Controlling Capital Costs in High Performance Office Buildings:

15 Best Practices for Overcoming Cost Barriers in Project Acquisition, Design, and Construction

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Executive Summary

First costs, or capital costs, for energy efficiency strategies in office buildings often present a significant barrier to realizing high-performance buildings with 50% or greater energy savings over the American Society of Heating, Refrigerating and Air-Conditioning Engineers 90.1-2004 Standard. Historically, the industry has been unable to achieve deep energy savings because it has relied on energy cost savings and simple payback analysis alone to justify investments. A more comprehensive and integrated cost justification and capital cost control approach is needed. First cost barriers can be overcome by implementing innovative procurement and delivery strategies, integrated design principles and cost tradeoffs, life cycle cost justifications, and streamlined construction methods.

It is now possible to build marketable, high-performance office buildings that achieve LEED Platinum, save more than $\$1/ft^2$ annually in energy costs, and reach net zero energy goals at competitive whole-building first costs. This is illustrated by the U.S. Department of Energy's and the National Renewable Energy Laboratory's latest high-performance office building, the Research Support Facility (RSF) on the National Renewable Energy Laboratory's campus in Golden, Colorado. The RSF is a 220,000-ft^2 headquarters and administrative office building with a corporate-scale data center. The RSF reached its energy goals while maintaining a firm fixed price budget at competitive whole-building capital construction costs (move-in ready) of $\$259/ft^2$. This report presents a set of 15 best practices for owners, designers, and construction teams to reach high-performance goals and maintain a competitive budget. They are based on the recent experiences of the RSF owner and design-build team, and show that achieving this outcome requires that all key integrated team members understand their opportunities to control capital costs.

Owner Best Practices

- Best Practice #1: Select a project delivery method that balances performance, best value, and cost savings.
- Best Practice #2: Incorporate measureable energy use performance requirements into a performance-based design-build procurement process.
- Best Practice #3: Clearly prioritize project objectives at the beginning of the design process.

- Best Practice #4: Competitively procure an experienced design-build team using a best value, firm-fixed price process.
- Best Practice #5: Include best-in-class energy efficiency requirements in equipment procurement specifications.

Design Best Practices

- Best Practice #6: Leverage nonenergy benefits to efficiency strategies.
- Best Practice #7: Consider life cycle cost benefits of efficiency investments.
- Best Practice #8: Integrate simple and passive efficiency strategies with the architecture and envelope.
- Best Practice #9: Allow for cost tradeoffs across disciplines.
- Best Practice #10: Optimize window area for daylighting and views.
- Best Practice #11: Maximize use of modular and repeatable high-efficiency design strategies.
- Best Practice #12: Leverage alternative financing to incorporate strategies that do not fit your business model.

Construction Best Practices

- Best Practice #13: Maximize use of off-site modular construction and building component assembly.
- Best Practice #14: Include a continuous value engineering process as part of the integrated design effort.
- Best Practice #15: Integrate experienced key subcontractors early in the design process.

Nomenclature

ARRA	American Recovery and Reinvestment Act
DBIA	Design Build Institute of America
DOE	U.S. Department of Energy
FFP	firm-fixed price
ft	foot, feet
ft^2	square foot, square feet
in.	inch, inches
kBtu	1000 British thermal units
kW	kilowatt, kilowatts
LCC	life cycle cost, life cycle costing
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
MW	megawatt, megawatts
NREL	National Renewable Energy Laboratory
PPA	Power Purchasing Agreement
PV	photovoltaics
RFP	Request for Proposals
RSF	Research Support Facility
WWR	window-to-wall ratio

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1.0 Introduction

First costs, or capital costs, for energy efficiency strategies in office buildings often present a significant barrier to realizing high-performance buildings. Innovative procurement and delivery strategies, integrated design principles, and streamlined construction methods can help overcome these barriers. This report presents a set of 15 best practices for procurement, design, and construction teams to reach high-performance goals and maintain a competitive budget. It is based on the recent experiences of the owner and design-build team for the U.S. Department of Energy's (DOE) and the National Renewable Energy Laboratory's (NREL) latest high-performance office building, the Research Support Facility (RSF) on NREL's campus in Golden, Colorado. By fully exercising each best practice, DOE and NREL were able to deliver a Leadership in Energy and Environmental Design (LEED) Platinum, capital cost-competitive, large-scale office building with net zero energy use and more than $200,000/yr in energy cost savings. From the beginning, the RSF presented a unique opportunity to demonstrate the state of the art in efficient, cost-effective commercial office design and operation. The RSF and the innovative procurement process demonstrate that significant, cost-effective energy efficiency gains can be realized in new office buildings with current technologies, if careful attention is paid to project energy goals, building procurement, and integrative building design.

1.1 Research Support Facility Background

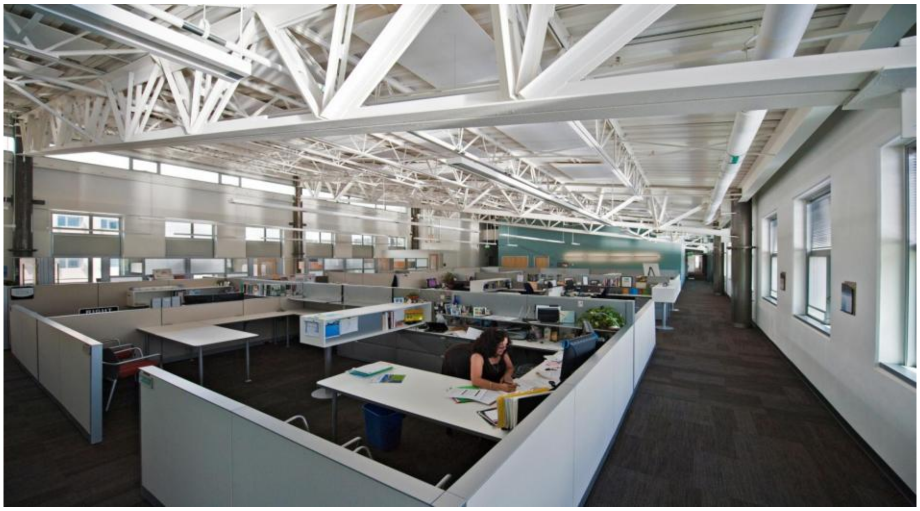
The RSF is a recently completed 220,000-ft^2 headquarters and administrative office building with a corporate-scale data center. It is a showcase for cost-competitive, marketable, and sustainable high-performance design; it uses a whole-building integrated design process to incorporate the best in cost-effective energy efficiency, environmental performance, and advanced controls. The RSF showcases numerous high-performance, cost-effective, energy-efficient design features, passive energy strategies, and renewable energy technologies:

- **Building orientation.** The relatively narrow floor plate (60 ft wide) allows all occupants to enjoy daylighting and natural ventilation. Building orientation and geometry minimize east and west glazing. North and south glazing is optimally sized and shaded to provide daylighting and minimize unwanted heat losses and gains.
- **Labyrinth thermal storage.** A labyrinth of massive concrete structures is integrated into the RSF crawlspace below the first floor. The labyrinth stores thermal energy and increases passive heating capacity.
- **Transpired solar collectors.** Outside ventilation air is passively preheated via a transpired solar collector. A perforated dark metal panel on the south-facing wall delivers warmed outdoor air to the labyrinth and occupied space (see Figure 1–1).
- **Daylighting.** All workstations are daylit for Colorado's sunny days, typically numbering 300/yr. Daylight enters the upper portions of the south-facing windows and is reflected to the ceiling and deep into the space with light-reflecting devices. North windows provide daylighting to the enclosed offices.

NREL PIX 17826

Figure 1–1 South façade of RSF

- **Triple-glazed, operable windows with individual sunshades.** Aggressive window shading is designed to address different orientations and positions of glazed openings. Occupants can open some windows to bring in fresh air and cool the building naturally.
- **Precast concrete insulated panels.** A thermally massive exterior wall assembly with an insulated precast concrete panel system provides significant thermal mass to moderate the building's internal temperature.
- **Radiant heating and cooling.** Approximately 42 miles of radiant piping runs through all floors, using water instead of forced air as the cooling and heating medium in most workspaces.
- **Underfloor ventilation.** A demand-controlled dedicated outdoor air system provides fresh air from a raised floor when windows are closed on the hottest and coldest days. Evaporative cooling and energy recovery systems further reduce heating and cooling loads.
- **Energy-efficient data center and workstations.** A fully contained hot and cold aisle data center configuration allows for effective airside economizer cooling with evaporative boost (when needed), and captures waste heat for use in the building. Plug loads are minimized with extensive use of laptops and high-efficiency office equipment.
- **On-site solar energy system.** Approximately 1.6 MW of on-site photovoltaics (PV) are installed and dedicated to the RSF. Rooftop PV power was added through a Power Purchase Agreement (PPA), and PV power from adjacent parking areas was purchased with 2009 American Recovery and Reinvestment Act (ARRA) funding.
- **Workplace of the future.** The RSF provides a new type of office space that is open and encourages interaction and collaboration. Low-profile, modular workstations allow employees to enjoy daylight and views (see Figure 1–2). Workstations are located within 30 ft of a window, and employees can open windows when conditions permit, allowing for natural ventilation and improved indoor air quality.



