Living in a High-Performance Green Building: The Story of EPA's Region 8 Headquarters

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Acknowledgements

This report summarizes research by teams with expertise in sustainable design, building performance, and occupant experience. Their combined efforts have created a story that is rich in detail and insight. We want to thank them for their contribution to our knowledge about designing, operating, and living in a high-performance green building.

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Executive Summary

Every building is a hypothesis waiting to be tested—a hypothesis about performance, occupant work effectiveness and comfort, and support for agency mission. And it remains a hypothesis until it is lived in, experienced, and evaluated through rigorous testing and observation.

This report is about living in a high-performance green building. As such, it is about adaptation and change, not about a “finished” product. Even as this report is completed, the building and its occupants are co-evolving to meet new challenges.

The Wynkoop building in downtown Denver, which houses a regional office of the US Environmental Protection Agency (EPA), is a “demonstration project” of the General Services Administration’s (GSA’s) Office of Federal High-Performance Green Buildings. This “build-to-suit” Leadership in Energy and Environmental Design (LEED) Gold office and retail space was designed and constructed through a design-build public-private partnership to be as sustainable as technology and budget could support, incorporating sustainability elements developed jointly by GSA (the government lessor) and EPA (the tenant agency). A prime objective of the design team was a sustainable facility that looked and functioned like “normal” class A commercial office space in its market.

As a learning laboratory, the EPA Wynkoop building may be the most extensively studied building in the country. The research deployed scientific teams from two national laboratories as well as academic and public-sector organizations to assess performance in acoustics, under-floor air distribution, data center energy use, daylighting, indoor water use, thermal comfort, occupant experience, workplace functionality, and green roof applications for the Denver climate. In all cases where the building was underperforming, the research teams made recommendations for improvements. Some of those improvements were made, while others wait for future funding. This full final report documents key findings and lessons learned regarding the facility’s design, construction, and actual sustainability performance.

The research provides a unique insight into how a complex building works. Most buildings go through fine tuning that may take many years. Yet we know little about how occupants and buildings learn to adjust over time and what kinds of changes they make. Building performance results are seldom made public. Furthermore, fine tuning is often ad hoc rather than subject to the rigorous research necessary to identify causes and propose solutions. Solutions were tested where time and funding permitted.

Key Findings from the Wynkoop Research

1. Performance-based contracting and integrated teaming were key factors in achieving sustainability goals and ensuring that the building was delivered on time and on budget.

The solicitation for offer (SFO) for design and construction included detailed lease terms; technical specifications for architectural, mechanical, and electrical components; and a detailed program of requirements. It detailed numerous requirements and preferences relating to sustainable design and efficiency and established strict terms for achieving LEED and ENERGY STAR certification. The design and development team was required to achieve a minimum of LEED Silver certification within 14 months of reaching 95 percent occupancy, or risk a penalty of $250,000 annually to be subtracted from the rent. Similarly, the developer was required to provide and maintain an ENERGY STAR rating within 14 months of occupancy, or make changes to achieve the rating and offer the government a rent reduction during noncompliance.

Communication. The performance-based framework encouraged the team to share and respond to new information and design issues in real time, which moved the project forward more rapidly than would have been the case if lengthy change orders were needed to resolve every issue. Numerous examples show how the multidisciplinary nature of the core team allowed more thorough evaluation of potential outcomes, without the constraint of specifications hard-wired into the contract. One example of the team's effort to balance sustainability and construction cost was the evolution of the exterior sunshades. Both the team and EPA wished to enhance daylight, prevent solar gain, and control low-angle glare in the early morning and late afternoon. In addition, the project needed to balance the desired performance with construction cost and blast security. The original design called for 36-inch-deep horizontal shades on the south facades, and 36-inch-deep vertical fins on the north facades. The security and blast consultant recommended changing the shades and fins from fritted laminated glass to perforated metal, to perform better in the event of a blast. Consulting engineers Syska Henessy performed energy and daylight studies to reduce the depth, and therefore the cost, of the shades and fins. As a result, the horizontal shades were reduced to a depth of 20 inches and the fins to 11 inches. The interior light shelves called for on the south facades were also studied to see if they could be removed without compromising daylight performance, but were left in the design. Architects Zimmer Gunsul Frasca (ZGF) used both an Ecotect software model and a physical model to study these issues, and passed the models to Syska Henessy for further study, in an unusually direct collaboration process.

Risk issues. The overall process was not without difficulties. For instance, in an effort to transition this project from conceptual design to an engineered solution, after the development contract was awarded significant changes were proposed to the structural ceiling system; heating, ventilation, and air conditioning (HVAC) mechanical system; and the developer's team structure. GSA and EPA had to evaluate the impact of each change and negotiate with the developer to find a fair agreement that provided good value to the government. The SFO requirements were largely performance-based, with some prescriptive terms. This played a role in the evaluation of the HVAC system change, since government team members realized that they had to accept any system that met the basic performance requirements. The SFO required LEED Silver certification, which is performance-based, but did not prescribe exactly how to accomplish this. It included a LEED scorecard showing EPA's preferences for which LEED credits to pursue, but there was no way to enforce this preference. In the end, the building exceeded goals and achieved LEED Gold certification. However, some LEED credits were not achieved due to documentation issues.

Although GSA and EPA assumed the risk of items that were not strictly controlled in the contract, Opus (developer and architect) assumed risk on unknowns such as the level of changes required by local governments and the site contamination. For example, GSA's option to negotiate the land purchase before selecting a developer required Opus to commit to contract terms beyond its control. When soil contamination was discovered on the site, the government-negotiated contract and accelerated closing schedule allowed Opus no recourse with the landowner, resulting in increases in onsite costs for the project.

Despite these risks, the performance-based nature of the contract allowed the core team to adjust strategies in real time, completing the project on budget, on schedule, and at a higher level of performance than the minimum specified in the SFO.

Click here to skip to Chapter 3: Integrative Teams and Performance-Based Procurement.

2. Building performance was significantly influenced by occupant behavior patterns and variations in occupancy, yet these social factors were either not taken into account in design development or accounted for in a very rudimentary manner.

Several studies in the Wynkoop building showed that occupant behavior could influence a range of performance factors, including energy, water, and daylight. *For more information on occupant behavior and satisfaction, click here to skip to Chapter 7: Occupant Experience.*

Energy. Even though the building is performing well and has an ENERGY STAR rating of 96, it consumed substantially more energy than projected. The actual energy use is 76 kBtu per square foot per year, versus 52 kBtu modeled in the "as built" final model.

Much of this greater usage can be attributed to the building's data center and to plug and process loads, which account for a large share of energy use but were not factored into the original modeling. For instance, after video technologies were installed in the conference center and meeting rooms, the building's ENERGY STAR rating decreased by 2 points. The report recommends several commonsense, cost-neutral conservation strategies for the data center, as well as greater attention to efficient use of work technologies by occupants. Recommendations included turning off computers when away from the desk for more than 30 minutes, as well as turning off shared resources (printers, copiers) when they are not being used. Another factor in the higher than anticipated energy usage is a pronounced “stack effect” in the building, with the upper floors noticeably warmer than the lower floors, which also affected energy use by requiring additional conditioning on these floors.

Click here to skip to Chapter 4: Energy Design Goals and Whole Building Performance.

Water. In the first year of operation, total water use was 1.65 million gallons higher than expected. Correcting an installation error at the steam system discharge point reduced water consumption dramatically, but additional questions were raised about the use of water fixtures in the restrooms and fitness center. Research showed that occupants were not using the dual-flush toilets properly, because of a strongly conditioned response to push the flush handle down, triggering a full flush that uses more water. EPA installed new handles on all toilets that now trigger a low flush when the handle is pushed down and a full flush when pulled up. It was not possible, however, to confidently quantify the savings that this change produced from the data developed in this study. Other water issues studied were related to building occupancy, which turned out to be difficult to ascertain because data on occupancy are not gathered systematically for either employees or visitors. Occupancy is a key element of water modeling, so the lack of accurate data makes it difficult to project actual water use.

Click here to skip to Chapter 5: Water Performance.

Daylighting. The daylight design included expectations that occupants would operate the blinds effectively in some areas of the building—that is, close them to control direct sunlight or glare, and open them again when the situation improved. However, a survey conducted as part of a daylight assessment found that very few occupants actually operated the shades as expected and that they were frequently left closed, negating the use of daylight for general lighting purposes. An environmental quality survey administered to all employees found concerns with glare.

Vegetated roof. An extensive study of the building’s vegetated roof, compared with a standard control roof on a nearby LEED building, showed that the vegetated roof provided significant benefits by modulating roof temperatures that increased the overall lifespan of the roof and decreased energy use. However, the study also concluded that the plantings would need to be irrigated during the growing season. The vegetated roof was also effective in retaining stormwater. Using consolidated findings from the Wynkoop research, EPA concluded that converting just 1 percent of roofs in the United States from conventional to green roofs could avoid about 70,000 tons of construction and demolition waste annually, based on the assumption that the serviceable lifespan of a green roof is 2.5 times that of a conventional roof.

To learn more about the vegetated roof, click here to skip to Chapter 10: The Vegetated Roof.

3. The interior design of the space is successful in supporting solitary work and planned meetings, but the space and work technologies are less beneficial for informal work, flexibility, and mobility within and outside the building.

A functionality assessment by GSA focused on better understanding how the physical environment influenced individual and group work effectiveness, and how the changing nature of work is influencing EPA's approaches to the workplace.

Informal work. GSA identified a need for more space devoted to informal and unstructured group work. People cited difficulty knowing who was at work and a lack of space for networking and "light conversation." There are some informal teaming areas, but these are largely unused to avoid creating noise that could disturb adjacent individual workstations. People appear to want more informal, opportunistic connections and interaction within and across teams and a greater sense of camaraderie—the very qualities that are inhibited throughout the building by the high workstation panels valued for providing visual privacy and promoting concentration. Several survey respondents also mentioned a desire to be able to have quick meetings focusing on visual materials used in their work, such as maps and data printouts. However, EPA rules prohibit posting such materials on cubicle partitions or walls in the work areas.

Investing in flexibility. Investment in appropriate technologies and changes in policy are necessary to promote shifts to new ways of working. Responding to changes in the nature of work requires an integration of policy, communication, and procedural solutions to traditional workplace and technology challenges. As an experimental step in this direction, some EPA groups have rearranged their workspaces to enable greater personal choice and to better suit their flow of work. Wireless technologies for mobility and headsets for improved voice privacy make it easier to move work to new locations within the building.

Adoption lag. The interest in flexibility and new ways of working have taken hold more strongly among EPA regional leaders than among the employees in the building. However, as more experiments are rolled out, there will be more opportunity to test what works and what doesn't and how to solve lingering concerns. An "action research" effort is especially valuable to capture lessons learned and best practices while changes are being made, rather than waiting until the end of a project when policies, behaviors, and spaces feel set in place and more difficult to revise. Such experimentation and testing will enable EPA to make more informed decisions and set up appropriate training as it pursues goals for space reduction and increased telework.

Click here to skip to Chapter 6: Indoor Environmental Quality Design and Goals.

4. Commissioning of a complex building takes considerably more time and effort than normally planned for. The Wynkoop experience shows that commissioning is an ongoing process as the building and its occupants co-evolve over time.

Translating design intent to facility management and operations can be challenging. This is especially true when the technology in the building is new and requires intense research and learning. EPA's commitment to using the building as a learning lab and teaching tool has played an important role in fine-tuning building performance, but it has also taken more time and effort than expected. Another tenant might not have been as inclined to accommodate the effort of fine-tuning the many systems. As noted by one of the project leaders, “If it had been someone less patient, they would just say, ‘This system is not working; it needs to be replaced now.’”

Active management. Shortly after moving in, EPA realized that active management would be required to ensure that the building met its high-performance goals and that occupant behavior was a critical factor in reaching this end. EPA and the building management team established a performance tracking system and actively collaborated on everything from operation of mechanical systems to cleaning and recycling and tenant education. EPA also developed an environmental management system that integrates federal building performance and reporting requirements with building operations and interlocks with building management systems.

Ambient conditions. In addition to water and energy research, EPA assessed the performance of the interior lighting system and occupant response to it. The T5 fluorescent pendants are linked to daylight sensors that control the amount of light emitted depending on the amount of natural light available. Shortly after occupancy, defective ballasts in the dimming lights led management to replace all of the original ballasts at significant expense. Also, an error in the program controlling the automated blinds was creating significant glare, which took several months to resolve. Even with the systems working properly, building management’s perception is that the staff generally is not satisfied with the dimming lights. The occupant survey supports this perception. Results show that when occupancy is low and lights are turned off in work areas, the light is perceived as too dim.

Concerns with the sound masking system, located in the under-floor air plenum, also led to extensive acoustic testing and recommendations for improvement. Unlike the ceiling grid where the sound from the masking system is diffuse, the sound from the under-floor distribution system is likely to have high spatial variation in sound level and spectrum. Essentially, a diffusive sound field is more difficult in an under-floor system, because each air diffuser becomes a point source or “hot spot.” The research showed that the HVAC system is unusually quiet; HVAC is generally an important part of acoustic treatment, because it provides low-frequency noise. However, the sound masking in the UFAD system lacked output capacity at low frequency. The research team recommended and tested a successful solution to reduce hot spots and diffuse the sound more effectively.

5. Building components (energy, water, air, light, sound) were designed and studied largely as separate entities, yet their interactive effects may be much greater than realized.

The Wynkoop research explored several areas of interaction between design components and approaches, but much remains unexplored. For instance, a workplace functionality assessment identified ways in which the interior design, coupled with EPA rules about space use, created barriers for teamwork and informal collaboration. Furthermore, the daylighting research revealed that design for daylight to reduce energy consumption may run into difficulties, as noted above, when building occupants don’t behave as anticipated.

Another area worth further study is the energy-water nexus. Energy is needed to circulate and pressurize water used inside the building. The building is served by city-supplied water pressure for floors 2 through 5; a booster pump generates proper water pressure on floors 6 through 9. Tests showed that pressure varied dramatically between the floors. This could affect toilet flushing and faucet use. Water for showers, washing hands, and other uses (washing dishes) is heated through an energy-efficient heat transfer process from city-supplied steam. Anecdotal accounts show that occupants complained about the faucet water in the restrooms being too cold. This could be the result of either low water pressure or insufficient temperature. In either case, this situation could lead occupants to keep faucets running longer while they wait for the water to heat up.

Another issue is the gap between measures of ambient conditions in the building and occupant comfort. Even though temperature and acoustic conditions fell within the recommended ranges, occupants were uncomfortable. Fifty percent or fewer were satisfied with temperatures, noise, and speech privacy. It should be noted, however, that similar problems exist in most buildings where occupants have little or no control over thermal conditions or acoustics.

Summary and Conclusions

Research value. Research at the Wynkoop building has produced or demonstrated methods for assessing indoor water use, building thermal performance, workplace functionality, acoustic performance of sound masking in the under-floor air plenum, rapid assessment of indoor environmental quality, installation of systems to avoid air leakage, green roofs for the high mountain desert climate, data center energy improvements, and behavior change to reduce plug load energy use. The results will be widely shared through webinars, conference presentations, white papers, and outreach to audiences who can use the findings to improve the performance of their own buildings.

The building can readily be considered a success as a living laboratory and teaching tool. It is also a successful example of performance-based contracting, an integrated team process, and overall environmental performance. There continue to be some comfort problems, especially with thermal conditions, which are notoriously difficult to resolve without high levels of individual control over temperatures and airflow. Other problems, such as noise from human activity, are behavioral and outside the control of designers. Some problems will require changes in rules or in funding allocations.

The research also raises important questions about designing for change and flexibility, and anticipating the future during design and development, especially for modeling energy and water use for green building certification. Changes in demographics, occupancy levels, occupant behaviors, organizational policies, and operational practices can affect the data used in models.

Above all, the research shows that an office building is more than a structure to house a workforce. It is a complex ecosystem of people, work practices, and business decisions all linked toward one end—carrying out an organization’s mission. The work will continue to fine-tune the building and address the myriad challenges of the future, from energy to changes in work practices, even as the formal research program comes to an end.

Is the Wynkoop building a "successful" green building? The project has certainly met many of its goals, many of them tied to achieving a LEED-New Construction Gold rating for its design. But this certification, like all evaluations, is a snapshot representing a certain moment with particular conditions, measured with particular techniques and technologies, and based on specific assumptions. Different and ongoing analyses employing different techniques, assumptions, and technologies at different time periods are crucial—to verify previous findings, to examine whether conditions have changed, and to determine whether any changes have affected building performance.

Finding the source of problems and ways to fix them requires serious analytical and creative work by a motivated interdisciplinary team. Prominent examples in this case were the building's vast overuse of water due to the steam system and the creative shading solution for the atrium. Sometimes the more intensive focus of professional research is needed to understand both how technical systems are working and how occupants are interacting with them, as with the under-floor system, energy use in the data center, and the toilet fixtures.

Ultimately, "success" is not something that can be declared based on any single snapshot in time, but only based on an ongoing, broad-based, interdisciplinary commitment to measure, evaluate, invest in, and maintain performance. EPA's ongoing focus on and commitment to this building, therefore, is the most positive indicator of its continued success and improvement.

For more on the success of the Wynkoop building, click here to skip to Chapter 11: Is the Wynkoop Building Successful?

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Chapter 1

Purpose and Approach

This report assesses the sustainability performance of the Wynkoop building, located at 1595 Wynkoop Street in downtown Denver. The facility houses a regional office of the Environmental Protection Agency (EPA) and is a test bed for sustainable practices—from integrated project team and design/build practices to operational performance, workplace functionality, and occupant comfort and productivity.

The building is a demonstration project of the Office of Federal High Performance Green Buildings (OFHPGB). Such demonstration projects, mandated by Congress in the 2007 Energy Independence and Security Act (EISA), are expected to document the effectiveness of high-performance technologies and strategies with measured performance data and to evaluate impacts on building occupants. The Wynkoop building is the first completed demonstration project.

EPA Region 8 committed to using the Wynkoop building as a learning lab and a teaching tool, opening the facility up to researchers, sharing performance data, and developing lessons learned to enhance understanding of the operational aspects of high-performance green buildings. EPA's partnership with General Services Administration (GSA) involved coordinating research teams from two Department of Energy (DOE) national laboratories (the Pacific Northwest National Laboratory and the National Renewable Energy Laboratory [NREL]); the Center for the Built Environment at the University of California, Berkeley; and private-sector firms specializing in water and acoustics.

This build-to-suit Leadership in Energy and Environmental Design (LEED) Gold office and retail space was designed and built to be as sustainable as technology and budget could support. A prime objective of the design team was a sustainable facility that looked and functioned like other class A commercial office space in its market. When completed, this building became the flagship facility for both the owner, Opus Northwest, and for tenants GSA and EPA. It was one of the first sustainable commercial office buildings built in downtown Denver, and it influenced design of the next generation of Denver-area buildings through media publicity and a tours program that engaged several thousand visitors.

The question is: Does it work?

This report draws on information from numerous sources: case studies on the design and construction of the facility, LEED documentation, whole-building performance for energy and water, and research on specific building features and components, including indoor water use, acoustics, the under-floor air distribution (UFAD) system, thermal conditions, air quality conditions, occupant satisfaction and comfort, overall workplace functionality, and the building's green roof.

Study Purpose

This report focuses on answering several key questions:

- Is the building meeting its performance goals? Why or why not?
- Does the building support the core purposes of a commercial office space, providing a healthy and productive work environment for occupants? Does it facilitate organizational effectiveness?
- How did facility managers respond to challenges encountered after occupancy?
- How has management of this building evolved post-occupancy? Are there lessons learned, best practices, and operational experiences that can be applied to designing and operating other buildings?
- Is the building a success, and how do we measure success?

Organization of the Report

The organization of this report largely parallels the structure of the building process. It begins with an overview of the integrated team process—how decisions were made, how conflicts were resolved—and discusses design development and tradeoffs necessary to meet both performance goals and budget constraints. A discussion of building commissioning is followed by an evaluation of overall post-occupancy building performance compared with expectations, as well as detailed assessments of indoor water use, energy use for desktop plug loads and the building data center, and the green roof.

A section on indoor environmental quality (IEQ) addresses both quantitative measures of environmental quality (thermal, air, acoustics) as well as occupant experience of the building (ambient comfort, response to specific sustainability features, and functionality analysis). This section also examines how well the building and its interior infrastructure enable EPA to meet new challenges, such as federal space reduction goals and new work methods that require greater personal mobility and supportive technology.

The final chapter deals with how to judge the building's success.

The web-based summary report gives links to the full reports from each of the research teams.

Appendix A provides additional information on the following aspects of the Wynkoop building:

- Notable certifications, awards, and presentations.
- Construction and operating costs.
- High performance features.
- High performance design targets and measured performance.
- LEED credits pursued and points achieved.

Appendix B provides links to additional research and articles about the Wynkoop building, and Appendix C provides a list of acronyms.

Chapter 2
Introduction

The Wynkoop building in Denver's Lower Downtown (LoDo) historic district is an ambitious building. It is intended to convey the mission, values, and goals of two agency partners, GSA and EPA. For GSA this means signaling a more sustainable government and leading with innovation. For EPA it means protecting human health and the environment. These agencies and their partners collaborated to design, build, and occupy a living laboratory that tests the principles and practices of sustainability in its broadest sense.

A video highlighting features of the Wynkoop building is available on the EPA website at: http://www.epa.gov/region8/building/index.html.

A self-guided tour itinerary is available on the EPA Region 8 website at: http://www.epa.gov/region8/building/mobiletour.html.

For additional research and articles on the Wynkoop building, see Appendix B.

This report investigates whether those principles have worked as intended. It is not a simple description of design goals, whether they were achieved, and what level of certification was awarded. Nor does it deal only with the immediate effects of building performance and occupant satisfaction. It probes deeper to identify the causes of operational problems or occupant dissatisfaction and recommends how to improve conditions. Some recommendations have already been implemented; others have proved more difficult, due to financial or organizational issues.

Figure 2-1. Wynkoop Building—EPA Region 8 Headquarters

This privately owned building is at a prominent intersection on the 16th Street Mall, a bustling pedestrian avenue (Figure 2-1). The 9-story building includes retail space on the first floor, a fitness center, conference center, library, break rooms on each floor, a data center, and a records center. Two transit hubs are within a 3-block radius. The facility was designed and built through a design-build public-private partnership, incorporating sustainability elements developed jointly by GSA (the government lessor) and EPA (the tenant agency). The building uses energy and water efficiently and showcases environmentally preferable building materials and design. The private operator and federal tenant use coordinated environmental management systems to track and manage facility environmental performance and monitor progress in meeting federal high-performance building requirements.

PROJECT GOALS

The following were among the project goals established in the initial solicitation for offers:

- Security and safety goals:
  - Increase security features and blast resistance in the context of sustainable design features to meet GSA medium-level security, with a blast-proof envelope.
  - Use principles of crime prevention through environmental design, especially along the historic streetscape.
- Sustainability goals:
  - Achieve a minimum LEED Silver level and ENERGY STAR certification within 14 months of reaching 95 percent occupancy.
  - The building owner will maintain these certifications throughout the lease term or be penalized with rent reductions until the certifications are attained.
  - Follow best practices for energy conservation, water conservation, resource conservation, and indoor air quality.
  - Foster operational sustainability by reducing a reliance on paper and implementing an electronic equipment recycling program.
- Schedule and cost-effectiveness goals:
  - Ensure that EPA occupancy occurs on time and on budget, with no lease extensions for the agency's existing space.
  - Build the new facility within the costs established by the lease, combining age-old strategies for responding to the natural environment with state-of-the-art building systems to reduce energy use by 30 percent.

- Functional and productivity goals:
  - Design a building allowing EPA to consolidate its 850 staff on fewer floors, and enhance occupant health, well-being, and productivity. The Solicitation for Offer (SFO) required a space of 250,000 gross square feet (gsf) with 231,281 to 232,000 rentable square feet.
  - Create a pleasant, cohesive, more productive, and well-lit office environment.
  - Respond to the neighborhood historic context and the urban environment, while respecting the local surroundings.
- Accessibility goals:
  - Meet or exceed all current accessibility codes.
  - Provide pedestrian-friendly access to the light rail system, buses, and bicycle riding opportunities in the LoDo district.
- Aesthetic and historic preservation goals:
  - Establish a bridge between the LoDo historic neighborhood and the adjacent more modern development area of lofts and commercial high-rise buildings.
  - Express the building's goals for sustainability to the public on the exterior and to tenants on the interior.
  - Effectively incorporate LoDo design principles for paving patterns, street furniture, cornice heights, fenestration, density, setbacks, and requirements for ground-level retail use.

Summary of Measured Performance

Table 2-1 shows the specific design targets and measured performance for the LEED certification process.

Table 2-1. Summary of High Performance Design Targets and Measured Performance

Target area	Baselines	Design goals	Measured performance
LEED New Construction (NC) (2008) Certification		Silver	Gold
Energy		ENERGY STAR 86	ENERGY STAR 96[c] (90 in 2013)
	CBECs: 88 kBtu/gsf ASHRAE 90.1-1999: 71 kBtu/gsf GSA: 55 kBtu/gsf	Modeled: Solicitation ▶ 47.5 Btu/sf/yr and 39% better than ASHRAE 90.1-1999[a] Modeled: Final design ▶ 52 kBtu/gsf/yr and 25.4% better than ASHRAE 90.1 1999[b] ◆ Energy cost improvement method (LEED, final design): 35% better than ASHRAE 90.1-1999	76kBtu/gsf/yr[c] Scope 2 GHG emissions(CO_2e): 4.09 MT/occupant[c]
Water	Design case: 3,372,189 gal/year	◆ 1,719,738 gal/year[d] ◆ 49% below LEED base case (EPAct 1992)[e] ◆ Water closets: 1.6 gpf ◆ Urinals: 1.0 gpf ◆ Showerheads: 2.5 gpm ◆ Faucets: 2.5 gpm	3,970,00 gallons/year[c] 3,500 gallons/occupant 13.18 gallons/gsf
Vegetated Roof		Estimated 26.7% reduction in stormwater runoff	Not measured
		Estimated removal of 80% of total suspended solids and 40% of total phosphorus	Not measured
		Heat island mitigation (demonstration research)	
Materials	None	◆ SFO required construction waste management plan with list of minimum items to be recycled[f]	◆ All LEED construction waste management credits achieved
		◆ SFO required recycling collection system built into design with recycling plan for operations	◆ LEED prerequisite achieved ◆ 80% waste diversion rate ◆ GHG reduction of 447 $MTCO_2$e (2010)
		◆ SFO required that building façade be made	◆ LEED credit achieved

Target area	Baselines	Design goals	Measured performance
		from local/regional materials	
		◆ SFO specified that "environmentally preferable products" and materials be used where economically feasible; such products and materials: ▶ contain recycled material, are biobased, or have other positive environmental attributes; ▶ minimize the consumption of resources, energy, or water; ▶ prevent the creation of solid waste, air pollution, or water pollution; and ▶ promote the use of non-toxic substances and avoid toxic materials or processes	◆ All LEED credits for alternative materials achieved, except rapidly renewable materials
IEQ—Occupant Health and Productivity	None	SFO specified ASHRAE standards for basic and increased ventilation, thermal comfort and control, CO_2 and indoor chemical pollutant control, construction IAQ management plan, and pre-occupancy flushout	All requirements achieved, but some LEED credits not awarded due to documentation issues
		SFO specified sustainable cleaning products and integrated pest management plan, no urea formaldehyde or arsenic treated wood, low VOC carpets, plastic laminate, wall coverings, paints, adhesives and sealants, low lead paint	Achieved; all but one LEED credit awarded (documentation issues)
		Maximize daylight	84% of occupied spaces daylit; LEED credit not awarded due to documentation issues
		◆ Allow consolidation of 850 staff on fewer floors (relative to previous space) ◆ Enhance occupant health, well-being, and productivity through indoor air quality and access to daylighting	Occupant satisfaction 57th percentile (41% return rate) Categories: workplace, communication, acoustic quality, air quality, windows and daylighting, thermal comfort, cleanliness, maintenance, security above median; lighting below median

Target area	Baselines	Design goals	Measured performance
Transportation	None	Access to alternative transportation options was a site selection criterion	87% occupant commute rate, avg. 26 miles/occupant
		Provide 70 secured bike parking spaces, 31 carpool spaces	Achieved Scope 3 GHG emissions (CO_2e): 0.58 MT/occupant

[a] Whole Building Design Guide case study, Zimmer Gunsul Frasca (ZGF)/Opus presentations.

[b] LEED NC documentation and approval letter (Energy & Atmosphere Credit 1).

[c] K. Fowler, E. Rauch J. Henderson and A. Kora, 2010. Reassessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings. Pacific Northwest National Laboratory.

[d] LEED NC documentation (Water Efficiency Credit 1).

[e] LEED NC approval letter (Water Efficiency Credit 1).

[f] The SFO list of minimum items to be recycled during construction includes: ceiling grid and tile, light fixtures, including proper disposal of any transformers, ballasts, and fluorescent light bulbs; duct work and heating, ventilation, and air conditioning (HVAC) equipment; wiring and electrical equipment; aluminum and/or steel doors and frames; hardware; drywall; steel studs; carpet, carpet backing, and carpet padding; wood; insulation; cardboard packaging; pallets; windows and glazing materials; all miscellaneous metals (as in steel support frames for filing equipment) and all other finish and construction materials; land clearing debris; wood composite materials, such as plywood, oriented strand board (OSB), and particle board; concrete masonry units; bricks, concrete, and asphaltic concrete; paint; and plastic film (including high density polyethylene).

Note: CBECS = Commercial Building Energy Consumption Survey; ASHRAE = American Society of Heating, Refrigerating and Air Conditioning Engineers; kBtu = thousands British thermal units; GHG = greenhouse gas; CO_2e = carbon dioxide equivalent; MT = metric ton; EPAct = Energy Policy Act; gpf = gallons per flush; gpm = gallons per minute; CO_2 = carbon dioxide; IAQ = indoor air quality; and VOC = volatile organic compound.

SUMMARY OF COSTS

Table 2-2 shows the specific design targets and measured performance for the LEED certification process.

Table 2-2. Summary of Design & Construction and Operating Costs

Building phase	Cost
Design & Construction Costs[a]	Core & Shell Costs: $90 million Premium costs: • Security: $10-12 ft² (principally concrete hardening and progressive collapse) • Sustainability not tracked Tenant improvements: ~$3.5 million (interior workspaces, upgrade lighting, carpets, wall treatments)
Operating Costs (Annual)[b]	Average 43% lower than industry baseline (energy, water, maintenance, janitorial and grounds are lower than baseline; waste and recycling are higher than industry baseline) Energy: $1.48/RSF Water: $0.04/RSF,$9.95/occupant General maintenance: $0.74/RSF Janitorial: $1.04/RSF Grounds: $0.07/RSF
Facility Website	http://www.epa.gov/Region8/building/

[a] EPA Region 8 Headquarters: Denver, Colorado, Harvard Legacy Case Study," Julie Walleisa and Professor Spiro N. Pollalis (2006).

[b] K. Fowler, E. Rauch J. Henderson and A. Kora, 2010. Reassessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings. Pacific Northwest National Laboratory.

Chapter 3

Integrative Teams and Performance-Based Procurement

While integrative teams and performance-based procurement are increasingly popular today, this approach was still a novelty in federal facilities in 2003–2006 when this EPA project was initiated. The challenges faced by the project team and their resolution are highlighted in this chapter. These challenges ranged from significant changes in building systems and team structure after the development contract was awarded to issues of risk that were not controlled in the contract.

Everyone involved in the design, construction, and operation of this building points to two key factors for attaining the high levels of performance that have been achieved:

- The ongoing, committed engagement of project teams for all of the stakeholders: designers, constructors, operators, and occupants.
- A design-build contract built around integrative design and performance specifications.

This chapter summarizes significant aspects of team experiences involving these two key enablers, integrative teams and performance-based procurement. This discussion draws principally on two Harvard Legacy Series Case Studies commissioned by GSA.[1] It follows the project process from the SFO through design, highlighting the kinds of decisions that the teams needed to make and how they resolved conflicts. The final section of the chapter identifies key lessons learned from the process.

PROJECT TEAMS

Table 3-1 identifies the teams that collaborated on this building project.

[1] "EPA Region 8 Headquarters: Denver, CO, Harvard Legacy Case Study," Julie Walleisa and Spiro N. Pollalis (2006), and "EPA Region 8 Headquarters: Denver, CO (Case B)," Anthony Kane and Spiro N. Pollalis (2010).

Table 3-1. Project Teams and Stakeholders Involved in Wynkoop Building Design, Construction, and Post-Construction

Stage	Organization
Development and design	Design Architect: Zimmer Gunsul Frasca Architects LLP Developer and architect of record: Opus Northwest, LLC, and Opus A&E Consulting architect: Shears Adkins Architects, LLC Mechanical, electrical, plumbing: Syska Hennessey Group, Inc. LEED consultant: Architectural Energy Corporation (AEC))
Construction and occupancy	Lessee: US GSA—Contracting officer and project manager Tenant: US EPA—Owner's representative; sustainable facilities architect; move coordinators; team leads; 10 employee "move action teams" EPA's LEED review consultant: Ensar/RMI Tenant improvements (TI) and program: Metropolitan Architects and Planners (MAP)
Post-construction operations	Owner: Northmarq—Building manager; building engineer Tenant: US EPA—Infrastructure director; facilities manager; environmental management system coordinator Lessee: US GSA—Contracting officer and contracting specialist

Getting Started: The Solicitation for Offer

The SFO for the design and construction included detailed lease terms; technical specifications for architectural, mechanical, and electrical components; and a detailed program of requirements. It detailed numerous requirements and preferences relating to sustainable design and efficiency and established strict terms for achieving LEED and ENERGY STAR certification. The development team was required to achieve a minimum of LEED Silver certification within 14 months of reaching 95 percent occupancy, or risk a penalty of $250,000 annually to be subtracted from the rent. Similarly, the developer was required to provide and maintain an ENERGY STAR rating within 14 months of occupancy, or make changes to achieve the rating and offer the government a rent reduction during noncompliance.

The criteria for selecting the development team were, in order of priority, sustainability (25 percent), design (20 percent), workplace (20 percent), building operations (20 percent), and price (15 percent).

The SFO outlined detailed requirements for the design, building materials, and construction and reporting procedures. The selected team was required to register the project with the US Green Building Council (USGBC) during design development, update the project LEED scorecard and energy calculations at each phase, and submit plans for final commissioning, IAQ, and construction waste management (CWM) upon completion of construction documents. The team was also required to achieve a minimum of LEED Silver certification within 14 months of reaching 95 percent occupancy, or risk a penalty of $250,000 annually to be subtracted from the rent. Similarly, the developer was required to provide and maintain an ENERGY STAR rating within 14 months of occupancy, or make changes to achieve the rating and offer the government a rent reduction during noncompliance.

The team process in the traditional design-bid-build model, design and construction are separate procurement steps, making it difficult to effectively incorporate sustainability design goals into construction project budgets and schedules. In contrast, the Wynkoop project's integrated design approach took advantage of benefits produced by sustainable design, allowing the flexibility to offset initial costs by communicating issues raised by one team member or across all the disciplines. At the same time, the approach enabled greater communication among architects, engineers, and sustainability consultants.

During construction, the team had to provide information on the VOC levels for all interior finishes, a monthly CWM report, commissioning reports, documentation on certified wood, EPA green report documentation, monthly construction photos, and quarterly reports on recycled content. Upon construction completion, the team was required to provide final LEED documentation, final CWM reports, a final operations plan, a test report on drinking water, a final report on IAQ testing, and a final commissioning report. After occupancy, the developer was required to submit annual reports on recycling operations and quarterly energy use reports, and provide read-only access to a graphical user interface for data collection.

The strategy of the selected developer, Opus Northwest, was to form a team in which every member acted as a LEED design consultant. The team's expertise encompassed the five selection criteria—sustainability, building operations, design, workplace, and economics.

Figure 3-1. Partnerships and Teams Supporting Operations of the Wynkoop Building

EPA put together its own extensive team for the project (Figure 3-1). Its headquarters in Washington, DC, typically manages facility construction projects. The Facilities Management group oversees planning, construction, renovation, and leasing for facilities nationwide. Its Architecture, Engineering and Asset Management Branch (AEAMB) holds the major construction funding and does the majority of project management, while the Sustainable Facilities Practices Branch (SFPB) acts as a consultant to AEAMB. AEAMB typically hires outside consultants for space planning, interior design, furniture design, and move logistics. Metropolitan Architects and Planners (MAP) was hired to help create the program and act as design architect for tenant improvements (TI). However, since the project required significant effort to coordinate the building requirements, Region 8 decided to hire a full-time project manager to manage local activities for design, construction, and occupancy.

Given the complexity of the design requirements, EPA and GSA were committed from the beginning to having several people review the project milestones and provide technical advice. The project manager and the team members from EPA's national office reviewed drawings and specifications throughout the project. In addition to EPA's own regional and national staff and GSA's project staff, each agency hired additional consultants. They included the NREL for energy design; the Denver Botanic Gardens and Colorado State University's Horticulture Department and Agricultural Extension Service for maintaining the vegetated roof; and the Denver Water Department and Urban Drainage and Flood Control District for designing the stormwater management system. In addition, ten teams of EPA staff totaling between 120 and 150 people conducted research on issues such as health and safety, environment, furniture, and more.

Dealing with Risks

Risk is present on both sides of a performance-based contract. Although GSA and EPA assumed the risk of items that were not strictly controlled in the contract, Opus assumed risk on unknowns such as the changes that the LoDo Historical District would require and mitigation of whatever site contamination existed. For example, GSA's option to negotiate the land purchase before selecting the developer required Opus to commit to contract terms beyond its control. When soil contamination was discovered on the site, the government-negotiated contract and accelerated closing schedule allowed Opus no recourse to the landowner for adjustment, causing on-site project costs to increase.

Given the complexity and sophistication of the building, EPA and GSA tried to limit their risk by assembling knowledgeable internal teams and hiring outside experts for technical advice. EPA relied on Ensar/RMI to fill in information gaps by suggesting products and strategies in the absence of answers from the team.

