energy analysis programs were written by large international HVAC system manufacturers. These programs are useful for modeling conventional building designs and equipment as provided by these manufacturers and for sizing equipment. These programs do not respond well to new and non-conventional design approaches.

eQUEST, EE4 and Visual DOE: These energy analysis programs are based on Department of Energy (DOE) engines or analysis approaches. Typically, these have a broader range of mechanical systems that can be modeled, but have a North American bias to systems and envelopes that are considered. eQUEST (Quick Energy Simulation Tool) and EE4 are free downloads.

IES Virtual Environment and TAS: IES and TAS are UK based programs that have a broad range of capabilities. A number of European approaches have been included as well as more North American approaches. IES now offers ASHRAE calculation protocols for the North American market. Building heating and cooling loads, effects of thermal mass and natural ventilation, daylighting, basic Computational Fluid Dynamic analysis and energy modeling can be carried out. IES is becoming more common in North America. TAS is similar to IES but does not have as significant a market penetration in North America.

TRNSYS: TRNSYS is not commonly used for energy modeling in North America. TRNSYS is a unique tool that can analyze complex and interactive building systems that other tools cannot consider.

EnergyPlus: The Department of Energy has combined a number of energy analysis tools into one. Building researchers often work with this tool, however, few commercial energy modelers use the tool as it is complicated. Efforts are underway to provide a windows interface to the tool that could make it more easy to use.

Additional tools and resources are provided in Section 6.3 of this article.

4.0 DELIVERABLES FROM AN ENERGY MODELING ANALYSIS

4.1 Report Overview

The energy modeling report should include all of the critical information used to develop the model and the required results. It is not sufficient to only state the anticipated LEED energy points. The list of input information is required to confirm that the model and design data are in agreement. Verification of clear understanding of the project is critical to the accuracy of the results of the model. The energy modeling report should include:

- *Executive summary* – key results of the energy model.
- *Building description* – location, uses and areas.
- *Energy goals for project* – the Reference Energy Code (i.e. ASHRAE 90.1 2007), the modeling program used and the weather data used. Note that various modeling software programs are strong in some areas and weak in others. The software selection should suit the project. At the end of Section 3 "Energy Model Methodology", selected energy modeling programs are discussed.
- *Summary table of inputs* – for base case and proposed case parameters including insulation performance, glazing specifications, mechanical system parameters, lighting power/daylighting/occupancy and additional project features. An example summary table is included later in this

section. Also included is an example from an ASHRAE Advanced Energy Design Guide outlining similar program input data as an industry example.

- *Energy conservation measures* - ECM's and preferred bundles of ECM's. The ECM's are project design options that the team wishes to explore. They may include various envelope insulation levels, glazing options for performance, area shading and mechanical and electrical system options. A description of the ECM's should be provided.
- *Work-arounds* – Work-arounds are needed when the modeling program is only able to use one type of system, but another is proposed. For example, a chilled beam system may be modeled as a fan coil system with no fan energy. This work-around would be described so it can be verified for appropriateness.
- *Key assumptions* – these should be highlighted. Envelope data may be taken at, for instance, R-20 as an assumption rather than detailed takeoffs of construction details; lighting power density may be assumed at 1 W/ft^2 rather than from a detailed count of fixtures. These assumptions would change as more detailed project information is available. Energy models done in the later stages of design should not be using assumptions, but real project data.
- *Energy usage results for base case and proposed case with usage breakdown* – including space heating, space cooling, fans, pumps, lights, domestic hot water (DHW) and plug loads. Results are discussed in Section 4.4.
- *Energy use, energy cost, and GHG emission parameters and emissions* – Results are discussed in Section 4.4.

4.2 Summary of Inputs

An example input summary table is shown in Table 1 for the base case and proposed models.

For each of the assumptions made for the proposed building design, the energy modeler should provide a footnote that indicates the assumption and the source. The sources for the utility rates used should also be provided.

As a starting point for establishing envelope and system performance factors for a lower energy building, the ASHRAE Advanced Energy Design Guides are available for consideration in some market sectors. The guides are aimed at building performance that is 30 percent less than ASHRAE 90.1-1999. Table 2 is an example from the Small Hospitals and Healthcare Facilities Advanced Energy Design Guide[4].

4.3 Work-Arounds

Due to modeling limitations, it is often necessary to create a work-around method or calculation to determine energy savings for a design component or system. The work-around method should be discussed in the report to enable the design team to review the methodology. An example table of model work-arounds is shown below in Table 3.

4.4 Energy Modeling Results

After the models are built and simulated, the proposed design model is compared to the base case model and results are compared by total and by end-use.

The model results can be entered into the LEED Energy and Atmosphere Credit 1 (EAc1) forms with utility rates to determine the energy cost savings. The energy cost savings are used to determine how many LEED points could be achieved through energy efficiency measures.

To help the design team understand the impacts of various ECM packages and to review the models, it is useful to create a visual representation of the savings by end-use. An example comparison chart is shown in Figure 4 (on page 84) with results of energy savings and GHG savings.

Table 1: Example table of simulation inputs with base case data from ASHRAE 90.1-2007[3].

General Building Information	PROPOSED				BASELINE (ASHRAE 90.1-2007)			
Name:	Project Name				Project Name			
Location:	Seattle, WA				Seattle, WA			
Climate Zone	5B				5B			
Orientation of Plan North:	North-West				North-West			
Total number of storeys: (above grade / below grade)	8 storey residential tower				8 storey residential tower			
Total floor area:	104,000 ft^2 (9,600 m^2)				104,000 ft^2 (9,600 m^2)			
Footprint area:	13,000 ft^2 (1,200 m^2)				13,000 ft^2 (1,200 m^2)			
Footprint aspect ratio: (specify orientation)	4.3 on the north-south axis				4.3 on the north-south axis			
Space type(s): (include % breakdown)	100% residential				100% residential			
Hours of operation:	24 hr light occupancy				24 hr light occupancy			
Occupant density:	250 ppl total				250 ppl total			
Floor-to-floor height:	10 ft (3m)				10 ft (3m)			
Average size per unit, or by main unit type:	775 ft^2 (72m^2) per unit				775 ft^2 (72m^2) per unit			
Glazing Information	NW	NE	SE	SW	NW	NE	SE	SW
Window-to-wall ratio per face:	40%	40%	40%	40%	40%	40%	40%	40%
% of windows with horizontal shading (per face):			100%	100%			0%	
Horizontal shading dimension (per face):			1.5 ft	1.5 ft			-	
% of windows with vertical fin shading (per face):								
Vertical fin dimension (per face):								
Glazing assembly u-value (including frame):	Double-glazed, low-E, reflective, with argon (U-0.32)				U-0.55			
Glazing solar heat gain coefficient (SHGC):	SHGC = 0.40, SC = 0.46				SHGC = 0.40, SC = 0.46			
Envelope Information								
Overall wall R-value:	R-24.5 overall (R-19 + R-5.5 c.i.)				U-0.064 / R-15.6 overall (R-13.0 + R-7.5 c.i.)			
Roof Type:	Green roof or high-reflectance				Insulation entirely above deck			
Overall roof R-value:	R-41 c.i.				U-0.048 / R-20.0 c.i.			
Skylight % roof coverage:	none				none			
Quantity and dimensions of skylight assemblies:	-				-			
Floor construction R-value:	U-0.057 / R-14.6 c.i.				U-0.057 / R-14.6 c.i.			
Balconies:	Thermal break between floor slab and balcony				Continuous floor and balcony slab			
Lighting Information								
Targeted % lighting savings above baseline: [1]	25%				LPD = 0.7 W/ft^2			
Lighting controls:	Occupancy				Occupancy			
Daylighting controls:	None				None			
Exterior % lighting savings above baseline: [1]	25%				LPD = 0.2 W/ft^2			
Equipment Information								
Equipment Loads: [1]	0.75 W/ft^2				0.75 W/ft^2			
List additional equipment:	none				none			
Design Conditions	Heating		Cooling		Heating		Cooling	
Indoor design temperatures: (heat / cool) [1]	71°F / 22°C		76°F / 24°C		71°F / 22°C		76°F / 24°C	
Thermostat set-back temperatures: (heat / cool) [1]	64°F / 18°C		82°F / 28°C		64°F / 18°C		82°F / 28°C	
Humidity design conditions: [1]	No mimimum humidity req.		Max 50% RH		No mimimum humidity req.		Max 50% RH	
Air System Information								
System type: [1]	Fan coil units with integral heat recovery				Packaged Terminal AC / Gas-fired heating			
Additional ventilation requirements:	30 cfm central and 80 cfm per unit				30 cfm central and 80 cfm per unit			
Overall fan power efficiency: [1]	2.33 W/cfm (premium efficiency)				4.45 W/cfm			
Room Fan Operation:	Intermittent				Continuous, cycle when unoccupied to meet loads			
Exhaust Air Heat Recovery? (Y/N)	Y				N			
Other system features:								
Plant Information								
Heating plant type: [1]	Distributed heat pump system at 150°F, Backup gas boiler				Gas-fired boiler			
Heating plant efficiency: [1]	Gas boiler = 85%				80%			
Variable speed pump control? (Y/N)	Y				N			
Cooling plant type: [1]	Centrifugal chiller				Air cooled split system			
Cooling plant efficiency: [1]	0.6 kW/ton (20 SEER)				0.92 kW/ton (13 SEER)			
Variable speed pump control? (Y/N)	Y				N			
Domestic hot water heating type: [1]	Heat Pumps (2/3), solar / gas-fired boiler top-up (1/3)				Gas-fired boiler			
Domestic hot water heating efficiency: [1]	85%				80%			
Domestic hot water use: (gal/person/day)	16 gallons/person/day (35% reduction)				25 gallons/person/day			
Utilities								
Electricity:	Seattle City Light: Energy: \$0.0459/kWh for 10kWh; \$0.0955/kWh above (April-Sept) Energy: \$0.0459/kWh for 16kWh; \$0.0955/kWh above (Oct-Mar)				Seattle City Light: Energy: \$0.0459/kWh for 10kWh; \$0.0955/kWh above (April-Sept) Energy: \$0.0459/kWh for 16kWh; \$0.0955/kWh above (Oct-Mar)			
Natural Gas:	Puget Sound Energy: \$1.04885/therm				Puget Sound Energy: \$1.04885/therm			

Notes:

1. Baseline is ASHRAE 90.1-2007 and LEED 2009 unless specified otherwise.

Table 2: Climate zone 4 recommendation table for small hospitals and healthcare facilities. Used with permission from ASHRAE[4].

