COST CONTROL STRATEGIES FOR ZERO ENERGY BUILDINGS

High-Performance Design and Construction on a Budget

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

EXECUTIVE SUMMARY

The National Renewable Energy Laboratory (NREL) has compiled a set of successful cost control strategies through the design and construction of multiple high-performance and zero energy buildings on its campus in Golden, Colorado. *Photo by Dennis Schroeder, NREL 25839*

The prevailing industry perception is that zero energy is cost prohibitive and suitable only for showcase projects with atypical, large budgets; however, there is mounting evidence that zero energy can, in many cases, be achieved within typical construction budgets.

To ensure that the momentum behind zero energy buildings (ZEBs) and other low-energy buildings will continue to grow, this guide assembles recommendations for replicating specific successes of early adopters who have met their energy goals while controlling costs. The intent is to inspire confidence in building owners and project teams to change the way they view ZEBs. Rather than asking, "How much more will zero energy cost us?," we should be asking, "How can we achieve zero energy on our budget?"

To help users maximize the opportunity for cost control in their projects, this guide provides the following content:

- Detailed discussion of recommended cost control strategies, which are grouped by project phase (acquisition and delivery, design, and construction) and accompanied by industry examples
- Recommendations for balancing key decision-making factors
- Quick reference tables that can help teams apply strategies to specific projects.

RECOMMENDED MARKET-FACING STRATEGIES

The cost control strategies recommended in this guide have been demonstrated at the U.S. Department of Energy's NREL campus in Golden, Colorado, and reflect the review and contributions of industry practitioners in the design and construction community. For clarity and ease of use, strategies have been organized by project phase.

Strategies for Acquisition and Delivery

- Utilize performance-based procurement to balance energy savings, other benefits, and budget constraints.
- Prioritize project objectives early on.
- Incorporate one or more measurable energy goals into the project request for proposals or contract.
- Procure a project team that demonstrates experience and provides best value.
- Address equipment efficiency in procurement specifications.

Strategies for Design

- Integrate simple and passive efficiency strategies.
- Consider life cycle cost impacts.
- Allow for cost tradeoffs across disciplines.
- Leverage the value-added benefits of efficiency strategies.
- Maximize the use of modular, repeatable design strategies.
- Size the glazing area to balance daylighting, thermal performance, and architectural amenities.
- Consider alternative financing for higher cost systems.

Strategies for Construction

- Integrate experienced subcontractors early in the design process.
- Use a continuous, integrated approach to value engineering to preserve features critical for meeting energy goals.
- Maximize the use of offsite prefabrication.

RECOMMENDED APPROACH

A holistic, comprehensive approach to cost control will result in the most market-competitive zero energy solution. Strategies in early phases set the stage for cost control opportunities later in the project. For example, setting a clearly defined energy goal at the beginning makes it possible to identify and preserve critical efficiency features later. Therefore, we encourage potential adopters to implement the full set of recommended cost control strategies whenever possible.

For projects that do not align with certain strategies or aspects of the high-level workflow recommended here, implementing a subset of the strategies will still be beneficial. In general, building owners and project teams should take advantage of as many of the recommended strategies as possible to get the most value out of the project budget, while pushing the energy performance envelope.

NREL's successes in demonstrating this comprehensive set of cost control strategies have occurred within a firm-fixed-price, design-build framework. Although this guide does not specifically recommend that all projects adopt this framework, NREL has found that it provides a number of benefits over other common alternatives. When paired with the recommended strategies in this guide, the firm-fixed-price, design-build framework enables and motivates competing teams to innovate, while assuring owners that the proposals will be economically feasible. This combination creates a culture of innovation and multidisciplinary collaboration that empowers design and construction teams to develop creative solutions that achieve aggressive energy goals on a budget.

OVERARCHING PRINCIPLES

To get the most out of cost control opportunities, the recommended strategies should be implemented with the following overarching principles in mind.

Select a delivery method that elevates the importance of energy performance to be on par with other project objectives

Including energy efficiency as a minimum requirement in a competitive delivery process promotes the innovation in the design and construction industry that is necessary to meet an owner's goals of high performance on a budget.

Emphasize integrated design and team communication

Integrated design results in design and construction solutions that cost less and perform better. Making design and construction decisions as a team limits misunderstandings during construction and ensures that individual expertise is effectively utilized. This level of communication and collaboration is critical to leveraging integrated design principles and implementing cost control strategies.

Leverage energy modeling early and often

When design and construction options are being evaluated, energy modeling should be used to assess the energy performance implications of those options. Energy modeling throughout the project can help ensure that project decisions contribute to the achievement of energy performance goals.

1. INTRODUCTION

The National Renewable Energy Laboratory's (NREL) Research Support Facility (RSF), a 360,000-ft^2 (33,400-m^2) administrative and office building, demonstrated that zero energy can be achieved on a budget. *Photo by Dennis Schroeder, NREL 17826*

CONTENTS

TARGET AUDIENCES

- Owners/developers
- Design teams
- Construction teams

Momentum behind zero energy design and construction is increasing, presenting a tremendous opportunity for advancing energy performance in the commercial building industry. At the same time, there is a lingering perception that zero energy buildings (ZEBs) are inherently cost prohibitive and therefore must be limited to showcase projects. More generally, design teams and building owners commonly cite the incremental first costs of efficiency strategies as a significant barrier to high performance in commercial construction projects [1].

THE OPPORTUNITY

Fortunately, an increasing number of projects are demonstrating that high performance can be achieved within typical budgets. To ensure that the momentum behind ZEBs and other low-energy buildings will continue to grow, this guide assembles recommendations for replicating the successes of early adopters. It highlights practices from successful projects and provides replicable strategies for achieving high performance on a budget.

When applied holistically, the recommended cost control strategies promote innovative design and construction solutions that can facilitate the achievement of a wide range of aggressive energy goals, whether zero energy or otherwise.

EARLY STEPS TOWARD ZERO ENERGY

In the past decade, innovators have dramatically improved the economic viability of ZEBs and other high-performance buildings. Both technology improvements and a progressive shift in industry practices have contributed to this progress. Historically, project teams have relied on simple payback analysis to justify energy efficiency strategies somewhat independently of other design decisions. Recently, project teams have begun to leverage more integrated approaches—spanning the procurement, design, and construction phases of a building's life cycle—to meet increasingly aggressive energy performance goals, including zero energy.

In 2006, Torcellini et al. of NREL compiled a case study report on six high-performance commercial buildings and found that integrated design and early prioritization of energy performance goals could be used to cost-effectively achieve significant energy savings (25%–70% better than required by ASHRAE 90.1-2001) [2][3]. In the same year, Griffith et al. used a large-scale simulation analysis to estimate the portion of the commercial sector that could achieve zero energy under different scenarios with varying levels of energy savings relative to the minimum requirements of ASHRAE 90.1-2004 [4][5]. To help guide early industry zero energy efforts, Torcellini et al. developed a set of zero energy definitions that reflect different project boundaries and objectives. Common zero energy targets include zero site energy and zero source energy; a site or source ZEB produces as much renewable energy as the total energy it consumes on an annual basis [6]. For buildings with high energy use intensity (e.g., large hospitals) or little onsite area available for photovoltaic (PV) systems (e.g., urban, high-rise office buildings), alternative paths to achieving zero energy with offsite renewable generation are possible [7].

ACHIEVING ZERO ENERGY IN PRACTICE

Recently completed buildings have shown that cost-competitive ZEBs are a reality today for several combinations of commercial building types and climate zones. NREL's RSF illustrates that a large office building can achieve Leadership in Energy & Environmental Design (LEED®) Platinum certification and zero energy in a cold-arid climate (Golden, Colorado) with a competitive first cost [1]. Construction cost is a common industry metric for comparing budgets of projects that may have different design and delivery methods. The first phase of the RSF, a 220,000-ft^2 (20,400-m^2) headquarters and administrative office building with a corporate-scale data center, was completed in 2010 and achieved its ambitious energy performance goals at a competitive move-in ready construction cost of \$259/ft^2 (\$2,790/m^2), excluding design costs and PV; this budget was comparable to those of less energy-efficient institutional and commercial buildings in the region [1]. The building was later expanded to a total of 360,000 ft^2 (33,400 m^2); aggregate costs for the second phase of construction were reduced by \$14/ft^2 (\$150/m^2), while energy performance was improved by 11%.