Despite the expertise of the design and government teams, some lessons came too late to be applied to the project. For instance, using demountable partitions for interior walls was discussed, but the project was too far along to consider this change. The partition module was different from the module for stud walls, and it was too late to redo the floor plans. Furthermore, the amount of work completed before award made it difficult to fully investigate alternate daylighting schemes that might have worked with the building rotation. The term of the lease, which was established based on budget scoring issues, may have also influenced the building's sustainability, according to one of the consultants. A longer lease term would have allowed a higher initial investment with a longer payback period. Some design strategies were not pursued because of this limitation. These issues illustrate the importance of timing in forming a team and evaluating strategies for this level of sustainable design.

The team structure linked the LEED certification process with the developer, causing tension between the goals of EPA and Opus. In an effort to transition this project from conceptual design to an engineered solution, significant changes were proposed to the structural system, mechanical system, and team structure after the development contract was awarded. GSA and EPA had to evaluate the impact of each change, and negotiate with the developer to find a fair agreement that provided good value to the government.

Facility Management and Operations Impacts

Translating design intent to facility management and operations can be challenging. Engaging the facility and building staff was a critical element of the project. One team leader cited the EPA building engineer as the reason this building has continued to perform so well: "We gave him the tools, and he knows how to use them."

The complexity of the systems contributed to the length of the commissioning process, which took a year and a half to complete. One project leader stated, "I've worked on project commissioning that took a month, … but [with this project] we wanted to make sure everything was perfect before we handed it over." Having the facility group and property manager involved from the beginning, as well as working for the developer, gave them perspective and an incentive for diligence during commissioning. "We weren't willing to accept something merely 'working,'" said the building engineer. "We were asking, 'Is it working right?'"

EPA's commitment to using the building as a learning lab and teaching tool has played an important role in fine-tuning its energy performance. This commitment allowed the building engineer significant leeway in adjusting the building systems. Another tenant might not have been as likely to accommodate the discomfort involved in fine-tuning the many systems. As one team leader noted, "If it had been someone less patient, they would just say, 'This system is not working; it needs to be replaced now.'"

Education played a significant role in acculturating EPA staff to accept the new sustainable systems. During the initial months after occupancy, the property management team held voluntary educational sessions in the building's large atrium, where vendors who installed various systems explained their purpose and use.

The integrative team approach has continued into the operational phase. Shortly after moving in, EPA realized that active management would be required to ensure that the building met its high performance goals and that occupant behavior was a critical factor in reaching this end. EPA and the building management team established a performance tracking system and actively collaborate on everything from operation of mechanical systems to cleaning and recycling and to tenant education. EPA developed an environmental management system that integrates federal building performance and reporting requirements with building operations and interlocks with building management systems.

Living Laboratory

Because of EPA's mission, extra resources were devoted to achieving the project's sustainability goals so it could be a teaching tool for the agency. The building regularly hosts symposia and workshops, and more than 9,000 people have toured it. Visitors have included elected representatives and staff from local and state governments, developers, architects, designers, lenders, other federal agencies, and foreign visitors. The EPA library in the Wynkoop facility has a reference center on green building as well as information on the building's performance and LEED certification. An early addition to the building after occupancy was an environmental information center on the first floor, which acts as a miniature model of the building, displaying the many sustainable materials and furniture systems.

Lessons Learned

Changing Team Members

During the competition phase, ZGF was introduced as the architect and main LEED strategist, but after award, Opus assumed the role of architect of record and hired AEC to prepare the LEED documentation, limiting ZGF's involvement. Though ZGF was particularly involved in design development, its involvement tapered off quickly in the construction documents phase. Since the team and major systems are selection factors, these changes raise the question of when changes become so significant that, if proposed initially during the competition, they would have changed the developer's score. However, as others have stated, awards are made at a conceptual level, and there needs to be flexibility for the systems to change once the team starts engineering them. A key lesson from this experience is for future teams to be fully aware of and be able to anticipate the potential risks of design-build projects by actively pursuing information, taking classes, and talking with others who have been involved with similar projects. Having a team member who has good experience in integrative teams and performance-based contracts would also be beneficial.

The Design-Build Process and LEED Certification

Although the design-build model is increasingly popular today, the approach used for the EPA headquarters was a hybrid that presented both challenges and opportunities. In an effort to move this project from conceptual design to engineered solution, significant changes were proposed to the structural system, mechanical system, and team structure after the development contract was awarded. GSA and EPA had to evaluate the impact of each change and negotiate with the developer to find a fair agreement with good value for the government.

Cost to the developer and value to the government were key motivators behind changes, but the evaluation of changes also involved issues of philosophy and trust. The SFO requirements were largely performance-based, with some prescriptive terms. This played a role in the evaluation of a mechanical system change, since some team members felt that they had to accept any system that met the basic performance requirements. The SFO required LEED Silver certification, which is performance-based, but did not prescribe exactly how this was to be accomplished. It included a LEED scorecard showing EPA's preferences for which LEED credits should be pursued, but no real way to enforce this preference. Opus is proud of the fact that it offered an estimated 37 LEED points at the time of its best and final offer, and is now targeting 44 points. However, questions were raised about whether it should be required to deliver those specific 37 points, rather than just meeting the overall performance goal. The situation resulted in numerous design features not being documented, and thus, the points not received toward certification.

Post-Construction Documentation

LEED certification was achieved 9 months after occupancy and highlighted differing expectations between EPA and Opus. The SFO required Opus to submit LEED documentation upon construction completion, but allowed 14 months after reaching 95 percent occupancy to achieve at least LEED Silver certification without penalty. By the time the LEED certification process began, the GSA project manager had been reassigned to a new project. The absence of the project manager during this critical time presented additional challenges for EPA; extraordinary diligence and persistence was required of EPA in collecting documents such as warranties to create a single, comprehensive file. The lesson learned from this experience is to assure that critical tasks, such as LEED documentation, have a continuity plan. Because project managers shift quickly to new jobs, it may have been better for someone else to be assigned the documentation responsibility.

Best Practices: Internal Teams

The EPA project manager (PM) put together internal teams on a volunteer basis to decide on many aspects of the project. During design, the PM organized 10 teams of EPA staff, totaling between 120 and 150 people, who researched issues such as health and safety, environment, furniture, and more. The process created buy-in among these future occupants. Special care was taken to assign a union representative to each of the research teams, and the union was kept constantly updated on the project. As a result, the project team was able to ask for the union's input at any point, saving significant amounts of time. The critical lesson learned from this effort is that engaging the occupants early in a meaningful way can have unanticipated benefits, such as greater buy-in and reduced resistance to decisions made exclusively by a few people only.

CONCLUSION

Despite the difficulties and issues described above, team members credit the combination of a performance-based contract and an integrative team as crucial to delivering the project on time and within budget. Team members cooperated to work through design changes and resolve conflicts. The multidisciplinary nature of the core team allowed for more thorough evaluation of potential outcomes, with the constraint of performance specifications hard-wired into the contract. The performance-based framework allowed the team to share and respond to new information and design issues in real time, which moved the project forward more rapidly than would have been the case if lengthy change orders were required every time an issue was resolved.

Chapter 4

Energy Design Goals and Whole-Building Performance

This chapter describes the design process and trade-offs made to achieve energy goals within the project costs. The site itself created challenges for energy performance and daylighting design. The street grid in the LoDo district where the building is located is rotated 45° to the compass directions, which the daylighting designer called “the most difficult condition for daylighting.” This chapter will also look at how factors left out of the energy discussion could have had a significant influence on building energy performance.

LEED Credit Elements

Table 4-1 shows the LEED credits earned for design elements related to energy and atmosphere.

Table 4-1. Summary of LEED Credits: Energy and Atmosphere

Design element	LEED credit
Optimizing energy performance: 35% less than 90.1-1999 (52kBtu/gsf/yr) (Exemplary performance point)	6 points
Green power (Exemplary performance point)	2 points
Commissioning	1 point
No chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), or halons in HVAC	1 point

Design element	LEED credit
Mechanical and ventilation (metering) ◆ Lighting systems and controls ◆ Constant and variable motor loads ◆ Variable frequency drive operation ◆ Chiller efficiency at variable loads (KW/ton) ◆ Cooling load ◆ Air and water economizer and heat recovery cycles ◆ Air distribution static pressures and ventilation volumes ◆ Building related process energy systems ◆ Indoor water risers and outdoor irrigation systems	1 point
Total	11 points

Summary of High-Performance Features

The following is a summary of the high-performance features of the Wynkoop building envelope: The remainder of the chapter will discuss the design rationale, the tradeoffs made during design process, and innovative strategies used in the building and the atrium to achieve energy performance and daylighting goals.

Envelope

- "Double L" design of building plan responds to local site conditions; HVAC is separately controlled in the two Ls.
- Central daylight atrium extends the entire height of the building.
- Insulation values are R19 for walls and R31 for roof; exposed concrete interiors provide thermal mass.
- Low-emissivity, solar heat gain, and visible transmittance windows are fitted on the southeast/southwest (SE/SW) building L.

- Vegetated green roof is installed on all three levels of roof (8th and 9th floors and equipment penthouse).

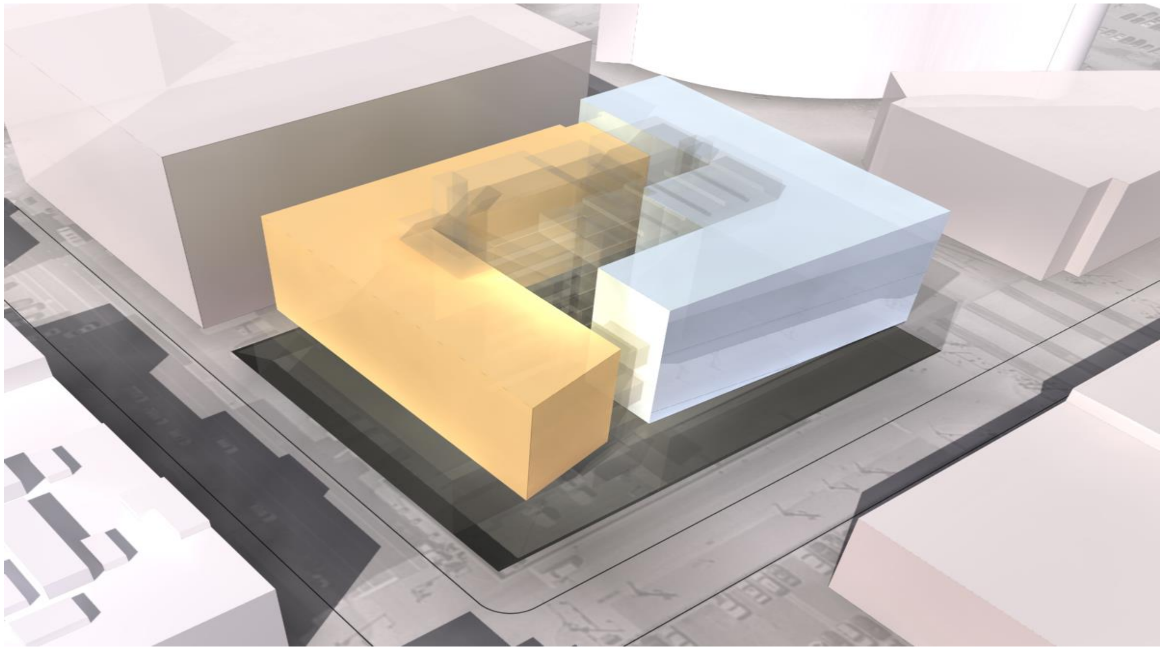
Massing Options

The design team began by studying several massing options, all of which were 9 stories high and approximately 250,000 square feet and had the same proportions of brick and glass for the exterior skin. One scheme included an atrium, which would respond to the programmatic desire to accommodate EPA's all-hands meeting of 900 staff, while letting daylight into the center of the building.

Although other schemes had lower projected energy use, the atrium scheme was considered to offer the best combination of energy efficiency and daylighting.

Having selected the basic concept of a square building surrounding an internal atrium, the team started looking more closely at the site and environmental influences. The street grid in LoDo is rotated 45° to the compass directions, which the daylighting designer called "the most difficult condition for daylighting." To address this and the prevailing winds from the north, the concept evolved into two differently articulated L shapes wrapping an atrium (Figure 4-1). The SE/SW legs were designed to deal with the daylight and solar gain, while the northeast and northwest (NE/NW) legs were designed for wind. The NE/NW leg is 9 stories and the SE/SW leg 8, to allow for a green roof on the SE/SW leg that is sheltered from the wind.

Figure 4-1. General Concept for the Building's Outer Shell



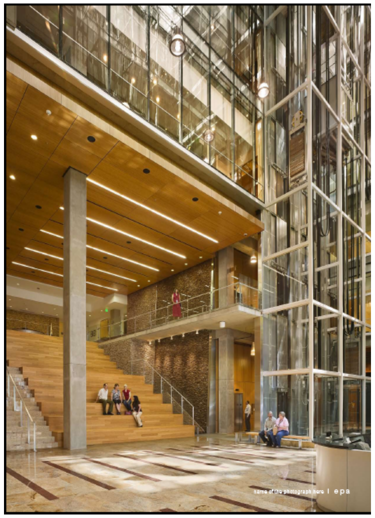
Building Structure

Exposed concrete throughout the building constitutes a considerable thermal mass that slowly captures and releases heat. This makes it easier to maintain constant temperatures, because the HVAC system does not have to respond as often to changing building conditions. It also allows for pre-cooling of the building during summer nights, when cooler outside air is circulated in the building to cool the thermal mass. Extra insulation was also built in: R19 in the walls and R31 in the roof. The vegetative roof also provides additional insulation, although its specific insulation value was difficult to quantify during design. Windows were also upgraded. Compared with the glazing that faces northeast and northwest, the glazing that faces southeast and southwest has a lower U factor (indicating a lower rate of heat loss), a lower solar heat gain coefficient (SHGC), and lower visible transmittance (VT). The following are the glazing factors:

- SE/SW glazing: U factor, 0.29; SHGC, 0.38; VT, 0.7

- NE/NW glazing: U factor, 0.47; SHGC, 0.7; VT, 0.9
- Atrium skylight: U factor, 0.29; SHGC, 0.38.

Figure 4-2. Wynkoop Building Atrium



Atrium Design

The central atrium raised issues about how best to direct light down to the bottom of the atrium while protecting the upper levels from heat and glare. During the competition phase, the team included a faceted reflector on the roof, to ensure that some cost for a reflector would be carried in the construction budget. ZGF then explored a number of options for cost-effective interior reflectors that would direct light into the interior. They built a physical model of the atrium, and of different reflector options, and studied them using the heliodon at the University of Oregon's energy studies laboratory.

Inspired by the array of parabolic faces on the reflector grid of a light fixture, which in testing increased brightness and uniformity of illumination, ZGF began to experiment with a similar form.

Figure 4-3. Fabric Sails in the Atrium to Help Direct Daylight

ZGF contacted tensile structure companies for fabrication, but their bids were very high, and there was concern that solar radiation would degrade elastic in the proposed fabric. ZGF then approached a sailmaker in the Portland, OR, area about fabricating the sails, and a Denver-based theatrical rigging company for information on installation and maintenance. ZGF printed a cutting pattern from its computer model, from which the sailmaker created a scale model. The bids for fabrication and installation from these two sources fell within the allowable budget, allowing the sails to remain in the project. (For more information see "Atrium Daylight Control System," Architect Magazine, September 1, 2007; and "The Butterfly Effect," Holly Richmond, Greendesign.com, May/June 2009. Links to both articles appear in Appendix B.)

Plug and Process Loads: An Unaccounted Factor in Energy Modeling

"Plug" and "process" loads are the building energy loads unrelated to general lighting, heating, ventilation, cooling, and water heating. Examples of plug load equipment include computers and peripheral devices, task lights, personal electronics, and appliances. Process loads are wired directly into a building's electrical system and include a wide range of equipment, such as smoke detectors, air quality monitors, wall-mounted computer projection screens, security cameras, elevators, and escalators.

Consistent with standard practice at that time, projections of future energy use in this building did not include consideration of plug and process loads. Together these loads can account for as much as 30 to 40 percent of a building's electrical energy use.

> Energy and Cost Savings: Multifunction Devices
>
> Replacing single-function printers, copiers, scanners, and fax machines with multi-function devices yielded energy savings of 80 percent and saved $100,000 per year in operational costs.

High-efficiency elevators installed in the building were projected to use 50 percent less energy than traditional traction elevators. The installed elevators are operated by a hoisting machine inside the elevator shaft, requiring no machine room. Since there is little or no oil involved with this technology, groundwater contamination risks are also minimized. (For more information, see Appendix B "Elevators Enhance EPA Headquarters," Kone, March 2009.)

EPA took steps to reduce plug load energy before occupancy. Several years before the move, as computers became eligible for replacement, they were replaced with energy-efficient laptops and flat panel monitors. EPA's Information Systems Program conducted a pilot test of multifunction devices to determine whether they could eliminate "convenience" copiers and reduce the number of electronic devices overall.[2] EPA Region 8 also required that plug board wiring be built into workstations for easy access through the under-floor system, and it instituted strict policies regarding the use of small electronics at workstations.

In accordance with security policies, this facility was designed to meet the standards for a "Level IV" building.[3] In addition to physical features built into the shell, the facility has extensive electronic equipment related to the security system, including more than 50 cameras, a closed-circuit television system with multiple monitors, more than 50 ID key card readers, and several x-ray machines and magnetometers. No information is available on the energy use of this equipment, a topic needing further research.

Renewable Energy

During the competition phase, the Opus team proposed strategies for incorporating photovoltaics (PVs) and wind power into the building, but it emphasized that these items were not part of the base offer and would require separate funding. Building-integrated PV panels were proposed as the spandrel panels—panels between the tops of windows and the sills of windows

[2] Multifunction devices combine printing, copying, scanning, and faxing in one device.

[3] Level IV buildings are those with 150,000 square feet or more, more than 450 federal employees, and a high level of public access.

above them within the curtain wall system on the south-facing facades. Since funding for the panels was not secured by the time the curtain wall package had to be released, and the vertical placement of the panels reduced their efficiency, they were removed from the facade design.

Colorado law requires utilities to allow customers to install renewable energy systems on their properties and sell the generated energy to the utility servicing that property ("net metering"). EPA installed a 48-panel, 10 kilowatt (kW) PV system on the southeast corner of the 9th floor as a demonstration feature for building tours (Figure 4-4). According to the tour script, the system generates enough electricity to power three to five energy-efficient homes. However, the PV array does not make a meaningful contribution to the building's energy use. EPA purchases green power certificates to support renewable energy sources.[4]

Figure 4-4. Photovoltaic System on Southeast Corner

The Opus team also suggested the installation of wind turbines on the NE/NW roof, under an airfoil canopy. The team evaluated several turbines with horizontal and vertical axes, and selected a vertical-axis model from a Finnish company that was designed for an urban environment. Vertical models are less efficient, but using a horizontal propeller on an occupied roof garden posed a concern. EPA asked the Department of Energy's NREL to assess the opportunities and concerns posed by wind turbines, using grant funding from the department's Federal Energy Management Program. The main concerns were that little was known

[4] EPA defines green power as electricity produced from solar, wind, geothermal, biogas, biomass, and low-impact small hydroelectric sources.

about the effectiveness of wind turbines in urban environments, since most studies were based on open areas, and it was unclear how their noise and vibration would affect the building. Due to the uncertainty and lack of funding, wind power was not pursued, but the structural system was designed to support turbines if funding becomes available in the future.

HVAC

The following is a summary of high-performance features of the Wynkoop building's HVAC system:

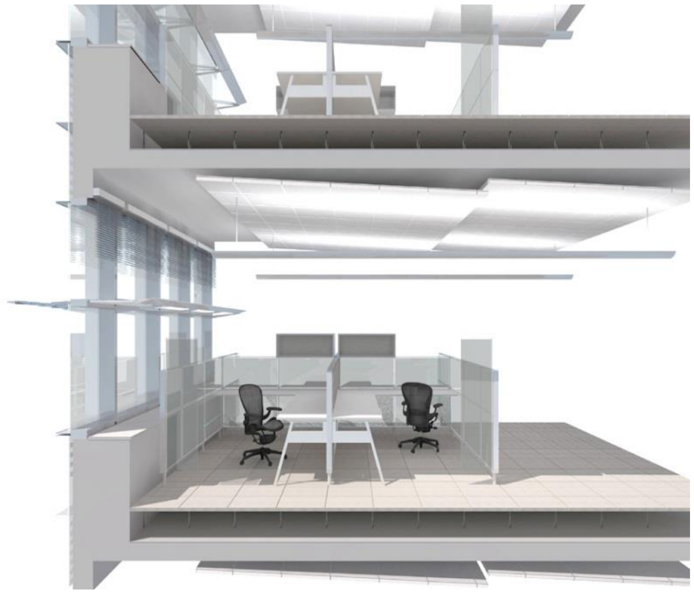
- Two 450-ton variable-frequency-drive chillers offer air-side economization.
- Hot water is provided through a heat exchanger attached to a district steam line.
- Chillers and fans have variable-frequency drives and low-energy premium motors.
- An UFAD system delivers 240,000 cubic feet/minute (cfm) of tempered air while reducing the cooling demand by approximately 7°F (on floors 4–9).
- CO_2 is monitored throughout building, using Minimum Efficiency Reporting Value (MERV) 11–13 filters.

HVAC System Features

HVAC is separately controlled in the two Ls, to allow for maximum response to differing site conditions (hot summer sun on the southeast, cold winter winds on the northwest). Most outside air for the HVAC system enters a central intake on the roof at a rate of 15–20 cfm per occupant, where it is filtered through MERV 8 pre-filters and MERV 11–13 box filters. The air is then tempered by hot or chilled water coils. The chilled water is supplied by two 450-ton variable-frequency-drive chillers that operate in conjunction with a rooftop cooling tower. Hot water is piped from a heat exchanger in the basement that is attached to a district steam line. Two air handlers are on each floor, one in the southeast portion of the building and the other in the northwest.

A perimeter system on all floors provides conditioned air to the edges of the occupied space, directing air to the windows. The perimeter system conditions air by piping hot water to fan power boxes in registers along the perimeter. This system bathes the windows in hot air when the outside temperature is below 50°F.

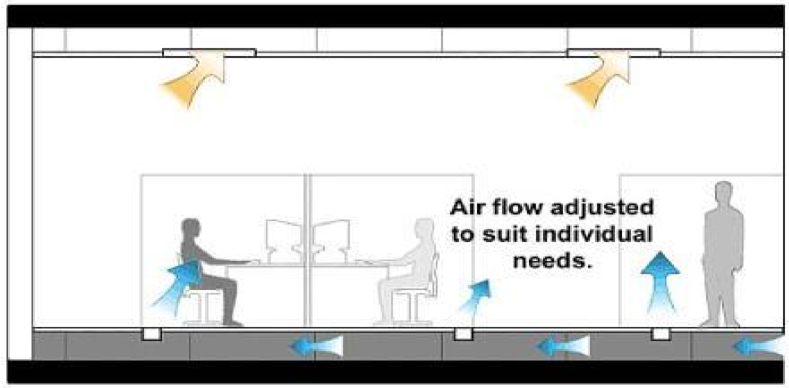
Figure 4-5. Under-Floor Air Delivery System



Floors 1–3 use a traditional overhead-delivery HVAC system. Floors 4–9 (office spaces) are conditioned through a UFAD system (Figure 4-5). Under-floor systems offer several advantages:

- The cool supply air does not need to be forced down to the occupants from the ceiling, through ambient rising warm air, so the system needs less pressure than a traditional overhead system. This allows smaller fans to be used throughout, and smaller fans use less energy.
- Supply air coming up from the floor does not get mixed as much as supply air from an overhead system, so the air does not need to be cooled as much. In this building, UFAD supply air is typically cooled to 62–65°F, whereas supply air from an overhead system might be cooled to 55–58°F.
- Supply ports (diffusers) can be easily relocated to accommodate office reconfigurations or respond to tenant comfort needs (Figure 4-6). Air flow from the diffusers can be easily manipulated by tenants, which allows for some degree of individual temperature control.

Figure 4-6. Air Flow in Under-Floor System



The following are other features that boost energy performance in the HVAC system:

- Premium fan motors use less electricity per unit of air moved. Chillers and 80 percent of the fans in the building have variable-frequency drives, which allow motors to adjust their speed as necessary to handle varying building requirements.

- The system uses air-side economization. When outside temperatures are 50–55°F, outside air is brought into the building and directed to the occupied space with little or no conditioning.

- The building gets heat from Xcel Energy's district steam system rather than having its own boiler. Centralized district boilers are thought to be more efficient than individual boilers. Condensate from the district steam system is collected in a holding tank and then piped to radiant panels in the parking garage to provide heat, and into a snowmelt system in the garage driveway. District steam also supplies the building's domestic hot water.

- Restroom exhausts have heat recovery units.

LESSONS LEARNED: HVAC TRADE-OFFS

The building's mechanical system was designed for energy efficiency and increased ventilation effectiveness. The Opus team originally proposed a system based on two air-handling units per floor, with water-side economizers. This was based on the team's understanding that the system needed to meet the standards of GSA's Facilities Standards (P100), which require air-handling units to be no larger than 25,000 cfm. According to the GSA project manager, “Nothing in the lease tied the building to the P100 for mechanical standards. This is only required for government-owned buildings. GSA has the option to use this for lease projects but didn’t do that here.” Shortly after award, the Opus team proposed changing the system from two air handlers per floor with water-side economizers to centralized rooftop air handling units with air-side economizers. The Denver climate was considered reasonable enough to use outside air for some amount of time throughout the year. Since air can be delivered at higher temperatures with an under-floor air system, proponents of the change argued that free cooling with outdoor air could be used for even more hours than normal. However, very large ducts and shafts would be needed to take outside air throughout the building. The original design would require large mechanical rooms on each floor for the floor-by-floor air handlers, and it was not considered feasible to take up more floor space and reduce the leasable area to accommodate these ducts and shafts.

In the final design, cooling is provided by a chilled water distribution system with variable-speed chillers and centralized rooftop air-handling units with air-side economizers. On floors 4–9, air is delivered through an under-floor air system. The first three floors serve multiple uses and have conventional overhead delivery to better deal with the variable loads and higher peak loads in this type of use. District steam from the local utility generates heating and domestic hot water, so the building has no boilers. An energy recovery system pre-cools or preheats the ventilation air, depending on the season, to save energy year-round. A direct digital control building automation system governs the HVAC and lighting systems.

Although some projects use both air-side and water-side economizers, the team’s analysis showed better energy savings and indoor air quality using only the air-side economizer, and limited savings in operating both types of economizers simultaneously. The original and final systems both have advantages and disadvantages. The small floor-by-floor air handlers allow for more flexibility and efficient after-hours operation. However, air-side economizers could not be included unless the air handlers were moved to the corners of the building, which is difficult to reconcile with most space plans. The revised system was presented as equal in energy efficiency to the original design, with improved indoor air quality due to the increased supply of fresh outdoor air. GSA estimated that the revised system would save Opus around $800,000–$1 million due to savings in equipment, controls, piping, and valves. An inadvertent omission in the original energy simulations by the engineering firm Syska Hennessy Group, Inc., made during the competition phase, complicated the discussions of energy savings.

A Syska team member explained: “The base-case ASHRAE model used for comparison of several systems should have included an air-side economizer, but this was inadvertently left out. Due to this omission, the energy savings of the original scheme were overestimated. It took a great team effort to develop a system that, when modeled, resulted in an equivalent energy performance to that presented during the competition.” (Harvard Legacy Case Study, Julie Walleisa under the supervision of Professor Sprio N. Pollalis, Harvard Graduate School of Design, July 2006.)

Lighting

The following is a summary of the high-performance features of the Wynkoop building's lighting:

- Open floorplan workspaces are located around the perimeter, with enclosed offices clustered around the core; 90 percent of occupied spaces have daylighting.
- The lighting design uses exterior shading and interior light shelves.
- Lighting controls are daylight-responsive (within a 30–100 foot candle range).
- Lighting power density is reduced, using direct and indirect T5 fluorescent pendants with compact fluorescents (approximately 0.8 watts/ft^2).
- The building is equipped with occupancy sensors (auto on); the building control system turns lights on and off around normal working hours.

Lighting System Features

Lighting is designed to meet GSA's Facility Standards (P100) for light levels, and includes daylight dimming and occupancy sensors (auto-on). Daylight-responsive lighting controls will adjust output within a range of 30 to 100 foot candles, depending on the amount of natural light entering the windows. Ambient lighting is provided through reduced lighting power density T5 fluorescent direct and indirect pendants, with compact fluorescent down lights (approximately 0.8 watts/ft^2). Task lighting is provided in all workstations and offices. The building control system controls lights around normal working hours, shutting lights off at 7:00 p.m. This can be done because the cleaning crews conduct their work during normal daylight hours.

A primary concern for project designers was to control direct sun on the south (summer) and north (winter) facades. Interior light shelves (20 inches wide) were built between clerestory and view windows in the SE/SW portion of the building to reflect direct sun and direct light deeper into the occupied spaces building. Horizontal exterior shading on the SE/SW L provides additional control. Horizontal, manual blinds below the light shelf can be controlled by occupants; computer-operated automatic blinds were installed above the light shelves to control daylight throughout the year. However, programming and support problems encountered upon occupancy rendered the automatic blinds less effective than anticipated. Vertical fins are installed on the exterior of the NE/NW portion of the building to deflect winter sunlight. Both clerestory and view windows in this portion of the building have vertical manual blinds.

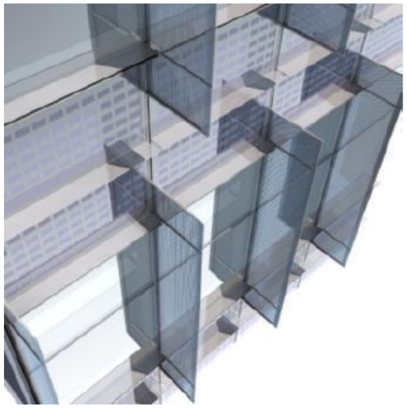
Figure 4-7. The Central Atrium and Double L Design Provides Occupants With Access to Daylight

LESSONS LEARNED: COST TRADEOFFS AND EXTERIOR FINS

The curtain wall design was modified for each facade with an emphasis on responding to environmental conditions while managing the cost of the system. According to a member of the architectural team, "Cost issues were prominent during design; we were always very aware that this was a developer building."

One example of the team's effort to balance sustainability and construction cost is the evolution of the exterior sunshades. Both the development team and EPA were concerned about enhancing daylight, preventing solar gain, and controlling low-angle glare in the early morning and late afternoon. In addition, they needed to balance the desired performance against construction costs and blast security. The original design called for 36-inch-deep horizontal shades on the south facades, and 36-inch-deep vertical fins on the north facades. The security and blast consultant recommended that the shades and fins be changed from fritted laminated glass to perforated metal, to perform better in the event of a blast. Syska performed energy and daylight studies to reduce the depth, and therefore the cost, of the shades and fins. As a result, the horizontal shades were reduced to a depth of 20 inches and the fins to 11 inches. The interior light shelves on the south facades were also studied to see whether they could be removed without compromising the daylight performance, but were left in the design. ZGF used both an Ecotect model and a physical model to study these issues, and passed these models to Syska for further study, in an unusually direct collaboration process. (Harvard Legacy Case Study, Prepared by Julie Walleisa under the supervision of Professor Spiro N. Pollalis, Design Technology and Management, Harvard Graduate School of Design, July 2006.)

Figure 4-8. Curtain Wall Design for the Exterior Facade



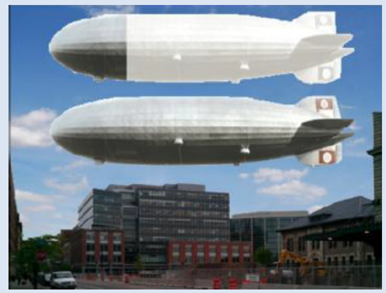
WHOLE-BUILDING ENERGY PERFORMANCE

Analysis of building energy performance reveals that this facility is operating 42 percent below industry baselines.[5] This is reflected in the building's ENERGY STAR rating: since occupancy, the facility has consistently ranked in the 94–98th percentile for low energy use relative to similar buildings in the market today. The building manager cites the UFAD, the automatic dimming lighting systems, general use of energy-efficient devices, and the daytime janitorial program as the major factors in energy reduction.

[5] "Re-Assessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings," Pacific Northwest National Laboratories, June 2010, p. 136.

Greenhouse Gas Emissions

"Our emissions in 2011 were 1.3 percent below the 2008 baseline, representing an almost 10 percent reduction from 2010. … CO_2 emissions associated with the operation of our building are still enough to fill 1 and a 1/4 airships the size of the Hindenburg every month."



—2011 Environmental Report Card for U.S. EPA Region 8 HQ Office, http://www.epa.gov/region8/building/BuildingReportCardMarch2011.pdf.

However, the facility is using substantially more energy than projected by energy modeling performed during project design and construction: 76 kBtu/gsf/yr actual versus 52kBtu/gsf/yr modeled in the "as built" final design.[6] Possible reasons include a "stack effect" and lack of attention to plug and process loads. The building has demonstrated a pronounced stack effect since shortly after occupancy. Temperatures on the lower floors are noticeably cooler than temperatures on the upper floors. This differential in temperature has required more heating for lower floors in winter, and an early Monday morning chilled air "flushout" to cool the upper floors in summer.

[6] K. Fowler, E. Rauch J. Henderson and A. Kora, 2010. Reassessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings. Pacific Northwest National Laboratory.

> Energy and Cost Savings: Daytime Cleaning
>
> While most buildings continue to consume energy throughout the night, the EPA's evening closing time means the building can be "turned off" for 10 hours for 42 percent of each day. This results in a substantial reduction in energy expenses and light pollution. In 2007 alone, daytime cleaning reduced the building's energy costs by 28 percent, saving building ownership nearly $250,000 ($.80/square foot).
>
> —"The Case for Daytime Cleaning," Amy Smith, EDC 11.01. 2008.

The energy models primarily focused on envelope, glazing, and HVAC; plug and process loads were not factored in. Such loads typically account for 30–40 percent of building energy use and represent the fastest growing component. Process loads not accounted for in this building may be substantial, given the large amount of electrically powered security equipment and large EPA investment in projection monitors built into most conference rooms. The building's changing ENERGY STAR rating evidences how these kinds of process loads contribute to total energy consumption: immediately after conference room monitors were installed, the building's ENERGY STAR rating dropped 2 points.[7]

EPA Region 8 has an aggressive "electronic stewardship" program to manage electronics, including reducing the plug load:

- It established procedures to procure electronic equipment that meets ENERGY STAR and Federal Electronics Challenge recommended ratings.[8]
- It upgraded all Regions' computer monitors from CRT (cathode ray tube) to LCD (liquid crystal display) models, which reduces energy costs significantly.
- It programmed all desktop and laptop computers to use power-save software that automatically put monitors into "sleep" mode when not in use.

EPA also uses a daytime cleaning strategy to reduce energy use and the costs of nighttime cleaning. (See above, Energy and Cost Savings: Daytime Cleaning.)

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[7] For a useful primer on how to reduce the plug and process loads, see "Assessing and Reducing Plug and Process Loads in Office Buildings," NREL (2012), online at http://www.nrel.gov/docs/fy11osti/51199.pdf.

[8] EPA, "Federal Electronics Challenge (FEC)," online at http://www.epa.gov/fec/.

Lighting

Lighting is the only area where the Wynkoop building ranks below industry averages in occupant satisfaction. The T5 fluorescent pendants are linked to daylight sensors that control the amount of light emitted depending on the amount of natural light available. Shortly after occupancy, defective ballasts in the dimming lights led management to replace all of the original ballasts at significant expense. Also, an error in the program controlling the automated blinds was creating significant glare, which took several months to resolve. Even with the systems working properly, building management's perception is that workers generally do not enjoy the dimming lights.

Occupancy sensors in the building turn off lights after a period of inactivity, then automatically turn them on when someone enters a room. Behavioral observations suggest that sensors promote more energy savings when occupants turn lights on when they enter a room (if they feel like additional light is needed) and then automatic sensors turn lights off when the space is unoccupied (referred to as "vacancy sensors").

Research Case Study: Daylight Effectiveness and Shade Use

This section includes excerpts and summaries from a small-scale pilot analysis of daylight at the Wynkoop building was conducted by Cara Carmichael of the University of Colorado.[9] (A full version is available in the appendices.) The research assessed daylight effectiveness in four open plan workstations, two each on the southwest side of the building and the northeast side of the 5th floor. As noted above on daylight design, the windows have upper daylight windows and lower view windows. On the southeast, the top daylight windows have 3.5-inch-deep automated horizontal blinds, and the lower view windows have manual horizontal blinds. On the northeast side of the building, both window components have manual blinds, with vertical blinds on the daylight window and horizontal on the view window.

Carmichael's study assessed the combined electric and daylight levels in four workstations on the 5th floor. The methods included a survey completed by 95 occupants (a response rate of 74 percent), luminance measures in four cubicles using data loggers, and analysis of approximate energy and financial savings due to daylight. The data loggers collected illuminance measures on the vertical and horizontal workspace surfaces at 30-minute intervals during the work-day for 2 consecutive days (March 26 and 27, 2007).

[9] C. Carmichael, 2007. Daylight Effectiveness Study. Paper completed for the master's degree in the Building Systems Program, Colorado University, Boulder.

Key Findings from Lighting Measurements

The following were key findings of the study regarding light levels:

- The lighting levels in the cubicles on the south side of the building fluctuated significantly more than lighting levels in cubicles on the north side.
- For both the south and north sides of the building, light levels on vertical surfaces were higher than on horizontal work surfaces.
- Light levels on the horizontal work surfaces on the north side were more even across the day than light levels in the cubicles on the south side. The illuminance measures on the north side cubicles ranged from 25 to 41 foot candles.
- The south side lighting measures on the horizontal surfaces ranged from 19 to 55 foot candles.
- The difference between the north and south locations may be due to the operation of electric light controls, which were not studied as part of this research.
- Projected savings from daylight was estimated at 244,000 kWh/yr for the open-plan office space, with an estimated 72 percent reduction in lighting energy from overhead fixtures.