NREL PIX 17904

Figure 1–2 Fully daylit open office space

During construction of the RSF, the 2009 ARRA injected more funding into the project to add a third wing. An additional 138,000 ft^2 of office space for more than 500 NREL employees, including NREL executive management, was added. The RSF north wing expansion was completed by the same design-build team, with substantial completion in fall 2011. Figure 1–3 shows the north wing expansion construction progress in May 2011.

NREL PIX 19088

Figure 1–3 RSF and RSF expansion, May 2011

Additional design strategies and modeling process details are available at www.nrel.gov/rsf.

2.0 Research Support Facility Capital Costs

Capital costs can be measured and evaluated for multiple purposes with multiple metrics. Making quantitative comparisons between projects is difficult when capital costs across multiple commercial buildings are being evaluated. Every project has a different program, project-specific constraints, varying local labor and construction costs, and different site requirements. However, general cost comparison trends can be evaluated with certain capital cost metrics such as core and shell construction costs, total construction costs, and total project costs. To compare the RSF capital costs to other projects, we attempted to document total construction costs and total project costs for a range of recent projects. We used multiple sources, including the Design Build Institute of America's (DBIA) project database and other publically available capital cost sources, to document their total and capital costs. Appendix A lists each project and source of cost information used for RSF comparison purposes. We focused on identifying comparable projects with either documented total project costs (which typically include all core and shell costs, finishings, furniture and equipment, site costs, and soft design costs) or total construction costs (which typically include total project costs and exclude soft design costs). Land costs are typically not included in capital cost metrics.

The RSF total project costs were about \$64 million, or \$291/ft^2, and include all core and shell costs, interior design such as furniture, finishings, audiovisual equipment, information technology infrastructure, all "soft" design costs, and related site costs. The total project costs do not include direct PV system costs, data center equipment, independently provided electrochromic demonstration glazing, owner-directed change orders, or owner-provided computer equipment. The total construction costs for a move-in-ready office building, which excluded design costs and PV, were \$259/ft^2.

The original RSF design concept to reach net zero energy within the \$64 million budget was to provide all the necessary 1.55 MW of PV with a PPA without adding to the overall project costs. A third-party for-profit company would finance, own, and receive all applicable tax credits and rebates for the PV system, and DOE and NREL would agree to purchase the energy over 20 years at a competitive electric utility rate. The first 450 kW of PV on the roof of the RSF was procured through such a PPA. The remaining 1.1 MW needed to offset RSF energy use was initially intended to also be part of this PPA, but 2009 ARRA funding was allocated to purchasing the remaining PV for the RSF and the expansion. Therefore, RSF construction costs with a full PPA for PV and without any PPAs (full PV purchase without rebates) are presented for comparison purposes. If the project's construction costs included all the RSF PV needed to reach net zero, an additional \$29/ft^2 would be added to the RSF construction costs, for a total construction cost with PV of \$288/ft^2.

As the same design-build team was commissioned to build the 138,000-ft^2 RSF third wing expansion, more cost reductions were expected. By applying lessons learned from the first phase, repeating the fundamental design concept, and leveraging subcontractor familiarity with the various building components, an additional \$14/ft^2 was saved in the total project construction costs and energy use was reduced by 11% compared to the first two wings. The RSF expansion construction costs were \$246/ft^2 without PV and \$275/ft^2 including the PV needed to reach net zero energy use. Figure 2–1 compares the RSF and RSF expansion total project costs and total construction costs (with and without PV) to those of other recent projects. In general, the RSF and RSF expansion cost trends for our capital cost metrics (with and without PV) are within competitive and market-acceptable capital cost ranges.

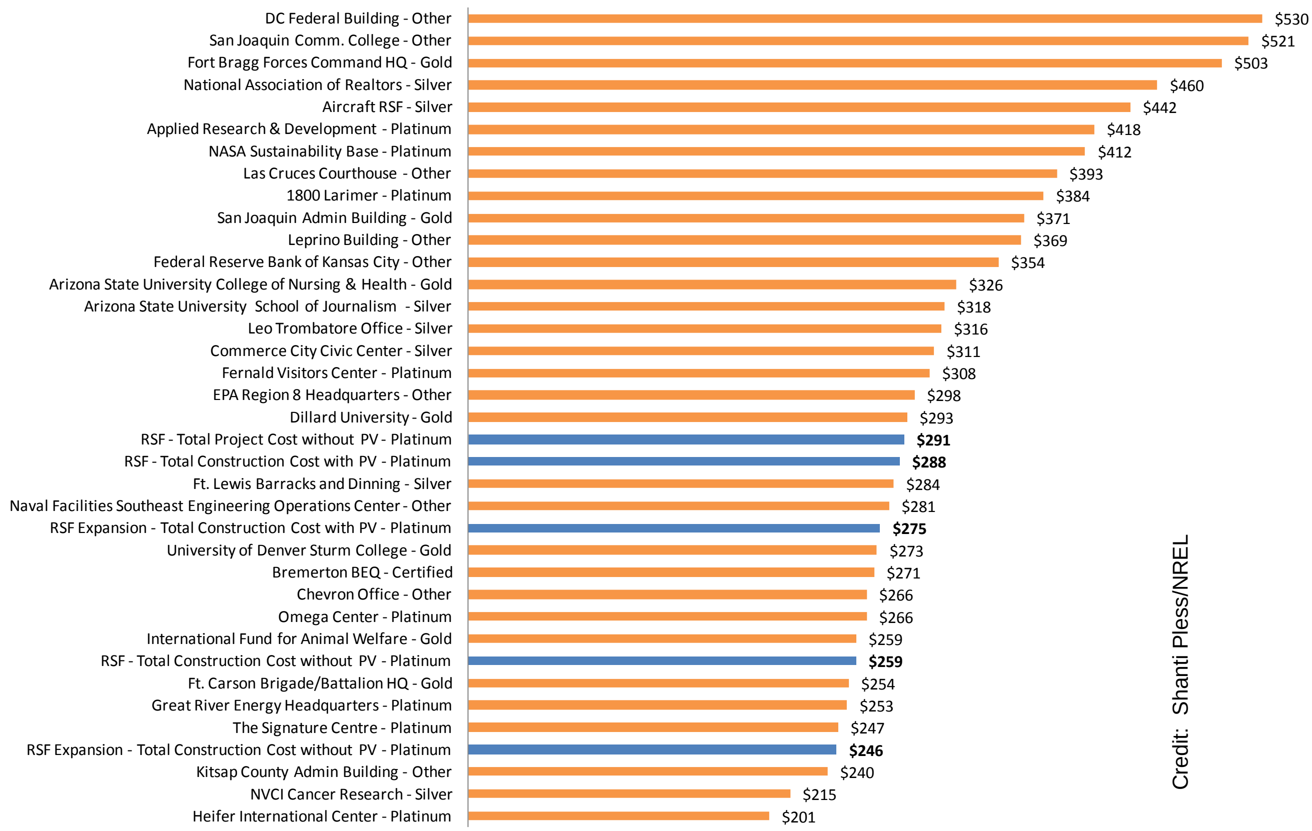


Figure 2–1 RSF and RSF expansion total project and construction costs compared to other recent projects

2.1 Research Support Facility Payback Analysis

Because the innovative procurement and delivery process required energy use goals with a firm-fixed price (FFP), no explicit analysis was done to determine payback of efficiency strategies. Payback analysis implies that if a decision is made based on the technique, additional funds must be available so decisions can be implemented. In this case, we established a fixed energy goal and the design-build team had to make the design and construction process decisions about how to incorporate these goals into the FFP. The design team used an effective value engineering process and made design decisions based on the most cost-effective efficiency strategies to meet the performance requirements (Best Practices #6 through #15), as these decisions all had to be made within the FFP requirements. The result is a building that meets the energy goals on a market-competitive first-cost budget, without an incremental total project cost.

2.2 Capital Cost and High Performance: Other Industry Perspectives

The RSF project is not the first to claim that energy efficiency and green design do not have to cost significantly extra. A local example is the Aardex Signature Center, a twice-certified LEED Platinum speculative office building. According to published claims by the developer and design team, the LEED Platinum and energy efficiency strategies had to pay for themselves within three years or be considered on a "whole project" basis, considering all benefits and cost tradeoffs. A commonly cited example is the dedicated underfloor air with chilled beam mechanical system, which included components that might be more efficient, but are more expensive than a conventional system. Those "additional" costs are offset by reductions in other building costs, such as the reduced building height of 10 in. per floor, resulting in less envelope, reduced ducting, and higher delivery air temperatures, so that the overall project costs were similar to office buildings with conventional mechanical systems (Aardex 2011). Ben Weeks, the Aardex principal in charge of the Signature Center, has identified a key strategy for incorporating the best in energy efficiency and LEED:

> "A vertical integration of the development interests—design, construction, and ownership—will result in significant savings to a project—as much as 15% or more of overall costs. This allows implementation of the most beneficial strategies and features at a delivery price at or below market rates for conventional facilities." (Aardex 2011)

Two sector-wide studies of LEED ratings and capital costs have also concluded that there is no significant difference in average costs for green buildings compared to nongreen buildings. A survey of capital costs (Davis Langdon 2007) of institutional projects such as libraries and academic buildings documented a range of construction costs from $225/ft^2 to more than $500/ft^2—construction costs similar to our precursory survey of publically available project capital costs.

