Controlling Capital Costs in High-Performance Buildings Using a Performance Based Design-Build Process

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www.nrel.gov/rsf
Maximum Efficiency with Deep Integration

- Cost and energy efficiency concepts
- Introduction to a high-performance office building
- Best practices for controlling capital costs
  - Acquisition and project delivery
  - Design
  - Construction
- Additional NREL projects
- Questions
NREL/DOE’s Mission
What We Do

Advanced Commercial Buildings Research, through applied research and demonstration, supports DOE’s speed-and-scale goals to reduce building energy use.

Focus areas:
• Whole-building systems integration
• Comprehensive building energy modeling
• Cutting-edge energy efficiency technologies
• Systematic performance metrics and monitoring

Our team’s key strength lies in combining all these tools to design well-integrated new buildings and cost-effective retrofits.
Advanced Energy Design Guides

30% guides
- Small office buildings
- Small retail buildings
- K-12 school buildings
- Small warehouse and self-storage buildings
- Highway lodgings
- Small hospitals and healthcare facilities

50% guides
- Small to medium office (SMO) buildings
- K-12 school buildings
- Medium to big box retail (MBR) buildings
- Large hospitals (LH)
What Is an AEDG?

Developed in collaboration with ASHRAE, AIA, IES, USGBC, DOE

Two series:
- Original series targeted 30% savings over 90.1-1999
- Current series targets 50% savings over 90.1-2004

Educational guidance—not a code or standard

Available for free as a PDF download from www.ashrae.org/freeaedg
Great Potential in Commercial Buildings

Where we are today
90 (1020) Existing commercial buildings (2003 CBECs)

Where we would be if all buildings were built to current code
70.7 (803) New buildings base scenario (Standard 90.1-2004)

Where we could be with current technologies
40.3 (458) Max Tech energy efficient scenario (Griffith et al. 2007)

Add renewables and we’re almost to net-zero
12.2 (139) Max Tech energy efficient scenario w/PV
The Future of Zero Energy Buildings

- ASHRAE Vision 2020
- AIA 2030 Challenge
- Living Building Challenge
- California Public Utilities Commission ZEB Action Plan
  - All new residential ZEB by 2020
  - All new commercial ZEB by 2030
- EU ZEB requirement by 2019
  - International Energy Agency ZEB Definitions Task
- All Federal Buildings ZEB by 2030
  - October 2009 Executive Order
  - Beginning in 2020 all new Federal buildings that enter the planning process are designed to achieve zero-net-energy by 2030
Research Support Facility Vision

• A showcase for sustainable, high-performance design
  o Incorporates the best in energy efficiency, environmental performance, and advanced controls using a “whole-building” integrated design process

• Serves as a model for cost-competitive, high-performance commercial buildings for the nation’s design construction, operation, and financing communities
Research Support Facility

- 824 people
- 220,000 ft\(^2\)
- 25 kBtu/ft\(^2\)
- 50% energy savings
- $259/ft\(^2\)
- LEED® Platinum
- Replicable
  - Process
  - Technologies
  - Cost
- Site, source, carbon, cost net zero energy building
  - Includes plugs loads and data center
- Design/build process with required energy goals
  - $64 million firm fixed price

Credit: RNL
Procurement process attributes *pre-2007*:
- Design-bid-build project delivery
- LEED-driven sustainability goals

Procurement process attributes *post-2007*:
- Design-build project delivery with firm fixed price
- Specific energy performance requirements in the Request for Proposal (RFP, also referred to as the contract)
  - RSF I, office example: 25 kBtu/ft²/yr
  - SEB, guard house example: net zero energy
- Energy modeling required to substantiate goals
- Energy end-use metering requirement
- Voluntary incentive ($) program to ensure measurement and verification outcome has a chance to meet predicted performance
• First, focus on **energy efficiency features**.

• Then, focus on adding **renewable energy** into the equation.

• Unlike traditional design where architecture defines the form and impacts the function of a building, **energy performance requirements** drove the design of the RSF.

• **Extensive energy modeling** established the basic building architecture and structure.
Key Design Strategies

- Optimal orientation and office space layout
- Fully daylit office wings with high-performance electrical lighting
- Continuous insulation and precast wall panels with thermal mass
- Operable windows for natural ventilation
- Radiant heating and cooling
- Outdoor air preheating
  - Transpired solar collector
  - Data center waste heat
  - Exhaust air heat recovery
  - Crawl space thermal storage
- Aggressive plug load control strategies
- Data center outdoor air economizer with hot aisle containment
- Roof top- and parking lot-based PV
#1. Select a project delivery method that balances performance, best value, and cost savings.

