Living Proof

THE BULLITT CENTER

High Performance Building Case Study

University of Washington
Center for Integrated Design

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with support from
Northwest Energy Efficiency Alliance (NEEA)

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Figure 1. The Bullitt Center nearing completion, January 2013 (John Stamets).

I INTRODUCTION

"There is not a single urban office building in the United States that is truly designed for today's environment, much less for tomorrow's, so we set out to build one: the greenest urban office building in the world."

- Denis Hayes, President & CEO, the Bullitt Foundation, Seattle, WA

1.1 EXECUTIVE SUMMARY

This report encapsulates the story of the origins, the design, and the performance of the Bullitt Center, an ambitious experiment to create a new paradigm for 21st century buildings. The realization of this building is a story of how a visionary building owner, an integrated design and construction team, supportive regulatory agents, and progressive financial partners came together with a common purpose to achieve an extraordinary result.

This building manifests the vision of Denis Hayes, president and CEO of the Bullitt Foundation. It was his tenacious advocacy for the idea of a living building, and his conviction that the mission of the Bullitt Foundation would be served well through this large commitment of the Foundation's resources to create a model for a completely new kind of building, one aimed at catalyzing a radical shift in our thinking about what's possible for buildings of the 21st Century.

Figure 2. The Bullitt Center's 242 KW PV (photovoltaic) array (Benjamin Benschneider).

This report is an effort to provide building owners, designers and builders with useful lessons to inform the creation of the next generation of super high performance buildings. It illustrates some of the critical elements of both the integrated design process that guided the building's development and construction, as well as the integrated design systems employed in the building. This includes how the design and construction team was organized, and the iterative, synthetic design process used in its creation. The process of integrated design is aimed at creating a building that operates as an integrated system, a whole that is greater than the sum of its parts. Individual energy efficiency measures are not discrete strategies, and can neither be added nor subtracted without disrupting the whole, since each measure is a part of an intertwined system of architectural and mechanical elements working in concert to achieve very high levels of performance.

The building has exceeded expectations for thermal comfort and daylighting, as well as energy use during its first year of operation. Throughout the first year of operation the building was warm and draft-free in the winter, cool and comfortable in the summer, and beautifully daylit year around. Occupants of the building express a high level of satisfaction with the quality and comfort of the indoor environment.

PAE Consulting Engineers established two performance benchmarks to measure its energy performance against. One is the EUI (Energy Use Index) for an average office building in Seattle (Energy Star score = 50), which has a EUI of about 72 kBTU/sf year. The second is an approximation for a 2009 Seattle Code minimum building built on this site; it has a EUI of about 42 kBTU/sf year. The target EUI for the building was 16.1 kBTU/sf year. From May 2013 – April 2014, the first 12 months of occupancy, the building's EUI was 9.4 kBTU/sf year, about 41% better than *predicted performance* and 77% better than a 2009 Seattle Code minimum building.

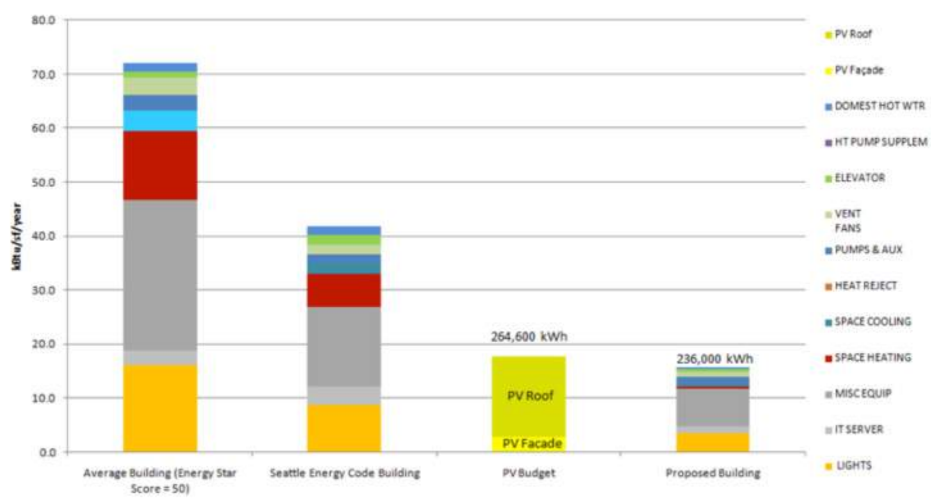


Figure 3. *Energy performance benchmarks during early design: average Seattle office building (EUI = 72 kBTU/sf yr); Seattle code office building, 2009 (EUI = 42 kBTU/sf yr); target for the Bullitt Center (EUI = 16 kBTU/sf yr). (PAE)*

Occupancy accounts for part of the Bullitt Center's exceptional energy performance. On average the building was occupied at about half of its *design occupancy* during the first year. Since about half of the building's predicted energy use is from "activity loads" directly tied to the number of people using the building, the corrected target for the building's energy use is about 12.3 kBTU/sf year. At the Center for integrated Design we're working with the design team to understand how energy is used in this building to know why its performance is exceeding predictions.

Whole building energy and power use, and energy production data, has been collected since the PV power production plant went on-line and began supplying the building with energy in early 2013. But while every circuit in the building has the capability of being monitored, validating end-use, circuit-by-circuit data has been elusive. Until we have reliable end-use data, we can only speculate why the building is performing even better than anticipated.

		ACTUAL		PREDICTED		DIFFERENCE	
	Month	Consumption	Production	Consumption	Production	Consumption	Production
		kWhr	kWhr	kWhr	kWhr	kWhr	kWhr
	May	8,360	34,372	17,775	34,220	-9415	152
	June	7,770	37,831	18,832	36,850	-11062	981
	July	8,060	42,429	20,314	38,870	-12254	3559
2013	August	8,070	31,880	20,612	33,210	-12542	-1330
	Septamber	7,950	20,543	19,837	24,020	-11887	-3477
	October	11,530	14,106	18,211	16,140	-6681	-2034
	November	13,460	7,664	19,981	7,260	-6521	404
	December	17,370	4,914	22,376	4,830	-5006	84
	January	16,210	5,993	21,551	5,950	-5341	43
2014	Feburary	15,010	10,496	18,086	10,660	-3076	-164
	March	13,160	16,450	20,352	19,850	-7192	-3400
	April	10,850	25,207	18,462	25,910	-7612	-703
	Year One Totals	**137,800**	**251,885**	**236,389**	**257,770**	**-98,589**	**-5,885**
						-41.7%	-2.3%

Table 1. *Bullitt Center First Year Energy Use and Production, May 2013 – April 2014.*

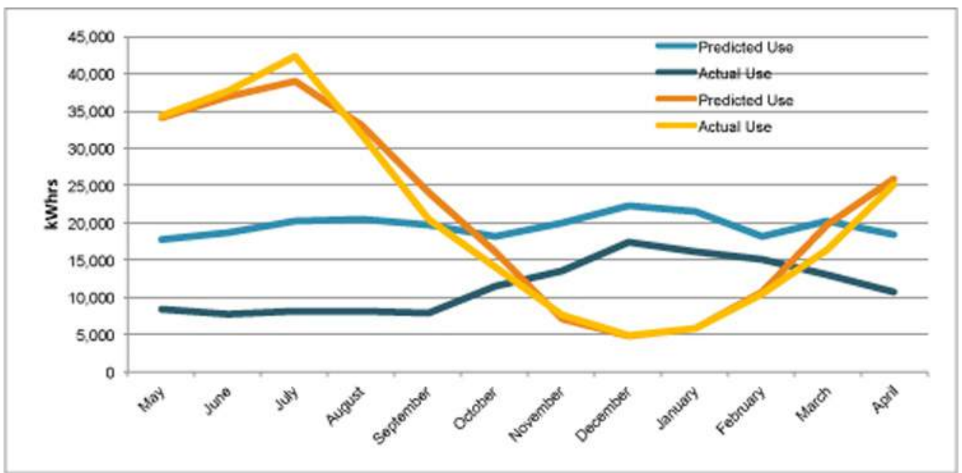


Figure 4. *Bullitt Center year one energy use and production: predicted vs. actual.*

Brief project perspectives by the building's owner and members of the design and construction team are included at the end of this report. With the benefit of hindsight, the project team describes some of what went well, and some lessons learned that might be applied to other living buildings.

The Bullitt Center is an audacious and provocative experiment. It challenges expectations for how efficiently a modern office building can operate. It raises questions about the optimum scale for a power plant, a water purification plant and a waste treatment facility. It is living proof that a large, urban office building can operate on the rainwater that falls on it and can generate as much energy as it uses over the course of a year - in the least sunny city in the country.

The Bullitt Center is a work-in-progress, an experiment whose results are just beginning to emerge. Unless it informs, inspires and propagates other super high-performance buildings, the experiment will have been a failure. This report is intended to inform discussions regarding the design, construction and operation of truly sustainable 21st Century buildings.

1.2 FORWARD

Rays of Hope: The Transition to a Post-Petroleum World, by Denis Hayes, was first published in 1977. It describes the existential threat posed by climate change caused by human sources of atmospheric carbon, and it proposes an alternative energy future, one based on efficiency and renewable sources of energy. When it was first published, air pollution and disruptions to the nation's energy supply, a result of two OPEC oil embargoes during the 1970s, dominated the public conversation about energy. There was growing interest in solar energy and technologies to reduce our dependence on imported oil. However, there was almost no public awareness about the larger consequences of atmospheric greenhouse gases. Ahead of his time, Denis' message is even more compelling now than it was then.

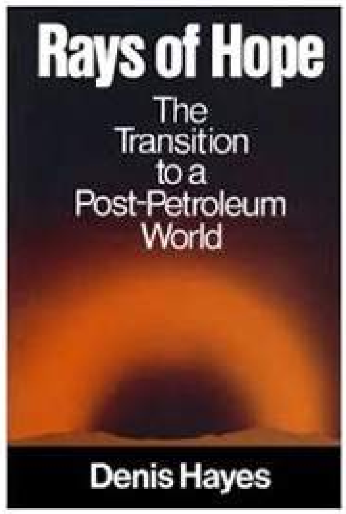


Figure 5. Rays of Hope: The Transition to a Post-Petroleum World, Denis Hayes, 1977

Denis was well known for his role in launching the first Earth Day in 1970, an event that catalyzed my own thinking about our relationship to nature, and the use of resources. In *Rays of Hope*, Denis introduced many of us to this much larger imperative for moving beyond fossil fuels.

Rays of Hope outlined the parameters for a sustainable energy economy based on the twin pillars of energy efficiency and renewable sources of energy from the sun. It also drew a clear connection between energy use in buildings and atmospheric carbon, and the critical importance of building performance in in the coming battle against climate change.

In 1970, Earth Day and the teach-ins held at my middle school catalyzed my early environmental activism. In college, *Rays of Hope* pointed me towards a career in high performance buildings and renewable energy. So when I graduated from the University of Colorado, I pursued an internship at the Solar Energy Research Institute (SERI) in nearby in Golden. SERI was a new national laboratory inaugurated by the Carter administration and headed by Denis Hayes. Its mission was to move the country away from fossil fuels to renewable energy sources, with the goal of 20% renewables by 2000.

This was the summer of 1980, six months into the presidency of Ronald Reagan. Three weeks into my internship, the entire lab, nearly 700 employees at the time, were gathered for an address by Denis Hayes. To everyone's surprise Denis delivered a powerful resignation speech in protest of the new administration's slashing of federal funding for renewable energy and energy efficiency. These budget cuts resulted in the loss of nearly 80% of SERI's funding and employees that summer; and it changed the course of my own career.

I left SERI at the end of the summer and returned to New Mexico where I worked for two years in structural engineering before going back to school for a graduate degree in architecture. At UC Berkeley I worked with the building science faculty and focused my studies on environmental control systems and urban ecology. Since then I've been in professional practice with firms specializing in high performance buildings, and have taught design and environmental control systems. I've had the good fortune to teach and practice architecture with some of the modern pioneers of green architecture including Sim Van der Ryn, Ed Mazria, John Reynolds and G.Z. Brown.

Shortly after arriving at the University of Washington in 2007 to teach energy and design in the Department of Architecture, I was invited by Denis Hayes to discuss the idea for a super-green, high performance building in Seattle. Shortly afterwards, with support from BetterBricks and the UW College of Built Environments, the UW Integrated Design Lab (IDL) began working with Denis and the Bullitt Foundation to identify a path towards making the highest performing green urban office building in the world.

Since then, my colleagues and I at the IDL have served in a variety of roles on the development, design and operation of the Bullitt Center. Joel Loveland, the IDL's director, helped the Bullitt Foundation draft a request for proposals (RFP) seeking architectural firms to lead the design effort. Parallel with the design team selection process, we lead an interdisciplinary design studio at the University of Washington where students developed three conceptual design proposals for the Bullitt Center. Candidates from the short-listed firms served as reviewers and advisors to the students working on conceptual design proposals. The completion of this academic

Figure 6. *Conceptual design proposals for the Bullitt Center developed by two teams of University of Washington architecture, construction management, and engineering students, 2009*

design studio coincided with the selection of the Miller Hull Partnership to lead the design of the Bullitt Center. The student design concepts and the research and analysis behind them, along with the studies done by the Integrated Design Lab, were provided to the design team to set the table for their work.