More recently, Kats (2010) used a dataset of 170 projects to document that most green buildings have slightly higher costs than similar conventional buildings, but that some had no incremental costs. Kats proposed that the cost premiums for green buildings are a function of the project teams' experience with cost-effective green design and construction rather than of the LEED certification level. In fact, more than 80 of the projects in Kats' dataset reported 0%–2% green cost premium, with no correlation between the LEED level achieved and the cost premium.

> "For instance, many of the buildings in the data set with low (no more than 2%) or zero reported premiums are either Gold (29 buildings) or Platinum level (five buildings). Indeed, the data demonstrate that relatively green buildings can be built with virtually no cost premium, while some slightly green buildings can have a substantial cost premium." (Kats 2010)

In reviewing our own preliminary survey of construction costs and those available in industry, energy-efficient and green buildings *may* cost more, but do not necessarily *have* to cost more. The best practices in this paper are presented in an attempt to help owners and project teams build high-performance green buildings that do not have to cost more. The following best practices for controlling capital costs in high performance buildings are documented as owner, designer, and construction strategies in Sections 3, 4, and 5.

3.0 Owner Strategies

3.1 Best Practice #1: Select a Project Delivery Method That Balances Performance, Best Value, and Cost Savings

The RSF incorporates a range of readily available energy efficiency strategies combined in innovative ways; however, the DOE/NREL team's real breakthrough was rethinking the project delivery and acquisition process. The team decided early on that a traditional design-bid-build would not deliver the RSF—with its challenging performance requirements—on time and on budget while mitigating costs and risks. Rather than designing the building and then putting it out to bid, the ownership team opted for a performance-based design-build procurement process. The energy savings goal could not override the focus on cost effectiveness and ensuring DOE obtained the best value. DOE budgeted the RSF's construction costs of 259/ft^2 to be competitive with today's less energy-efficient institutional and commercial buildings.

Traditionally, DOE uses a design-bid-build approach to project acquisition, selecting separate design and construction contractors. This process usually provides a competitive price, but it limits the design team's creativity in developing the most cost-effective, integrated, energy-efficient solution. And as learned from past research and demonstration projects, the design-bid-build process often limits the design team's full integration with the builder, cost estimators, and subcontractors, resulting in a longer, costlier delivery process and lower value. To overcome these limitations, DOE and NREL selected a performance-based "Best Value Design-Build/Fixed Price with Award Fee" delivery approach.

To understand the full potential of this best practice, we must first evaluate the various project acquisition and delivery methods to better understand how to deliver cost-competitive, energy-efficient projects. A traditional design-bid-build scenario includes the following steps:

1. The owner enters into a contract with a designer to develop building plans and specifications.
2. The owner and designer determine the project's scope, including budget and construction type.
3. The designer estimates building costs based on experience and input from engineers and other consultants.
4. When the design is complete, the owner puts the job out for bid (often with the help of the designer). This process can take weeks, or even months, for a complex project.
5. During the bid phase, the owner receives and evaluates bids (again, often with the help of the designer) from a number of contractors competing for the job.
6. The owner then enters into a contract with the successful bidder and warrants that the plans and specifications for the building are complete and correct.
7. The contractor agrees to build the project according to the plans and specifications developed by the designer, and the parties agree on a price and schedule.

In this scenario, the designer and contractor often have no contact or relationship with each other until after the contract is awarded, which limits the potential of a contractor and estimator's integrated design concepts to provide the most cost-effective energy efficiency strategies. If the bids come in higher than the designer's estimates, the owner and designer must decide how to bring costs back within the budget. This process takes time, and may mean that energy efficiency and other nonaesthetic building components and strategies will be eliminated. Energy efficiency strategies that are not well integrated with the building architecture or envelope are likely to be eliminated, as these can be easily replaced with less efficient alternatives. Because the design and construction contracts are separate, this method offers some checks and balances for the owner (Molenaar 2009), but the owner pays a price in scheduling and minimally integrated efficiency solutions. This method is also the most time consuming and may create adversarial relationships. The resulting value engineering process, disputes, cost overruns, and construction delays can result in less-than-optimal performance, headaches (and often litigation), and increased project costs.

In design-build, the owner contracts with a single legal entity—the design-builder—to construct a building based on the owner's design criteria. Unlike design-bid-build, in design-build, the design-builder controls the design and construction processes. To support this process, the owner takes the responsibility to develop a clear, comprehensive request for proposals (RFP) that outlines the program and performance specifications and proposal requirements. Then the design-builder assumes complete responsibility for delivering the project as specified in the RFP, on time and on budget. This method solicits a teaming approach between the architectural and construction communities from the outset to offer best value bids for specified owner objectives. Design-build streamlines project delivery through a single contract between the owner and the design-build team by transforming the relationship between designers and builders into an alliance that fosters collaboration and teamwork. As a subset of the typical design-build process, performance-based design-build attempts to elevate design and performance requirements to be on par with budget and schedule. The object is to create an instrument that motivates marketplace providers to offer greater value for the owner's asset—value defined as performance over time acquired at a competitive cost.

- **Design-build and singular responsibility.** With design and construction in the hands of one entity, there is a single point of responsibility for coordination, quality, cost control, and schedule adherence. This prevents finger pointing between designers and builders for errors or shortcomings. This singular responsibility removes the owner from the role of referee and allows for productive time spent focusing on other project needs and timely decision making.
- **Quality.** The singular responsibilities inherent in the design-build process motivate the parties to ensure high-quality, proper performance of building systems. Once the owner's requirements and expectations are documented (and the design-build entity agrees), the design-builder is contractually responsible to construct a facility that meets or exceeds those criteria.
- **Cost savings and value.** Design professionals and construction personnel, working and communicating as a design-build team, evaluate alternative materials, building systems, and construction methods efficiently, accurately, and creatively. Value engineering and constructability reviews are used more effectively when the designers and builders work as one body.
- **Time savings.** Because design and construction can overlap, and because general contract bidding periods and redesign time are eliminated, total design and construction time can be significantly reduced. A contractor-driven schedule, integrated project team,

and no project-driven change orders all contribute to reducing delivery time, thus saving significant capital costs. NREL and DOE committed to adopting the design-build process in spring 2007, and the RSF opened a little more than three years later, saving months compared to typical DOE design and construction schedules. The construction phase was only 16 months (see Table 3–1).

Table 3–1 RSF Design and Construction Timeline

Event/Milestone	Date
Planning started	April 2007
$63 million appropriated	April 2007
National request for qualifications advertised	April 2007
Design charrette	June 2007
DBIA training	August 2007
Three highly qualified teams shortlisted	September 2007
Haselden/RNL selected	April 2008
Contract signed	July 2008
Preliminary design completed	November 2008
Construction started	February 2009
Final design completed	July 2009
Building dried in	December 2009
Substantial completion	June 2010
Final completion	July 2010

- **Risk management.** After the project requirements are outlined in the RFP, the owner will receive different design solutions and cost proposals representing the best thinking of several design-builders. These alternative designs provide the owner the opportunity to better weigh the risks and benefits of several competing proposals before committing to any single design solution. Change orders caused by errors and omissions in the construction documents are eliminated because their correction is the responsibility of the design-builder, not the owner. Assigning risks to those best capitalized, staffed, and experienced to assume and manage them is another advantage of this method.
- **Innovation and commercialization.** Because prescriptive specifications are substituted by performance requirements, design-build teams are free to develop creative and innovative responses to a stated problem.

In performance-based design-build, the owner does not rely on plans and specifications to describe the scope of the project, but focuses on the problems to be solved and leaves the solutions to the design-builder. This delivery method allocates control and accountability differently, in that the owner sets an FFP for the project, establishes program and performance requirements, prioritizes these requirements in an RFP, and then invites design-builders to propose solutions that best achieve the requirements. The intent is to provide the design-build experts creative freedom to meet the owner's objectives in a competitive forum. The owner then selects a design-builder to complete the project for an FFP based on the best value, which includes the design-builder's specified scope of requirements proposed. The successful design-builder is responsible and accountable for designing, building, and delivering the project that meets the contractually proposed requirements, within a proposed fixed schedule and for the FFP (Pless et al. 2011).

3.2 Best Practice #2: Incorporate Measurable Energy Use Performance Requirements Into a Performance-Based Design-Build Procurement Process

Performance-based design-build has been used historically to reduce costs, increase value, and reduce project delivery time. As documented by Konchar (1997), a Penn State researcher compared the design-build and design-bid-build project delivery methods. He found that design-build projects cost an average of 6% less, were an average of 12% faster to build, and were an average of 33% faster to deliver (from conception through completion) compared to conventional design-bid-build processes. Especially for an innovative building, design-build delivery coupled with clear and prioritized energy performance requirements (*performance-based* design-build) appears to be a successful combination. And establishing prioritized performance goals from the beginning greatly increases the probability that the completed building will meet the project's critical goals.

