BEST4 Paper and Presentation Panel: Validating the Performance of Integrated Facades

PERFORMANCE VALIDATION CASE STUDY— Federal Office Building with an Integrated Facade¹

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ABSTRACT

The GSA Edith Green Wendell Wyatt Building (EGWW) has undergone an extensive retrofit and is distinguished by its new integrated facade.⁶ It has been transformed from a poorly performing office building into a highly efficient LEED Platinum facility. The unitized curtain wall includes fixed exterior shading tuned for each solar orientation. The new interior environment optimizes daylight and electric lighting, thermal comfort, and air quality.

This paper reports on post occupancy evaluations (POE) to validate and fine-tune the performance of EGWW. The focus is on POE studies that relate to the integrated facades. Overall, post occupancy evaluations address three categories:

- 1. Resource use and generation—energy and water
- 2. Occupant satisfaction
- 3. Indoor Environmental Quality Measurements

During design, the impact of building enclosure measures and internal loads was linked directly to the selection of the mechanical system. The team determined that strategic use of glazing and exterior shading would support highly efficient hydronic radiant heating and cooling.

POE methods include installed data sources (BMS and other M&V systems) and proposed field testing. Occupant satisfaction has been evaluated with CBE's⁷ on-line survey. The results have been filtered by solar orientation, floor, and other criteria to understand the facades' impact on occupant satisfaction. Pre-occupancy results and additional benchmarking compare the results with GSA and other office buildings. As of January 2015, many of the POE studies have been completed, but some are still on-going.

POE objectives include: demonstrating federal energy compliance, refining building performance, and providing feedback for future work.

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1. INTRODUCTION

Although more and more buildings have high sustainability aspirations, performance intentions are seldom fully met in building operations. In an attempt to respond to individual occupant complaints, it is common for building operators to compromise efficiency by overriding mechanical system and lighting control sequences. In many cases the modifications are only minimally effective at satisfying on-going occupant comfort. To address this disconnect, the client, design team, and contractor for a significant federal office building in Portland, Oregon, collaborated to establish a set of AFTERCARE services and studies which include extended commissioning, building operator and occupant training, and a set of post-occupancy evaluations. In addition to optimizing actual building performance for this particular project, these services and studies also provide valuable feedback for application to future projects.

The Edith Green Wendell Wyatt Federal Building (EGWW) in Portland has undergone an extensive retrofit and is distinguished by its new integrated facade. The building has been transformed from a poorly performing 18-story, 380,000 square foot, 1974 office building into a highly efficient, LEED Platinum facility that has become a cornerstone in the GSA's⁸ green building portfolio. The upgrades included seismic and other structural elements, and efficient MEP systems. The unitized curtain wall facades include fixed exterior shading that is tuned for each solar orientation. New interior work environments with optimized daylight and electric lighting and improved air guality have been created. Construction of the project was executed using a variation of "Integrated Project Delivery" methodology that the team referred to as "i-Delivery." This methodology was tested and improved by GSA Region 10 on three other projects beginning with the Eugene, Oregon Courthouse in 2002. Principles employed by the team included: a sense of ownership by all team members; continuous improvement; innovation and learning; transparent processes; optimized technology; and best value. To foster communication and collaboration, the core team (owner, architect, engineers, construction manager, and major sub-contractors) co-located during design and construction and utilized BIM on a shared server. This method of design and construction reduced the schedule by about 40% and supported solutions that avoided compromising the building's efficiency and design quality. Construction was completed for occupancy in the summer of 2013.

High performance and occupant comfort were identified early as priority objectives by the client (GSA) and the design team. While energy efficiency performance is an important component of equal or greater importance is occupant satisfaction—including health, productivity, and wellbeing. Post-occupancy monitoring for EGWW includes stormwater collection, water use, and PV generation, but this paper focuses only on the topics directly related to the integrated facades:

- a. Energy use for both electric lighting and mechanical systems.
- b. Thermal comfort in perimeter zones—based in part on solar heat gain control.
- c. Daylighting—including light quality and glare management.

⁸ GSA: The General Services Administration includes the Public Buildings Service which owns, leases, and manages buildings for federal government functions.





Figure 1. EGWW from southwest

Figure 2. EGWW from northeast



Figure 3. Typical office floor plan

2. BACKGROUND

Built in 1974, EGWW was operated as a federal office building for over two decades, but by 1996 the mechanical, electrical, and other systems were worn to the point where the GSA commissioned a comprehensive study to analyze the architectural and engineering system deficiencies. In 2003 SERA was hired, along with and Cutler Anderson Architects, for repair and alterations as part of the design excellence program.

Although the design and most documentation work were completed earlier, construction funding was not secured until 2009 through the American Recovery and Reinvestment Act (ARRA). A cost benefit analysis revealed market changes in both cost of construction and Central Business District lease space, which made it more economical to completely vacate the building during construction, a game changer for the project in terms of the opportunities it allowed for achieving deep energy savings.

Improvement of the interior workplace environment was an important project goal to support increased productivity, reduced absenteeism, and lower operation costs. Modernization goals for the project also included the following:

- Replacing the building envelope with a new energy efficient and blast-resistant curtain wall.
- Upgrading the building structural / seismic systems.
- Upgrading to highly efficient mechanical and electrical systems.
- Replacing the electrical system to provide clean, uninterruptable power.