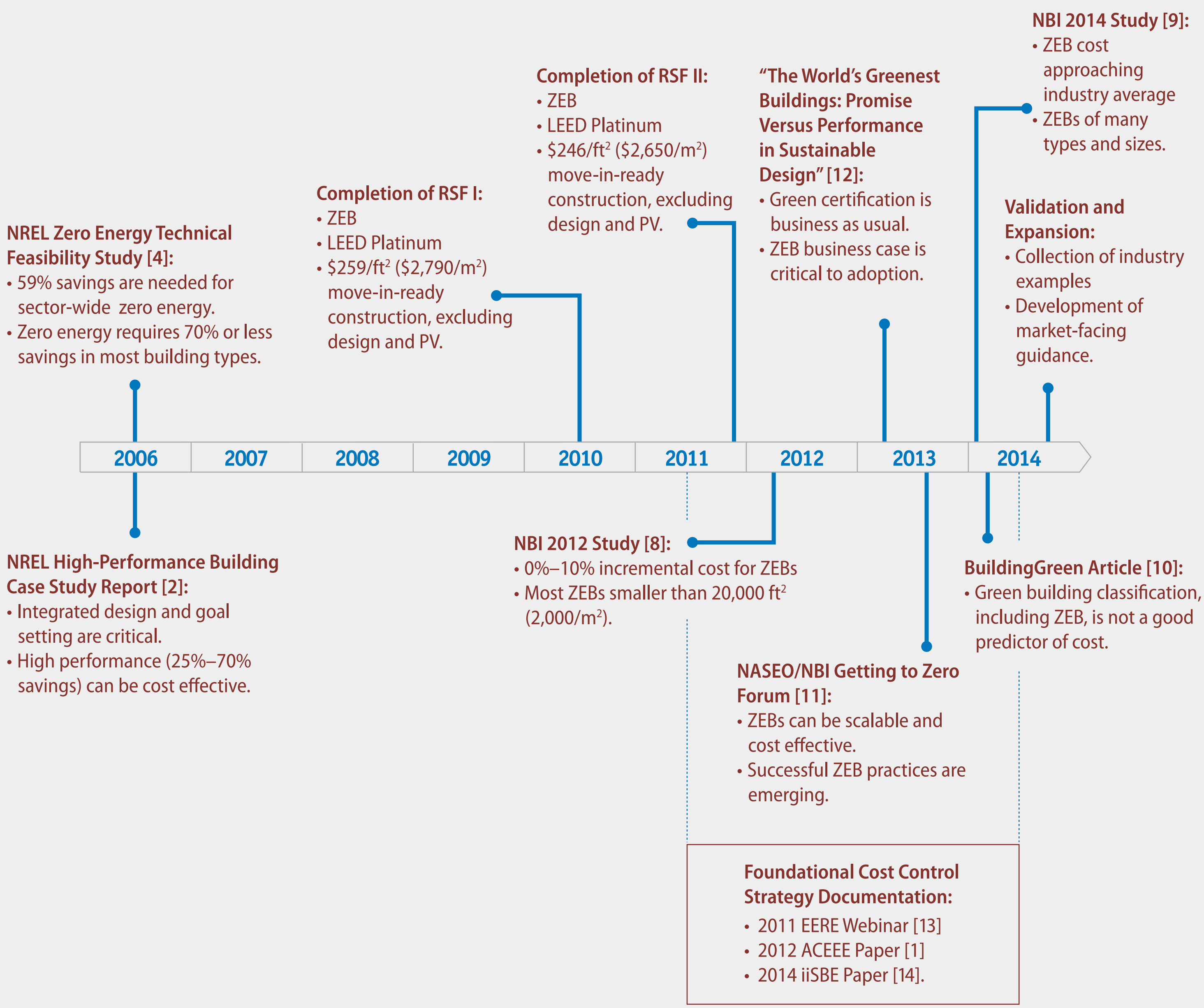
In a 2012 study, the New Buildings Institute (NBI) found that multiple projects had achieved zero energy at incremental costs of 0%–10% in comparison to standard practices [8]. NBI also found that most ZEBs had been constructed using technologies that were readily available, though there was a significant need for practical guidance to help designers, developers, and owners understand the value of zero energy and the resources available to help them get there. In a 2014 update to this study, NBI found that zero energy has expanded from the domain of a few small demonstration projects by universities or nonprofits to an increasingly mainstream presence that spans a variety of building types and sizes [9]. NBI documented that the number of buildings achieving or targeting zero energy have more than doubled in the past 2 years and that high-performance building costs in general are approaching industry averages. BuildingGreen echoed the latter idea in a recent article, suggesting that green building classification, including zero energy, is often a poor predictor of cost [10].

Evaluation of recent zero energy construction projects (both new construction and comprehensive retrofits) points toward trends in design, construction, and operation that include: (1) increased use of passive energy efficiency strategies that leverage the capabilities of the building envelope; (2) increased use of innovative heating, ventilation, and air conditioning (HVAC) strategies that decouple ventilation from space conditioning and reduce fan energy; (3) increased and ongoing attention to tuning controls in response to performance monitoring and building feedback; and (4) greater realization that occupant interaction with the building is critical to achieving zero energy in operation. These findings are consistent with the earlier analysis of Griffith et al. [4].

In September of 2013, the National Association of State Energy Officials (NASEO) and NBI sponsored the "Getting to Zero National Forum" as part of NASEO's 2013 Annual Meeting [11], where the cost of ZEB design and construction was a key topic of discussion. One takeaway was that integrated design allows for crucial tradeoffs that can keep the cost of ZEBs within typical budgets. This meeting indicated that: (1) there is a growing consensus throughout the commercial construction sector that certain types of ZEBs can be scalable and cost effective; and (2) successful emerging design and construction practices are making this possible.

In *The World's Greenest Buildings: Promise Versus Performance in Sustainable Design*, Jerry Yudelson and Ulf Meyer assert that pursuing "green" certification has become business as usual, due in part to the fact that building developers, managers, and owners, both public and private, have embraced intangible benefits of high-performance buildings, including enhanced marketability, higher productivity and morale, and improved public relations [12]. They stress that making a business case for high-performance buildings is essential for obtaining buy-in from project decision-makers, and that highlighting the long-term economic benefits of sustained utility cost savings, higher rent and increased occupancy, and greater availability of equity funding, can go a long way toward making the case. The authors also note that the additional cost of renewable generation required to make the leap from high performance to zero energy can be justified by considering the capital cost reduction that can be achieved through an integrated design strategy that leverages best-in-class efficiency to reduce overall system and envelope costs.

Bringing Zero Energy to the Mainstream



2. HOW TO USE THE GUIDE

The Packard Foundation successfully utilized a number of cost control strategies, including investing in the exterior envelope to reduce HVAC system costs, during the design and construction of its zero energy headquarters building. *Photo © Jeremy Bittermann.*

GUIDANCE PROVIDED

- See Section 3 for a discussion of strategies, grouped by project phase and accompanied by industry examples.
- See Section 4 for guidance on balancing key decision-making factors and quick reference tables that can help teams apply strategies to other projects.

This guide shares successful cost control strategies currently used by industry leaders to motivate widespread adoption by the commercial building sector mainstream.

The guidance is divided into two main parts. Section 3 provides recommended strategies, grouped by project phase (acquisition and delivery, design, and construction). Section 4 provides recommendations for balancing key decision-making factors and ties the strategies together in a set of quick reference tables to facilitate application to other projects.

RECOMMENDED APPROACH

A holistic, comprehensive approach to cost control will result in the most market-competitive zero energy solution. Strategies in early phases set the stage for cost control opportunities later in the project. For example, setting a clearly defined energy goal at the beginning makes it possible to identify and preserve critical efficiency features later. Therefore, we encourage potential adopters to implement the full set of recommended cost control strategies whenever possible.

For projects that do not align with certain strategies or aspects of the high-level workflow recommended here, implementing a subset of the strategies will still be beneficial. In general, building owners and project teams should take advantage of as many of the recommended strategies as possible to get the most value out of the project budget, while pushing the energy performance envelope.

NREL's successes in demonstrating this comprehensive set of cost control strategies have occurred within a firm-fixed-price, design-build framework. Although this guide does not specifically recommend that all projects adopt this framework, NREL has found that it provides a number of benefits over other common alternatives.

When attempting zero energy through a traditional design-bid-build delivery process, project teams are limited to solutions that rely on incremental improvements to well-established technologies. This is because a design-bid-build approach results in the selection of separate design and construction contractors. Without true integration between the design and construction teams, the opportunity for creativity and innovation is limited. Architects may be reluctant to push the limits of efficiency, because they may feel uncertain that the project contractor will implement solutions according to a preliminary budget estimate based on quality historical cost data. At the same time, when presented with innovative designs, contractors may bid more conservatively because of lack of confidence in the constructability of less proven efficiency strategies. Additionally, separate design and construction contracts incentivize contracted parties to focus on their own interests, rather than seeking out collaborative solutions.

Alternatively, a firm-fixed-price, design-build framework enables and motivates competing teams to innovate, while assuring owners that the proposals will be economically feasible. This creates a culture of innovation and multidisciplinary collaboration that empowers design and construction teams to develop creative solutions that achieve aggressive energy goals on a budget.

