The Bullitt Center Experience:
Building Enclosure Design in an Integrated High Performance Building

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ABSTRACT

The Bullitt Center is a 50,000 square-foot (4645 square-meter), 6-story, speculative office building recently completed in Seattle. The Center is on track to be certified through the Living Building Challenge (LBC), a green building standard which incorporates several advanced sustainability requirements including net-zero energy use, net-zero water use, and materials selection standards that adhere to a chemical red list and procurement limits based on distance.

This case study gives an overview of the project, describing the design process and results. It then delves into the details of how design decisions and technologies used in the building enclosure helped achieve these high performance goals, and in turn, how the envelope design decisions, technologies and performance were influenced by the project requirements.

The energy goals were met with contributions from a building enclosure that exceeded Seattle's already stringent energy code by 40%. A highly-effective daylighting design was also required, and window operability was needed to reduce energy use and ensure occupant satisfaction. Balancing all of these objectives was a critical part of the project design. Net zero water design - where all water used on site is captured from rainwater and all wastewater is treated on site - necessitated new products and design strategies as well.

The project also spurred innovation in terms of material choices for the enclosure. New products were used on the project that hadn't previously been available in the local marketplace, but are now being mainstreamed in the local economy. And, the materials chemical requirements of the LBC spurred some companies to reformulate their products and led to innovative substitutions in others.

INTRODUCTION

The Bullitt Center is a 50,000 square-foot (4645 square-meter), 6-story, speculative urban office building recently completed in Seattle. The Center is on track to be certified through the Living Building Challenge (LBC) version 2.0 (ILBI 2010), a green building standard which incorporates several advanced sustainability requirements including net-zero energy use, net-zero water use, and materials selection standards that adhere to a chemical red list and procurement limits based on distance.

The requirements led to incorporation of some new technologies that the design team had not used in the past, but for the most part, the project uses typical assemblies with incremental improvements in performance. More important, the requirements pushed new ways of designing, considering the building envelope as a more integrated part of the energy, comfort, and user experience. This paper presents some of the major findings of the project as they relate to the design process for the building enclosure and systems used.

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PROJECT OVERVIEW AND INTENT

The project was originally conceived by the Owner as one that would push the envelope of high performance/low energy design, and would present a new standard for the development of urban buildings. The desire for replicability, however, meant using a fairly typical developer financial model. The project was developed as a core-and-shell speculative office building, to be owned by the Bullitt Foundation, and used as headquarters for their small staff, with the remaining space leased to tenants with like-minded goals for environmental stewardship and innovative approaches to urban development.

The building is a 6-story building with partial basement, encompassing 50,000 gross square feet (4645 square meters). A grade change of 12 feet (3.7 meters) occurs across the project site which means the ground floor is partially buried. The main entry lobby for floors 2 through 6 is on the second floor along with a service entrance. The building is in the Capitol Hill Neighborhood in Seattle, a vibrant, mixed use district with housing and commercial uses.

Figure 1. Views of the Bullitt Center from the Southwest (left) and Northwest (right)

Figure 2. Ground floor/site plan (left) and typical Upper Floor (right)

The LBC incorporates several requirements; the most important discussed in this paper are:

- Net Zero Energy: Annual energy provided by on-site renewable energy systems shall supply 100% of the *site* energy needs of the project on an annual basis. LBC also requires no on-site combustion during operations.
- Net Zero Water: Annual water supply needs provided by captured rainwater, and all wastewater treatment to occur on-site. In an urban location, annual stormwater runoff consistent with “pre-development” condition is allowed.
- Materials Criteria: Avoidance of 15 chemicals on the LBC “red list” in systems, products, and materials used to build the project. Procurement of materials to come from within distance as established by material weight, categorized by Masterspec section. Any exceptions shall be approved by the International Living Building Institute (ILBI), the authors of the Standard.

Design began in July 2009, construction began in July 2011, and the project was substantially complete in February 2013. Construction cost was $18.5 million with a $30 million total project cost.

ENVELOPE SYSTEMS

In addition to meeting the LBC requirements, an additional project criteria was to use an idea of building lifetime, based on considerations of long-term value and resilience, to further reinforce decisions about design and materials. The building was conceived with a long-life structure that could modify over time as technology and programmatic requirements changed. The structure was given a 250-year lifetime target. The building skin was to be designed around a 50-year lifetime. And technology – MEP systems as well as renewable technologies – were to be seen as 25-year elements. Thus the skin was to be designed to be changed several times within the overall life of the building, but with a longer life expectancy than a traditional model which might target something more like a 30-year economic life. The durability targets also highlight the greater importance of decisions about the building envelope as compared to mechanical and electrical systems.