28 ADVANCED ENERGY DESIGN GUIDE FOR SMALL HOSPITALS AND HEALTHCARE FACILITIES

Climate Zone 4 Recommendation Table for Small Hospitals and Healthcare Facilities

	Item	Component	Recommendation	How-to Tips in Chapter 5	✓
Envelope	Roof	Insulation entirely above deck	R-30 c.i.	EN2, EN11, EN13	
		SRI	Comply with Standard 90.1*	EN1	
	Walls	Mass (HC > 7 Btu/ft^2)	R-13.3 c.i.	EN3, EN11, EN13	
		Steel-framed	R-13 + R-7.5 c.i.	EN4, EN11, EN13	
		Below-grade walls	R-7.5 c.i.	EN5, EN11, EN13	
	Floors	Mass	R-14.6 c.i.	EN6, EN11, EN13	
		Steel-framed	R-38	EN7, EN11, EN13	
	Slabs	Unheated	R-15 for 24 in.	EN8, EN11, EN13	
	Doors	Swinging	U-0.50	EN9, EN13	
		Non-swinging	U-0.50	EN10, EN13	
	Vertical Fenestration	Total fenestration to gross wall area ratio	40% Max	EN15, EN17–18	
		Thermal transmittance (all types and orientations)	U-0.29	EN14	
		SHGC (all types and orientations)	SHGC-0.34	EN14, EN23–24	
		Visible transmittance	VT-0.69	EN14, EN25	
		Exterior sun control (S, E, and W only)	Projection factor > 0.5	EN16, EN21–22 EN26–31, DL5–6, DL20	
	Skylights	Area (percent of roof area)	3% maximum	DL13–16	
		Thermal transmittance (all types)	0.60	DL18	
		SHGC (all types)	SHCG-0.40	DL19	
Lighting/Daylighting	Daylighting	Design the building to maximize access to natural light through sidelighting and toplighting: · Staff areas (exam rooms, nurse stations, offices, and corridors) · Public spaces (waiting and reception)	Diagnostic and treatment block: shape the building footprint such that the area within 15 ft of the perimeter exceeds 40% of the floorplate	DL1–20	
			Inpatient units: ensure that 75% of the occupied space not including patient rooms lies within 20 ft of the perimeter	DL1–20	
	Interior Finishes	Daylighted room interior surface average reflectance	88% on ceilings and walls above 7 ft 50% on walls below 7 ft	EL1, DL14	
	Interior Lighting	LPD	1.0 W/ft^2 or space-by-space method using values in Table 5-9 in EL13	EL13–31, DL1–19	
		Light source system efficacy (linear fluorescent and HID)	90 mean lumens/watt minimum	EL2, EL3	
		Light source system efficacy (all other sources)	50 mean lumens/watt minimum	EL4, EL5	
		Lighting controls (general)	Manual on, auto-off all zones except: no auto-off in 24-h patient care areas (patient rooms, nurses station, etc.)	EL7–11, EL15–32, DL16	
		Daylight-harvesting dimming controls	Dim fixtures within 15 ft of sidelighting edge and within 10 ft of toplighting edge	EL12, DL16	
HVAC	Critical Care Areas – Central Air-Handling System	DX air conditioner (≥ 240 kBtu/h and < 760 kBtu/h)	10.0 EER/10.5 IEER	HV1, HV5, HV6	
		DX air conditioner (≥ 760 kBtu/h)	9.7 EER/10.2 IEER	HV1, HV5, HV6	
		Air-cooled chiller efficiency	10.0 EER/11.5 IPLV	HV1, HV5, HV6, HV19	
		Water-cooled chiller efficiency	Comply with Standard 90.1*	HV1, HV5, HV6, HV19	
		Chilled-water pumps	VFD and NEMA premium efficiency	HV19	
		Cooling towers	VFD on tower fans	HV19	
		Gas boiler	90% E_c at peak design heating water temperature	HV1, HV5, HV6, HV20	
		Economizer	Humid zones A: Not required Dry zones B: Yes Marine zones C: Yes	HV9	
		Fans	bhp ≤ supply cfm x 0.0012+A, NEMA premium efficiency motors	HV7, HV11, HV14, HV21	
		Zone airflow setback	Yes	HV1, HV23	

Table 2: Climate zone 4 recommendation table for small hospitals and healthcare facilities. Used with permission from ASHRAE[4] (continued).

CHAPTER 3—RECOMMENDATIONS BY CLIMATE 29

Climate Zone 4 Recommendation Table for Small Hospitals and Healthcare Facilities *(Continued)*

		Item	Component	Recommendation	How-to Tips in Chapter 5	✓
HVAC (cont.)	Non-Critical Care Areas	Central VAV Air-Handling System	DX air conditioner (≥ 240 kBtu/h and < 760 kBtu/h)	10.0 EER/10.5 IEER	HV1, HV5, HV6	
			DX air conditioner (≥ 760 kBtu/h)	9.7 EER/10.2 IEER	HV1, HV5, HV6	
			Air-cooled chiller efficiency	10.0 EER/11.5 IPLV	HV1, HV5, HV6, HV19	
			Water-cooled chiller efficiency	Comply with Standard 90.1*	HV1, HV5, HV6, HV19	
			Chilled-water pumps	VFD and NEMA premium efficiency	HV19	
			Cooling towers	VFD on tower fans	HV19	
			Gas boiler	90% E_c at peak design heating water temperature	HV1, HV5, HV6, HV20	
			Economizer	Humid zones A: Not required Dry zones B: Yes Marine zones C: Yes	HV9	
			Fans	bhp ≤ supply cfm x 0.0012+A, NEMA premium efficiency motors	HV7, HV11, HV14, HV21	
			Space temperature setback	Yes	HV17, HV22	
		WSHP System	WSHP < 65 kBtu/h	Cooling: 12 EER at 86°F; Heating: 4.5 COP at 68°F	HV2, HV5, HV6	
			WSHP ≥ 65 kBtu/h	Cooling: 12 EER at 86°F; Heating: 4.2 COP at 68°F	HV2, HV5, HV6	
			Water pumps	VFD and NEMA premium efficiency	HV19, HV20	
			Cooling towers/fluid cooler	VFD on fans	HV19	
			Gas boiler	90% E_c at peak design heating water temperature	HV2, HV5, HV6, HV20	
			Economizer	Comply with Standard 90.1*	HV9	
			Exhaust-air energy recovery in DOAS	Humid zones A: 50% total effectiveness Dry zones B: 50% sensible effectiveness Marine zones C: 50% total effectiveness	HV4, HV10	
			WSHP fans	0.4 W/cfm	HV7, HV11	
			Other fans (DOAS, exhaust)	bhp ≤ supply cfm x 0.0012+A, NEMA premium efficiency motors	HV7, HV11, HV14	
			Space temperature setback	Yes	HV17, HV22	
		Fan-Coil and Chiller System	Air-cooled chiller efficiency	10.0 EER, 11.5 IPLV	HV3, HV5, HV6, HV19	
			Water-cooled chiller efficiency	Comply with Standard 90.1*	HV3, HV5, HV6, HV19	
			Chilled-water pumps	VFD and NEMA premium efficiency	HV19	
			Cooling towers	VFD on tower fans	HV19	
			Gas boiler	90% E_c at peak design heating water temperature	HV3, HV5, HV6, HV20	
			Economizer	Humid zones A: Not required Dry zones B: Water-side economizer Marine zones C: Water-side economizer	HV9	
			Exhaust-air energy recovery in DOAS	Humid zones A: 50% total effectiveness Dry zones B: 50% sensible effectiveness Marine zones C: 50% total effectiveness	HV4, HV10	
			Fan-coil units	0.4 W/cfm	HV7, HV11	
			Other fans (DOAS, exhaust)	bhp ≤ supply cfm x 0.0012+A, NEMA premium efficiency motors	HV7, HV11, HV14	
			Space temperature setback	Yes	HV17, HV22	
		Ducts and Dampers	Outdoor air damper	Motorized	HV8	
			Duct seal class	Supply and ducts located outdoors = Seal Class A Return and exhaust = Seal Class B	HV13	
			Insulation level	R-6	HV12	
SWH		Service Water Heating	Gas storage (>75 kBtu/h)	90% E_t	WH1–5	
			Gas instantaneous	0.81 EF or 81% E_t	WH1–5	
			Electric (storage or instantaneous)	EF > 0.99–0.0012 × Volume	WH1–5	
			Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in./1.5 in.	WH6	

*Note: If the table contains “Comply with Standard 90.1” for a component, the user must meet the more stringent of either the applicable edition of Standard 90.1 or the local code requirements.

Figure 4 also includes the annual energy use intensity numbers for both proposed and base case models. This can assist in project benchmarking allowing for comparison with industry norms or similar buildings.

Simple calculations for greenhouse gas emissions savings should also be conducted to inform the design team. Two figures showing example greenhouse gas emissions, per fuel source, are shown in Figure 5 for the proposed design case and the baseline case. The figure on the left represents the GHG emissions reduction using GHG emission rates per fuel source in British Columbia[6,7] while the figure on the right shows the GHG emissions reduction using average GHG emissions rates for the United States[8].

Table 3: Example table listing work-around methodology for a given proposed design feature.

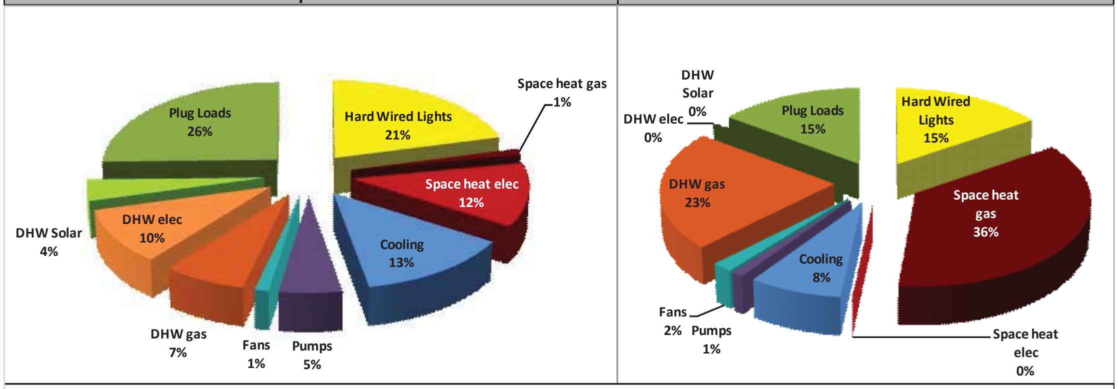
Proposed Design	Work-Around Description
Radiant heating and cooling floors	Modeled as a 4-pipe fan coil system with zero fan power.
Occupancy sensors	Modeled by reducing lighting power density by % as listed in Appendix G of ASHRAE 90.1-2007.

In Figure 5, the scale for the tonnes of CO_2e is different for the two locations, British Columbia in Canada and (average) USA. It can be seen that the emissions rates are much higher on average in the United States than they are in British Columbia. This type of results diagram demonstrates how design decisions are affected differently based on project location and GHG reduction goals.