Integrating additional parking spaces into ramps between floors maximized space efficiency for NREL's 1,800-space parking garage. This was one of multiple cost control strategies that enabled the project to achieve zero energy at no additional cost ($14,172 per space, compared to between $15,500 and $24,500 per space for a typical garage). *Photo by Dennis Schroeder, NREL 27807*

CATEGORIES OF STRATEGIES

The cost control strategies are divided into three categories, according to the primary audience addressed:

- Owners and developers
- Architects and design engineers
- Contractors and subcontractors

Note that recommendations may also apply to secondary audiences. In general, cost control is a team effort that requires start-to-finish collaboration between all major parties. Tasking isolated team members to carry out strategies without input or buy-in from the larger team is not recommended. To aid in integration and communication between building owners, designers, and contractors, Section 4 highlights actions for both primary and secondary audiences.

INSPIRING ACTIONS THROUGH EXAMPLES

To illustrate the practical potential of the recommended cost control strategies, we have paired them with examples of implementation by industry leaders in ZEBs and other high-performance building projects where possible. Though specific project parameters, challenges, and solutions will vary from project to project, the examples offer real-world context and potential reference points for users of the guide. The goal of the examples is to motivate others to proceed with zero energy goals by showing that high performance on a budget is possible.

APPLYING STRATEGIES TO A PROJECT

The final section of the guide describes how to balance key decision-making factors and provides quick reference tables to help building owners and project teams apply the recommended strategies to their projects. Cost control strategies have the highest potential for impact when considered early in the process by all relevant members of the team. These materials may be particularly useful when starting project planning, when the project team is first assembled, and when the project progresses from one phase to another.

The following steps can be taken to effectively apply the recommended strategies to a project. Note that the owner starts the process and takes the initial steps that set the stage for success. Once the full project team has been assembled, cost control becomes a team effort in which each team member plays a key role in specifying and implementing a package of cost control strategies.

1. Owner and owner representative: Review the full set of recommended strategies at the start of a project.
2. If possible, apply a comprehensive approach that leverages the full set of recommended strategies.
3. If necessary, modify or downselect strategies according to project-specific constraints.
4. Apply acquisition and delivery strategies to define project goals and select a design and construction team.
5. Team: Review the design and construction strategies and adjust them as needed based on project-specific conditions.
6. Apply design and construction strategies through an integrated team effort, ensuring along the way that team decisions reflect both budgetary constraints and energy goals.
7. Revisit strategies as the project progresses from one phase to another.

3. RECOMMENDED COST CONTROL STRATEGIES

The design team for the RSF was able to secure decision-maker buy-in for key efficiency technologies, including a transpired solar collector and exterior solar shades, by seamlessly integrating them into the building architecture. *Photo by Pat Corkery, NREL 17424*

GUIDANCE PROVIDED

- See Section 3 for a discussion of strategies, grouped by project phase and accompanied by industry examples.
- See Section 4 for guidance on balancing key decision-making factors and quick reference tables that can help teams apply strategies to other projects.

Through campus improvement efforts at NREL, a set of recommended strategies was identified for controlling capital costs in high-performance office buildings [1][13][14]. These practices have also been used to inform guidance for other building types. For example, subsets of these practices were incorporated into the 50% Advanced Energy Design Guides (AEDGs) for K-12 schools, large hospitals, and medium to big box retail buildings [15][16][17].

NREL's campus-proven strategies and ongoing discussions with industry experts form the basis for the recommendations in this guide. The following subsections provide a high-level summary of the recommended strategies, which are grouped by project phase (acquisition and delivery, design, and construction).

OVERARCHING PRINCIPLES

To get the most out of cost control opportunities, the recommended strategies should be implemented with the following overarching principles in mind.

Select a delivery method that elevates the importance of energy performance to be on par with other project objectives

Including energy efficiency as a minimum requirement in a competitive delivery process promotes the innovation in the design and construction industry that is necessary to meet an owner's goals of high performance on a budget.

Emphasize integrated design and team communication

Integrated design results in design and construction solutions that cost less and perform better. Making design and construction decisions as a team limits misunderstandings during construction and ensures that individual expertise is effectively utilized. This level of communication and collaboration is critical to leveraging integrated design principles and implementing cost control strategies.

Leverage energy modeling early and often

When design and construction options are being evaluated, energy modeling should be used to assess the energy performance implications of those options. Energy modeling throughout the project can help ensure that project decisions contribute to the achievement of energy performance goals.

3.1 ACQUISITION AND DELIVERY

NREL has successfully implemented a performance-based, firm-fixed-price, design-build approach to project delivery for multiple campus projects, including the South Entrance Building, a ZEB. *Photo by Dennis Schroeder, NREL 23219*

PRIMARY AUDIENCE

Owners and developers

RECOMMENDED STRATEGIES

- Utilize performance-based procurement to balance energy savings, other benefits, and budget constraints.
- Prioritize project objectives early on.
- Incorporate one or more measurable energy goals into the project RFP or contract.
- Procure a project team that demonstrates experience and provides best value.
- Address equipment efficiency in procurement specifications.

Thoughtful execution of the acquisition and delivery process is critical to ensuring that desired building performance is achieved. There are a number of actions that owners and developers can take in the early stages of a project to set the stage for success down the road.

SETTING THE STAGE FOR SUCCESS

Recommended Strategies:

- Utilize performance-based procurement to balance energy savings, other benefits, and budget constraints.
- Prioritize project objectives early on.
- Incorporate one or more measurable energy goals into the project request for proposals (RFP) or contract.

For recent campus projects, including the RSF, NREL and the building owner, the U.S. Department of Energy (DOE), have implemented a performance-based, firm-fixed-price, design-build procurement process to most effectively address performance and cost priorities. A performance-based approach to procurement encourages innovation and creativity, whereas prescriptive efficiency requirements limit design flexibility and cost control opportunities.

The owner can set a positive tone for the project from the outset by prioritizing project objectives early on. In particular, incorporating measurable energy performance goals into the project RFP and design and construction contracts clearly establishes energy efficiency expectations and provides the owner or developer with a fixed metric for evaluating energy performance.

Industry Example

Incorporate one or more measurable energy goals into the project RFP or contract

Jim Bradburn of M.A. Mortenson Company, a commercial building construction contractor, reports that incorporating energy performance requirements into a project's RFP significantly elevates energy efficiency in a project's list of priorities. In one recent project, an aggressive energy goal led the team to the conclusion that a radiant heating and cooling system, as opposed to a traditional ducted forced-air system, would be the most viable and economical approach. Despite its higher base cost, the radiant system was justified by its ability to meet the energy goal.

To reduce the radiant system's first cost, the team increased the thermal performance of the exterior envelope; this reduced the need for perimeter cooling and enabled a reduction in the capacity of the radiant system.

ASSEMBLING THE RIGHT TEAM

Recommended Strategy:

- Procure a project team that demonstrates experience and provides best value.

Competitive procurement of an integrated project team (design team, contractor, and trade partners) facilitates cost-effective delivery of high-performance buildings. Team members must collaborate across disciplines to develop a package of integrated solutions that achieve the level of efficiency and cost control needed for a marketable ZEB. Additionally, when construction contractors are given the opportunity to influence design, they become more invested in project goals and are more likely to seek energy-saving solutions for challenges that arise during construction.

When evaluating prospective project teams, including experience as a key criterion increases the likelihood of achieving zero energy on a budget. Ideally, the strongest examples of experience would include past success in controlling costs for a zero energy project of similar scope. Other strong examples include transferable experiences with practices, systems, or strategies from other types of projects that controlled costs while delivering high performance. Building owners should seek a project team that has been successful with multidisciplinary collaboration and measured achievement of energy performance goals. The best value proposal will include a competitive strategy for achieving aggressive energy performance goals, as well as evidence that the project team is capable of providing the desired outcome.

For more high-performance building procurement resources, visit NREL's performance-based acquisition website (https://buildingdata.energy.gov/cbrd/energy_based_acquisition/).

Industry Example

Procure a Project Team That Demonstrates Experience and Provides Best Value (Example 1)

Construction detailing can significantly impact the overall energy performance of a building. Jim Bradburn of Mortenson relayed an anecdote from a building in which the performance of a displacement ventilation system was significantly compromised due to lack of construction detail at the intersection of a wall and an attic space. A significant air gap at the intersection created a "chimney effect" that pulled conditioned outside air from the ventilation system directly into the unconditioned attic space.

Because of the substantial performance implications, Bradburn emphasizes the importance of standardizing successful practices through construction detailing. To leverage construction lessons learned, contractors can communicate those lessons to the project design team. Once the designers are able to convert lessons learned into improved detail specifications, those standardized practices can then be applied to reduce cost and improve energy performance in subsequent projects. Such improvements in detailing can significantly reduce the energy impact of building infiltration (e.g., via air barrier testing and leak sealing strategies) and thermal bridging (e.g., via continuous insulation systems).