The design team led by Miller Hull included several consulting partners, including the IDL. Chris Meek at the IDL led the daylight analysis of the building, and we were advisory members of the AEC (architect/engineer/contractor) team throughout construction of the building.

The IDL is now a tenant in the Bullitt Center, operating as part of an enlarged organization called the UW Center for Integrated Design (CID). The IDL operates the research and technical assistance side of the Center, while the Discovery Commons is dedicated to education and outreach. Our mission is to inform the public about energy efficiency and renewable energy in buildings, and to educate the next generation of designers and builders to create super high-performance buildings that are prepared to meet the challenges of the 21st century and beyond.

The Bullitt Center is a living laboratory that we're using to learn all we can about how to design, construct and operate super high-performance buildings. Our intention is to share everything we learn from this experiment and to apply this knowledge towards the creation of other high performance buildings and a more healthy and sustainable built environment.

Figure 7. ***The Center for Integrated Design Discovery Commons on level one of the Bullitt Center***

1.3 ACKNOWLEDGEMENTS

This case study was produced by the University of Washington's Center for Integrated Design (CID) with support from the Northwest Energy Efficiency Alliance, BetterBricks initiative. When this building was still just an idea, Joel Loveland, the retiring director of the Integrated Design Lab, had the wisdom and foresight to recognize not only the significance of this project, but its potential as a vehicle to help teach and prepare the next generation of architects to design super high performance buildings. John Jennings at NEEA shared this vision and has been a steadfast advocate for documenting the design and construction of this project, monitoring and analyzing its performance, and sharing the lessons learned with the design community. John's patience and perseverance in the development of this study, and ongoing support to monitor its performance, are gratefully appreciated. Jeff Cole provided valuable feedback and editorial assistance on this and many previous studies at the IDL. He is a most valued partner.

We would like to express our gratitude to the members of the Bullitt Center project team for their contributions to this report. Special thanks go to Miller Hull Architects who were interviewed for this report and developed many of the illustrations, including Margaret Sprug, Brian Court, Ron Rochon, Craig Curtis, Dave Miller, Cory Mattheis and Nicole Reeves.

PAE consulting engineers have generously provided illustrations and information that went into this report. The PAE team includes Paul Schwer, Justin Stenkamp, Marc Brune, Conrad Brown, Scott Bevin and Steve Reidy.

The Bullitt Foundation made a courageous decision to devote a large portion of its endowment to this project. In a world that operates for the short-term, this commitment to progress on a long-term horizon energizes our hopes for the future. But it took the vision, commitment and persistence of Denis Hayes to make this idea a reality. We are all grateful for his leadership and his example.

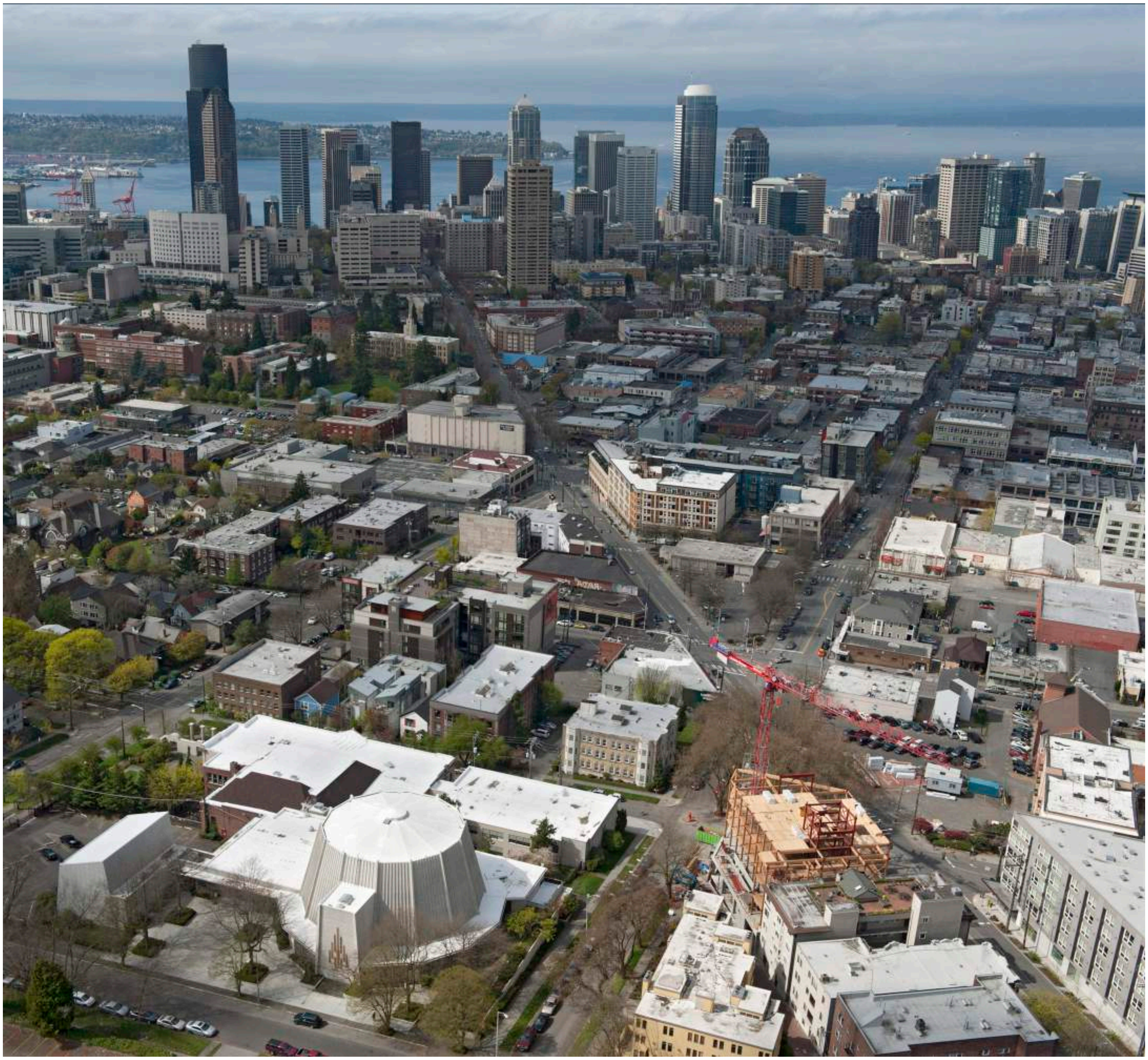


Figure 8. Aerial view of the Bullitt Center under construction, spring 2012 (John Stamets)

2 PROJECT ORIGINS

The Bullitt Center is owned and operated by the Bullitt Foundation, a sixty-year-old Seattle Philanthropy that seeks to make the Pacific Northwest a global model for sustainable, resilient prosperity. Its mission is to safeguard the natural environment by promoting responsible human activities and sustainable communities in the Pacific Northwest.

In it's early years the Foundation supported parks and open spaces. Later, its focus was on preservation of natural landscapes and wildlife habitat. The Bullitt Foundation now supports a balance of efforts to nurture the health and sustainability of both natural and built environments. It envisions a future that safeguards the vitality of natural ecosystems while accommodating a sustainable human population in healthy, vibrant, equitable, and prosperous communities.

2.1 PURPOSE

The Bullitt Center wasn't built to house the Foundation and its six employees, who have operated effectively for decades out of the converted carriage house of the Stimson-Bullitt mansion in Seattle's First Hill neighborhood. The Board of the Bullitt Foundation made the bold decision to dedicate a major portion of its endowment to create this model for 21st Century sustainability. It is a physical demonstration of the foundation's commitment to urban ecology, the idea that cities must ultimately address their resource flows locally and sustainably in order to sustain the wild places from which the majority of our resources are drawn.

The Bullitt Center is a manifestation of the vision of Denis Hayes, President and CEO of the Bullitt Foundation. Denis has been a leading advocate for the global transition from a fossil-fueled economy to a sustainable system based on energy efficiency and renewable energy sources. He was selected by President Jimmy Carter to be the first director of the Solar Energy Research Institute (SERI), now the National Renewable Energy Laboratory (NREL), where he led the early efforts to move the US towards a renewable energy future. He was among the early voices to warn of the existential threat of global climate change caused by the burning fossil fuels. In his 1977 book, Rays of Hope, Denis outlined a roadmap for the transition to a post-petroleum world based on energy efficiency and renewable energy sources.

Figure 9. *US Energy Use by Sector: Industry, Transportation, Buildings (source: US Energy Information Agency).*

But why did Denis and the Bullitt Foundation choose to develop the world's greenest building? Emissions from cars and power plants are generally the focus of carbon-cutting efforts, but of the US contribution to global greenhouse emissions, nearly 48% can be directly attributed to buildings. Buildings are the conduits through which the majority of electricity (75%) in this country flows. Most of this energy is produced by combusting coal (37%) and natural gas (30%). Reducing atmospheric greenhouse gas emissions in this century will require both significant performance gains in our stock of existing buildings, and the design, construction and operation of super high-performance new buildings.

While energy efficiency and renewable energy was central to the vision for this building, Denis believed it was imperative to raise the bar exceptionally high for this building and to address all of the building's resource flows and environmental impacts. He wanted to challenge the notion of buildings as disposable commodities, instruments for speculative investment with an effective lifespan measured in decades rather than centuries. And while he chose to create a new building rather than renovate an existing building, he imagined that the lessons learned from the design, construction, and operation of this building will inform both new and existing buildings.

Figure 10. The Bullitt Center under construction, spring 2012 (John Stamets).

Buildings are the most widespread and durable artifacts of human society. They exert a tremendous influence on our lives and on the health of the biosphere for decades after their creation. Most contemporary office buildings are developed as commodities with an imperative for quick returns on their investment. The Bullitt Center is designed and built for the long-term. It will operate largely on available site resources and will pay for energy embodied in its materials and construction through carbon offsets; it will provide ecosystem services by restoring the natural hydrology of the site and return nutrients to the land; and it will provide a healthy environment to support the activities of the people who visit and work in the building for the next 250 years.

2.2 PLACE

The design of this building grew from the conditions of the site, neighborhood, city, and region. Understanding the circumstances of the place that supported its inception, design, permitting, financing and construction may help replicate the conditions needed to create super high performance buildings in other places.

Cascadia, the region encompassing the northwest corner of the United States and the southwest corner of Canada, is emerging as ground zero for sustainable development. Originally endowed with an extravagant abundance of natural biological capital, this region is at an inflection point in its history. Following more than a century of intensive exploitation of its natural resources, Cascadia is now turning green. It is restoring its abused landscapes, and it is on the cusp of becoming a global model for a new approach to human ecology.

Cascadia has built a reputation for environmentally enlightened leadership. Through its innovations in science, technology, commerce, and culture, the region exerts a disproportionate national, and even global impact relative to its size and population. Its political leaders tend to be unusually knowledgeable about, and committed to, environmental values.

Seattle is at the forefront of a movement toward green architecture, and one ambition for this project is to help Seattle as a whole take a big step forward in this arena. Creating this building anywhere else in the country would have been illegal, as it would have been here were it not for the willingness of the public agencies responsible for permitting this building to interpret codes through their intention rather than by their letter. The project has been built on partnerships with multiple city and county agencies that share the goal of achieving carbon neutral development. It would not have happened without the visionary leadership and support of the City of Seattle, the Mayor, and the City Council. The City Council's adoption of the Living Building Ordinance cemented Seattle as a leader in sustainable development, and facilitated a number of departures and variances from existing land use, water, waste and building codes.

This project has also had extraordinary support from the Department of Planning and Development, the Office of Economic Development, Seattle Public Utilities, Seattle City Light, the Department of Transportation, and the Department of Parks and Recreation.

The location was chosen for its high visibility and accessibility in a neighborhood that is predominantly residential, yet striving for economic and commercial development. The Central Area Action Plan identified targeted improvements for the Madison-Miller neighborhood to include improved walkability, economic development that takes advantage of the strategic positioning of Madison Street as a vibrant connector, sensitive infill development and the creation of interesting urban spaces.

Figure 11. Seattle's central business districts: Downtown and Capitol Hill.

As part of this project, McGilvra Place Park, immediately to the west of the building, has been revitalized into a vibrant public space complete with a public plaza, places to sit, and an all-weather Ping-Pong table. An improved pedestrian crossing on Madison Street serves nearby retail businesses, schools and churches.

The project site at Madison Street and 15th Avenue was chosen for its high visibility, accessibility and ability to meet neighborhood development goals of Capitol Hill and the Central Area. It is a mixed-use neighborhood surrounded by a variety of locally owned shops and restaurants, parks, public and private schools, medical centers and hospitals, and a wide variety of housing.