The building is designed as four stories of heavy timber structure over two stories of reinforced concrete. Lateral systems within the heavy timber section are steel. The building was permitted as a Type IV Heavy Timber (HT) structure. Given that, the structure was to be either HT or one-hour-rated construction, and the exterior enclosure was required to be of non-combustible construction.

The high roofs are constructed of solid wood – 2x4 on edge (38 mm x 89mm) with a plywood diaphragm. Roofing is a membrane roof over rigid insulation and cover board. A 6-mil poly vapor retarder is included under the insulation and is detailed as the air barrier. Lower green roof/constructed wetland and plaza roof areas are concrete structure with fluid-applied rubberized asphalt waterproofing and an inverted assembly with rigid insulation over the waterproofing. Interior floors are solid wood – 2x6 on edge (38 mm x 140 mm) with plywood diaphragm - and 3-inch (76 mm) concrete topping slab, or structural concrete within the concrete base.

Above-grade walls are constructed of standard metal stud construction. While thermal performance of steel stud walls is sub-optimal, the non-combustible requirement for the construction type gave fewer options for lightweight, flexible and replaceable wall systems. The stud walls have exterior mineral wool semi-rigid insulation over a fluid-applied, vapor permeable, air and weather barrier. The project was one of the first installations of a thermal clip system for the exterior cladding support – the spacers are made of fiberglass to reduce thermal bridging through the exterior insulation. Overall, with the stud cavity insulation and exterior insulation, constructed as curtainwall balloon-type framing, the performance of the wall system exceeds R-25 (R-4.4 SI).

Window selection was of utmost importance. The windows are aluminum curtainwall with triple-glazed, argon filled, glazing units with two low-E coatings. Fixed curtainwall achieves NFRC-certified U-0.17 (U-0.96 SI). Operable units are estimated to achieve approximately U-0.30 (U-1.7 SI). Operables are 4-foot by 10-foot (1.2-meter by 3.0-meter) parallel opening vents that project out 7 inches (180 mm), and are electronically actuated. Windows on the South (SE), West, and North (NW) elevations, on floors 3 through 5, are shaded with motorized exterior blinds that are automatically controlled to mitigate glare using a calendar and sky condition sensor.

Construction quality control testing was utilized during construction to verify water and air tightness of the windows and envelope. Sections of the window system were tested using the ASTM E1105 standard at 7 psf (340 Pa) and passed. The building was pressure tested to verify performance of the air barrier system, and it passed with a leakage rate of 0.19 cfm/ft^2 (0.96 L/s-m^2) at 75Pa, bettering the design target of 0.25 cfm/ft^2 (1.3 L/s-m^2) and the code maximum of 0.40 cfm/ft^2 (2.0 L/s-m^2). Other commissioning efforts related to the building envelope systems included the operable windows and also the dynamic shading systems. A comprehensive approach to envelope commissioning was not a part of the project.

One last system related to the building envelope is the solar photovoltaic (PV) array. While not part of the actual building enclosure – the array is not intended to be weathertight - the presence and scale of the array required to meet the net zero energy goal was a significant design challenge. The final design places the array on an elevated steel structure held approximately 3 feet (1 meter) above the roof surface, as directed by the jurisdiction fire marshal for access. The array extends out approximately 20 to 25 feet (6 to 8 meters) beyond the principal wall surfaces, and actually 7 feet to 19 feet (2 to 6 meters) into the public right-of-way, depending on orientation. Provision of the array required extra consideration of how drainage would occur, the impacts on daylight for upper floors, and the impacts on adjacent properties.

ENVELOPE ENERGY PERFORMANCE

Achieving net zero energy required driving down the energy use to the point where it could be provided by the rooftop array. Early in design an energy use target below 20 kBtu/ft^2-yr (63 kWh/m^2-yr) was established. As the design progressed, the target was further reduced to an EUI of 16 (50 SI), which was below what was being achieved in any comparable US office building at the time. An efficient envelope was a critical component in meeting this target.