5.0 UTILITY METERING GUIDELINES FOR BENCHMARKING

The most basic building performance data is for building utility electrical, gas and water usage. A more detailed breakdown can be helpful to verify building operational

Annual Energy Use		
	Proposed	Reference



	Proposed	Reference
Total (kWh/m2)	72	124
Heating - Elec	9	0
Heating - Gas	1	45
DHW - Elec	7	0
DHW - Gas	5	28
DHW - Solar	2	0
Cooling	10	10
Pumps	4	1
Fans	1	2
Lighting	15	19
Plug Loads	18	18

Total Elec (kWh)	879,000	703,000
Total Gas (kWh)	81,000	1,007,000
Total Energy (kWh)	960,000	1,710,000
Total Cost	$ 73,000	$ 97,000
Total Regulated Energy Cost Savings*	**30%**	Compared to ASHRAE 90.1-2007
Anticipated LEED points	**9**	**Points according to LEED NC 2009**
Total GHGs from Electricity† (lbs CO_2e)	237,000	181,000
Total GHGs from Natural Gas†† (lbs CO_2e)	32,000	402,000
TOTAL GHGs (tonnes CO_2e)	**122**	**265**
GHG Savings	**54%**	

** The cost savings is different than the energy savings, as the cost of electricity is much greater than the cost of natural gas.*

† GHG emissions factor for Electricity: 0.287 lbs CO_2e / kWh

†† GHG emissions factor for Natural Gas: 0.4 lbs CO_2e / kWh

Figure 4: Results comparison for proposed and baseline models including annual energy utilization by end use, estimated LEED points and GHG emission savings[5].

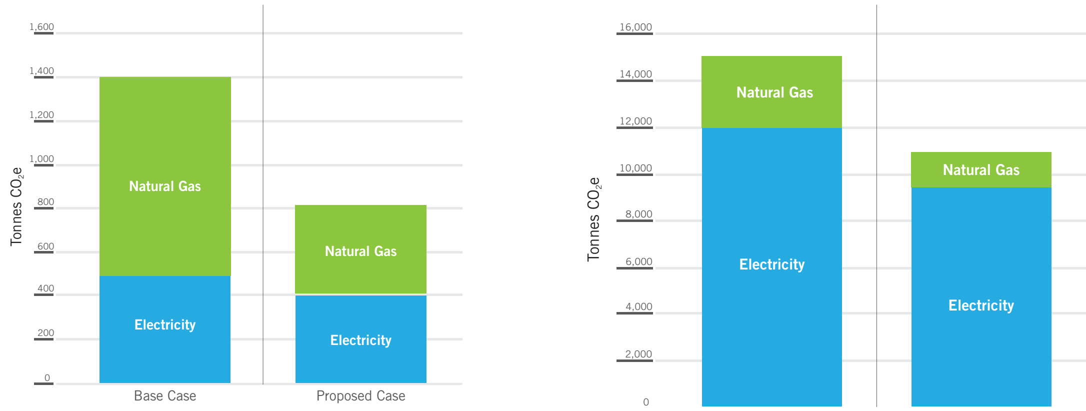


Figure 5: GHG emissions per fuel source for the proposed case compared to the baseline case. The figure on the left represents the GHG reductions in BC, Canada while on the right, GHG reductions in the US.

energy and end use breakdown. Full "Measurement and Verification" as per the LEED Energy and Atmosphere Credit 5 (EAc5) is often prohibitively expensive.

The following measures in addition to the base utility meters should be provided and should be suggested to the design team. When incorporated at the early stages of the project, the additional cost is quite modest.

- Separate electrical panels (and risers where appropriate) to serve on floor lighting and plug-in power needs. It is important that the electrical team does not make connections to any electrical panel with spare space and instead connects to the correct panel. This way, one meter can measure all of the lighting or plug power in an area. Plug power loads often consume much more energy than anticipated.
- Monitor power to mechanical rooms with submetering for chillers, related pumps and equipment. Some metering may be included in control panels with BacNet or LON connectivity to a Building Automation System (BAS).
- Sub-meter gas loads in a building such as for a kitchen.
- Elevator loads, kitchen loads and exterior lighting should be sub-metered.
- Install water meters on DHW, irrigation, reclaimed water systems and makeup for cooling towers and heating/cooling systems.

The meter readings should feed into the building automation system for recording of the data. Avoid new data over-writing older data. An advantageous arrangement with the client/owner would be that this utility data would be available to us for collection. A number of systems like Pulse Energy (being used in some of our offices) can provide tracking of data with alerts for abnormal energy or water usage.

6.0 RESOURCES

6.1 Benchmarking in Canada

The Canadian Green Building Council (CaGBC) has started a green building performance program called "Green Up" to track actual building performance across the country, normalized for weather and other factors. Results from the years 2005 and 2007 have been compiled for this pilot program and are available online at: http://www.cagbc.org/initiatives/green_building_performance/pilot_projects.php.

Charts showing commercial office buildings, administrative office buildings and K-12 schools are shown in Figure 6, Figure 7 and Figure 8[9].

6.2 Benchmarking in the United States

In the United States, the US Environmental Protection Agency and the Department of Energy have co-created the Energy Star program offering guidance and tools for energy efficiency. While the 2007 data is still being compiled, the 2003 Commercial Building Energy Consumption Survey (CBECS) provides the national average for building performance based on building type. This is shown in Table 4[10]. Detailed breakdown of energy per end-use type per building type are also available and can be found at: http://www.eia.doe.gov/emeu/cbecs/

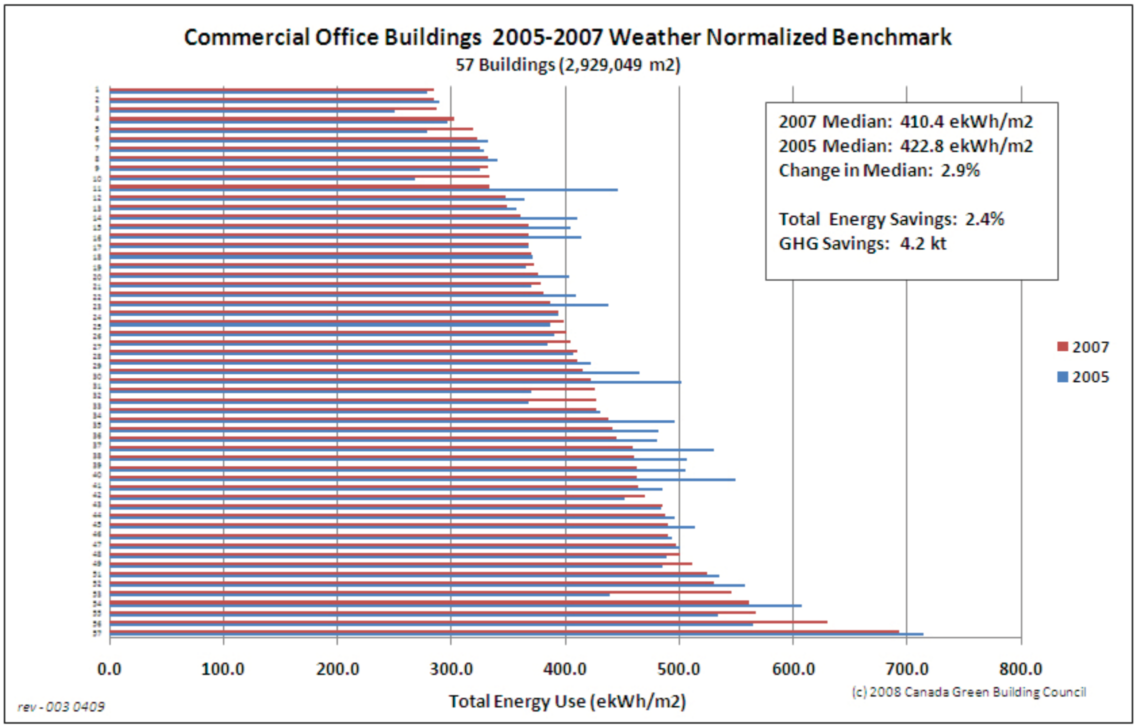


Figure 6: Building performance benchmarking for commercial office buildings in Canada[9]. For reference, 100 kWh/m^2 is approximately equal to 32 kBTU/ft^2

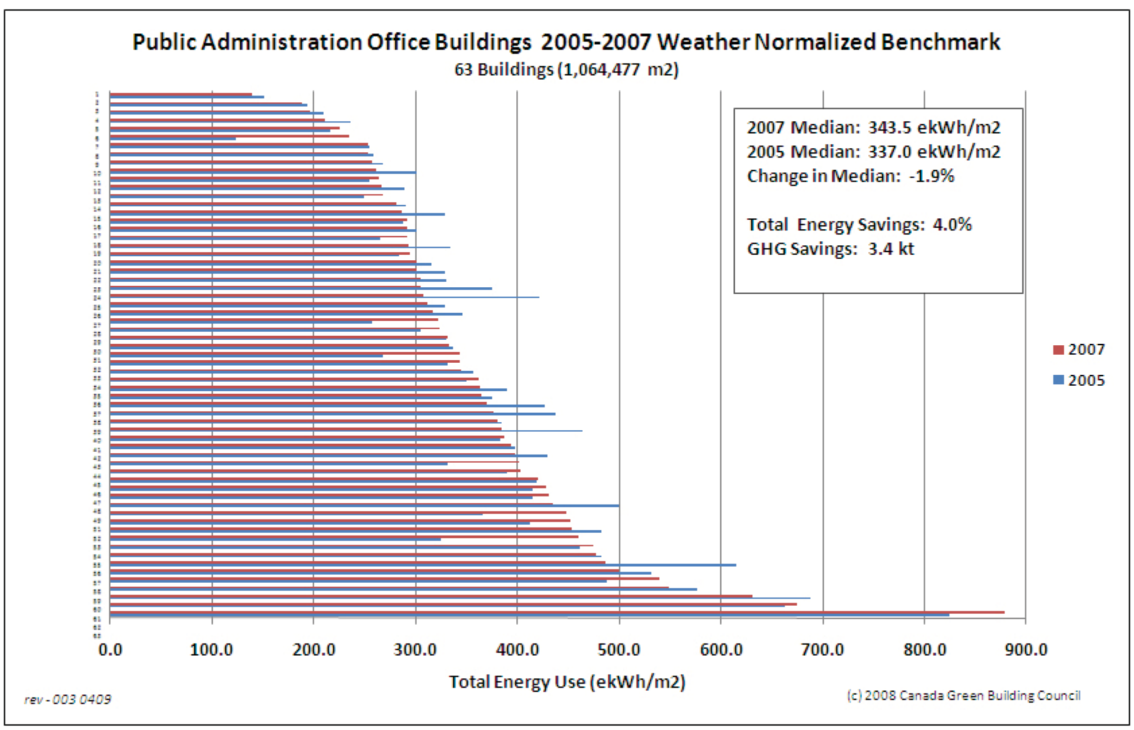


Figure 7: Building performance benchmarking for administrative buildings in Canada[9]. For reference, 100 kWh/m^2 is approximately equal to 32 kBTU/ft^2.