Figure 12. Site of the Bullitt Center, bounded by E. Pike St. and E. Madison St., and adjacent to McGilvra Park.

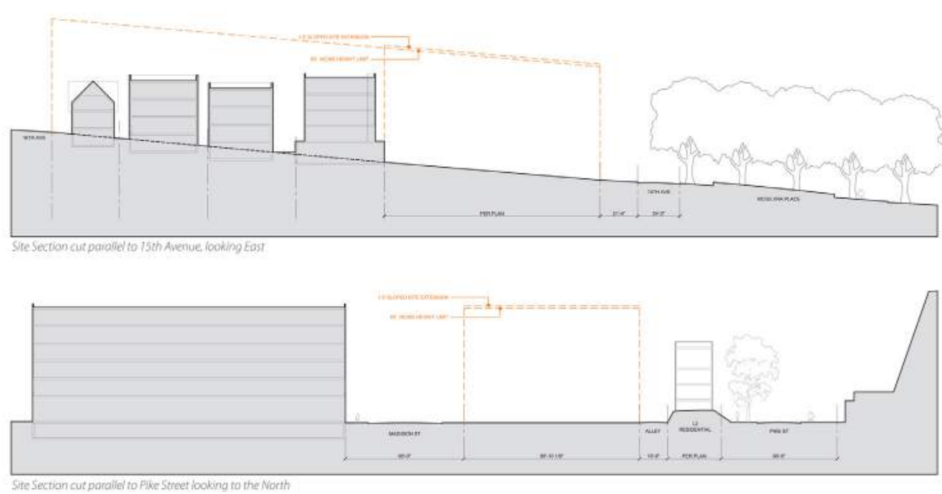


Figure 13. Site sections through the Bullitt Center: parallel and perpendicular to E. Madison St.

The site is within the Capitol Hill Urban Center Village. The neighborhood commercial zone (NC3-65) allowed for a 65' tall building, and a total building area of 42,823 square feet for a commercial structure. Additionally, the project is an approved participant in the City of Seattle's Living Building Pilot Program. The Pilot Program allows for flexibility under the Land Use Code to improve performance in both energy and water self-sufficiency. Living Building projects are eligible for an expanded list of Land Use Code departures, including building height, floor area ratios and extent of solar equipment, for example, to accommodate solar energy or water collection systems and to improve daylighting, natural ventilation and the quality of the indoor environment.

2.3 PERFORMANCE

The US Green Building Council has successfully advanced LEED as the industry standard in voluntary green building certification. It has advanced the conversation about high performance buildings well beyond regulatory codes, to voluntary adoption of much higher standards for buildings. But there are shortcomings to LEED as a mechanism to advance the super high performance buildings needed to address the challenges of the 21st century. Among these, it is a prescriptive and a predictive standard. If a project team accumulates the requisite number of points during the design and construction process, employing both prescribed features and predicting high energy performance, the building earns it's certification along with a plaque that can be displayed on its first day of operation. Unfortunately, the correlation between high levels of LEED certification (gold and platinum) and actual energy performance has not been consistently demonstrated.

Figure 14. The seven "petals" of the Living Building Challenge™: Site, Water, Energy, Health, Materials, Equity, and Beauty.

The Bullitt Foundation chose to pursue the more rigorous Living Building Challenge™ (LBC) because it is performance-based. In selecting the LBC for green certification of the Bullitt Center, Denis Hayes said "we no longer have time for good intentions, to check-off boxes that say we've done this and done that, but result in a building that doesn't perform as it was designed to perform." Under the LBC, the building must perform as designed and meet all the criteria for energy, water, materials, as well as criteria for the site, health, equity and beauty, during a full year of operation before it can obtain Living Building certification.

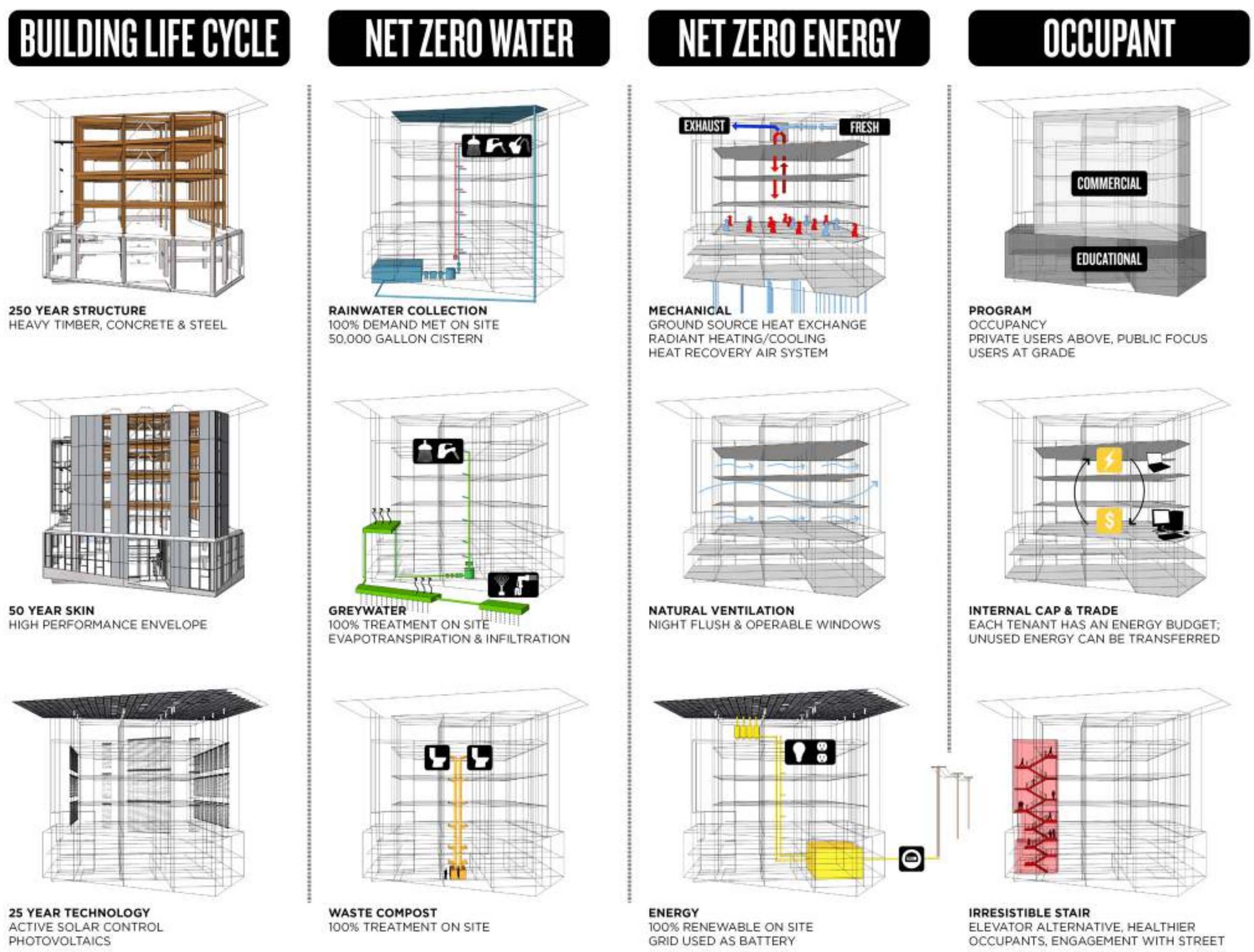


Figure 15. Integrated Design elements of the Bullitt Center (Miller Hull).

3 INTEGRATED DESIGN

"We wanted to set up a new regional vernacular for architecture; to make a building that is designed from the ground-up for the people who are going to be in it. A building that will use no more energy per year than it can generate from the solar panels on its roof"

- Denis Hayes

Integrated design is a holistic approach that views the building as an interdependent system rather than an accumulation of separate components. It isn't about the individual pieces but about how the pieces work together. When elements of a building take on multiple functions, this is one indication that integrated design has happened.

As a design process, integrated design involves multidisciplinary collaboration from conception to completion and delivery of the building. Integrated design strategies are a marriage of architectural and mechanical elements working in concert to achieve higher performance than they could on their own. The design strategies employed in the Bullitt Center are relatively common in modern buildings, and the technology used is readily available. But so far there are only a handful of buildings that have fully integrated the state-of-the-art technologies and high-performance design strategies employed in the Bullitt Center, and none are as large and as ambitious in their performance goals.

Perhaps the single most important step in creating a super high performance building is the commitment of the owner and the design and construction team to unambiguous performance targets. The requirement of net-zero energy imposed by the Living Building Challenge™ made the energy performance target for this building crystal clear; it was the most compelling force informing the design process.

Achieving net-zero for a six-story commercial office building in Seattle means achieving energy efficiency improvements of upwards of 77% compared to an average Seattle office building (EUI = 72 kBTU/sf year), or 62% better than 2009 Seattle Code minimum building (EUI = 42 kBTU/sf year). This is an extremely ambitious goal, all the more for a building aimed to be cost competitive with other Class-A commercial office buildings in Seattle.

The margin of error between the projected power supply from the building's photovoltaic power plant and the building's energy demand was razor thin, requiring every design decision to get the building closer to the goal of net-zero energy. The goals for Bullitt Center are so ambitious that it pushed the design team beyond merely an integrated design model into performance-based integrated design.

3.1 PROCESS

An integrated design process requires early involvement of all the key players to leverage their knowledge and expertise for the highest possible performance outcomes throughout the project lifecycle.

Orchestrating the entire process, from project inception and feasibility to building management, was the Bullitt Foundation's owner representative, Point 32. Headed by Chris Rogers and Chris Faul, Point 32 managed site and design team selection, permitting, financing, construction, media and communications. They worked with the City of Seattle to develop and enact the Living Building Pilot Program, Ordinance123206, which facilitated permitting for some of the building's departures from typical methods for water supply, stormwater management, waste treatment, and power supply, and it signaled the City's support of much higher standards for building performance. The role that Point 32 has played in this process was absolutely critical to the project's success. It would not have happened without the range of services that they brought to the table, along with their talent and tenacity. While the architect and the developer typically provide some of these services, a project of this ambition required the integration services provided by Point 32.

The Miller Hull Partnership was selected to head the design team based on their proven record of achievement, their architectural design talent, their technical prowess, and their demonstrated effectiveness at managing an integrated design process. Working with Point 32 and the Bullitt Foundation, engineers, builders, and consultants were selected, again with the criteria of both excellence in their field and the proven ability to work as part of an integrated team.

Miller Hull and Point 32 gathered up all the information and research already done on the project then assembled the entire design team and the project stakeholders for a two-day hands-on design charrette aimed at identifying all the critical parameters for the project and outlining the form of the building.

The first day all the cards were laid on the table. Denis Hayes gave his vision for the project and expectations for its performance; the design team presented all the known facts about the place and purpose for the project; and the stakeholders voiced their expectations, concerns, and recommendations. During this elaborate brainstorming process the parameters for the project emerged. Among the biggest decisions of that first day, the program shifted from a mixed-used commercial office plus housing, to a commercial office plus ground floor retail. Most important though

Figure 16. Concept sketch of the Bullitt Center from the project design charrette, June 2009.

was the commitment by the Bullitt Foundation and the design and construction team to achieve Living Building certification for the building. This commitment to achieve an unprecedented level of performance for an urban building of this scale was perhaps the single most consequential decision of the entire project.

Overnight the first day's discussion was synthesized and turned into a concept sketch of the building. From this initial design concept the floor areas and volume could be determined, and the available area for photovoltaic panels to generate power could be estimated. The result was a floor area of approximately 48,000 sf, and a photovoltaic (PV) array capable of supplying the annual energy requirements for a building with an energy use index (EUI) of 20 kBTU/sf-year. This was the preliminary energy performance target for the building.