- Encourages innovation
- Reduces owner’s risk
- Faster construction and delivery
- Better cost control
- Makes optimal use of team members’ expertise
- Establishes measurable success criteria
#2. Incorporate measurable energy use performance requirements into a performance-based design-build procurement process.

- Measurable goals are better
- From bad to good…
  - I want a green building
  - Design a LEED <rating> building
  - Design a building to use 30% less energy than ASHRAE 90.1-2004
  - Design a building to use less than 25,000 Btu/ft²
  - Design a [NET] ZERO ENERGY BUILDING

- Influencing purchasing decision—the owner
Energy Performance Based Design-Build Process

• Performance based design-build with absolute energy use requirements
  o These are NOT bridging documents.
    – Owner has significant input into the preliminary design
    – Some overlap of A/E costs
  o These ARE performance specifications.
    – What something must do, not what it must be
    – Subcontractor must substantiate that the design meets requirements
    – Owner must not give the subcontractor technical direction

No drawings/plans in RFP!

Don’t change your mind
Details of 25 kBtu/ft² in a contract....

1. Set energy goal based on past measured office building research
2. Need to provide normalization for space efficiency
3. Need to provide adjustment for energy use for external users
   - Datacenter
4. Calculation method for delivered campus utilities
   - Didn’t want to let design team “assume” unknown delivered efficiency
5. Benchmark current plug loads and operational schedules
6. Thermal comfort requirements
7. Energy monitoring requirements
8. Unique substantiation requirements
9. Provide ZEB Definitions and Classification System
When energy performance is required…

• Force “integrated” design
  • Design decisions based on early energy modeling
  • Make optimal use of “free” energy sources
    • Data center waste heat recovery
    • Evaporative cooling in dry climate
    • Daylighting
  • Radiant heating and cooling integrated into building structural elements

• Architectural amenities budget applied to integrated envelope efficiency solutions
  • Near real time value engineering
#3. Clearly prioritize project objectives at the beginning of the design process.

- Use of a project objectives checklist to prioritize project goals in the RFP
  - Mission critical
  - Highly desirable
  - If possible

- “Crystal clear” about what the owner wants at the beginning of design
  - Saves time trying to “understand” owner wants
Developing a Performance Based Request for Proposals

- Up-front planning drives success
  - Design charrettes
  - Based on industry best practices
  - Owner’s representatives
- Design challenge
  - Suite of performance goals to challenge team
  - Substantiation criteria

**Tier 1: Mission Critical Goals**
- Attain safe work/design
- LEED Platinum
- ENERGY STAR® “Plus”

**Tier 2: Highly Desirable Goals**
- 800 staff capacity
- 25 kBTU/ft^2·yr
- Architectural integrity
- Honor future staff needs
- Measurable ASHRAE 90.1
- Support culture and amenities
- Expandable building
- Ergonomics
- Flexible workspace
- Support future technologies
- Documentation to produce “how to” manual
- Allow secure collaboration with visitors
- Completion by 2010

**Tier 3: If Possible Goals**
- Net-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
Owner Best Practices

#4. Competitively procure an experienced design-build team using a best value, firm fixed price process.

- $64M project cost limit
- Every project always has more scope than funding
- Design-build team selection based on competitions focused on amount of scope that can be provided for the money available

- Results in industry design, integration, and teaming innovation
#5. Include best in class energy efficiency requirements in equipment procurement specifications.

- Laptops and monitors
- Multifunction devices
- Data center servers
- 6-Watt LED task lights
- Break room refrigerators
- 55” LED LCD flat screen

- ENERGY STAR® product database and “Best in Class” program
Energy-Efficient Workspace

- **Workstation load:** 55 Watts
- **0.4 W/ft²** whole-building plug load intensity

- **Power strip on the desktop**
  - Easy to access power button

- **VOIP phones:** 2 Watts

- **Removing personal space heater**
  - Saves 1500 Watts

- **LED task lights**
  - 6 Watts

- **Fluorescent task lights**
  - 35 Watts

- **Desktop computer (ENERGY STAR®)**
  - 300 Watts

- **Multi-function devices**
  - 100 Watts (continuous)

- **Removing desktop printers**
  - Saves ~460 Watts/printer

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- **24” LCD energy-efficient monitors**
  - 18 Watts

- **Typical 19”-24” monitors**
  - 30-50 Watts

- **Laptop**
  - 30 Watts
Design Best Practices

#6. Leverage value added benefits to efficiency strategies.

