THE ROLE OF LEAN PRACTICES FOR ZERO NET ENERGY RETROFITS

Akash Ladhad[1] and Kristen Parrish[2]

ABSTRACT

Many in the construction industry view lean practices as a means for reducing cost and schedule while maintaining or improving quality. We argue lean practices can also be used to promote energy savings throughout a building's lifecycle. This paper presents a case study of an existing building retrofit in Phoenix, Arizona. The project owner, a general contractor, self-performed much of the building construction and worked to ensure the project team aligned around the project's zero net energy goal. All building systems, excepting the walls and roof, were re-designed and re-constructed. After retrofit, the building has achieved net-zero energy consumption; that is, the building produces as much energy as it consumes on an annual basis. In this paper, we discuss the role of lean principles and construction practices in making this zero-net-energy retrofit project successful. Specifically, we discuss the effect of shared understanding, work breakdown structure, and early integration of the design and construction teams on energy performance. We highlight the role of these practices in design and construction activities. This case study illustrates the effectiveness of lean practices for achieving energy performance goals and proves feasibility of new work structures on retrofit projects. Based on this case study, we make recommendations for application of lean practices on future zero-net-energy retrofit projects.

KEYWORDS

Lean construction, work structure, retrofitting, deep energy savings, integration, process, collaboration.

INTRODUCTION

Deep building energy retrofits typically result in larger energy savings than operational changes can provide as these retrofits take a whole-building approach to design (i.e., optimize the whole) and implement integrated project delivery methods. This paper discusses a net-zero energy retrofit and how lessons learned on this project could apply to other deep energy retrofits for commercial buildings (where "deep" refers to energy savings of 25% or more) that may significantly improve building value (Miller and Pogue 2009). The inefficiency of existing building stock supports the need for retrofitting: energy consumption in the existing building stock in the United States accounts for approximately 41% of the total primary energy consumption (US DOE 2012). In order to reduce this consumption, we must retrofit

[1] Graduate Student, Del E. Webb School of Construction, Arizona State University, Akash.Ladhad@asu.edu

[2] Assistant Professor, Del E. Webb School of Construction, Arizona State University, Kristen.Parrish@asu.edu; +1-480-727-6363

the existing buildings, through replacement or upgrade of their existing building systems, to improve their energy performance. Beyond the energy argument, a building's operating costs account for the largest portion of the lifecycle cost. Thus, deep energy retrofit projects offer an opportunity to significantly reduce national energy consumption and expenditures. While much research exists on the topic of energy retrofits, very little explores the role of the contractor. Thus, we chose to explore the contractor's role (rather than the designer's or engineer's role) in delivering deep energy retrofit projects. The contractor plays a critical role in delivering a project that meets the owner's expectations and goals and satisfies the specifications (Ahn and Pearce 2007). Namely, the contractor executes the plans and specifications, giving physical reality to the design team's vision. In the case of deep energy retrofits, this role is particularly important, as installation and operation must conform to the design intent to achieve the predicted energy performance. Moreover, the contractor must understand the existing condition to effectively retrofit the building. This paper explores through case study critical building elements and processes for achieving deep energy savings in retrofit projects. Specifically, we present the role of the contractor in a case study project in Phoenix, Arizona where the contractor was engaged in the project early in the design stage. We conclude this paper with a discussion of recommendations that, if applied in part or whole, will increase the effectiveness of the construction team in delivering low energy retrofit projects.

BACKGROUND

In a design-bid-build environment, the design team releases plans and specifications at the outset of the construction phase, creating a situation where contractors are expected to build without necessarily knowing the owner's project requirements and goals. Late involvement limits the contractor's ability to establish project controls and anticipate probable risks, let alone provide meaningful feedback on constructability. In particular, the contractor is unable to suggest energy efficiency measures (EEMs), nor is (s)he able to analyze the constructability or the cost-effectiveness of the designer's proposed EEMs. Thus, contractors may be responsible for installation, and in some cases, performance of, EEMs without being able participate in their selection. Further, as a result of late involvement, energy goals may not be communicated well to the contractors (LEED is often transparent, but the energy measures are not). Unclear goals may also hinder the contractor's ability to suggest efficient alternatives.