Key Survey Findings

The following were key findings of the survey:

- Occupants on the north sides of the building were more satisfied overall with the lighting than those on the south sides.
- Occupants on the south sides of the building were more likely than those on the north sides to say they had direct sun on their cabinets or partitions for “half of the day” or “a short time.”
- More than half of the respondents said the overhead electric lights turned on and off at the right time, but 34 percent felt the system was not operating effectively. The most common complaints occurred when fewer people were in the space and thus more lights were turned off as a result of the automatic sensors signaling that the space was unoccupied (after 4:00 p.m.).

- The respondents lacked a good understanding of the capabilities and controls of the lighting system and were not able to locate lighting switches or figure out how to operate them.

- More than 90 percent of respondents said they did not adjust the window blinds to control glare or the amount of light entering the space. Others indicated that the automated blinds on the southwest facade were not fully blocking the direct sunlight.

Recommendations

The following were recommendations from the study:

- Reorient computers in workstations near windows so that monitors are perpendicular to windows, not parallel with them, to reduce potential glare problems.

- Educate occupants on the lighting system.

- Fine-tune automated blinds on the upper southwest windows.

- Fine-tune occupancy sensors.

- Provide additional adjustable task lighting.

- Perform a more detailed analysis of operational costs.

Lessons Learned: Daylighting

Problems with daylighting stem in part from a deficiency of the design-build process. The controls and commissioning were left up to the installer, rather than having the design team document and follow through bidding, installation, and commissioning. Automated systems also require ongoing attention and maintenance to provide continuing performance.

The vertical blinds in the NE/NW daylight zone are intended to be adjusted seasonally in winter and summer, but this does not appear to be happening. Adjusting the blinds twice a year will allow more daylight with minimal glare. If seasonal adjustments aren’t reasonable, the winter angles can be used for the full year. A simple adjustable triangle can be used to adjust the blinds.

Plug Loads

EPA Region 8 has policies in place controlling the number and kinds of electronic devices that can be used in workstations. However, an inventory of devices conducted as part of the plug load research discussed below indicated that the 120 participants in the plug load study had 121 electrical devices, not including computers and task lamps provided by EPA. The devices ranged from phone and headset chargers to radios, heavy duty calculators, speakers, fans, printers, faxes, and personal lamps.

This section summarizes two studies by NREL. The first was a field experiment on desktop plug loads and the second focused on energy use in the building's data center.

RESEARCH CASE STUDY: PLUG LOADS

Behavioral Change and Desktop Plug Loads

NREL conducted a field experiment in the Wynkoop building in 2011 to assess the effectiveness of different strategies to reduce desktop energy use for equipment and devices. This section provides summaries and excerpts from the NREL research.[10]

Any device that plugs into wall outlets distributed throughout a building is a plug load. These loads do not relate to general lighting, heating, ventilation, cooling, or water heating, and typically do not provide comfort to the occupants.[11] Plug loads account for an average of 9 percent[12] but as much as 28 percent of the electricity consumption in office buildings, depending upon the nature of the work.[13] Plug loads can also affect cooling and heating loads and associated cooling energy use, but this study does not consider these effects. An organization that strives to reduce energy use, energy costs, and greenhouse gas emissions in an effort to operate sustainably must devise a strategy to reduce plug load electricity consumption.

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[10] I. Metzger, A. Kandt, and O. Van Geet, 2011. Plug Load Behavioral Change Demonstration Project, Technical Report, NREL/TP-7A40-52248.

[11] Lobato, C., Pless, S., Sheppy, M., and Torcellinin, P. 2011."Reducing Plug and Process Loads for a Large Scale, Low Energy Office Building: NREL's Research Support Facility." NREL/CP-5500-49002.

[12] "Buildings Energy Data Book," Energy Efficiency and Renewable Energy: http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.1.13. Accessed July 26, 2011.

[13] "Survey of Plug Loads," Energy Efficient Products: http://www.efficientproducts.org/product.php?productID=11. Accessed July 26, 2011.

In an office building, plug loads typically include desktop computers and other devices, office equipment (printers, copiers), and break room appliances (refrigerators, coffee makers, dishwashers), in addition to other desktop electronics and devices.

Study Methods

The NREL study tested ways to reduce plug load energy at the workstation level using two primary approaches. The first was an automated energy management system that turns off equipment unused for a certain time. The second involved behavioral change using either information feedback or competition among the participant groups.

The research established a baseline for comparative purposes and then implemented the experimental applications, with a return to baseline to see whether the behaviors would “stick” when the messaging was no longer deployed. Each condition ran for 4 weeks, and all study participants took part in each condition. The study was conducted from February to June 2011. A total of 126 EPA staff on four different floors of the building participated. Staff sit in clusters of 6 to 8 people, called pods. Energy usage data was collected at the pod level.

The experimental protocol required participants to plug selected desktop devices into special outlets if they agreed to have these shut down when they were not in their workspace. They could also opt out of the shutdown by plugging devices into another outlet that was not turned off. Only 28 percent of the study participants plugged their computers into the outlet that was controlled by the energy management system, thus reducing the potential energy that could be saved. The study participants could identify how much energy their group was using by visiting a web page that showed how much energy their group was consuming on a daily basis. During the competition phase of the study, participants could also see how much energy other groups were using compared to their own group.

A second baseline period ran for 4 weeks following the experimental phase. The goal of this second baseline period was to evaluate the extent to which behavioral changes continued with no interaction or communication with the occupants. Therefore, no messaging or control was conducted during this baseline period; however, occupants could use the online dashboard system by visiting the web page.

Plug loads were monitored with the Herman Miller Energy Manager with Monitoring (EMM) system. This technology monitors occupancy and electricity use and can shut off non-critical equipment after an area is unoccupied for a preset amount of time. Up to four separate circuits can be attached to an EMM, with four output zones. Two of the output zones remain energized to power critical equipment, such as computer CPUs (central processing units) and clocks. The other two output zones are switched off based on whether the entire pod is unoccupied for a preset amount of time, which in this case was 30 minutes. This is accomplished by mounting a passive infrared motion sensor to the underside of the work surface of each workstation. The EMM is connected to a system that reports the energy usage data. An online dashboard made feedback available to the occupants during the behavioral change phases of the experiment.

Study Results

The study found that the most effective method for reducing plug loads was through the control system, which turned off plug load devices after 30 minutes of no occupancy in a pod. Competition among pods was also effective at reducing plug load consumption, although less so than the control system. The letters sent to occupants educating them about plug load energy use and opportunities for conservation led to an increase in energy consumption.

Table 4-2. Comparison of Energy, CO_2, and Cost Savings for the Three Experimental Methods

Experimental method	Total annual energy savings (extrapolated for 775 people) (kWh/yr)	Percentage energy reduction from baseline	Percentage of whole-building electricity reduction (extrapolated for 775 people)	Total annual cost savings ($/yr)	Total CO_2e savings (tons)
Control system	34,757	21%	0.9%	$3,476	30
Letters	-407	0%	0.0%	-$41	0
Competition	9,912	6%	0.3%	$991	9

Extrapolated annual energy and cost savings for the 126-person test group are presented in Table 4-2. The results from a simple payback analysis (not shown here) indicate that the use of the energy management system for plug loads alone would not be cost effective. It is intended also to control overhead lighting which was not included in this study.

The results also showed that prolonged savings were achieved during the post-experiment baseline period. Savings were observed during occupied periods and weekend periods.

These results indicate that behavioral change did have an effect on the overall operating practices of the test group. These savings, extrapolated to the entire building (775 occupants) for the entire year, would total 15,669 kWh/yr, representing a 0.4 percent reduction in whole-building electricity consumption and a 9 percent reduction from the baseline. However, data collection for a longer period would be required to confirm that these prolonged savings would be permanent.

Study Conclusions

Assuming that a sub-metering system needed to be installed to verify savings for each experimental method, none of the methods individually would achieve a reasonable payback period. The best case for energy savings would consist of a control system and occupant competition with significant promotion of occupant awareness.

LESSONS LEARNED

Installation of Submetering and Controls

Site support and occupant participation and interest are critical to the outcome of behavioral change research. Approval from the employee union required additional time and planning for all interactions with the occupants and required the research to comply with protocols that would ensure occupant anonymity. Such anonymity is typically required for field research and should be built into dashboard interfaces for displaying data.

Installation of the control and submetering system took longer and cost more than expected. However, costs are expected to decrease significantly with scale and experience working in federal facilities. The wired installation of the control system and communications were very cumbersome and complex. Wireless communications and controls with “plug and play” installation are expected to be less complex and cost less, and they are currently commercially available.

Cyber-security also created a hurdle for the dashboard and data storage at NREL. The dashboard needed to be accessed at an external site, which required additional work by EPA, NREL, and the vendor. The transfer of data to NREL for processing also created unanticipated security-related issues.

Occupant Engagement and Behavioral Change

Occupants were initially hesitant to participate in the study due to concerns about their electronic devices being turned off and to having their behavior monitored. The NREL team worked closely with EPA to obtain approval from the EPA union before the study could be implemented. Issues of privacy were resolved through guarantees of anonymity for all participants.

Although incentives were not offered as part of this research, future behavioral change programs should consider including incentives such as prizes and recognition to encourage and sustain change. Previous studies have indicated that the level of occupant involvement usually correlates with the incentive.[14] Although the control system was more effective than behavioral

[14] Birch, D., and Veroff, J. (1966). Motivation: A Study of Action. Belmont, CA: Brooks/Cole.

change methods at reducing energy, it was too costly, especially if used only to control desktop equipment and devices, and if occupants can opt out of having their computer turned off. Computers are the most energy-intensive desktop equipment. In this study, only 28 percent of the participants allowed their computer to be turned off when they were away from their desk for at least 30 minutes.

Higher energy savings from plug loads could be accomplished by expanding the research beyond just workstations. This study did not include equipment typically found in shared spaces such as large multifunction printers, copy machines, water-coolers, and other equipment.

Research Case Study: Data Center Analysis

Data centers currently consume 2 percent of all energy in the United States, and their carbon footprint is projected to exceed that of the airline industry by 2020. Nearly 50 percent of a data center's energy goes to non-information technology (IT) loads such as cooling and power conditioning. Improvements in energy efficiency in the EPA data center could have significant payoffs for the building's overall energy use. The EPA data center study, completed by NREL, focuses on recommendations for energy savings, the associated costs, and simple payback of the investments. This section includes excerpts and summaries of findings in the NREL report.[15]

Data Center Description

The EPA data center consists of servers, network equipment, and storage. The servers currently in use are categorized as "legacy" servers because they are older and less efficient than modern servers. Site staff has begun the process of virtualization, an important first step toward data center efficiency. Currently, IT staff are still in the early stages of virtualization and consolidation. The highest CPU utilization was recorded at 27 percent, but should be 60–70 percent. Storage utilization also afforded possible opportunities to improve efficiency.

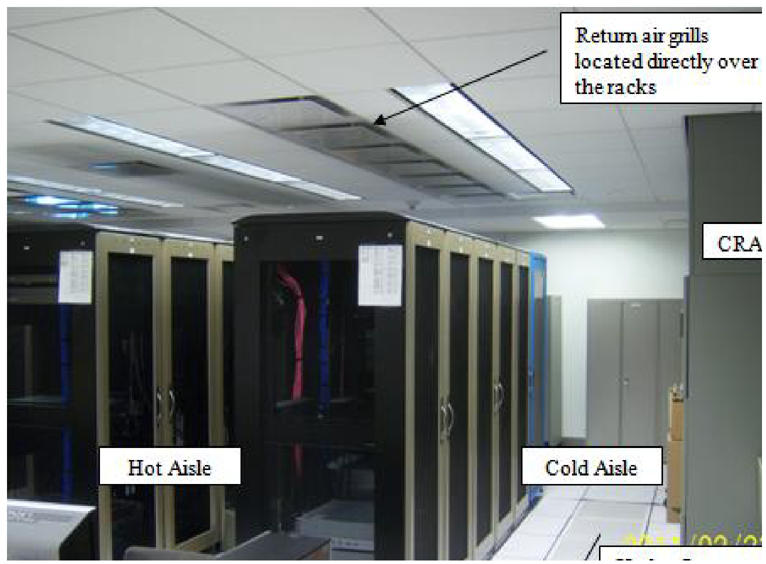
There are typically three general categories for improving the IT environment: equipment replacement, consolidation, and virtualization. Replacing legacy servers with modern, energy-efficient models can significantly reduce energy consumption, and therefore cooling requirements. Consolidating underutilized data center spaces to a centralized location can ease the implementation of data center efficiency measures by requiring the work to be performed in one location, rather than several. Virtualization is a method of running multiple independent virtual operating systems on a single physical computer. It is a way of allowing the same amount of processing to occur on fewer servers by increasing server utilization. Instead of operating many

[15] NREL, "EPA Wynkoop Data Center; Data Center Energy Efficiency Site Assessment," May, 6, 2011.

servers at low CPU utilization, virtualization combines the processing power onto fewer servers that operate at higher utilization. Virtualization can drastically reduce the number of servers needed in a data center, thereby reducing the power and cooling equipment required. Some overhead is required for virtualization, but it is minimal compared with the savings that can be achieved.

The Wykoop data center (Figure 4-9) consists of four rows of rack-mounted computer equipment. The racks are arranged in a hot aisle/cold aisle configuration on a floor raised 1 foot. The air intake for rack-mounted equipment is primarily on the cold aisle side, with heat discharged into the hot aisle. Although the current layout attempts to achieve hot and cold aisles, there are some layout insufficiencies; for example, return air grills are directly above the racks instead of over the hot aisle as intended. Also, no separation barrier prevents the hot and cold air from mixing inside the space.

Figure 4-9. Layout of the Data Center



Cold air is generated by two 15-ton capacity Liebert Computer Room Air Conditioning (CRAC) units. Cool air is distributed through an under-floor system and discharged in front of the racks via perforated tiles.

The temperature of the room is maintained at about 73°F at the return air of the CRACs. The CRACs discharge supply air at about 62°F. The CRACs each have a 5 horsepower (HP), 87.5 percent efficient 480V motor (replace with 90 percent or higher premium-efficiency motor if CRACs are to remain active) that is running at 5 amps (4.2 kW) from the test and balance report to provide 9,400 cfm. The total power demand of each CRAC when fully loaded (including compressors, humidifiers, reheat, and fan) is 43kW.

The CRAC condensers are water-cooled with a roof-mounted cooling tower. The data center condenser loop water pump is rated at 10 HP and connected through a plate-and-frame heat exchanger to the building cooling tower water circulation pumps. The way in which the pumps are connected on the other side of the heat exchanger requires constant operation of a 10 HP and 25 HP pump plumbed in the series, feeding the cooling tower. Therefore, the rated tower water pumping power is 45 HP. The cooling tower has two cells, each with a 40 HP fan motor and on a variable-frequency drive controlling the speed and a 12 HP basin pump.

Cooling System

A psychrometric bin weather analysis tool developed by NREL was used to model the applicability of various alternative cooling opportunities. The analysis examined four different cooling technologies, including direct expansion, the air-side economizer, the direct evaporative cooler, and the multistage indirect evaporative cooler (Coolerado). These technologies were examined individually and in combination with others to categorize seven distinct alternative cooling strategies.

The analysis of the data center produced specific recommendations for improving energy performance. In addition to those noted below, the study also recommends installing a light switch. Currently the light is on 24 hours/day.

RECOMMENDATIONS

Improve the IT Environment

- Through regular technology refresh cycles, replace legacy servers with energy-efficient servers. Many servers use energy-efficient power supplies and variable speed fans to reduce their energy consumption.

- Continue to virtualize and consolidate IT equipment. Virtualization saves money, because it requires less hardware and significantly reduces energy consumption. A CPU utilization goal should be set at 60–70 percent.

- Monitor server utilization, and actively consolidate workloads. Many servers run at 10 percent CPU utilization or less. As virtualization continues, it will become more important to formalize capacity management practices. Continue to monitor server utilization, and actively consolidate workloads on few servers to achieve CPU utilization goals. NREL expects to see its server CPU utilization rates at around 70 percent sustained.

- Move additional storage capacity to network-attached storage or a storage area network wherever possible. It is easier to achieve greater utilization rates by using pooled resources.
- In the future, consider using cloud services (software as a service) for commodity IT products and services that demonstrate a solid return on investment, where cyber security policy will allow. Using a cloud service provider that can achieve great economies of scale and being able to "use only what you need and pay for only what you use" is a highly efficient approach to IT service delivery.

Optimize Airflow Management

There are two main approaches for optimizing airflow management: hot and cold aisle containment, and cable management. Hot and cold aisle containment prevents the mixing of the hot and cold airflows. Therefore, cool air is supplied directly to the computing equipment, and hot air is removed from the space to be exhausted or reconditioned. The current conditions in the data center include a variety of mixing and "short circuiting," such that cold air goes directly from the supply diffusers to the return grills without supplying any useful cooling to the computing equipment. This increases the load on the cooling system and puts warmer mixed air at the front of the racks. In addition, many airflow restrictions are created by poor cable management, which increases the fan energy required to overcome the restrictions.

In the future, when adding computing equipment to the racks, load it from the bottom upward. The racks are currently loaded in random order, leaving openings at the bottom of the rack where there are easy pathways for cool air. Equipment at the top of the racks is more susceptible to hot and cold air mixing. Loading equipment from the bottom up will put it closer to the cool supply air and increase cooling effectiveness of the system.

Expected Data Center Energy Improvements and Payback

The NREL team conducted an analysis of the cost effectiveness of the various energy conservation approaches that could be used to reduce the data center's energy use. Table 4-3 shows the costs of the material/equipment and also includes labor time and rate which are frequently left out of economic analyses. The results show that simple payback for each of the approaches varied from a high of 6.3 years for virtualization and consolidation to a low of 0.23 years for the light switch. It also shows that one of the most expensive options (a new AHU with economiser and evaporative cooling) also yielded the greatest energy savings at a payback of 1.8 years. EPA will be able to use the results for making future decisions about the data center upgrade. The results from the NREL analysis are shown in Table 4-3.

Table 4-3. Summary of Total Savings for Recommended Data Center Energy Conservation Measures

Energy conservation measure	Material/installed cost ($)	Labor time (hours)	Labor rate ($/hr)	Total cost ($)	Energy savings (kwh/yr)	Cost savings ($/yr)	Simple payback (years)
Replace, virtualize, and consolidate IT	$100,000	500	$100	$150,000	239,148	$23,915	6.3
Optimize airflow management	$4,000	54	$50	$6,600	32,675	$3,267	2.0
Replace uninterruptible power supply (UPS) with high-efficiency UPS	$75,000	—	—	$75,000	131,400	$13,140	5.7
Install new air handling unit with economizer plus evaporative cooling	$100,000	—	—	$100,000	555,384	$55,538	1.8
Install light switch	$5	2	$50	$105	4,555	$456	0.23

Interactive effects between measures are not captured in this analysis and would require a detailed energy model of the data center, and possibly a computation fluid dynamics model. If multiple energy conservation measures are implemented, the total savings will in most cases be less than the sum of the savings for the individually considered measures. Replace, virtualize, and consolidate IT.

Chapter 5
Water Performance

This chapter focuses on the building's water use, including a summary of LEED water use projections, whole-building water performance, and research on indoor water use.

PROJECTED WATER PERFORMANCE

LEED Goals

Table 5-1 shows LEED credits earned for design elements related to water efficiency.

Table 5-1. Summary of LEED Credits: Water Efficiency

Design element	LEED credit
Water efficient landscaping ◆ Drip irrigation of street trees	2 points
Water use reduction (Exemplary performance point) ◆ Low-flow faucet fixtures ◆ Low-flow dual-flush toilets ◆ Waterless urinals ◆ Low-flow, time- and weather-station-controlled irrigation system (vegetated roof)	3 points
Total	5 points

Projected water performance was developed using the LEED template for water efficiency. Installation of low-flow fixtures, waterless urinals, and dual-flush toilets formed the basis for projected water savings. The building has 72 pressure-assisted dual-flush toilets (1.6 or 1.1 gallons per flush), 20 waterless urinals, 7 low-flow showerheads, and automated faucets in the bathrooms. Other water uses in the building that were not included in the calculations for LEED certification include an irrigated green roof, HVAC-related process water, and a closed-loop water feature in the atrium. (Issues relating to irrigation water are discussed in the vegetated roof chapter.)

During development of construction drawings for the building, interactions with local building codes and building officials drove changes to the original design. The local health department objected to using stormwater in the atrium water feature, so the team created a simple atrium water feature using recirculated water. This revised design provides aesthetic benefits and reflects EPA's land-water-air mission, but it is no longer a sustainable feature. The local health department had historically banned waterless urinals based on a past negative experience, but this design team was able to overcome the ban based on another successful project involving the design team members. The Opus team allayed the department's concerns about waterless urinals by obtaining an administrative modification that included future commitments to modify the waterless urinals in case of performance failure.

Water Submetering

In addition to the building's main utility water meters, the Wynkoop site has 12 sub-meters that can track domestic and non-domestic water use separately. However, no sub-meters are installed within the building to directly measure domestic demands floor by floor. The existing sub-meters afford no insight on specific characteristics of the domestic water demand—specifically, characteristics such as toilet flush volumes, number of flushes per day, and shower and faucet demands.

The Energy-Water Nexus

According to the US Census Bureau, in 2005, 83 percent of the US population lived in metropolitan areas, up 6 percent from 2000.[16] Two key resources necessary to support an urban lifestyle are drinking water and the infrastructure necessary to treat wastewater. The average American is estimated to use about 90 gallons of water and produce 66 to 192 gallons of wastewater each day, according to the EPA. As the demand for drinking water and wastewater treatment in urban areas grows, it is expected that water utilities will have to increasingly seek out alternative sources of water and treatment methods to increase the water supply, especially in areas of water scarcity where demand outpaces supply. However, treating and using these alternative sources, such as seawater, come with a cost because, in addition to other factors, they tend to be heavily energy-dependent. Providing drinking water and wastewater services to an urban environment involves extracting, moving, and treating water—referred to as the urban water life cycle.[17] Energy plays a crucial role throughout this life cycle in the following ways:

- Ability to grow in conditions of high light intensity, low relative humidity, limited soil moisture, and extreme temperature fluctuations
- Customer use—Energy is needed to circulate, pressurize, and heat water for use inside households and businesses, and for outdoor water-related uses by customers, such as watering lawns.
- Wastewater processes—Energy is needed to convey wastewater to treatment facilities, treat the wastewater to levels required under the Clean Water Act, and discharge the treated effluent into a receiving body of water.

Whole-Building Water Use

Table 5-2 shows actual building water use compared to the design goals. As the table indicates, in the first year after the building was occupied, total water use was significantly higher than projected. The building water research started with an investigation of why water use was so much higher than expected.

[16] "ENERGY-WATER NEXUS: Amount of Energy Needed to Supply, Use, and Treat Water Is Location-Specific and Can Be Reduced by Certain Technologies and Approaches," Government Accountability Office, March 2011 http://www.gao.gov/new.items/d11225.pdf.

[17] "Water Conservation=Energy Conservation: A Report for the Colorado Water Conservation Board," Water Resource Advocates, June 30, 2009.

Table 5-2. Summary of High-Performance Design Targets and Measured Performance for Water Use

Baselines	Design goals	Measured performance
Design case: 3,372,189 gal/year	1,719,738 gal/year[a] 49% below LEED base case (EPAct 1992)[b] Water closets 1.6 gpf Urinals 1.0 gpf Showerheads 2.5 gpm Faucets 2.5 gpm	3,970,00 gallons/year[c] 3,500 gallons/occupant 13.18 gallons/GSF

[a] LEED NC documentation (WEc1).

[b] LEED NC approval letter (WEc1).

[c] K. Fowler, E. Rauch, J. Henderson and A. Kora, 2010. Reassessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings. Pacific Northwest National Laboratory.

Identifying Water Performance Problems

Connection to the Steam System

The water research was originally undertaken to identify the cause of excess water use in the building. The investigation started with the steam system in the building. The Wynkoop building is in a downtown Denver steam and chilled water district. Steam heat is supplied to buildings in the district via distribution lines under adjacent city streets. Steam is piped into the Wynkoop building and around the 1st floor parking level, transferring heat to the potable hot water lines and some heat to this unconditioned space. As it circulates, the steam changes to hot water condensate, which is discharged to the sanitary sewer and returned to the local water plant.

During a visual inspection of the steam system, the building engineer discovered that, sometime before occupancy, a plumber had installed a cold water make-up valve next to the steam system's discharge point. Water temperature at this discharge point was above 175°F, hot enough to melt plastic parts in the pumping system that returned hot water to the sanitary sewer. The cold water make-up valve was installed to reduce water temperature before discharge. This make-up valve operated almost continuously, dumping large volumes of potable water into the sanitary system—31,000 gallons of potable water in just 2 days.

The building engineer reprogrammed the circulation system to send the steam and condensate through the parking level piping three times (instead of once), which brought the temperature down sufficiently to discharge it safely into the sanitary sewer pumping system.

ASSESSING PATTERNS OF WATER USE

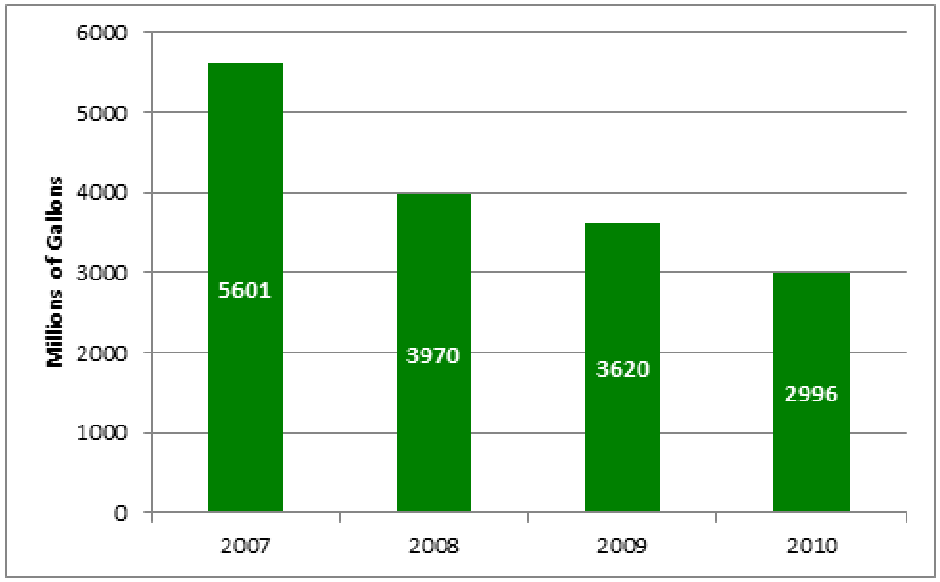
In addition to the visual inspection, an ultrasonic meter fitted with a data logger was installed on the main water supply piping to the building to record data on the building's daytime water demand patterns, weekend vs. weekday demand volumes, and any indication of leakage in the entire building. At numerous times throughout the monitoring period the building water demand reached 0 gallons per minute, indicating no evidence of leakage. It is possible, however, that some small level of leakage may exist in the building, with a flow rate too low to be recorded by the monitoring equipment.

The findings from this analysis show that building plumbing systems need to be addressed as part of the normal overall commissioning. Formal commissioning was never done on the water system. The system was investigated only after the problems with higher than expected water use was discovered. Formal commissioning of water systems as part of the normal commissioning process would identify problems with the overall system. However, it would not have identified the behavioral aspects of water use. That requires systematic research.

Building Water Use 2007–2010

Potable water use has declined significantly since the building was occupied in 2007. As displayed in Figure 5-1, consumption dropped from 5.6 million gallons in 2007 to just below 3.0 million gallons in 2010. Much of the first year's drop was due to changes made to the building steam system, where the need for tempering water at the condensate drain was reduced as discussed above. In 2008 and 2009, annual demands fell by 9 percent and 17 percent respectively. Identifying the specific source of those reductions was not within the scope of this study. Thus, it remains largely unknown at the present time.

Figure 5-1. Annual Potable Water Consumption at Wynkoop Building



FIXTURE WATER USE

After the source of excess water use was identified and a solution implemented, building management decided to continue with its investigation, in light of numerous documented complaints regarding toilet double-flushing and questions regarding the accuracy of the LEED modeling assumptions for domestic water use.

The overall objectives of the additional research were as follows:

- Assess water pressure on all floors of the building to determine if differences in pressure could affect toilet water use.
- Assess the compliance of the plumbing systems with prevailing building code standards.
- Identify the source of any water use anomalies and recommend actions to reduce water use. Handles for tankless toilet flushometer valves and the building water pressure were examined in detail.

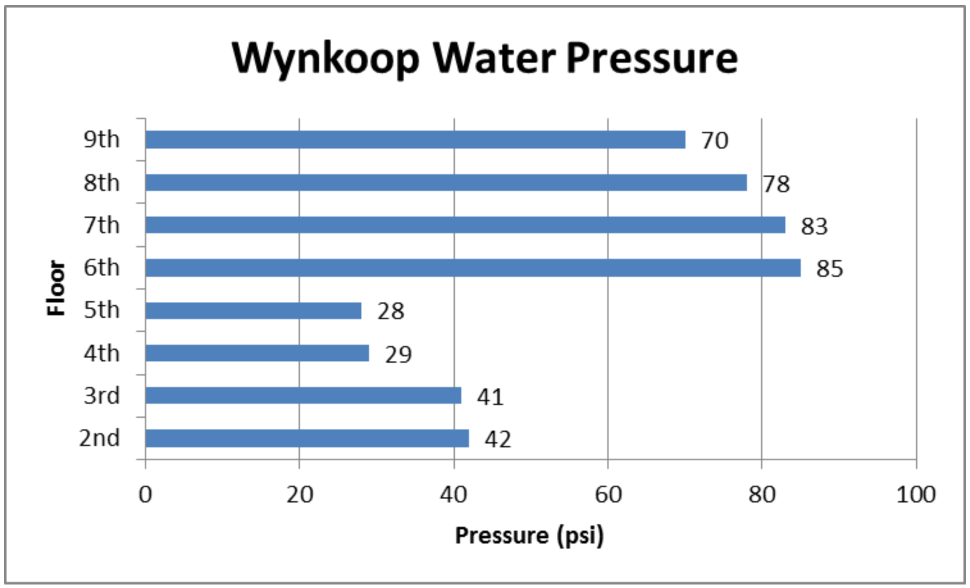
- Determine the building's actual water demand (related to building occupancy) and compare actual use to the water demand estimate calculated as part of the building's design and LEED application. Provide data to support development of water use baselines for future projects of a similar nature.

The water use research in this section summarizes findings from two reports: "Fixture Water Use Analysis" by the Pacific Northwest National Laboratory, and "Water Use Field Research and Baseline Assessment" by Koeller & Co. and Gauly Associates.

Building Water Pressure

Occupant feedback indicated that water pressure varied throughout the building and was particularly low on the 5th floor. Complaints about needing to double-flush toilets were most numerous on this floor. The building is served by city-supplied water pressure for floors 2–5; a booster pump assists water pressure on floors 6–9. The pressure readings taken on each floor are shown in Figure 5-2; they illustrate that water pressure varies floor to floor, with a significant increase from the 5th to 6th floor.

Figure 5-2. Wynkoop Water Supply Pressure by Floor



Water pressure ranged from a low about 30 pounds per square inch (psi) on the 5th floor, the uppermost floor serviced by municipal water pressure, to as high as 82 psi on the 6th floor, the lowermost floor serviced by the in-building booster pump. Varying pressures such as these can significantly affect flush and flow rates of installed fixtures and fixture fittings. In some cases, toilet fixtures will not perform adequately at low pressures (such as below 30 psi). Other products, such as showers and appliances, may not function satisfactorily at extremely high pressures (such as above 80 psi). These pressure differences could be one reason for the variances in fixture performance observed on the 2nd, 5th, and 7th floors.

Plumbing Systems' Conformance to Standards

The LEED formulas for calculating the baseline case for lavatory faucets erroneously used a flow rate of 2.5 gallons per minute rather than the 2.2 gpm at 60 pounds per square inch of supply pressure maximum mandated by federal law.[18] However, since the mid-1990s, the American National Standard (ASME-ANSI A11218.1 for plumbing supply fittings) and the US model codes (International Plumbing Code and Uniform Plumbing Code) have specified a maximum flow rate of 0.5 gpm for non-residential lavatory faucets. USGBC recognized and corrected this error in 2009; the current LEED documentation now incorporates the correct baseline of 0.5 gpm for non-residential faucets.

This erroneous flow rate created a non-compliance situation in the building. A site visit in September 2010 noted that lavatory faucets were set to flow at approximately 1.5 gpm for 30 seconds (0.75 gallons per 30-second cycle), compared to the prevailing national plumbing standard of 0.5 gpm (0.25 gallons per 30-second cycle) for a metering faucet. Building management responded immediately to correct the situation by replacing the faucet aerators with 0.5 gpm aerators. Once that was completed with the metering time set to no more than 30 seconds, the faucets were compliant as defined in Table 1 of ANSI standard ASME A112.18.1/CSA B125.1 and LEED.[19]

Water Fixture Analysis

Evaluating water use required an on-site inventory of the installed plumbing systems and measurements of consumption in selected building locations. Virtually all water fixtures and appliances in the building were inspected, but specific water demand data were collected for restrooms on the 7th-floor, considered a typical office floor in the building. This research also assessed water used in the fitness center.

[18] EPAct 1992, as interpreted by the Department of Energy.

[19] Metering faucets flowing at 1.5 gpm would have been acceptable and compliant, provided the programmed shut-off time was 10 seconds or less. However, given a cycle time of 30 seconds, the faucets would not qualify under the standard until the flow rate was reduced to 0.5 gpm.

Study Methods

During March 2011, an ultrasonic sub-meter and data logger were installed on the cold water supply to washrooms on the 7th floor. Data were collected in 1-second intervals to capture short water use events and determine average volume per event. The data were then used to determine the following:

- Total water demands of the floor, which was used along with the floor occupancy to determine the average gallons per capita per day[20]
- Flush volume characteristics (average flush volume and use of the reduced-flush option on dual-flush fixtures)
- Whether there was any indication of leakage on the 7th floor.

Data collected during this time indicated that the reduced-flush option was not being used, resulting in higher water use than projected for toilet flushing. On the recommendation of researchers, the toilet handles on this floor were retrofitted and a second round of metering was planned.

Additional metered data were collected in November and December 2011. Two ultrasonic sub-meter data loggers were installed on the 7th floor to assess water savings from the retrofitted toilet handles. The 5th floor restrooms were metered as a comparison with the 7th floor and to better understand the implications of the lower water pressure found to exist on the 5th floor. Once again, data were collected at 1-second intervals; however, several factors prevented exact replication of data results, such as variable occupancy as well as variation in sampling locations and the data collection protocol. These results and the toilet handle retrofit are discussed in more detail below.

Dual-Flush Toilet Performance

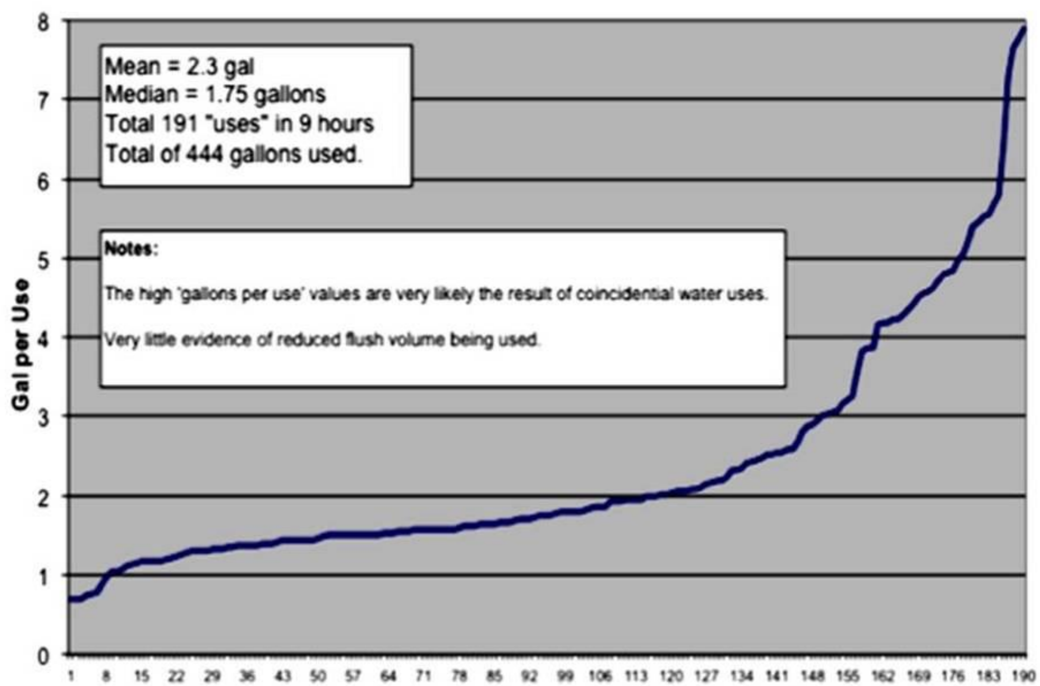
The handles on the flushometer valves give users a choice about which flush volume to use. The handles are designed to perform a full flush (1.1 gallons) when pushed down, and a reduced flush (0.8 gallons) when pulled up. Analysis of the water use associated with toilets examined whether the handles were being used properly.

[20] Building staff estimated that there are typically 68 men and 73 women working on this floor, a total of 141 people, although this number varies from day to day and even hour to hour. The men’s and women’s toilets were fed by the same water line and thus could not be metered separately, so gender differences could not be captured.