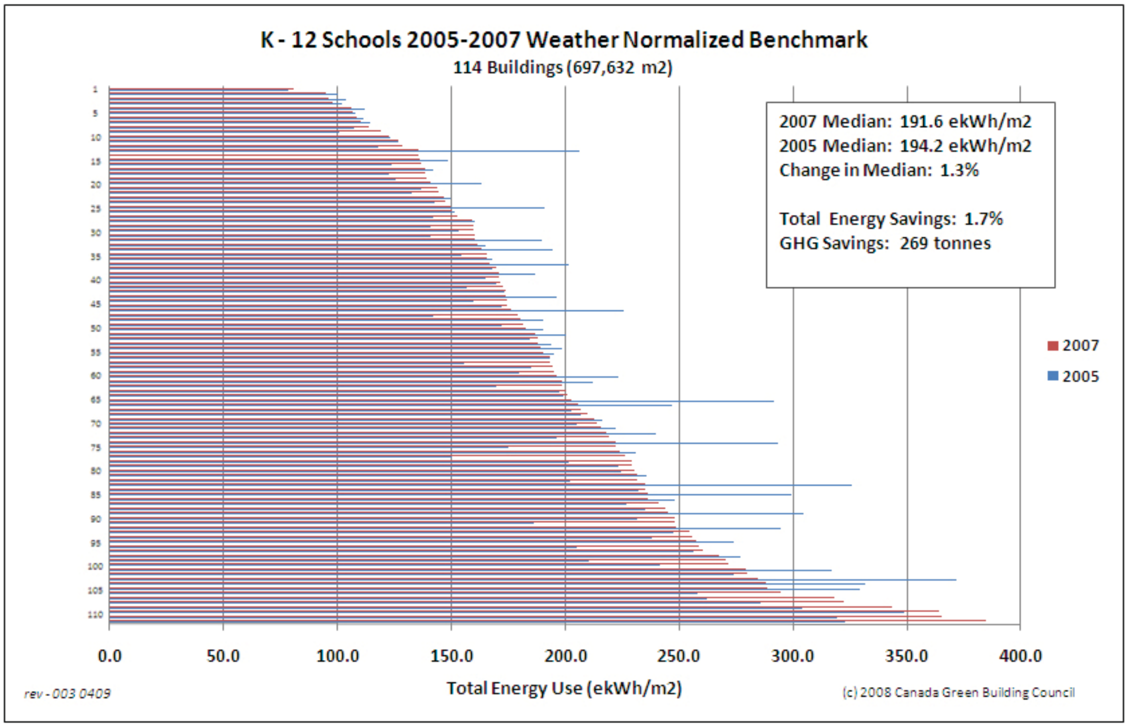


Figure 8: Building performance benchmarking for K-12 school buildings in Canada[9]. For reference, 100 kWh/m² is approximately equal to 32 kBTU/ft².

Table 4: 2003 CBECS national average energy benchmarking[10].

How to Use this Table:

- *The building types listed in blue define a broad building activity category. Some of the broader building type categories are broken down into more specific building activities.*
- *When identifying your building within this table, first identify where your building's function falls within the broader blue categories. Then determine if you are able to identify your building's function more specifically by the white categories underneath. Matching your building's main use activities most closely with the building use descriptions below, will give you the most accurate energy performance target.*

2003 CBECS[1] National Average Source Energy Use and Performance Comparisons by Building Type			
Building Use Description[2]	**Average Source EUI[3] (Kbtu/Sqft)**	**Average Percent Electric**	**Average Site EUI (Kbtu/SqFt)**
Education	170	63%	76
K-12 School	*See Target Finder / Portfolio Manager*		
College/university (campus-level)	280	63%	120
Food sales	681	86%	225
Grocery store/food market	*See Target Finder / Portfolio Manager*		
Convenience store (with or without gas station)	753	90%	241
Food service	786	59%	351
Restaurant/cafeteria	612	53%	302
Fast food	1306	64%	534
Inpatient health care (hospital/ rehabilitation)	*See Target Finder / Portfolio Manager*		
Lodging	194	61%	87
Dormitory/fraternity/sorority	*See Target Finder / Portfolio Manager*		
Hotel, Motel or inn	*See Target Finder / Portfolio Manager*		
Mall (Strip Mall and Enclosed)	271	71%	107
Nursing/Assisted Living	255	54%	124
Office	*See Target Finder / Portfolio Manager*		
Outpatient and health care	183	72%	73
Clinic/other outpatient health	219	76%	84
Medical Office	*See Target Finder / Portfolio Manager*		
Public Assembly	143	57%	66
Entertainment/culture	265	63%	95
Library	246	59%	104
Recreation	136	55%	65
Social/meeting	102	57%	52
Public order and safety	189	57%	90
Fire station/police station	157	56%	78
Service (vehicle repair/service, postal service)	150	63%	77
Storage/Shipping/Nonrefrigerated warehouse	56	56%	25
Self-storage	12	44%	4
Non-refrigerated warehouse	*See Target Finder / Portfolio Manager*		
Distribution/shipping center	90	61%	44
Refrigerated warehouse	*See Target Finder / Portfolio Manager*		
Religious worship	*See Target Finder/Portfolio Manager*		
Retail (non-mall stores, vehicle dealerships)	191	67%	82
Other[4]	213	56%	104

2003 CBECS National Average Source and Site Energy Use and Performance Comparisons by Building Type
Notes:

[1] *Commercial Building Energy Consumption Survey (CBECS), conducted in 2003, was used to calculate values presented in this table. The data is gathered from the Dept. of Energy's – Energy Information Administration (EIA). These are building types that are not currently available in EPA's Portfolio Manager.*

[2] *Buildings Use Descriptions are taken from valid building activities as defined by EIA in the 2003 CBECS data. The average Source EUI and Site EUI are calculated in kBtu/sqft as weighted averages across all buildings of a given type in the 2003 CBECS data set. The building type listed in blue is defined according to the CBECS variable for "Principal Building Activity" (PBA8) which is a broader defined category. The subset of building types listed below those broader categories are defined according to the CBECS variable for PBAPLUS8. These are defined as a more specific building activity within the broader PBA8 category. Note all building type definitions can be found at: http://www.eia.doe.gov/emeu/cbecs/building_types.html*

[3] *Source Energy is a measure that accounts for the energy consumed on site in addition to energy consumed during generation and transmission in supplying energy to the site. Converting site to source energy: Source energy value are calculated using a conversion factor for electricity of 1 kBtu site energy = 3.34 kBtu source energy; a conversion factor for natural gas of 1 kBtu site energy = 1.047 kBtu source energy; a conversion factor for district heat of 1 kbtu site energy = 1.40 source energy; and a conversion factor for fuel oil of 1 kbtu site energy = 1.01.*

Explanation of Source Energy: The source energy intensity target cannot simply be converted into an equivalent site energy value because different design strategies may yield different fuel mixes. Thus the different fuel mixes translate into the corresponding site to source ratios for a specific building. It is important to note that reducing source energy by 50% is not always mathematically equivalent to reducing site energy by 50%. For the most equitable peer comparison, the associated fuel mix should be used to convert the modeled site energy into the total source energy. The source energy use can then be compared to the values in this table.

[4] *Other: For all building types not defined by the list above, these buildings may choose to use the performance benchmark categorized by "other". Note that this category is not well defined therefore source energy use varies greatly with source EUI ranging over 1500 kBtu/sqft. As categorized by EIA, "other" may include airplane hangers, laboratory, crematorium, data center, etc.*

6.3 Energy Simulation Software

Section 3.10 of this report listed and outlined capabilities of some of the most common building simulation software packages.

United States
In the United States, the Department of Energy maintains a list of building energy software tools including whether the software is free for download and has been recently updated. This list is available here:
http://apps1.eere.energy.gov/buildings/tools_directory/subjects.cfm/pagename=subjects/pagename_menu=whole_building_analysis/pagename_submenu=energy_simulation

The list of qualified software for calculating commercial building tax deductions is also available through the US-DOE website located here: http://www1.eere.energy.gov/buildings/qualified_software.html

The building simulation research group at the Lawrence Berkeley National Laboratory (LBNL) contributed to the joint development of the EnergyPlus software and offer tutorials and resources on the software available here: http://simulationresearch.lbl.gov/

The National Renewable Energy Laboratory in Boulder Colorado also offers a list of software and training resources available here: http://www.nrel.gov/buildings/energy_analysis.html

In addition to the above list, the USGBC also references the US-DOE software tool list (mentioned previously). The USGBC's summary on energy modeling tools and resources for LEED projects is available here: http://www.usgbc.org/ShowFile.aspx?DocumentID=3478

Canada
In Canada, the Canadian Green Building Council (CaGBC) provides direction on which software can be used to demonstrate LEED compliance. Currently the list includes:

- EE4
- eQUEST
- DOE-2
- EnergyPlus
- IES Virtual Environment
- Hourly Analysis Program (HAP)
- Trace 700

In addition to providing energy model reviews for models created in the EE4 software, Natural Resources Canada (NRCan) maintains a website for free simulation software tools, available here:
http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/software_tools.html

7.0 QUICK ENERGY MODELING PROCESS – CONCEPT DESIGN STAGE OR LATER

7.1 Introduction

Estimates of the energy and GHG performance of buildings are often needed at very early stages of the project to inform the design and achieve ambitious goals. Often a detailed energy model is not completed until much later in the design process and the opportunity to inform the design is lost. In conjunction with the process outlined herein, early quick computer energy models can be used to refine façades, system options or other design features. This process can inform the team about where work is needed or areas of interest.

The goal of this process is to quickly give the design team a good idea of what the potential energy consumption of a project is and the impact on GHG emissions. More detailed studies on specific issues can then be carried out with a detailed energy model confirming and refining the work done to date. This leads to a much more informed design process.

These quick energy estimates provide an important benchmark in the design process, but should be followed up by more conventional energy models.

A quick energy estimate can be done in an hour or so, if necessary information is available and the project goals are not overly ambitious. A half a day may be needed if the project is examining more complicated building geometry or HVAC systems.

There are a couple of methods to do a quick energy model in an hour or so:

- *Input Wizard* and basic building shapes in software like eQUEST (Quick Energy Simulation Tool) or IES: VE-GAIA (Integrated Energy Solutions: Virtual Environment – GAIA) or the Revit Conceptual Energy Analysis Tool.

- *Spreadsheet analysis* based on previous energy models or breakdowns.

7.2 Project Goals

The project team has to decide on the project goals. The goals could include:

- LEED certification level and suggestion of level of energy savings.
- Specific energy savings compared to the energy code.
- Specific energy use target – in kBTU/ft^2/yr or kWh/m^2/yr.
- 2030 Challenge GHG emissions for a specific completion time (such as 2015).

7.3 How is a Detailed Energy Model Done?

Refer to Section 3.0 on “Energy Modeling Methodology” for details.