A performance-based RFP focuses on measurable performance outcomes rather than on prescriptive solutions to design problems. It describes in clear, measurable terms how the building will perform—what it will do rather than what it will be. This frees the owner to concentrate on functional expectations rather than worrying about how to meet those expectations, and allows the design-builder to draw from all possible solutions rather than only those prescribed by the plans and specifications. The clearer and more measurable the performance criteria are, the more likely the project will successfully meet them.

Absolute and measurable energy use performance goals were incorporated into the RSF RFP and the design-builder contract to leverage the benefits of the design-build process to meet energy goals at a competitive first cost. Instead of specifying technical standards such as building size, configuration, efficiency measures, conceptual drawings, and other attributes, DOE and NREL used the RFP to prioritize key performance parameters with "Mission Critical," "Highly Desirable," and "If Possible" designations. During the competitive design-build team selection process, teams were selected, in part, based on their ability to incorporate and support as many prioritized objectives as possible within the overall fixed budget and schedule constraints. These objectives included key absolute energy performance goals, such as 25 kBtu/ft^2, and net zero energy performance. The full set of performance objectives in the RFP included:

1. Mission Critical
    a. Attain safe work performance and safe design practices
    b. LEED Platinum designation
    c. ENERGY STAR® appliances, unless another system outperforms.
2. Highly Desirable
    a. 800 staff capacity
    b. 25 kBtu/ft^2 (later adjusted to 35.1 kBtu/ft^2), including NREL's data center
    c. Architectural integrity
    d. Honor "future" staff needs

e. Measurable 50% or greater energy savings versus American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1-2004
f. Support culture and amenities
g. Expandable building
h. Ergonomics
i. Flexible workspace
j. Support future technologies
k. Documentation to produce a how-to manual
l. Public relations campaign implemented in real time for benefit of DOE/NREL and design-builder
m. Allow secure collaboration with outsiders
n. Building information modeling
o. Substantial completion by June 2010.

3. If Possible
    a. Net-zero design approach
    b. Most energy efficient building in the world
    c. LEED Platinum Plus
    d. Exceed 50% savings over ASHRAE baseline
    e. Visual displays of current energy efficiency
    f. Support public tours
    g. Achieve national and global recognition and awards
    h. Support personnel turnover

Based on the RSF team's experience, incorporating absolute energy use intensity performance requirements into a performance-based design-build procurement process appears to be an effective strategy for achieving aggressive energy performance goals at an FFP. In this delivery method, the owner establishes performance goals for the building (energy use, percent savings, LEED rating, etc.), and the design-builder is contractually bound to meet those goals on budget and on schedule. Including energy goals into the contractual agreements elevates the importance of energy use to be on par with scope, budget, and schedule objectives.

The more measurable the energy goals during actual operations, the more easily the owner can verify that the design can operate as intended. Incentive programs can then be integrated into the project management process to reward superior design-build contractor performance during the warrantee period, ensuring successful measurement and verification of the absolute energy goals. (See Pless et al. [2011] for further details on how to include absolute energy goals into a contractual agreement.)

By hiring a design-build team and contractually obligating that team to satisfy measurable energy use requirements, NREL drove the formation of an integrated design process comprising architects, engineers, and builders (which included cost estimators and key subcontractors). This arrangement resulted in an iterative pattern between the architects, engineers, and builders aided with detailed computer simulations to assess whether the building design, as it evolved, would meet the owner's performance requirements and cost constraints. An added advantage is that members become familiar and comfortable with each other long before construction begins.

Because the general contractor and key subcontractors—typically the team members most familiar with cost and constructability issues—have input during the design process, this delivery method takes full advantage of the contractor's experience and knowledge.

3.3 Best Practice #3: Clearly Prioritize Project Objectives at the Beginning of the Design Process

At the beginning of the design process, design teams often spend significant time learning specifically what the owner needs, then persuading the owner that a particular design will meet the needs. Therefore, the more direction an owner can provide a design team at the beginning, the more time can be invested early on to optimize and analyze efficiency opportunities.

Before the RSF design-build team was selected, the owner clearly prioritized project objectives with an FFP in the RFP. When the design-build team began the early design process, all the owner needs were clearly identified and prioritized in the form of the Objectives Checklist (see Section 3.2). This allowed the design-build team to focus early design time on developing an integrated solution that met all the performance objectives, including cost, schedule, and energy.

Once the project objectives are communicated (preferably in the form of an RFP and contract), the owner needs to fully commit to them so the design-build process can optimally address the needs in an integrated, cost-effective manner. Any changes to the owner's objectives or needs after the design has begun slows the process, increases costs, and results in a suboptimal process.

3.4 Best Practice #4: Competitively Procure an Experienced Design-Build Team Using a Best Value, Firm-Fixed Price Process

To encourage the innovative design and construction processes needed to reach world-class performance at competitive first costs, the design-build team selection process should encourage and reward novel approaches. Including "if possible" stretch objectives in a competitive design competition for an FFP rewards innovative design, construction, and teaming concepts. The teams with the most innovative, integrated, and cost-effective solutions can provide the most performance objectives within an FFP, increasing their chances of winning the competition. Limiting the design competition to three highly qualified teams and providing stipends to the losing teams to partially offset their participation costs ensure high-quality proposals.

The design-build team that won the RSF design competition developed a novel teaming arrangement with a third-party PV financer. The design thus met all performance objectives within the FFP contract limit, including the stretch goals such as net zero energy performance. Additional design and construction innovations such as modular office space concepts, high thermal mass exposed precast wall panels, and ceiling slab integrated radiant heating and cooling systems were all developed in a competitive design environment.

Kats (2010) documented that the highest LEED certification levels are possible with virtually no cost premiums; however, experienced design and construction teams are needed to select the most cost-effective strategies and apply industry best practices for reducing any possible premiums. Therefore, teams must be selected who have experience delivering innovative designs and construction processes to reach the high levels of green design at competitive first costs. As the RSF process demonstrates, when the owner's RFP requests a net zero energy building, and the criteria for selecting the design-build team clearly reflect that goal, all the players will focus on that outcome and consider management, design, teaming, construction, commissioning, and operational strategies based on how they affect that outcome.

3.5 Best Practice #5: Include Best-in-Class Energy Efficiency Requirements in Equipment Procurement Specifications

In modern high-performance office buildings, plug and process loads are becoming the dominant end use. To reach aggressive energy savings levels, owners need to consider all possible plug load efficiency strategies. Plug and process loads represent half the RSF's energy consumption, so the owner deployed a wide range of plug load efficiency strategies, as documented in Lobato et al. (2011). Plug load and data center energy savings of 49% are expected compared to business-as-usual practices in NREL's leased office space (as measured in 2007). One of the most cost-effective plug load control strategies has been to develop equipment procurement specifications that include best-in-class energy-efficient office equipment. This specification can be incorporated into the normal (and often frequent) legacy equipment replacement cycle. For example, manufacturers of the following RSF equipment were identified as best in class, and were included in the normal equipment procurement:

- 48-Watt average hourly use refrigerators
- 18-Watt 22-in. light-emitting diode (LED) liquid crystal display monitors
- 25-Watt laptops with docking stations
- 120-Watt 55-in. flat screen LED backlit displays
- Multifunction devices that print, copy, fax, and scan
- Blade servers in the data center.

The ENERGY STAR equipment database (www.energystar.gov) is a good starting point for identifying best-in-class energy-efficient equipment; however, the best-in-class equipment is often significantly more efficient than a typical ENERGY STAR alternative, often without added first costs. Therefore, such equipment should be carefully selected from the ENERGY STAR database. In addition to specifying the most efficient equipment, all the ENERGY STAR-enabled efficiency settings must be appropriately configured to realize all possible savings.

4.0 Design Strategies

4.1 Best Practice #6: Leverage Nonenergy Benefits of Efficiency Strategies

Often, energy savings alone may not be sufficient to justify the most efficient strategy. In these cases, leveraging related nonenergy benefits can help to justify an energy efficiency design decision. For example, it is often difficult to justify—with energy cost savings alone—the best-in-class traction elevators with regenerative drives for low- and medium-rise buildings. High-efficiency traction elevators such as those installed in the RSF do not require a machine room, a deep elevator pit, or significant overhead accommodations, and therefore, they use less space and minimize costly support spaces. These cost savings help to offset any additional costs for a high-efficiency traction elevator system. Also, their regenerative drives can capture braking energy as electricity to power the building, rather than generating waste heat, which then has to be removed from the elevator control room with air-conditioning. Although the regenerative drives may cost slightly more, capital cost increases can be absorbed by eliminating the need for an elevator control room air-conditioning system.

Purchasing laptops for all RSF staff was also justified, in part using benefits unrelated to their energy savings versus standard desktop computers. Even though laptops are significantly more efficient than desktops, the energy cost savings alone do not necessarily justify their higher costs. Laptops increase worker productivity by increasing office space flexibility, enabling work from home and travel mobility, and reducing redundant computing systems (having both a desktop and laptop). Mini-desktops are now also available that have the efficiency of a laptop without the cost or security concerns associated with laptops if workers do not require mobility.