- Replacing the plumbing system and install low flow fixtures for water conservation.
- Updating the voice, data, telecom, fire and smoke control systems.
- Updating the work environment: advanced electric lighting systems, optimizing daylighting, improving indoor air quality.
- Replacing the elevators with new, energy efficient equipment.
- Improving accessibility.
- Upgrading of security to meet post-Oklahoma and 9/11 standards.

The resulting building has achieved LEED Platinum, and for the first year of operation following commissioning (October 2013 through September 2014) the actual energy use is 31.5 KBtu/sf/yr. This is an energy savings of 41% compared to a typical code office building modeled per ASHRAE 90.1-2007. EGWW has been designed to exceed the EISA requirements and is meeting the GSA's intentions for it to be a national model for energy efficient building renovation.

3. DESIGN / ANALYSIS / DOCUMENTATION

3.1 HIGH PERFORMANCE OBJECTIVES

ARRA funding brought requirements for the project to meet significant energy and water conservation requirements of the Energy Independence and Security Act (EISA) which were documented in the Owner's Project Requirements (OPR).⁹

- Energy Star Requirement¹⁰: 97.
- Water conservation requirement: 20% indoor potable reduction, 50% outdoor potable reduction.
- Energy Conservation Requirements: 55% Fossil fuel reduction, 30% Energy use reduction.
- LEED-NC Gold minimum was required (Platinum was achieved under LEED-NC 2009).

Strategies to meet project goals included the use of high efficiency fixtures, the use of rainwater for non-potable use, cooling water makeup, alternate cooling tower water use and the review of methods to manage the 95th percentile rain event. Additional strategies to meet energy goals included the use of advanced meters for gas, electricity and water, complete envelope design, glazing systems selected by orientation, and use of life cycle cost analysis to select HVAC equipment. The intended operation hours were identified as 6 AM to 6 PM on Mondays through Fridays.

To ensure the goals of EISA would be meet, the project team performed extensive technical studies and early modeling of strategies ranging from exterior shading and daylight, to thermal

⁹ See also the 2009 Draft of P-100, "Facilities Standards for the Public Buildings Service"

¹⁰ Web resource, <u>http://www.energystar.gov/buildings/</u> accessed 13 January 2014.

comfort and occupant behavior. Energy conservation measures (ECMs) were identified in a "High Performance Building Workshop" held in May of 2009. Incorporation of radiant heating and cooling was found to be one of the top performing strategies in terms of energy savings through an Energy Model by Stantec Engineering.



Figure 4. Energy Use Breakdown Comparison ¹¹

To delineate the evaluation process and communicate the iterative and integrated nature of the overall study, an ECM flow chart was developed. The chart illustrates the impact of building envelope measures and internal loads on the selection of the mechanical system.

¹¹ SERA Architects and Stantec Consulting, "EGWW Parametric Analysis of Energy and Water Conservation Measures," V1.1, September 2009.

ECM Decision Flow Chart



Figure 5. Energy Conservation Measures—Decision Flow Chart¹²

¹² SERA Architects and Stantec Consulting, "EGWW Parametric Analysis of Energy and Water Conservation Measures," V1.1, September 2009.

3.2 INTEGRATED FACADE ANALYSIS—THERMAL CONTROL

Although radiant systems are very efficient, the initial analysis showed that radiant ceiling panels could not be used if peak cooling loads exceed 20-30 Btu/sf. While eQuest was used to estimate annual energy loads, Stantec Engineering modeled each facade using IES Virtual Environment V5.9 software to estimate peak loads. The study determined the amount of solar control needed to optimize space performance by reducing cooling loads to the point where radiant cooling would be able to ensure comfort.

Once the energy model was set up in IES, two modules were used to perform the analysis: the "Suncast" module was used for solar calculations and the "Apache" module was used for the thermal analysis. The peak cooling load criteria, 35 BtuH/hr/sf (floor area) was set to match the cooling capacity that can be provided by radiant ceiling panels and a dedicated outside air system providing code minimum ventilation at 55°F.

This study produced a table that showed which solar altitudes required shading and which did not, giving the project team valuable information to guide the shading design. The next step was to determine a percentage of time that the west¹³, south, and east façades would need to be in shade during peak cooling hours. The depth of the shading device was used as a variable: 6 inch increments from 18 inches up to 36 inches were tested. 24 inches was found to be the minimum depth that provided the shading required by the radiant cooling system.

Adding shading reduces the amount of daylight available which can drive up the energy used by lighting, increasing the peak load. Since many variables needed to be tested simultaneously, the team iterated using the glazing percentage and shading design and then reviewed the results relative to shading percentage and daylight factor.

The three different shading strategies were modeled for daylighting and shading at the University of Oregon, Energy Studies in Buildings Laboratory: a horizontal only condition (Figure 6, Column A), a system with vertical and horizontal fins with the horizontal element as a light shelf (Figure 6, Column B), and a system with vertical and horizontal shades with a horizontal element as a sill reflector (Figure 6, Column C). Each shading strategy was modeled with three exterior glazing percentages (41% glazing, 47% glazing, and 57% glazing), on east and south facades. The effectiveness of each shading strategy was compared to the criteria established in the initial thermal analysis. The west façade required a different shading design to meet the required shaded and was modeled separately in an iterative process.