Industry Example

Procure a Project Team That Demonstrates Experience and Provides Best Value (Example 2)

When considering new strategies, uncertainty and risk perception can be significant barriers to cost control. For example, Ken Seibert of CMTA Consulting Engineers shared the following insights:

- A contractor unfamiliar with ground source heat pump (GSHP) systems is likely to compensate for perceived risk by bidding higher. Likewise, a less experienced engineer might oversize the well field to ensure that load requirements are met. Design and construction teams with past success in implementing a technology are more likely to price it competitively. Once system designers understand the installation requirements of GSHP systems and have confidence from past experiences that they can perform with minimal problems, the designers can specify and implement GSHP at a lower price.
- Monitoring of existing GSHP systems builds the confidence needed to design smaller, less costly systems with more reasonable safety factors and fewer fallback features. Monitoring summer and winter peak ground loop temperatures and seeing that they were well within the desired operational range has given CMTA the confidence to size subsequent GSHP systems more aggressively. It has also enabled CMTA to design systems without glycol in appropriate climates. If glycol is added to ground loops that do not need freeze protection, first costs increase and energy performance decreases (about 5%–10% HVAC penalty).
- Experience can also help with material selection. Subcontractors typically use Schedule 40 black steel for interior piping, according to familiarity and standard practice, whereas high density polyethylene (HDPE) is typically used for GSHP ground wells because of its low cost and corrosion resistance. Inexperienced subcontractor teams tend to construct GSHP water loops with a combination of interior steel pipe and exterior HDPE pipe, but this increases costs and introduces corrosion that can clog strainers and coils. As subcontractors become more familiar with joining HDPE pipe, the natural progression is to move to an all HDPE system, which reduces cost by reducing clogs and eliminating the need for chemical treatment of ground loop water.

CMTA transitioned to all-HDPE GSHP system designs after finding that they reduce both first costs and long-term maintenance costs. *Photo from CMTA Consulting Engineers.*

Example Energy Goals From the RSF

Tier 1: Mission Critical Goals

- Attain safe work/design
- LEED Platinum
- ENERGY STAR® "Plus"

Tier 2: Highly Desirable Goals

- 800 staff capacity
- 25 kBtu/ft²·yr
- Architectural integrity
- Honor future staff needs
- Measurable performance better than ASHRAE 90.1
- Support culture and amenities
- Expandable building
- Ergonomics
- Flexible workspace
- Support future techologies
- Documentation to produce "how to" manual
- Allow secure collaboration with visitors
- Completion by 2010

Tier 3: If Possible Goals

- Zero energy
- Most energy-efficient building in the world
- LEED Platinum Plus
- 50% better than ASHRAE 90.1
- Visual displays of current energy efficiency
- Support public tours
- Achieve national and global recognition and awards

The goals set forth in the RFP set the tone for the RSF project, establishing that energy performance would be a critical driver throughout design and construction.

TAKING CONTROL OF EQUIPMENT LOADS

Recommended Strategy:

- Address equipment efficiency in procurement specifications.

NREL has found that developing equipment procurement specifications that require best-in-class equipment efficiencies and incorporating those specifications into the project RFP is a highly effective approach to plug and process load control. As improved building designs reduce HVAC and lighting energy consumption, plug and process loads are becoming a more dominant end use. In the RSF, plug and process loads make up half of the building's energy consumption.

This approach applies both to loads that are integral to the building (such as elevators and security systems) and to those associated with occupants (such as personal computers and multifunction printing equipment). In a design-build scenario, building-integral plug and process loads are normally the responsibility of the design-build team, whereas occupant-specific plug and process loads are normally the responsibility of the building owner or tenant.

To ensure that plug load mitigation is sufficient for achieving whole-building energy goals, the owner must work together with the design-build team to consider all loads. Although the design-build contractor is responsible for meeting the overall energy goal, a successful partnership will also hold the occupant responsible for occupant-provided plug loads. The owner should provide designers with estimated load profiles for occupant-provided equipment and take responsibility for maintaining equal or lower energy use for these loads. These profiles serve as a communication bridge between the owner's needs and the project team's design.

For more detailed guidance on cost-effective plug load mitigation, see the collection of plug load control resources at the DOE Commercial Buildings Resource Database (https://buildingdata.energy.gov/cbrd/search/resources/?f[0]=im_field_collections%3A781).

Plug load control was a critical aspect of achieving zero energy for the RSF project. To ensure that plug loads would not prevent the zero energy goal from being achieved, strict performance specifications for workstation plug load equipment, including laptops, monitors, task lights, phones, and even surge protectors, were incorporated into the owner's procurement guidelines. *Illustration by Matthew Luckwitz, NREL*

3.2 DESIGN

Guaranteed 24-hour operation was a critical value-added nonenergy benefit used in justifying the RSF data center configuration that included hot aisle and cold aisle containment, and outside air economizer cooling. *Photo by Dennis Schroeder, NREL 18784*

PRIMARY AUDIENCE

Architects and design engineers

RECOMMENDED STRATEGIES

- Integrate simple and passive efficiency strategies.
- Consider life cycle cost impacts.
- Allow for cost tradeoffs across disciplines.
- Leverage value-added benefits of efficiency strategies.
- Maximize the use of modular, repeatable design strategies.
- Size the glazing area to balance daylighting, thermal performance, and architectural amenities.
- Consider alternative financing for higher cost systems.

As the creative force behind a project, the design team has considerable flexibility in choosing how to meet the programmatic and energy performance goals of a construction project. A number of simple, repeatable design strategies can be incorporated into the design process to consistently reduce cost and improve performance.

TAKING ADVANTAGE OF NO-COST STRATEGIES

Recommended Strategy:

- Integrate simple and passive efficiency strategies.

Some efficiency strategies do not require additional capital investment, and these are an excellent starting point for high-performance design. In particular, innovative design teams can integrate a range of simple, passive energy efficiency strategies into the building architecture, including the exterior façade as well as structural elements. Building orientation, massing, and layout can be designed to reduce building thermal loads without increasing material or construction costs. Other passive strategies, including daylight redirection, thermal massing, natural ventilation, and solar shading, can be integrated with the building structure to create architectural features that also save energy.

Industry Example

Integrate Simple and Passive Efficiency Strategies

Ken Seibert of CMTA emphasizes the importance of measuring and evaluating operational performance in projects, both to reduce ongoing operational costs for the project being evaluated and to identify opportunities for improving future designs. Evaluating operational performance provides insight into the practical maintenance and reliability considerations associated with particular design technologies or strategies.

In the case of control systems, sensors provide the basis for automated energy-saving strategies, but some sensor-based control strategies require more maintenance than others to achieve predicted savings. Designers can work with owners to assess maintenance capabilities. If an owner does not have the resources to provide the ongoing maintenance for a particular system option, the designer may choose a simpler control system and invest instead in other capabilities.

These decisions will depend on owner-specific constraints. For K-12 schools, long-term maintenance budgets and in-house capabilities are often limited, and simplifying the design of control systems can benefit these buildings. For instance, Seibert reports that K-12 schools often have difficulty maintaining photocell-based daylighting control systems. Alternatives include investing in other lighting control systems (e.g., vacancy sensing or multilevel lighting) or other types of buildings systems (e.g., increasing PV system size). Similarly, maintenance tradeoffs might lead some teams to dry bulb temperature-based sensors instead of enthalpy-based sensors for economizer control.

The RSF's south-facing daylight redirection design is an example of a successful, low-maintenance, passive strategy that saves energy. Rather than employing adjustable blinds or automatic roller shades, the design uses fixed, light-redirecting devices that minimize glare and maximize daylight penetration without requiring occupant interaction or adjustment. Well-integrated solutions such as these can avoid the need for additional controls or active mechanical components that would otherwise increase first costs and require long-term maintenance. In the case of the RSF, application of simple, passive, well-integrated efficiency solutions also enabled mechanical systems to be substantially downsized.

BALANCING COST AND VALUE

Recommended Strategies:

- Consider life cycle cost impacts.
- Allow for cost tradeoffs across disciplines.
- Leverage value-added benefits of efficiency strategies.

For efficiency strategies that do have incremental first costs, there are a few different ways to justify their implementation. Design teams commonly use predicted energy cost savings to evaluate such measures. In some cases, however, energy savings alone may not be sufficient for decision-makers. To overcome this obstacle, contractual requirements play a critical role. For projects in which a performance-based procurement process has established clear energy goals and capital budget requirements from the outset, project teams are motivated to find the most affordable solution that meets the project's energy goals. In such cases, some efficiency strategies may be justified on the basis that they contribute to energy goals more effectively than alternatives or that they have life cycle cost benefits. Collaboration across disciplines will help ensure that such strategies are designed in a way that balances multiple project needs, including keeping total costs within budget.

Rather than solely viewing design decisions in terms of individual building components and assuming that their costs are independent, a well-integrated team will allow cost tradeoffs between building systems as another method for securing budget for efficiency strategies. Energy modeling plays a key role in evaluating tradeoffs and interactions between building systems, enabling design teams to predict the relationship between building loads and the appropriate capacity of HVAC components. For example, in the recently constructed, LEED Platinum, zero energy headquarters building for the Packard Foundation in Los Altos, California, the design team was able to avoid the cost of a $150,000 perimeter heating system and more than $300,000 in additional PV by investing $75,000 in triple-pane glazing to reduce perimeter thermal gains and losses [18].