7.4 Input Wizard Method

The Input Wizard work is carried out by an engineer, an energy modeler or an ambitious architect using general building shapes. Data like 5 floors at 12 feet floor-to-floor spacing, 50 percent glazing with a certain envelope performance, lighting power density, mechanical system inputs and standard operating schedules gets to a quick answer on potential energy use. By using the parameters for the local code or ASHRAE 90.1, the base case for energy use can be modeled. Options for different glazing, exterior shading, lighting levels or basic mechanical systems can be considered. If the team is familiar with the code insulation, glazing and system parameters a couple of energy models can be run in about an hour.

Some software providers claim that early stage SketchUp and BIM models can be directly imported into the software in order to allow light-weight intuitive energy modeling. One such software is IES VE-GAIA. The new Revit Conceptual Energy Analysis tool may allow architects to quickly convert conceptual design models into analytical energy models and conduct integrated whole building energy analysis within Autodesk Revit Architecture 2011.

Figure 9 is the 3D output from the quick model for a simple office building (eQuest). Note that exterior shades have been added to the west glazing and not to the north glazing. Table 5 shows the energy use output from the quick energy model.

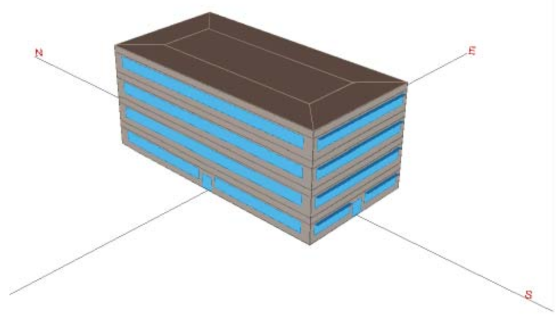


Figure 9: 3D output from a quick model for a simple office building.

7.5 Spreadsheet Analysis

Starting Point

A basic energy performance breakdown is required for the type of project being studied. The energy model base case from a similar project in a region can be used as a starting point for the quick analysis. If the total energy use in kBTU/ft² is known or estimated, a representative end-use breakdown can be estimated.

An example office building in Vancouver, BC is evaluated below that has ASHRAE 90.1- 2004 as an energy code requirement.

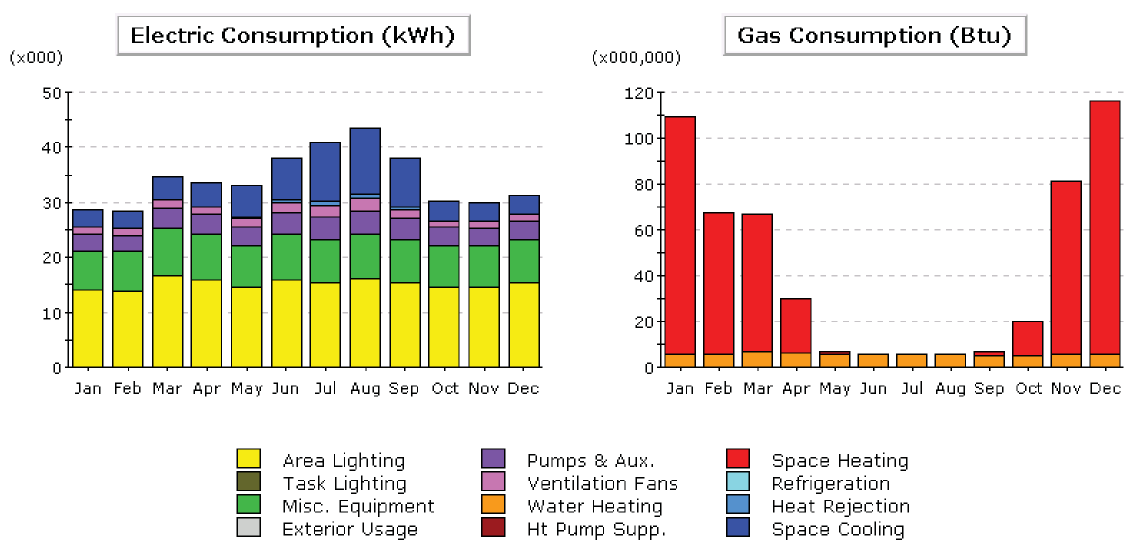
Develop the Data

As an example, the following data outlines some energy use for an office building by end-use group. These are example numbers only. The main end uses such as heating, cooling and others can then be subdivided to assist in analyzing the alternative design options. Generally, this data is not easily available to architects unfamiliar with energy models. An energy modeler can review the model output files on similar projects to obtain the breakdown. No two projects are exactly alike, but it will give a starting point. If this is not available, a quick eQUEST model could produce the data.

Consultants can be put on the spot to provide estimates of the breakdown of energy into the groups and the sub-groups. In the example Table 6, the mmBTU/hr for gas usage has been converted to kWh/yr.

Each of the main groups of cooling, heating, lighting and fan/pumps can next be broken down into sub-groups for analysis.

Table 5: Energy use output from a quick energy model.



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	3.13	3.12	4.09	4.36	5.75	7.56	10.89	11.87	8.77	3.57	3.38	3.43	69.92
Heat Reject.	0.00	-	0.02	0.05	0.20	0.32	0.68	0.76	0.49	0.02	0.01	-	2.55
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	1.36	1.20	1.46	1.33	1.44	2.00	2.21	2.28	1.73	1.22	1.26	1.37	18.87
Pumps & Aux.	3.06	3.06	3.74	3.62	3.45	3.92	4.03	4.26	3.83	3.25	3.23	3.38	42.82
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	7.23	7.11	8.49	8.13	7.55	8.13	7.86	8.18	7.82	7.55	7.50	7.86	93.39
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	13.94	13.87	16.73	16.00	14.64	16.00	15.33	16.03	15.31	14.64	14.61	15.33	182.45
Total	28.72	28.36	34.52	33.49	33.03	37.93	40.99	43.38	37.96	30.24	29.99	31.37	409.99

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	104.15	62.24	60.01	23.68	1.35	-	-	-	1.65	14.82	76.09	110.43	454.43
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	5.53	5.55	6.66	6.30	5.58	5.81	5.39	5.49	5.25	5.16	5.34	5.82	67.88
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	109.68	67.79	66.67	29.98	6.93	5.81	5.39	5.49	6.90	19.98	81.43	116.25	522.30

- The cooling load is broken down into solar load through glass, heat gain from walls and roof, ventilation and other internal loads.
- The heating load is broken down into envelope heat loss and ventilation load.
- The fan and pump energy are also separated.

The quick eQUEST model can provide the breakdown of, for instance, heating energy using the LS-B, LS-C and LS-D pages in the results "Detailed Output Simulation" file. A chart showing the heating energy breakdown for an example office building in Chicago is shown below in Figure 10.

The heating energy breakdown for the example office building in Chicago shows that most of the heating energy is used to heat the outdoor air and offset the window and frame losses. The breakdown will provide an indication of which energy conservation measures will achieve the most energy savings.

The following breakdown figures are for example only and are not figures to use for every project as regional differences and building uses will vary. It is advisable to work with the consultants to generate these figures (and there will probably be some discomfort for the first time, as designers often do not think in energy use terms).

Table 6: Energy use estimates and breakdown. Note that the following data represents the baseline case using inputs from the ASHRAE 90.1-2007 Standard[3].

Energy Use	kWh/yr	mmBTU/yr	Total kWh/yr	% Energy
Cooling	200,000		200,000	5.8%
Heating		4,800	1,406,740	41.0%
Lights	600,000		600,000	17.5%
Misc Equipment	500,000		500,000	14.6%
Fans & Pumps	650,000		650,000	19.0%
DHW		250	73,270	2.1%
TOTAL			3,430,000	100.0%

Table 7 (on page 94) shows the sub-groups and the energy for each is expressed in terms of base building energy use.

The potential savings for various energy conservation measures are then considered and discussed. Estimates of each of these options are made. The percentage reduction of each option is provided and the effect and the resulting percentage of building energy use for that option is determined as seen in Table 8 (on page 94). Some options, like the lighting, are cascaded. The daylight saving only operates on the lower lighting power proposed, not the base load.

These quick methods are used to get a good idea of what the energy use or percentage of energy savings might be for some global design options. Often a detailed energy model could take weeks to complete and this may be too slow for the design process. The results of this quick analysis should be confirmed by more complete energy models.

7.6 GHG Emissions

The preceding energy use data can also be used to calculate GHG emissions. Using the emissions rate for the Vancouver region, electricity is about 25 tonnes/GWh and gas is about 178 tonnes/GWh[6,7]. The summary data from Table 9 can be seen in Table 10.

The GHG emissions rate for electrical utilities varies significantly. Regions with mostly coal fired power can be in the 900 tonnes/GWh range, regions with a blend of nuclear and coal may be in the 600 tonnes/GWh range (near the USA average) and West Coast regions with hydro-electric power can be in the 20 to 80 tonnes/GWh range.

7.7 Summary

The quick energy modeling processes presented are not a replacement for detailed energy modeling, but can provide guidance quickly and early in the design process. The concepts used in this process are also effective for generally reviewing the results of energy models to see if they are operating correctly. The spreadsheet process has been used in the concept stages of a number of projects and the results have been within a few percent of the final energy model results.

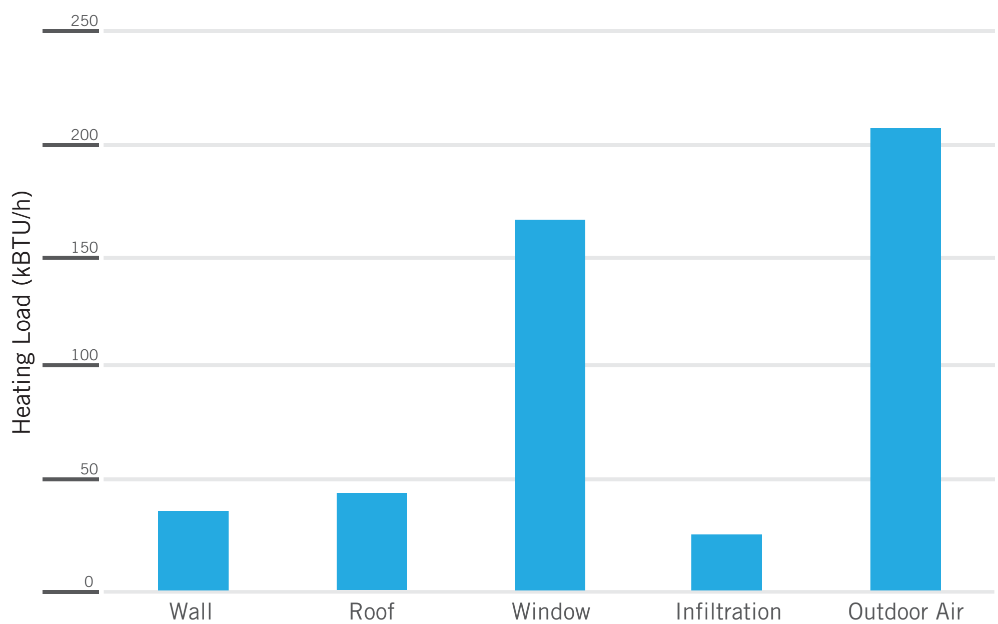


Figure 10: Heating energy breakdown for an example office building in Chicago, IL.