¹³ The solar orientation of the block grid for this area of downtown Portland is rotated approximately 21 degrees clockwise. The actual orientations identified in this paper are as follows: North is NNE, East is ESE, South is SSW, West is WNW.



% annual shading, south facade

Figure 6. Facade Shading Study

3.3 INTEGRATED FACADE ANALYSIS—LIGHTING AND DAYLIGHTING ¹⁴

To meet the performance goals for EGWW, the lighting and daylighting systems were developed as integral systems, working together to minimize the energy use of the building. The design incorporates two features to enhance daylight penetration, a higher than typical window location and exterior sill reflectors that act as light shelves. These features work in tandem to increase the amount of natural light and the distance it penetrates into the building, which in turn allows electric lighting use to be minimized.

As is the case in most office buildings, operable shades are required to minimize glare and achieve project goals. This section summarizes the systems employed at EGWW for lighting control and recommended adjustments to maximize occupant comfort. As reported in Section 5.3 from occupant surveys, unfortunately glare issues have not been fully resolved to the satisfaction of all tenants and will receive further attention (following publication of this paper.)

Facade Components for Daylighting

The project incorporates a high performance curtain wall that is highly insulated. The façade design incorporates 2'-0" deep horizontal shading devices on the east and south sides with 3'-0" deep vertical shading elements every 10'-0" to minimize solar load. The shades are designed to provide thermal protection from the high angle summer sun, to minimize contrast and maximize

¹⁴ SERA Architects, EGWW "Lighting and Glare Analysis," V1.0, 6 December 2013.

daylighting. In addition, the design incorporates a 2'-0" deep sill reflector to maximum the daylighting on the south and east facades.

On the west façade the late afternoon sun is mitigated by a series of curving fins that utilize vertical rods spaced to allow for views out, while providing the required 50% shading. This configuration allows high angle summer sunlight to be blocked before it enters the building and turns into heat. However, the exterior shades do not block all of the direct sunlight the building receives, especially not the low angle winter sun, which is beneficial in that it provides additional heating. At these times other measures are needed to maximize occupant comfort when direct sunlight strikes the glass.

Lighting and Daylighting Controls

The project uses a "best practice" approach to lighting that incorporates several systems. The primary electric lighting in the space utilizes energy efficient, direct/indirect suspended pendants to provide general, ambient lighting in the space.

Because people's illumination needs vary based on age and the type of work they perform, it was intended that local workstations would have energy efficient task lights to provide additional illumination should someone need a higher lighting level than provided by the overhead lights. When the lighting in the space is dimmer than the occupant's preferred lighting condition, task lights are to be used to maximize occupant visual comfort.

To control the overhead lighting, EGWW uses a number of automatic lighting control strategies to help the building meet its energy efficiency goals:

- Daylighting controls maintain even light levels by automatically dimming electric lighting when sufficient natural daylight is available.
- Occupancy sensors in conference rooms, restrooms and private offices automatically shut off lights if a room is unoccupied for a short time; when the next person walks in the room, the lights will come back on.
- Time-clock sweep controls have been provided to turn off all lights during hours when the building is typically unoccupied. There are override switches on each floor that enable lights to be turned back on after hours.

These systems minimize the time electric lighting is in use. Since electric lights also generate heat, limiting the amount of time they are operating provides additional energy use reductions by reducing the cooling load.

Finishes

Another strategy used in designing the workspace was to use light color finishes for the ceiling and walls. By using light colored materials, the light reflected in the space is maximized, further reducing energy usage. In addition, the color palate allows eye strain to be reduced and occupant comfort to be maximized.

Shades for Changing Light

While the exterior shades, lights and materials are intended to work together to maximize occupant comfort, there are times during the year (and during the day) when the sun reflects off of interior materials, causing glare and/or reflection issues. This is a phenomenon that changes throughout the year as the sun angle changes with the season. In the summer, the high angle sun is blocked by the shade above while in the winter, the low angle sun is not blocked as much. Since the sun's path is dynamic, how the sun enters the building changes throughout the day. When glare becomes an issue, the interior shades are to be lowered manually by occupants to provide additional control to reduce glare. After the sun is no longer present, the shades are to be raised.

While direct sunlight is the most likely reason for needing to deploy the shades, surrounding buildings also reflect the sun at different times during the day. Lowering the shades during these events also provides enhanced occupant comfort. It is expected that lowering the shades will minimize occurrences of light entry into the workspace that causes discomfort to occupants.

3.4 INTEGRATED DESIGN, ANALYSIS, AND PROJECT DELIVERY

In an effort to create a well-integrated and high-performing building, the EGWW team utilized an integrated process of design and analysis, as well as an integrated construction delivery method. One of the results of this process was the realization of an elegant and effective exterior shading solution. After establishing the basic performance parameters, SERA Architects worked in tandem with the project's designer, Cutler Anderson Architects, exchanging sketches and analytics back and forth until the daylighting and shading goals of the project were realized in form. One of the first options Cutler Anderson proposed was a diagonal version of the shading strategy (Figure 6, middle) initially proposed in the physical modeling. Although this option was found to meet the shading criteria it was not cost effective. In design development when Benson Industries, the curtain wall manufacturer, was engaged, a cost effective version of the design emerged where the vertical elements of proposed shade were made up of a series of vertical tubes, achieving the shading criteria by their placement relative to each other (Figure 6, right). This revised design was tested using computer and hand calculation methods to ensure the shading criteria were met.