Climate Analysis

The Seattle, WA climate is one that has moderate annual heating requirements (4900 HDD65F, 2722 HDD18.3C) and low annual cooling requirements (173 CDD65, 96 CDD18.3C). Heating design temperature is 23ºF (-5ºC) and cooling design temperature is 81ºF (27ºC) (ASHRAE 2007). The moderate loads lend themselves well to passive design strategies, including thermally-efficient building envelope design to minimize heating energy use and natural ventilation for cooling. At the same time, solar income is low in Seattle due to extended periods of overcast and precipitation. So the benefits of the moderate climate, and the lower energy use that might be a result, are offset by lower available daylight for daylighting strategies and for energy production from solar PV.

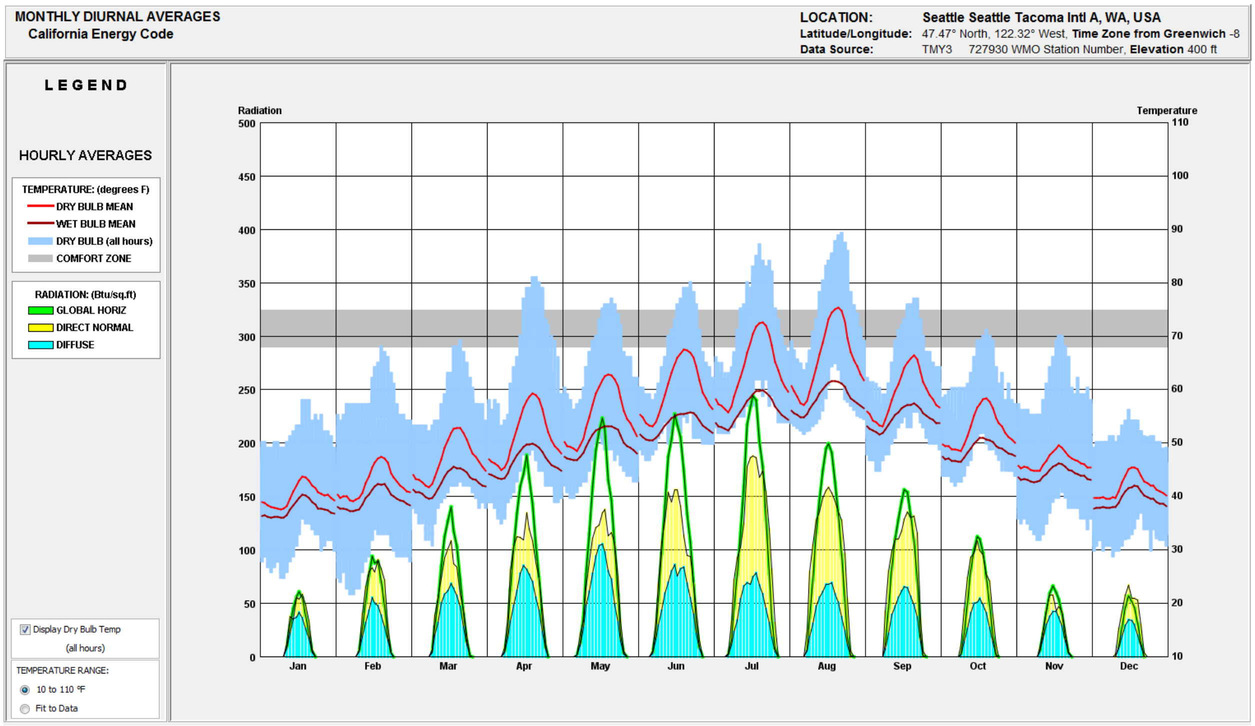

Figure 3. Annual climate summary for Seattle, Washington. (SeaTac International Airport TMY3)

Orientation

As is the case with urban buildings, building orientation is dictated by much more than just optimizing passive design. The longest facades of the 5-sided site are on the NW and SE elevations, so these facades are used as the primarily daylight apertures. Windows are minimized on the NE party wall, and used selectively on the west-facing façade. The orientation actually sets the building up well for solar control and daylighting except that the NW façade receives direct sunlight at challenging angles in late Spring, Summer, and Fall.

Thermal Performance

The design intent of the thermal envelope was to minimize heating energy requirements in order to meet the net zero energy imperative. Moreover, the good thermal performance allows for a downsized mechanical system. One way of thinking about this is to consider balance point temperature. The design target for building envelope performance, coupled with heat recovery on ventilation air, produced a building with a balance point of between 45 and 50ºF (7.2 and 10ºC). With this type of envelope performance, the number of hours where heating is required are reduced to less than 33% of heating hours at 65ºF (18.3ºC).