We postulate an integrated project delivery (IPD) environment best promotes deep energy savings. It eliminates major issues associated with late involvement, providing the contractor awareness of the owner's goals and the design team's intent for each EEM. Moreover, this environment allows the contractor to suggest EEMs as well as the best project approach from a constructability perspective, which may provide a cost advantage to the owner. The contractor may also have ideas about alternative methods to achieve the owner's project goals. Given the contractor's experience with field conditions and EEM installation, the contractor's suggestions may prove invaluable. Finally, an IPD environment encourages collaboration between the design and construction teams to identify elements of the retrofit project critical to achieving deep energy savings and develop practices that increase the effectiveness of the construction team in delivering these energy savings.

CASE STUDY

This paper presents the case of a 1536 m^2 office building retrofit in Phoenix, Arizona. This is an ideal case study project as the general contractor is also the owner – DPR Construction self-performed the work for their own Phoenix office. Though this is not a typical process, it illustrates the value of early contractor involvement. While selecting a Phoenix office, DPR knew they wanted to retrofit an existing space rather than build a new space. DPR began this project shortly after finishing construction of their net-zero-energy San Diego office, and sought to apply lessons learned in San Diego on this project. They chose a space in central Phoenix built in 1972, with windows on either side of the building that provided sufficient daylight and ventilation (Blair 2012).

Similar to the energy goal in San Diego, DPR set a goal of net-zero energy consumption for their Phoenix office at the project outset. (This requires the building produce as much energy as it consumes on an annual basis (Crawley 2009). The Phoenix team applied lessons learned in San Diego to achieve net-zero on this project. Specifically, staying engaged throughout the process, full resource planning, and follow through were critical for the success of the Phoenix office retrofit. This allowed the Phoenix team to complete the project – from conceptual design through construction – in ten months. DPR worked with several sub-contractors on this project to accomplish the task of saving energy affordably: the project payback period is 7.5 years. Moreover, this project is the first net-zero private office building in Arizona (DPR Review 2011).

Table 1 lists the low-energy features in the building. Figures 1 and 2 show some of these features as well. Solar tubes (Figure 1) bring natural light to interior spaces, functioning as windows for the interior. This feature allowed DPR to reduce their lighting power density, as they installed fewer artificial lights. DPR reduced their lighting energy consumption by 70% due to the combined effect of daylighting and reduced lighting power density. Solar chimneys provide outside air and light to interior space using metals that heat up to create a stack effect. DPR opted for a zinc-clad solar chimney as they had zinc inventory they had from a previous project. This allowed DRP to pursue both their lean and green goals –they reduced their inventory while promoting energy savings in their new office. Evaporative cooling shower towers (Figure 2) are long towers with water showers within that cool incoming hot air. The Big Ass fans (Figure 1) are high volume low speed fans that maintain airflow at low energy expense. The operable doors and windows (Figure 1) allow large volumes of outside air to enter the office. The PV-covered canopies serve a dual purpose: they provide shade to the cars parked below and the photovoltaic (PV) panels on the roof surface provide a means of renewable energy generation. Finally, a Vampire Switch is a single manual switch. Located near the exit of work place and wired to all the electrical outlets, this allows the last person leaving the office to shut off power to all outlets so equipment like computer monitor screens do not draw any power overnight (thus, so-called vampire loads are eliminated). This featured reduced night-time plug load consumption by 90%. Not only do these low-energy features reduce electricity loads in the building, they contribute to a comfortable, appealing and pleasant workspace.