Metering Results

The data collection protocol for the dual-flush toilets, described above, provided a means to record the number of flushes that were low-flow vs. full-flush. The data showed very few flush volumes of 1.1 gallons or less, indicating that either the dual-flush valves were not operating properly or that building occupants were only infrequently selecting the reduced-flush volume option.

Figure 5-3. Metered Volume of Water per Flush for 9-Hour Sample Period



Flushometers

Tests performed on the 7th floor toilets in March 2011 indicated that the toilets were operating properly: water volumes for the full- and low-flush options were consistent with design specification. However, the November-December field research performed more detailed comparative testing of toilets on the 3rd, 5th, and 7th floors. Variable performance in water savings was observed. Other federal water assessments have indicated that diaphragm-type valves, the type installed in the Wynkoop building restrooms, are less reliable than piston-type valves, especially at low pressures.[21] Commissioning the fixtures when installed would have allowed a conclusion that the differences in measured data arose from occupancy use, rather than equipment or installation differences. Investigating piston-type valves or other technologies in future applications could result in more consistent performance.

Two options were identified to reduce the excess water demand related to toilet flushing:

- Remove the existing dual-flush fixtures in their entirety and replace them with single-flush, high-efficiency toilets that flush with 1.28 gallons or less.

- Remove only the existing flush handles and replace them with dual-flush handles that require users to push down to activate the reduced flush option.

Because of the cost associated with the first option, building staff decided to initially explore the less expensive option of replacing the dual-flush handles. A suitable aftermarket replacement handle was identified and laboratory tested by Veritec Consulting Inc. of Mississauga, Ontario, Canada.[22] The laboratory testing verified that the new dual-flush handles used a reduced flush volume when pushed down and delivered the correct volume of water for each of the two flush options.

Following the laboratory testing and evaluation of the replacement handle, the facility manager arranged for its installation on all 7th-floor washroom flushometer toilets. Next, a short period of time was allowed the 7th floor occupants to become familiar with the new flush handles. Then the ultrasonic meters and data loggers were reinstalled, and the resultant data were analyzed. Preliminary data collected at this time indicated that more low-flow flushes were occurring. The research team recommended monitoring the 7th-floor washrooms for at least 14 days to develop post-retrofit water use profiles.

Based on these preliminary results and a reduction in occupant complaints about having to double-flush toilets, building management retrofitted all toilets in the building with handles that activate a low-flow flush when pushed down.

Impact of Handle Retrofit on Whole-Building Water Use

A research team from Pacific Northwest Laboratory returned to the Wynkoop building in November 2011 to conduct the post-retrofit monitoring and attempt to track whole-building water savings attributable to the toilet handle retrofit. Unfortunately, the research team could not quantify building-wide water savings for the following reasons:

[21] K. McMordie Stoughton, water efficiency expert, Pacific Northwest National Laboratory.

[22] The replacement handles are manufactured by Advanced Modern Technologies Corporation – AMTC, Woodland Hills, CA.

- Determining an exact full-time equivalent (FTE) occupancy rate for the Wynkoop building is complicated, because employees work flexible shifts, telework, and work off-site or in the field. All of these conditions contribute to some degree of uncertainty regarding calculations of per capita water demands.

- The water savings related to the new flush valve handles is relatively small compared with the water demands of the entire building. As a result, it is difficult to quantify the savings related specifically to the flush handle change, when there may be other changes in water demand related to commercial tenants, irrigation, cooling tower make-up, and other factors.

- Domestic water demand is calculated by starting with total building demand and subtracting the volume recorded by the 12 sub-meters for non-domestic use. The accuracy of the domestic demand calculation, therefore, is affected by the cumulative accuracy of the sub-meters and the recorded sub-meter readings (both the reading value and the date and time of the reading).

- The accuracy of an ultrasonic meter is limited by a number of factors: the temperature, density, and viscosity of the fluid; the density, thickness, and condition of the pipe wall; and the accuracy of recording transducer installation. Unlike turbine or positive displacement meters, ultrasonic meters can be affected by how they are programed and installed, as well as by the condition of the piping on which they are installed.

While whole-building water savings could not be verified using the sub-metering data, facility personnel noted that the toilets appeared to flush better after the handles were retrofitted. Perhaps more importantly, the number of complaints about toilet plugging problems and other flushing issues fell significantly (to virtually none) after the new handles were installed. In fact, following the initial trial, facility personnel received no comments at all from 7th-floor occupants regarding the flush handle replacements, indicating that the occupants may not have even been aware of the change-out.

Toilet Handle Retrofit and Occupant Behavior

Anecdotal reports from other sources over the past 3 years suggest that lifting up on a handle for a reduced flush is inconvenient, so this option is seldom used. Facility managers and water efficiency professionals have asserted that until a reduced flush is activated by pushing down on the handle—the normal user custom when activating a flush valve—water savings from these types of dual-flush valves will be minimal.

The fact that most water uses were greater than 1 gallon per flush indicated that users were selecting mostly full flushes, suggesting that they were pushing down on the handles.

These results are consistent with a recent field study of a similar dual-flush toilet.[23] The researchers tested whether the design of the flush handle influenced the amount of water saved. The toilet handle was designed to provide a large flush for solid waste when pushed down and a small flush for liquid waste when pulled up, as in the Wynkoop building. The researchers hypothesized that users would be much more likely to push the handle down, regardless of whether the flush was for liquid or solid waste, because they have been conditioned to do so. The field experiment studied flushes in eight women's toilet stalls in a small municipal building in the Midwest. The flushes were measured with specially designed sensors that counted the number of up and down flushes. The results showed that users regularly used a full, downward flush. The behavior did not change when the researchers installed signage in the stalls instructing users on how to properly use the flush handles. The researchers concluded that the best way to resolve the problem was to reverse the handles so that the downward push activated a low flush.

Actual Water Use versus Modeling Assumptions Used in Design

LEED calculations are completed during building design and, therefore, must use projected values for total building occupancy, ratio of men to women, the flow rates and flush volumes of the building's plumbing fixtures, and the frequency of plumbing fixture use. In accordance with the USGBC certification template for LEED NC, total annual water consumption by indoor plumbing at the Wynkoop building was estimated during design as follows:

- Baseline water use: 3,372,168 gallons
- Projected water use: 1,719,738 gallons
- Design reduction from baseline: 1,652,430 gallons (49 percent).

The values above were based on the following assumptions about weekday demands, for the baseline and projected cases:

- Building occupancy is 1,240 FTE personnel, divided equally between males and females.
- Men flush toilets once (1.6 gallons per flush), and urinals twice per day at 1.0 gpf for the baseline and 0 gpf with non-water urinals for the projected case.
- Women flush toilets three times per day at 1.6 gpf for the baseline case, and four times per day in the projected case at 1.6 gpf twice and 1.1 gpf twice with dual-flush toilets.

[23] Arocha, J.S. and McCann, LMJ, 2013. Behavior economics and the design of a dual flush toilet. Journal of the American Water Works Association, in press.

- Men and women use lavatory sinks three times per day for 15 seconds each time: 2.5 gallons per minute for the baseline case, and 0.5 gpm for the projected case.[24]

- Men and women use kitchen sinks two times per day for 15 seconds each time: 2.5 gpm for the baseline case and 5 gpm for the projected case.

- Twenty-five percent of the staff take a shower on-site each day for 5 minutes: 2.5 gpm for the baseline case and 1.6 gpm for the projected case.

- The janitor sink is used eight times per day for 15 seconds each time: 2.5 gpm for the baseline case and 2.0 gpm for the projected case.

Based on the water use in the projected case, the facility earned 3 points for water-efficient plumbing fixtures and fittings as follows: 1 point each for meeting 20 percent and 30 percent water use reduction thresholds, and 1 point for innovative design by having achieved a 49 percent reduction threshold from a calculated baseline.

The building's total domestic water use in 2010 was 1.06 million gallons, or about 35 percent of the total building water demand. As also noted in Table 5-3, the total domestic use in 2011 was nearly the same, 1.04 million gallons, or about 32 percent of total building water use.

Table 5-3. Annual Water Use (Gallons)

Year	Total building	Domestic	Domestic, % of total
2010	2,996,305	1,061,947	35%
2011	3,201,348	1,044,884	32%

The 2010 domestic demand equates to

- an average workday demand of 4,084 gallons, based on 260 workdays per year; and

- an average per capita demand of 5.34 gallons per day, based on FTE occupancy rate of 765 persons.

[24] See discussion below regarding errors in code compliance requirements relating to lavatory faucets.

The 2010 domestic demand performance is about 1.8 percent lower than the LEED target design of 5.44 gallons per day.

The 2011 domestic demand equates to

- an average workday demand of 4,019 gallons, and
- an average per capita demand of 5.25 gallons per day.

The 2011 domestic demand is about 3.5 percent lower than the LEED target design of 5.44 gallons per day.

As illustrated in Figures 5-4 and 5-5, the use of plumbing fixtures and fixture fittings by building occupants represented about 39 percent of total potable water use in 2010, rising to 48 percent for the first 6 months of 2011.

Figure 5-4. Potable Water Use at Wynkoop Building—2010

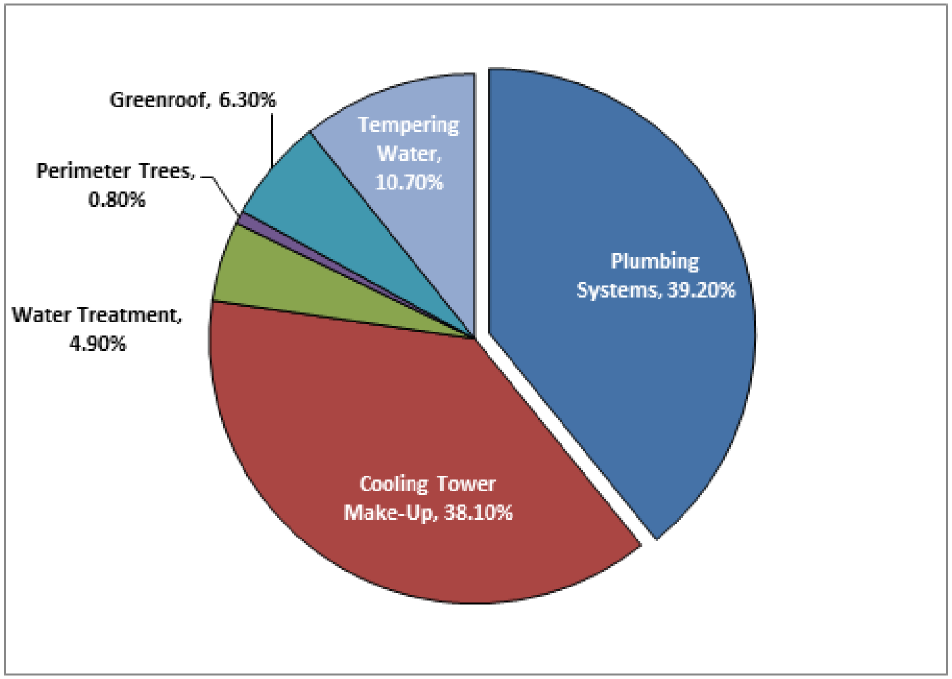
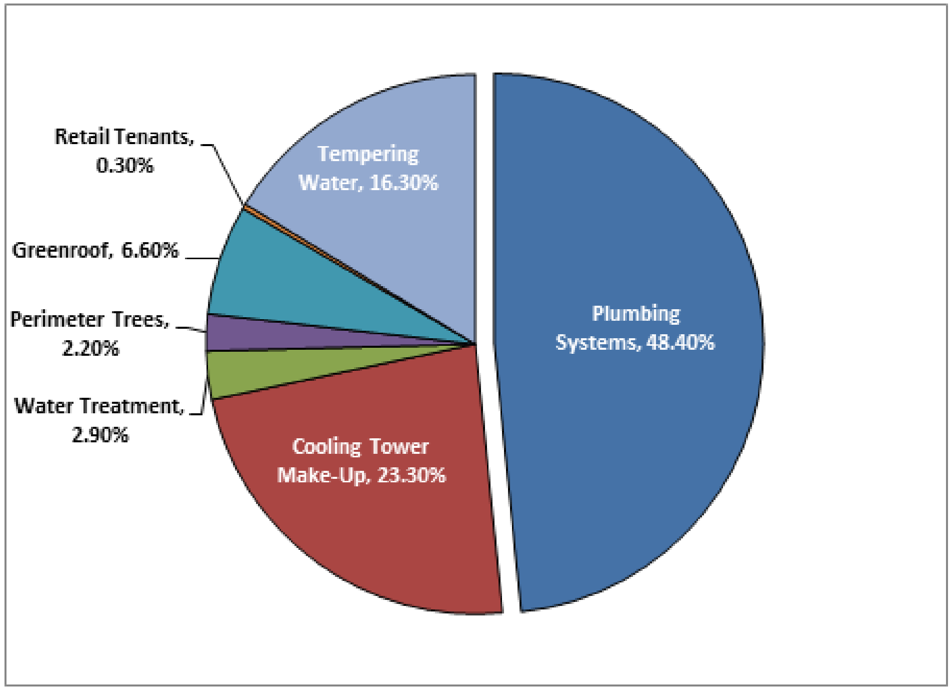


Figure 5-5. Potable Water Use at Wynkoop Building—2011



Impact of Occupancy Levels and Demographics

The actual average population in the Wynkoop building for the 24-month period from April 2009 through March 2011 was estimated to be only 765 persons, including EPA employees, contractors, visitors, and others, compared with 1,240 FTEs used in the modeling assumptions. Of these occupants, 54.6 percent were female (418 people) and 45.4 percent were male (347 people).

Recalculating the indoor water use estimate based on the LEED template and the actual (reduced) occupancy numbers yields the following reduced annual projections:

- Adjusted baseline water use: 2,093,520 gallons (versus 3,372,168 gallons). Based on design projections of FTE building occupancy.

- Projected water use: 1,082,900 gallons (versus 1,719,738 gallons). (Based on design projections.)
- Reduced baseline water projections, based on estimated actual 2010 and 2011 FTE building occupancy: 1,010,620 gallons (48 percent) vs. 1,652,430 gallons. The adjusted baseline aligns closely with LEED calculated demand.
- Design reduction from baseline: 1,010,620 gallons (48 percent) vs. 1,652,430 gallons is, according the water report, “a best estimate of the FTE building occupancy; actual 2010 and 2011 demands follow closely with the LEED calculated demands.”

The flush volumes and flow rates used for the revised LEED calculations are expected to be reasonably accurate, but it is important to note that the final LEED demand value is very sensitive to the assumed number of toilet flushes and the duration of lavatory use and shower use per capita per day. For example, site staff have indicated that men will sometimes use a toilet to urinate instead of using Americans with Disabilities Act (ADA)-compliant urinals, which are installed lower on the wall and can cause “splash back.” If the number of toilet flushes for men in the building is actually two per day vs. only one as assumed in the LEED calculation, the LEED calculated per capita value would be just over 6.0 gallons per day and greater than the actual demand of 5.9 gallons per capita per day.

LEED Calculations versus Actual Water Use, 2010–2011

An analysis of total domestic water demands in the Wynkoop building during 2010 and 2011 showed water use to be very close to those estimated as part of the original LEED application, once the LEED values were adjusted to reflect actual building occupancy and faucet flow rates. Actual domestic water use of approximately 5.34 gcd in 2010 and 5.25 gcd in 2011 tracked closely with the LEED projected demand of 5.44 gcd.

The projected LEED water use, based on installation of design-specified plumbing systems, originally showed a 49 percent reduction from the LEED template baseline. However, after adjusting for the faucet calculation within the LEED template formula, the estimate was revised to a projected 40 percent reduction, still sufficient to earn the LEED credit point for innovative design.

RECOMMENDATIONS

Supply Water

Pressure measurements of supply water pressure should be taken at the fixtures and fittings on each floor to aid in identifying the possible source of plumbing performance issues.

Water Sub-Metering

The water study authors recommend that LEED-certified buildings be equipped with sub-meters, enabling domestic water demands to be delineated from other building water demands and tracked through a real-time management system designed to quickly identify water consumption anomalies.

Most buildings consume water for both domestic and non-domestic purposes. For instance, water can be used in a building for cooling tower make-up, boiler make-up, trap priming, landscape irrigation, process water use, general cleaning, humidification, and other uses, in addition to typical domestic uses like lavatory sinks and toilets. These non-domestic demands can be segregated from domestic demands either by having separate domestic and non-domestic supply piping or using an array of sub-meters installed on every non-domestic demand use.

The following are guidelines for using sub-meters:

- Types—Where possible, if a high level of accuracy is required, sub-metering should employ either permanent turbine or positive displacement meters.
- Location—Where possible, meters should be installed per the manufacturer's instructions, such as with adequate lengths of straight pipe upstream and downstream of meters.
- Size—Meters should be properly sized for in situ flow rates.
- Readings—Meter readings should be recorded to the highest level of accuracy allowed by the meter. The date and time for each reading should be recorded, as well as the name of the person taking the reading. To the extent possible, all readings for a given project or site should be taken by the same person.

- Temporary ultrasonic water meters—Such meters are typically used for temporary monitoring or where it is not practical to install a permanent mechanical flow meter. Ultrasonic transducers are strapped to the outside of the pipe in specific locations based on the physical characteristics of the pipe (diameter, material, etc.). The meter determines flow velocity by measuring the transit time for a beam of ultrasound to cross back and forth across the inside of the pipe. The accuracy of an ultrasonic meter is affected by the temperature, density, and viscosity of the fluid; the density, thickness, and condition of the pipe wall; and the accuracy of the installation of the transducers.

  While ultrasonic meters can be fairly accurate under ideal conditions, errors can be introduced if the transducers are installed on different pipe sections (sometimes even different locations on the same pipe), pipes of different diameters or materials, pipes of different temperatures, or even by a different technician. Care must be taken to eliminate as many sources of error as possible when using ultrasonic sub-meters to verify water demands.

A precautionary note: Although it is beneficial to use sub-meters to distinguish between domestic and non-domestic water demands, no meter is 100 percent accurate. As the number of sub-meters in a facility increases, their cumulative level of accuracy is correspondingly diminished, owing to their combined margins of error. If there is a small margin of error in each meter, the cumulative effect can be a large inaccuracy in data.

Other Domestic Water Uses Tested in the Wynkoop Building

The two ultrasonic meters were also used for two other domestic water uses to obtain additional data about water consumption, in the visitor restroom and fitness center.

Visitor Restroom

The 2nd floor includes a technical library and conference center that are open to the public. The restroom used by most visitors on this floor was metered to better understand the impacts of visitors on water use. Total water use per day was collected for 4 days and compared to daily visitor logs. Water use was an estimated 0.08 gallons per building visitor. For comparison, occupants on the 7th floor averaged 2.3 gallons per person per day, while occupants on the 5th floor averaged 1.3 gallons per person per day.

Fitness Center

The hot and cold water lines serving the men's fitness center washroom were metered separately. The original intent was to measure both women's and men's fitness center washrooms, but the piping layout made the desired metering point inaccessible.

Over a 4-day average, men's fitness center total water use ranged from 110 to 235 gallons per day. The cold water meters showed little to no usage, indicating that hot water is the primary water type used for showering. This finding was not wholly unexpected: water is heated through steam-heat transference, and feedback has indicated that the water temperature does not reach temperatures where mixing with cold water is necessary.

No reliable data were available regarding the number of fitness center users per day. A sign-in sheet is provided in the fitness center to track users, but building management indicated that most users do not sign in. Proxy card data were not available in time for analysis, due in part to security concerns. As a result, it was not possible to estimate how much of the total building water consumption was due to fitness center use.

Lessons Learned from Building Water Use Research

Modeling Assumptions for Occupancy and Use

Calculating per capita domestic water demands in any building requires an accurate determination of the volume of water supplied for domestic purposes and the number of persons served by this volume. Many buildings—including the Wynkoop building—have highly variable occupancy rates. Not only can occupancy change from year to year as projects ramp up or wind down, but they can also change from month to month because of employee vacations, holiday breaks, and other schedule variations, and even from day to day, such as when employees take Mondays or Fridays off as part of compressed work schedules. Some employees work off-site occasionally or routinely, or work overtime or on weekends; and some buildings have varying levels of visitors. All of these factors complicate the accurate determination of FTE building occupancy values, which is an important component of all modeling assumptions.

Improving Occupancy Data

The research findings led to suggestions for improving the accuracy of occupancy data:

- Where employees and visitors are required to log in or otherwise note their entry and departure from the building, use that documentation as the starting point for establishing FTE occupancy levels.
- Consider the variability of occupancy based on factors such as flexible work schedules, telework, work at off-site locations, overtime and after-hours work, field work, vacations, and visitor use.

Commissioning Plumbing Systems

The experience with the steam system, discussed at the beginning of this chapter, underscores the importance of careful commissioning of plumbing system components. Ensure that equipment and fixtures are installed correctly, and that the building managers and occupants know how to use them properly.

Occupant Behavioral Habits

Strong habitual behaviors, such as the toilet flushing behavior described in this chapter, can run contrary to manufacturer's claims and the projected savings for many sustainable technologies. Research in behavioral economics is especially important for design teams to review when making design assumptions and technology decisions.

Chapter 6

Indoor Environmental Quality Design and Goals

This chapter focuses on the Wynkoop building's goals for indoor environmental quality, including a summary of LEED goals and design elements for temperature, air quality, daylighting, and workstation characteristics. Achieving a high quality, healthy, and productive work environment for its employees was a major goal for EPA. This chapter looks at how these goals were achieved and what kinds of tradeoffs needed to be made during design development and implementation.

Actual performance of the building with respect to these goals is discussed in the Chapter 7.

LEED Goals

Table 6-1 shows LEED credits earned for design elements related to indoor environmental quality.

Table 6-1. Summary of LEED Credits: Indoor Environmental Quality

Design element	LEED credit
CO_2 monitoring (Denied: Drawings did not show location of the CO_2 monitors)	—
IAQ performance/ventilation effectiveness ASHRAE 62-1999 ventilation air quality standard and ASHRAE 129-1997 air change effectiveness Non-smoking facility	1 point, 2 prerequisites
Construction IAQ management plan (Denied: Insufficient documentation) Partial flush-out and air monitoring	—
Low-emitting materials (1 point denied: Inadequate documentation) Low emitting adhesives/sealants, paints/coatings, carpet, composite wood	3 points
Indoor chemical and pollutant source control (Denied: Template incorrectly filled out) Separately ventilated areas for high-volume copiers and mixing of chemicals (cleaning supplies)	—
Controllability of systems (Denied: Need separate control of lighting and thermal comfort)	—

Design element	LEED credit
UFAD diffusers	
Thermal comfort Indoor thermal comfort set-points in accordance with ASHRAE standard 55-2004 Temperature and humidity monitoring system controls the HVAC system	2 points
Daylight and views (Denied: Documentation not legible) 90% of occupied spaces have access	—
Total Points Earned	5 points

IEQ Design Goals

As illustrated in Figure 6-1, IEQ consists of complex interrelated elements that must be considered together in designing a sustainable facility. The following is a summary of the IEQ goals for the Wynkoop building:

- SFO-specified ASHRAE standards for basic and increased ventilation, thermal comfort and control, CO_2 and indoor chemical pollutant control, construction IAQ management plan, and pre-occupancy flushout
- SFO-specified sustainable cleaning products and integrated pest management plan, no urea formaldehyde or arsenic treated wood, low VOC carpets, plastic laminate, wall coverings, paints, adhesives and sealants, low-lead paint
- Maximize daylight
- Consolidation of 850 staff on fewer floors than previous space
- Enhanced occupant health, well-being, and productivity through indoor air quality, access to daylighting, and improved workstation design.

Figure 6-1. Integrated Components of IEQ

The IEQ research that addressed these goals included human factors research (a web-based survey and functionality analysis), and measurement of physical conditions such as acoustics, UFAD, thermal conditions, air quality, and daylighting. The results of that research are discussed in Chapter 7.

THERMAL ENVIRONMENT DESIGN

The project team earned LEED credits by designing an HVAC system that was sized using indoor thermal comfort set-points in accordance with ASHRAE standard 55-2004. The HVAC system is designed to keep all office space, conference rooms, and restrooms within the following parameters:

- Summer temperatures: 75°F ±3°F
- Winter temperatures: 72°F ±3°F
- Relative humidity: 0–65 percent, depending on outdoor humidity.

Credits were also earned by installing a permanent temperature and humidity monitoring system that operates throughout the year to control the HVAC system so that occupied spaces stay within these comfort ranges. All workstations and offices have at least one air flow diffuser so people can control the amount of air flow in their own space. Credits were attempted for "controllability of systems" but were denied because lighting and thermal comfort must be separately controlled.

During design and construction, considerable controversy arose about the best way to ensure thermal comfort in this particular building. Conditioned air moves through a UFAD system: an 18-inch raised floor that serves as a sealed, pressurized plenum. This type of plenum was a relatively new technology at that time, and team members disagreed on its merits and the most effective way to install it. Engineers in GSA's headquarters office for facility management had seen poor results in some recent UFAD installations and recommended against using it. Engineers in EPA's headquarters office for facilities management, however, believed that additional ductwork should be installed within the plenum to avoid leaks and to ensure that conditioned air was effectively circulated. Engineers on the general contractor's team, though, had experience with effective UFAD systems and believed that the problems seen in previous buildings could be avoided. The local EPA team envisioned valuable benefits from the UFAD system in terms of both energy performance and space reconfiguration, since electrical and local area network (LAN) wiring runs through the open plenum.

These concerns were addressed in several ways. Members of the local team (representing GSA, EPA, and Opus) visited a Denver-area GSA facility with a poorly performing UFAD system for lessons learned. At this facility, post-occupancy infrared camera testing revealed large numbers of perforations in the floor, causing the pressurized plenum to leak. These perforations were made by electrical and plumbing subcontractors installing wiring and piping after installation of the floor. This approach is standard practice in traditional flooring. In this instance, however, the subcontractors were unaware that the plenum was pressurized and that their perforations would affect thermal performance. Opus addressed this in the Wynkoop building by developing standard operating procedures for subcontractors, reinforced through training, weekly meetings, and on-site inspections.

Large amounts of construction debris were also found inside the plenum at the older facility, creating obstructions and interfering with the free flow of air through the plenum. Opus maintained very tight housekeeping requirements during construction and thoroughly cleaned the raised flooring before occupancy.

The team also researched issues brought out by UFAD performance testing, ultimately contacting the Center for the Built Environment (CBE) at the University of California–Berkeley for advice. A CBE engineering team specializes in HVAC systems and was very familiar with UFAD systems. It noted that tests then in use to evaluate UFAD performance involved super-pressurizing the plenum and were not representative of actual operating conditions. This team suggested using the Wynkoop facility to develop more representative testing methodology after occupancy, and the regional EPA and GSA offices agreed.

> Best Practices: UFAD Construction
>
> Develop standard operating procedures for electrical and plumbing subcontractors governing where and how to make perforations to the pressurized plenum. Reinforce these standard operating procedures through training, weekly meetings, and on-site inspections.
>
> To avoid airflow obstructions in the plenum, keep raised floors free of construction debris through stringent housekeeping requirements. Clean the raised flooring before occupancy.

Because this was a performance-based contract, final decision-making authority—and the contractual risk of failure—was with the general contractor, who proceeded with a modified installation. After occupancy, EPA and Opus worked with CBE and GSA to test performance of the UFAD system; results of that research are summarized in Chapter 7.

Indoor Air Quality Design

Air change effectiveness is a measure of how well the system moves all the air in the building: all the air should circulate through the building at roughly the same rate, minimizing pockets of dead, stale air. The UFAD system is an important part of the strategy to achieve highly effective ventilation in this building. It provides supply air through diffusers in the floor while return air exits the ventilated space at the ceiling. This system avoids the short-circuiting that commonly occurs in buildings where air is supplied through the ceiling and exits through the ceiling. The UFAD system is in place on floors 4–9; the three lowest floors employ the traditional system of supply and return air in the ceiling. There was concern that UFAD systems could not support the weight of the high density shelving (record center floor 3 and library floor 2) and servers (data center floor 3).

An elevated concentration of carbon dioxide inside a building indicates poor indoor air quality. The project team attempted to achieve a LEED credit by installing CO_2 monitors in most return air ducts in the building to assess the quality of return air. This information is fed into the building's automated monitoring system and is used to adjust ventilation rates, especially in areas of intermittent use, such as conference rooms. The LEED credit was denied, however, because the submitted documentation did not show the location of the CO_2 monitors.

The project team also attempted to achieve LEED credit by designing and constructing separately ventilated areas for high-volume copiers and mixing of chemicals such as cleaning supplies, and installing mats at the building main entrance to reduce contamination brought in by occupants and visitors. This credit was denied because the project team did not submit a letter template declaring that these tasks were completed. The building owner was also required to provide a moisture control plan to deal with issues related to flooding or moisture incursion into the building.

Environmental Attribute Tradeoffs

The project team attempted to earn LEED credit for construction air quality management by combining an abbreviated flush-out period with indoor air testing. During the flush-out period, all outdoor air coming into the building was subject to MERV 13 filtration. The air quality measurements were performed in accordance with an established EPA protocol.[25] Credit was denied because the LEED review team sought additional documentation on flush out, the IAQ testing option, and the filtration media used during implementation.

Bamboo is a bio-based, rapidly renewable material (regenerating in less than 10 years). The building has 5,000 square feet of bamboo flooring, and about 13,500 square feet of bamboo paneling. Before its installation, however, a review found that this otherwise “green” product included urea formaldehyde, a highly toxic chemical that causes acute respiratory health effects. One of the project requirements was to have “no added-urea formaldehyde anywhere in the building.”

At the time, no manufacturer anywhere was making this product without urea formaldehyde. The developer found a company in China that was changing its process and convinced it to speed up its transition to lower installed toxic emissions as an alternative to predecessor products. This is an example of how projects like this can accelerate market transition for products that are “green” in all of their attributes.

Many materials common in building interiors release hazardous or toxic air pollutants into indoor air through “off-gassing.” Controlling sources of potential indoor air pollution was a primary concern of both EPA and the project team. The SFO identified products requiring low-emitting materials, and specifications were developed in the following LEED credit areas:

- Adhesives and sealants[26]
- Paints and coatings[27]
- Composite wood,[28] including wheat board work surfaces, bamboo flooring, wall panels, and agrifiber door cores

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[25] Protocol for Environmental Requirements, Baseline IAQ and Materials, for Research Triangle Park Campus, Section 01445.

[26] Concentrations of VOCs below the limits set by the South Coast Air Quality Management District (SCAQMD) Rule #1168, and all sealants used as fillers meet the requirements of the Bay Area Air Quality Management District Regulation 8, Rule 51.

[27] VOC and chemical concentrations do not exceed limits in Green Seal’s Standard GS-11. This credit was denied with a request for additional documentation about VOC content for one of the paints used.

[28] No added urea-formaldehyde resins.

- Carpet tiles[29] (carpet tiles were installed instead of broadloom carpet to reduce maintenance costs; spills or wear can be treated more easily by replacing carpet tiles than by matching dye lots in broadloom carpets).

As a confirmation step, the industrial hygienist for US EPA Region 8 reviewed material safety data sheets, a product specification sheet that identifies chemical hazards, to ensure that all materials met the specifications.

All federal working spaces are required by executive order to prohibit environmental tobacco smoke.

Daylighting Design

The project met requirements for daylighting and views by designing building and workstation layouts so that occupants have a direct line of site to windows in 90 percent of the regularly occupied spaces. Credits were denied with a request to submit larger scale floor plans indicating interior and exterior glazing, solid walls, and room names and numbers.

Figure 6-2. Direct Line of Sight to Windows in Regularly Occupied Spaces

[29] Carpet and Rug Institute's Green Label Indoor Air Quality Test Program.

Acoustics, Ergonomics, and Workstation Functionality

Well-designed workspaces improve employee health and productivity and reduce "churn" costs for building managers.[30] A team of EPA employees managed procurement for workstations and chairs. Three highly ergonomic, adjustable chair models were selected by the team. Employees were able to select their chair during 3 days of "hands-on/seats-on" tryouts, during which vendor representatives were present to answer questions and make adjustments. The chairs also contain high recycled content (from 30 to 66 percent) and were designed to be recycled themselves.

Figure 6-3. Typical Workstation Layout

A number of ergonomic and environmental attributes were specified in the workstation procurement:

- Adjustable-height computer work surfaces allow people to stand or sit at a comfortable working height. Adjustable monitor arms enable people to optimally position computer screens.

[30] Churn costs are transaction costs involved in refitting workstations as people move in and out.

> Cost Tradeoffs: Adjustable Monitors
>
> When the workstations were procured, flat-panel monitors had a higher first cost than desktop monitors. However, the narrower profile for flat panels enabled workstation designers to produce a curved countertop beneath the monitor, which saved material costs and provided more interior workstation space for occupants.

- Electrical power strips were provided at belt height for easy access to plugs.
- Acoustical panels were built into workstation interior.
- All fabrics and surfaces are Greenguard certified, tested by an independent organization to certify that they contain little or no chemical emissions. When people moved in, many commented that there was no “new building smell.”
- Panel fabrics are made from corncloth (beige) and recycled polyester (green).
- Work surfaces are made from wheat board, an environmentally friendly fiber board substitute for wood made from agricultural waste (wheat straw) bonded together with water-based adhesive.
- All furniture was designed with a minimal amount of polyvinyl chloride.

A sound masking system was built into the UFAD system to achieve acoustical privacy. The sound masking speakers serve a dual role as an emergency communications system.

Chapter 7

Occupant Experience

Occupants experience buildings through their sensory and behavioral systems. What they see, touch, smell, and hear influences their comfort and health. How they use the environment, what constraints and opportunities they experience—these factors influence their work effectiveness and sense of well-being. Building design emphasizes the physical qualities of the environment that are expected to influence health, performance, and comfort—the amount of light, acoustical properties, thermal comfort, air quality—but it is the occupant's actual engagement with space that determines whether those intentions are realized.

This chapter looks at occupants' experience of the Wynkoop building. The research summarized includes:

- Web-based post-occupancy surveys
- Workplace functionality analysis
- Thermal performance of the UFAD system
- Acoustic performance of the sound masking system and workstation voice privacy
- IAQ analysis.

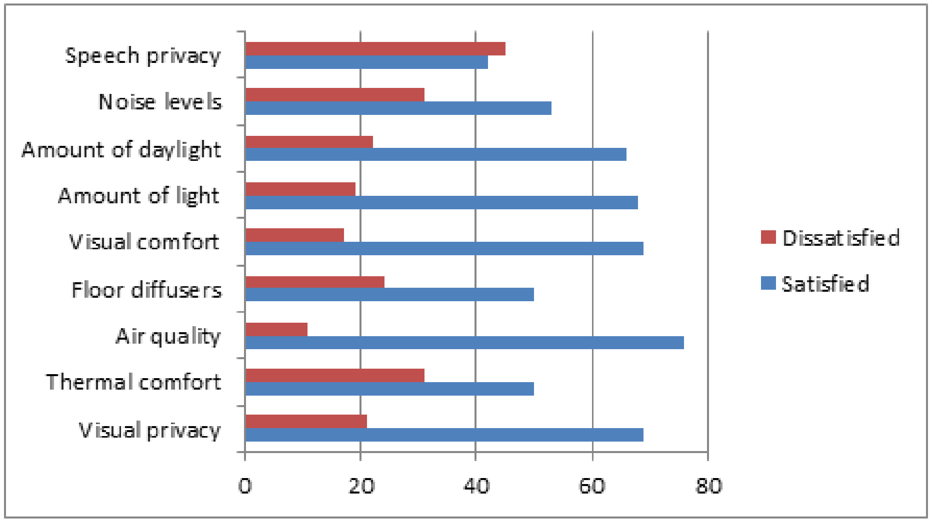
Occupant Comfort, Satisfaction, and Work Effectiveness

Two IEQ surveys have been conducted in the Wynkoop building, both administered by the CBE at the University of California–Berkeley. The first evaluation, conducted in April–May 2008, was sponsored by the design architect, ZGF, which held a membership in CBE. ZGF was interested in the building's post-occupancy performance; it suggested that EPA do an occupant survey, and the regional office agreed. The second survey, administered May–July 2009, was conducted by CBE as part of the UFAD system testing summarized later in this report. Since the results of both surveys are very similar, only the results of the second occupant survey are summarized below.

The survey was completed by 340 EPA employees, for a response rate of 41 percent. It included questions on ambient comfort, reasons for discomfort, functional support, self-rated productivity, and response to specific building technologies.

Figure 7-1 shows the results for ratings of ambient conditions. As the figure indicates, close to 70 percent or more of the survey respondents were satisfied with the amount of daylight and electric light, visual comfort, air quality, and visual privacy. Ratings were somewhat lower for thermal comfort, speech privacy, noise levels, and floor diffusers.

Figure 7-1. Level of Satisfaction or Dissatisfaction with Ambient Conditions—2009



For each of the ambient factors in the CBE survey, occupants who said they were dissatisfied were asked additional questions about their discomfort. The results are summarized below.