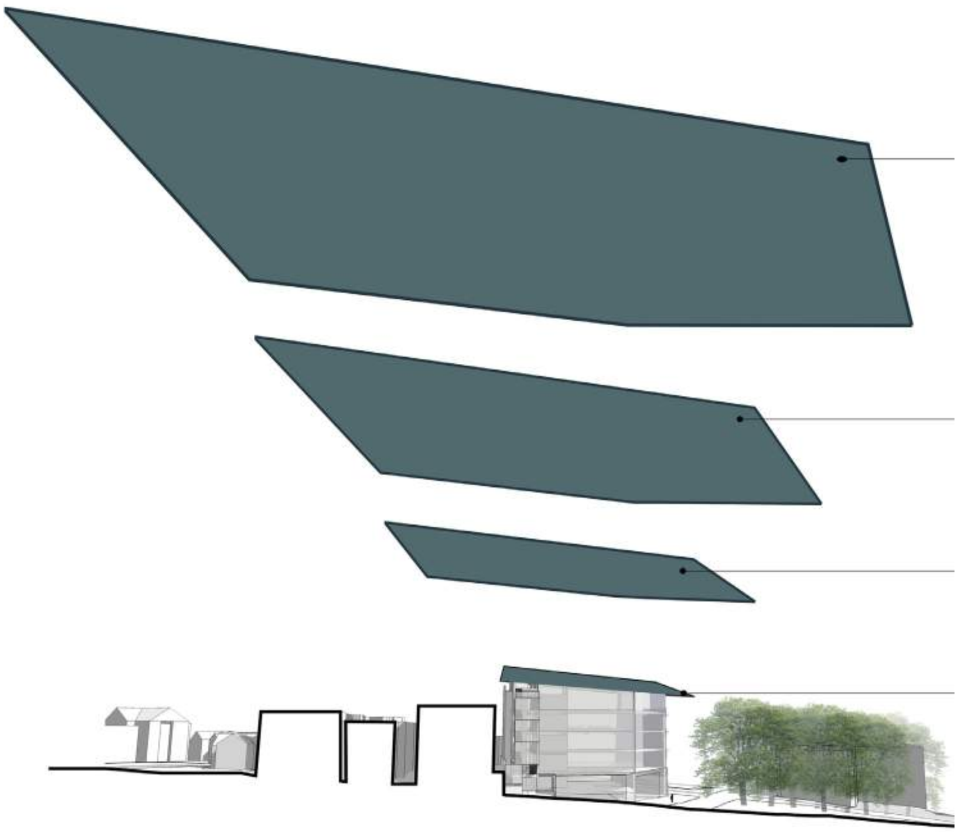


Figure 17. The Imperative for High Efficiency.

A typical building of this size has an EUI of 72 kBTU/ft^2 year. A PV array with an area of 51,004 ft^2 is required to meet its energy needs.

A building of this size meeting Seattle Energy Code has an EUI of 42 kBTU/ft^2 year. A PV array with an area of 36,855 ft^2 is required to meet its energy needs.

A LEED Platinum certified building of this size has an EUI of 32 kBTU/ft^2 year. A PV array with an area of 28,599 ft^2 is required to meet its energy needs.

The proposed building, meeting the Living Building Challenge, has an EUI of 16 kBTU/ft2 year and needs only 14,303 ft2 of PV to meet its net-zero energy goal.

With the performance target and building program established, and a very preliminary concept for the form of the building in front of them, day two of the charrette dug into the details. The design team and stakeholders were organized into small teams to focus on a particular element of the project such as energy and systems, water and waste, materials and construction, building program and use, landscape and neighborhood. Teams alternated between intensive focus on a particular part of the project, to large-group discussion and synthesis of the project as a whole. This day was less about problem solving than it was about issue seeking. It was also a chance to identify expertise and assign roles, to find gaps in the collective knowledge and seek additional team members to fill those gaps. And it was a chance for all the players to begin building the relationships that would be critical to the success of the work ahead. The charrette gave the design team a solid platform to begin their work and it launched the project in a spirit of shared ownership and expectation.

3.1.1 PERFORMANCE BASED DESIGN

The goal of achieving a net-zero building influenced virtually every step of the design process. This imperative resulted in *a performance-based design* approach, necessitating early and persistent coordination and collaboration between all the members of the design team. Integrated design aims to harness the talents and insights of all participants to optimize project goals, reduce waste, increase value to the owner, and maximize efficiency through all phases of design, fabrication and construction.

These were the steps followed by the Bullitt Center design team:

Step 1: Set Aggressive Goals

To achieve high performance there must be a commitment by everyone involved to high performance goals. Net-zero was the energy performance goal for the Bullitt Center. Further design and energy analysis following the design charrette resulted in a six story, 50,000 square feet, with space for a PV "power plant" that could supply the annual energy needs of a building with an EUI of 16 kBTU/sf • year. This was the design team's energy target.

Step 2: Analyze the Site and Climate

High performance design is about designing with nature. It begins by asking three questions: What is here? What will nature allow us to do here? And what will nature help us do here? This means considering conditions during all 8,760 hours in a year and includes understanding the day-to-night temperature swings, rainfall, cloud cover, and the hourly availability of sun, wind and light. Informed by this understanding, the design team established climate design priorities and architectural design strategies.

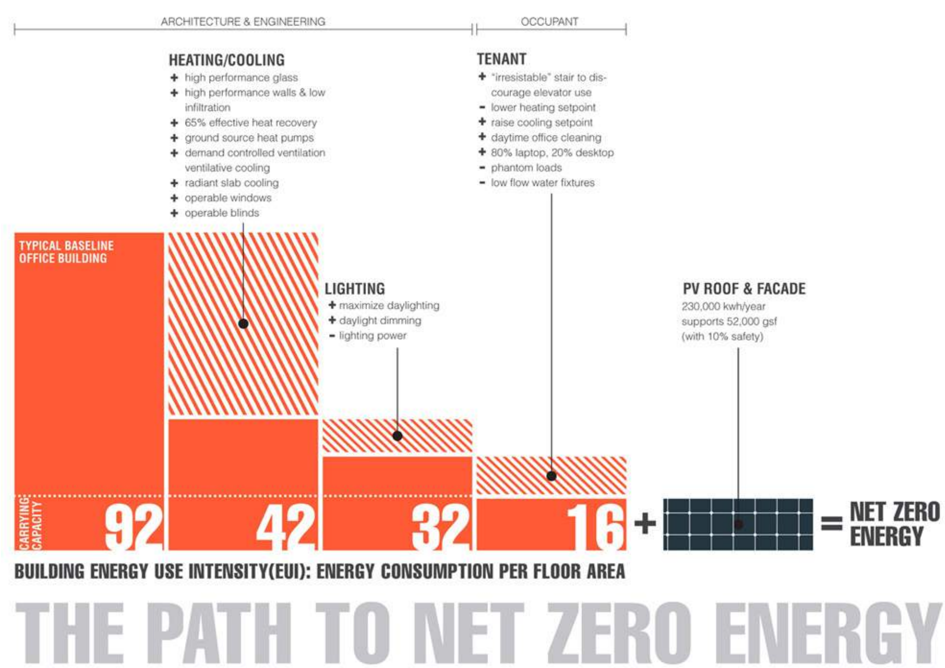


Figure 18. *The Path to Net Zero Energy, showing the architecture and engineering energy efficiency measures, and the measures that require tenant engagement, to reach the target set by the size of the PV power plant.*

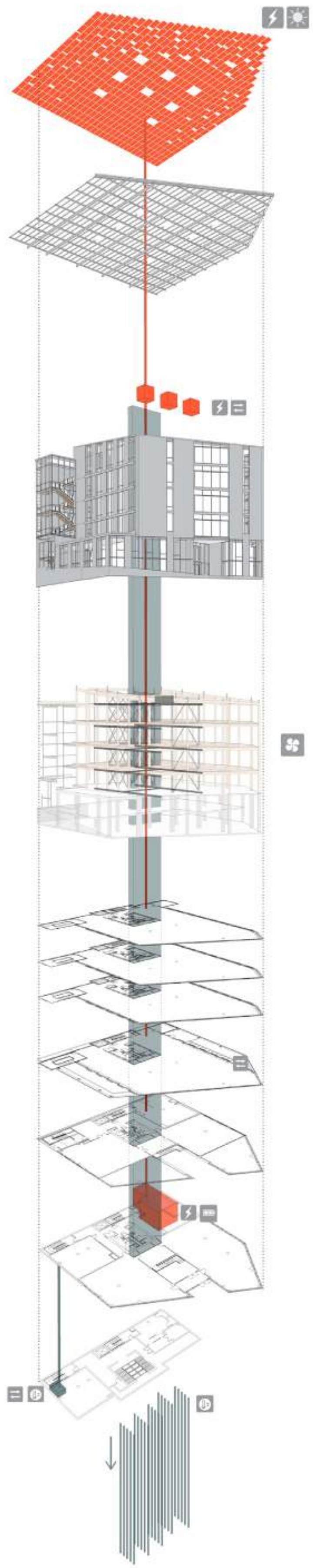


Figure 19. *Exploded view of the primary elements of the buildings energy supply and energy efficiency measures.*

Step 3: Design for Reduced Energy Demand

The building's form, envelope, and organization was informed by the climate, use, and building systems, and rigorously tested, modeled and evaluated to optimize its performance. The objectives are a comfortable, healthy, beautiful building that can "sail" without the need for mechanical assistance as long and as often as possible. Reducing the energy demands of the building is half the challenge. The other half is to make it easy and natural for people who work here to use as little energy possible. An "irresistible stair" to reduce elevator use, showers and bike parking to promote human-powered transportation, and low-flow fixtures and composting toilets are just some of the ways "activity loads" are reduced or eliminated.

Step 4: Use Efficient Equipment

The design team selected smart, energy efficient equipment and systems to deliver the remaining need for heating, cooling, ventilating and illumination. Sensors connected to the building's central nervous system monitor light levels, CO_2 levels, temperatures indoors and outdoors, as well as wind and sun, to control and deliver heating, cooling, ventilation and illumination efficiently and effectively.

Step 5: Use Renewable Energy

The sunlight that falls on the building, and the energy source or sink of the earth beneath it, are the only sources of sustainable, renewable energy used to operate this building and power the equipment inside.

Step 6: Verify Performance

Stewardship is a process of steady commitment informed by constant feedback. It requires careful maintenance and vigilance to the performance goals for the project. This building's vital signs will be monitored and its performance analyzed with the goal of continuous improvement in its operational use of energy.

3.2 BUILDING FORM

The form of the Bullitt Center isn't driven by metaphor or aesthetics but rather by performance metrics. Each dimension of the building's design - its energy and water use, the durability, longevity, toxicity and origins of its materials, its function, form and organization - all had exceptionally high performance thresholds to meet.

Space heating accounts for about 1/3 of the energy load of a typical Seattle office building of this scale. Early energy analysis by the UW Integrated Design Lab (IDL) employed Ecotect, sustainable design analysis software, to study the relationship between conductive heat loss through the envelope and solar heat gains through the windows. A variety of building forms were tested, each with a different surface-to-volume (S/V) ratio but with the same proportion of window to wall area. Larger S/V ratios increase winter heat loss; however, this loss may be offset by an increase in heat gains through the windows on a sunny winter day.

Figure 20. Form Option 1: Heating EUI 10.00 kBTU/SF year

These early form studies revealed that the marginal passive solar heat gains achieved with more south-facing windows were less than the heat lost by having more wall and window surfaces for heat to escape from. A comparison of multiple massing configurations, from low surface-to-volume cube-like forms to shapes with higher surface-to-volume ratios, showed that compact, low S/V climate-rejecting forms resulted in lower overall energy loads than forms with more envelope area and higher S/V ratios.

Figure 21. Form Option 2: Heating EUI 12.08 kBTU/SF year

Conceptual design was driven by the tension among competing objectives for energy performance, requirements for daylight and fresh air, response to the neighborhood context and anticipated future development, and achieving the most cost effective structure possible. As with any building, construction cost was an important factor, especially if this building is to serve as a replicable model for commercial office development in Seattle and elsewhere. But it was the competition for light that drove that drove the development of this building's form more than any other single factor.

Figure 22. Form Option 3: Heating EUI 11.46 kBTU/SF year

3.2.1 DAYLIGHT DESIGN

The Living Building Challenge specifies that, "every occupiable space must have operable windows that provide access to fresh air and daylight." Workstations, places where people will spend a significant portion of their working days, can not be located further than 30 feet from an operable window. To address these requirements, each of the initial design concepts employed an atrium to get more of the floor plate close to a source of daylight and fresh air and to drive daylight deep into the building's core. The potential to enhance cross- and stack-ventilation with an atrium also informed these early design decisions.

Figure 23. "O" Scheme: central atrium for light and ventilation.

Figure 24. "U" Scheme: central atrium for light and ventilation.

Figure 25. "T" Scheme: narrow floor plate for light and ventilation.

This resulted in an "O" scheme and a "U" scheme. But when digital daylight analysis was performed using Radiance, a digital daylight design tool, to calculate the daylight distribution and intensity on each floor level, we found that the atrium delivered relatively modest levels of daylighting to the third and fourth floors (3 and 4 levels from the roof). Not only were the roof apertures too small relative to the depth of the atrium, but also the opening competed for light with the rooftop PV array and the additional building envelope area increased heat loss.

The scheme that was ultimately used is a "T-shaped" plan where the top four levels step back 15' from the northwest and southeast perimeters, resulting in a higher proportion of the floor space within 30' from the perimeter. These top four floors are organized around a 21-foot deep central service core with bathrooms and service spaces flanked by 24-foot deep workspace zones extending to the building's perimeter. These floors are constructed of engineered heavy timber, and a bathroom core of concrete to carry both lateral and gravity loads. They rest on a 2-story concrete platform that contains a 2-story lobby and exhibition space on Level 1 at the building's west side, and a mezzanine (Level 2) that meets the ground level at the building's NE entry, where the lobby and stairs for the commercial office floors are located.