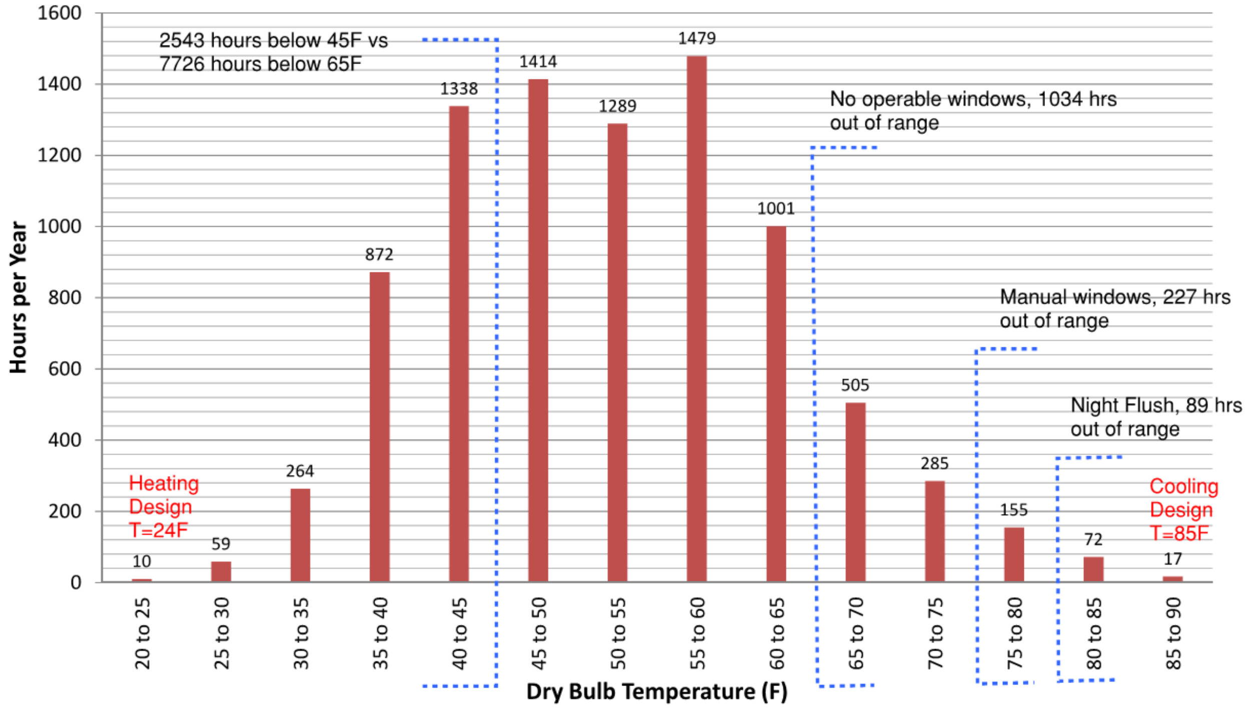

Figure 4. Annual Hourly Ambient Temperatures, Binned Data. Shows Heating and Cooling balance point temperature impacts. (SeaTac International Airport TMY3)

Energy modeling in the project feasibility phase was used to establish envelope thermal parameters that would support net zero energy design. In the end, these were generally adhered to. Daylighting performance required a greater window area than originally envisioned, but the performance of each element was maintained. The design achieved an overall average R-value of 10 (R-1.8 SI), compared to an R-value of 7 (R-1.2 SI) for Seattle's aggressive energy code (SEC 20XX), or R-4.9 (R-0.86 SI) for a design complying with ASHRAE 90.1 (ASHRAE 2007). The tested infiltration rate is also below industry standards.