Table 7: Sub-divide energy uses into sub-components.

Main Group	% Bldg Energy	Sub Group	% Group	% Bldg Energy
Cooling	5.8%	Glazing	30%	1.75%
		Skin	10%	0.58%
		Ventilation	20%	1.17%
		Internal	40%	2.33%
Heating	41.0%	Skin + Glazing	60%	25%
		Ventilation	40%	16%
Lights	17.5%		100%	17%
Misc Equipment	14.6%		100%	15%
Fans & Pumps	19.0%	Fans	55%	10%
		Pumps	45%	9%
DHW	2.1%		100%	2%
TOTAL				100%

Table 8: Sub-divide energy uses into sub-components.

Energy Conservation Measures	% Reduction	% Bldg Energy
Provide exterior shading to reduce solar cooling load by	40%	1.05%
Provide better glazing and wall insulation - cooling reduction of	30%	0.41%
Reduce lighting load by 25% - internal cooling load reduction of	40%	1.40%
Provide better glazing and wall insulation - heating reduction of	30%	17.23%
Provide ventilation heat recovery - heating reduction of	50%	8.20%
Reduce lighting load by 25% - lighting power reduction of	25%	13.12%
Daylight control on perimeter - 35% of area, 30% reduction	10.5%	11.74%
Occupancy control for lighting - lighting power reduction of	10%	10.57%
Minimum vent system like chilled beam - fan power reduction of	70%	3.13%
Low air pressure fan system - fan power reduction of	40%	1.88%
Low pump head design - pump power reduction of	30%	5.97%

Table 9: Energy conservation measures are applied to the energy sub-components.

Energy Use	kWh/yr	mmBTU/yr	Total kWh/yr	% Energy	Revised % Bldg Energy	Revised kWh/yr	% Savings
Cooling	200,000		200,000	5.8%	4.0%	138,000	31%
Heating		4,800	1,406,740	41.0%	25.4%	872,180	38%
Lights	600,000		600,000	17.5%	10.6%	362,480	40%
Misc Equipment	500,000		500,000	14.6%	15%	500,000	0%
Fans & Pumps	650,000		650,000	19.0%	7.9%	269,100	59%
DHW		250	73,270	2.1%	2%	73,270	0%
TOTAL			3,430,000	100.0%	64.6%	2, 215,030	35%

Table 10: GHG emissions for the example scenario.

	Base Case kWh/yr	Base Case GHG tonnes/yr	Revised Case kWh/yr	Revised Case GHG tonnes/yr
Electricity	1,950,000	49	1,269,580	32
Gas	1,480,000	264	945,440	170
TOTAL	3,430,000	313	2,215,020	201
				36% GHG reduction

8.0 CONCLUSIONS

In achieving energy-efficient building design, metrics for understanding the impact of specific design features are needed. Without some frame of measurement, the economic and environmental impacts cannot be gauged but only estimated and the risk of using high-cost and low energy savings design features is increased. The timeframe for using energy analysis tools is associated with when the design features are being considered. At very early design discussions, a simple energy model can give an estimate of the project energy needs and review basic design options. As the design progresses to conceptual stage, quick energy modeling can assist in evaluating design and system options or added energy conservation measures. Revising the quick energy model at the late stages of design (i.e. design development) can help ensure the project is on track for energy performance before the final LEED compliance (or similar rating system) energy model.

Energy modeling analysis is conducted on proposed building designs using code-guided assumptions and detailed building inputs, actual building geometry, historical weather files and appropriate usage patterns and internal loads. Project teams provide insight into the proposed mechanical system design and other project-specific parameters. As energy analysis software is generally limited, an experienced energy modeler can simulate a proposed building design by either manipulating the software within the limitations or using external analysis tools to compliment the software analysis. A review of the energy analysis is necessary to avoid unrealistic results or bypass software errors.

After energy analysis has been completed on a proposed building design or after the building has been constructed and is operating as normal, the building performance can be measured in comparison to other similar buildings to determine relative performance. In the United States, the Energy Information Association produces the Commercial Building Energy Consumption Survey. In Canada, the Canada Green Building Council has developed a pilot program to compare Canada's Building Performance by building sector. To assist in ensuring that the building operates as designed and as predicted, measurement devices can be provided that help identify changes in operation or unexpected loads.

Several methods for early-stage quick energy modeling and analysis were presented as an alternative to waiting for the final compliance energy model to estimate building performance. Quick analysis tools, such as eQUEST or the demonstrated spreadsheet analysis, may be used to evaluate design decisions and predict energy use or GHG emissions. In contrast to a final and detailed energy model, quick energy analysis can be conducted within a few hours to a few days providing prompt feedback to design teams.

REFERENCES

[1] Hunn, B., and Conover, D., (2010). “35 Years of Standard 90.1: Early and Mid-1970s & Late 70s, Early 80s”, *ASHRAE Journal*, Vol. 52, No. 3, pp.36-38.

[2] Lawrence, T., (2010). “Understanding Standard 189.1-2009: High Performance, Green Buildings”, Presentation, Retrieved on 9/2010 from http://ali.ashrae.biz/2010FallOnlineCourses/standard189/Standard_189.1-2009_Fall%20Online%202010%20FINAL_CD.pdf.

[3] ASHRAE, (2007). Standard 90.1-2007: Energy Standard for Buildings Except Low-Rise Residential Buildings, Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

[4] ASHRAE, (2009). “Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities: Achieving 30% Energy Savings Towards a Net Zero Energy Building”, Design Guide, Retrieved on 9/2010 from http://www.engineeringforsustainability.org/aedg.html.

[5] Leonardo Academy, (2003). “Leonardo Academy’s Guide to Calculating Emissions Including Emission Factors and Energy Prices”, Report, Retrieved on 2/2004 fromhttp://www.cleanerandgreener.org/resources/reports.html.

[6] BC Hydro, (2009). “Climate Action & Greenhouse Gases”, Webpage, Retrieved on 9/2010 from http://www.bchydro.com/about/our_commitment/sustainability/greenhouse_gases.html#emission.

[7] Terasen Gas, (2007). “The Cleaner Way to Heat Your Home”, Webpage, Retrieved on 9/2010 from http://www.terasengas.com/_AboutNaturalGas/WhyChooseNaturalGas/CleanerWayHeatHome/EmissionsChart.html.

[8] Department of Energy and Environmental Protection Agency, (2000). “Carbon Dioxide Emissions from the Generation of Electric Power in the United States”, Report, Retrieved on 9/2010 from http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2emiss.pdf.

[9] Canada Green Building Council, (2009). “Green Up: Canada’s Building Performance Program”, Pilot Projects Report Results from 2005-2007, Retrieved on 9/2010 from http://www.cagbc.org/initiatives/green_building_performance/pilot_projects.php.

[10] U.S. Energy Information Administration, (2003). “2003 Commercial Buildings Energy Consumption Survey”, Report, Retrieved on 9/2010 from http://www.energystar.gov/ia/business/tools_resources/new_bldg_design/2003_CBECSPerformanceTargetsTable.pdf.

05.
DESIGN CONSIDERATIONS FOR POOL ENVIRONMENTS:
Cold Climates

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ABSTRACT
The natatorium environment is one of the most challenging environments to design and build in northern climates. This is due to the large swings in levels of humidity and temperature between interior and exterior conditions. The challenge remains how to balance the interior pool environment, requiring a consistent temperature and humidity level with the exterior; while taking into account the atmospheric by-products of chlorination.

This article reviews the predominant elements present within the pool environment. It discusses elements that cover a broad range of pool related design issues and explores considerations to be aware of when designing a natatorium and its interfaces. The discussion will first define the basic elements within the pool environment that must be understood, air temperature and humidity, air quality and movement and air pressure. The remainder of the article will cover a broad range of pool-related design issues and explore considerations to be aware of when designing a natatorium and its interfaces. Some of the factors that should be considered during the design phase of a project include the functionality of the mechanical system, the ratio of solid to void in the exterior skin, massing of the pool volume, curtain wall and glazing, finishing materials (interior and exterior) and their durability and control of the vapour migration and roof and ceiling finishes. All will have an impact on decision making. The intention of all decisions is to create an enduring enclosure that provides comfort and recreation to its patrons.

KEYWORDS: air vapour barrier, air handling systems, chloramines, envelope design

1.0 INTRODUCTION
One of the most important elements that we first look at when we begin a project is the environment. We examine the context, site, the weather patterns, views and vista, circulation and a localized characteristics. All together this information provides us with the knowledge that will inform the design process.

When developing a natatorium the approach is similar. By examining the composition of the pool environment, air temperature and humidity, air quality and movement and air pressure, we can establish the type of environment within which we are working.

When the environment is known, we begin to design the necessary elements that will physically generate the pool environment. Any decisions regarding the exterior envelope, interior materials, glazing, roofs and ceilings, volume orientation and structural materials must be considered in relation to the overall pool environment for compatibility. When these items have been thoughtfully considered, we have a better understanding of the functioning of the pool and its limitation and the possibilities of the natatorium typology.

2.0 RESEARCH CONTEXT AND PAST STUDIES
The basic elements contained within a natatorium are: pool(s), deck, slides, change rooms, monitoring, patron viewing, saunas, whirlpools and spray features. All of these items contribute to the functionality and patron experience within a pool. The factors that affect conditions include air temperature and relative humidity, air

movement and air pressure. These elements are impacted by the large swings in external temperatures to which the pool environment must adjust to maintain its operation balance. The following sections review considerations for interior natatorium environments.

2.1 Air Temperature and Humidity

The air temperature of the pool environment needs to be set higher than the temperature of the pool water to prevent condensation occurring on interior surfaces. Typically, it is set to be two-three degrees warmer than the water temperature and is typically designed to be 77 degrees F for competitive pools to a warmer 94 degrees F for therapy pools. The humidity level will be approximately 60-65 percent. These conditions influence design considerations such as choice of materials within the pool area, air handling and condensation issues[1].

Materials within a pool should always be impervious to moisture penetration. By preventing the use of carpet, untreated gypsum board, wood laminates as well as untreated metals premature deterioration can be avoided. Elements like door and window frames should always be constructed of aluminum due to their inherent resistance to constant moisture (the composition of the wall assemblies will be discussed later). Permanent elements within the pool area such as spray features, hand rails, hanging acoustic panels, lighting and signage should all be considered for materiality.