As a major supplier and sub-contractor for the curtain wall, Benson became a part of the core integrated team that included the owner, architect, engineers, construction manager, and other major sub-contractors. Through a series of hands-on work sessions, SERA Architects and Cutler Anderson developed a level of trust and collaboration with Benson. The team utilized full-scale mock-ups for confirmation of design intent, daylighting performance, and lab testing.¹⁵

¹⁵ Lab testing included the following: Air Infiltration/Exfiltration (ASTM E 283-04), Static Water Penetration (ASTM E 331-00), Dynamic Water Penetration (AAMA 501.1-05), Uniform Structural Deflection (ASTM e 330-02), Interstory Drift (AAMA 501.4-00).



Figure 7. Facade analysis, design, and construction process

3.5 INTERIOR SPACE CONDITIONING

The project includes a highly energy efficient, high performance mechanical system consisting of hydronic radiant ceiling panels combined with a dedicated outdoor air system (DOAS) for ventilation. Hydronic radiant heating/cooling ceiling panels in combination with DOAS utilizing heat recovery ventilation was estimated to save approximately 10%-15% of total building energy use when compared to a VAV¹⁶ system for a building of this type. A well-designed, constructed and operated radiant panel/DOAS system was shown to outperform a VAV system in all critical mechanical functions: occupant comfort, indoor air quality and long-term system maintainability. In addition, the radiant panel/DOAS required significantly less vertical shaft space, thereby increasing the project's net leasable area on all floors. As a result of the analysis, the EGWW design team recommended the use of a hydronic radiant panel/DOAS combined with heat recovery ventilation as the most appropriate HVAC system option for EGWW. This combination of systems was projected to meet or exceed the stringent energy efficiency requirements of EISA which is required by ARRA. In addition, these systems would provide a high level of occupant comfort and long-term maintainability for the project.

This system distributes heating and cooling in a different way than more conventional air systems. It provides a high level of thermal comfort and indoor air quality, although it was noted that it would initially feel different to occupants accustomed to conventional air systems. Conventional air systems rely on moving large volumes of air through the building to heat and cool – and most of that air is re-circulated. Moving these large quantities of air causes noise and air motion that people accustomed to these systems may associate with a heating /cooling system that is properly functioning. In contrast, for EGWW, heating and cooling is provided by hot or cold water circulated through the ceiling-mounted radiant panels. Since water is 4 to 5

¹⁶ Variable air volume mechanical system.

times more efficient than air at transporting heating and cooling, this is a much more efficient means of heating and cooling the building. In this system, the only air distributed through the building is 100% filtered outside air (no recirculation) for meeting high indoor air quality ventilation requirements. The occupants may perceive minimal air movement because the air provided is only for ventilation, reducing energy use while ensuring quiet operation and clean, healthy air for the occupants.

The heating and cooling system design is flexible in its ability to maintain a range of temperature setpoints during most outside weather conditions. However, the building is projected to save a substantial amount of energy when a modest widening of temperature setpoints is allowed. The GSA identified adjusting workplace temperatures to be higher in summer months as one of the top 7 energy saving strategies for federal office facilities. During the AFTERCARE work, this range was adjusted to improve the balance between energy savings and occupant comfort.

3.6 THERMAL COMFORT ANALYSIS¹⁷

As a result of the enhanced commissioning process feedback, Glumac raised a concern regarding thermal comfort in perimeter zones. To address the concern, Stantec Consulting analyzed thermal comfort within a south perimeter space of EGWW. Levels 2-17 of the building are designed to provide heating and cooling using radiant ceiling panels with a dedicated outdoor air system (DOAS) for minimum ventilation. The study was performed to ensure that thermal comfort will be achieved in the worst-case (south) zone during peak heating and cooling scenarios with the current building design and panel configuration. The study also provides insight into the benefits of an alternative to the current design where active radiant panels are relocated from an interior zone to the perimeter soffit (i.e. closer to the exterior curtain wall).

IES Virtual Environment was used to determine the operative temperature (i.e. temperature perceived by the occupant) in the south perimeter zone and how it varies through the depth of the space with increasing distance from the exterior curtain wall. The operative and surface temperatures from the IES model were then entered into the Center for the Built Environment (CBE) Advanced Human Thermal Comfort Model (Thermal Comfort Model) to determine the effects on human comfort within the perimeter space for peak cooling and heating scenarios.

Summary of Results for Cooling

The operative temperatures (i.e. perceived temperatures) were presented for four scenarios in cooling mode:

- 1. original design with blinds up
- 2. original design with blinds down
- 3. relocated soffit radiant panel with blinds up
- 4. relocated soffit radiant panel with blinds down

¹⁷ Stantec Consulting Inc. and SERA Architects, EGWW "Thermal Comfort Analysis Report" v2.0, 15 September 2010

The CBE Thermal Comfort Model showed that thermal comfort would be achieved during peak cooling with the original design provided that the occupant is not exposed to direct solar radiation (i.e., located in shade or with blinds drawn). The analysis further showed that the design alternative to relocate a row of active radiant panels to the soffit adjacent to the perimeter would provide more uniform temperatures throughout the depth of the space. In either case, occupants would need to lower blinds to avoid direct solar radiation on the skin to maintain thermal comfort. It was noted that this is not solely a feature of the radiant ceiling panel & DOAS system, but would be a requirement for any right-sized, high-performance mechanical system.