Industry Example

Consider Life Cycle Cost Impacts

When evaluating an efficiency investment, it is important to consider not just first costs, but also long-term operational costs. Many building owners and project teams would consider postconstruction air barrier testing to be an unnecessary capital expense. However, Ken Seibert of CMTA and Jim Bradburn of Mortenson have found that air barrier testing has life cycle benefits that outweigh the initial fee.

Air barrier testing identifies leakage issues prior to occupancy, enabling mitigation measures to be taken that can significantly reduce long-term operational costs. Additionally, identifying systemic construction deficiencies can lead to standardized improvements in construction detailing.

Traditionally, design teams have preferred to oversize HVAC systems to compensate for infiltration due to leaky envelopes. However, if the design team has a specific airtightness expectation that will be ensured through testing and mitigation measures, safety factors used during HVAC sizing can be reduced. Seibert reports that:

- The benefit of air barrier testing can be accounted for by reducing design infiltration rates during system sizing. Downsizing HVAC systems saves both first costs and operational costs.
- Measurable improvement in operational performance can be achieved by establishing an airtightness requirement and verifying results with air barrier testing. When a design team knows that its architectural decisions will be evaluated for airtightness, there is an increased emphasis on identifying and mitigating potential leakage points. Every envelope penetration is a potential source of air leakage. For instance, soffits create weak points, making pitched roof designs more prone to infiltration than are flat roof designs.
- It is essential for the project team to coordinate with the air barrier test contractor to schedule the test at the appropriate time. The envelope needs to be completely closed; at the same time, the test should be as early as possible to limit the need for postconstruction fixes. For example, a contractor might not want to install certain exterior doors until the end of a project to maintain an easy access point for equipment and materials. This would prohibit air barrier testing until the end of construction, drastically limiting the potential effectiveness of leakage mitigation. In such a scenario, it would be more cost effective to install the doors early to enable the blower door test, and then to remove them for the rest of construction. Although this is an extra effort, it has the potential to save money in the long run. Seibert estimates that K-12 projects with poor airtightness can consume up to 10% more energy annually. At that rate, for a middle school that spends $150,000 per year on utility bills, a $10,000 blower door test could pay for itself within a year.

Bradburn emphasizes that effective team integration is essential to maximizing the benefit of air barrier testing. For raised airtightness standards to impact HVAC sizing calculations, the contractor ensuring airtightness must be able to communicate load reduction benefits to the design team.

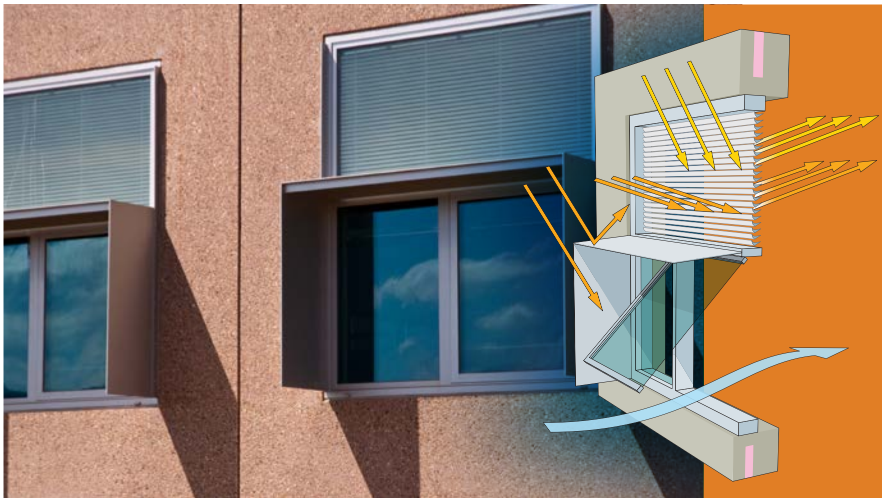
Industry Example

Allow for Cost Tradeoffs Across Disciplines

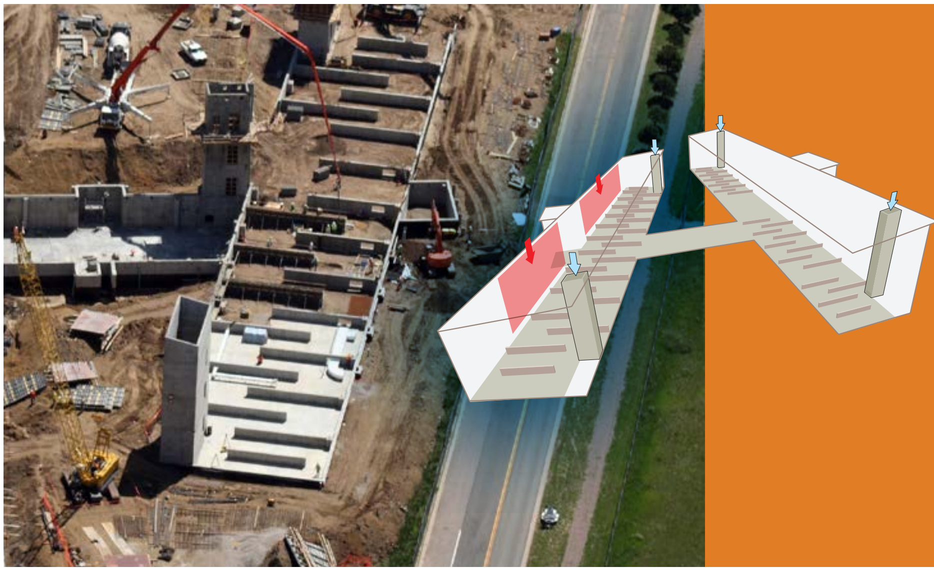
By considering construction process impacts, project teams can more effectively compare the first costs of construction alternatives during the design phase. A common mistake that project teams make when evaluating the first costs of competing design and construction strategies is to consider only material or equipment costs. In reality, installation costs can also differ significantly for different strategies. Exterior walls constructed with insulated concrete forms (ICFs) illustrate this concept well. Ken Seibert of CMTA observes from projects in Kentucky that:

- Traditional masonry construction has a lower material cost, but ICF walls can be constructed more quickly, reducing labor costs. ICF also enables streamlined scheduling of skilled trades work. With typical masonry construction, electrical and plumbing subcontractors need to be onsite throughout wall construction; with ICF, electrical and plumbing subcontractors do not need to be onsite until after the walls go up, further reducing labor costs.
- After accounting for streamlined construction, the cost of ICF becomes comparable to that for typical masonry construction. For these reasons, ICF has become a popular option for education, commercial office, healthcare, and hotel construction projects in Kentucky.
- Because of the speed of ICF construction, many projects also use ICF for interior masonry. As contractors gain experience with ICF construction, the cost of implementing ICF continues to decrease.
- There is an overall shortage of skilled masonry labor, and the availability of masonry subcontractors can often dictate construction schedules.

From an energy perspective, ICF is helpful because it provides a tight air barrier, which helps to reduce HVAC loads. Careful accounting of construction costs enables projects to leverage ICF and take advantage of the energy efficiency benefit.



The RSF envelope was designed to integrate a number of features into the exterior façade, including daylight redirection, glare control, solar heat gain reduction, and natural ventilation. *Photo by Pat Corkery, NREL 17411 (background); Illustration by Josh Bauer, NREL (foreground)*



The RSF team integrated a heat recovery feature into the structure of the building by designing its open office wings to sit on top of a shallow basement labyrinth. Air is pulled down into the labyrinth through ventilation shafts. As that air travels in S-turns through staggered concrete walls, the labyrinth acts as a thermal battery. In the summer, cool night air is used to charge the labyrinth for daytime cooling. In the winter, waste heat from the data center and additional heat from the transpired solar collector are captured for heating. This heat recovery solution enables outside air to be preheated by 5°–10°F (3°-6°C). *Photo by Duncan Foss, NREL 16461 (background); Illustration by Josh Bauer, NREL (foreground)*

Regardless of the business case for a design, the project team may have difficulty convincing decision-makers to approve innovative strategies outside of its comfort zone. In these cases, designers may need to identify additional mission-oriented benefits to attain owner buy-in.

To increase daylight penetration and enhance natural ventilation, the RSF design team proposed an open office layout that diverged significantly from NREL standard practice in space planning and office allocation. Before approving the layout, NREL wanted to fully understand its impacts, not only on budget and energy performance, but also on the productivity and satisfaction of building occupants. By convincing NREL decision-makers that the open office layout would improve productivity by promoting collaboration and increase occupant satisfaction through enhanced connection to the outdoors, the design team was able to obtain approval for its cost-effective but uncommon design approach.