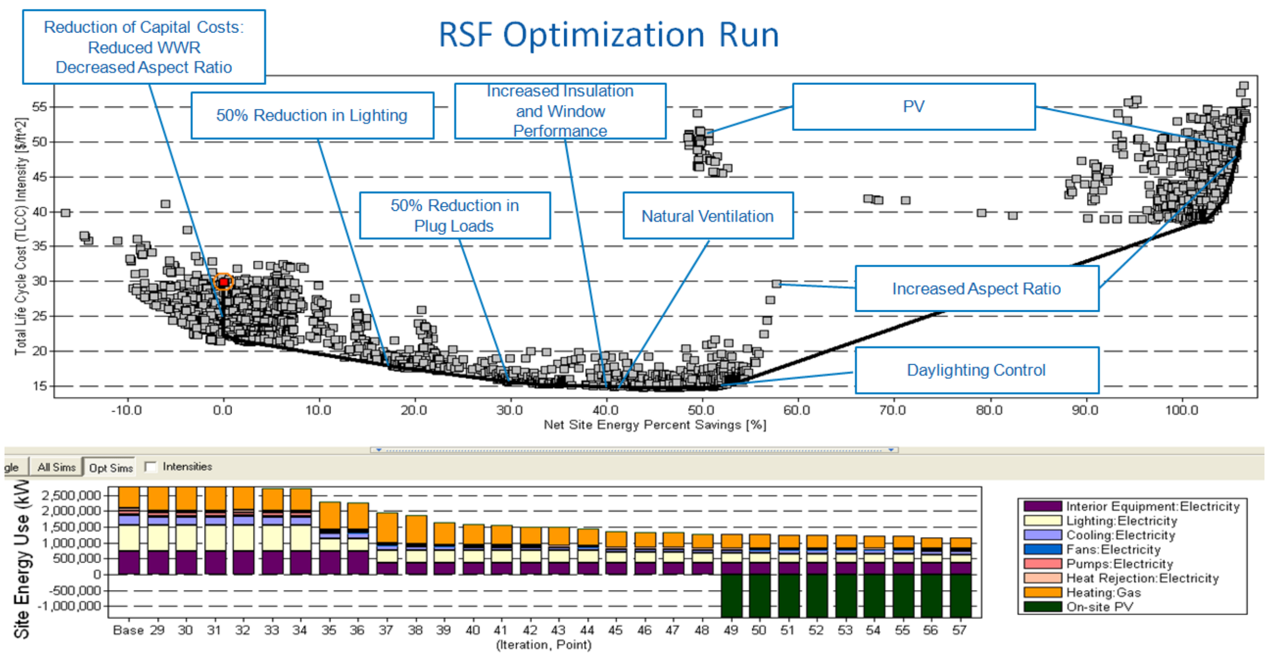
NREL's move to using a single centralized high-speed multifunction printer/copier/scanner/fax on each floor of each RSF wing was justified through the overall reduction in maintenance costs and unique toner support versus individual printers. Minimizing, centralizing, and standardizing the RSF's document services greatly increase the ease of implementing robust standby power configurations and significantly lower service costs. Not only did NREL significantly reduce the total number of devices with unmanageable power settings, volatile organic compounds from the printer toners were isolated to a few copy rooms with dedicated exhaust, increasing the office space indoor air quality. In the RSF, we replaced more than 300 individual printers with 18 multifunction devices, which are distributed throughout the building. Each also has effective and robust standby modes.

A final example was the move from drywall-enclosed offices and high cube walls to a demountable and reconfigurable open office furniture system. This plan was a key daylighting and natural ventilation component, but the furniture systems are not necessarily cost justifiable from energy savings alone. The added flexibility of minimizing hard walled offices saves significant costs when spaces are reprogrammed. Also, the open environment and narrow floor plan mean that all occupants are within 30 ft of windows with a view from their workstations to the outside, and encourage and promote interaction and collaboration.

4.2 Best Practice #7: Consider Life Cycle Cost Benefits of Efficiency Investments

Life cycle costing (LCC) has long been a key element of integrated design, and is becoming more commonplace in many commercial building projects. It compares first costs to long-term energy cost savings and maintenance, replacement, and operational costs over a given life cycle.

NREL used a preliminary design LCC and optimization tool called OpenStudio to help set the RSF project's energy savings targets. The tool currently requires considerable computing resources and is intended for in-house research to assist with DOE-funded research. Building energy simulation and LCC analysis are often used for trial-and-error evaluation of "what-if" options in building design—a limited search for an optimal solution, or "optimization." Computerized searching has the potential to automate the input and output, evaluate many options, and perform enough LCC simulations to account for the complex interactions of strategy combinations. The predesign RSF optimization analysis (Figure 4–1), with a 30-year LCC, suggests 40%–50% energy savings is theoretically the lowest LCC. Based on this analysis, NREL selected the optimal LCC solution at 50% savings and a corresponding energy use intensity of 25 kBtu/ft^2 to be included in the project's performance objectives.



Credit: Shanti Pless/NREL

Figure 4–1 RSF predesign LCC optimization

When long-term maintenance costs are incorporated into design decisions, simpler, longer lasting, and more passive systems are often considered advantageous. These costs helped to justify strategies such as exterior LED lighting in the RSF. The lighting fixtures may be more expensive, but energy cost savings, longer lifetimes, and lower relamping costs justify the first cost investment. Similarly, the extended lives of lamps in daylit spaces that are off all day help to justify the daylighting control system. The reduced maintenance costs from easily controllable hydronic radiant heating and cooling systems compared to an optimally and continuously tuned variable air volume system help to justify the investment in the hydronic piping in the ceiling slabs.

In general, simpler systems that require minimal attention have lower LCC to ensure performance. Simple, passive strategies such as high thermal mass exposed concrete, good insulation, reduced lighting power density, rightsized heating, ventilation, and air-conditioning systems, and overhangs have low to no operations and maintenance costs and high assurance of actual performance. More complex efficiency strategies such as daylighting controls or carbon dioxide sensors require almost constant retro-commissioning and maintenance to ensure they are working as intended. These strategies may save significant energy, the long-term maintenance, calibration, and operational costs must be considered to ensure a successful LCC exercise.

Net zero projects require an additional LCC evaluation step. Investments in efficiency strategies must be compared to an investment into the equivalent renewable energy generation needed to offset the same amount of energy use. For the RSF net zero energy LCC accounting, every continuous Watt that could be saved through efficiency strategies avoided purchases of $33 in PV. To reach the RSF net zero goals, more than $6 million in PV costs were saved by reducing the annual energy use by 50% through efficiency strategies.

4.3 Best Practice #8: Integrate Simple and Passive Efficiency Strategies With the Architecture and Envelope

Integrating energy efficiency strategies into the architecture and building envelope is a key incremental cost control strategy for any high-performance commercial building. Well-integrated strategies start by identifying single building components that can perform multiple functions. For example, if the building orientation, massing, and layout can help reduce energy use, they typically do not have to cost extra. Other passive strategies, such as daylighting, thermal mass, natural ventilation, and shading, which integrate efficiency with the building envelope and structure, can be effective architectural designs that also save energy.

The RSF design team looked to the pre-industrial age for guidance on how buildings were designed before the advent of air-conditioning or electrical lighting. High mass stone and concrete buildings provided passive cooling with ample daylighting and natural ventilation. These simple, passive strategies were integrated into the RSF's envelope components through the use of a narrow floor plate with full access to daylighting, operable windows, insulated precast concrete panels with exposed interior thermal mass, solar shading, and optimal orientation. Continuous insulation in the concrete precast panels also substantially reduce thermal bridging, a common weak spot in commercial building insulation systems.

Another project-specific example of leveraging the building structural elements as an efficiency strategy is the RSF's concrete crawlspace. The expansive soils at the site prevented a slab-on-grade foundation. Therefore, the RSF is supported on concrete piers and grade beams, creating a crawlspace under the first floor. Through minimal additional cost, the concrete grade beams were positioned to allow the building's outdoor air to be drawn through the full crawlspace. The remote thermal mass in the concrete grade beams and ground slab allow the outdoor air to be preheated or precooled, reducing air-conditioning energy use.

The investment in simpler, passive systems is also evident in the south daylighting control strategy. Typical south daylighting windows may include adjustable blinds or expensive automatic roller shades to control direct glare into the workspace. The RSF daylighting design incorporates passive fixed light redirecting devices that require no adjustment, maximize daylighting, and eliminate direct glare.

The design evolution of the RSF's south façade exemplifies the trend toward robust, simple, and cost-effective architectural solutions to energy efficiency. Figure 4–2 shows that the original design incorporated a complex double-skin façade. As the team optimized its solution and evaluated the energy benefits against the first costs, it developed a simpler south façade design that meets the cost and energy goals. A transpired solar collector and simple exterior overhangs took the place of an expensive double skin façade, offering both efficiency and cost gains.