Table 1: Low-Energy Features of the DPR Phoenix Office

Low energy Feature	Description	Details
Solar tubes	Natural source of light, serving the purpose of artificial lighting.	82 in number.
Zinc-clad solar chimney	A thermal chimney used to create an updraft of air and improve indoor ventilation.	26.5 m(87-foot) long, 1 in number.
Evaporative cooling shower towers	The hot air moving through the tower is cooled with a shower of water.	4 in number.
Isis® Big Ass Fans®	Circulates the air.	2.4 m diameter, 12 in number.
Oversized roll-up doors	Operable massive doors which can be rolled up.	3 in number.
Operable windows	Operable windows to let the air flow in, during extreme heat.	87 in number.
PV-covered canopy covers	Photo-voltaic system to generate solar power.	Over half parking space, 79Wdc.
Vampire shut off switch	A single switch to turn off the plug loads.	To eliminate plug, like computer monitors.

Figure 1: Solar tubes; Big Ass fans; Operable windows (Photo by Akash Ladhad, 10/22/13)

Figure 2: Evaporative cooling shower towers (Photo by Akash Ladhad, 10/22/13)

Table 2 lists the total average electricity consumed per day by each building system (DPR Phoenix Dash Board). Note the office consumes 255 kW-hours of energy on average each day, but it produces 270 kW-hours of solar energy on average each day. Thus, the DPR office is a net-energy producer, producing more energy than it consumes on an average day. Similarly, Table 3 lists the average amount of water consumed in liters per day for various purposes. (DPR Phoenix Dash board).

Table 2: Daily Average Energy Consumption for Various Building Systems

System	Average electricity consumed per day (kW-hours).
Mechanical loads	71
Plug loads	122
Lighting loads	62
Total	255
Net Energy Consumption	28.85 kBtu/sf/year

Table 3: Water consumption for various building uses

Purpose	Average water consumed per day (Liters).
Domestic use	1780
Irrigation use	1740
Shower towers	30
Total	3550

DPR implemented design-build delivery on this project. They used several innovative teaming and delivery practices on the project and decided to implement ordinary construction methods. DPR believed that the sub-contractors were very important on this project as the quality of their work determined the effectiveness of EEMs. Hence, proper communication and coordination were vital. Specifically, DPR facilitated an open exchange of information so everyone had all the information they required to complete their work. Moreover, DPR aligned the team around the net-zero energy goal for the project. Lean principles made the entire process of construction very efficient. DPR ensured the right people were in the right place at the right time by requiring all subcontractors be present at regularly scheduled project meetings. Lack of participation results in wasted time and resources, and given that no decision could be made in the absence of even one party, attendance was imperative. Further, DPR required attendance to capture the benefits of complete involvement outlined by Alarcon (2011), including confirmation of assumptions, plan validation, and expedited and improved decision-making. This complete involvement allowed the subcontractors to share their expertise and helped in making the right decisions quickly, which in turn prevented drawing revisions and reduced rework.

DISCUSSION

This project features a unique situation in that the contractor is also the owner. However, we argue the success can be replicated on other projects, even in cases when the owner and the contractor are different entities. Key success factors include aligning the team around a common net-zero-energy goal and the team's willingness to question and examine design assumptions.

Projects may be plagued by lack of alignment between the design, construction, and owner teams about the project goals. Though this lack of alignment manifests itself in different ways, dissatisfaction is often a result. In particular, the owner may be dissatisfied with the final product if it does not meet their goals. Thus, the project lead should seek goal alignment across teams at the project outset. The owner team will most likely accept this responsibility. However, the project delivery team may need to educate the owner about relative costs and benefits of various EEMs, and analyse this data to determine the best EEMs for the retrofit project.

Contractors have many responsibilities in a deep energy retrofit projects. They help in detailing the project, identifying and delivering cost savings, and coordinating subcontractors. However, the most important responsibility the contractor has in a deep energy retrofit project is arguably providing constructability input. If contractors provide constructability information to designers and owners at the project outset, they can support improved decision-making. Further, contractors can and should help the owner to clearly define the project objectives based on their construction expertise. Finally, the contractor can help the owner to define project needs based on the objectives (e.g., if the objective is net-zero energy consumption, the project needs daylighting). These project needs provide a true basis for design, and may allow the project delivery team to re-visit and adjust typical design assumptions, generally used for worst-case scenarios.