Industry Example

Leverage Value-Added Benefits of Efficiency Strategies

Leveraging the nonenergy benefits of efficiency strategies can be critical to obtaining decision-maker buy-in. Jim Bradburn of Mortenson shared an example of a warehouse that was converted to an office space. The existing warehouse had 30-ft (9-m) high ceilings, making ventilation and air conditioning a challenge. To meet the energy goals for the project, an underfloor HVAC system was recommended, but energy performance was only one aspect of the pitch to decision-makers—the underfloor system was also identified as the best option with respect to comfort and aesthetics. The underfloor system was expected to improve air quality and leverage thermal stratification, whereas the overhead ducted alternative would create a "diffuser forest" aesthetic. By emphasizing comfort and aesthetic benefits, in addition to energy performance, necessary buy-in was obtained from the project decision-makers.

Philip Macey of JE Dunn, a commercial building construction contractor, echoes the importance of aligning efficiency strategies with key project values. In particular, Macey observes that occupant benefits are becoming a more influential factor for decision-makers: the healthcare sector is asking design teams for "patient-centric" hospitals, and designing "from the desk out" is the new expectation of office building owners and developers. Productivity and well-being have become greater drivers of budget allocations, and demonstrating how efficiency strategies help to enhance the occupant experience can be very persuasive. For instance, daylighting designs that connect occupants with the exterior environment are now a standard expectation for multiple building types, including healthcare facilities, where the benefit of natural light for patient outcomes is a key driver.

UTILIZING MODULAR DESIGN

Recommended Strategy:

- Maximize the use of modular, repeatable design strategies.

Modular, repeatable design elements can reduce project costs through economies of scale and increased speed. In the RSF, this strategy is exemplified by the south- and north-facing window system design. More than 200 south-facing windows in the RSF are the same size, have the same operable component, are shaded with the same overhang, and are fitted with the same daylight-redirection device. Likewise, more than 200 north-facing windows are the same size and have the same operable components. This standardization significantly reduced the overall cost of building glazing systems, enabling significant fenestration-related energy efficiency improvements—overhangs for solar shading, triple-pane glazing, and thermally broken window frames—to be incorporated into the budget.

TAKING A BALANCED APPROACH TO GLAZING

Recommended Strategy:

- Size the glazing area to balance daylighting, thermal performance, and architectural amenities.

Glazing facilitates daylighting and natural ventilation, improving the quality of the indoor environment, but it is also more costly compared to opaque envelope construction in terms of both first costs and thermal loads on the HVAC system. An effective approach for specifying glazing area is to:

1. First specify the amount of daylighting glazing necessary for the project's daylighting goals.
2. Then identify key opportunities for implementing view glazing that improves the interior environment while minimizing thermal gains.
3. Limit east- and west-facing glazing to the extent possible.

At the RSF, a balanced approach to glazing design enabled daylighting and energy objectives to be met with a window-to-wall ratio of 11%.

SPECIFYING OWNED VERSUS FINANCED SYSTEMS

Recommended Strategy:

- Consider alternative financing for higher cost systems.

Minimizing energy consumption is a critical first step to reducing the cost of renewable energy systems in a zero energy project. After that, the economics of owning renewable energy systems are highly case specific. Some projects are able to offset the first cost of installing onsite renewable generation systems with savings from other aspects of the design. Other projects are able to justify an incremental first cost based on the alignment with the owner organization's mission or the benefit to an organization's public image. For cases in which the owner lacks sufficient capital to directly purchase renewable generation systems, third-party financing is an alternative that can help a project meet the onsite generation portion of zero energy goals without increasing project first costs.

For the first phase of the RSF, the design-build team leveraged a third-party power purchase agreement (PPA) to secure the PV needed to achieve zero energy without exceeding the project budget (and without increasing the utility rate at which NREL purchases onsite power). Applying lessons learned from the first phase, the design team was able to significantly reduce the overall cost of the second phase of the building. Those savings, in part, enabled NREL to purchase rather than finance the PV required for the second phase.

Another consideration is the handling of renewable energy certificates (RECs) for onsite renewable energy systems. For onsite renewable system owners, selling the RECs can improve return on investment and monthly cash flow, but selling RECs (such as through a utility or state incentive program) reduces or eliminates the ability to claim use of the renewable energy for ZEB accounting and LEED certification purposes. When comparing options that involve REC sales, building owners should refer to the evolving industry guidance on requirements for maintaining ZEB status. More information on REC markets is available from the DOE Green Power Markets website [19].

3.3 CONSTRUCTION

Offsite prefabrication of exterior wall panels improved quality control and streamlined the construction process for the RSF expansion project. *Photo by Dennis Schroeder, NREL 18574*

PRIMARY AUDIENCE

Contractors and subcontractors

RECOMMENDED STRATEGIES

- Integrate experienced subcontractors in the design process.
- Use a continuous, integrated approach to value engineering to preserve features critical for meeting energy goals.
- Maximize the use of offsite prefabrication.

It is important to incorporate contractors into the overall decision-making process early in a project to ensure that construction considerations are properly weighed during design. Ensuring that designers and contractors are on the same page and fully understand the energy and cost implications of their decisions will pay dividends down the road by streamlining the construction process.

EARLY AND ONGOING ENGAGEMENT

Recommended Strategies:

- Integrate experienced subcontractors early in the design process.
- Use a continuous, integrated approach to value engineering to preserve features critical for meeting energy goals.

Integrating key trade partners into the design process at an early stage can help control the construction costs for less common or emerging efficiency strategies (such as natural ventilation, radiant heating, and daylighting). When faced with implementing strategies via a nonintegrated approach, trade partners are forced to account for uncertainty in their bids. When trade partners are brought into the design process early on, it ensures that they fully understand the design intent and can collaborate to devise and implement construction approaches that will maximize building system performance while minimizing installed cost. For example, by leveraging subcontractor familiarity with building components and applying lessons learned from the first phase of the RSF's construction, total project construction costs of the second phase were reduced by $14/ft^2 ($150/m^2), while energy performance was improved by 11%.

In a typical project, a traditional "value engineering" approach is systematically employed to reduce first costs by eliminating features considered to be nonessential. Without contractual energy goals, value engineering can also eliminate energy efficiency strategies that were justified with factors other than first cost. This can prevent a project team from achieving desired energy performance results.

Alternatively, if the energy goal is part of the construction contract, critical energy-saving features are less likely to be eliminated. Furthermore, an integrated project team should engage cost estimators from the outset to achieve buy-in and enable continuous performance-based evaluation of decisions as the project progresses. This approach will enable the team to view budgetary constraints more holistically and to consider both economic and energy implications of potential changes.

Facing an extremely tight construction schedule, the contractor who installed the radiant heating and cooling tubing in the RSF looked to prefabrication. Custom-designed, prepressurized, prefabricated rollout mats enabled the contractor to manufacture and test all 42 miles of radiant slab tubing in a controlled offsite environment. The tubing mats were customized to fit the design of the floor plan and its radiant heating and cooling zone network. Once the RSF decks were ready, the mats were simply crane-lifted into the appropriate place, rolled out, tied down and connected to the larger network. The mats were installed in just 2 days, beating the aggressive 5-day construction deadline by a full 3 days. The contractor estimates that conventional radiant system installation techniques would have taken 60 days longer—far longer than allowed by the schedule. *Photo courtesy of Uponor, Inc.*

OFFSITE PREFABRICATION

Recommended Strategy:

- Maximize the use of offsite prefabrication.

In the same way that modular design elements can be utilized to reduce design costs, offsite building component prefabrication techniques can be utilized to reduce construction costs. Offsite construction allows components to be manufactured or assembled in a controlled environment, improving construction safety as well as quality control. Additionally, offsite construction simplifies the onsite construction process and can significantly reduce the length of the construction schedule.

This strategy was used extensively during construction of the RSF. Precast insulated exterior wall panels were fully assembled offsite. When exterior wall panels reached the RSF construction site, exterior concrete surfaces had already been finished. This resulted in a significantly simplified onsite construction process for the first phase of the project: (1) panels were hung on the steel structure; (2) panel joints were sealed; (3) windows were installed and sealed; and finally, (4) interior concrete surfaces were painted. The result was better quality control with respect to exterior wall air leakage and a shorter construction schedule. During the second phase of the project, the onsite construction process was further simplified by installing and sealing the windows during offsite assembly. This refinement contributed to the cost savings that enabled the PV for the second phase to be purchased outright, rather than financed by a third party.