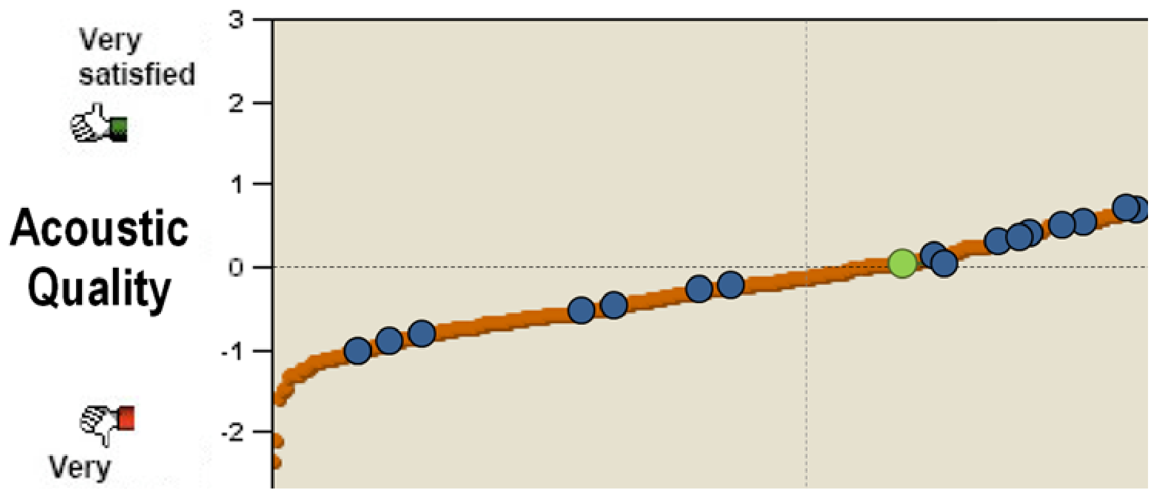
Acoustic Concerns

Analysis of follow-up responses to comfort questions and open-ended survey questions show concern with noise levels from people talking on the phone at their desk or in areas adjacent to the open-plan workspaces (such as in doorways or at printers). When asked during the functionality walkthrough about taking conference calls at their workspace rather than in conference rooms, staff members said it was difficult to move calls because of the need to access their computer or documents during the calls. Several also noted that taking a call on a cell phone in a more isolated location was difficult because of non-uniform reception across the building. There was also some concern that the sound masking system itself created an additional noise source in some areas.

Despite the modest ratings for acoustic conditions, EPA employees were more satisfied with speech privacy than employees in six renovated federal workplaces studied by GSA. This GSA research, which also used the CBE survey, found that only 22 percent of the 415 survey respondents were satisfied with speech privacy, compared with 42 percent at EPA. The GSA workplace research also shows that only 23 percent of the respondents were satisfied with noise levels, compared with 44 percent for EPA.

Figure 7-2 shows how the EPA building compares with 21 other green federal buildings as well as the CBE database as a whole. The graph, from GSA's Reassessing Green report, shows percentile rankings rather than average scores.[31] The green dot represents the Wynkoop building; the 21 other federal buildings are shown in blue. As the figure shows, 13 of the federal buildings had higher scores than the Wynkoop facility, which scored in the 60th percentile.

Figure 7-2. Occupant Satisfaction with Acoustic Quality, Compared with Other Federal LEED Facilities



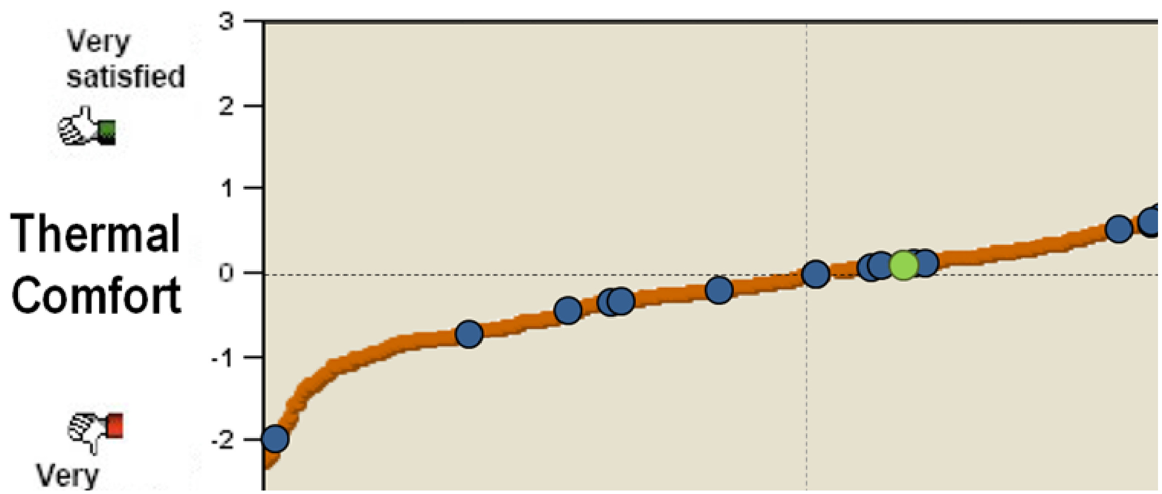
[31] K. Fowler, E. Rauch, J. Henderson, and A. Kora, 2010. "Reassessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings, Pacific Northwest National Laboratory."

Temperature Concerns

Dissatisfaction with thermal conditions in the Wynkoop building was largely due to cold discomfort in both summer and winter; 68 percent of those who were uncomfortable said it was too cold in warm or hot weather, and 76 percent said it was too cold in winter.

Figure 7-3 shows that the Wynkoop building (green dot) falls in the 60th percentile in the CBE database on thermal comfort. As with the acoustic ratings, there is considerable variation across the LEED buildings.

Figure 7-3. Occupant Satisfaction with Thermal Comfort, Compared with Other Federal LEED Facilities

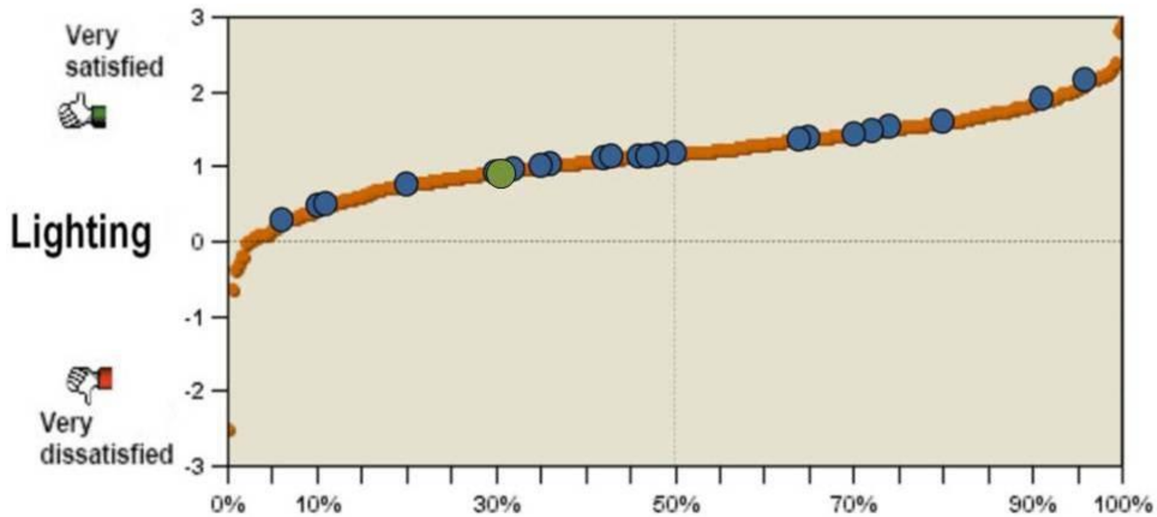


Lighting Concerns

Although satisfaction with lighting was higher than with either thermal or acoustic conditions, 20 percent of respondents were dissatisfied with some aspect of lighting. Of these, more than 30 percent said the light was either too bright or too dark, or created glare on computer screens. An equal percentage said they experienced glare from sunlight or had no control over sunlight in their workspace. Analysis of open-ended comments at the end of the survey showed concern over the automatic control of the electric lights, which several described as “random,” “turning off when I am in my space,” and not having enough light for work when electric lights are off. Several also commented on the impact of the interior design: the workstations in the middle of the floor did not have enough light, floor spaces with good daylight were filled with cabinets, and blending of light across the space was inconsistent. As one person noted, it is really hard to get daylight or sunlight right because "some want more, others less."

GSA's Reassessing Green report shows that lighting satisfaction in the Wynkoop building was in the 30th percentile (Figure 7-4). The figure also shows that satisfaction with lighting overall is higher than with either acoustic or thermal conditions. All of the 22 LEED buildings scored in the satisfied range.

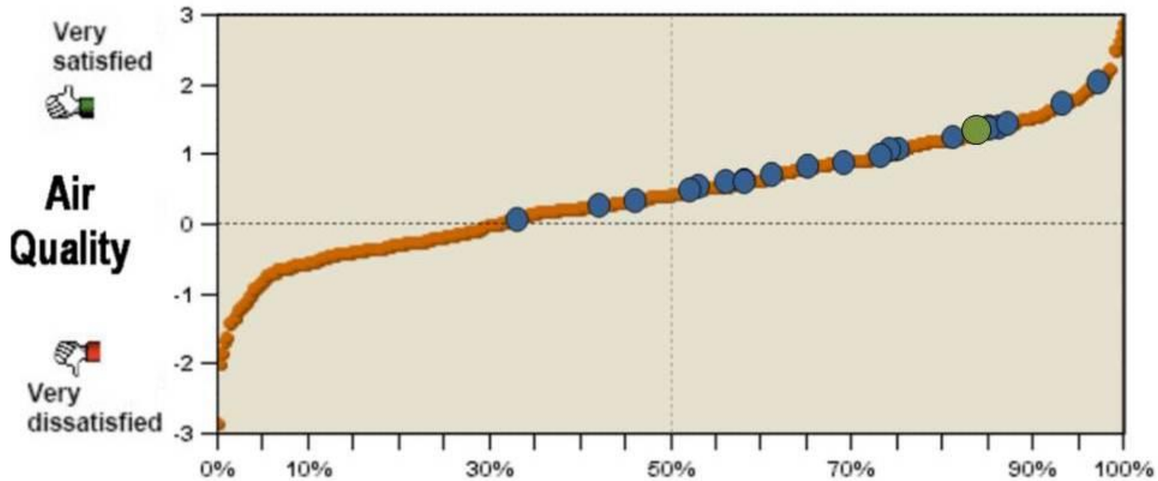
Figure 7-4. Occupant Satisfaction with Lighting, Compared with Other Federal LEED Facilities



Air Quality Concerns

The high satisfaction with air quality in the EPA building is reflected in Figure 7-5, which shows a ranking in the 85th percentile for the building. Only three of the federal buildings in the GSA report had higher percentile scores for air quality.

Figure 7-5. Occupant Satisfaction with Air Quality, Compared with Other Federal LEED Facilities



Perceived Productivity Impact

The CBE survey asked occupants to assess the impact of the environment on their productivity; 62 percent of respondents said the overall quality of the office environment had a positive impact. Although this represents a subjective self-assessment, research that includes both subjective and objective measures of performance tends to show a positive correlation between these measures.[32]

Despite concerns with ambient conditions, 83 percent were satisfied with the building overall, placing it in the 57th percentile of buildings in the CBE database.

Overall Workspace Satisfaction

Ratings of overall workspace satisfaction was higher than what might be expected, given the concerns with lighting, acoustics, and thermal conditions: 79 percent of the survey respondents said they were satisfied with their personal workstation.

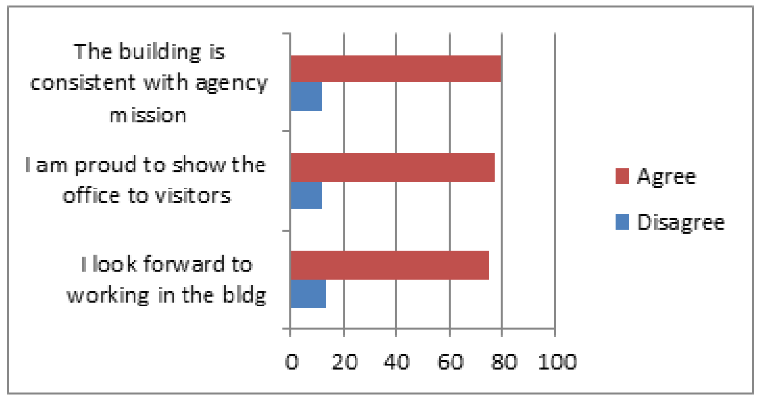
[32] J. Heerwagen, 2000. "Green Buildings, Organizational Success, and Productivity." *Building Research and Information*, 28 (5/6):353-367.

Workplace and Work Behaviors

In addition to assessing comfort and satisfaction with ambient conditions, the CBE survey included sections on workplace and work behaviors.

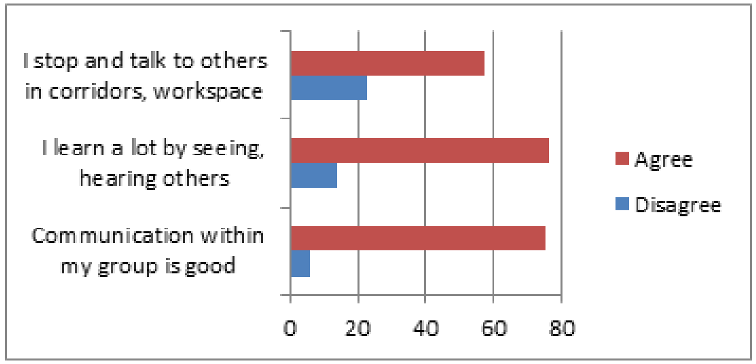
Survey questions addressed social behaviors, communication, and overall response to the building (Figure 7-6). Close to 80 percent of respondents said they were proud to show the office to visitors and that they looked forward to working in the building. An equal percentage also said the building overall was consistent with the agency mission.

Figure 7-6. General Occupant Attitudes toward the Building



Additional questions addressed social and communication behaviors. As noted above, there was considerable concern about noise, especially from colleagues talking on the phone or in the open-plan workspace. Yet, as Figure 7-7 shows, most respondents said they engaged in the very activities that they complained about. Fifty percent or more of the respondents said they stopped and talked to people in corridors and workspaces and that they learned a lot by seeing and hearing others. They also strongly agreed that communication within groups was good, perhaps due to the frequent interaction with others and informal learning that comes from observations and hearing conversations.

Figure 7-7. Acoustic-Related Behaviors



WORKPLACE FUNCTIONALITY, WORK EFFECTIVENESS, AND NEW WAYS OF WORKING

A workplace functionality assessment by GSA in February 2011 focused on better understanding how the physical environment influenced individual and group work effectiveness. The assessment was not intended to be a robust analysis, but rather to gain a better understanding of how people worked, how spatial features and furnishings aided or inhibited work, what role technology plays in work effectiveness, and how the changing nature of work is influencing EPA's approach to the workplace.

Methods

The walk-through analysis included opportunistic conversations with employees encountered in their offices and workspaces, a photographic record, identification of "workarounds" or other evidence of personal or group adaptations to spatial conditions, and opportunities for change.

Key Findings from the Functionality Analysis

The findings from both the CBE survey and the walkthrough showed high satisfaction with the existing conference rooms, the layout and ergonomics of personal workstations, and working in a green building. The focus in the remainder of this section is on the perceived barriers and challenges to individual and team work, especially as work is evolving toward greater mobility.

- *Challenges to individual work*—Individual work at EPA requires extensive reading, writing, and analysis and is heavily paper-based. The size of workstations is determined to some extent by the need to store documents for ready referral. This makes it difficult for staff to move to a new location if they need to concentrate without distractions. Also, many use desktop computers rather than laptops, further reducing their mobility. Moving phone conversations is also difficult, because cell phone reception within the building is not consistent; furthermore, EPA does not provide BlackBerries or other personal devices for all employees, so personnel take calls either at their workstations or on conference phones in enclosed rooms.

- *Challenges to team work*—Scheduled team work is well supported with a wide range of conference rooms, most of which have conference phones, presentation equipment, and video capability. In addition, a formal conference center in the building provides additional support for large meetings. The functionality assessment identified a need for better support for informal interaction, a sense of camaraderie, and the ability to know who is at work. Because the high cubicle partitions block visibility into spaces, the building can at times appear to be largely unoccupied because people cannot see each other. Conversations with several staff identified ways to better enable teams to gather rapidly and to maintain a connection to ongoing work. The ability to post maps, schedules, and other materials on vertical surfaces would greatly aid quick gatherings to discuss project work. Current EPA policies, however, prohibit tacking any materials on walls or external cubicle partitions. Several staff also suggested that dedicated team rooms would be especially valuable for storing and quickly retrieving materials while a project is ongoing. Moveable storage would enable others to also use the room. Existing informal meeting rooms within the open-plan areas are seldom used because of concerns with noise generation and privacy.

- *Challenges to remote work*—Staff working at home or in the field have difficulty connecting to people or electronic files in the Wynkoop building due to lack of mobile technologies, as well as to difficulties with accessing EPA computer networks and resources. In addition to technological difficulties, some staff interviewed said they did not work from home frequently or regularly due to the desire to interact face-to-face with their colleagues. It is not known whether telework would increase if access to computer networks and resources improved, or whether the barriers are primarily psychological or social and thus require different solutions.

- *Sense of place and community*—Although the EPA staff expressed pride in the building and its sustainable features, the functionality assessment identified concerns that the building lacked a sense of warmth and “buzz” that was apparent in the old building. Several staff also commented that current policies prohibiting most wall décor (paintings, photographs, artifacts, maps) created what one called “a beautiful corpse” lacking a connection to EPA’s environmental mission.

- *The importance of space, tools, and policies*—The challenges identified above strongly support the notion that effective work requires the integration of space (both physical and ambient conditions), tools (especially support for mobility within and outside the office), and policies that enable employees to work in a variety of places and in a variety of ways.

RECOMMENDATIONS TO IMPROVE CURRENT WORKPLACE FUNCTIONALITY

The following recommendations address the challenges of improving the current space while also enhancing mobility to support the changing nature of work.

Reduce or Neutralize Acoustic Problems and Noise Distractions

Findings from post-occupancy surveys and opportunistic discussions with EPA staff showed high levels of concern with noise distractions, primarily from people talking on the phone or near the open-plan work areas. There were also concerns with noise spilling from conference rooms. Specific suggestions include the following:

- Expand the use of phone headsets to reduce distractions, allow quiet voices, and maintain conversational privacy.
- As much as possible, use enclosed meeting rooms for conference calls to avoid distracting neighbors.
- Collaborate on workplace protocols: Clarify and distribute expectations in a publicly accessible, living document. Allow employees to make suggestions and interact with the protocols to ensure that they support the intended workplace culture.
- Move shared printers away from the workstation areas to eliminate noise hotspots associated with people talking while waiting for print copies.
- Implement recommendations from the workplace acoustic quality analysis (see Chapter 8: Research on Ambient Conditions).

Improve Support for Group Work

Staff expressed a need for more team support, especially for spontaneous discussions and long-term projects. Existing informal team spaces, located within the open-plan workspace, were seldom used due to concerns about disturbing others. Specific recommendations include the following:

- Provide surfaces for displaying maps and time lines to keep group work visible and to enable informal, ad hoc discussions. The current workplace rules do not permit posting documents outside cubicles.
- Provide dedicated team rooms or enable shared team rooms with appropriate supports (such as mobile display surfaces).
- Locate informal teaming spaces away from workstations to reduce noise distractions and support confidentiality of team work.

Create More Opportunities for Informal Collaboration and Interaction

Conversations with staff revealed a sense of lost camaraderie that was more apparent in the old EPA building. Staff wanted to bring back the positive “buzz,” “serendipity,” and extemporaneous meeting features of the old EPA space. Even though the new EPA building has informal meeting spaces with comfortable chairs near the open-plan work areas, they do not appear to be used often. Research on the use of informal teaming areas in a high-tech firm in Silicon Valley found low use patterns due to concerns over distracting people working nearby and lack of privacy for work discussions.[33]

Specific recommendations include the following:

- Increase internal awareness so people know who is at work and where they are located. One group solved this problem with a white board at the entrance to their work area that noted who was in the office that day.
- Provide a variety of spaces to support quick discussions on topical matters.
- Hold internal open houses for co-workers from other floors or teams to visit specified work areas at a given time to meet people and hear about their current projects and activities.
- Provide team displays that communicate the projects, focus, and culture in play in specific office areas, to bring them alive and communicate them to others.

[33] G. Brager, J. Heerwagen, et al., 2000. “Team Space and Collaboration,” Research Report of the Center for the Built Environment, University of California–Berkeley.

Improve Access to Windows and Daylight in Perimeter Areas to Support Psychological Comfort

In the interior workspaces, access to the outdoors consists primarily of sky views, due to the high panels for increased privacy. However, in other areas it is possible to increase access to daylight and views. Specific recommendations include the following:

- Reduce panel heights by windows to improve access to natural light and views to the outdoors. While equal panel heights for all staff may be motivated by a desire for egalitarian design or conflict avoidance, more is lost than gained by blocking window light and outside views.
- In addition, some of the spaces adjacent to windows consist of storage or temporary drop-in spaces; lower panels in these areas would not disrupt work.

Improve Support for Mobile Work, Especially From Home or the Field

At the present time, personnel working outside the Wynkoop building have limited access to EPA computer networks and resources. This is a significant barrier to individual productivity and increases the reluctance to work from home. EPA headquarters is proposing to provide all employees with remote access as a basic service.

Specific recommendations include the following:

- Reexamine policies and roadblocks that inhibit mobility, such as the low number of days people can work from home.
- Improve external access to IT resources.
    - Deploy the new headquarters remote access to all employees as quickly as feasible, and provide training and adequate support.
    - Recognize that employee work-arounds are not cost-free, effective, or highly secure.
- Provide smart phones for those working away from the office, especially in the field, to improve connectivity during the day.

In addition to external mobility, tools for internal mobility—laptops and smart phones—would better enable personnel to move to spaces that best support their work needs at any given time.

Improve Sense of Place and Connection to EPA Mission

Specific recommendations include the following:

- Relax current “no posting” rules to enable more wall decor to enhance the color palette and connect to EPA’s environmental mission, such as landscape photographs and paintings that also add visual interest and color to a largely gray space, and more indoor plants. (After this recommendation was conveyed to EPA, the agency launched a program to beautify the interior space with large landscape photographs taken by EPA staff.)
- Aim for a professional atmosphere that doesn’t stifle the sense of place, inhibit communication, or reduce workplace buzz to a whisper.

Mobility Solutions

The recommendations in this section address a request by EPA management to identify how the agency could respond to the changing nature of work that requires an integration of policy, communication, and procedural solutions to traditional workplace and technology challenges. We call this mix “Integrated Mobility Solutions” because it leverages the overlapping worlds of space design, hardware, software, furniture, technical support, human capital, and others to craft practical solutions to problems by recognizing that neither problems nor their solutions obey traditional professional boundaries. The Integrated Mobility Solutions approach aligns and communicates policies, practices, and technology resources to support mobility, collaborative work, and distributed teams.

Create an Experimental Space

Reconfigure and reprogram existing space to support internally mobile experiments that aim to improve how well space works for teams and individuals. (In response to this recommendation, several groups have reconfigured and altered their existing workspace to test new approaches.) Specific recommendations include the following:

- Loosen policies that govern posting on walls and public spaces to improve the communication infrastructure.
- Include EPA employees at all levels in discussions about why the space is designed and operated the way it is.
- Validate design by cycling at least three cross-program teams through the space.

Use Existing Technologies More Effectively

At the time of the research, remote IT access was inconsistent. People working from home or in the field often could not access files and data. Specific recommendations to improve this situation include the following:

- Educate employees about their remote access options.
- Change procurement calculations: Factor the cost and risk of ad hoc solutions to remote data access into the calculations of how much EPA should invest in securing employee licenses for remote data access, and include the benefits of increased mobility solutions in the equation. Employees who don't have a clear understanding of the policies that govern remote data access have developed several work-arounds, including the use of zip drives, thumb drives, and portable hard-drives, some at EPA expense. Even when purchased at employee expense, many such ad hoc solutions circumvent the cost control and data security goals that govern the data access policies in the first place.
- Establish an accessible list of supported technologies and clarify how people can access them securely. The blend of technologies that support mobile work can easily confuse users, leading to apprehension about mobile work.

Plan for an Integrated Set of Technologies

Specific recommendations include the following:

- Continue the move toward replacing desktop computers with lightweight laptops to enable mobility, including travel and telework, while reducing energy use.
- Consider supporting multiple devices, including tablets and e-book readers, which can reduce or eliminate the need for printers and paper processes, thereby saving time, money, and energy.
- Consider the use of hubs, air cards, portals, and cloud services. A wireless network that piggybacks EPA's secure office network lines within the office could enable devices to be online in the workplace without compromising security.

Experimental Workspace Based on Recommendations

As a result of the functionality assessment, one EPA group rearranged its workspace to enable greater personal choice and better support the flow of work. The changes were done by reconfiguring existing workstations rather than purchasing new furnishings or equipment. Because the group is small, no formal post-occupancy research was conducted. However, opportunistic conversations show that the group has adapted well to the space and has created informal behavioral protocols to increase the overall functionality. Group members are also using recommended new technologies that better support mobility, including voice over Internet Protocol (VoIP) phones with headsets. Two new workspaces were created by EPA staff in the year following the launch of the first experimental space.

Have IEQ Goals Been Achieved?

Addressing the "success" of the indoor environment from the EPA employees' perspective is problematic, due to the lack of performance goals. Although there are goals for building performance, there are none for occupant experience. The aspirational goal of "enhancing" occupant health and productivity is difficult to operationalize. What does "enhance" mean? Relative to what? What is a reasonable goal, and should it be the same for all health and productivity outcomes?

One possible way to approach this issue is to use the logic of thermal comfort measurement and aim for 80 percent of occupants satisfied with all ambient conditions. If 80 percent were the target satisfaction level, how well would the Wynkoop building have performed? Looking back at the CBE survey data, none of ratings of satisfaction with the ambient conditions achieved

80 percent, although air quality was close, at 78 percent satisfied. Satisfaction with thermal conditions, speech privacy, and noise levels were close to 50 percent, while lighting satisfaction was around 70 percent for the three variables assessed (visual comfort, amount of light, and amount of daylight).

In contrast to satisfaction with ambient conditions, ratings were higher for overall building satisfaction (83 percent) and workspace satisfaction (79 percent). These higher levels of satisfaction for building and workspace are a common thread throughout the CBE survey research[34] as well as workplace research by GSA.[35] This suggests that satisfaction with a workspace or building cannot accurately predict satisfaction with its ambient conditions, nor can satisfaction with ambient conditions predict overall building or workspace satisfaction. It may be that other factors, such as workspace ergonomics or overall aesthetics and amenities of the building are critical components of occupant experience, and that if these are done well, the occupants will be satisfied with the building overall—despite concerns with thermal, lighting, or acoustic discomfort. That does not mean, however, that these concerns should be ignored. Ambient conditions have known effects on task performance that can influence individual and group productivity.[36] The importance of psychological experience is evident in the high ratings—close to 80 percent—for three survey questions: “I look forward to working in this building,” “I am proud to show the building to visitors,” and “The building is consistent with the mission of the agency.”

Another approach to judging the success of the building from the occupants’ perspective is to consider the percentile ranking for satisfaction. The percentile rankings presented in this report combine findings from the entire CBE database. For the Wyknoop building, air quality had the highest percentile ranking (85th). Thermal and acoustic ratings were both at the 60th percentile. Lighting was the lowest, at the 30th percentile. Percentile rankings are problematic, however, because the database includes highly variable building designs, occupancy, size, and age.

The functionality assessment incorporated open-ended conversations and discussions about the workplace that identified building features and policies not addressed in the survey. It thus provided a closer look at how well the building environment supported EPA as an organization with a specific mission and characteristic work patterns. The assessment addressed issues not covered in the survey, such as technologies for mobile work and the need for more effective support for spontaneous team interactions, team rooms for on-going work, and stand-up meetings around large-scale documents (maps, photos, work plans).

[34] G. Brager, J. Heerwagen, et al., 2000. “Team Space and Collaboration.” Research Report of the Center for the Built Environment, University of California–Berkeley.

[35] “The New Federal Workplace,” GSA report on Workplace 2020 research, www.gsa.gov.

[36] J. Heerwagen, K. Kampschroer, K. Powell, and V. Loftness, 2004. “Collaborative Knowledge Work Environments,” *Building Research & Information*, 32(6)3: 510-528.

The opportunistic conversations with EPA employees also revealed an unintended side effect of a workplace design that emphasizes individual-focused work supported by high-panel workstations. The panels essentially block views into contiguous spaces or across the atrium. As a result, the building appears devoid of life. Although the atrium was designed to enable views into spaces across the building, the visual field consists largely of grey panels. Finding the right balance between privacy and engagement, open and closed spaces, is a common challenge across organizations today.

Chapter 8

Research on Ambient Conditions

This chapter summarizes several research studies completed on ambient conditions in the Wynkoop building since it was occupied in 2007. This research includes a rapid IEQ assessment, UFAD system performance, and acoustic performance of the sound masking system.

Rapid IEQ Assessment

Researchers from Battelle in Columbus, OH, conducted a rapid assessment of the indoor environmental quality of the building in July 2009. The intent was to compare the results to industry standards and occupant satisfaction scores from the CBE's online survey.

Battelle took IEQ measurements of temperature, relative humidity, atmospheric pressure, sound level, CO_2, ozone, particulate matter, fungal spores, VOCs, and semi-volatile organic compounds (SVOCs) at five indoor locations and one outdoor location. The full report, with a detailed discussion of measurement methods, is in the appendices. This section summarizes findings from the Battelle report.

Study Methods

Sampling locations

Indoor sampling locations were selected to characterize the IEQ in different areas of the building where staff spend the most time. One location was outdoors on the roof of the building near the air intake for the HVAC system. This location was on a tiled path near the outer edge of the building, on the "green" portion of the roof (vegetation was present close to the sampling location).

Of the five interior locations, four were in office spaces and one in a dedicated copy room. Two of the office spaces were closed offices and two were open. One each of the open and closed offices had under-floor ventilation, while the others had overhead ventilation.

DATA COLLECTION

Data collected during field sampling included continuous measurements of CO_2, ozone, PM10 (particulate matter with an aerodynamic diameter of less than 10 microns), temperature, relative humidity, atmospheric pressure, and sound level. In addition, integrated samples were collected to quantify concentrations of fungal spores, VOCs and SVOCs. A portable instrumentation package (Figure 8-1) measured conditions in the sampling locations described above (Figure 8-2).

Figure 8-1. Continuous Measurement Instrumentation Package

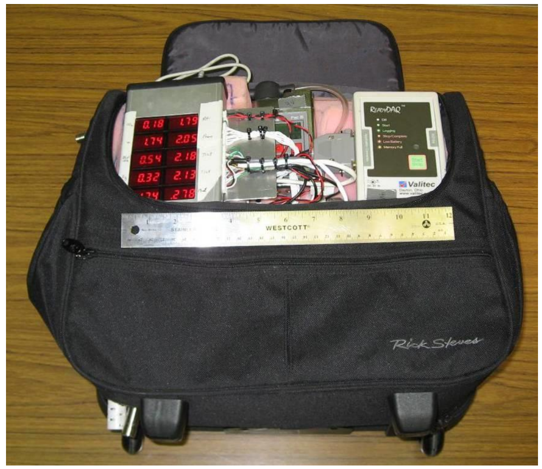


Figure 8-2. Office Sampling Location with SVOC Sampler

Key Findings

TEMPERATURES

All temperature and relative humidity combinations were within the acceptable range (23–28°C) according to ASHRAE Standard 55-2004. However, temperatures in four of the indoor spaces exceeded the optimal range for workplace productivity (20–23°C) reported by Seppänen and Fisk (2006). The CBE survey showed thermal comfort at 46 percent of occupants satisfied, which falls into the 59th percentile in the CBE database of more than 500 buildings.

AIR QUALITY

To assess indoor air quality, Battelle measured CO_2, ozone, particulate matter, VOCs, and SVOCs. CO_2 concentrations indoors (585–697 parts per million [ppm]) were acceptable based on the recommendation that indoor CO_2 levels not exceed outdoor levels by more than 650 ppm. Indoor ozone concentrations were all less than 27 parts per billion (ppb), and the indoor/outdoor ozone ratios were in the range of 0.09–0.17, which is comparable to the ratios observed in other indoor spaces with central air conditioning. Particulate matter concentrations were less than 25 $\mu g/m^3$ in the indoor spaces—less than half of the LEED NC standard of 50 $\mu g/m^3$. The CBE survey showed that 76 percent of respondents were satisfied with the building's air quality, which falls into the 85th percentile within the CBE database.

Indoor fungal spore concentrations were measured to be less than 100 spores/m^3 in all locations, well below the 1,000 spore/m^3 level of concern. Indoor formaldehyde concentrations (20–26 µg/m^3) were greater than the outdoor concentration (5.3 µg/m^3), but still less than IAQ guidelines (the LEED new construction standard is 64.1 µg/m^3) and below levels of concern. Ethanol (133–217 µg/m^3) and acetone (46–79 µg/m^3) were detected at levels higher than outdoor concentrations because of typical human activity in the building; hazardous air pollutants 2-butanone (6.8–11 µg/m^3), toluene (7.3–13 µg/m^3), and hexane (2.5–3.7 µg/m^3) were also detected at concentrations higher than the outdoor air, but below levels of concern.

Synthetic musks AHTN[37] (3.7–23 ng/m^3) and HHCB[38] (40–467 ng/m^3) were found in the indoor air, with concentrations in one office approximately an order of magnitude higher than the other indoor locations. Bromodiphenyl ethers (BDEs) and phthalates were, in general, at levels similar to those reported for other indoor environments. Limonene and its oxidation products were present in the indoor samples, at relatively low concentrations. Samples from the copy room had elevated concentrations of several poly-aromatic hydrocarbons (PAHs) (predominantly those of lower volatility). The concentration of total PAHs found in the copy room was higher than in the other spaces measured in the building.

Acoustics

Sound levels measured indoors (61–65 dBa) did not exceed the range of normal conversation (60–70 dBa). In the CBE survey, 46 percent of occupants were satisfied with acoustic quality, which falls into the 59th percentile within the CBE database.

Conclusions

In general, the various IEQ parameters measured fell within the ranges of applicable standards and were similar to the results of measurements in other indoor spaces, with the exception of PAH concentrations in the copy room.

UFAD System

As discussed in the previous chapter, installation of the UFAD system was a controversial issue among engineers representing the various stakeholders. Eighteen months after occupancy, once the building's "shakedown period" was complete, Opus and EPA regional facility staff worked with a team from the University of California–Berkeley CBE to evaluate post-occupancy performance of the UFAD system.

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[37] 6-Acetyl-1,1,2,4,4,7-hexamethyltetraline; trade names Tonalide, Fixolide, Astralide.

[38] 1,3,4,6,7,8-Hexahydro-4,6,6,7,8,8-hexamethylcyclopenta-γ-2-benzopyran; trade names Galaxolide or Abbalide.

EPA funded a field visit by a team of CBE researchers to test the UFAD system's air delivery. CBE and Opus covered the costs of equipment as well as researcher and facility engineer time. The objectives of this study were to

- determine the characteristic air flow leakage rate from the pressurized plenum in the under-floor air distribution system, using the 7th floor as a "typical" office configuration; and
- using alternative testing methods, assess the overall accuracy and effectiveness of the GSA leak testing protocol.

GSA engaged CBE to assess overall performance of three GSA buildings with UFAD installations. The measurement protocol included an occupant comfort survey, a survey of building operations personnel, thermal performance assessment using a portable measuring cart, analysis of utility bills, and assessment of information from the design and operation of the system. CBE selected Wynkoop as one of the three case study facilities.

The CBE team conducted these performance tests over 3 working days and a weekend in May 2008.[39] This section summarizes the report findings; the full report is available in the appendices.

UFAD Design

Figure 8-3 presents a schematic plan view diagram of the 6th floor (nearly identical to the 7th floor). The atrium is centrally located on the north half of the floor plate. Two HVAC supply shafts each serve four air highways that deliver and direct supply air into various regions of the open plenum, shown in yellow on either side of the larger central return air shaft. Eight pressure sensors (small green circles) are in the large open under-floor plenum, each controlling the volume of air delivered by one of the eight supply air highways, as indicated, to maintain the desired plenum pressure set-point. Each of these supply ducts contains an airflow measurement station.

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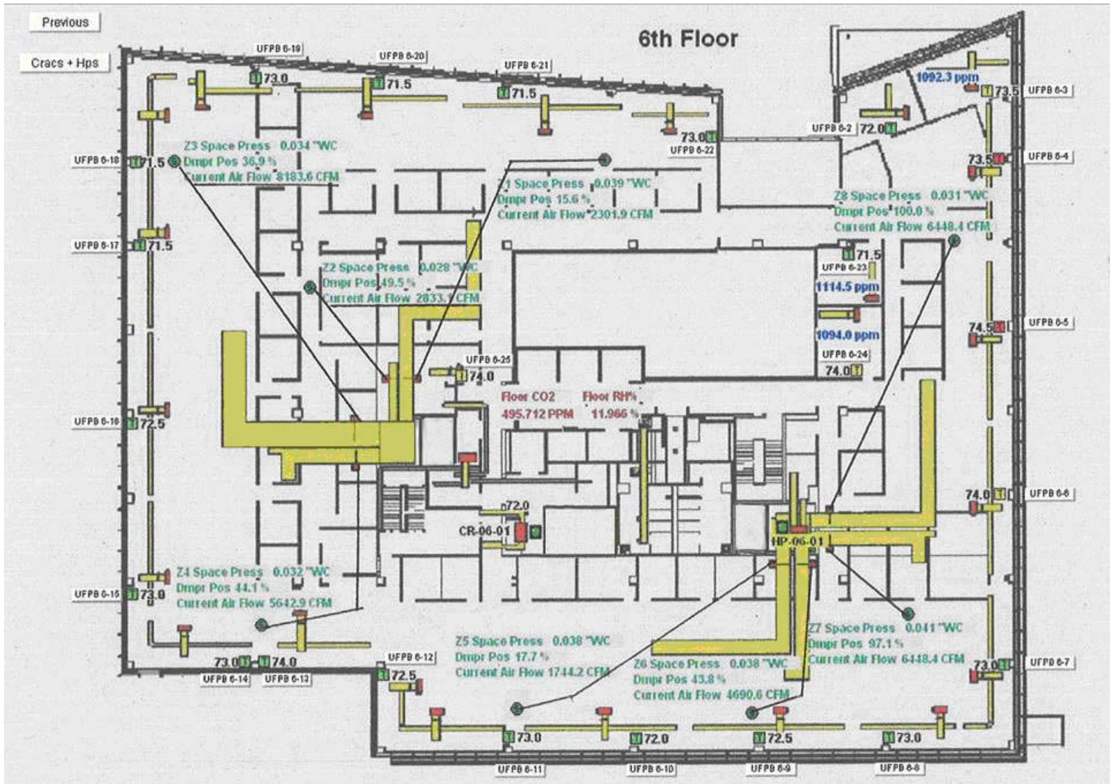
[39] GSA, "Case Study of Environmental Protection Agency (EPA) Region 8 Headquarters Building Denver, Colorado," September 2008.