	ASHRAE 90.1-2007	2006 Seattle Energy Code	2009 Seattle Energy Code	2012 Seattle Energy Code	Pre-Design Target	Final Design	As-Built final
Roof	R-20ci	R-30ci	R-38ci	R-38ci	R-38ci	R-40ci	no change
Walls (Steel Framed)	U-0.064 $R_{effective}$-15.6	U-0.062 $R_{effective}$-16.1	U-0.055 $R_{effective}$-18.2	U-0.055 $R_{effective}$-18.2	U-0.040 $R_{effective}$-25.0	U-0.047 $R_{effective}$-21.3	U-0.038 $R_{effective}$-26.6
Fenestration Area	40% max	45% max	40% max	40% max *	25%-35%	40%	no change
Fenestration U-value	U-0.50 fxd U-0.55 opl	U-0.40	U-0.38	U-0.34 fxd U-0.36 opl	U-0.25 Non-N U-0.20 North	U-0.25 U-0.17 fxd U-0.30 opl	no change
Average R-value (calculated)	4.9	6.3	6.8	7.2	12.1	9.6	10.0
Infiltration	NR	NR	0.40 cfm/SF @75Pa	0.40 cfm/SF @75Pa	better than NR	0.25 cfm/SF @75Pa	0.19 cfm/SF @75Pa

* - fenestration area over 30% is allowed with better performance. Performance values used are for 30-40% fenestration range

Table 1. Bullitt Center Building Assembly Heat Loss Characteristics: Code and Design values.

DAYLIGHTING, VENTILATION, AND THERMAL COMFORT

Beneficial daylighting was the most significant driver of the architectural design related to the facades. Building occupants' access to daylight is a requirement of the LBC. Good daylight performance that reduces use of electric lighting is also critical to meeting net zero energy. Finally, a well daylit building is what defines a sustainable building in the Pacific Northwest, a region which is daylight challenged much of the year.

The design team relied on detailed daylight modeling of selected spaces to support decision-making around massing, floor-to-floor heights, floor plate sizing, window configuration, glazing characteristics, and interior surface finishes. For example, the studies showed the 14-foot (4.3-meter) floor-to-floor height provided a 20% increase in daylit area (measured as percent of floor area meeting a minimum 2% daylight factor under overcast skies) compared to 10-foot (3-meter) height, and helped overcome a 70-foot (21-meter) typical floor plate depth that was being driven primarily by the configuration of the site. Window configurations looked at continuous clerestories with lower view windows vs. ribbon windows vs. the vertical ribbons that formed the ultimate design. The design team assumed the clerestory design would outperform the others but in fact there wasn't significant difference between them. Window characteristics were studied and showed that a minimum glass visible transmittance of 50% would be required.

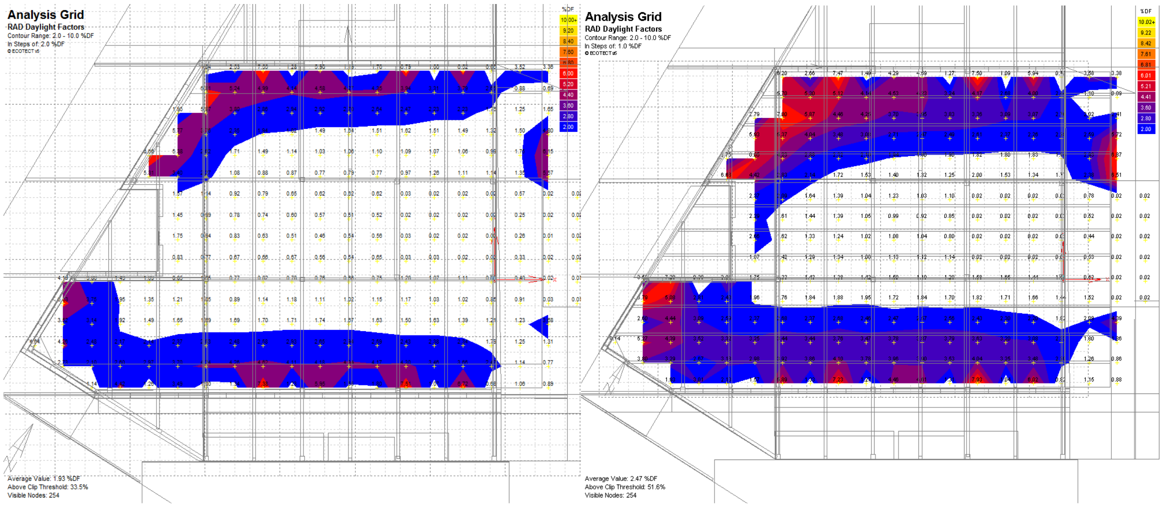

Figure 5. Daylighting Studies of typical upper floor showing impact of floor-to-floor heights. Colored areas achieve minimum 2% daylight factor. 11'-4" floor-to-floor on left. 14'-2" floor-to-floor on right.