Summary of Results for Heating

The operative temperatures were presented for two scenarios in heating mode: current design and relocated soffit radiant panel. The CBE Thermal Comfort Model showed that thermal comfort would be achieved during heating with the original design. Relocating an active radiant panel to the perimeter soffit would provide a higher degree of thermal comfort, and more uniform temperatures throughout the depth of the space.

Recommendations

It was noted that the results indicated that thermal comfort would be achieved with the original design (within 80% satisfaction per ASHRAE 55); however, the team recommended relocating active radiant panels to the perimeter soffit for improved thermal comfort throughout the space and to achieve a more uniform temperature between the perimeter and interior.

The thermal comfort advantages of relocating a panel included the following:

- Greater consistency of temperature between perimeter and interior zones
- Faster achievement of setpoint temperatures
- Greater temperature uniformity throughout the day
- Enhanced levels of comfort for occupants both immediately adjacent to curtain wall as well as slightly removed

The thermal comfort study was directly related to deep review provided by the enhanced commissioning process which questioned whether the Owner's Project Requirements (OPR) were being fulfilled. This input drove the design engineer of record to provide a deeper analysis of their approach, and provided the owner with actionable information to direct the team. The Owner made the change recommended by the team.

4. COMMISSIONING

Commissioning (C_x) for EGWW included "fundamental" and "enhanced" services as defined by the GSA's requirements and the USGBC¹⁸. The services were commenced in the design and documentation phases with the Owner's Project Requirements (OPR) and Basis of Design (BOD) by the design team. This peer review process led to project modifications, including the

¹⁸ USGBC LEED 2009, Energy and Atmosphere (EA) Prerequisite 1 and Credit 3.

adjustment to the radiant panels at the perimeter noted in section 3.6 above, "Thermal Comfort Analysis." Commissioning tracked the construction process and included testing at the completion of construction. While these services helped assure that the most appropriate systems were designed, specified, installed, and tested—further support was needed to optimize the actual operation of these systems. In part, this is due to the complexity of the HVAC and control systems, as well as the familiarity of the building operators. As a part of the AFTERCARE scope, the design team developed a set of services to provide extended C_x and training to help assure that the performance potential of the systems is actually achieved. The extended C_x included logging tenant issues, creating a trend summary, making recommendations for fine-tuning system operations, and developing process templates for each complaint type. The extended commissioning is also integrated with the "Measurement and Verification" systems and services which are discussed in the next section as a part of the post occupancy work.

5. POST OCCUPANCY EVALUATIONS

5.1 OVERVIEW, PROCESS, COLLABORATORS

As of January, 2015, many of the post occupancy evaluation (POE) studies to validate and fine tune the performance of EGWW have been completed, but some are still on-going. The focus in this paper and presentation are on aspects of POE that directly or indirectly relate to the integrated facade. The studies fall into three primary categories:

- Resource use—energy for electric lighting and mechanical systems. (Other resource use and generation being measured, but not covered in this paper include water use, stormwater collection, and photovoltaic electricity generation.
- 2. Occupant satisfaction through occupant surveys.
- 3. Measurement of actual interior conditions.

The POE results will be benchmarked against GSA and other North American office buildings, actual weather data for the study period, using a calibrated energy model. POE methods include a combination of installed data sources (including the BAS and other M&V systems) and field testing. In collaboration with the design team, luminance and illuminance levels in a number of representative building spaces are being measured in both unfurnished spaces and actual spaces in a typical occupied conditions.

Occupant satisfaction was evaluated with a customized version of the CBE¹⁹ on-line survey. The results were filtered by solar orientation, floor level, and other criteria to understand the impact of the integrated facades on occupant satisfaction and workplace functionality. Additional data mining and benchmarking will compare the results with pre-occupancy satisfaction in a comparable nearby office building, as well as GSA and other office buildings in North America.

¹⁹ Center for the Built Environment (CBE) University of California, Berkeley

There are several objectives for the POE: demonstrate compliance with federal energy efficiency objectives (per EISA), refine and further improve the building's actual performance, and provide feedback to the GSA and design team for future work.

The post occupancy studies are being conducted collaboratively by members of the design and construction teams, GSA Region 10, GSA Office of Federal High Performance Green Buildings, and third-party research entities. Additionally the University of Minnesota is collaborating with the GSA on a study of the integrated delivery construction process that was engaged for EGWW. While this study also addresses building performance, it focusses on the contractual and working relationships and is largely outside of the scope of this paper and presentation.

5.2 MEASUREMENT & VERIFICATION²⁰

Objective and goals

The overall objective is to drive energy efficiency through knowledge. The measurement and verification (M&V) plan provides a tool for the building owner to evaluate whether the building is performing as it was designed. Additional goals were identified as follows;

- Create ongoing accountability of building energy use.
- Provide a means for ongoing reductions in building energy use through a higher level of awareness.
- Monitor and document what actions affect energy use most significantly.
- Provide detailed information on building operations to future design professionals performing building modifications and alterations.
- Ongoing Building Commissioning and Energy Auditing.