Daylighting was first analyzed with the presumed ideal case of a fully glazed façade and an 11'- 6" floor-to-floor height (10'- 9" ceiling). This was modeled using the third floor at 3:00 pm on a uniformly overcast day in December. When compared to a facade with fewer windows in alternating vertical bands of glass and insulated opaque wall, the daylight distribution and intensity was remarkably similar. However, in both scenarios, nearly 77% of the floor area fell below the target 2% daylight factor.

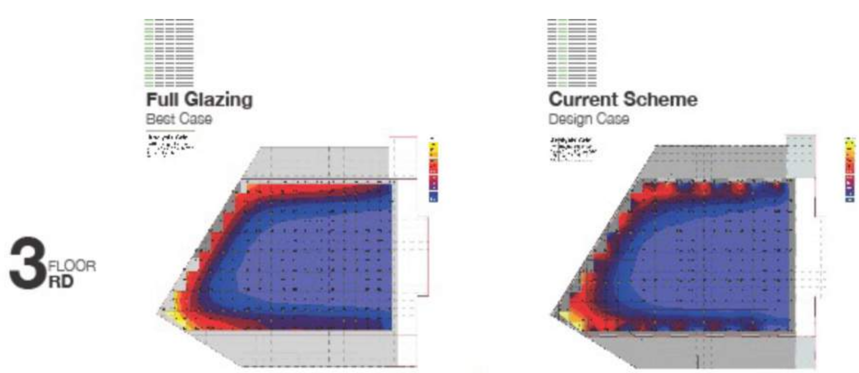


Figure 26. Daylight distribution for 100% vs. 50% window area of façade.

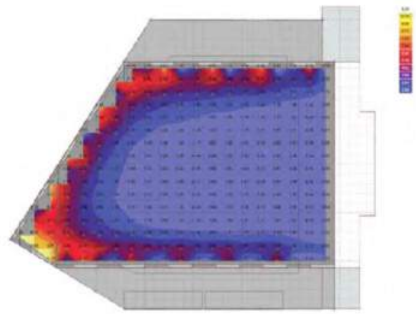


Figure 27. *Daylight distribution (measured in daylight factor) for an 11'-6" floor-to-floor height.*

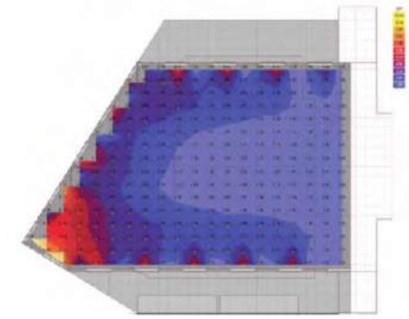


Figure 28. *Daylight distribution (measured in daylight factor) for an 14'-2" floor-to-floor height.*

The next design investigation was to explore the effect of raising the ceiling heights to distribute daylight deeper into the building. The floor-to-floor height was raised to 13'- 10" (13'- 1" ceiling). Modeled with the same alternating window and opaque wall configuration, the area that fell below the targeted DF was reduced to 38%, and most of this area is in the service core of each floor. Under the Living Building Ordinance a 10' extension of the building height was granted, making it possible to have a sufficient amount of daylit workstation area to create an economically viable commercial office building. Because of the building site's unusual pentagon-shaped geometry, it would have been virtually impossible to make this work without increasing the floor-to-floor heights of the upper four floors.

3.2.2 BUILDING ENVELOPE

Even in large office buildings with relatively high internal heat gains, the number one climate design priority for buildings in the Pacific Northwest is to keep the heat in and cold out in the winter. A well-insulated envelope using thermal breaks, to minimize conductive pathways where heat can escape, and an airtight enclosure are both critical to reducing the heating load and achieving the net-zero energy target.

Designing a high-performance building envelope involves an iterative process of finding the optimal balance between windows for views, daylight, and ventilation, and insulated opaque walls, to keep the heat in and the cold out. More glass also means a greater need for shading to reduce solar heat gains in the summer. Recent high performance offices in Seattle have favored fully glazed facades with operable openings aimed at lowering energy demand through natural ventilation and daylighting. While these schemes reduce electric lighting demand, heating demand increases proportionally, particularly in buildings employing natural ventilation without heat recovery.

To arrive at the optimal proportion of glass-to-floor area and glass-to-insulated-wall area, Ecotect and then EnergyPlus models were used for thermal analysis, and Radiance and physical models were used for daylighting. The resulting window area is somewhat less than typical for a comparable contemporary office building.

Pre-design analysis using simple Ecotect form studies suggested that there might be significant potential to lower the building's heating loads by increasing the insulation levels in the walls and roof, and by improving the performance of the windows. In these studies, using simplified building geometry, increasing the wall insulation from R-19 to R-25, and the roof insulation from R-30 to R-39, along with improving the window U-factors from 0.60 (insulated glass) to 0.14 (multi-pane/film assembly), resulted in a 62% reduction in the heating load.

The Bullitt Center's exterior wall assembly begins with a rain screen system composed of a metal panel, air space, and 4 inches of mineral wool (R-16.8). This assembly is attached with fiberglass clips outboard of a 6" light steel-framed wall sheathed with 5/8" glass mat gypsum, containing fiberglass batt insulation (R-19), and finished on the interior with gypsum wall board. This results in a wall R-value of about 36. Accounting for framing and other portions of the wall assembly with somewhat lower levels of insulation, the area-weighted average R-value is 21.4 for the opaque portions of the exterior walls.

Infiltration can be one of the largest individual heating loads in a building. Careful detailing, construction and testing were needed to achieve a measured infiltration rate of 0.24 cfm/sf at 75 Pa. This was achieved by developing a whole-building air barrier plan that identifies all air barrier components in the construction documents along with details of all joints, interconnections and penetrations of the air barrier components.

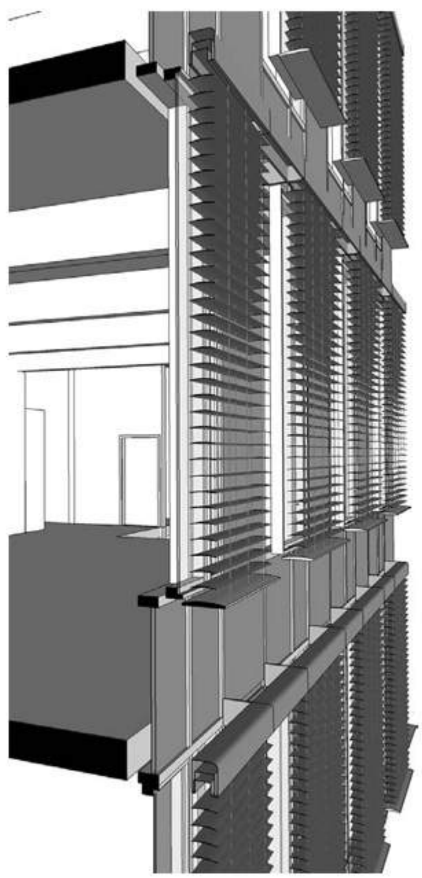
3.2.3 WINDOWS & EXTERIOR SHADES

Windows are the weakest link in any building's thermal enclosure, so this building uses the highest performing triple-glazed curtainwall system available. During the design process, numerous windows, glazing, and configurations were evaluated for thermal, daylighting, and ventilation performance. Kawneer, Crystalite, and Schüco curtainwall systems were top contenders. When measured against required air tightness (0.25 cfm/sf @ 1.57 psf), water penetration resistance, and thermal performance, the Schüco system was superior in all three measures.

Figure 29. South terrace at level 3 showing exterior blinds deployed and tilted for maximum daylight.

Figure 30. *Schüco triple-glazed, "pop-out" windows open, during construction.*

Figure 31. *Section of the Schüco window and integrated blind system.*



Vertical fenestration systems are triple glazed assemblies with 1 or 2 low-E coatings, argon filled, with warm edge spacers for a maximum center-of-glass U-value of no more than 0.18. Numerous glazing assembly configurations were modeled to arrive at the optimum summer shading and winter solar heat gain. Various façade configurations using Solarban 60 and 70, and Sungate 500 assemblies (SHGC: 0.36, 0.29, 0.59, respectively) were modeled. While the glazing with the lowest SHGC performed the best in terms of reducing the cooling load in the summer (Solarban 70), this was more than offset by the reduction in beneficial solar heat gain in the winter. The winning combination was to use an assembly with a higher SHGC (Sungate 500, SHGC 0.59), in combination with exterior automated venetian blinds.

Automated exterior louvered blinds have several objectives. First, they block direct solar radiation outside the building envelope to minimize overheating in the summer. They minimize glare by blocking direct sunlight penetration while scattering daylight, and redirect diffuse daylight to the ceiling and other interior surfaces. Unlike fixed exterior shades, automated blinds get completely out of the way on cloudy days to maximize the potential for daylighting.

The Bullitt Center's Warema exterior automated venetian blinds have 100 mm (4") aluminum slats with a reflectance of approximately 50%. Blind deployment and slat angles are controlled by a combination of an astronomical time clock that locates the sun's altitude and azimuth, and a sensor to signal whether it's clear or cloudy. Under clear sky conditions, blinds deploy by façade orientation at the minimum slat angle required to just block direct beam sunlight. They periodically adjust to the sun angle and they retract as the sun passes around the building or the skies become overcast. Once blinds are deployed they remain in clear sky deployment mode for a specified time period regardless of sky conditions to avoid excessive cycling. To avoid damage, the blinds will not deploy below a temperature of 36°F, or when wind exceeds 30 mph.

3.3 SYSTEMS

Because of the performance targets for this building, much of the equipment used is the best available. But all of it is "state-of-the-shelf" technology, readily available and commonly used in the building industry. For instance, the Schüco triple-glazed curtainwall is the best on the market, and the ground-source heat pumps have been employed for years as a highly efficient way to heat and cool buildings. These are high-cost components that even when specified have a hard time surviving the inevitable "value engineering" process. However, when integrated into systems of reinforcing elements, these "top shelf" components are critical to achieving high levels of performance. What sets this building apart from others is the degree to which systems are integrated with one another to achieve the highest levels of performance and efficiency.

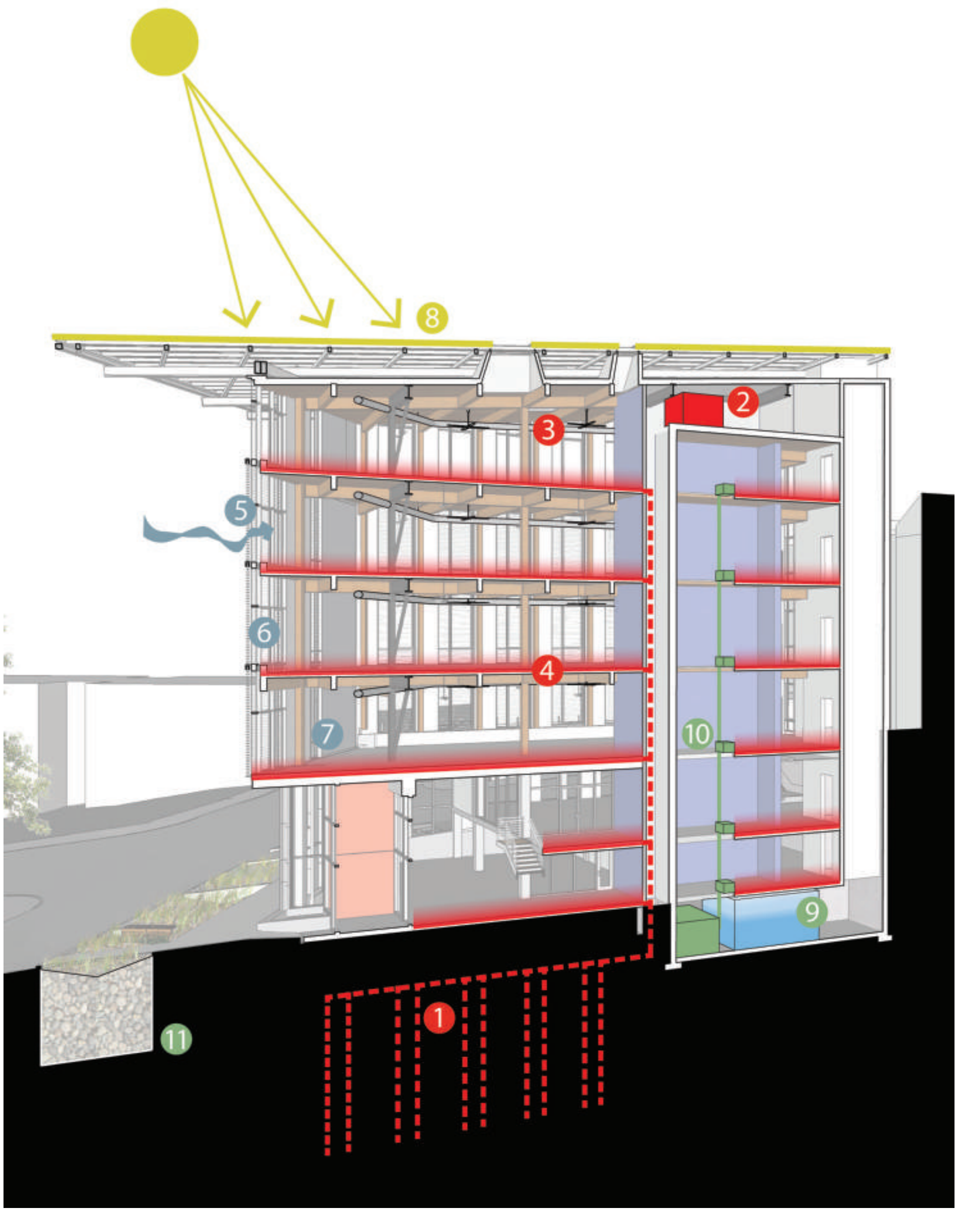


Figure 32. Bullitt Center integrated systems for power production, daylighting, heating, cooling and ventilation.