Solar Control

The resulting primary daylighting facades (NW and SE) were then highly glazed, at over 60% window-to-wall ratio. This required the design to incorporate glare control for sunny conditions and conditions with low sun angles typical of winters in the higher latitudes. The design team studied a variety of shading types, including dynamic glass, and determined that dynamic exterior shading would be the best strategy. Dynamic shades allow daylight penetration under cloudy skies, cut off low winter sun angles, and for modulate to meet the dynamic exterior conditions.

These shades also control solar heat gain. The glass design evolved to where two solar control lowE surfaces were incorporated to achieve low U-value, so the windows are already set up to achieve low SHGC, but the addition of the dynamic shading allows direct solar heat gain to be almost eliminated on the affected facades. Because of the office occupancy, glare control was given a higher priority than beneficial solar gain.

Ventilation

The building envelope system plays a significant role in thermal comfort as well. The building's heating is provided primarily through radiant concrete slab floors. This system can also be run with chilled water although the design is built around heating. A minimal amount of space conditioning is also provided through the ventilation air. The thermal performance and solar control thus are critical to maintaining occupant comfort with the downsized HVAC system.

At the same time, operable windows are the primary cooling system in the building. Manual or automated windows for free daytime cooling and nighttime flush of the building mass were determined to be critical to the overall net zero energy design from the outset. Various ventilation strategies were considered in design, including stack ventilation, but ultimately a simple cross-ventilation (single or double-sided) approach was deemed to provide adequate airflow, and therefore comfort, as studied using bulk airflow modeling. The original target openable area was 4% of floor area, which the design team found difficult to achieve. The openable area achieved is 3% of floor area, of which slightly more than half is automated.

Fenestration Properties

	2009 Seattle Energy Code	2012 Seattle Energy Code	Pre-Design Target	Final Design
Fenestration WWR	40% maximum	30% maximum (40% w/better U)	25%-35%	40%
Fenestration				
U-value	U-0.38	U-0.38 fxd U-0.40 opl (U-0.34/U-0.36)	U-0.25 Non-north U-0.20 North	U-0.25 - U-0.17 fixed - U-0.30 operable
SHGC	SHGC-0.35	SHGC-0.35	SHGC-0.25 Non-N SHGC-0.49 North	SHGC-0.31
Tvis	NR	NR	Tvis-0.60	Tvis-0.51 (glazing is 0.56)
Natural Ventilation	NR	NR	automated, 4% of floor area	automated - 1.8% manual - 1.2%
Exterior Shading	NR	NR	NR	yes, automated

Table 2. Fenestration Properties

NET ZERO WATER AND THE ROLE OF THE BUILDING ENVELOPE

The LBC net-zero water requirement introduces challenges to the building envelope design that are not present on other sustainable projects. One is that the building becomes a collector for all water used in the building, including the potable water. Through discussions with the local health department, one of their primary concerns regarding the collection of rainwater for potable use was the purity of the collection surface. The jurisdiction originally required that the roof catchment material be certified under NSF International (NSF) standards. When the design team determined that there were no products that could be used as building roofing that had that certification, an NSF P151 certified coating was allowed to be used. The design team identified a simple acrylic coating made in Florida with P151 certification. So far, the coating has not been applied because the jurisdiction is not allowing use of rainwater for potable water at the site. The owner is pursuing certification as a water utility, after which rainwater will be used for all supply and the roof coating will be applied.

Net zero water also requires on-site treatment. With the decision of the design team to use composting toilets, blackwater treatment was eliminated. However, graywater treatment is still required, and a rooftop constructed wetland was determined to be the best way to treat the water prior to re-infiltration. The wetland is constructed on a small roof area on the north side at level 3. In this location it is between the basement graywater collection location and the ultimate disposal site in the ROW on 15th Avenue. Design of roof systems that are meant to hold water, especially water that needs treatment, will be a consideration for urban sustainable buildings.

A third finding regarding the design of this project related to the idea of net zero water is the impact of the PV array on roof catchment and drainage. The slope of the array and the closely spaced panels means that rainwater tends to collect and sheet off the entire array. This takes away the ability for the building to act as a catchment system, and means the rainwater would then drain off at the lower edge over the public right-of-way. To offset these concerns, the PV panels were spaced every so often to allow drainage down to the roof membrane. This also serves to open up the array and allow light down through so that from street level, the large overhangs do not appear as monolithic as they otherwise would.