Data Collection Protocol

Data is being collected for the plan through a Building Management System (BMS), utility bills, and manual meter readings. The building operator is required to periodically collect and aggregate the data in an excel spreadsheet for the purpose of building performance verification.

As building energy use is typically unstable during the first few months of operation, a one year stabilization period from when 75% of tenants have moved in was allowed before measurements taken from the building were analyzed for calibrating the energy model. Following stabilization, tenants and operations staff were required to forward information to the party executing the energy model calibration portion of the M&V plan for a 12 month period. In addition to measured data, input on hours of operation, lighting use, equipment, and temperature setpoints and setbacks were required on a tenant by tenant basis.

Measurements are being recorded in the Building Automation System at 30 minute intervals. This information is being reviewed on a quarterly basis to ensure the information is correct and can be effectively used for post occupancy simulation calibration.

²⁰ Measurement & Verification Plan, 27 Oct 2013, Version 5.1

Data collection sources:

- City water main and booster pumps
- Main gas meter
- Main electrical meter
- Central Server Room electrical and cooling
- Rainwater harvesting for irrigation, lavatory flushing, and cooling tower
- Heating hot water
- Domestic hot water
- Cooling system
- Air handling units
- Radiant floor (level 1)
- Exhaust fans
- Elevator machine room cooling
- Photovoltaic production
- Generator

Verification Plan

Collection of measurement information includes a general outline of specific energy usages:

- Interior lighting
- Exterior lighting
- Miscellaneous equipment (tenant & house plug, elevator, and other)
- Space heating
- Space cooling
- Heat rejection
- Pumping
- Ventilation fans
- Domestic hot water
- Photovoltaic production
- Rainwater system performance

M&V Approach: IPMVP Option D Model Calibration

At the conclusion of one full year of operation after the completion of commissioning and the establishment of stable full occupancy, the building management firm engaged an energy modeler to calibrate the original energy models used during the construction process. The original eQuest baseline and proposed building models are being adjusted for as-built deviations from the original design assumptions to create a revised baseline and as-built model calibrated with information from the following:

- Once a full year of information was available, the energy consultant reviewed items outlined under the "Measurement Plan" section.
- For missing data, one of the following methods is being used to replace the information
 - Based on a graphical review of the trended information interpolation is being used if it provides a logical curve fit.

- If interpolation cannot be used a review of current building operating values for the missing information will be assed and the values will be estimated.
- eQuest energy models that were used for calculating LEED credits are the starting point for the modeling calibration. Two Energy models are being created for this process.
 - Adjusted Baseline Calibrated ASHRAE 90.1-2007 Energy Model
 - EGWW Model Calibrated Proposed Energy Model (Calibrated to match utility data)
- Specific categories are being analyzed to determine whether the model matches the actual usage. The model will be tuned so that it more closely matches actual consumption in these categories depicted in the Verification Plan section above.
- The Calibrated Baseline model is being used to verify actual energy savings using the following formulae.
 - Estimated Energy Savings (EES) = (Original Baseline Model Energy Use Original Proposed Model Energy Use) / Original Baseline Model Energy Use
 - Verified Energy Savings (VES) = (Adjusted Baseline Energy Use EGWW Model Energy use) / Adjusted Baseline Energy Use
 - Note Actual Energy Use = Calibrated Actual Energy Model. Calibration of the Actual Energy model is required for correct adjustment of the Calibrated Baseline model.
- The project will have met the design goals if EES \leq VES.
- Based on the analysis and modeling, systems that are underperforming the goal will be investigated using the Calibrated energy models and available operational data to try and identify which areas are causing discrepancies. Recommendations will be made for corrective actions or follow-up work that would be beyond the scope of the M&V plan. Systems that are performing adequately will also be evaluated for potential further improvements.

Overall Energy Use

For the first year of operation following commissioning (October 2013 through September 2014) the actual energy use is 31.5 KBtu/sf/yr. This is an energy savings of 41% compared to a typical code office building modeled per ASHRAE 90.1-2007. Further analysis of the M&V data will occur in 2015.

5.3 OCCUPANT SATISFACTION SURVEYS

To determine how well the interior conditions meet the needs of EGWW inhabitants, on-line occupant surveys were completed in the fall of 2014. Pre-occupancy surveys were run for occupants at two previous locations in downtown Portland to help provide a more complete understanding of the results.

Pre-occupancy Survey Results

Occupants were surveyed at one previous location that is still partially occupied by the GSA, the 1st & Main Building which is diagonally across from EGWW to the northeast. It shares many

similarities with EGWW, but also some important differences. 1st & Main is a new building that was completed in 2011 and achieved LEED 2.2 Platinum. It has 20 floors and is 366,500 sq.ft. Unlike EGWW, it is a speculative office building. It has somewhat more transparent glass area than EGWW, but has no exterior shading. The HVAC utilizes variable air volume (VAV) distribution, unlike EGWW's hydronic heating and cooling with dedicated outside air system (DOAS). Of the 591 GSA occupants at 1st & Main who were offered the survey and encouraged to respond, 130 participated (22%). General building satisfaction was good at 78%. The lowest category was acoustics at 34% satisfied and the highest was cleanliness and maintenance at 90%.