- Machine-room-less traction elevators
  - Requires less building footprint support structure than hydraulics
- Laptops for all staff
  - Increases mobility and workspace flexibility
- Centralized copy/print functions with multifunction device
  - Exhaust volatile organic compounds (VOCs) from toners
  - Minimize unique toner replacement stock
- Views and daylighting for all with demountable open office plan
  - Increase space reconfiguration flexibility
  - Give all staff views
Daylighting

• Light enters through the upper glass and highly reflective louvers direct it toward the ceiling and deeper into the space.

• Light-colored, reflective surfaces and low cubicle heights permit the penetration deep into workspaces.
#7. Consider life cycle costs benefits of efficiency investments.
Design Best Practices

#8. Integrate simple and passive efficiency strategies with the architecture and envelope.

- Reduce loads first
  - Insulation and thermal bridging mitigation
  - Effective shading
  - Orientation and window placement
- Then focus on passive systems
  - Simpler and more robust envelope solutions
  - Minimize moving parts
Efficiency Integrated into Architecture

- Daylighting
- Thermal mass
- Natural ventilation
- Shading
- Orientation
- Massing and form
- Thermally activated building structure
- Transpired solar collector
Daylighting
• Two long 60-foot wide wings with east-west orientation
• Design reduces electrical lighting
Daylighting: Glare Control

A light-redirecting device reflects sunlight to the ceiling, creating an indirect lighting effect.

Fixed sunshades limit excess light and glare.

Credit: RNL
Labyrinth Thermal Storage

- Massive, staggered concrete structures in the basement crawl space stores thermal energy to provide passive heating and cooling of the building.

Credit: RNL
#9. Allow for cost tradeoffs across disciplines.

Transfer costs from mechanical and electrical systems to building architecture.

- Total cost same
- Mechanical/electrical costs less
- Invest in architecture, design, and modeling
- Active to passive
- Fragile to robust
- Longer life
- Less cost over life
- Simpler

Credit: RNL
#10. Optimize window area for daylighting and views.

Optimal window area strategy that balances cost, thermal performance, daylighting, and views.

- 24%-26% window-to-wall ratio
- 11% window-to-wall ratio for daylighting windows
#11. Maximize use of modular and repeatable high-efficiency design strategies.

Focus on repeatable design elements.

- Minimize unique and expensive building elements
- No curved walls
- Punched windows
- Increase space efficiency
Modular Design: Kit of Parts

Credit: RNL
Modular Floor Plans

267 ft² per occupant workstation

Credit: RNL
Modular Office Space

- Maximizes space efficiency
- Allows for 72 ft$^2$ and 120 ft$^2$ office cubicles
- Reduces drywall costs
- Building designed around 30 ft x 60 ft office space modules
#12. Leverage alternative financing to incorporate strategies that don’t fit your business model.

- Power purchase agreements
- Energy services contracts
- Utility rebate programs
Photovoltaic System

- Power Purchase Agreement (PPA) provides full rooftop array on RSF 1
- Net-zero energy: building, parking lot and future parking garage arrays

- 1,156 KW
- 449 KW
- 408 KW
- 524 KW
#13. Maximize use of off-site modular construction and building component assembly.

- Off-site assembly reduces on-site construction time
- Faster site assembly
- Increases quality and reduces costs
- Minimizes site coordination details and safety concerns
Precast Wall System

• Incorporates many passive heating and cooling techniques.

• Six inches of concrete on the interior provides thermal mass that helps moderate internal temperatures year-round.

• Nighttime purges in summer months trap cool air inside, keeping temperatures comfortable for the warm summer days.
• **42 miles** of radiant heating tubes run through the ceilings throughout the building.
Radiant Heating/Cooling

- Office wings are hydronically heated and cooled using radiant ceiling slabs.
- Five zones in each wing of the building are controlled by the radiant zone control valves.
Construction Best Practices

#14. Include a continuous value engineering process as part of the integrated design effort.

- A well-integrated design-build team can identify value additions during the design process.
- Balance cost models with energy models in early design.
A Value Addition Process

View looking East into the Entry Plaza
A value engineering process that adds value
#15. Integrate experienced key subcontractors early in the design process.

The big 5 subcontractors – select early for cost control and constructability verification

- Structural steel
- Mechanical/plumbing – AHU’s, hydronic, pumps
- Electrical – lighting, cabling, electrical distribution
- Envelope – the single most costly per SF and the most impactful to energy
  - Glass and glazing
  - Precast concrete wall system
Metrics of Success…

- Received elements/value that were not in the RFP (or did not help the energy efficiency)
  - Fancy woodwork detail
  - Extra glazing
- Comparison with other costs
Reclaimed natural gas piping serves as support for the building.

The lobby and other common areas feature beetle-kill pine from Western forests.