PRODUCTS, TECHNOLOGIES AND MARKET TRANSFORMATION

The intent of the materials requirements in the LBC is to introduce a simple way to identify proper selection for materials content and procurement in lieu of doing a full lifecycle assessment on each and every system, product, or material. With clear imperatives, it then becomes easier to move consideration of these issues into the more traditional decision-making process that considers performance, cost, aesthetics, constructability, durability, and the like.

Red List

Materials red list requirements drove some of the decision-making over envelope materials and systems but did not have as large an affect as originally envisioned. Exterior wall systems were selected to be steel stud backup walls primarily based on constructability and cost, despite the poor inherent thermal performance. Wood stud walls were considered but rejected because fire-retardant treated wood would have been required to be used by the building code.

Exterior insulation was used to deliver effective wall performance, but there was a choice of what material to use in this location. Foam plastic insulation had a pre-existing exception for the included fire-retardants, as granted by the ILBI. The design team preferred to use mineral wool because of its vapor permeability and because the formaldehyde used in its manufacture was considered by us to be less problematic than the fire retardants. Other insulations were considered, for example vacuum panels and cellular glass, but these didn’t meet project standards for constructability and cost. In the end, the design team sought, and was granted, an exception for the phenol formaldehyde binder used in mineral wool insulation.

Weatherproofing systems were, at the outset, assumed to be a minefield of red list chemicals but were found to be mostly free of problematic components. The only problem encountered was in the originally-specified fluid-applied air/weather barrier. This product had been locally-developed and is well suited to the climate but was found to contain phthalates. In the end, the manufacturer agreed to change the formulation of the product to allow its use on the Bullitt Center, and that is now their standard formulation.

One area where the red list drove aesthetic decisions was in the metal siding panel selection. The PVDF coatings used on the siding product selected for use on the project contained red list materials. The design team considered and accepted use of an unpainted panel for the building exterior.

Radius

Materials radius impacts were primarily about the windows and exterior blinds. The window technology was from a German-based company. Recently, the product had been introduced locally by a glazing contractor, but many of the pieces were still manufactured in Germany. During the course of design and development of this building, the German manufacturer evolved production of their systems to one where almost all of the components were manufactured in the US and then final fabrication took place at the glazing contractor’s location, which allowed the products to be used on this project.

The exterior blinds were also German made although they were being marketed in the US by a US company. The design team sought and was granted an exception for use of this product because they were shown to be essential to the desired level of energy and daylighting performance.

DISCUSSION

At the outside of the design for this project, the design team had many questions about how the design process, and the end product, would be different for a high performance building that would meet net zero energy and water requirements and stringent materials limits. This section presents a few key findings.

Renewable Integration

With a large urban building, very early considerations of how renewable energy will be deployed are required. It is not possible to simply design a highly energy efficient building and then begin to consider where the on-site generation will be located. For solar PV, considerations of tilt, angle, drainage, and impact on daylighting, make the PV an integrated piece of the architecture even if it is not true "Building Integrated PV."

Envelope-Related Energy Performance and Project Benefits

Energy savings from building envelope measures that support achieving net zero is actually a small piece of the move from a code-complying building to a net zero building, although in this case it needs to be clarified that the Seattle code as a baseline is already one of the most stringent codes in the country for similar climate zones. Envelope measures on their own do not make a huge impact – the estimated contribution is only 3% of the "road to net zero." Natural ventilation and daylighting design strategies – which are related to envelope design – are significant, but still not a determining factor. Overall, decisions about envelope design were estimated to contribute about 10% of the efficiency improvement required.