The second previous location at which occupants were surveyed is 9 blocks to the north (NNE), the Robert Duncan Plaza Building (RDP). This building is quite different from EGWW—it was built in 1991 and renovated in 2001, has 12 floors, and a total floor area of 408,800 sq.ft. The building has less transparent glazing than EGWW and no exterior shading. This building has an air-based HVAC system. Of the 640 GSA occupants, 254 responded (40%). General building satisfaction was slightly above average at 71%. The lowest category was acoustics at 29% satisfied and the highest was office layout at 81%.

The results of the surveys of occupant satisfaction for EGWW and the two previous locations (1st & Main, and RDP) are provided in the following categories:

- Acoustics
- Air quality
- Cleanliness and maintenance
- Lighting and daylighting
- Office furnishings
- Office layout
- Building features
- Thermal comfort

The lighting and daylighting results are of particular interest because of the careful attention given to daylight design at EGWW. As shown in Figure 8, at 1st & Main, satisfaction with daylight was 65%, but there was a small number of neutral responses in this category (7%). 55% were satisfied with glare conditions. As shown in Figure 9, at RDP 64% were satisfied with the amount of daylight in their workspace and 15% were neutral. Satisfaction with glare conditions was reported to be 58%. EGWW results are discussed below.



Figure 8. 1st & Main daylight amount (left) and glare satisfaction (right) responses



Figure 9: RDP daylight amount (left) and glare satisfaction (right) responses



Figure 10: EGWW daylight amount (left) and glare satisfaction (right) responses

The thermal comfort category is also of particular interest since the integrated facade at EGWW is well insulated to minimize winter discomfort and manages solar heat gain through carefully designed exterior shading elements. Satisfaction was somewhat better at RDP, but at both previous buildings, especially 1st & Main, levels of satisfaction and dissatisfaction were quite evenly distributed across the spectrum.



Figure 11: Thermal comfort responses for 1st & Main on left and RDP on right

Post-occupancy Survey Results

Results from the EGWW occupant satisfaction survey are good, but point to a number of areas where additional commissioning will further improve satisfaction. Of particular interest due to their relationship to the integrated facade are thermal comfort and daylighting.





Thermal Comfort

While the design and engineering intentions for the exterior shading elements at EGWW are to provide uniform thermal comfort throughout the building by minimizing the impacts of solar heat gain, results from the occupant survey show that thermal conditions within the building are varied. And contrary to expectations, the areas of the building with the lowest reported thermal comfort are not where anticipated—at the upper floors facing south and west.

The overall mean thermal comfort response from occupants for EGWW is -0.21 (Figure 12). The lowest thermal comfort response is from the lower floors facing east (-0.81), and the most positive thermal response is just around the corner on those same lower floors to the south (+0.39). The areas of the building on the upper floors facing west also have a positive thermal comfort score (+0.37). Surprisingly, the north areas of the building received low thermal comfort responses at all levels (-0.23 overall).

Another metric for reviewing thermal discomfort is the range of "too hot" responses relative to "too cold" responses during "warm/hot" weather. These results for EGWW also are contrary to expectations. For the building overall, occupants who reported thermal discomfort, 78% stated that they are too hot, and 21% stated that they are too cold. The south-facing work areas have the best range which is relatively close (59% too hot, 38% too cold). The north has the worst (broadest) range with 90% too hot and 20% too cold. The upper floors of the west and east have ranges that are roughly similar to the north (west upper floors: 86% too hot, 14% too cold; east upper floors: 84% too hot, 8% too cold).

Figure 12: Thermal comfort responses for EGWW

By comparison, results from the occupant survey at 1st & Main, indicates that the VAV system over-delivers cold air during warm weather causing thermal discomfort. The percentage of occupants who report being "too cold" during warm weather is 65% while 48% report being too hot. This is most extreme at the south and north areas of 1st & Main.

Occupants at EGWW reported a range of responses as the source of thermal discomfort, but "air movement too low" and "incoming sun" were most frequently cited. For the building overall, 50% of occupants reporting thermal discomfort attributed it to "air movement too low" and 25% noted "incoming sun." The upper floors to the east and west had the highest percent of occupants noting "air movement too low" (64%). Not surprisingly, the upper floors at the south most frequently noted "incoming sun" as the source of discomfort (50%) and only 5% occupants to the north noted it as an issue. And contrary to expectations, only 7% of occupants on the upper floors to the west noted "incoming sun" as a comfort issue.



10.6 How would you best describe the source of this discomfort? (check all that apply)

Figure 12: Sources of thermal dissatisfaction for east-facing work areas at EGWW on floors 10-17.

Daylight, Electric Light, and Glare Management

EGWW occupants reported general satisfaction with daylight amounts (building mean score +1.03) with a reasonable range of variation, particularly give the variability of the solar orientations. (See Figure 10.) The highest satisfaction was reported at the upper west floors (+1.43) and interestingly the lowest satisfaction was reported at lower floors of the same elevation (+0.63).

The most significant lighting issue identified in the survey, was glare control from low sun angles and reflections. Occupants with workspaces on the north side of the building reported the fewest issues with glare (mean score of +1.31). Occupants on the west also reported reasonable conditions (mean score of +0.71). The lowest satisfaction with glare was reported to be on the lower floors to the east (-0.30) and on the upper floors to the south (-0.33). These are locations that receive low-angle sun during certain periods of the year, and may also receive reflections off other buildings and the river to the east. A number of occupants reported that the manual interior roller shades do not provide sufficient shading. The percent openness of the roller shades is less than 3 percent, so further investigation is recommended to more closely identify the problematic locations and test a range of interior shading solutions.