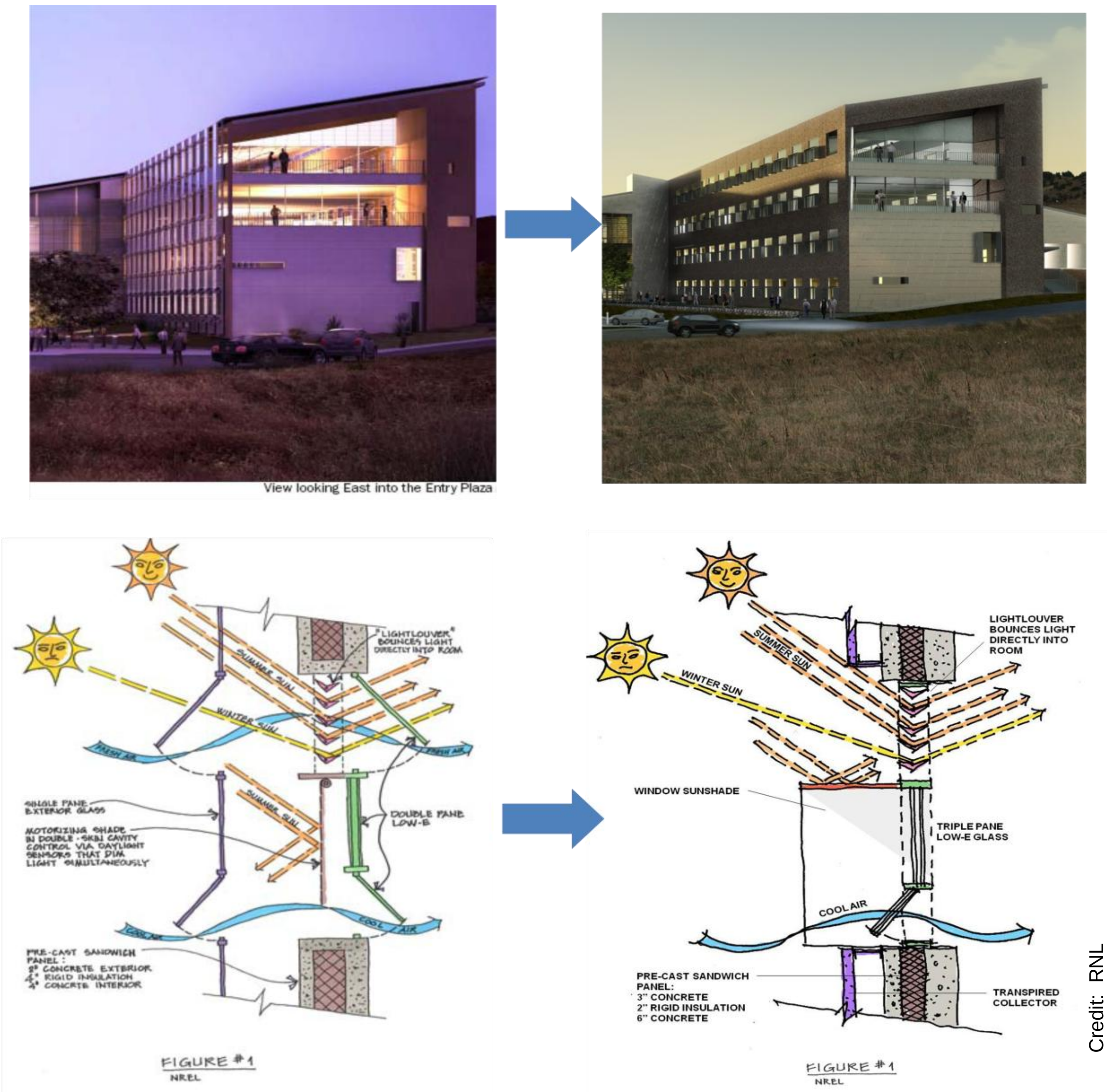


Figure 4–2 Design progression from a complex to a simple envelope efficiency solution

In general, well-integrated passive solutions are cheaper, simpler, and more reliable than technological solutions added after the architecture has been designed. If efficiency strategies are not well integrated, additional controls and moving components (all with additional costs) are typically pursued to reach aggressive energy goals.

4.4 Best Practice #9: Allow for Cost Tradeoffs Across Disciplines

To ensure investments in architecture and building envelope measures (see Section 4.3) are cost effective, the possible cost tradeoffs available in rightsizing the corresponding smaller heating, ventilation, and air-conditioning systems must be evaluated. Investments in shading, insulation, triple-pane windows, thermal mass, lower lighting power density, and lower installed plug loads all result in smaller peak air-conditioning loads. First cost savings from installing a smaller cooling system to meet these reduced loads will help to offset any first costs associated with the load reduction strategies. Smaller outdoor air heating and cooling systems enabled by exhaust air energy recovery also help to pay for the energy recovery system. Investment in energy modeling, starting in the early design phases, is also required to optimize the architectural and mechanical efficiency strategies and maximize the benefits.

To ensure these types of cost tradeoffs are possible, the typical discipline-based construction budget allocations need to be reconsidered. Similarly, the traditional discipline-based fee percentages may also prevent the disciplines that are most capable of developing energy reduction strategies from applying their analytical technologies and abilities. Figure 4–3 shows that simple and passive efficiency investments in architecture and envelope can have corresponding mechanical and electrical system benefits and maintain the same overall project costs. The RSF's passive and envelope measures resulted in a mechanical cooling system sized at 1000 ft^2/ton, whereas a conventional system may often be sized at 400 ft^2/ton. Reduced pumping and chilled water capacity cost savings helped to offset many integrated envelope measures.

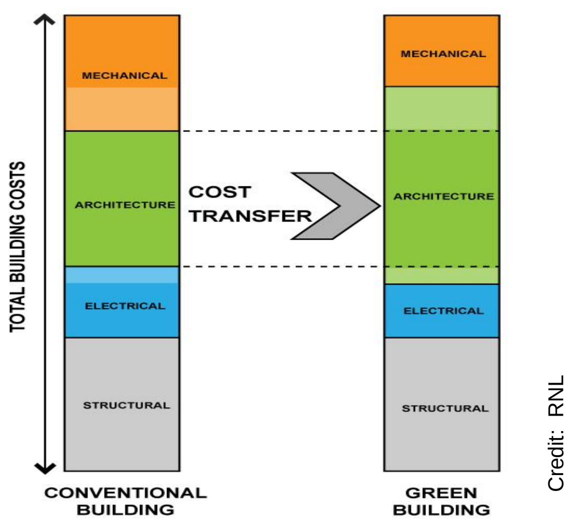


Figure 4–3 Cost tradeoff concept

4.5 Best Practice #10: Optimize Window Area for Daylighting and Views

High-performance office buildings must include a high-performance envelope, of which window size, type, orientation, and shading are all key cost control and thermal performance parameters. Reduced window area decreases overall envelope costs and improves thermal envelope performance. A purely theoretical optimal window area based on energy consumption would be a small amount of glass for daylighting purposes only; however, views would be significantly reduced, which would lessen the quality of the space. Therefore, an optimal window area strategy that balances cost, thermal performance, daylighting, and views should be pursued. Such a strategy would first provide enough glass area for full, glare-free daylighting, and then identify key opportunities for view glazing without overglazing the envelope.

The RSF design team implemented this best practice by dedicating the upper windows to daylighting and the lower windows to views and natural ventilation (see Figure 1–1). The south office wing façade has a 24% window-to-wall ratio (WWR); the north façade slightly more (26% WWR). The daylighting dedicated windows are sized at only 11% WWR, with the remaining window area for views and natural ventilation. East and west windows were also limited to views through appropriately located punched windows. In strategic top floor areas, fully glazed east- and west-facing curtain walls were included. Because these design elements were less than optimal or cost effective, their use was limited. Compared to conventional fully glazed 60% WWR office buildings, an optimal window area strategy significantly improves the thermal properties of the envelope, reduces unwanted solar gains, and provides abundant views and full daylighting, all while significantly reducing the overall envelope cost.

The size of the view windows was further reduced in the RSF expansion by raising sill heights by 6 in. This change did not meaningfully impact daylighting, but decreased the amount of direct sun on desktops and thermal losses through the envelope. The reduced window cost savings were captured and used to upgrade the window framing system to the latest thermally broken frame.

4.6 Best Practice #11: Maximize Use of Modular and Repeatable High-Efficiency Design Strategies

Modular and repeatable design elements and space types reduce design and construction costs. Unique space types or design elements such as curved wall sections add costs. Therefore, highly replicable building block modules are often the most cost-effective design and construction strategies. The primary office space block module in the RSF was a 30-ft × 60-ft open office bay, (see Figure 1–2 and Figure 4–4). This bay design incorporates standard dimension precast wall panels, a well-planned clear-span open and modular office space layout, standard south and north window details optimized for daylighting and views, a repeatable electric lighting layout, and a modular underfloor air delivery system. This optimized open office bay was then replicated for each wing, reducing the overall design optimization time needed for the full facility. Integrating energy efficiency with modular construction techniques can save significant energy at similar overall project costs.

The added costs of the RSF's selected premium efficiency lighting fixtures and controls were offset by reduced design and optimization time related to the modular and repeatable configuration and minimized unique fixtures in unique spaces. This results in a high-efficiency lighting system with similar total first costs to a standard office lighting system.