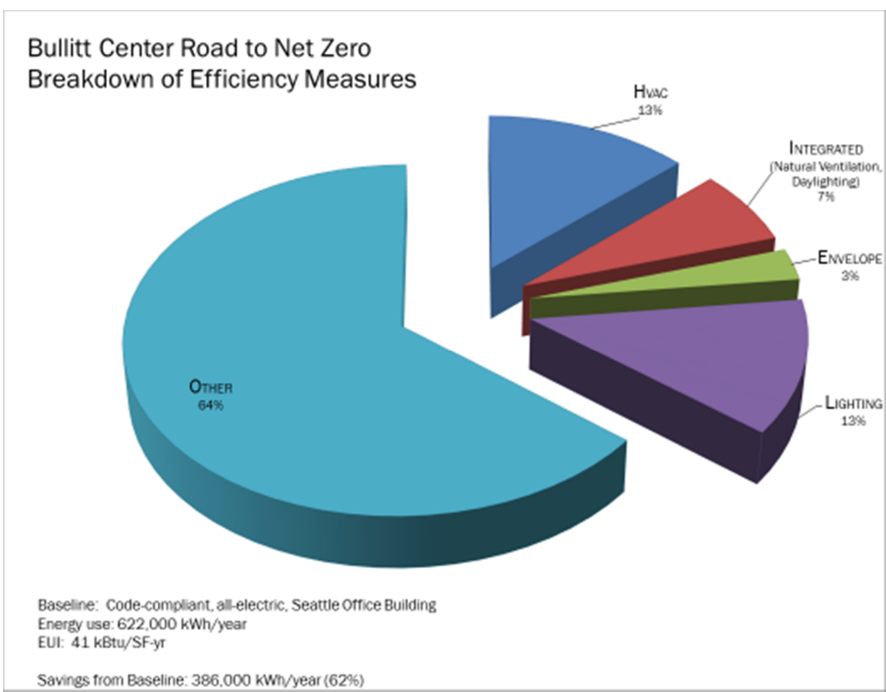

Figure 6. Composition of Energy Efficiency Improvements to meet Net Zero Level of Energy Efficiency. Baseline is a Code-compliant all-electric Seattle Office building, EUI = 41

The better justification for investment in envelope design in a high performance building is that is works in synergy with the mechanical and lighting system to provide an integrated approach to lighting and thermal comfort. The efficient envelope does many things on this building. It allowed reducing the ground source well field so that it fit under half of the building footprint. It allowed a reduction in cooling loads to the point where the HVAC design could be designed around heating, making radiant systems more appropriate. It promotes good workplace visual and comfort environment. It doesn't just reduce energy consumption.

Windows

The project also illustrates the overriding importance of window system design in a high performance building. The design needs to balance thermal performance (U-value), solar control, daylighting performance, visual comfort, operability and ventilation, and of course initial cost, and many of these work at cross-purposes to each other. For example, operable windows perform less well thermally than fixed windows but are required for ventilation. Questions of total glazed area, configuration, glazing type, shading, and operability were fluid throughout the design of the project. Moreover, window system design forms much of the architectural expression of the building.

In fact, a post-occupancy survey of the building users, intended to elicit from them which aspects of the design most bring "Beauty and Spirit" to the built work, identified the plentiful daylight and views and connection to the outside as one of most important design features in what makes the building a good place to work, second only to the exposed heavy timber structure.

Decision-Making process

Setting a strong performance target for the building envelope in the feasibility stage was essential to the success of this project. The use of energy modeling and good judgment to set thermal criteria, and to establish natural ventilation and daylighting as essential components of a net-zero-energy and democratic design, was critical.

Considerations about envelope performance were then seen as part of the integrated energy performance system, and could be traded off with any other measure that reduced energy use. For example, an additional inch of insulation in an assembly could be traded off with better desktop computer performance, or an additional number of trips up the stair instead of using the elevator.

As a result, "cost effectiveness" of particular building envelope measures as it pertained to energy performance was not the primary consideration as it was impossible to separate out any one design feature. On other sustainable projects it is typical to take a "baseline" code-complying design concept and then improve systems incrementally until the incremental cost – or the total cost – can no longer be justified on a first cost/energy cost savings basis. In this project, performance goals and the means to meet them were identified first, and then the design proceeded and those design elements that were found to have a cost but little or no contribution to performance were dropped from the design. Cost benefit analysis and lifecycle cost assessment of performance were not used.

CONCLUSIONS

The project shows that creating highly sustainable buildings, even in urban areas, is doable. There is the technical capability to create net zero energy and water buildings of significant scale using currently available technologies. Well-designed and performance-based building envelope systems are an essential part of achieving these goals. We also found that high performance/low energy and regenerative design, although it is challenging to take on, can be aesthetically and architecturally liberating.

The work of design teams is to find ways to do it better and more cost-efficiently, and with less reliance on unhealthy chemicals, and with more reliance on regionally-produced products and materials that will benefit local economies. As an industry, we need to find the will to make these types of design goals a new standard for development.

ACKNOWLEDGEMENTS

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