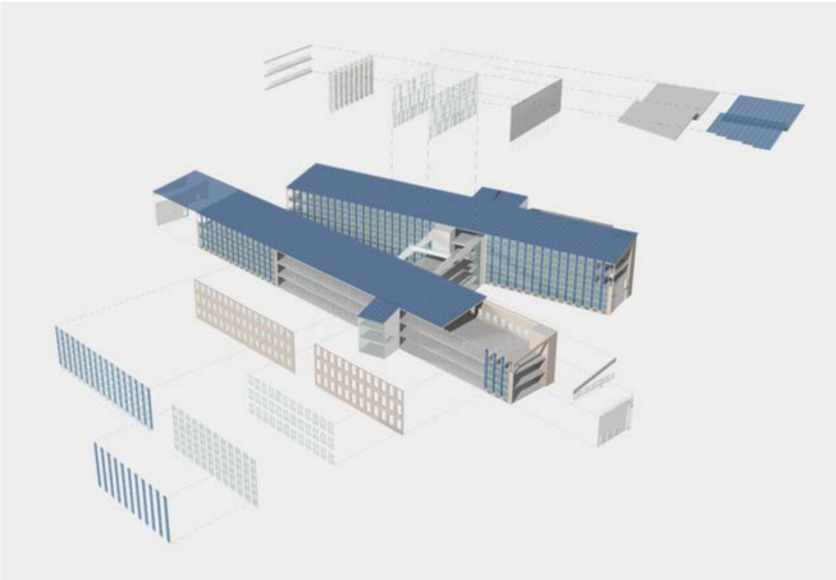
Industry Example

Maximize the Use of Offsite Prefabrication

Jim Bradburn of Mortenson is a strong proponent of offsite prefabrication, having found that it results in a construction process that is faster, safer, and more standardized. Because offsite assembly environments can be more readily controlled than building construction sites, standardized offsite assembly processes can be used to produce higher quality constructions in less time and with less risk for error or injury. Bradburn has found that:

- Precast exterior wall panels can significantly improve airtightness compared to typical onsite exterior wall construction.
- For a project at the Ft. Carson Army base in Colorado, precast exterior wall panels resulted in infiltration rates 50% lower than the already stringent airtightness requirements specified by the Army.
- Construction cost savings that result from offsite construction can be used to absorb the incremental costs associated with increasing the thermal insulation of exterior constructions.

For the 484,000-ft^2 (45,000-m^2) Miami Valley Hospital in Dayton, Ohio, the project team reduced the construction schedule by more than 2 months and saved 1%–2% on the cost of the $152-million building via multitrade prefabrication of 178 identical patient rooms and 120 corridor utility racks [20].



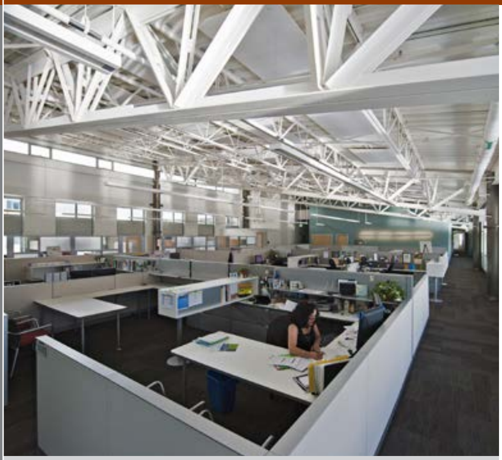
The RSF envelope was assembled in a modular fashion, using a "kit" of preassembled parts that included exterior wall panels, packaged glazing units with integrated solar shades, and clip-in PV panels. Offsite manufacturing of modular components improved construction safety and quality control, and it significantly reduced onsite construction time. A shortened construction schedule resulted in substantial construction cost savings that could be reinvested in further envelope performance improvements. *Illustration courtesy of RNL Design*

Photo by Dennis Schroeder, NREL 31142

Lessons learned from the first phase of RSF construction (RSF I) informed additional modularization strategies that further reduced construction costs in the second phase building expansion (RSF II):

- For RSF I, preassembled glazing units were installed onsite. For RSF II, glazing units were installed offsite during exterior wall panel fabrication.
- To mount PV panels onto the roof of RSF I, a dedicated support structure was built onto the standing seaming roof. To streamline the PV installation process for RSF II, the PV contractor designed mounting clips (photo at right) that enabled the PV panels to be mounted directly to the standing seam roof. These improvements generated enough construction cost savings to enable the PV for RSF II to be purchased outright, rather than financed through a third-party agreement.

4. APPLYING GUIDANCE TO PROJECTS



Dedication to team integration and communication enabled the RSF project team to maximize cost control opportunities by seamlessly blending efficiency with building architecture and the organizational mission, as illustrated by the fully daylit, naturally ventilated, open office floor plan.
Photo by Dennis Schroeder, NREL 17904

KEY QUESTIONS FOR PROJECT DECISIONS

- Does each option address the energy goal?
- Is one option the best long-term investment?
- Can I afford the best long-term investment?
- Does other value added change the solution?

To help building owners and project teams apply the recommended strategies to their projects, this section describes how to balance key decision-making factors and provides quick reference tables that assign audience-specific action items to strategies from previous sections.

BALANCING KEY DECISION-MAKING FACTORS

To avoid premature screening of design and construction options by first cost alone, the flowchart on page 22 summarizes a high-level decision process that effectively balances four types of factors: energy goals, long-term cost metrics, first costs, and value added.

1. Energy Goals

First, energy goals (e.g., a whole-building energy use intensity target) should be used to eliminate design decisions that would result in failure to achieve the desired level of efficiency.

In certain cases, RFPs may include stretch energy goals that are highly desirable but not mandatory. For the RSF, for example, zero energy was a stretch goal that the winning design-build team determined to be achievable on budget. When responding to an RFP with stretch goals, a design-build team may choose to target stretch goals at the outset, revisiting feasibility as it refines and downselects concepts. If the team later finds the stretch goals to be too challenging, it might shift to less aggressive concepts. Nonetheless, if owners include and incentivize stretch goals through RFPs, competitive teams will be motivated to attempt them.

2. Long-Term Cost Metrics

Once packages of solutions that do not meet the selected energy goals have been eliminated, the remaining design options should be evaluated based on long-term metrics, such as life cycle costs, to determine which option is the best long-term investment. Long-term cost metrics account for a combination of factors, such as first costs, energy cost savings, operation and maintenance costs, and replacement costs.

For some decisions, life cycle cost comparisons may be limited to rough, conceptual discussions between team members; in other instances, more robust analyses with energy modeling or other tools may be necessary to provide decision-makers with sufficient confidence to proceed.

3. First Costs

For a given design decision, the package of solutions that represents the best long-term investment may or may not be the package with the lowest first cost. Prematurely screening by first cost, however, can limit a team's ability to find optimal solutions that address multiple project objectives and take advantage of cost-saving synergies between strategies. Building owners and project teams will generally benefit from considering long-term impacts before assessing first costs. Knowledge of long-term benefits will encourage project teams to pursue innovative cost control or budget allocation strategies.

Teams should also set first cost constraints that are as holistic or high-level as possible, because this will allow teams to consider cost tradeoffs between lower level systems or disciplines. For example, high equipment and material costs can sometimes be offset by savings generated through design and construction process efficiency improvements.

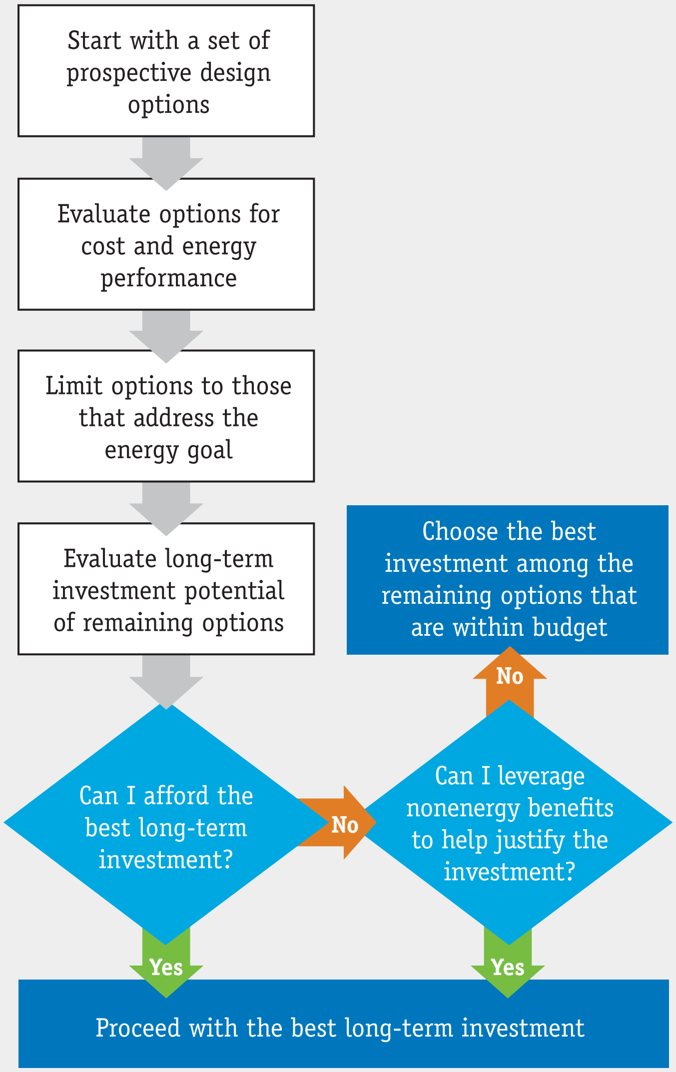
If the best long-term investment is affordable within the allocated portion of the project budget, the team can proceed with the investment. For cases in which multiple options have similar long-term investment potential, teams can favor options that meet energy goals at lower first cost.