2.2 Air Quality and Air Movement

Perhaps the largest misconception is that the quintessential 'smell' of a pool is attributed to the use of chlorine. In fact this odour is created by chloramines. Chloramines are a by-product of the interaction of bather's sweat, body oils and other ammonia-nitrogen compounds with lower than required levels of chlorine, creating chloramine compounds. Airborne chloramines in large quantities will begin to irritate bathers and can begin to infiltrate spaces creating on overpowering smell that can affect patrons not involved in the pool function[2].

This is one compelling reason why the decision regarding air movement within the pool environment is pivotal. Another is that chloramines are corrosive and will hasten the deterioration of unprotected metal surfaces. Even stainless steel is not fully resistant to the actions of chloramines. There are various mechanical air and water treatments that can be used to lessen the quantity of chloramines in the pool environment, but these will not negate the need to separate the pool environment or choose resistive materials and finishes.

Several methods can be used to deliver air to a pool volume, but the most effective is the method that will provide the best air movement within the volume. While low-level supply air will provide maximum comfort for bathers, it also creates the condition for condensation at the ceiling level. The amount of air flow created with perimeter supply at the exterior walls will prevent condensation at the exterior glazing, but will do very little to address the temperature needs of the bathers. Higher level return with low level supply creates a convective current of air that maximizes air circulation through the pool volume. Separate perimeter supply at glazing will address the issue of sweating glass during the seasonal shifts in temperature. The components of the supply and return of air will be discussed in more detail.

2.3 Air Pressure

The air pressure that builds up in the humid pool environment will inevitably seek to escape through the easiest path to the location of lesser pressure. In a pool environment, controlling and mitigating this pressure is necessary to maintain the necessary relative humidity and temperature, but also to protect the HVAC system, the exterior shell and the surrounding interior spaces. Serious air leakage due to pressure against poorly installed, poorly detailed or incompatible materials will force the HVAC system to continually condition air, thus reducing its efficiency and its life span. To guard against this scenario, the pool volume should remain in constant negative pressure. By doing so, chloramines and moisture will not be permitted to escape into the remainder of the facility and at the same time the pool will be replenished with dryer air than what is present within the pool. This is especially advantageous in the summer months when the exterior air can be warmer and more humid than the pool environment. Drawing the already conditioned interior air, albeit a small amount, will allow the HVAC to run more smoothly, negating the need for make-up air from the exterior.

The environmental considerations discussed in this section will have a significant effect on the design decisionmaking process. Detailing to avoid air leakage, maintaining negative air pressure and protection against material adjacencies for prolonged durability of the facility, program, circulation, enclosure, cost and construction all play a role. To determine the course of action, a series of basic design decisions become necessary without which these elements can cause problems within a pool environment, leading to prolonged shut-down and costly repairs. The following section dis-

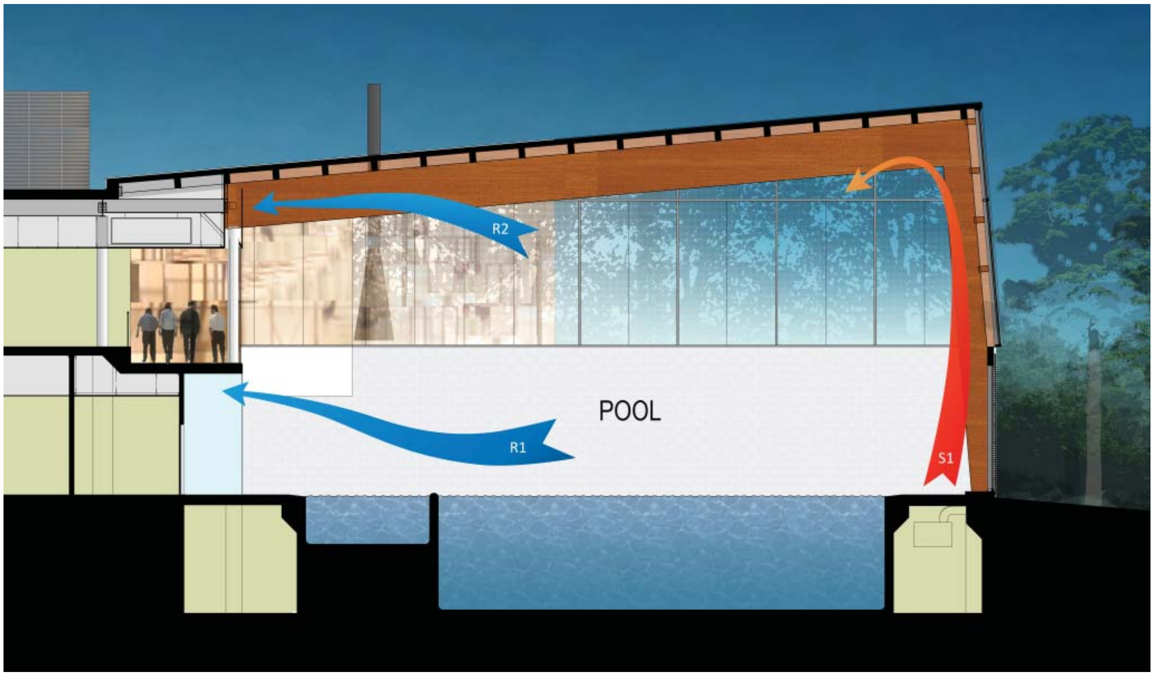
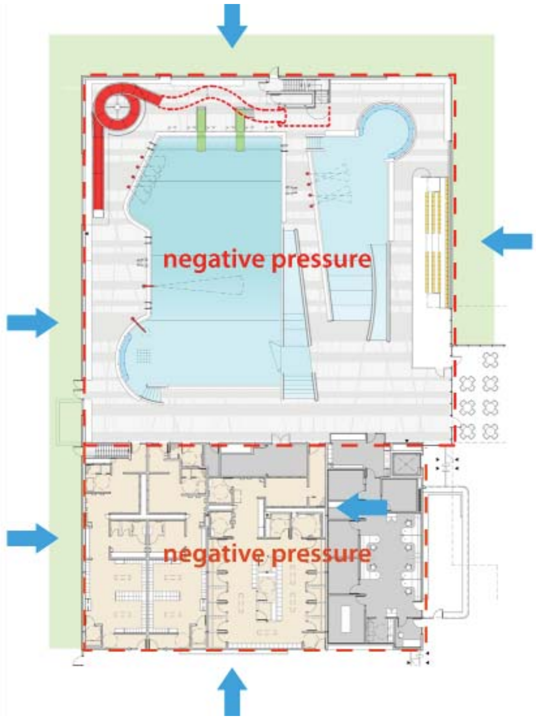


Figure 1: Air movement; S1- provides perimeter low level air supply, moderates temperature at glazing; – R1 - return air draws air from above the pool tank; R2 - return air draws air from high level.



Figures 2: Illustrates the pressure required in a pool environment and the adjacent spaces.

cusses design considerations and guidelines that can be followed.

3.0 DESIGNING FOR QUALITY 'DECISION POINTS'

3.1 Air Handling Systems

Two points of view exist when considering options for HVAC systems to be used in a pool environment:

1. The 'push-pull' system consists of a make-up air handling unit sized for six air changes/hour. The unit is capable if exhausting 100 percent of the supply air during a period when the exterior air conditions permit free cooling. The unit will typically run with minimal outdoor air to control the humidity. The air handler is complete with filtration and heating coil, but no cooling coil, which can cause problems in northern climates. The problem is that the unit is much less effective in the warmer summer months where the exterior air can be equally, if not more, humid than the air within the natatorium. No cooling coil means that the increase in temperature and humidity within the pool cannot be controlled. This condition would occur approximately 15 percent of the time depending on the geographic location.

2. Pool Area Dehumidification Systems (PADS) are sized for approximately four air changes/hour. The compartmentalized unit contains a supply fan, heating coil, refrigerant cooling coil and has the ability to transfer recovered heat into the supply air stream or into pre-heating of the pool water creating energy savings and reducing the operational cost of the overall pool system.

Both systems are suitable for use in northern climates, but as the demand continues to grow for more energy efficient buildings, so will the demand for the systems that are required to handle a greater range of conditions.

Evaluating the two systems will bring three considerations to light. The PADS system will provide continuous control of the environment during all seasons while the 'push-pull' will be forced to mimic the summer temperatures in temperature and humidity. A higher capital cost of the PADS will be offset by a four-six year payback through the heat recovery used for the pool water and the outdoor air. The final, perhaps the most important and least tangible, is the effect that a consistent humidity level has on the structural elements within the pool and its adjacent spaces. Pool environments that are susceptible to swings in relative humidity will allow conduits of corrosion to develop and will pre-maturely deteriorate the facility over time. Due diligence suggests that a PADS type system is perhaps the best solution given its potential for energy savings and ability to maintain a constant negative pressure while providing a relatively short payback.

3.2 Envelope Design

There are two envelope considerations: the internal and external. The design of exterior walls requires a balance of achieving design intent to attract visitors while maintaining a comfortable interior environment. In this case, careful decisions will ensure that the building is suitable aesthetically, but also tectonically. For both the internal and external envelope, the designer must bear in mind that the goal is to ensure the aquatic space remains in negative pressure. Proper material selection and detailing is required to ensure the wall system withstands the pressure differential from interior to the exterior.

3.2.1 Air Vapour Barrier

A continuous vapour barrier is critical to maintaining air pressure differential and separation of environments. All exterior solid walls will be required to have a vapour barrier that ties into the curtain wall/screen system to ensure continuity. Care should be taken to ensure that the impermeable vapour barrier is installed on a flat surface and should be overlapped by 12 inches and tapped at all joints on the warm side/pool side of the insulation. This will ensure that the pressure being exerted on the exterior envelope, from keeping the pool volume in negative pressure, is not escaping into the wall and condensing. To further protect the wall system, using spray-applied urethane foam is ideal for use in a pool environment. It is forgiving in terms of its application over less than perfect wall constructions and it will also expand to fill all voids leaving less chance that small capillaries will remain through which moisture can migrate. It should be noted that spray-applied urethane foam is not a vapour barrier. Spray foam insulation should be used in conjunction with a compatible adhered membrane to ensure maximum moisture protection[3].

3.2.2 Structure and Exterior Wall Materials

Masonry is a logical choice for the interior wythe of an exterior pool wall. It will provide a durable base on its own or can act as a substrate for an impervious finishing material. It also has spanning capabilities. Typically, a block wall can span vertically a sufficient distance to interface with a horizontal steel girt that will be performing two functions (supporting the curtain wall system and providing lateral support at the top of the masonry wall). Depending on the volume and the configuration of the curtain wall system, the introduction of several levels of girts supporting block is an acceptable way to create the overall wall system.

The supporting steel structure must be thoughtfully detailed and the layer of finishing should be clearly specified. Columns, girts, roof decking, supports and bracing should be factory cleaned and primed with final painting taking place on site. Site welding should also take place at steel connections in lieu of bolted connections. This will reduce areas where condensation can occur creating staining on the surrounding steel and the pool deck. The use of other metals in the pool should be approached with care. Door frames, grilles, escutcheon plates and handrails should be constructed out of stainless steel or aluminum, depending on what is appropriate. Both provide good moisture resistance[3].