Figure 8-3. Schematic View of 6th Floor



The interior zones of the floor plate are served by swirl diffusers located in workstations and aisle ways. There are roughly 240 of these diffusers on a typical floor plate. Airflow from these diffusers is controlled to maintain a given pressure setting in the supply plenum. However, occupants have some degree of control by manually adjusting diffuser openings. In this building the plenum pressure is controlled to a constant value, resulting in a semi-constant air volume system for the interior. Normally, with constant pressure in the plenum, the interior airflow would be constant; however, when occupants adjust diffusers, the overall airflow rate changes, since the pressure does not change.

Air Leakage Analysis

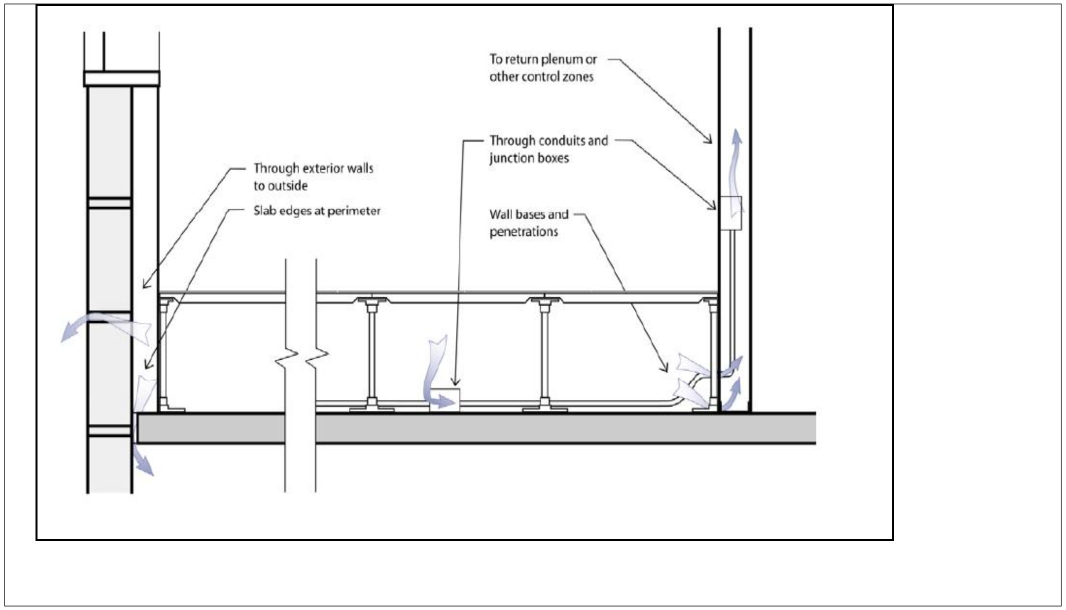
As a result of this field work, CBE developed a new multi-path air leakage testing method for UFAD systems. Its report stated,

> The multi-path method gives a more realistic and accurate measure of each of the two air leakage types (Category 1: construction quality leakage, and Category 2: floor leakage to room). Leakage results are expressed as a function of pressure difference, allowing the determination of leakage under peak design conditions. Although we are continuing to research and develop this method, based on the results of this test, we recommend that the multi-path method be considered as part of revised leakage testing protocols.

Air leakage from pressurized under-floor air supply plenums is one of the most important issues facing the UFAD industry. Evidence from completed projects indicates that uncontrolled air leakage from a plenum can impair system performance. In some documented cases, the amount of leakage has been substantial (greater than 50 percent of design airflow). To date, plenum air leakage has been divided into two primary types, as defined below:

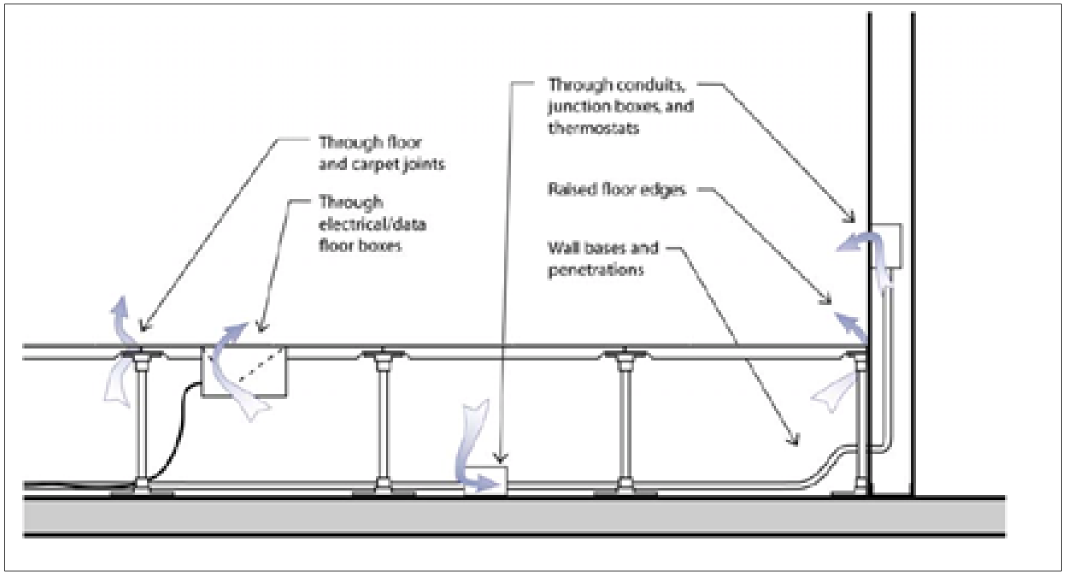
- Category 1—Construction quality leakage (Figure 8-4): The most detrimental to system performance is leakage out of the plenum walls and joints that result in air passing through wall cavities, columns, and other short-circuiting pathways to the return plenum above, directly to the outside the building, or back to the return of the floor below via fire stops or other floor penetrations. These leaks represent air loss that is detrimental to the operation of the system, causing an increase in fan power, and possibly an increase in cooling load.

Figure 8-4. Category 1 (Construction Quality) Leakage



- Category 2—Floor leakage (Figure 8-5): Leakage from the plenum through the raised floor into the occupied space is a class of leakage with varying consequences that depend on a number of factors. In general, this leakage is not necessarily detrimental to the operation of the system; in fact, under certain circumstances, it may actually help performance. However, if the leakage rate is large, or if it occurs at the wrong place (such as near an occupant), it may cause comfort problems. These leaks occur through floor panel gaps, electrical outlets, and other floor openings, and joints at the edges of the floor and around columns.

Figure 8-5. Category 2 (Floor) Leakage

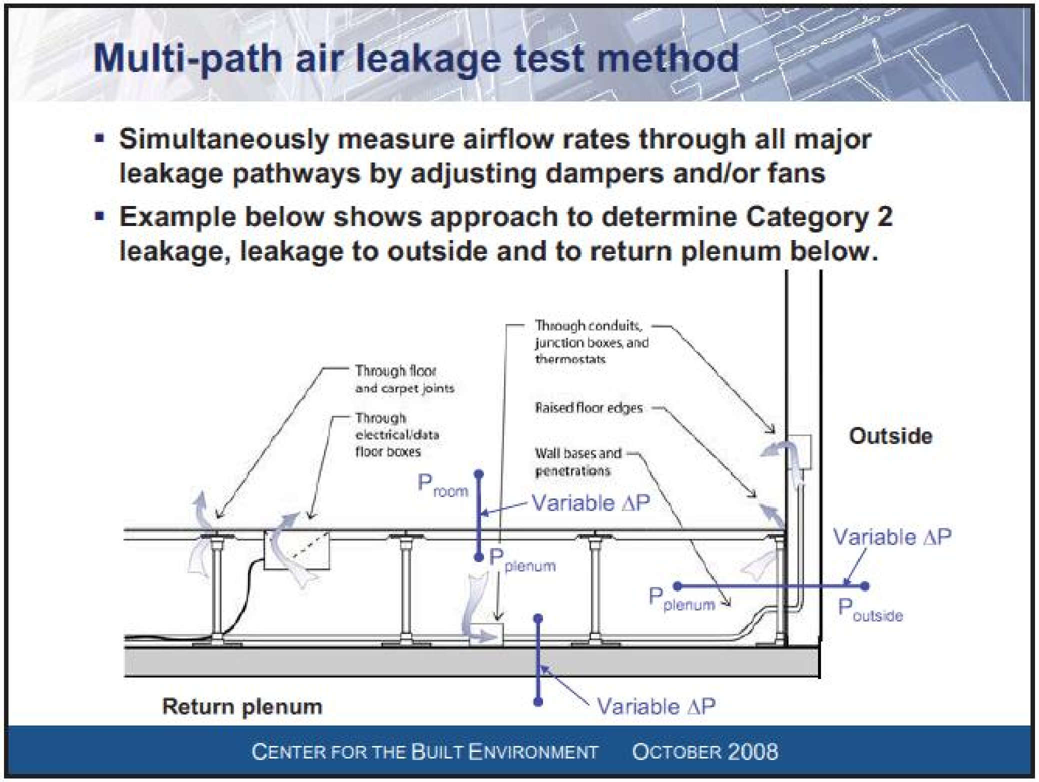


Prior to this research, GSA used two test methods to evaluate UFAD leakage: a sealed diffuser test and a "dynamic airflow test."[40] One of CBE's objectives was to evaluate a new "multi-path" test method developed to measure leakage independently from these GSA procedures (Figure 8-6). The report notes that:

> The purpose of this test was to simultaneously characterize airflow rates through all major leakage pathways from the under-floor plenum, including to the room (Category 2 leakage), to the adjacent 6th floor, and to outside the building. The advantage of the multi-path leakage test is that by developing a unique correlation for the leakage from the plenum to all openings, it can accurately predict true Category 2 leakage as a function of pressure difference. This can be accomplished without the difficulty of finding and sealing all such openings, a limitation of the GSA protocol.

[40] Detailed descriptions and critiques of each test are included in the full CBE UFAD case study report.

Figure 8-6. Multi-Path Air Leakage Test Method



The CBE team observed that occupant complaints about being cold correlated with a perception that cold air was coming from the “fans” in the UFAD systems. The “fan” noise was actually coming from the sound masking system, which the CBE team noticed was louder than sound they had heard in other systems. Based on this feedback, the EPA and GSA teams decided to conduct an evaluation of acoustical performance of the sound masking system. That research is summarized later in this chapter.

Best Practice: Multi-path Air Leakage Test for Pressurized Plenums in UFADs

As a result of this field work, CBE developed a new multi-path air leakage testing method for UFAD systems.

The multi-path method gives a more realistic and accurate measure of each of the two air leakage types:

- Category 1: construction quality leakage, and
- Category 2: floor leakage to room.

Leakage results are expressed as a function of pressure difference, allowing the determination of leakage under peak design conditions. Although we are continuing to research and develop this method, based on the results of this test, we recommend that the multi-path method be considered as part of revised leakage testing protocols. The updated test protocol was incorporated into ASHRAE TRG7-UFAD for inclusion in a new UFAD Design Guide.

UFAD Study Methods: Thermal Performance

The building has roughly 240 UFADs on a typical floor plate. Each workstation has its own diffuser, which contains a damper that occupants can adjust to some extent (Figure 8-7). The system was designed to save energy by supplying air at 62–65°F rather than the 55°F common for overhead ventilation systems. This approach reduces the energy used to cool the air.

Figure 8-7. Diffuser with Interior Adjustable Damper

THERMAL PERFORMANCE RESULTS

Measurements showed the following results:

- In most UFAD areas, the average occupied zone temperatures were within, but at the lower end of, the comfort range calculated by ASHRAE procedures. The fact that these temperatures are at the lower end of the comfort range is dictated, primarily, by room set-points in the range of 72–74°F. The thermal comfort survey responses appear to corroborate the short-term cart measurements showing that the interior zone temperatures are reasonably well controlled, despite the absence of interior thermostats.

- Stratification in the occupied zone—temperature differences between workspace head and foot areas—was generally low, at 1–2°F, except in some private office spaces where it ranged up to 3–4°F; the CBE team considers the latter range to be normal for UFAD systems.

- Supply plenum temperatures on the 7th floor ranged from 62–71°F, but the average was consistently near 67°F. Overall thermal decay in the supply plenum was about 5°F.

A range for average temperatures of 65–67°F is typical for well-operated systems. Thermal decay is low compared with other projects the CBE team has studied. Low thermal decay improves economizer performance (in dry climates like Denver's) by allowing the air handlers to operate at higher supply temperatures (62°F).

Occupant Satisfaction and Comfort

As noted in Chapter 7 on the occupant experience, 50 percent of survey respondents were satisfied with temperature conditions and 30 percent were dissatisfied (the remaining 20 percent said they were neither satisfied nor dissatisfied). Although these satisfaction levels appear modest, the Wynkoop building falls into the 73rd percentile of all CBE survey respondents. The high ranking is a reflection of the generally low satisfaction with temperature conditions across the entire CBE building database. The survey also showed that most people dissatisfied with temperature conditions said it was too cold, both in summer and winter.

UFAD-Related Survey Responses

The survey categories most related to UFAD system performance are thermal comfort, air quality, floor diffusers, and, to a lesser extent, acoustics and cleanliness and maintenance. The following are major findings from the survey results:

- All of the UFAD-related categories except floor diffusers had high percentile rankings of satisfaction, ranging from 73 percent for thermal comfort to 87 percent for air quality.
- A thermal comfort satisfaction percentile ranking of 73 percent and low dissatisfaction scores at about 31 percent, reinforced by portable cart measurements, indicate that the occupied areas are operating within comfort standards overall.
- Air quality scores are very high, with an 87th percentile ranking and dissatisfaction scores ranging from 9–11 percent.
- The building operator's response to 13 questions concerning problems that have been conjectured to be inherent to UFAD systems were positive overall. Excluding the neutral scores for occupant control, thermal decay, and stratification, all responses were +2 and higher on a -3 to +3 scale, where +3 represents "No problem."
- Occupant comments and detailed responses from the UFAD diffuser section of the survey indicated low dissatisfaction with the UFAD.

UFAD Floor Diffuser Performance

Survey results show that 50 percent of occupants were satisfied with the diffusers, and about 25 percent were dissatisfied with the diffusers overall, their location, or their impact on work. Dissatisfaction centered on noise, drafts, interference with chair movement, and problems adjusting the diffuser. However, as discovered during the acoustic analysis, the noise that occupants believed was HVAC-related was actually noise generated by the sound masking system. Comparison to other UFAD installations is limited due to lack of building data on UFAD performance.

The following are other findings on diffusers:

- Many occupants do not know how to adjust them; 42 percent said they had not been informed how to operate them.
- Few have requested diffusers to be relocated; many did not know that relocation was possible.
- Most occupants are too close to the diffusers; 87 percent said the diffuser is within 3–4 feet of their primary work area, which increases the likelihood of exposure to high air velocities that can cause discomfort.
- Most occupants prefer the UFAD to overhead air distribution, despite comfort complaints; 75 percent of respondents said they prefer the UFAD.

A brief survey administered to building operations personnel show that they rated UFAD as better than non-UFAD systems with respect to hot and cold complaints, quality of ventilation, energy use, effort and cost of maintenance, and making changes to tenant space. Also, the UFAD was rated as much less of a problem for dust accumulation, moisture in the supply plenum, and air leakage from the supply plenum.

Conclusions

The following are study conclusions regarding the UFAD system:

1. It is operating well as determined by both physical measurements and occupant responses.
2. Room temperatures are within ASHRAE standards, but at the lower end of the comfort zone, which may explain concerns with cold discomfort.
3. Temperature stratification is acceptable, but lower than is normally found.
4. Supply plenum performance is satisfactory, and air leakage is low.

5. Dissatisfaction with diffusers could be reduced by improving the acoustic functioning of the sound masking system and informing occupants about how to make adjustments.

Workplace Acoustics

In response to concerns about acoustical conditions—such as noise from people talking, lack of voice privacy, and noise from the sound masking system itself—the Greenbusch Group conducted a field study of the building's acoustic performance.[41] Its goals were to characterize the acoustic conditions and sound masking noise levels of the UFAD system, correlate occupant comments with measured criteria, and suggest and test ways to improve the acoustical conditioning of the office. This section includes excerpts and summaries from the Greenbusch final report on the sound masking system. A complete copy of the report is available in the appendices.

Importance of Office Acoustics

Distracting noise, especially speech, is one of the most often cited factors affecting work performance and satisfaction with the work environment. Excessive noise lowers concentration and can increase stress. Noise distractions and interruptions also increase the amount of time to do work.[42]

The audibility of an intruding sound depends upon the amount of acoustic separation provided by the elements separating two adjacent spaces and on the amount of background sound in the area receiving the intruding sound. In spaces with higher background sound levels, listeners are less able to hear intruding sounds. Conversely, in quieter locations, intruding sounds can be heard more easily. For an open-plan space to work effectively acoustically, all elements of the design must work together.

Sound Masking

Sound masking techniques can be used to make intruding sounds more difficult to hear. The most common form of sound masking is to place sound-generating speakers in the ceiling plenum to degrade the intelligibility of speech. This increases perceived privacy and reduces the ability to hear spoken words clearly. In many offices, the HVAC system serves the same function as sound masking.

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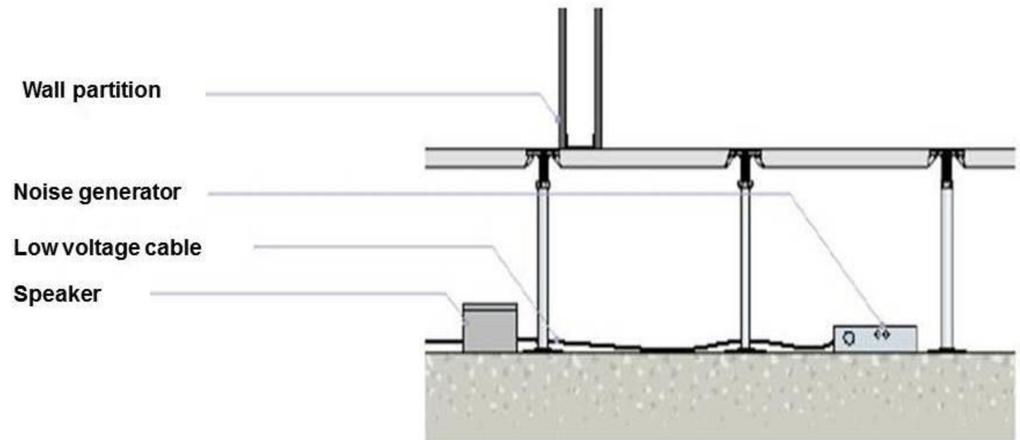
[41] GSA, "Acoustical Study EPA Region 8 Headquarters Building," December 2011.

[42] Heerwagen et al., 2006, "Collaborative Knowledge Work Environments," *Building Research and Information*, Vol 32(6):510-528; J. Heerwagen et al., 2006, "The Cognitive Workplace," in D. Croomes, Ed., *The Productive Workplace*. London: Spon Press.

In contrast to placing sound masking in the ceiling plenum, the Wynkoop building uses the UFAD system (Figure 8-8). Masking speakers are placed in the raised floor plenum near the air grilles, which serve as the delivery mechanism for the masking noise. Unlike with a ceiling grid, where the sound from the masking system is diffuse, the sound from an under-floor distribution system is likely to have high spatial variation in sound level and spectrum. Essentially, a diffusive sound field is more difficult in a UFAD system, as each mechanical diffuser becomes a point source of noise, or a hot spot. The speakers in the Wynkoop building UFAD system are also used to deliver emergency messages.

Figure 8-8. Typical Placement of Under-Floor Masking Speaker



Field Testing Methods

The field research included opportunistic conversation with occupants, characterization of existing acoustic features, and measurements in 10 locations with a variety of conditions that are known to affect acoustics (e.g., glazing or hard wall nearby, corner locations, workstations in middle of the floor). Field measures included the HVAC noise spectrum, the sound masking noise spectrum, and noise reduction when both HVAC and masking are turned off.

Using a test loudspeaker of known spectral power output placed at an office occupant’s head location, test noise was produced. The levels and spectra received in adjacent cubicles at that occupant’s head location were measured, in addition to the ambient levels with the test noise turned off. This allows calculation of the noise reduction, in 1/3 octave bands. This noise reduction is then subtracted from an assumed source power level for a normal male voice, to calculate a receiving level, which is then compared to the ambient level (essentially the masking sound level) to derive a set of weighted Articulation Index values for each band. These are summed and used to calculate a Privacy Index, expressed as a percentage, which ranges from 0 (no privacy) to 100 (confidential privacy).

Key Findings

The following were significant findings of the acoustics study:

- The HVAC system is unusually quiet; HVAC is generally an important part of acoustic treatment, because it provides low-frequency noise. The sound masking in the UFAD system lacked output capacity at low frequency. Sound masking noise comes predominantly through the air grilles and is not diffused through the raised floor; this results in hot spots and localized sound.
- The noise spectrum showed a wide variation and was deficient at the low frequency levels most important to successful masking. The variation in spectral characteristics affects the privacy index (the ability to achieve speech privacy). Stated simply, the spatial variation of sound is not within an acceptable range, even though the average level is about right.
- In the UFAD system, the sound masking speakers are placed under the floor and the sound leaks through the air grilles, causing them to become a point source rather than creating the desired random, diffuse sound. This creates the noise disturbance that was identified in the survey and in the opportunistic conversations.
- Many occupants covered up the UFAD air grilles. Although Greenbusch could not identify the reasons for this behavior, it is likely due to both the noise distraction and thermal discomfort. Numerous and innovative means were seen, including covering the grilles with duct tape, mouse pads, trash cans, rugs, and file cabinets, and stuffing the grille assembly with rags.

Figure 8-9. Blocked UFAD Air Grilles

WORKSTATIONS

The measured privacy levels show that 49 percent of workstations have normal privacy, and 38 percent have marginal privacy. However, occupant satisfaction is low, owing to spatial variation in masking levels; a sharp, hissy "bump" in the masking spectrum; lack of low frequencies in the masking sound; and localization of air grilles for masking sound.

In addition to the issues surrounding the masking sound itself, multiple reflective surfaces further degrade potential privacy. The workstation furniture does not absorb sound. Panels are fabric-covered, but the core is fairly hard and reflective. The ceiling is appropriately absorptive directly over the workstations, but exposed concrete structure occurs between panels. Fixed walls in the open plan areas are not treated for absorption. Perimeter glazing also provides surfaces to reflect sound back into the workstations.

ENCLOSED OFFICES

The enclosed offices that were tested have marginal sound isolation qualities. The greatest deficiency in sound isolation was along the doors. Poor seals or no seals at all along the door perimeter allowed sound to transfer between spaces easily. The expanse of glass included in many of the enclosed spaces also contributed to the lower sound isolation qualities. In spaces abutting the atrium, the continuous hollow mullions allowed sound to transfer between floors. However, the masking system was included in these enclosed offices as well, so that while irritation and dissatisfaction were high among occupants, speech privacy between enclosed offices was for the most part “confidential” in nature.

Conclusions

Improving acoustic privacy requires one or both of two things: increasing noise reduction between the source and receiver (talker and listener), or raising the masking sound. Unfortunately, the masking sound overall is already at the recommended level, and it exceeds the recommended level in some places, so making it even louder is not recommended. It may be possible to achieve 2 or 3 dB more masking by further optimizing spectrum and spatial coverage, but that by itself would not significantly improve privacy. In other words, significant improvement in privacy will require changes to the acoustics of the space.

The suspended ceiling is a highly absorptive fiberglass tile. This is appropriate for the open office areas. However, the absorption is provided in strips, with some areas open to and exposing the concrete deck. Although the absorptive material is directly over workstations, it may be that in some instances sound reflected from the concrete deck adjacent to the acoustical tile is contributing to the sound transfer between workstations.

The privacy levels measured in the open office spaces showed 38 percent of the workstations at “marginal” and 49 percent at “normal” privacy. Only 13 percent of the open-plan spaces were rated at “no privacy,” and these were typically the “hotel” spaces, which did not include a complete enclosure. However, the privacy rating reflects only the level of intelligibility of speech, or lack thereof, not the level of annoyance associated with the masking sound.

The quality and intensity of the sound introduced into the work environment governs the level of irritation experienced. In the Wynkoop building, the sound spectrum has been adjusted to boost the mid-frequencies. This is consistent with the school of thought that privacy is increased by this mid-frequency bump. In this case, however, privacy may be slightly increased, but the resulting sound quality is annoying.

The current masking spectrum is also deficient in low-frequency energy. This deficiency does not degrade privacy, but it does degrade the subjective acceptance of the background sound quality. The primary cause of occupant dissatisfaction at this building is the delivery of the masking sound through the UFAD diffusers. The spatial variation in sound level resulting from this method of masking distribution is significant throughout the office areas. The level of sound emanating from the diffuser is governed by the number of masking speakers in each area and their proximity to the diffuser. Each diffuser is also adjustable to allow occupant control of airflow. This adjustment is an additional factor affecting the sound level. Fully opening or closing the diffuser resulted in an approximately 3 dBA level change.

The most straightforward approach to improving occupant acceptance of the masking sound may be to “boot” each of the diffusers to minimize the spatial variation in sound level. It is likely that the sound level of the speakers will need to be increased once the boots are in place to create sufficient level for masking. It may also be possible to augment the existing system with a larger speaker type to add some low frequency and additional sound level. It is important to consider that emergency paging is not working well under the current conditions, so a page may not be intelligible at all with the retrofit.

Recommendations

Open Offices

If the spatial variation of masking sound can be reduced and the spectrum smoothed, as discussed below, it might be possible to raise the overall level of masking sound in open areas, but only by 2 or 3 dB. This small difference might not be significantly audible to occupants. Further improvements would require extensive revisions to partitions and ceilings.

Enclosed Rooms

Many of the recommended mitigation treatments would be costly and disruptive to the work environment. The one, single treatment that would significantly improve the sound isolation of every office or conference room would be to add seals to the doors. We highly recommend this action.

Sound Masking

Possible improvements to the existing masking systems could include the following modifications:

- Retune (readjust the equalizers) to smooth out the average spectrum, to flatten and/or widen the “bumps.”
- Retune (readjust the equalizers) to increase the low frequencies. It is possible, if not likely, that this would require additional amplifiers and/or additional or different under-floor loudspeakers.
- Add boots or acoustical barriers to the air grilles to reduce the sound leakage through them, then retune and reset the levels of the masking system. It is possible, if not likely, that this would require additional amplifiers and/or additional or different under-floor loudspeakers, or possibly the addition of supplemental speakers above the suspended ceiling. The most straightforward approach to improving occupant acceptance of the masking sound may be to “boot” each of the

diffusers to minimize the spatial variation in sound level. This solution could trigger additional requirements, described above, for adjusting or augmenting the speakers and emergency paging system.

Additional Experiment and Testing the Boot Installation

Experimental boots were constructed and installed directly under all air grilles in the test area (Figure 8-10). To complete the setup, it was necessary to alter the equalization and power levels of the test area speakers. The equipment layout of the original installation did not lend itself to separating the selected test area, so a temporary amplifier and equalizer with integral masking noise generator was installed and temporarily connected to all speakers in the test area (Figure 8-11). The masking levels were measured in cubicles throughout the test area.

Figure 8-10. Experimental Boot for Air Grille

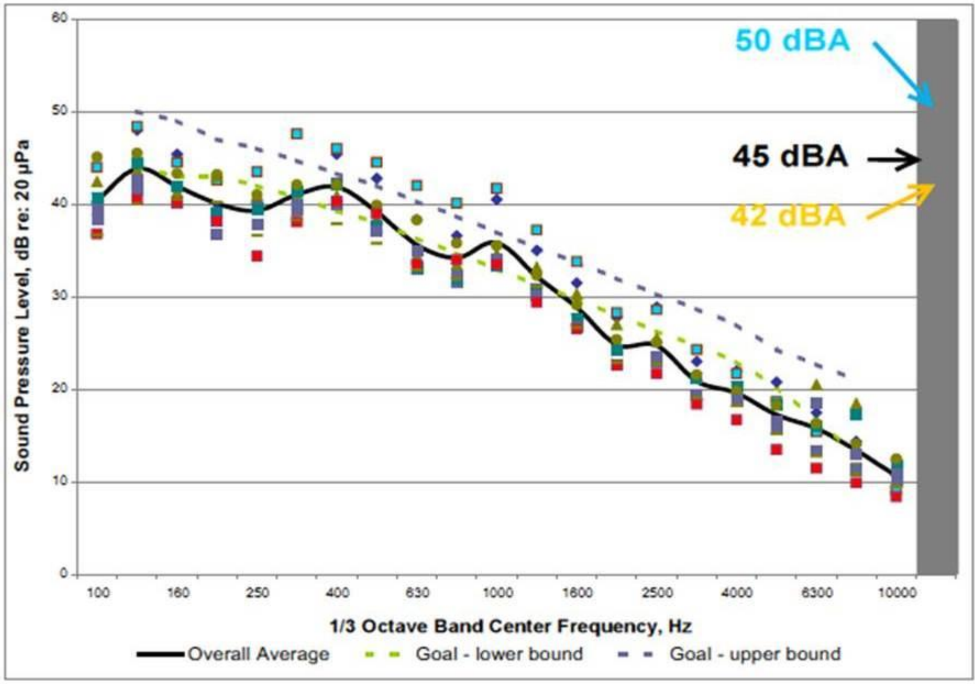
Figure 8-11. Temporary Test Amplifier and Equalizer/Generator

Figure 8-12 shows a scatter plot summary of the resulting readings. The average level, as tuned by the installing contractor, is 45 dB-sound pressure level, A-weighted, which is exactly the target level. The general slope of the spectrum, indicating the balance of frequencies, is also as intended. The overall spectral shape has two “bumps,” which are undesirable, but the shape is smooth enough for a valid test. The slight deficiency at the low frequencies is a weakness of the installed loudspeakers, as discussed above, although it has been improved slightly from the original tuning, within the limits of the existing loudspeakers.

The spatial variation, as represented by the length of the vertical bars (scatters), is reduced from that of the original system. Although the total variation from highest to lowest is not reduced, the general grouping is somewhat tighter, with the high and low anomalies being fewer. This reduction in spatial variation is the intended result.

For comparison, scatter plots are also shown in Figure 8-12 for the corridor areas near the exterior windows, and the one enclosed office that was included in the test area. The corridor and window areas are 4 dB higher in level, which is higher than desirable. This is a consequence of leakage from the under-floor plenum through the air grilles at the windows, which were not booted. In practice, the elevated masking sound at the windows is not likely to be a significant problem, as it is not a work area.

Figure 8-12. Average Masking Level with Booted Grilles



The level in the enclosed office is a bit lower, which is desirable, as the office is enclosed and has inherently more privacy than open office cubicles. Its spectrum is otherwise similar to the open office areas.

Recommendations for Acoustics Design

Ceilings must be highly absorptive, lighting fixtures should have faceted rather than flat lenses, and partial partitions between workstations should be at least 60 inches high and highly absorptive. Workstations should be arranged so that there is no direct line of sight between them.

Wall surfaces can also provide a reflective path between workstations. Absorptive panels should be located on the fixed walls, in a band between 3 feet from the floor and door height.

Background noise levels are also critical to the privacy afforded by an open-plan space. The sound masking system is an integral part of the total design approach to achieving maximum acoustic privacy between open-plan workstations. However, it is not intended to substitute for any of the above elements. Increasing the level of masking sound to compensate for a lack of absorption, direct sight lines between workstations, or other issues is not an effective approach. Higher sound levels will not increase the level of privacy, only the level of staff dissatisfaction with the workplace environment.

Activity zoning is also recommended as a way to separate noise-generating activities from quiet work. Acoustical comfort is achieved when the workplace provides appropriate acoustical support for interaction, privacy, and concentration. (For additional information on workplace acoustics, see GSA's publication, *Sound Matters*.[43])

[43] GSA Public Buildings Service, 2012. Sound Matters: How to achieve acoustic comfort in the contemporary office.

Chapter 9

Materials Use, Waste Reduction, and Recycling: Design Goals

This chapter focuses on the design goals for using sustainable materials, reducing waste, and recycling.

LEED Credit Elements

Table 9-1 shows LEED credits earned for design elements related to sustainable use of materials and resources.

Table 9-1. Summary of LEED Credits: Materials and Resources

Design element	Credit
Storage and collection of recyclables	Prerequisite
Construction waste management ◆ 80% of construction waste recycled	2 points
Recycled content (31% total) ◆ Recycled steel rebar (80–100%) and aluminum in construction materials ◆ Fly-ash (25%) in concrete ◆ Recycled glass content in bathroom countertops ◆ Recycled aluminum in reception countertops ◆ Recycled content in carpets (average 40%, including both polyethylene terephthalate (PET) and recycled carpet content) ◆ Floor coverings made from recycled cork, recycled tires and linoleum	2 points

Design element	Credit
◆ Local/regional materials ◆ 50% of the materials used were manufactured locally ◆ 59% of materials were extracted, harvested, or recovered within 500 miles	2 points
Certified wood (89%) ◆ Wheatboard, plywood, doors and finish woods (maples and cherry)	1 point
Total	7 points

DESIGN TARGETS

Table 9-2 shows the measured performance for waste reduction and recycling.

Table 9-2. Materials Design Targets and Measured Performance

Baselines	Design goals	Measured performance
None	◆ SFO required construction waste management plan with list of minimum items to be recycled[a]	◆ All LEED construction waste management credits achieved
	◆ SFO required recycling collection system built into design with recycling plan for operations	◆ LEED prerequisite achieved ◆ 80% waste diversion rate ◆ GHG reduction of 447 $MTCO_2e$ (2010)
	◆ SFO required that building facade be made from local/regional materials	◆ LEED credit achieved
	◆ SFO specified that "environmentally preferable products" and materials be used where economically feasible; such products and materials: ▪ contain recycled material, are biobased, or have other positive environmental attributes; ▪ minimize the consumption of resources, energy, or water; ▪ prevent the creation of solid waste, air pollution, or water pollution; and ▪ promote the use of non-toxic substances and avoid toxic materials or processes	◆ Environmentally preferable products used throughout the building.

[a] The SFO list of minimum items to be recycled during construction includes: ceiling grid and tile, light fixtures, including proper disposal of any transformers, ballasts, and fluorescent light bulbs; duct work and HVAC equipment; wiring and electrical equipment; aluminum and/or steel doors and frames; hardware; drywall; steel studs; carpet, carpet backing, and carpet padding; wood; insulation; cardboard packaging; pallets; windows and glazing materials; all miscellaneous metals (as in steel support frames for filing equipment) and all other finish and construction materials; land clearing debris; wood composite materials, such as plywood, oriented strand board (OSB), and particle board; concrete masonry units; bricks, concrete, and asphaltic concrete; paint; and plastic film (including high density polyethylene).

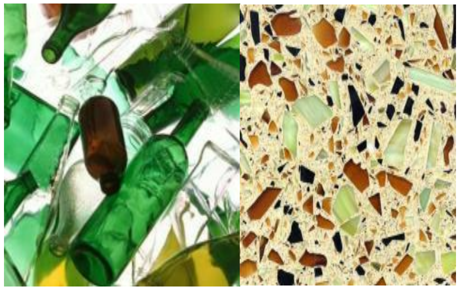
EPA created its own program of requirements (POR) for design and construction of this facility. To ensure that the new building would meet EPA's standards, EPA and GSA worked together to craft a series of very detailed performance criteria for many elements of the SFO. This is especially apparent in the area of materials, waste, and recycling. EPA identified a long list of items that should be recycled during construction, required development of a construction waste management plan, and required regular reporting on progress. The project team was required to develop a recycling operations plan and design a recycling collection system into the building floor plan.

Indoor air quality was a high priority; the SFO specified ventilation performance metrics and a variety of source control strategies to consider. The SFO highlighted cost-effective use of environmentally preferable products[44] and identified some specific types that were applicable, such as for landscaping, insulation, acoustical ceiling tiles, wallboard, ceramic tile, toilet partitions, bathroom paper products, and carpet. An example was the restroom countertops made of IceStone (Figure 9-1), a composite material consisting of recycled glass and concrete (Figure 9-2).

[44] http://www.epa.gov/epp/.

Figure 9-1. IceStone Countertops Installed in Bathrooms

Figure 9-2. Recycled Materials in IceStone Countertop



The project team was able to achieve the construction waste management credit by setting up bins throughout the construction site so that waste material from the construction site could be collected and diverted to recycling and/or other non-landfill uses. A total of 76.94 percent of construction waste was diverted. One of the project's LEED consultants stated that "the construction waste management is the most aggressively tracked on any project I've experienced. They are even recycling drywall, by providing it to a farmer for use as a soil amendment."[45]

[45] EPA Region 8 Headquarters, Denver, CO, "Harvard Legacy Case Study," p.12.

Chapter 10

The Vegetated Roof

This chapter focuses on the design goals for a vegetated roof (Figure 10-1) and the roof's sustainability performance. This was the first planned installation of this type of vegetated roof system in a North American high-mountain desert eco-region. As such, it was subject to extensive investigation, from the best types of plantings to use to its performance for stormwater retention and its effects on the building energy performance.

Figure 10-1. Vegetated Roof

LEED Credit Elements

Table 10-1 shows LEED credits earned for design elements related to the vegetated roof.