1 26 - 400' geothermal wells

2 Demand controlled heat recovery ventilation

3 Low-velocity ceiling fans

4 Radiant in-floor heating & cooling

5 Automatically actuated windows

6 Triple glazed curtainwall

7 High performance building envelope

8 242 kW PV array

9 56,000 gallon rainwater cistern

10 Composting toilets

11 Greywater return to groundwater

3.3.1 NATURAL VENTILATION AND PASSIVE COOLING

The Bullitt Center is a fresh air building. When CO_2 sensors detect the need for fresh air, the windows open. If it is too cold or too hot outside, the windows remain closed and the ventilation system provides 100% outside air, tempered during the heating season by energy recovered from the exhaust air leaving the building.

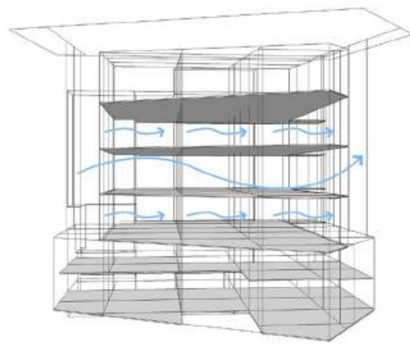


Figure 33. Cross ventilation and night flush cooling strategies.

The natural ventilation system provides fresh air but is designed primarily as a passive cooling system. This system displaces approximately 750 hours of annual cooling that would otherwise be needed without operable windows. Motorized actuators open the windows at night, during the summer, to flush the building with cool air to keep the building from overheating the following afternoon. Night-flush cooling typically lowers the slab temperatures 3°F to 5°F, allowing this mass to absorb more unwanted heat on warm summer afternoons.

The operable Schüco windows, throughout the building, measure approximately 4' x 10'. These "parallel opening" windows project directly outward on scissor-hinges located along the sides, top and bottom of these large openings. Motorized actuators project the triple-glazed window assemblies horizontally outward approximately 4". These "pop-out" windows have larger effective openings than comparably sized casement, awning, or hopper windows. The operable window area on floors 3 through 6 is approximately 4% of the perimeter ventilated floor area. Additional benefits of these parallel opening windows is that they do not interfere with movable exterior or interior blinds, and they seal more effectively, compressing window gaskets uniformly and minimizing infiltration heat loss.

Weather sensors located on the roof monitor rain, wind speed and direction, temperature, relative humidity, and sunlight. When the building is occupied, if the outside temperature is greater than 65°F and the space temperature is above the (adjustable) natural ventilation cooling setpoint of 72°F, the windows automatically open. If the outside air temperature is greater than 78°F or if the space temperature drops 2°F below the natural ventilation setpoint, then the windows close. Occupants can manually override the control system and open or close the windows, by zone, with buttons located on each floor. After 30 minutes the automated functions will resume. Windows will automatically close if it is raining or if the wind maintains a sustained wind speed of greater than 15 mph, or any wind gust of 20 mph.

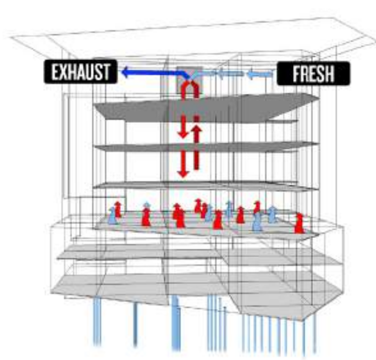


Figure 34. Radiant in-floor heating & cooling using ground-source heat pumps, and heat recovery ventilation strategies.

3.3.2 HEATING & COOLING

Heating starts with internal gains from people, lights and equipment. On cool but sunny days, the windows let in free solar heating. The building envelope is designed to keep the heat in and the cold out. Under typical occupied conditions, supplemental heating isn't needed until outdoor temperatures drop below about 46oF, the building's operational balance point temperature. When this happens, the building's

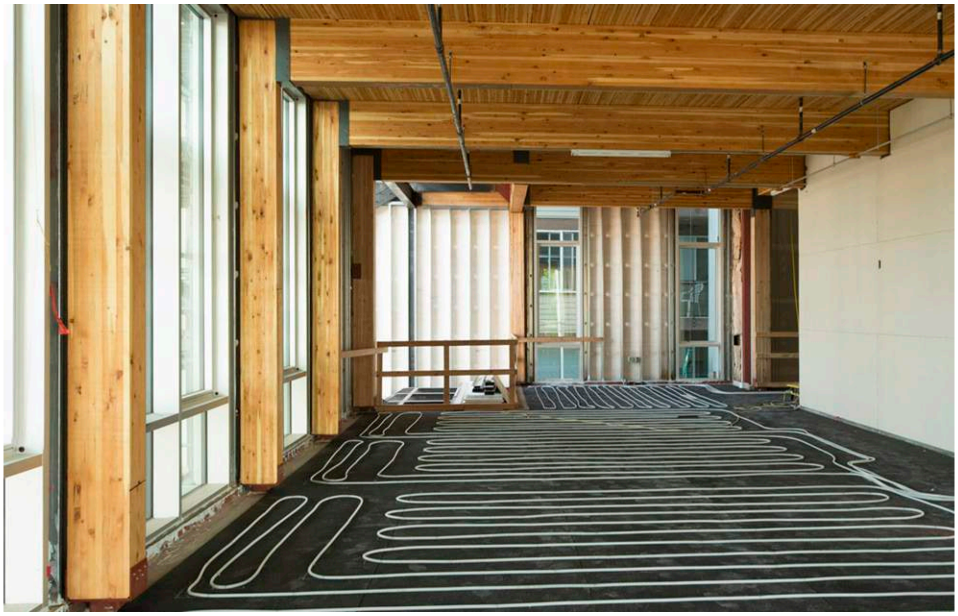


Figure 35. Tubing for in-floor radiant heating during construction, fall 2012.

ground source heat pump system kicks-in to produce hot water that is circulated throughout the building and delivered as radiant warmth through the building's concrete floor slabs.

When cooling is necessary, the windows automatically open to provide cool, outdoor air. As the day warms and outside air no longer effectively cools the building, the windows close and the building's concrete floors and hard surfaces, cooled by night-flush ventilation the previous evening, absorb excess heat to maintain indoor comfort. If the cooling capacity of the building's mass is exhausted, cool water is cycled through the floors, drawing in excess indoor heat and transferring it, via the ground source heat pumps, to the earth beneath the building.

These heating and cooling systems are powered by electricity produced by the building's photovoltaic ("PV") system, or purchased from Seattle City Light with credits from surplus PV production during the summer months. (Under the rules of the Living Building Challenge combustion can't be used for heating and cooling.)

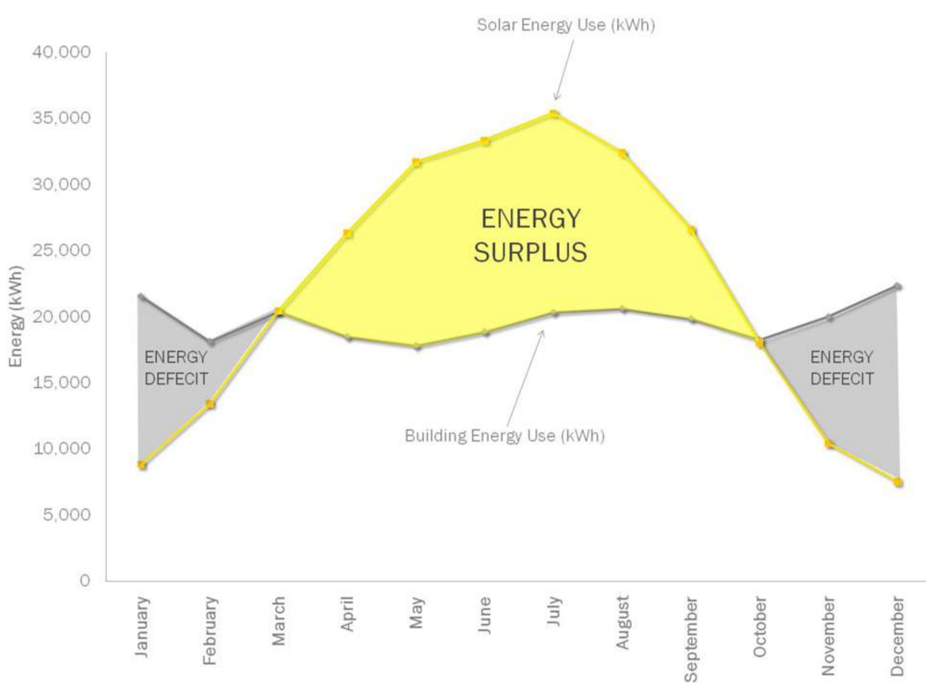


Figure 36. Net-zero energy use: energy use vs. energy production, and the periods of energy deficit and surplus that balance over the course of the year.

3.3.3 THERMAL SOURCE AND SUPPLY SYSTEMS

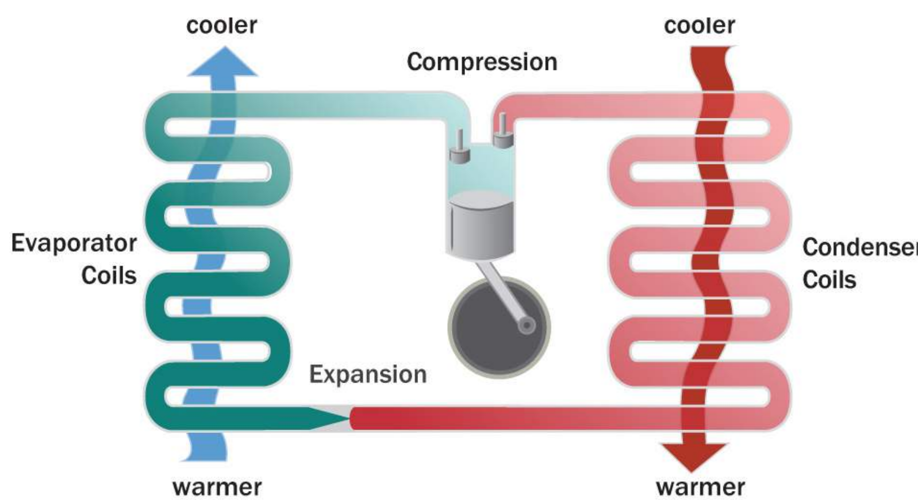
The thermal production and delivery system at the Bullitt Center has both a source side and a supply side. The source side consists of a pair of pumps that circulate a solution of water and glycol (anti-freeze), through one of twenty-six, 400' deep wells, drilled directly under the building. Each hole is about 5-1/2" in diameter and contains a loop of 1" diameter plastic pipe that extends to the bottom of the well and back up again. Because the ground maintains a temperature of around 55°F year around, cold fluid sent down the well returns about 10°F warmer, depending on the heating load.

The thermal energy in this relatively warm fluid is used in a heat pump to create warm water to circulate through the floor slabs for space heating. Two supply pumps circulate warm water, typically between 90°F and 100°F depending on the demand for heating, through tubing organized by thermal zones on each floor in the building. In the summer, the heat pump can be reversed to circulate cool water through the floor and to use the ground as a heat sink rather than a heat source. In this mode, the evaporator and condenser coils in the heat pump switch roles, allowing the system to absorb excess heat from inside the building and reject this heat into the relatively cool earth.

The building has five heat pumps. Three are used to produce warm water in the winter, and occasionally cool water in the summer, to circulate through the floors for space heating or cooling. One is used to provide warm water in the winter to temper the incoming fresh air from the heat recovery air handler. A fifth heat pump is dedicated to producing domestic hot water.