Figure 4–4 RSF floor plans showing modular office plan

Panelized precast wall modules significantly reduced the need for interior design finish costs. The precast wall panels were fabricated off-site with careful attention to interior concrete surface finishes. This allowed the exposed concrete to be painted white, maximizing the thermal benefit of exposed thermal mass and reducing interior finishing costs. Similarly, the exposed ceiling deck with appropriate acoustical treatments was less expensive than a suspended ceiling, and allowed for the radiant heating and cooling system to be integrated into the ceiling deck in a modular fashion.

Any component that can be significantly replicated through repeatable design and manufacturing will, through economies of scale, be less expensive than a custom component. This best practice resulted in the largest savings in the south and north window system design in the RSF. The RSF has more than 200 south windows, all with the same overhang, window size, operable component, and daylighting redirection device. Similarly, more than 200 north windows are the same size with the same operable components. Standardization reduced the overall window costs; thus, other energy efficiency elements such as overhangs, triple-pane glazing, and advanced thermally broken window frames could also be included.

Finally, increasing space efficiency through modular and open office space design strategies is a key cost control element for the RSF. Increasing space efficiency allows the owners to include more of the building purpose in a smaller footprint, resulting in more project scope for less first costs. The overall space efficiency results in 267 ft^2 of building gross area per workstation. NREL's space efficiency in previous leased office space with typical enclosed offices and high cubicle walls was 350–400 ft^2 per workstation. Because the furniture system determined the building design, wasted space was minimized. The open office system, which includes workstations for 824 occupants, allows for slightly smaller cubicles (reduced from 84 ft^2 to 72 ft^2), which feel much larger than enclosed cubicles. The building also includes support spaces such as huddle rooms, a lunchroom and coffee bar, numerous conference rooms with capacity ranges of 8–100 occupants, a data center, an exercise room, and a library. In general, reinvesting space efficiency cost savings into efficiency strategies can result in high performance with similar overall first costs.

4.7 Best Practice #12: Leverage Alternative Financing To Incorporate Strategies That Do Not Fit Your Business Model

Alternative financing models should be used when available for more expensive strategies such as on-site renewable generation. Owners commonly use PPAs and performance contracting to incorporate on-site renewables without investing project capital. DOE and NREL, as nontax-paying entities, used PPAs to include on-site building-mounted PV systems and a woodchip-fueled campus water boiler. The PPA provider can take advantage of various tax deductions and credits, as well as local utility rebates, offering a competitive rate to the owner. Without a PPA, the RSF would not have been able to reach its net zero energy goals. Numerous demand-side rebate programs are also typically available from the local utility; these can help to defray the cost of efficiency investments. The local utility rebate was reinvested into the project to help fine-tune controls during the measurement and verification process in the first year of occupancy.

5.0 Construction Strategies

5.1 Best Practice #13: Maximize Use of Off-Site Modular Construction and Building Component Assembly

Owners who have projects that are designed to maximize the modularity of key building blocks may be able to save manufacturing and assembly costs by having these manufactured offsite in a quality-controlled assembly process. Moving as much of the building construction process off-site eases site coordination details and safety concerns, and results in faster, safer, and higher quality installation, both of which save total project costs. The off-site manufacturing of the RSF's precast wall panels resulted in a simplified construction process: the wall panels were hung on the steel structure, the panel joints were sealed, and then the interior concrete was painted. This resulted in a high-quality, easily constructible, finished wall system.

Further off-site manufacturing advances allowed the RSF expansion's precast wall panels to be glazed off-site at the precasting manufacturing facility. The panels with the windows installed were then craned into place (see Figure 5–1). This approach reduced installation costs by reducing the site scheduling and coordination, freeing project funds for triple glazing at the east and west balconies.

Credit: Shanti Pless/NREL

Figure 5–1 Precast wall panels with windows being installed in the RSF expansion

Another example of off-site assembly and modularity was the installation of the 42 miles of radiant heating and cooling tubing that is integrated into the ceiling slabs. To reduce site coordination and setup time during the ceiling slab concrete pours, mats of preplumbed zones were prefabricated off-site and rolled up for transportation and placement. A crew of five spent three months in the mechanical subcontractor's yard prefabricating each zone—laying out the tubing, tying it to the rails, and then rolling each mat for storage until the decks were ready. Then the mechanical subcontractor used a crane to lift the huge bundles of tubing onto the decks. A crew unrolled the tubing, tied it down, and made the necessary connections (see Figure 5–2). The construction schedule allowed five days to install the tubing on each deck, but the off-site fabrication enabled the work to be completed in just two days, saving 28 days in the construction schedule. This installation model was a precursor to a new product now offered by the radiant tubing manufacturer: a custom-designed, prefabricated, prepressurized network of tubing connected with engineered plastic fittings. This product can now be installed approximately 85% faster than conventional radiant tubing methods (Sullivan 2011).

Credit: Shanti Pless/NREL

Figure 5–2 Radiant tubing mat installation

5.2 Best Practice #14: Include a Continuous Value Engineering Process as Part of the Integrated Design Effort

To reach a high level of energy efficiency while meeting a FFP contract limit requires an early and continually evolving understanding of construction costs, energy performance, and construction scheduling. To develop an early and robust understanding of various project cost options, cost estimators must be integrated as key members of the project team. This results in nearly continuous value engineering throughout the design process. Early design decisions made without input from either constructability or energy experts often do not represent an optimal balance of schedule, scope, budget, and energy performance.

In the RSF, before the first design team project charrette, the energy modeling team was engaged to evaluate and recommend key conceptual design features, such as high mass concrete wall systems, radiant heating and cooling, building orientation, and a 60-ft cross section. With these considerations understood early in the process, design development and value engineering were able to integrate these critical energy features into the FFP contract and meet all required project objectives. As discussed in Section 4.3 and Figure 4–1, the envelope design concepts evolved from a double-skin façade to a transpired solar collector because of the effective value engineering process.

5.3 Best Practice #15: Integrate Experienced Key Subcontractors Early in the Design Process

To control the construction costs for novel or untested efficiency strategies, the key mechanical and electrical subcontractors must be included in the design process. This reduces excessive bids from subcontractors who are uncertain about the design and who do not fully understand the design intent, and reduces the installation risk and added contingency carried by inexperienced subcontractors. Some of the most cost-effective and critical efficiency features were designed in conjunction with key subcontractors to ensure constructability. The RSF design-build contractor developed a team with its subcontractors and design partners. The team continuously evaluated bids from the subcontractor community to find the best value—the combination of complete scope, best experience, and past performance—compared to the lowest first costs.

The design-build team leveraged the experience, relationships, and investment of the original subcontracting team to manage costs for the RSF expansion. The contractor's preconstruction team worked with all the primary subcontractors to negotiate commitments for cost reductions by leveraging the replication between the RSF and the expansion, the subcontractors' success at executing the first project, and the proven abilities in managing the overall work to support efficient construction of their scope. As simple as it sounds, every owner should consider leveraging this simple opportunity to get more for less—an expansion or additional building that follows while the construction team is already on-site can leverage cost control. By applying lessons learned from the building's first phase, repeating the fundamental design concept, and leveraging subcontractor familiarity with the various building components, an additional $14/ft^2 was saved in the total project construction costs and energy use was reduced by 11% compared to the first two wings.

6.0 Conclusions

The RSF is a recently completed 220,000-ft^2 headquarters and administrative office building with a corporate-scale data center. It is a showcase for cost-competitive, marketable and sustainable, high-performance design that incorporates the best in cost-effective energy efficiency, environmental performance, and advanced controls using a whole-building integrated design process. A series of 15 best practices for controlling capital costs in procurement, design, and construction was developed based on experiences with the RSF project. During the design process, the integrated design-build team used an effective continuous value engineering process to ensure the energy performance requirements were met in the most cost-effective way. This included early energy modeling balanced with continuous cost modeling to optimize efficiency strategies. Strategies that integrated energy efficiency with the architectural design and envelope components are key elements of the RSF design. Conceptual design strategies such as a double-skin façade provided limited value in reaching the energy goals relative to cost. In this case, a transpired solar collector was identified to provide superior value. Additional cost controls, such as a simple modular structure and office layout, no curved walls, an optimized WWR, and precast concrete wall panels allowed the design-build team to meet the energy requirements at a construction cost that is competitive to other government and institutional campus office buildings. Combining the cost-effective energy efficiency strategies with a PPA PV system allowed the RSF to reach a net zero energy position and save more than $200,000/yr in energy costs on schedule and on budget.