Table 10-1. Summary of LEED Credit Elements: Vegetated Roof

Design element	Credit
Stormwater management, treatment Growing medium in the vegetated roof system captures and slows rainfall/snowmelt, directing water through interior "gutters" Downsized detention tank in the parking detains and slows water from non-vegetated areas of the roof	1 point
Landscape and exterior design to reduce heat islands, roof High-albedo, ENERGY STAR branded ethylene propylene diene monomer (EPDM) membrane with a high-emissivity acrylic coating Vegetated roof on all three levels: 19,200 ft2 square feet Modular system—2'x2' and 2'x4' 4" growing medium; sedum varieties & native/adaptive xeric plants	1 point
Total	2 points

Design Goals and Objectives

Table 10-2 shows baseline best practices and design goals for the roof.

Table 10-2. Vegetated Roof Design Targets and Measured Performance

Baselines	Design goals	Measured performance
Best management practices outlined in Chapter 4, Part 2, Urban Drainage, of the US EPA Guidance Specifying Management Measures for Sources of Non-point Pollution in Coastal Waters (1993)	Estimated 26.7% reduction in stormwater runoff	Not measured

Baselines	Design goals	Measured performance
	Estimated removal of 80% of total suspended solids and 40% of total phosphorus	Not measured
	Heat island mitigation (demonstration research)	

Stormwater management was a primary objective for the vegetated roof, included at the very outset of the project. The Clean Water Act (implemented through local governments) requires that facilities capture large-volume deluges and release the water at a controlled rate. The architect initially wanted to express the movement of stormwater through the building, and explored features such as vertical bioswales, with water cascading down through the atrium planters. However, Colorado's complex water rights laws require that stormwater can only pass through the building one time before being directed back into the system. This allowed detention, but not retention strategies, and limited the possibilities of strategies such as gray water reuse.

Design Adjustments

The design team originally proposed an "intensive"[46] vegetated roof with 2–3 feet of soils and plantings, but construction personnel expressed concerns about leaks, and how leaks could be found and addressed with this type of system. The "intensive" system was changed to an "extensive" modular system, consisting of 4" deep recycled plastic trays in modules measuring 2×2 feet or 2×4 feet, with lightweight growing medium, that sit on top of the roof membrane. The trays lie adjacent to each other over the roof, so no roof penetrations are required relative to an intensive system. This system—rated at about 15lbs/square foot, comparable to a heavy snow load—reduces load on the roof and allows for easier maintenance. The architects estimated that the extensive system installed could retain about 50 percent of the building stormwater, while performing some limited treatment, primarily by capturing sediments. Figure 10-2 illustrates the layers in the extensive modular system.

[46] "Intensive" green roofs have growing medium greater than 8-inches thick. "Extensive" green roofs have growing medium that is under 8-inches/20 cm in depth.

Figure 10-2. Vegetated Roof Layers

Some changes were made to the roof assembly to accommodate this system. The building's roof is an EPDM membrane with a high-emissivity acrylic coating; the membrane was changed from 60 mil to 90 mil, a fleece protection mat was added to protect the membrane from friction, and the warranty was extended from 10 to 15 years. Recycled rubber pavers provide walking paths around the perimeter of the modular systems for use by maintenance personnel.

Cost Tradeoffs: Vegetated Roof

Costs:

- Typical roof costs: approximately $4 psf
- Green roof premium: approximately $12 psf
- EPA green roof premium: approximately $240,000.

Offset Savings:

- Reduced detention vault: $150,000
- Parking revenues: 12 spaces × $25,000/yr = $300,000
- Additional savings:
    - Roof temperature moderation = reduced energy costs
    - Lower stormwater utility fees assessed by local utility
    - Protects roof membrane from ultraviolet rays and hail, prolonging roof lifespan.

Because this was the first planned installation of this type of vegetated roof system in a North American high-mountain desert eco-region, Opus initially planted a modular test bed on top of one of the construction trailers 1 year before installing the system on the roof. The LEED credit required that irrigation be removed from the roof after 2 years (allowing time for plants to establish themselves). However, experts at the Denver Botanical Gardens and Colorado State University's horticulture program advised that the plants would likely not survive hot dry summers and desiccating winter winds without ongoing irrigation. (As noted later in this chapter, the research team also concluded that the plants would not survive without irrigation.)

Photovoltaic Array Added to the Roof- Photovoltaic panels were initially removed from the roof design due to a lack of funding. However, Opus decided to install the support structure fittings for the panels in case EPA should decide to install them in the future. Later in construction, when EPA decided to install a 10 kW array of PV panels over the vegetated roof, Opus resisted. The untested configuration was a risk, and negotiations were necessary to release Opus from liability if the shade from the PVs were to kill the vegetated roof (Figure 10-3).

Figure 10-3. Solar Panels Shade Portions of Vegetated Roof

Tree Canopy Effect

Contrary to concerns about detrimental shading, EPA research discovered that reflection off the glass and metal siding resulted in overexposure detrimental to the plantings in other areas. This suggests that the ambient sunlight in the region is in excess of what plants require. The coolest daytime and warmest nighttime temperatures were recorded beneath the vegetated substrate surface in the shade of the solar panels. The photovoltaic panels loosely mimic the canopy structure of complex and productive ecosystems by producing gradients in temperature and solar irradiance. The shading from the panels helps conserve moisture that would otherwise have evaporated faster with direct sun exposure. These observations may have important design implications for enhancing performance, energy efficiency, and water conservation attributes of green roof applications.

These observations also suggest that the rate of heat transference (heat flux) into the building and heat loading into the atmosphere is reduced most in the area of vegetated roof below the solar panels. Heat contributed to the atmosphere by the solar panels is compensated to some degree by the cool temperatures of vegetation in the shade of solar panels and reduction of waste heat from HVAC.

Vegetated Roof Research

EPA and the building owner agreed to set aside a portion of the vegetated roof system to experiment with irrigation, plant species, and thermal performance. EPA also secured an agreement with a nearby property owner to use its conventional membrane and gravel roof as a control roof. Weather stations were installed on both roofs to track temperature, humidity, and solar irradiance. Selected results from these studies are summarized below.

The discussion below is a summary of selected research results contained in the following:

- "Cities Alive 10: Thermal characteristics of an extensive green roof and a gravel ballasted roof in high elevation, semi-arid, temperate Denver, Colorado, U.S.A," EPA: Thomas Slabe, Thomas O'Connor, Angela Loder, Karla Dakin, Andy Creath, and Mark Fusco, October 2012.
- "Thermal characteristics of an extensive green roof and a gravel ballasted roof in high elevation, semi-arid, temperate Denver, Colorado, U.S.A.," EPA: Thomas J. Slabe and Thomas P. O'Connor, December 2011.
- "Extensive Green Roofs in Colorado: Plant Species Performance, Growing Media Modifications and Species Response to Growing Media Dry Down," PhD Dissertation, Jennifer McGuire Bousselot, Department of Horticulture and Landscape Architecture, Colorado State University, Spring 2010.
- "Extensive Green Roof Species Evaluations Using Digital Image Analysis," Jennifer M. Bousselot, James E. Klett, and Ronda D. Koski, Department of Horticulture and Landscape Architecture, Colorado State University, HortScience Vol. 45(8), August 2010.
- "Moisture Content of Extensive Green Roof Substrate and Growth Response of 15 Temperate Plant Species during Dry Down," Jennifer M. Bousselot, James E. Klett, and Ronda D. Koski, Department of Horticulture and Landscape Architecture, Colorado State University, HortScience 46(3): 518–522, 2011.

Research Findings and Operational Lessons Learned

Background

Vegetated roofs can be used for stormwater retention and urban heat island mitigation while extending roof membrane life. In some cases, vegetated roofs can also provide habitat for small insect and animal species.

However, Denver's high mountain desert environment exerts challenges that green roofs in most other major cities do not encounter, including highly variable solar irradiance, low moisture (about 15 inches/year average), and an exceptionally wide range of temperatures (from -20°C/-4°F to 40°C/104°F). Hot dry summers and desiccating winter winds make year-round irrigation a necessity for most cultivated plants in this region. A primary objective for EPA in installing the Wynkoop vegetated roof was to develop evidence-based best management practices for vegetated roof installation and maintenance in this challenging environment. From 2007 to 2009 research was conducted on four interrelated topics:

- Plant species diversity
- Irrigation requirements
- Stormwater management
- Thermal performance and heat island mitigation.

The research results summarized here have been published in the academic literature and were used to inform development of Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West (Leila Tolderlund, University of Colorado at Denver, 2010). EPA Region 8 has also developed an operations and maintenance (O&M) manual for the vegetated roof, which is summarized in this chapter. More information about this vegetated roof and links to additional green roof research can be found at http://www.epa.gov/region8/greenroof/index.html.

Study Methods

The Experimental Conditions

The vegetated portions of the Wynkoop roof are divided into three sections on three terrace levels covering the 8th, 9th, and 10th floors. The study site is situated in the southern portion on the 9th floor, and totals nearly 8,000 square feet (740 m2). In addition to the vegetated roof system, the 9th floor terrace includes two patios and a perimeter walkway of rubber pavers that provides access across the roof while protecting the waterproof EPDM membrane. Vegetative coverage varies across the surface from thick stands of sedum to bare substrate.

The conventional (control) roof is located on on an extensively renovated, LEED Gold Certified historic building located across the street from the EPA facility (Figure 10-4). The control roof is a low-slope dark EPDM membrane roof topped with gravel ballast (about 1.5 inch or 3.8 cm). Concrete pavers border the perimeter of the roof. The roof membrane is overlain in most areas with a single layer of gravel, with the membrane visible through the porous gravel. The study site is located in the north corner.

Figure 10-4. Control Roof (Left) and Vegetated Roof

Selecting and Testing the Plant Species

A healthy vegetation layer is essential for achieving green roof benefits. Knowledge about plant tolerance to severe moisture stress is essential—especially for extensive green roofs, where moisture is typically a limiting factor for plant health. The substrate used for extensive green roofs is lightweight, well drained, and prone to extreme fluctuations in moisture content. As a result of the characteristics of the substrate, plant species used in extensive green roof systems, among other things, must be able to adapt to periods of low moisture availability in their root zones.

Plant Diversity: Selection Criteria

Selection of plants for use on extensive green roofs in the semi-arid West should be based on the following criteria:

- Ability to grow in conditions of high light intensity, low relative humidity, limited soil moisture, and extreme temperature fluctuations
- Relatively low-growing growth habit
- Shallow or fibrous root systems (tolerant of soil moisture deficit)
- Evergreen foliage
- Long period of bloom
- Plants with an erect growth habit can be used as accent plants (good for contrast with groundcovers in heights and bloom time).

Succulents, especially species of the genus Sedum, have been the most studied and used plants for green roofs. One of the main reasons sedums seem ideally suited to green roof cultivation is the fact that many possess Crassulacean acid metabolism (CAM). During periods of soil moisture deficit, CAM plants keep their stomata closed during the day when transpiration rates are normally high and open them at night when transpiration rates are significantly lower. In contrast, most other kinds of non-CAM plants do not keep their stomata closed during the day and therefore have higher water use rates than CAM plants.

To avoid issues associated with sedum monocultures, additional plant species need to be incorporated into the extensive green roof plant palette. Sedum monocultures result in an unvarying, monotone effect and—like all crop monocultures—may have a higher probability of pest problems than a system with diversity. A diversified plant palette on an extensive green roof may be able to adapt to variable moisture conditions and maximize the evaporative cooling benefit, thus extending the benefits of extensive green roofs. Enhancing plant species biodiversity can also make extensive green roofs attractive to beneficial native arthropod and avian species.

In most previous studies conducted on non-sedum species, the non-succulents tested were typically native to areas with high annual precipitation and relatively deep soil profiles, significantly different from the shallow, well-drained, green roof substrate used on extensive green roofs. Plants native to the Rocky Mountain region, especially those that inhabit areas with shallow, rocky, well-drained soils, were hypothesized to be more suited for use in extensive green roof systems. Such species should tolerate the low moisture conditions found in the semiarid region in which this study was situated. Native plants should not be considered for use on green roofs based on the fact that they are adapted to local conditions as a sole criterion. However, native species found growing in shallow and well-drained soils, which mimic the conditions typical of an extensive green roof, have a greater likelihood of being suitable for extensive green roof culture.

Regardless of plant species origin, the establishment, survival, and success of plants on an extensive green roof in a semiarid region require irrigation. Predictions have been made that success is unlikely for extensive green roofs in areas with infrequent precipitation without supplemental irrigation.

During 2008–2009, two study approaches were designed to examine plant response to arid conditions that characterize the Wynkoop building's green roof:

- Six plant species were evaluated to determine their suitability for use on extensive green roofs in a semiarid, high-elevation region. One intended outcome of this study was to add diversity to the list of species suitable for extensive green roof cultivation in a semiarid climate.[47]

- Fifteen plant species were studied to determine the impact of gradual drying of the extensive green roof substrate on growth and to determine the relative water use for each species. Results from this study are intended to inform irrigation requirements for extensive green roofs in semi-arid climates using an expanded plant palette.[48]

First Study

The first study evaluated "quantification of plant cover," a method to determine how quickly and completely a plant species can cover an area. This measure is valuable for green roofs, because it shows which particular species are best adapted to green roof conditions and thus reduces initial and ongoing maintenance costs. The six evaluated species are listed in Table 10-3. With the exception of Hardy Iceplant, these species are all native to the Denver region and are not widely used in green roof applications today.

[47] "Extensive Green Roof Species Evaluations Using Digital Image Analysis," Jennifer M. Bousselot, James E. Klett, and Ronda D. Koski, Department of Horticulture and Landscape Architecture, Colorado State University, HortScience Vol. 45(8), August 2010.

[48] "Moisture Content of Extensive Green Roof Substrate and Growth Response of 15 Temperate Plant Species during Dry Down," Jennifer M. Bousselot, James E. Klett, and Ronda D. Koski, Department of Horticulture and Landscape Architecture, Colorado State University, HortScience 46(3):518–522, 2011.

Table 10-3. Species Evaluated on Qualification of Plant Cover

Species	Antennaria parvifolia	Antennaria parvifolia	Bouteloua gracilis	Delosperma cooperi	Eriogonum umbellatum aureum 'Psdowns'	Opuntia fragilis
Common name	Small-leaf pussytoes	Small-leaf pussytoes	Blue grama	Hardy ice plant	Kannah Creek buckwheat	Brittle pricklypear
Growth habit	Groundcover	Groundcover	Upright (grass)	Groundcover	Groundcover	Decumbent (cactus)

Kannah Creek buckwheat experienced low winter survival and was removed from the study. The other five species were determined to be appropriate for use in extensive green roof applications in semiarid regions.

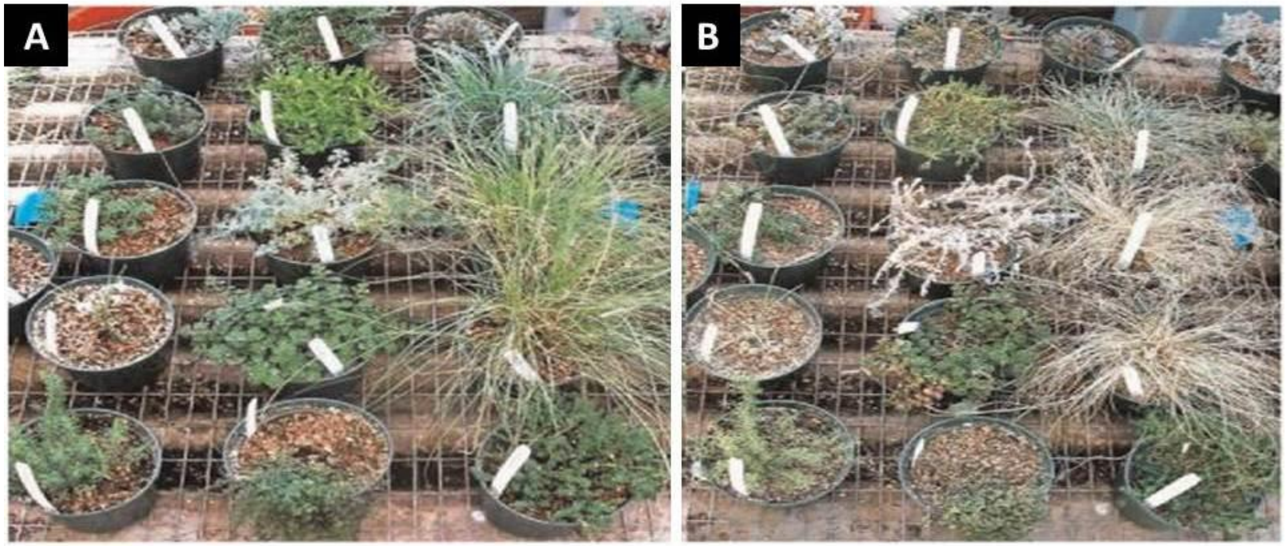
Second Study

The second study evaluated the ability of selected species to withstand periods of prolonged drought, a particular challenge for plants in the shallow planting medium of an extensive vegetated roof system. Fifteen species were evaluated over two growing seasons in a greenhouse on the Colorado State University campus. Water was withheld for 151 days. Once the top growth of an individual plant had died back, the plant was re-watered to determine whether the plant had entered into drought-induced dormancy or died. If plants had not died during the 151-day study, water was applied at the end of the study to evaluate their revival rate after an extended drought.

Figure 10-5. Five Plant Species Used in Dry-Down Trial—Top Row (from Left): Saxifraga Granulata, Fragaria Chiloensis (Beach Strawberry), Alpine Aster; Bottom Row (from Left): Sedum Alba (White Stonecrop), Pacific Stonecrop

Dieback and revival rates differed by plant type (Figure 10-6). The succulent plants retained viable foliage more than five times longer than the herbaceous plants. After dieback and subsequent rewatering, the succulent plants were nearly twice as likely to revive as the herbaceous plants. Therefore, not only are the succulents longer-lived during drought, but they have a better chance of surviving a period of drought once water is again made available.[49]

Figure 10-6. Change in Plant Appearance, Day After Trial Began (A) and Day 12 (B)



Vegetated Roof Irrigation

Irrigation was originally provided through a drip system with emitters spaced roughly 1 foot apart. It was found that only a small cone of moisture formed beneath each emitter, with dry media intervening between emitters, and considerable amounts of water draining through the medium to discharge drains. This system was replaced with an overhead spray type, which more uniformly distributed moisture across the roof, lowering the volume of wasted water.

[49] Based on plant relative water use and revival of species, these results suggest that succulents such as *S. Royal Ruby, A. cernuum*, and *S. lanceolatum* would be ideal on an extensive green roof in a semiarid environment with limited moisture content. Additionally, of the species tested here, herbaceous plants such as *A. parvifolia*, *T. pseudolanuginosus*, and *B. dactyloides* are the most likely to survive low moisture content of the substrate and revive once moisture is no longer limiting. Both *A. parvifolia* and *S. lanceolatum* have been successful in other extensive green roof trials in the same semiarid region.

Figure 10-7. Drip Irrigation of Vegetated Roof with Emitters Spaced at 12 Inches

For 2009 the targeted irrigation application rate was 0.5 inch per week, and for 2010 the targeted irrigation application rate was 0.25 inch per week. However, according to sub-meter readings, the actual application rate was more on the order of 0.75 inch per week during the growing season. It is estimated that over the duration of the study, 125,000 to 150,000 gallons of water/year were used for irrigation.

Green roof irrigation rates on the building were estimated to range from 0.25 to 0.75 inches per week throughout the 2009–2010 growing season. In combination with moisture from precipitation, moisture retained in the green roof substrate and plant materials is arguably a beneficial use of water even in this arid region. As discussed in more detail in the summary of thermal performance, retained moisture helps to cool the immediate environment during hot weather and warm the immediate environment during cold weather. This function protects the EPDM membrane from extreme temperature variations and helps to prolong the membrane’s life.

Best Practices Tip

The “EPA Region 8 Green Roof O&M Manual” includes a protocol for irrigation keyed to typical seasonal weather changes and anticipated plant growth.

Vegetated Roof: Stormwater

Analysis of latent heat transfer is an indirect approach for evaluating stormwater retention on vegetated roofs. The absolute quantity of latent heat transfer is easily calculated and provided the foundation for the architect's estimate of about 50 percent stormwater retention. Water absorbed within plant materials and growth media eventually tends to evaporate and is thus not discharged to grade level.

An analysis concluded that 77.5 percent of stormwater is retained on the vegetated roof portions. Since some portions of the green roof are not vegetated (approximately 39 percent), the assumption was made that the roof as a whole retains 50 percent of precipitation. The assumption for the control roof was that 10 percent of precipitation is retained, since it lacks the absorptive properties of the growth medium and vegetation.

For the study, precipitation amounts were obtained from a rain gage sited on the roof. An average annual precipitation of 14.87 inches was recorded over a 2-year period (38 cm); the 10-year average for the region given by the National Weather Service was 15.81 inches. Irrigation was conservatively estimated at 0.25 inch per week from May through October, or 6 inches for the season. The evaporation of 13.4 inches of water (50 percent of precipitation plus irrigation) results in the latent heat transfer during daytime hours of 44 Watts per square meter (W/m2).

For purposes of calculating estimates of latent heat transfer, presented below, the value of 50 percent of stormwater retention was assumed to be a reasonable approximation for the green roof. The assumption for stormwater retention for the control roof is 10 percent.

Vegetated Roof Thermal Performance

Research Methodology

Monitoring was conducted for the following parameters over a period of 24 months (2009–2010):[50]

- Roof surface temperatures: vertical temperature profiles at various surfaces of the roofs (exposed and sheltered) and 1 foot above the surface (including day, night and seasonal variations)
- Ambient air temperatures—at 1 foot above the green roof and control roof surfaces

[50] An additional 6 months of data collected in 2008 is also qualitatively evaluated in the research analysis.

- Relative humidity
- Solar irradiance
- Infrared radiation
- Precipitation
- Wind speed
- Wind direction.

The experimental design consisted of 14 sensors, two Campbell Scientific data loggers (model CR1000), and spread-spectrum radios (model RF401), which were used to communicate between the control roof and the base station in the Wynkoop building.

Summer Performance and Response to Cloud Cover

A representative summer day was selected that exhibited considerable variation in weather to compare thermal performance of the green roof and the control roof. Solar irradiance increased steadily in a typical manner for a clear day to more than 1.0 kW/m2. In early afternoon the data signature of falling and rising solar irradiance indicated passing scattered clouds. For about a 10-minute period, 0.04 inches (1.016 mm) of rain was recorded. The solar irradiance dropped from 1.064 kW/m2 to a low of 0.042 kW/m2 in 1 hour, and the precipitation was recorded 15 minutes later, as solar irradiance again began to briefly climb to 0.757 kW/m2 in late afternoon. Solar irradiance then generally trended downward with some variation until sunset. It is instructive to examine 1 day in detail, because the cumulative, subtle, day-to-day changes over time can be significant.

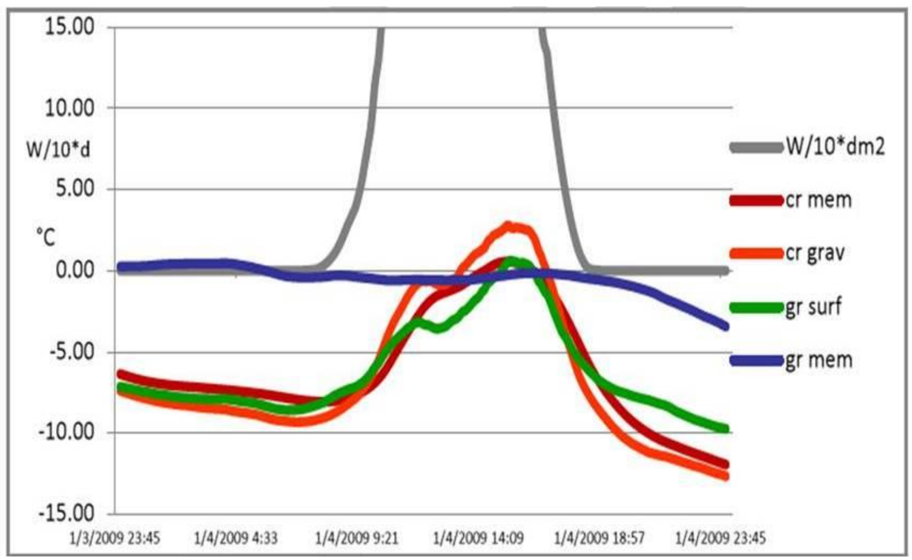
Around sunrise, the vegetated roof substrate surface warmed more quickly than the control roof, perhaps because of the vegetated roof's lower reflectivity. In mid-afternoon, this progression reversed: when roof surface temperatures reached roughly 35°C/95°F, the control roof surface temperatures exceeded the temperature of the vegetated roof by 3.3°C/5.2°F. The temperature difference between the two roofs continued to increase as the afternoon progressed, peaking at a difference of 20.8°C/37°F when the vegetated roof temperature was less than 34.7°C/94.5°F, while the control roof surface peaked at 55.6°C/132.2°F.

These data suggest that when solar intensity and temperatures are high, the vegetated roof radiates heat passively like the control roof. As solar irradiance falls in response to a lower sun angle and passing clouds, temperatures on the vegetated roof drop disproportionately relative to that of the control roof in step with the lower solar intensity. In early afternoon, another ecological mechanism begins operating: the vegetation responds to decreases and increases in solar irradiance and open and close their stomata accordingly, helping to lower the temperature of the roof. These results suggest that green roof plant communities can manipulate their surroundings toward optimal conditions when opportunities arise, as when a passing cloud provides a measure of relief from excessive solar irradiance and heat. Thus, as long as sufficient moisture is available, the plant community can effectively regulate temperatures in its immediate surroundings.

WINTER PERFORMANCE AND MODERATION OF TEMPERATURES

To illustrate processes of latent heat storage and fusion of retained water, we consider a period during which a moderately hard freeze occurred. The temperatures at the vegetated roof membrane beneath the substrate reached 0°C and leveled off, while ambient temperatures and other roof surface temperatures continued to fall (Figure 10-8). These data suggest that some factor was delaying a further drop in temperature at the green roof membrane, but not at the green roof or control roof surfaces. When ambient temperatures drop below freezing, moisture retained in a plant community can release a significant amount of heat energy during the transition from liquid water to ice (latent heat of fusion).

Figure 10-8. Solar Irradiance and Temperatures of Membrane and Gravel in Control and Green Roofs



The release of this heat energy would explain why the temperature at the vegetated roof membrane level beneath the substrate remains right at the freezing temperature for extended periods, while ambient temperatures, temperatures at the control roof, and the green roof substrate surface fall below freezing. In this manner, the green roof acts like an energy capacitor or battery and helps bridge high-frequency, short-duration hard freezes. The moisture freezes progressively from a surface to beneath the surface and releases heat energy into the substrate. Although it may seem counter-intuitive to consider near freezing (0°C) as "heated," that temperature is really 273°K and contains considerable heat energy.

Vegetated Roof Thermal Performance: Observations and Conclusions

Results from these studies show that vegetated roofs in regions with highly variable weather, such as those found in the intermountain West, retain the potential for benefits at individual building and city scales. Vegetated roofs retain moisture, and during the growing season the vegetation appears to respond to even small differences in solar irradiance or cloud cover and cool themselves through evaporation and evapotranspiration, unlike a conventional gravel roof. This reduces green roof surface temperature, as seen in these studies, by as much as 20.8°C (37°F) and tends to produce conditions that are more favorable for plant survival in an environment that can be extremely hostile for all but a relative few plant species.

The study findings indicate that the green roof plant community utilizes retained moisture to suppress temperature variation and extremes and sustain favorable growing conditions. Throughout most of the year, the vegetated roof functions as an energy sink, retaining heat in the thermal mass of the green roof growth substrate and plant materials and moderating daytime/nighttime temperature swings. Changes in temperature cause the EPDM membrane to expand and contract, which is the major cause of membrane failure.[51] As a result, the magnitude and frequency of temperature variation and wear on the waterproof membrane is reduced, and heat released into the atmosphere from the green roof is reduced compared with the control roof.

It is asserted that green roofs significantly lower building cooling costs and that heating costs may also be somewhat lower. This is understandable, because the latent heat of evaporation (2,260 kJ/kg) of water is seven times greater than the latent heat of fusion (334 kJ/kg). If this conjecture is true, though, savings on heating costs would likely be small—although the savings could still be an important consideration for green roof design. However, due to the cooling properties of green roofs during the summer months when urban heat islands are of particular concern, it is believed that if implemented on a large scale, in conjunction with urban forestry, green roofs could lower temperatures of urban areas. The results from the studies performed on EPA's green roof support that belief.

[51] A. Creath, Green Roofs of Colorado, personal communication.

Green Roof Costs

The initial cost of a green roof reportedly is greater than that of a conventional roof. However, over its serviceable life, the monetary cost, or valuation, of a green roof ranges from less than to greater than that of conventional roof, depending upon assumptions included in the analysis.[52] This is because a green roof's serviceable life span is significantly extended. The conventional roof will require replacement at least once during the serviceable life of a green roof.

Life Cycle Comparison: Vegetated Roof vs. Conventional Roof

- Conventional roof replacement is expected at 20 years.
- Typical vegetated roof replacement is expected at 40 years.
- Ultraviolet radiation and environmental conditions degrade roof membranes based on degree of exposure; vegetated roofs shield membranes.
- Building heating and cooling costs are reduced with added insulation from plants and planting substrate and related biological and physical processes (e.g., capacitor effect for physical and evapotranspiration).
- Land normally used for stormwater detention/retention facilities now available for other uses with vegetated roof.
- Reductions in stormwater runoff may reduce utility costs.
- Carbon credits may become available.
- Aesthetics of vegetated roof can increase the potential lease price.
- Detention vault is smaller and parking space is greater (alone, these two attributes seem to have paid for the green roof premium).

Temperature variation is greatest on exposed control roof surfaces, whereas it is lowest beneath the substrate surface on the green roof. This is an important observation, because the extent of variation seen is the likely reason for differences in the serviceable lifespan of a roof. The serviceable life of a green roof reportedly is 2.5-times longer than that of a conventional roof. The research results indicate that the temperature variation at the control roof membrane is 205 percent greater than that at

[52] T.Carter and A. Keeler, 2008. Life cycle cost-benefit analysis of extensive vegetative roof systems. J. Environmental Management, 87(3): 350-363.

the green roof membrane. Significant material expansion and contraction along with material fatigue and failure accompany temperature variations.

Increasing the lifespan of the roof membrane would reduce resource consumption and waste all along the chain from materials to disposal. According to EPA, based on 2003 data, 3.2 pounds of solid construction and demolition waste is generated per capita per day, and 4 percent of that waste is roofing material (EPA, 2003). In 2003, 170 million tons of such waste was generated. Converting just 1 percent of roofs in the United States from conventional to green roofs could avoid about 70,000 tons of construction and demolition waste annually, based on the assumption that the serviceable lifespan of a green roof is 2.5 times that of a conventional roof. Thus the financial benefits of extending the life of the roof membrane may be significant. This is one more aspect of green roofs that warrants further investigation, along with stormwater and urban heat island mitigation and the potential value of ecosystem services, which a conventional roof cannot provide.

Chapter 11

Is the Wynkoop Building Successful?

The Wynkoop building has provided a unique opportunity to capture building performance outcomes and issues, from an inside view of how decisions were made to how problems were identified and resolved, and how changing circumstances—such as increased mobility of work—affect future operational planning.

This final chapter addresses the following indicators of success, drawing on the full range of research conducted in the building:

- Achieving sustainability design goals
- Operational performance and cost savings
- Occupant experience and livability
- Organizational effectiveness
- The building as a learning lab and teaching tool.

Achieving Sustainability Design Goals

This criterion focuses on how well the building performs relative to the goals laid out at the beginning of the project, including LEED points achieved in each category, functioning as an integrated team, and the value of performance-based contracting.

Certification

The most common indicator of success in the green building world is achieving the level of certification sought by the project team. In the case of the EPA regional headquarters building, the project exceeded expectations by achieving a LEED Gold rating. The goal established in the design and construction contracts was to achieve a minimum of LEED Silver.

Integrated Design Process

An integrated team was established at the outset of the project and maintained into occupancy. The general contractor's team of architects, mechanical engineers, and LEED consultants worked closely with GSA's contracting office and project manager; architects and engineers from the national EPA Sustainable Facilities branch, and the local LEED advisor hired by them; and the Denver EPA owner's representative. The EPA owner's representative organized internal EPA teams who brought operational perspectives to the table. Maintaining knowledgeable internal teams was considered a key to managing and limiting risk in a complex, high-performance project such as the Wynkoop building.

The team faced some difficulties during transition periods. For instance, after the design was completed, the developer replaced the architectural firm presented in the proposal as the primary green building/LEED strategist with internal staff who managed the construction process. This change created distrust among some occupant representatives and may have contributed to loss of LEED credit points. Of the 49 points submitted for credit, 7 were rejected due to documentation problems.

Tradeoffs met with mixed success. In cases such as the changed HVAC systems, the tenants clearly felt they did not receive best value for their investment. With the wind turbines, research by the developer led to a mutually agreed upon decision, while for the bamboo flooring the developer took the initiative to deliver the best-value product to the client while assuming the cost. With the overdesigned chillers, it is questionable how much the system contributes to the building's energy efficiency compared with the large initial cost, but it is clear that an opportunity was missed for at least some cost recovery. Despite these difficulties, those involved in the team say the integrated process allowed the team to share and respond to new information immediately, instead of working through a lengthy change order process.

Performance-Based Contracting

The SFO requirements were largely performance-based, with some prescriptive terms. The SFO outlined detailed requirements for design, building materials, and construction and reporting procedures, using an ENERGY STAR target and a LEED credit "wish list" to reflect the occupant's preferences. The design team was required to register the project with USGBC during design development, submit an updated LEED scorecard and energy calculations at each phase, and provide plans for final commissioning, IAQ, and CWM at the completion of construction documents. During construction, the design team had to submit information on the VOC levels for all interior finishes, a monthly CWM report, commissioning reports, documentation on certified wood, EPA Green report documentation, monthly construction photos, and quarterly reports on recycled content. The multidisciplinary nature of the core team allowed for more thorough evaluation of potential outcomes, with the constraint of sustainability performance specifications hard-wired into the contract. All team members credit the combination of a performance-based contract and an integrated team as crucial to the project's ability to be delivered on time and on budget.

The results for LEED certification, integrated teams, and performance-based contracting show that the Wynkoop building achieved this indicator of success. The LEED tables indicating points received for each area show that many additional points could have been received with more careful documentation.

Operational Performance and Cost Savings

The Wynkoop building is likely one of the most intensively studied buildings in the United States. From the outset of the project, the intention was to treat the building design and operation as a series of hypotheses about performance that needed to be tested rather than assumed. This led to a series of projects based on a "test-adjust-retest" approach to building improvements over time.

Energy

At the time of initial testing, the facility was using 76 Btu/gsf/yr versus 52 kBtu/gsf/yr projected in the as-built final design. Possible reasons for this higher energy use include the following:

- The building has demonstrated a pronounced "stack effect" since shortly after occupancy. Temperatures on the lower floors are noticeably cooler than on the upper floors. This differential has required more heating for lower floors in winter, and an early Monday morning chilled-air flush-out to cool the upper floors in summer.

- The energy models used did not factor in plug and process loads, which can account for 30–40 percent of building electrical energy use and represent the fastest growing component of building energy use. Process loads not accounted for in this building may be substantial, given the large amount of electrically powered security equipment and large EPA investment in projection monitors built into most conference rooms. (Immediately after installing the conference room monitors, the building's ENERGY STAR rating dropped 2 percentage points.) The building data center may also have played a role in the higher than expected process energy loads EPA is responding to recommendations from the National Renewable Energy Laboratory on actions to reduce the data center's energy use. Some steps such as increased virtualization has already begun. Additional improvements will proceed as funds become available.

While most buildings continue to consume energy throughout the night, the EPA's evening closing time and daytime cleaning regimen means the building can be nearly turned off for 10 hours, or 42 percent of each day. This substantially reduces energy expenses and light pollution. In 2007 alone, daytime cleaning reduced the building's energy costs by 28 percent, saving building owners nearly $250,000, or $0.80/square foot. A final ENERGY STAR rating of 94 significantly exceeded the goal of 75.

Water

Water use in the Wynkoop building improved significantly once the building engineer identified the source of the initial high use—the building's steam system. During a visual inspection of the system, the building engineer discovered that a plumber had installed a cold-water make-up valve next to the steam system's discharge point. The valve was installed to reduce water temperature before discharge. The water temperature at the discharge point was above 175°F, hot enough to melt plastic parts in the pumping system that returned hot water to the sanitary sewer. This valve operated almost continuously, dumping large volumes of potable water into the sanitary system—31,000 gallons in just 2 days. The building engineer reprogrammed the circulation system to send the steam and hot water condensate through the parking level piping three times (instead of once), which brought the temperature down sufficiently to discharge it safely into the sanitary sewer pumping system.

Later research suggested that additional savings could be achieved by changing the flush handles on the dual-flush toilets in the building. Submetering on the 7th floor showed that a full flush intended for solid waste (a downward movement of the handle) was used more frequently than the low flush (an upward movement of the handle). As a result of these data, the flush handles on all toilets in the building were replaced. The new handle activated a low-volume flush with downward movement, and a high-volume flush with upward movement. However, the overall volume of water saved by handle replacement could not be accurately calculated, due to high variability in occupancy, concerns about the accuracy of the monitoring equipment, and the high variation in water pressure between floors, which may have influenced flush volumes.

An analysis of total domestic water demands in the Wynkoop building during 2010 and 2011, after the circulation system was reprogrammed, showed that water use was very close to the estimate for the original LEED application, once the LEED values were adjusted to reflect actual building occupancy and faucet flow rates. Actual domestic water use of approximately 5.34 gcd in 2010 and 5.25 gcd in 2011 tracked closely with the LEED projected demand of 5.44 gcd.

Waste

EPA maintains an active recycling program for all forms of mixed paper and cardboard; aluminum cans and metals; glass and plastic bottles; and batteries, videotapes, electronics, inkjet cartridges, and other "techno-trash." Used office supplies are collected through the central supply center and collection points on each floor. Two years after occupancy, EPA Region 8 successfully instituted a composting program, diverting bathroom paper towels (a major waste stream) along with food wastes. The waste management company used by the region provides monthly summaries of waste and recycling volumes, including GHG emission calculations.