Satisfaction with electric lighting was good overall (mean score of +0.87) with a reasonable range of variation (from +0.64 to +1.39). The area of lowest satisfaction was at the upper floors to the south where there are the most significant glare issues.



24.3 How satisfied are you with the building overall?

N=308

Figure 13: Overall building satisfaction with EGWW

Overall Building Satisfaction

Although overall occupant satisfaction is good as shown in Figure 13 with a mean score of +0.99 and 69% reporting that they are satisfied, initial analysis of the result reveals a number of areas where satisfaction could be significantly improved with relative minor modifications to building controls or interior shading. The GSA has expressed an interest in further analyzing the

survey results and working with the design team, both to make modifications to improve satisfaction, and to articulate lessons that can be carried forward to new projects.

5.4 MEASUREMENT OF ACTUAL INTERIOR CONDITIONS

The SERA team proposed that the post occupancy studies also include measurements of actual interior conditions. In conjunction with the measured energy use and occupant satisfaction survey results, this information would complete the picture of how the building is actually performing. Some information, such as temperature and humidity is provided from the mechanical system building automation system (BAS). Additional information would be collected through the proposed field studies. This paper and presentation are only addressing the thermal, electric light, and daylight studies, since these are the categories directly supported by the integrated facade. Other studies, including acoustic field measurements, have also been completed.

Proposed thermal field studies

Occupant's thermal comfort is determined by four major environmental conditions, only two of which are measured as part of building control systems – air temperature and humidity. The other two factors are air speed and radiant temperature (associated with surface temperatures), both of which function differently in the EGWW's radiant ceiling panel + DOAS system than in a more conventional air-based VAV thermal conditioning system. Surface temperatures in perimeter building zones are also significantly affected by solar heat gain and thermal loss at glazed portions of the exterior curtain wall. The SERA team proposed measurement of thermal conditions at a sampling of work stations to understand and verify the environmental factors that impact comfort at the occupants' seated workstation positions.

EGWW's use of hydronic radiant ceiling panels with DOAS is a new heating/cooling approach for GSA; the proposed thermal field study would validate the thermal conditions actually achieved in the occupied building. This validation would also demonstrate the extent to which the Owners Project Requirements (OPR) regarding thermal conditions have been achieved in perimeter zones by solar orientation.

In addition to validating the design approach of the radiant panel + DOAS mechanical system that is new in GSA's portfolio, the study outcomes could help tune/improve the occupied building as follows:

- Develop Corrective Action plan: Use measured thermal conditions at workstations in conjunction with Occupant POE Survey results to develop and tune building operational strategies based on actual conditions at workstations as well as reported occupant perceptions.
 - For example, building controls and setpoints may be adjusted based on understanding of the variability of thermal conditions within a perimeter zone (workstations close to exterior walls vs more interior)

 Communication tool for Occupants: use in conjunction with Occupant POE Survey results to communicate measured thermal conditions to the Occupants to assist in managing expectations and complaints.

Daylighting field studies

Why measure daylight / electric lighting levels in the space? GSA's P100²¹ design guide mandates that workspaces be designed for 30 fc. Because, lighting design protocols typically evaluate spaces prior to furniture being selected, designers use factors to try to account for the things that will be added by building occupants. However, they rarely include the "stuff" people bring with them into a space which can also affect lighting levels. The design team proposed a study to evaluate the actual lighting levels for spaces prior to incorporating any furniture, lighting levels after furniture is in place and lighting levels after tenant move in. The final measurement will be compared to tenant satisfaction during the POE survey. Phase one of the study was completed prior to tenant move in. As anticipated, light levels exceeded the 30 fc, however it is expected that light levels will be reduced due to light absorption by furniture, equipment and the personal equipment brought by occupants.

6. CONCLUSIONS

The deep renovation of the Edith Green Wendell Wyatt Federal Building has been a very successful project for the GSA as judged by the results from the design, analysis, and construction process, but it is in the actual operation of the building that building performance success can be judged. Recognition of this fact has led to a set of AFTERCARE services and studies to fine-tune operations to optimize the building's performance-both for energy efficiency and occupant satisfaction. These studies also demonstrate compliance with federal energy efficiency objectives. Some of the initial issues that have been raised in the AFTERCARE phase indicate nuances in performance that are critical to successful building operations, but are very challenging to fully identify in the design phases. These include personal thermal and light level preferences of building occupants, set up and actual use of work stations, and seasonal sunlight reflections off adjacent buildings that causes glare when shades are not incorporated. Calibration of mechanical and lighting control systems and training of the building operators are also essential, but require bridging the typical divide between engineering and building operations. Communication, engagement, and education of the building occupants also shifts typical complaint-oriented communications, to a more meaningful relationship between occupants and their work environment which can result in improved comfort, productivity, and well-being.

Although the post-occupancy evaluations of EGWW show that the building performance is very good, the most significant success is the feedback cycle which is still on-going, and will lead to further optimization of the building's performance and occupant satisfaction. The feedback cycle will also expand beyond EGWW and will lead to the improvement of future work.

²¹ GSA 2009 draft Facilities Standards for the Public Buildings Service (P100) baseline.