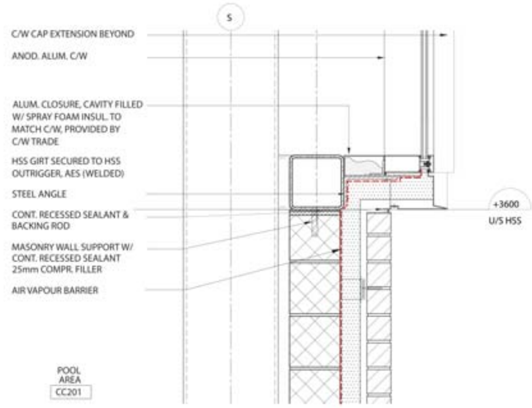
Another structural option is treated engineered wood. Due to the capacity of the treated wood to resist moisture and absorb thermal changes, wood has a significant advantage in the longevity of the wood surface that will not require maintenance in a continuously humid environment.

Curtain wall glazing is the recommended system for a pool environment due to its specified thermal performance. Whether annodized or pre-finished, the curtain wall should be aluminum with specified warm edge spacers, argon filled cavities within the glazed units and fiberglass pressure plates. These provide further protection against thermal bridging. Care should be taken to detail the tops of the curtain wall verticals and fill them with spray insulation. Premature failure of the curtain wall can occur through convective current within the curtain wall frames themselves. Air, heated from contact from the sun, will rise through the vertical mullions and, if not properly sealed, can exhaust warm air on colder steel either at parapet details or at intermediate supports and cause premature corrosion. The curtain wall should also be detailed to separate the horizontal mullion at the bottom from the ground condition. Freeze-thaw action underneath the caps of the curtain wall can rupture the sealed units and, within a pressurized pool environment, water vapour will quickly move into these locations and condense leaving the window units permanently foggy until they are replaced.

Wood is generally not acceptable in large quantities as an exterior wall construction material. Structural wood decking, however, is ideal as a roof plane. Depending on the species specified for the loading conditions, various treatments are available to prevent the typical degradation of material one would expect. The density, thickness and self-sealing ability of wood allow any anchored elements to the underside of the deck to be corrosion free, unlike a metal deck. The use of exposed unpainted wood warms the space giving a more tactile feeling to the facility and eliminates any future maintenance. For a lasting appearance, wood deck should be treated and sealed.

Exterior cladding will be in contact with the climatic elements on a continual basis. To perform as a cladding material, the pre-requisites are simple: have a very low water absorption, allow for and maintain the ability to construct a pressure equalized rain screen and be durable in all weather conditions. Standardized unit masonry will facilitate this with ease as will any number of pre-manufactured panel systems. Almost any combination of materials can be implemented as long as bulk water is not trapped against the insulation (to limit the possibility of water to move into the building through wind pressure and the cavity) and has the ability to dry out.

3.2.3 Interior Wall Materials
The use of masonry as an interior demising wall is acceptable as long as the following considerations are adhered to. The pool environment must be under negative pressure. This will allow a painted block wall, through its inherent properties, to act as an air barrier and retain the air within the pool enclosure. The demising wall of masonry should also separate the pool from the locker rooms and associated spaces. Adjacent spaces such as locker rooms do not require insulation or continuous vapour barriers, as the environments are complimentary and the condensation of moisture within the cavities of standard masonry block is not likely. Since the moist air is constantly being evacuated around the block and not through them.



Figures 3: Section detail locating the vapour barrier on the warm side of the insulation. *Note:* The detail shows interface and transition from the vertical wall into the anodized curtain wall system.

Separation of programs dissimilar from the pool environment can be achieved through the use of aluminum framed glazed screens. Hollow metal, stainless steel or galvanized metal frames, over time and without a diligent maintenance routine, will succumb to corrosion.

3.2.4 Roof and Ceiling Finishes
Material selection for the ceiling of a natatorium is connected to a multitude of elements: acoustics, ceiling fixtures, roofing materials selection, HVAC ducting and structural elements. There are three options for the finish of a ceiling in a pool: wood, concrete or steel. In all cases the structure should remain exposed, as suspension systems within aquatic centres can be problematic due to the possible erosion of suspension framing. For wood decking, the cross nailed tongue and groove profile of the decking provides a uniform continuous level surface. It is possible to specify the use of sleepers above the deck to create an interstitial space that sup-

ports the routing of conduit and plate bracing. Aesthetically the pool volume will be unencumbered with the visually distracting conduit and wiring that supports the lighting, alarms, controls and A/V equipment. If this is not possible or affordable, the depth of the wood decking will allow anchoring of the system elements with the advantage that wood will self-seal around the anchors and not deteriorate or rust. The same is not true for steel deck. Penetrations through steel deck may corrode, therefore, the specification for the decking must be upgraded from a typical assembly.

Any steel deck within the pool environment must have a prefinished synthetic non-corrosive coating finish on the top and bottom with a dry film thickness of 8mil to resist corrosion. The deck must be fastened to the structure and not welded to avoid damaging the surface. Any deck penetrations are to be corrosion resistant and painted to match the deck. To maintain the environment under negative pressure, it is necessary to fill the deck flutes top and bottom along the perimeter of the pool. This also supports the intent of preventing the mixing of colder air above the deck with the warm moist air of the pool creating condensation in an area that is impossible to drain. Maintaining the non-permeable enclosure is not possible with an acoustic deck and should be avoided in the pool area. The acoustic properties in this type of steel deck are achieved with the use of perforations in the deck, which will trap moisture and corrode the deck from above in a pool environment. Instead, the use of acoustic panels is one alternative that provides an opportunity to accentuate the environment.

Lastly, concrete can be used within a pool environment without issues. The robust nature of concrete gives it the longevity to continually perform. It will, however, require acoustic treatment more so than wood or steel decking systems.

Acoustic panels play an important role in the life safety of a pool. Pool environments tend to be large open volumes this creating the ability for sound to travel in many directions, continuously reverberating and creating an echo. This poses a problem for the life guards. With a long reverberation time, it becomes difficult to distinguish between sounds. The life guard's whistle, a call for help or just joyful shrieking can be confused. Acoustic panels in the pool can be mounted to the walls or ceiling. In either case the panels are made up of two inches of semi-rigid insulation within an aluminum frame that is fully wrapped in a perforated, moisture resistant material covering. The acoustic panels can be suspended with stainless steel fittings and cables. The quantity for acoustic covering required mainly depends on the volume of the environment and the desired reverberation time. Typically, a reverberation time of three to five seconds is common.

Perhaps the most common element that is overlooked in the pool environment is the roof membrane and the roof vapour barrier. The shift towards sustainable building practices has more buildings moving away from modified bitumen roofing, Ethylene Propylene Diene Monomer (EPDM) and built-up roofs in favour of Thermoplastic Polyolefin (TPO) or reflective roofing systems. These newer roofing systems can assist in achieving green building rating systems, such as LEED, but must be installed in the correct manner. Any membrane in-

Figure 4: a) Steel roof deck over a steel and concrete structure with perimeter and centralized supply of air; b) Wood deck over a steel structure with perimeter only air supply.

stalled over a natatorium roof must be fully adhered. Typically, they are mechanically fastened, which creates the opportunity for the deck to be penetrated by incompatible fasteners that will only serve to increase the pace of corrosion in a metal roof deck. The roof vapour barrier must be self-sealing and adhered to the substrate. This ensures that the penetrations will be sealed. Lesser quality vapour barriers such as craft paper should not be considered for this application.

3.2.5 Exterior Wall Orientation

When deciding on the ratio of solid versus void the orientation and site conditions become important. With pools, controlling glare and heat penetration should be at the forefront. Changes in latitude affect sun angles, but generally protecting the pool environment from intensely consistent southern sun path is ideal. Northern light is the most advantageous as it is the most constant in rendition. Depending on the programming of the facility, eastern morning light may be favorable due to lower bather count. Reducing the heat gain from exterior light would be more beneficial in the afternoon and evening where the bather count is high in a warmer environment.

3.2.6 Glazing

Using the variables above, the massing of the skin should be designed to have lower bands of transparent glazing that allows light in without glare. While a southern elevation may have double height glazing, there is an advantage to splitting the glazing to reflect/block the intense sun above, but allow segments of light to enter the volume from below. Similarly, the west elevation could take advantage of the vista created by the setting sun by having a translucent screen at high level and a more transparent screen at low level. Ceramic fritting can also be used within the curtain wall system to control and block glare and heat gain. The decision to frit glass is necessary early in the process and should be designed to provide the maximum glare control.

All together heat gain and glare can be controlled by glazing and by the installation of motorized blinds. Motorized blind installation may create other problems from long runs of exposed conduit to cutting and drilling into materials that may have only been face-treated, therefore, negating the resistance to corrosion. It is advisable to plan and implement motorized blinds against heat gain and glare within the design stages. If done correctly, the units can be incorporated into the horizontal girt system used to support the walls themselves.

Figures 5: Shading devices within a pool environment.

4.0 CONCLUSION

The intent of this article is to illustrate the varied and often interconnected levels of decision-making that are involved in designing a pool environment. From the outset, many decisions must be made that will affect not only the pool environment, but the cost of the project. It then becomes important to ensure that when the decisions are being made that a comprehensive pros and cons mode of evaluation be employed to give the designers and the clients the necessary information to make informed design decisions.

In the early phases of the design, decisions relating to the air temperature and humidity will be determined by the type of pool that is being designed and the types of services the client will be able to offer their end-users (leisure pools versus therapy pools). Deciding on how the environmental balance is to be maintained is perhaps one of the most important factors to be considered. The larger pool environments will require larger conditioning system. This affects everything from the assembly of the exterior walls to the orientation of the pool volume and the interior finishes. Assemblies have to be incorporated that are both robust and capable of withstanding air pressure and protect against moisture migration through the system from high to low pressure.

By understanding and addressing the issues of materiality, air temperature, humidity, placement and types of vapour barrier, glazing, ceiling materials, volume, wall assemblies and HVAC systems, we can begin to re-examine the use and functionality of these items and continue to innovate in the development of the pool typologies.

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REFERENCES

[1] John, G., and Campbell, K., (1996). *Ice Rinks & Swimming Pools: Handbook of Sports and Recreational Building Design Volume 3,* 2nd ed., Oxford, UK: Architectural Press.

[2] Griffiths, T.,(2005). "Clearing the Air: Chloramine Control for Indoor Swimming Pools", Retrieved on 10/2010 from http://www.waterandhealth.org/newsletter/cleaning_air.html.

[3] Lotz, W., (1995). "Indoor Pool Design: Avoid The Potential For Disasters", *Heating/Piping/Air Conditioning Engineering,* November, pp. 47-49.

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