The region also has an aggressive electronics stewardship program and has developed life-cycle management procedures to ensure that obsolete electronics are recycled, reused, or disposed of in environmentally safe manner.

Paper use is a major environmental impact. Region 8 used its move to the building as an opportunity to establish a centralized records management system, with electronic search aids and controls to make it easier for employees to file and retrieve documents. This system has reduced the need for large amounts of floor space dedicated to paper storage, which translates into reduced square footage and associated rent savings.

For LEED certification, the building achieved all LEED construction waste management credits, including an 80 percent waste diversion rate with a GHG reduction of 447 MT CO_2e, and all LEED credits for alternative construction materials except rapidly renewable.

Daylight and Electric Light

The lighting system includes several sustainable design elements:

- Open workspace around the perimeter, with enclosed offices clustered around the core to enhance daylight penetration
- Daylight in 84 percent of regularly occupied spaces
- Exterior shading and interior light shelves
- Daylight-responsive lighting controls (with a range of 30–100 foot candles)
- Occupancy sensors that turn off lights after a period of inactivity, then automatically turn them on when someone enters a room
- Reduced lighting power density—T5 direct/indirect fluorescent pendants with compact fluorescents (approximately 0.8 watts/ft^2).

The system overall has met with mixed success. Defective ballasts in the dimming lights led to a replacement of all ballasts at a significant expense, and an error in programming automated blinds took months to resolve.

An analysis of lighting levels over the course of several days in selected workstations showed high variation in daylight levels on the south side of the building, with some spaces near the windows very bright and those in interior spaces much dimmer. A survey showed that people were concerned with glare, but they said they did not operate the blinds manually to control glare. Feedback from employees to EPA building management staff indicated dissatisfaction with the automated controls that would turn lights on or off with changes in occupancy. Informal behavioral observations showed that electric lights in perimeter spaces would go on even when there was sufficient daylight in the space, suggesting that "vacancy" sensors that turn lights off when people leave a space would be more energy-efficient than lights that automatically turn on when someone enters.

Operating Costs

Operating costs average 43 percent lower than industry baselines for energy, water, and maintenance. Janitorial and grounds expenses are also lower than the baseline, while waste and recycling costs are higher than the industry baseline. Specific results include the following:

- Energy: $1.48/rentable square foot (RSF)
- Water: $0.04/RSF, $9.95/occupant
- General maintenance: $0.74/RSF
- Janitorial: $1.04/RSF
- Grounds: $0.07/RSF.

Continuous Improvement

The results for each of these major areas of operations show that EPA is deeply committed to continuous measurement and improvement of building operating conditions.

Overall, research and feedback on building operations show that this indicator of success has been largely achieved, with the exception of daylighting, which continues to pose some operational and comfort issues.

Occupant Experience and Livability

The central idea behind evaluating occupant experience is that buildings are habitats for people and, as such, should be healthy, productive, and inspiring. Assessing occupant experience includes analyzing occupant behavior and comfort as well as measuring the physical qualities of the workspace (acoustics, air quality, and thermal conditions).

Satisfaction with Ambient Conditions

Close to 70 percent of survey respondents were satisfied with air quality, visual privacy, visual comfort, amount of light, and amount of daylight. Air quality had the highest satisfaction level (78 percent); the lowest scores were for speech privacy (42 percent satisfied), thermal conditions (50 percent satisfied), and noise (52 percent satisfied). Noise concerns stemmed primarily from people talking nearby. Despite some concerns about glare and varying light levels, close to 70 percent of the occupants said they were satisfied with daylight. Air quality ratings were high, falling into the 85th percentile of the CBE's database. It is worth noting that acoustics and thermal conditions tend to have lower satisfaction levels in general in the CBE database and other research studies, due to high variation in thermal preferences and high variability in task needs for occupant focus and engagement.

Overall Building and Workspace Satisfaction

Occupants were highly satisfied with the building overall (83 percent satisfied) and with their personal workspaces (79 percent). The satisfaction levels were higher than what might be expected from the findings on ambient comfort, suggesting that many other factors enter into building and workspace satisfaction judgments.

Work Behaviors

The survey also addressed communication behaviors. Close to 80 percent of the occupants said that communication within their groups was good and, further, that they learned a lot by seeing and hearing others. This may appear to contradict concerns cited above regarding voice privacy and noise distractions from people talking nearby. However, research on the character and flow of knowledge work shows that people value focus as well as engagement and serendipitous encounters. These are mutually exclusive behaviors and thus create the potential for conflict.

Emotional Experience

Close to 80 percent of the occupants said they looked forward to working in the building and were proud to show the office to visitors. Open-ended comments showed that employees were most likely to show visitors the atrium and the green roof. The functionality analysis, however, revealed concerns about the building's lack of warmth and sense of place, with one person describing the building as a "beautiful corpse." Some suggested more visual decor and color. EPA took these comments to heart and asked employees to embellish the walls with their own photos. Large color photos of landscapes, water, and sky now adorn the office spaces and hallways throughout the building, creating a stronger sense of place and connection to the EPA mission.

Office Functionality

A functional analysis and opportunistic conversations by a GSA workplace team revealed challenges for individual and team work, as well as a lack of technology supports for mobile work. Many employees are largely deskbound due to extensive use of paper documents and conference calls that often require viewing documents on the computer. Cell phone reception is not uniform, so moving conversations to more private areas is difficult. Un-tethering and reconnecting laptops is also a challenge if people want to work in different locations within the building. Although there was high satisfaction with conference rooms and planned meetings, many felt the space afforded less support for spontaneous meetings and shared group materials. The fact that cubicle partitions were high in order to support visual and voice privacy meant that it was difficult to see activity elsewhere in the building. The atrium was intended, in part to provide visual access throughout the building, but partitions block views into work areas and greatly reduce the sense of social engagement.

Physical Measures of Ambient Conditions

Analysis of acoustics, thermal conditions, air quality, and lighting showed that conditions were largely within recommended ranges. Nonetheless, there were concerns and dissatisfaction, especially with thermal and acoustic conditions. The detailed acoustic analysis included recommendations on improving the sound masking system in the UFAD system to increase privacy and reduce noise hot spots.

Livability indicators overall show some mixed results. EPA staff are highly satisfied with the ergonomic features of the workstations, conference rooms, and sustainability features of the building. However, they express lingering concerns about the sense of community and ability to engage with colleagues informally.

ORGANIZATIONAL EFFECTIVENESS

An office building is more than a way to house an organization's workforce. Buildings are intended also to support an organization's mission and to carry out successfully its full range of activities and functions. For EPA, these organizational needs include support for current and future functionality, supporting the work of individuals and cross-program (or "multimedia") teams, ability to adapt to changing federal mandates, being viewed as a good neighbor, and having a reputation as a good steward of the environment.

Creating Work Environments to Support Cross-Program Teams

Effective teamwork requires a multiplicity of meeting types and meeting spaces. Some meetings are impromptu stand-ups around a data display, while others require working side by side at a computer, with a larger group in a technology-aided formal meeting, or with colleagues in different locations, including in the field and the office. In addition to meetings, teamwork is aided by spontaneous conversations at natural meeting places—in hallways, at the printer, at the coffee pot, or in doorways.

The functionality analysis showed that the conference rooms were very successful in supporting technology-aided meetings and presentations, but that informal, spontaneous meetings and conversations were more difficult. In part this is due to people being separated physically, often on different floors, and to organizational rules that disallow information displays (such as maps or data plots) on walls or cubicle partitions. The informal team meeting spaces within the open-plan space are unsuccessful, because the noise generated from meetings in them disturbs others trying to do focused work.

Ability to Adapt to New Ways of Working and Future Needs

Workplace design is largely an adaptation to past or current ways of carrying out business. As the nature of work changes—often in ways that cannot be fully anticipated—how does an organization adapt? This was a central question facing EPA during 2011 when GSA conducted its workplace functionality assessment. Conversations with regional leadership revealed a desire to "pull to the future"—that is, to gather intelligence on social, environmental, technology, and design trends that are likely to influence work practices, including where people will be working, how they work best in teams, and how to train and provision a more mobile workforce. Of the experiments now taking place in the private and public sector, what seemed to be working well and what didn't work as well? What lessons could be applied to EPA?

The functionality assessment showed a heavy focus on individual work at the office, dependence on paper documents, more scheduled than spontaneous team interactions, and a lack of technologies and policy to support shifts to new ways of working.

EPA began collaborating with the GSA regional team that was working on a new workplace initiative linking mobility, sense of community, sustainability, and health. The EPA facilities group and a couple of other groups decided to create experimental work spaces to implement some of the ideas from the GSA regional group and the functionality report. However, there was no strong interest among the employees beyond -these group to extend the experiment to other groups in the building.

While the interest in flexibility, new ways of working, more efficient use of space, and technology supports for a more mobile workforce remains strong among EPA regional leadership, these ideas have not taken hold among the staff. Furthermore, plans to redesign the space and invest in new technologies have run into budget constraints. As a result, workplace changes are largely on hold.

Personal Productivity Impacts

A major component of organizational effectiveness is the productivity of its workforce. Organizations invest heavily in training and development to improve work effectiveness. The work environment is increasingly being viewed as an investment in productivity enhancement and not just as a means of housing the workforce. Understanding how workers view their own performance is one useful indicator of the success or failure of the physical workplace. Survey results show that 62 percent of respondents believe the overall quality of the facility’s office environment improves their productivity.

Reputation and Awards

The Wynkoop building has received significant media attention and numerous design awards. Awards include the Office Development of the Year from the National Association of Industrial and Office Properties, Architecture Magazine’s Research and Development Award for the atrium daylight control system, the People’s Choice award from the Associated General Contractors of Colorado, the Chicago Athenaeum: Museum of Architecture and Design Award given to the building’s architect ZGF, and two White House Closing the Circle Awards.

The overall results for organizational effectiveness show that the building design and operational practices contribute strongly to EPA’s reputation. However, they afford less support for adapting to future work needs, including space, work practices, cross-program teams, technology supports, and policy changes.

THE BUILDING AS A LEARNING LAB AND TEACHING TOOL

In view of its mission, EPA devoted extra resources to achieving the project's sustainable goals so it might be used as a teaching tool for the agency. The building is regularly host to symposia and workshops, and more than 9,000 people have toured it. Visitors have included elected representatives and staff from local and state governments, developers, architects, designers, lenders, other federal agencies, and foreign visitors.

Working in an Integrated Team

The Wynkoop building was a learning lab from the beginning of the project. The integrated team process and design decisions became the basis for an internal GSA training module for the Learning from Our Legacy program. The module, prepared by the Harvard Graduate School of Design, is a real-life primer on how the team worked, the difficulties they faced, and how they resolved problems.

Establishing Best Practices

The project yielded numerous best practices for design and operations, as well as protocols for evaluating building performance, beginning with the integrated team process and performance-based contracting. The Harvard Legacy Series analysis of the project team affords many lessons learned and best practices for working across disciplines and solving problems as they emerge. The water research resulted in a protocol that can be readily adapted for use by others to evaluate indoor water use with temporary meters and other devices. The protocol can assess water pressure by floor, fixture use in restrooms and gym facilities, and whole-building use over time. The green roof research generated best practices that have been adopted by the Denver metro-area flood and stormwater management agency. The UFAD study provides guidance for evaluating the effectiveness of a UFAD system. Protocol components include a survey of occupants and building managers, analysis of plenum leakage, thermal performance measurement using a portable cart, analysis of utility bills, and information on the design and operation of the system. The analysis of sound-masking in the UFAD system is applicable to other buildings that use this workspace acoustic approach, while also providing guidance for placing and tuning sound-generating equipment. The data center research and recommendations are applicable to older data centers, which many buildings still support.

Using Data to Inform Practice

Each of the research studies produced results that were used by building operations as well as EPA leadership to improve the building's performance and identify areas for further investigation. For instance, the functionality assessment provided options for increasing flexibility and responding to the changing nature of work. The acoustics research identified solutions for reducing concerns with the sound masking system, and the data center analysis suggested numerous ways to reduce energy consumption.

The Building as a Teaching Tool

EPA has undertaken a number of activities to educate people about the building's performance, including publication of a case study, maintenance of a webpage, a video demonstrating building features, a tour program, and collaboration with several schools (from elementary to university level). Regional management has also made the building widely available to researchers and educators for ongoing evaluation of building performance and student projects. Many of these projects are highlighted in this report.

To ensure that findings and best practices reach audiences that can use them, GSA's Office of Federal High Performance Green Buildings will collaborate with EPA to create a communications program to reach a wide range of audiences, including building science and design faculty in architecture programs, academic researchers, facility managers, organizational decision makers, workplace experts, architects, and design consultants. The final overall report, plus all of the detailed research reports and other content created in the future, will be posted on various web sites, including those of EPA Region 8 and the GSA Office of Federal High Performance Green Buildings. Results from the research will be available on web sites for other federal agencies and organizations devoted to building research and information, such as the Whole Building Design Guide (http://www.wbdg.org) and GSA's Sustainable Facilities Tool (http://www.sftool.gov/).

The overall results for using the building as a learning lab and teaching tool show an unusual dedication by EPA to not only use information to improve the building's performance, but also to share that information with others who can use it to improve the design and operations of high-performance green buildings.

Concluding Remarks

We return at this point to the question we posed to start: Is the Wynkoop building successful? We have addressed issues of what success means, for whom, and how success itself is a continuous development, not a point in time.

The breadth and depth of research addressing this question indicate a remarkable achievement. Although many federal buildings have had post-occupancy evaluations, none have had as many researchers studying its design process or analyzing building performance across many facets to learn how it works and how to fix what is not working as well as desired.

The building can readily be considered a success on many levels. Like all research programs, the studies described in this report also identify knowledge gaps and issues that need further research, such as designing for change and flexibility, and anticipating the future during design and development, especially in modeling energy use and human behavior.

Even as the formal research program comes to an end, work will continue on fine-tuning the building and meeting the myriad challenges of the future, from energy to changes in work practices.

Appendix A
Additional Information on the Wynkoop Building

The tables in this appendix present additional information on the following aspects of the Wynkoop building:

- Notable certifications, awards, and presentations.
- Construction and operating costs.
- High performance features.
- High performance design targets and measured performance.
- LEED credits pursued and points achieved.
- Transportation features

Table A-1. Notable Certifications, Awards, and Presentations

Recognition	Description
LEED for New Construction 2008: Gold	40 of 69 points awarded (7 points not awarded because of poor documentation submitted by developer)
ENERGY STAR rating: 96 (2008)	Now 90 due to a recalculation in November 2011
Downtown Denver Partnership Annual Award (2006)	For incorporating the preservation of the environment into the design and construction process, setting the standard for future sustainable office development in downtown Denver, while designing a building that is sensitive to its place in the historic Lower Downtown district. http://www.downtowndenver.com/Membership/Opus.htm
National Association of Industrial and Office Properties (2006)	Office Development of the Year

Recognition	Description
Architect Magazine R&D Award: Atrium Daylight Control System (2007)	Katie Gerfen, Architect Magazine. http://www.architectmagazine.com/natural-metals/atrium-daylight-control-system.aspx
Associated General Contractors of Colorado (2007)	Jack Mincher's People's Choice Award
The Chicago Athenaeum: Museum of Architecture and Design: Zimmer Gunsal Frasca (2008)	This internationally recognized award highlights the most significant new contemporary architecture of the year. http://www.chi-athenaeum.org/archawards/2008/index.html
Federal Electronics Challenge, Gold Level (2008)	The Office of the Federal Environmental Executive and EPA recognized the achievements of the EPA Region 8 for leadership in the Federal Electronics Challenge during 2007. Electronics stewardship actions undertaken have helped the federal government improve its sustainable practices when purchasing, managing, and disposing of their electronics assets.
US Key Indicators and Performance Metrics, SB 08 Conference, International Initiative for a Sustainable Built Environment (2008)	GSA/USGBC (Poster session and slideshow): Showcased existing performance metrics, US project metrics (design to actual), and next steps toward future indicators and metrics
White House Closing the Circle Awards (2009)	Sustainable Design/Green Buildings and Electronic Stewardship. http://www.fedcenter.gov/opportunities/awards/greengovpresidentialawards/ctcwinners2009/

Table A-2. Summary of Construction and Operating Costs

Project phase	Associated costs
Design and construction costs[a]	Core and shell costs: $90 million Premium costs: ◆ Security: $10–$12/square foot (principally concrete hardening and progressive collapse) ◆ Sustainability not tracked Tenant improvements: ~$3.5 million (interior workspaces, upgrade lighting, carpets, wall treatments)
Operating costs (annual)[b]	Average 43% lower than industry baseline (energy, water, maintenance, janitorial, and grounds are lower than baseline; waste and recycling are higher than industry baseline) Energy: $1.48/RSF Water: $0.04/RSF, $9.95/occupant General maintenance: $0.74/RSF Janitorial: $1.04/RSF Grounds: $0.07/RSF

a "EPA Region 8 Headquarters: Denver, Colorado, Harvard Legacy Case Study," Julie Walleisa and Professor Spiro N. Pollalis (2006), and "EPA Region 8 Headquarters: Denver, Colorado (Case B)," Anthony Kane and Professor Spiro N. Pollalis (2010).

b K. Fowler, E. Rauch, J. Henderson and A. Kora, 2010. Reassessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings. Pacific Northwest National Laboratory.

Table A-3. Summary of High Performance Features

Building component	Features
Envelope	◆ Double-L design responds to local site conditions; HVAC is separately controlled in the two Ls ◆ Central daylight atrium extends the entire height of the building ◆ Insulation: R19 walls and R31 roof; exposed concrete interiors provide thermal mass ◆ Low emissivity, solar heat gain, and visible transmittance windows on southeast/southwest building L ◆ Vegetated green roof on all three levels of roof (8th and 9th floors and equipment penthouse)
HVAC	◆ Two 450-ton variable-frequency-drive chillers with air-side economization ◆ Hot water provided through a heat exchanger attached to a district steam line ◆ Variable-frequency drives on chiller and fans, low-energy premium motors ◆ UFAD system delivers 240,000 cfm tempered air while reducing cooling demand approximately 7°F (floors 4–9) ◆ CO_2 monitoring throughout building, MERV 11–13 filters
Lighting	◆ Open floor plan workspaces around the perimeter with enclosed offices clustered around the core; 90% of occupied spaces are daylit ◆ Exterior shading and interior light shelves ◆ Daylight-responsive lighting controls (within a 30–100 foot candle range) ◆ Reduced lighting power density: T5 direct/indirect fluorescent pendants with compact fluorescents (approximately 0.8 watts/square foot) ◆ Occupancy sensors (auto on); building control system turns lights on/off around normal working hours
Water	◆ Low-flow faucet fixtures ◆ Low-flow dual-flush toilets ◆ Waterless urinals ◆ Low-flow, time and weather station controlled irrigation system (vegetated roof)

Building component	Features
Vegetated roof	◆ High-albedo, ENERGY STAR branded EPDM membrane with a high-emissivity acrylic coating ◆ Vegetated roof on all three levels: ▶ 19,200 square feet ▶ Modular system—2×2 feet and 2×4 feet ▶ 4 inches of growing medium; sedum varieties and native/adaptive xeric plants ◆ Stormwater management system: ▶ Growing medium in the vegetated roof systems captures and slows rainfall/snowmelt ▶ Downsized detention tank in the parking detains and slows water from non-vegetated areas of the roof
Materials	◆ Recycled content materials: High volumes of fly ash in concrete, high percentages of recycled steel, countertops made from recycled glass and concrete, carpet tiles with post-consumer recycled materials, linoleum flooring from cork (post industrial waste), rubber (recycled tires), and linoleum ◆ Bio-based, rapidly renewable materials: Wheatboard workspace countertops; bamboo floors, stadium seating, and wall coverings; sustainably managed plywood and wood in doors and decorative finishes
IEQ: occupant health and productivity	◆ CO_2 monitoring ◆ Separately ventilated areas for high-volume copiers and mixing of chemicals (cleaning supplies) ◆ Low-emitting adhesives/sealants, paints/coatings, carpet, composite wood ◆ Indoor thermal comfort set-points, and temperature and humidity monitoring system controlling HVAC ◆ UFAD diffusers allowing occupant control ◆ 90% of occupied spaces have access to daylight and views
Transportation	◆ Adjacent to mass transit hub; EPA provides annual bus passes for all employees ◆ Bicycle access, bike parking, and shower facilities available in the building ◆ Preferential parking for car pools
Operations	◆ More than 80% of construction waste recycled ◆ 60% diversion rate for operational waste ◆ Electronics stewardship—Federal Electronics Challenge Gold Facility ◆ Daytime cleaning allows lights to be turned off at 6:00 p.m.

Table A-4. Summary of High Performance Design Targets and Measured Performance

Target area	Baselines	Design goals	Measured performance
LEED New Construction (NC) (2008) Certification	None	Silver	Gold
Energy	None	ENERGY STAR 86	ENERGY STAR 96[c] (90 in 2013)
	CBECs: 88 kBtu/gsf ASHRAE 90.1-1999: 71 kBtu/gsf GSA: 55 kBtu/gsf	◆ Modeled: Solicitation ▶ 47.5 Btu/sf/yr and 39% better than ASHRAE 90.1-1999[a] ◆ Modeled: Final design ▶ 52 kBtu/gsf/yr and 25.4% better than ASHRAE 90.1 1999[b] ◆ Energy cost improvement method (LEED, final design): 35% better than ASHRAE 90.1-1999	76 Btu/gsf/yr[c] Scope 2 GHG emissions(CO_2e): 4.09 MT/occupant[c]
Water	Design case: 3,372,189 gal/year	◆ 1,719,738 gal/year[d] ◆ 49% below LEED base case (EPAct 1992)[e] ◆ Water closets: 1.6 gpf ◆ Urinals: 1.0 gpf ◆ Showerheads: 2.5 gpm ◆ Faucets: 2.5 gpm	3,970,00 gallons/year[c] 3,500 gallons/occupant 13.18 gallons/gsf
Vegetated Roof	None	Estimated 26.7% reduction in stormwater runoff	Not measured
		Estimated removal of 80% of total suspended solids and 40% of total phosphorus	Not measured
		Heat island mitigation (demonstration research)	Not measured
Materials	None	◆ SFO required construction waste management plan with list of minimum items to be recycled[f]	◆ All LEED construction waste management credits achieved
		◆ SFO required recycling collection system built into design with recycling plan for operations	◆ LEED prerequisite achieved ◆ 80% waste diversion rate

Target area	Baselines	Design goals	Measured performance
			◆ GHG reduction of 447 $MTCO_2e$ (2010)
		◆ SFO required that building façade be made from local/regional materials	◆ LEED credit achieved
		◆ SFO specified that "environmentally preferable products" and materials be used where economically feasible; such products and materials: ▶ contain recycled material, are biobased, or have other positive environmental attributes; ▶ minimize the consumption of resources, energy, or water; ▶ prevent the creation of solid waste, air pollution, or water pollution; and ▶ promote the use of non-toxic substances and avoid toxic materials or processes	◆ All LEED credits for alternative materials achieved, except rapidly renewable materials
IEQ—Occupant Health and Productivity	None	SFO specified ASHRAE standards for basic and increased ventilation, thermal comfort and control, CO_2 and indoor chemical pollutant control, construction IAQ management plan, and pre-occupancy flushout	All requirements achieved, but some LEED credits not awarded due to documentation issues
		SFO specified sustainable cleaning products and integrated pest management plan, no urea formaldehyde or arsenic treated wood, low VOC carpets, plastic laminate, wall coverings, paints, adhesives and sealants, low lead paint	Achieved; all but one LEED credit awarded (documentation issues)
		Maximize daylight	84% of occupied spaces daylit; LEED credit not awarded due to documentation issues
		◆ Allow consolidation of 850 staff on fewer floors (relative to previous space) ◆ Enhance occupant health, well-being, and productivity through indoor air quality and access to daylighting	Occupant satisfaction 57th percentile (41% return rate) Categories: workplace, communication, acoustic quality, air quality, windows and daylighting, thermal comfort, cleanliness, maintenance,

Target area	Baselines	Design goals	Measured performance
			security above median; lighting below median
Transportation	None	Access to alternative transportation options was a site selection criterion	87% occupant commute rate, avg. 26 miles/occupant
		Provide 70 secured bike parking spaces, 31 carpool spaces	Achieved Scope 3 GHG emissions (CO_2e): 0.58 MT/occupant

[a] Whole Building Design Guide case study, Zimmer Gunsul Frasca (ZGF)/Opus presentations.

[b] LEED NC documentation and approval letter (Energy & Atmosphere Credit 1).

[c] K Fowler, E Rauch J Henderson and A Kora, 2010. Reassessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings. Pacific Northwest National Laboratory.

[d] LEED NC documentation (Water Efficiency Credit 1).

[e] LEED NC approval letter (Water Efficiency Credit 1).

[f] The SFO list of minimum items to be recycled during construction includes: ceiling grid and tile, light fixtures, including proper disposal of any transformers, ballasts, and fluorescent light bulbs; duct work and HVAC equipment; wiring and electrical equipment; aluminum and/or steel doors and frames; hardware; drywall; steel studs; carpet, carpet backing, and carpet padding; wood; insulation; cardboard packaging; pallets; windows and glazing materials; all miscellaneous metals (as in steel support frames for filing equipment) and all other finish and construction materials; land clearing debris; wood composite materials, such as plywood, OSB, and particle board; concrete masonry units; bricks, concrete, and asphaltic concrete; paint; and plastic film (including high density polyethylene).

Table A-5. Summary of LEED Credits: Energy and Atmosphere

Design element	LEED credit
Optimizing energy performance: 35% less than 90.1-1999 (52kBtu/gsf/yr) (Exemplary performance point)	6 points
Green power (Exemplary performance point)	2 points
Commissioning	1 point
No chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), or halons in HVAC	1 point

Design element	LEED credit
Mechanical and ventilation (metering) Lighting systems and controls Constant and variable motor loads Variable frequency drive operation Chiller efficiency at variable loads (KW/ton) Cooling load Air and water economizer and heat recovery cycles Air distribution static pressures and ventilation volumes Building related process energy systems Indoor water risers and outdoor irrigation systems	1 point
Total	11 points

Table A-6. Summary of LEED Credits: Water Efficiency

Design element	LEED credit
Water efficient landscaping ◆ Drip irrigation of street trees	2 points
Water use reduction (Exemplary performance point) ◆ Low-flow faucet fixtures ◆ Low-flow dual-flush toilets ◆ Waterless urinals ◆ Low-flow, time- and weather-station-controlled irrigation system (vegetated roof)	3 points
Total	5 points

Table A-7. Summary of LEED Credits: Indoor Environmental Quality

Design element	LEED credit
CO_2 monitoring (Denied: Drawings did not show location of the CO_2 monitors)	—
IAQ performance/ventilation effectiveness	1 point, 2

Design element	LEED credit
ASHRAE 62-1999 ventilation air quality standard and ASHRAE 129-1997 air change effectiveness Non-smoking facility	Prerequisites
Construction IAQ management plan (Denied: Insufficient documentation) Partial flush-out and air monitoring	—
Low-emitting materials (1 point denied: Inadequate documentation) Low emitting adhesives/sealants, paints/coatings, carpet, composite wood	3 points
Indoor chemical and pollutant source control (Denied: Template incorrectly filled out) Separately ventilated areas for high-volume copiers and mixing of chemicals (cleaning supplies)	—
Controllability of systems (Denied: Need separate control of lighting and thermal comfort UFAD diffusers	—
Thermal comfort Indoor thermal comfort set-points in accordance with ASHRAE standard 55-2004 Temperature and humidity monitoring system controls the HVAC system	2 points
Daylight and views (Denied: Documentation not legible) 90% of occupied spaces have access	—
Total Points Earned	5 points

Table A-8. Summary of LEED Credits: Materials and Resources

Design element	LEED Credit
Storage and collection of recyclables	Prerequisite
Construction waste management ◆ 80% of construction waste recycled	2 points
Recycled content (31% total) ◆ Recycled steel rebar (80–100%) and aluminum in construction materials ◆ Fly-ash (25%) in concrete ◆ Recycled glass content in bathroom countertops ◆ Recycled aluminum in reception countertops ◆ Recycled content in carpets (average 40%, including both polyethylene terephthalate (PET) and recycled carpet content) ◆ Floor coverings made from recycled cork, recycled tires and linoleum	2 points

Design element	LEED Credit
Local/regional materials ◆ 50% of the materials used were manufactured locally ◆ 59% of materials were extracted, harvested, or recovered within 500 miles	2 points
Certified wood (89%) ◆ Wheatboard, plywood, doors and finish woods (maples and cherry)	1 point
Total	7 points

Table A-9. Summary of LEED Credit Elements: Vegetated Roof

Design element	LEED Credit
Stormwater management, treatment Growing medium in the vegetated roof system captures and slows rainfall/snowmelt, directing water through interior "gutters" Downsized detention tank in the parking detains and slows water from non-vegetated areas of the roof	1 point
Landscape and exterior design to reduce heat islands, roof High-albedo, ENERGY STAR branded ethylene propylene diene monomer (EPDM) membrane with a high-emissivity acrylic coating Vegetated roof on all three levels: 19,200 ft2 square feet Modular system—2'x2' and 2'x4' 4" growing medium; sedum varieties & native/adaptive xeric plants	1 point
Total	2 points

Table A-10. Summary of LEED Credits: Alternative Transportation

Design element	Credit
Public Transportation Access, Bicycle Friendly, Alternative Fuel Refueling Station Adjacent to mass transit hub; EPA provides annual bus passes for all employees Bicycle access, bike parking and shower facilities available in the building Preferential parking for car pools	3 points
Parking Reduction (Denied: Documentation not adequate or submitted improperly)	
Total	3 points

ALTERNATIVE TRANSPORTATION

The building's proximity to public transport, coupled with transit passes provided to occupants, has enabled more than 80 percent of the occupants surveyed to take some type of alternative transportation to this workplace. The building's location near Denver's Union Station offers access to multiple public transportation options, including bus, light rail, and an extensive bicycling network. Bike parking and shower facilities are available in the building, along with preferential parking for car pools.

Electric vehicle charging stations were built into the parking area in anticipation of this new technology. Four years after occupancy, however, EPA began looking into purchasing electric cars and found that the charging stations were outdated and would have to be replaced.

The region has also invested heavily in video-conferencing to reduce energy-intensive travel for meetings. Decreasing travel budgets have also promoted greater utilization of video-conferencing.

Appendix B

Additional Resources

INTEGRATIVE TEAMS AND PERFORMANCE-BASED PROCUREMENT

Atrium Daylight Control System

Architect Magazine, Katie Gerfen, September 1, 2007
http://www.architectmagazine.com/natural-metals/atrium-daylight-control-system.aspx

US EPA Region 8 Green Building Self-Guided Tour

http://www.epa.gov/region8/building/mobiletour.html

EPA Region 8 Headquarters: Denver, Colorado, Harvard Legacy Case Study

Harvard, Julie Walleisa and Spiro N. Pollalis, October 2006
http://www.gsd.harvard.edu/images/content/5/3/538952/fac-pub-pollalis-case-EPA-Denver-public-version-Oct2006.pdf

EPA Walks the Walk on New Denver Headquarters

New West, Headwaters News, March 2007
http://newwest.net/main/article/epa_walks_the_walk_on_new_denver_headquarters/

Force of Nature

Buildings, Chelsea Houy, September 2009
http://www.buildings.com/article-details/articleid/5155/title/force-of-nature.aspx

Good Neighbors

Daily Kos, Mark Summer, August 2008
http://www.dailykos.com/story/2008/08/31/575517/-Good-Neighbors

Green Building and Green Operations

EPA Region 8 web page
http://www.epa.gov/region8/building/index.html

EPA Headquarters, Greening the Mile-High City: A dramatic central atrium and a green roof elevate the profile of this federal office building

Green Source, Jessica Boehland, September 2008
http://greensource.construction.com/projects/0809_EPAHeadquarters.asp

USEPA Region VIII Opens Green Denver Headquarters

Tree Hugger, John Laumer, March 2007
http://www.treehugger.com/corporate-responsibility/usepa-region-viii-opens-green-denver-headquarters.html

Whole Building Design Guide

EPA Region 8 Headquarters
http://www.wbdg.org/references/cs_epadenver.php

ENERGY DESIGN GOALS AND WHOLE BUILDING PERFORMANCE

Assessing Green Building Performance: A Post Occupancy Evaluation of 12 GSA Buildings

Pacific Northwest National Laboratory, Kim Fowler, Emily Rauch, Jordan Henderson, Angela Kora, June-July 2008
Full Report: http://www.gsa.gov/graphics/pbs/GSA_Assessing_Green_Full_Report.pdf
White Paper: http://www.gsa.gov/graphics/pbs/GSA_AssessGreen_white_paper.pdf

The Case for Daytime Cleaning

Edc, Amy C. Smith, November 2008
http://www.edcmag.com/articles/the-case-for-daytime-cleaning

Data Center Energy Efficiency Site Assessment

National Renewable Energy Laboratory, Ian Metzger, Otto VanGeet, and Chuck Powers, May 6, 2011

Plug Load Behavioral Change Demonstration Project

National Renewable Energy Laboratory, Ian Metzger, Alicen Kandt, and Otto VanGeet, July 2011

Re-Assessing Green Building Performance: A Post Occupancy Evaluation of 22 GSA Buildings

U.S. GSA Public Buildings Service, August-September 2011
Full Report: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19369.pdf
White Paper: http://www.gsa.gov/graphics/pbs/Green_Building_Performance.pdf

WATER PERFORMANCE

Behavioral Economics and the Design of a Dual-Flush Toilet

Journal of American Waterworks Association, Arocha, Jade S., McCann, Laura M.J., February 2013
Abstract: http://www.awwa.org/publications/journal-awwa/abstract.aspx?articleid=35092845

Water Use Field Research and Baseline Assessment

Koeller and Company, Yorba Linda, CA, and Gauley Associates Ltd. Acton, Ontario, Canada

VEGETATED ROOF

EPA Region 8 Headquarters Operations and Maintenance Manual

Bison Green Roof Consulting Services, 2010
Practice Manual

Extensive Green Roof Species Evaluations Using Digital Image Analysis

HortScience Vol. 45(8), Jennifer M. Bousselot, James E. Klett, and Ronda D. Koski, Department of Horticulture and Landscape Architecture, Colorado State University, August 2010
Full Report: http://greenroof.agsci.colostate.edu/species_evaluation_2010.pdf

Justification for Recommendations Green Roof Operations and Maintenance Manual

Bison Green Roof Services, Mark Fusco, 2010
Appendix to EPA Region 8 Headquarters Operations and Maintenance Manual

Moisture Content of Extensive Green Roof Substrate and Growth Response of 15 Temperate Plant Species during Dry Down

HORTSCIENCE 46(3), Jennifer M. Bousselot, James E. Klett, and Ronda D. Koski, Colorado State University, Department of Horticulture and Landscape Architecture, March 2011
Full Report: http://greenroof.agsci.colostate.edu/substrate_moisture_content_2011.pdf

PhD Dissertation: Extensive Green Roofs in Colorado: Plant Species Performance, Growing Media Modifications and Species Response to Growing Media Dry Down

Department of Horticulture and Landscape Architecture, Colorado State University, Jennifer McGuire Bousselot, Spring 2010

Thermal Characteristics of an Extensive Green Roof and a Gravel Ballasted Roof in High Elevation, Semi-arid, Temperate Denver, Colorado, U.S.A.

Environmental Protection Agency, Thomas J. Slabe and Thomas P. O'Connor, December 2011

Materials Use, Waste Reduction and Recycling: Design Goals

Region 8 Case Study on the Purchase of "Green" Office Furniture

EPA Region 8, Whitney Trulove-Cranor, January 25, 2006

Indoor Environmental Quality and Occupant Experience

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Appendix C

Abbreviations

AEAMB	Architecture, Engineering and Asset Management Branch
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
CAM	Crassulacean acid metabolism
CBE	Center for the Built Environment
CBECS	Commercial Building Energy Consumption Survey
cfm	cubic feet/minute
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CPU	central processing unit
CRAC	Computer Room Air Conditioning
CWM	construction waste management
DDC	direct digital control
DOE	Department of Energy
DX	direct expansion
EAc1	Energy and Atmosphere credit 1
EMM	Energy Manager with Monitoring
EPA	Environmental Protection Agency
EPAct	Energy Policy Act
EPDM	ethylene propylene diene monomer

FTE	full-time equivalent
gcd	gallons per capita per day
GHG	greenhouse gas
gpf	gallons per flush
gpm	gallons per minute
GSA	General Services Administration
gsf	gross square feet
HP	horsepower
HVAC	heating, ventilation, and air conditioning
IAQ	indoor air quality
IEQ	indoor environmental quality
IT	information technology
kBtu	thousands British thermal units
kW	kilowatt
LEED	Leadership in Energy and Environmental Design
LEED NC	Leadership in Energy and Environmental Design—New Construction
LoDo	Lower Downtown
MAP	Metropolitan Architects and Planners
MERV	Minimum Efficiency Reporting Value
MT	metric ton
NE/NW	northeast/northwest
NREL	National Renewable Energy Laboratory
OFHPGB	Office of Federal High Performance Green Buildings
OSB	oriented strand board

PAH	poly-aromatic hydrocarbon
PM	project manager
PNNL	Pacific Northwest National Laboratory
POE	Post Occupancy Evaluation
ppm	parts per million
psi	pounds per square inch
PV	photovoltaic
RSF	rentable square foot
SE/SW	southeast/southwest
SFO	Solicitation for Offer
SFPB	Sustainable Facilities Practices Branch
SHGC	solar heat gain coefficient
SVOC	semi-volatile organic compound
TI	tenant improvements
UFAD	under-floor air delivery system
USGBC	US Green Building Council
VOC	volatile organic compound
VT	visible transmittance
WEc1	Water Efficiency credit 1
ZGF	Zimmer Gunsul Frasca