Each heat pump uses a volatile refrigerant in a closed loop which changes state

Figure 37. Heat Pump, schematic diagram.



from liquid to gas and back again as it circulates through the pump. In Bullitt Center's system, heat from a ground well loop arrives at the evaporator stage of the heat pump and is absorbed by the fluid, which boils, converting the fluid to a gas. This gas is then compressed into a hot and high-pressure vapor by the compressor. This high temperature vapor is circulated through condenser coils in contact with water from a separate loop, heating this water that is circulated through tubing embedded in the concrete floors to heat the building. This causes the gas in the heat pump to condense into warm, pressurized liquid, which is passed through an expansion valve, converting it to a cold, low-pressure liquid. In the evaporator coils, this cold fluid draws heat again from the relatively warm ground water loop where it boils into a gas and the cycle is repeated.

3.3.4 VENTILATION AND HEAT RECOVERY

The building systems divide between water side and air side systems. The water-side is dedicated to heating and cooling, while the air-side delivers ventilation and passive cooling. The air-side is a hybrid system of operable windows for both fresh air and passive cooling, supplemented by fan-delivered ventilation air that is sometimes tempered by heating coils from the water-side.

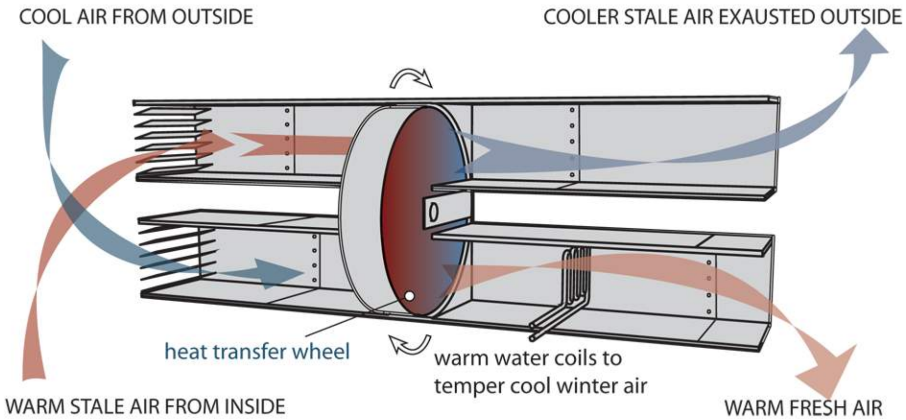


Figure 38. Heat Recovery Ventilator, schematic illustration.

The primary ventilation air for the building is supplied by a dedicated outside air handling unit located on the roof (Level 7). Fresh air is supplied by this system whenever CO_2 sensors indicate the need for additional fresh air, whether or not the windows are open. This system is equipped with a heat recovery wheel located in the rooftop air-handling unit. This energy recovery ventilator (ERV) is approximately 65% effective at recovering heat from the exhaust air and transferring it to the ventilation air. Variable speed drive fans regulate airflow based on CO_2 readings. Multiple CO_2 sensors located on each floor and in the exhaust air ducts communicate with the building management system to regulate the delivery of fresh air to maintain the building's CO_2 level at less than 500 PPM above the outside CO_2 levels.

Two additional supply fans serve five decentralized water-source heat pump systems, serving four conference rooms and the server/telecom space in the basement. One of these supply fans also provides ventilation air to eight terminal units serving smaller enclosed conference and quiet rooms in the building.

The building is also equipped with three exhaust fans serving the bicycle parking and recycling room, Seattle City Light's transformer vault, and the composting units in the basement. Each of the 10 composting units also has it's own small exhaust fan. These fans draw air from the bathrooms, through the toilets and urinals, facilitating aerobic digestion and keeping odors from the bathrooms and the basement.

3.3.5 BUILDING CONTROL SYSTEM

The direct digital control (DDC) of this building is driven by a KMC control system. This system monitors, logs and controls the building's mechanical heating and cooling systems, the supply and wastewater systems, the air supply and exhaust systems, and sump pumps. This system also monitors, collects and logs data from the weather station and indoor sensors, water meters, pump flows, thermal energy, fans and window operations.

Table 2. Bullitt Center Electrical Load Categories.

Load Category	
Lighting	Interior Lighting
	Exterior Lighting
	Emergency Lighting
Plug Loads	General Plug Loads
	Workstation Plug Loads
	Copiers & Printers
	Refrigerators
	Microwaves
	Dishwashers
	Coffee Machines
	Windows, Louvers, Blinds
	Door Operators
HVAC Systems	Mechanical Controls
	HVAC Pumps
	HVAC Heat Pumps
	HVAC Fans
	Ceiling Fans
Plumbing & Fire Protection Systems	Plumbing Systems
	Domestic HW
	Reclaim Water System
	Composting System
	Fire/Life Safety
Server Room	Server Room
	Server Room HVAC

Electrical circuits for the building are separated into thirteen panels. Seven panels located in the main electrical and mechanical rooms on level one, the basement, and the roof, serve whole building systems, and their metered loads are disaggregated by system. In addition, a panel on each floor disaggregates electrical load into four groups: 1) installed lighting; 2) plug receptacles; 3) HVAC systems and 4) plumbing and fire protection systems.

A third system, produced by Climatec, is used to gather and aggregate useful electrical data from the Schneider Electric system, and metered water and energy flows from the KMC system, for display and data logging on the building dashboard. An additional portal aggregates building energy data into useful "buckets" that are being used to track energy performance at a somewhat finer grain than the data fed to the building dashboard.

Figure 39. The Bullitt Center public dashboard showing real-time energy use and production.

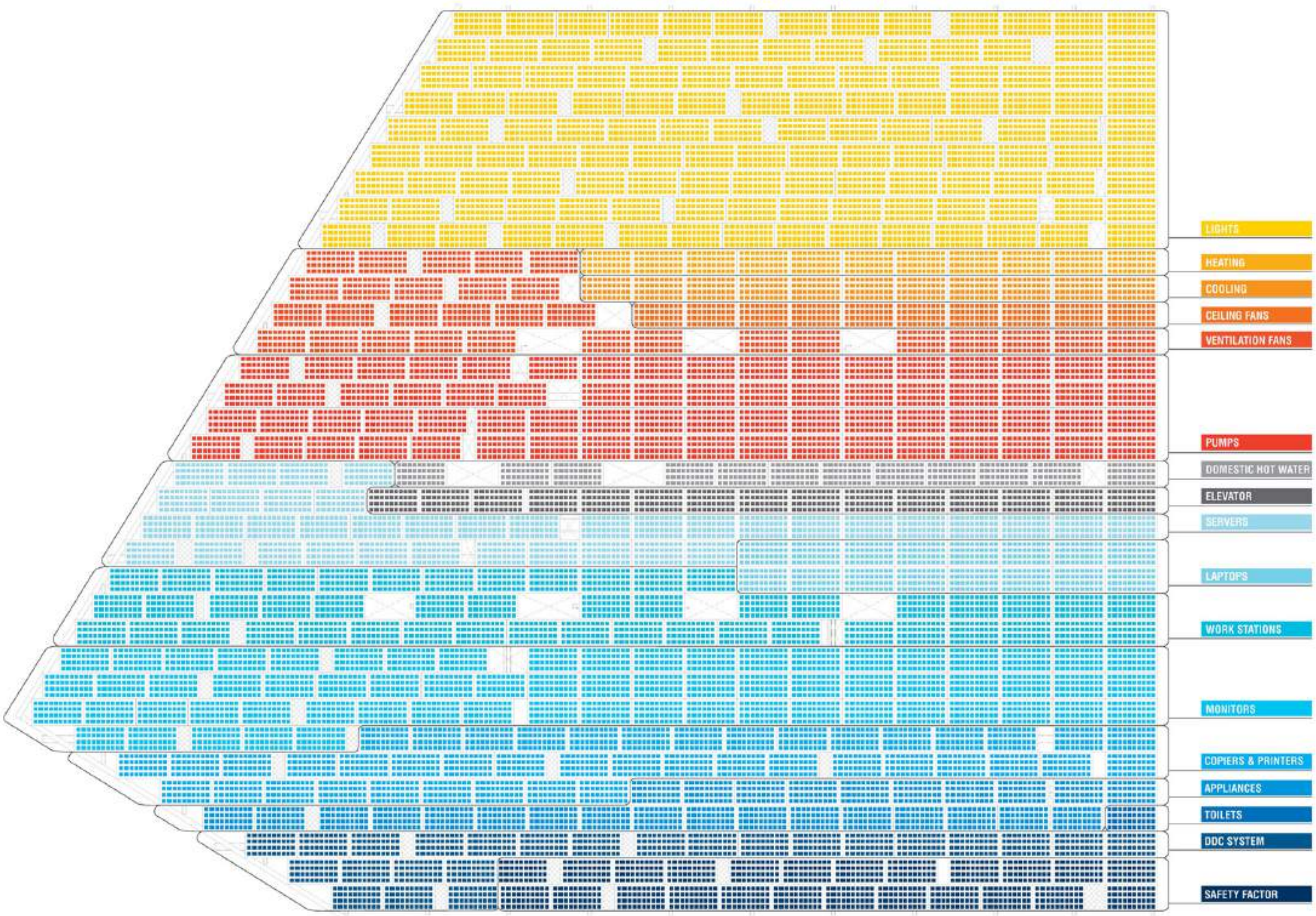


Figure 40. Plan of the PV array illustrating the proportion of array devoted to various end-uses; blue and gray are all "activity" loads.

4 PERFORMANCE

4.1 ENERGY PERFORMANCE

The energy performance of a building can be measured against a number of different benchmarks. Commonly used benchmarks include the energy used by other buildings of the same type, either nationally or regionally; a building built to energy code minimum requirements; a building earning the energy points needed to achieve LEED Silver, Gold or Platinum certification; and a building that generates as much energy as it uses (net-zero energy). All but the first method requires an energy model to approximate building energy use. The Bullitt Center used all of these, but *net-zero* was always the fundamental performance benchmark.

When benchmarks for the Bullitt Center were established, the Commercial Buildings Energy Consumption Survey (CBECS) national average for an office building was 92.7 kBTU/sf year. An average Seattle office building (Energy Star score = 50) was about 72 kBTU/sf year. A preliminary energy model used to approximate a 2009 Seattle Code minimum building built on this site was 42 kBTU/sf year. Determining the most important benchmark, the EUI for a 6-story, 50,000 sf net-zero energy building on this site was first determined by how much solar electricity could be generated using PV panels arrayed on the building. After a series of design explorations this value was estimated to be about 16 kBTU/sf year.

The Bullitt Center's photovoltaic "power plant," began providing the building power in February 2013, during the final stages of the building's shell-and-core construction and "tenant improvement" (TI) of interior spaces was underway. Tenants begin moving in to the building by mid-March, and the Bullitt Center was dedicated on Earth Day, April 22, 2013.

During its first year of occupied operation from May 1, 2013 through April 30, 2014, the building produced 114,085 kWhrs more electricity than it used. The actual EUI of the building, based on a gross floor area of 50,142 SF, was 9.4 kBTU/sf year, or 41.7% less energy than the predicted EUI was 16.1 kBTU/sf year. Compared to a 2009 Seattle Energy Code minimum building (EUI = 42 kBTU/sf year), the Bullitt Center's energy performance was 77% better.

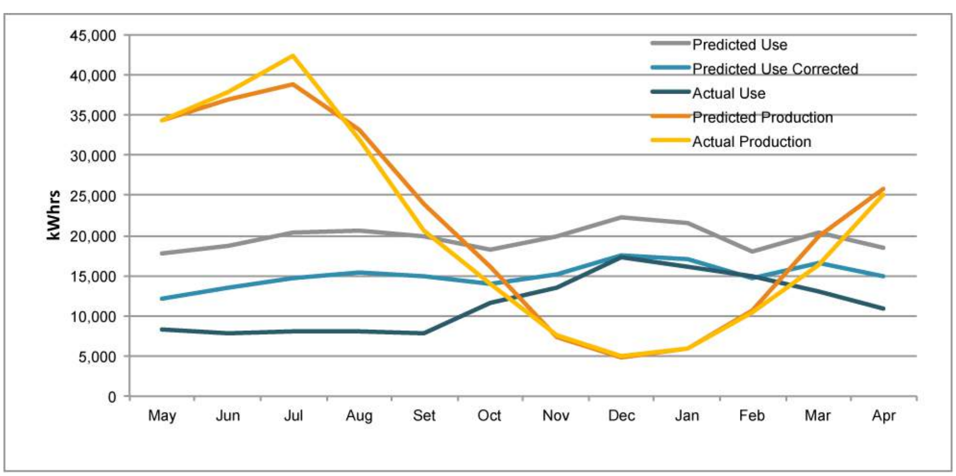


Figure 41. Bullitt Center year one energy use and production: predicted vs. actual. Predicted use is corrected (blue line) for the actual occupancy (difference between design and actual occupancy).

Actual energy production followed predicted production very closely. The energy production model predicted that the 244 kW PV array would produce 257,770 kWhrs of electricity in a typical meteorological year (TMY). The actual electricity generated was 251,885 kWhrs, 2.3% less than predicted. Seattle experienced more overcast days in September and October, and starting in February, had one of the rainiest winter/spring periods on record. This is reflected in the predicted versus actual energy production.