LEED Platinum rating, version 2.2 – 59 points.
How Much Did It Cost?

• $259/ft\(^2\) construction costs for site work, infrastructure, and building
  o Includes interiors, furniture, and cabling
  o Does not include PV, land, or design costs

• Third-party-owned power purchase agreement for PV
  o $29/ft\(^2\) or 11% additional cost if NREL had purchased all PV without tax breaks or subsidies (at $5/Watt)
### Compare

<table>
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Data used by permission from the Design-Build project database hosted by DBIA at [www.dbia.org](http://www.dbia.org)
RSF and Cost Concepts

The RSF will meet or exceed all the project objectives at our budget at a firm fixed price.

• So what is the payback?

The RSF construction costs are similar to other institutional office buildings.
Replicable – Cost Control Review

• Firm fixed price with required energy goals in design-build contract
• Integrated architecture and envelope as efficiency measures
• Simple and commercially viable
• No unique technologies required
• Modular precast wall panels with minimal finishes
• Optimized glazing area
• Repeatable office floorplate
• Takes a coordinated effort with the owner (and all user groups), architect, builder, and engineers
Replicable – Owner Review

• Owner made tough decisions up front  
  o Set budget  
  o Sought maximum value for that budget  
  o Prioritized goals

• Design-build procurement process  
  o Managed the team to the RFP and its substantiation criteria  
  o Rewards

• Allowed design-build team to use creativity to maximize value (innovation)

• Owner did not solve the problem (but knew the solution existed)
NREL RSF 3rd Wing

33 kBtu/ft², 50% savings, LEED Platinum 3.0

– Building 17% more efficient than the RSF
– Cost savings of 5% ($14/ft² cheaper)
1800 Car Staff Parking Garage

138 kBtu/parking stall
  - 0.5 kBtu/ft²
  - 175 kBtu/stall RFP goal
  - Does not include electric vehicle charging

Net-zero energy

Site Entrance Building

PV ready for 1.5 MW PV system
Parking Structure Project Overview

- Provides parking for full campus buildout
- $29.8 million
- Built sustainably at no additional cost
- Part of RSF complex net zero energy boundary
- Best value selection
- Additional $1 million award fee for superior performance
Design Solution—Metrics

Parking Spaces
- 1,806 total spaces
- 90 preferred spaces for carpooling and vanpooling, 90 preferred spaces for low-emitting vehicles, 36 electric vehicle charging stations

Cost
- $14,172 per parking space
- $15,500 to $24,500 for typical parking space in Denver area

Renewable Energy
- 1.13 MW PV (net zero energy for RSF complex)

Energy Performance
- 158 kBtu/space/yr, designed
- 90% energy reduction versus ASHRAE Standard 90.1-2007
NREL Cafeteria

30% savings over ASHRAE 90.1-2007
LEED Gold 3.0 minimum
  – Platinum if possible
Best in class commercial kitchen equipment
NREL Energy Systems Integration Facility

- NREL’s largest R&D facility (182,500 ft²)
- Space for 200 NREL staff and research partners
- Focus of the ESIF is to conduct R&D of integrated energy systems (Electricity, Fuels, Transportation, and Buildings & Campus systems)

October 2012 – substantial completion
November 2012 – commissioning and move-in
January 2013 – complete move

Images courtesy of JEDunn/SmithGroup
ESIF RFP Energy Requirements

26.7 kBtu/ft² Office wing
- not including waste heat use

1.06 PUE Super computer
- no mechanical cooling
- Waste heat reuse

30% Savings for all Labs
LEED Gold minimum
- Platinum if possible

Images courtesy of JEDunn/SmithGroup
ESIF High Performance Computing

Showcase Facility
- Use evaporative rather mechanical cooling.
- Waste heat captured and used to heat labs & offices.
- World’s most energy efficient data center, PUE 1.06!

20 year planning horizon
- 5 to 6 HPC generations.

Energy Data Hub
- Data mgmt, mining, analytics
- Smartgrid.gov
- High frequency data from technology deployment

Insight Center
- Scientific data visualization
- Collaboration and interaction.

Images courtesy of JEDunn/SmithGroup
PUE = Power Usage Effectiveness
Final Thoughts

World Class Efficiency is Possible within our Construction Budgets!

• Spend the time to get RFP right
  • Include absolute EUI requirements

• Set up acquisition process to “force” integrated design
  • Energy modeling guides conceptual design decisions
  • Architecture and envelope are also efficiency measures

• Unwavering commitment to problem statement
  • Unleash power of design/build team of experts to meet your needs – true value engineering
Thanks for your time and questions

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www.nrel.gov/rsf