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Appendix A Total Project Cost References

3rd Division Drive Fort Lewis Whole Barracks Renewal and Dining Facility
2/75th Ranger BN
Buildings 1062-A 3rd Division Drive
Fort Lewis, WA 98433
Built 2009
83,445 ft^2 of housing
23,390 ft^2 of dining
Total Project Cost: \$30,300,000 → \$284/ft^2
LEED Silver, 30% Savings over ASHRAE 90.1
Design Build Institute of America Database
www.dbia.org/

Aircraft Research Support Facility
47123 Bruse Road
Patuxent River NAS, MD 20670
Built 2009
49,000 ft^2 Administrative Office Building
Total Project Cost: \$21,676,000 → \$442/ft^2
LEED Silver
Design Build Institute of America Database
www.dbia.org/

Bremerton BEQ – Building 100
Naval Base Kitsap
Bremerton, WA 98314
Built 2005
99,800 ft^2
Total Project Cost: \$27,094,290 → \$271/ft^2
LEED Certified
Design Build Institute of America Database
www.dbia.org/

Chevron NorthPark Office Building
100 Northpark Blvd.
Covington, LA 70433
Built 2008
300,000 ft^2 Office Building
Total Project Cost: \$79,800,000 → \$266/ft^2
Design Build Institute of America Database
www.dbia.org/

Dillard University Professional Schools Building
2601 Gentilly Boulevard
New Orleans, LA 70122
Built 2010
130,000 ft^2 Classroom, Office and Lab Building
Total Project Cost: \$38,106,500 → \$293/ft^2
LEED Gold
Design Build Institute of America Database
www.dbia.org/

Fernald Preserve Visitors Center
7400 Willey Road
Harrison, OH 45030
Built 2008
10,800 ft^2 Visitor Center
Total Project Cost: \$3,332,709 → \$308/ft^2
LEED Platinum
Design Build Institute of America Database
www.dbia.org/

Leo J. Trombatore State Office Building
703 B Street
Marysville, CA 95901
Built 2008
208,000 ft^2 Office Building
Total Project Cost: \$65,627,900 → \$316/ft^2
LEED Silver
Design Build Institute of America Database
www.dbia.org/

NASA Sustainability Base
NASA Moffet Field, CA
50,000 ft^2 Office Building
Expected Completion 2011
Estimated Project Cost: \$20,600,000 → \$412/ft^2
LEED Platinum (Goal)
www.nasa.gov/centers/ames/greenspace/sustainability-base.html

Naval Facilities Engineering Command Southeast – New Engineering Operations Center
Naval Air Station
Jacksonville, FL
Built 2008
60,000 ft^2 Office Building
Total Project Cost: \$16,887,410 → \$281/ft^2
Design Build Institute of America Database
www.dbia.org/

New Federal Building
Washington, DC
Built 2009
111,000 ft^2 Office Building
Total Project Cost: $58,844,060 → $530/$ft^2$
Design Build Institute of America Database
www.dbia.org/

NVCI Engelstad Cancer Research Building
10530 Discovery Drive
Las Vegas, NV 89135
Built 2009
184,000 ft^2 Lab and Office Building
Total Project Cost: $39,496,840 → $215/$ft^2$
LEED Silver
Design Build Institute of America Database
www.dbia.org/

Omega Center for Sustainable Living
Rhinebeck, NY
Built in 2009
6,200 ft^2 Educational Facility
Total Project Cost: $1,650,000 → $266/$ft^2$
LEED Platinum
www.eomega.org/omega/about/ocsl/

San Joaquin County Administration Building
44 N. San Joaquin Street
Stockton, CA 95202
Built 2009
250,000 ft^2 Office Building
Total Project Cost: $92,727,770 → $371/$ft^2$
LEED Gold
Design Build Institute of America Database
www.dbia.org/

San Joaquin Delta Community College Student Services DeRicco Building
5151 Pacific Avenue
Stockton, CA 95207
Built 2009
50,000 ft^2 Courthouse
Total Project Cost: $26,066,320 → $521/$ft^2$
Design Build Institute of America Database
www.dbia.org/

U.S. Federal Courthouse at Las Cruces, NM
200East Griggs Avenue
Las Cruces, NM 88001
Built 2010
237,000 ft^2 Courthouse
Total Project Cost: $93,175,020 → $393/$ft^2$
Design Build Institute of America Database
www.dbia.org/

Kitsap County Administration Building
Port Orchard, WA
Built in 2006
75,379 ft^2 Office Building
Total Project Cost: $240/$ft^2$
www.wbdg.org/references/cs_kitsap.php

University of Denver Sturm College of Law
Denver, CO
Built in 2007
237,863 ft^2 Office and Classroom Building
Total Project Cost: $65,000,000 → $273/$ft^2$
LEED Gold
www.americas.rlb.com/documents/case_studies/americas/case-study_university-of-denver_colorado.pdf#zoom=75

Federal Reserve Bank of Kansas City
Kansas City, MO
635,000 ft^2 Office Building
Total Project Cost: $225,000,000 → $354/$ft^2$
www.americas.rlb.com/documents/sectors/sector_federal/pdf/Federal%20Reserve%20Bank%20of%20Kansas%20City.pdf#zoom=75

The Leprino Building
Aurora, CO
Built in 2007
276,655 ft^2 Office and Medical Research Laboratory Building
Total Project Cost: $102,000,000 → $369/$ft^2$
www.americas.rlb.com/documents/sectors/sector_commercial/pdf/Leprino%20Building.pdf#zoom=75

Applied Research and Development Building
Flagstaff, AZ
59,820 ft^2 Office, Laboratory, and Classroom Building
Total Project Cost: $25,000,000 → $418/$ft^2$
LEED Platinum
www.americas.rlb.com/documents/sectors/sector_research/pdf/Applied%20Research%20&%20Development%20Bldg.pdf#zoom=75

National Association of Realtors Building
Washington, D.C.
Built in 2004
100,000 ft^2 Office Building
Total Project Cost: $46,000,000 → $460/$ft^2$
LEED Silver
http://greensource.construction.com/projects/0606_NAR.asp

Heifer International Center
Little Rock, AR
Built in 2006
94,000 ft^2 Office Building
Total Project Cost: $18,900,000 → $201/$ft^2$
LEED Platinum
http://greensource.construction.com/projects/0701_COL.asp
http://buildingdata.energy.gov/content/heifer-international-headquarters

Great River Energy Headquarters
Maple Grove, MN
Built in 2008
166,000 ft^2 Office Building
Total Project Cost: $42,000,000 → $253/$ft^2$
LEED Platinum
http://greensource.construction.com/green_building_projects/2009/0907_Great-River-Energy-Headquarters.asp

International Fund for Animal Welfare
Yarmouth Port, MA
Built in 2008
54,000 ft^2 Office Building
Total Project Cost: $14,000,000 → $259/$ft^2$
LEED Gold
http://greensource.construction.com/green_building_projects/2009/0907_IFAW.asp

1800 Larimer
Denver, CO
Built in 2010
500,000 ft^2 Office Building
Total Project Cost: $192,000,000 → $384/$ft^2$
LEED Platinum
www.1800larimer.com/

BCT-H Brigade Battalion Headquarters
Fort Carson, CO
Built 2008
140,000 ft^2 Office Building
Total Project Cost: $35,641,460 → $254/$ft^2$
(Construction cost $225/$ft^2$)
LEED Gold
Design Build Institute of America Database
www.dbia.org/

EPA Region 8 Headquarters
Denver, CO
Built 2006
301,292 ft^2 Office Building
Total Project Cost: $90,000,000 → $298/$ft^2$
LEED Gold
Design Build Institute of America Database
www.dbia.org/
www.wbdg.org/references/cs_epadenver.php
www.energystar.gov/index.cfm?fuseaction=labeled_buildings.showProfile&profile_id=1006713

The Signature Centre
Golden, CO
Built 2007
186,000 ft^2 Office Building
Total Project Cost: $46,000,000 → $247/$ft^2$
LEED Platinum
www.usgbc.org/ShowFile.aspx?DocumentID=5111

Arizona State University College of Nursing & Health
Phoenix, AZ
Built 2007
84,000 ft^2 Office Building
Total Project Cost: $27,400,000 → $326/$ft^2$
LEED Gold
http://www.smithgroup.com/index.aspx?id=1584&section=47

Arizona State University Walter Cronkite School of Journalism and Mass Communications Building
Phoenix, AZ
Built 2008
223,000 ft^2 Mix Use Building
Total Project Cost: $71,000,000 → $318/$ft^2$
LEED Silver
http://cronkite.asu.edu/news/newBuilding-022107.php
www.worldbuildingsdirectory.com/project.cfm?id=1714

Commerce City Civic and Justice Center
Commerce City, CO
Built 2007
90,000 ft^2
Total Project Cost: $28,000,000 → $311/$ft^2$
LEED Silver
www.mortenson.com/SubIndustry_Civic_CivicJustice.aspx

Fort Bragg Forces Command and U.S. Army Reserve Command Headquarters
Fort Bragg, NC
June 2011 completion
600,000 ft^2
Total Project Cost: $302,000,000 → $503/$ft^2$
LEED Silver
www.fayobserver.com/articles/2010/08/22/1022542?sac=Home
www.fayobserver.com/articles/2010/08/22/1022542?sac=Home

NREL RSF1
Total project cost: 64,000,000 = $290/$ft^2$ ($259/$ft^2$ construction cost)
June 2010 completion
220,000 ft^2 office building
LEED Platinum
www.nrel.gov/rsf

NREL RSF2
Total project cost: $35,000,000 = $258/$ft^2$ ($246/$ft^2$ construction cost)
November 2011 completion
135,000 ft^2 office building
LEED Platinum
www.nrel.gov/rsf