Occupancy almost certainly accounts for at least some of the difference between predicted and actual energy use. The maximum design occupancy for the building is 214 people occupying offices, and 150 people using the classroom and exhibition space on Level 1. A typical design-day occupancy is 158 office occupants and 20 visitors to the exhibition and classroom space.

In May 2014 the building was 49% leased but had an average of only 34% of its typical daily design occupancy. From June through December the building was 77.6% leased, and the typical daily occupancy gradually climbed from 41% to 51%. Since December the building has been 82.2% leased and typical daily occupancy is 61% of design occupancy.

Activity loads, all the energy used by people and their equipment plugged into outlets, including refrigerators, copy machines, task lights and computers, in addition to all hard-wired lighting, accounts for approximately 48% of the whole building loads. The predicted whole building energy use is 236,389 kWhrs; correcting for occupancy, predicted energy use would be 180,693 kWhrs. The actual whole building energy use was 137,800 kWhrs, which is still 23.7% less than predicted energy use, corrected for occupancy.

Analysis to determine how and where energy is being used in the building, and the effect of occupancy on the building's performance, awaits access to reliable sub-metered electrical data. Because the building load and activity load data coming from the energy portal do not sum to the whole building load, this indicates that not all of the building's circuits are being accounted for through this metering portal. While we have confidence in the whole building electricity use and production data, access to accurate sub-metered data is pending.

Figure 42. Exhibition space in the CID Discovery Commons.

4.2 PROJECT PERFORMANCE

Few building projects are informed with the clarity of intent, nor executed with such commitment to the outcomes, as the Bullitt Center. Its success is a direct outcome of the attention given to its design and construction process, and to the commitment by the owner and design team to unambiguous performance targets. The client team did their homework and came to the table with information, analysis, and performance targets. This information informed both selection, as well as the preparation, of the design and construction team. They were selected for their talent and technical prowess as well as their proven ability to collaborate – to play well with others.

Here are some of the elements that contributed to the successful outcomes of this project.

4.2.1 PREPARATION

The Client (Denis Hayes and the Bullitt Foundation) and the Client's Representative (Chris Rogers and Point 32) spent well over a year setting the stage for the design of this building. In addition to a comprehensive site feasibility study (done by Weber Thompson Architects), they engaged the Integrated Design Lab in an analysis of architectural strategies to address the Living Building Challenge. Additionally, a multi-discipline design studio in the UW College of Built Environments conducted a 10-week elaborate brainstorming exercise to develop three alternative design concepts. During this time Denis and Chris recruited a 10-member Building Advisory Committee to conduct a systematic selection process to identify an architect with the right combination of technical skill, collaborative ability, and design talent to deliver this unprecedented project. Through this process they gathered critical information, assembled a stellar project team, and recruited a diverse cadre of technical advisors.

4.2.2 LEADERSHIP

Miller Hull's rigor, discipline, and talent, is demonstrated through their 34-year body of work, and was thoughtfully articulated in their written project proposal and in a day-long interview with the Building Advisory Committee. Among the firms in the US that are truly practicing ecological design, few are delivering large, complex building projects at a higher level of performance and beauty than the Miller Hull Partnership. Contributing to this success is their skill in orchestrating a collaborative design process with their consulting partners and project stakeholders, their performance-based design approach, and the rigor and discipline they bring to their work.

Brian Court says that not only did they have everyone they needed around the table, but that the Client knew more about the dimensions of a "living building" than they did. "Usually you spend a lot of time educating the Client and getting them to commit to high performance goals; in this project, the Client was always pushing the project team, not the other way around."

Denis also helped shape a culture of commitment on the construction site, both through his words and through his presence on the site. "Denis is not a soapbox sort of guy. He is very genuine. There's no baloney." Denis visited the site regularly, got to know the builders, and listened to their stories and aspirations for the project. His presence was instrumental in creating a culture of shared commitment to creating a truly extraordinary building.

4.2.3 INTEGRATED DESIGN PROCESS

The design process began with a 2-day design charrette with over forty members of the project team, stakeholders, and advisors present. Sharing all the project information, articulating goals and aspirations, and giving everyone a chance to weigh-in with their vision for the project, created a sense of shared ownership and responsibility for the project. Brian Court says that it was "comforting to have the client, the developer, the builders and the engineers around the table from the very beginning. It felt like the responsibility and liability were well distributed."

"We were there on day one of the design process, and it was still too late," says Christian LaRocco of Schuchart Construction. "You can never be at the table too soon." The builders were at the center of the design process and involved in all the major system decisions, and provided feedback on cost and constructability at each step.

The integrated process may be most evident in the degree to which the "silos" of responsibility were not evident on this construction site. Christian observed that during construction "the mechanical engineers were giving unsolicited recommendations on materials, the architects were expressing constructability concerns, and the builders were talking about energy performance." Project members transcended their disciplinary interests in ways that he hadn't seen before.

Figure 43. "Irresistible Stair" (Benjamin Benschneider)

4.2.4 SYSTEMS THINKING

This project compelled the design and consulting team to leave no stone unturned in pursuit of the best possible set of design and technology solutions. The water and resource recovery systems are a good example of this. 2020 Engineering, the water and waste systems designers, explored a wide range of possible systems, and since they all had architectural and mechanical system implications, these played a major role in shaping the form of the building. With Miller Hull (architects) and PAE (mechanical engineers), 2020 considered sunspaces, living machines, and resource stream diversion, each having both form and mechanical system implications. These systems were drawn into the building form by the architects and modeled by the engineers before collectively arriving at a resolved design for the systems as a whole. "This building, more than any we've built at Schuchart Construction, is an interconnected system," says Christian. "I call it the 'amoeba effect'– every change ripples down the line to other elements of the system. You can't change one part without effecting others."

Brian Court says "we knew it was going to be a completely different process because the goals were so high; where it's not really the architect making a couple big moves and then letting the engineers figure out how to get the systems to make it work. This building was going to have to be designed from the inside-out with the system strategies coming first." While response to climate forces have long been central to Miller Hull's design approach, the idea of the building as an integrated system, and a "science-based" approach to form-making was "liberating," says Brian Court. "Everything has a reason, nothing is done for the sake of just "composition." So early on the design team adopted the mantra of performance-based design; that virtually every decision would need to be measured against the project's performance metrics: energy, water, materials, beauty, cost, and longevity.

"What's best for the project," and more specifically, what best serves the design intent, is how Christian characterizes their approach to day-to-day decision making during construction. This design intent is clearly articulated through the energy, water, and material "petals" of the Living Building Challenge. The conceptual clarity of the LBC provided the builders, the carpenters, and all the trades with a framework to interpret the design intentions for the project.

4.2.5 COMMUNICATION

In an interview during the building's construction, Christian LaRocco explained that "Schuchart is the center of all communication for all participants in this project, and our mentality here is to embrace all of it." Christian believes that a large measure of their success on this project has been to see the project through the "frame" of each discipline's perspective – and each perspective is completely different. The third-party safety officer sees the project completely differently than the architect or the engineer. His role as project manager has been to listen so that he can facilitate the work of each role and discipline on the project. The more that he understands the constraints and challenges that each part of the project is up against, the better he's able to help them overcome obstacles.

Figure 44. Concept studies for vertical portions of the PV array.

4.3 LESSONS LEARNED

As a living laboratory, the operation and ongoing performance of the building will provide lessons to the design community for years to come. Here are some of the lessons learned from the design and construction of the Bullitt Center.

4.3.1 PROGRAM DEFINITION

The project began as a mixed-use building with retail, commercial offices, and housing. This was the program for the design charrette, and continued for a month or two afterwards. But it quickly became evident that complications of organizing uses and systems, predicting water use for residential tenants, and serving the energy needs of retail tenants, stacked the deck too high. While most of the time and effort spent on this diversion generated information that was still useful to the revised program of a commercial office building, it took time and effort that could have been focused on the ultimate program for the building.

Figure 45. Event in the Exhibition space of the CID Discovery Commons.

4.3.2 DESIGN ASSUMPTIONS

Two sets of assumptions that were ultimately dispelled persisted well into the conceptual design phase and consumed time and design effort. One was the assumption that there would be some sort of atrium condition to drive daylight deep into the building, and to facilitate cross- and stack ventilation. Two concepts emerged with this strategy: an "O" plan and a "V" plan, splitting each floor in two. After much design and analysis, these were ultimately rejected because an atrium did not significantly improve daylighting, it competed for light with the PV panels, it resulted in more heat loss, it presented real estate challenges, and most important, it resulted in a building that was too expensive. The scale and geometry of the site simply doesn't accommodate such a building form.

The second set of assumptions had to do with the orientation and distribution of photovoltaic (PV) panels. We assumed that panels would be tilted to the south, integrated into the building skin and/or carried in a south-facing armature. Despite elaborate Rhino + Grasshopper analysis of hundreds of PV configurations, it became clear that it is not a matter of efficiency (maximizing watts per panel), but about effectiveness: maximizing power production in the given area - and maximizing that area by extending over the public right-of-way of the sidewalks.

4.3.3 COST TARGETS

At the outset of the design process the team was instructed that the building's performance was paramount and that costs would be addressed after initial concepts and systems were developed. But of course budget is never a secondary matter, and a lot of time and design effort was expended before a cost analysis was carried out. When it was, the result was a major re-evaluation of the conceptual design, now informed by cost. Performance and cost targets should be equally unambiguous and arrived at as early in the design process as possible, and a cost estimator should be at the table from the beginning.

The initial cost targets where unrealistically low. The building initially used as a cost comparison was a Class-A office building previously built by the contractors with a cost of $180/SF. With Living Building Challenge premiums (mostly PV power, and alternative water and waste systems) the target was $250/SF; construction cost was ultimately $360/SF. There are at least two general factors that account for this cost premium. First, the most efficient technology is also the most expensive. For instance, early estimates for the curtainwall system were about $50/SF, while the actual Schüco curtainwall cost was approximately $110/SF. Secondly, some of the systems are small-production prototypes that haven't achieved the scale and market penetration to be competitively priced. Most notable in this category are the composting toilets, which are not truly in "production" yet, but were made-to-order prototypes. These have been expensive and have been plagued by performance problems.

One of the objectives of the Living Building Challenge and this building is to spur market transformation by creating markets for green, high performance building materials and equipment. For instance, *Prosoco*, the makers of the liquid-applied building membrane used to seal the building and prevent heat loss, re-formulated their product when it was discovered that it contained chemicals from the "red list" of banned substances under the rules of the Living Building Challenge™. Along with the windows and the composting toilet system, the hope is that their use in this building may help them get a foothold in the market. Early adopters of new technologies pay a higher price to support these emerging markets.

4.3.4 MEASURING PERFORMANCE

The primary challenge to fully analyzing the Bullitt Center's first year performance has been the lack of reliable sub-metered data from the electrical system via the information management system. The Schneider/Square D electrical system has robust capabilities for gathering and reporting highly granular electricity use data. However, because it uses a proprietary "back-of-house" system, which requires training as well as physical access, we've been unable to get all the data we would like.

Working closely with the Bullitt Foundation, PAE, and Unico, the building management company that "drives" the building, we're making progress getting the information needed to make an accurate accounting of all the building's loads and circuits, and begin getting a reliable flow of sub-metered system loads that will provide a much more complete picture of how the building is using energy.

The evidence to date indicates that the Bullitt Center is meeting or exceeding design expectations for energy use and energy production. While additional energy use data is needed to fully assess the influence of occupancy on energy performance, preliminary analysis indicates that occupancy alone may not fully account for the building's exceptionally strong first year's performance.

Anecdotal evidence suggests that thermal comfort and satisfaction with the indoor environment are meeting expectations. Tracking the building in both real-time through the DDC system, along with analysis of representative periods and building zones during the last year, indicate that the building's operation aligns well with the design intentions. In the coming year we hope to more rigorously study both occupant engagement and occupant satisfaction with the building environment.

Figure 46. The Bullitt Center (Nic Lehoux)

ABOUT NEEA

Working to Create a Vibrant, Sustainable Future for the Northwest

Mobilizing the market toward energy efficiency is the most cost-effective way to meet our future energy needs. The Northwest Energy Efficiency Alliance (NEEA) is an alliance of more than 140 Northwest utilities and energy efficiency organizations working on behalf of more than 13 million energy consumers.

ABOUT IDL

The Integrated Design Lab (IDL) is operated by the Department of Architecture in the College of Built Environments at the University of Washington. The IDL is a self-sustaining service that includes interdisciplinary faculty, staff, students, professional collaborators and partner organizations. The Integrated Design Lab carries out research to advance knowledge and policies that support the healthiest and highest performing buildings and cities. It measures and analyzes modeled and actual building performance data so as to influence the building industry's understanding of how to radically improve the design and operation performance of buildings. Our performance research includes energy efficiency, daylighting, electric lighting, occupant energy use behavior, human health and productivity in buildings, and advanced building management systems.