4. Value Added

If the best long-term investment is not affordable on a first-cost basis, building owners and project teams may consider whether the additional cost may be justified by other nonenergy benefits, or "value added," such as support of programmatic requirements. If so, the building owner or project team could assess whether funds can be shifted from some other aspect of the project. Alternatively, if efficiency strategies can be integrated into building features funded by separate budgets, it may be possible to improve building efficiency without affecting budget allocations.

After considering additional benefits, if the best long-term investment is affordable, the project team can proceed accordingly. Otherwise, the project team can choose the best long-term investment among the remaining options that are within budget.

Decision Flowchart



QUICK REFERENCE TABLES

The following pages summarize the recommended cost control strategies and highlight action items for primary and secondary audiences. These tables can be used by building owners and project teams to develop high-level workflows for controlling costs in their projects.

<table>
<tr><th colspan="6">ACQUISITION AND DELIVERY STRATEGIES</th></tr>
<tr><th>Audience</th><th>Use Performance-Based Procurement</th><th>Prioritize Project Objectives Early</th><th>Set Energy Goals in RFP/Contract</th><th>Seek Experience and Best Value</th><th>Include Efficiency in Specifications</th></tr>
<tr><td>Owners and Developers</td><td>Select a project delivery method that can meet challenging performance targets while mitigating costs and risks.

If possible, procure a combined design and construction team (e.g., via a design-build process).

Consider a firm-fixed-price RFP.</td><td>Develop a clear, comprehensive RFP that outlines program, performance, and proposal requirements.

Clearly identify and prioritize needs at the outset of the project.

Fully commit to project objectives defined in the contract and avoid changing objectives.</td><td>Incorporate measurable energy performance requirements into contractual commitments.

Use the energy goal to drive design and construction decisions and solutions.

Incentivize superior performance.

Ensure the ability to verify performance during design and building operation.</td><td>Define team selection criteria that clearly reflect project goals.

Request examples of measured energy performance from past successful projects.

Consider funding a design competition between the top teams to ensure high quality.

Incorporate stretch goals in the RFP to encourage innovation.</td><td>Include performance specifications in the RFP for as many plug and process loads as possible.

Provide estimated load profiles to the design team for occupant-provided plug loads and take responsibility for maintaining equal or lower energy use for these loads.

Clearly identify building-integrated plug and process loads and communicate that specifications for these loads are the design team's responsibility.</td></tr>
<tr><td>Architects and Design Engineers</td><td colspan="3" rowspan="2">Work with the owner and other team members to understand how performance will be assessed and incentivized.</td><td rowspan="2">When selecting partners or subcontractors, request examples of measured performance from past successful projects.</td><td rowspan="2">Work with the owner to address any gaps in the assignment of plug and process load responsibilities.</td></tr>
<tr><td>Contractors and Subcontractors</td></tr>
</table>

DESIGN STRATEGIES

Audience	Integrate Simple and Passive Strategies	Consider Life Cycle Cost Impacts	Allow for Cost Tradeoffs Across Disciplines	Leverage Value-Added Benefits
Architects and Design Engineers	Leverage orientation, massing, and layout to reduce thermal loads without increasing cost. Integrate efficiency strategies with the building envelope and structure. Avoid unnecessary controls and moving components. Consider strategies that minimize the need for ongoing calibration. Align design choices with knowledge of the owner's maintenance budget and capabilities.	Use energy modeling and life cycle analysis to identify integrated design packages that are favorable long-term investments. Consider long-term maintenance requirements when comparing strategies. Monitor and evaluate operational performance of past designs to provide insight into reliability, maintenance, and other operational considerations. Evaluate efficiency investments using an avoided cost of renewables metric.	Right-size HVAC systems to account for the load reductions provided by other efficiency strategies. Leverage cost savings from HVAC system capacity reduction to invest in other improved efficiency packages. Use energy modeling early and often to evaluate interactions between building systems and design choices and maximize cost tradeoff benefits.	Document and emphasize nonenergy benefits (comfort, aesthetics, productivity, flexibility, etc.) of efficiency strategies to secure decision-maker buy-in. Align efficiency strategies with the organizational mission to increase willingness of decision-makers to sign off on emerging or unconventional strategies.
Owners and Developers	Communicate maintenance capabilities and operational priorities to the design team.	Explore strong long-term investment options before screening by first cost.	Reconsider typical discipline-centric budget allocations to enable fluid cost tradeoffs.	Consider values of efficiency strategies beyond energy cost savings.
Contractors and Subcontractors	Identify opportunities for reducing first costs with simplified construction.	Inform team members of construction considerations that can affect life cycle cost.	Inform team members if options involve tradeoffs between material and installation costs.	Communicate value-added benefits related to construction processes.

DESIGN STRATEGIES (CONTINUED)

Audience	Maximize Use of Modular Design Strategies	Size Glazing Area for Daylighting, Views, and Efficiency	Consider Alternative Financing for Higher Cost Systems
Architects and Design Engineers	Leverage the replicability of modular elements to reduce design and construction costs. Standardize building constructions (punched windows, exterior wall panels, etc.) to reduce cost through economies of scale. Use modular elements to increase space efficiency and reduce footprints. Reinvest space efficiency cost savings into efficiency strategies. Leverage modular floor plans to simplify mechanical and electrical system design.	Size glazing area to balance daylighting, thermal performance, and architectural amenities. • First specify the amount of daylighting glazing necessary for the project's daylighting goals. • Then identify key opportunities for implementing view glazing that improves the interior environment while minimizing thermal gains. • Limit east- and west-facing glazing to the extent possible. • Eliminate unnecessary glazing to decrease overall envelope costs and improve thermal envelope performance.	Consider leveraging alternative financing to take advantage of tax deductions, credits, and local utility rebates that are available to third-party commercial entities. Take advantage of demand-side rebate programs provided by local utilities to help defray the cost of efficiency investments. Consider a PPA for renewable energy systems if adequate funds cannot be freed through other cost-saving strategies. When direct purchase and financing options are both feasible, evaluate the life cycle costs, mission impacts, and other value added for each scenario.
Owners and Developers	Encourage designers and construction contractors to pursue innovative, cost-saving modular design and construction strategies.	Recognize that glazing has a wide range of implications beyond aesthetics and that careful design can optimize benefits.	Provide input during evaluations of how alternative investment scenarios align with owner goals and constraints.
Contractors and Subcontractors	Identify opportunities to modularize specific building constructions.	Communicate energy performance implications of glazing constructions (e.g., thermal breaks in frames).	Relay to owner any construction cost considerations, such as system sizing or construction scheduling.

CONSTRUCTION STRATEGIES

Audience	Integrate Experienced Subcontractors Early In Design	Use a Continuous, Integrated Approach to Value Engineering	Maximize the Use of Offsite Prefabrication
Contractors and Subcontractors	Leverage the expertise of subcontractors with experience from successful projects to ensure constructability and cost effectiveness of critical energy efficiency features. Continuously evaluate subcontractor bids for the best combination of complete scope, experience, past performance, and cost to find the best construction value. Assemble a cohesive team composed of contractor staff and key subcontractors and coordinate with the design team to most effectively evaluate potential design and construction decisions.	Integrate cost estimators as key members of the project team to develop an early and robust understanding of cost implications of various project options. When considering deviations from the original design, consider budgetary constraints holistically and evaluate both cost and energy performance implications. Use energy modeling to evaluate whether and how potential design deviations may impact energy performance.	Reduce site coordination and setup time with offsite manufacturing. Improve quality control and safety by manufacturing constructions in a controlled offsite environment. Maximize the impact of offsite prefabrication strategies by informing the design team of benefits and collaborating with designers. Hire subcontractors with expertise in prefabrication construction techniques and practices.
Owners and Developers	Emphasize the importance of assembling an experienced, integrated team.	Early in project planning, use energy modeling to identify energy features critical to achieving performance goals, and incorporate those features into the contract.	Integrate contractors and trade partners into the decision-making process from an early stage.
Architects and Design Engineers	Coordinate with construction contractors and subcontractors to evaluate the constructability of potential designs.	Avoid making major early design decisions without input from constructability and energy experts.	Explore and weigh construction considerations during design.

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COST CONTROL STRATEGIES FOR ZERO ENERGY BUILDINGS

High-Performance Design and Construction on a Budget

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