The owners also play a very important role in deep energy retrofit projects, as they typically set the project goals. Owners may articulate energy goals, in particular, in terms of certification (e.g., LEED certification), energy savings goals (e.g., net-zero), or another means. Dependent on their goals, owners may need some education to appreciate the benefits of EEMs compared to their payback period and upfront cost.

Had DPR not been the owner, or had DPR not served as general contractor, the Phoenix office retrofit would likely not have achieved its net-zero energy goal. Moreover, the project would likely have taken longer to complete. The constructability input was essential on this project and design and construction would not have been executed as efficiently without it. The entire project was customized to meet the owner's needs. The selection of the HVAC system illustrates this customization. Energy calculations for the building revealed a conventional rooftop unit HVAC system would have consumed too much energy to allow the project to meet its net zero goal. However, the solar chimney system required a long hole (~30m) be cut in the structure, which would often be considered infeasible. However, since DPR was both the owner and the contractor, they authorized the installation of the solar chimney and the required hole in the structure. Had DPR not been the owner, this cut would likely not have been approved, and the energy performance would have suffered. Although constructability input may not seem to have great impact on design, if it is not considered, the owner often ends up spending more on design, construction, or both for the project.

RECOMMENDED PRACTICES

In the course of this case study, we discovered several practices that enabled this project to be successful from an energy performance perspective. We propose these practices be replicated on other retrofit projects, to the extent possible, to promote deep energy savings.

1. Learn from Previous Projects

The DPR Phoenix team implemented lessons learned in the course of the San Diego office project as described earlier in this paper. In this project, the Phoenix team placed the solar tubes more efficiently after learning from mistakes in placement at the San Diego office. Similarly, after seeing how much energy the San Diego office consumed at night, the Phoenix team opted to install vampire switches to manage night-time energy consumption. Owners, designers, and contractors should learn from their previous projects and adjust their approach on future projects accordingly. Lessons learned about improving constructability may be of particular importance.

2. Install Individual Performance Measuring Systems for each Building System

Separate energy monitoring systems for each building system enable the DPR office building to achieve net-zero energy. All the individual systems in the building have a separate monitoring system that allows the building manager to study the performance of individual systems and adjust those systems performing poorly to reduce their energy consumption. This also allows the building manager to ensure the systems are integrating properly (e.g., a reduction in lighting energy consumption should coincide with a reduction in HVAC energy consumption). Performance measurement at the system level enables energy management at the same level, and is thus a recommended practice for deep energy retrofits. Roth et al. (2006) suggest monitoring systems contribute to energy savings on the order of 20%.

3. Develop a Complete Understanding of the Existing Facility

Contractors and owners should ensure they have a complete understanding of the existing facility as the existing conditions may not reflect what is shown on the drawings. A laser scan of DPR office revealed that the building was 8 inches longer than that was represented in the drawings. Had this gone undiscovered in the design phase, it could have affected the layout of the office interiors and would have resulted in rework. Similarly, a full examination of DPR's office revealed confirmed existing insulation was sufficient. Understanding the current condition before beginning the retrofit allows contractors and owners to better plan the project and reduce the risk of redundant spending.

4. Conduct Value Analysis

Preplanning forms a major part of early involvement and encompasses the process of value analysis (Gibson et al. 1995). Preplanning and set-based design (e.g., Parrish et al. 2007) help to look into different options available and price each option early in the project. The process of value analysis helped DPR identify six different systems that enabled net-zero energy consumption and suited the project. This furnished options for the decision makers to choose from. This process helps the construction team determine several options, analyze their lifecycle cost and determine their payback periods. This process also enumerates the benefits of a particular measure while simultaneously assessing its first cost, its life cycle cost, and it's payback period. On DPR's project, this process revealed the ideal payback period is eight to ten years. This payback period allows the project team to include EEMs with relatively high initial cost and relatively low maintenance costs. On the one hand, if the payback period was lower, then high-first-cost EEMs would essentially not be considered, despite relatively low maintenance costs. On the other hand, if the payback period is higher, it is unlikely an EEM will prove a good investment.

5. Involve the Project Team Early and Often

We have discussed the benefits of early involvement throughout this paper. However, a few important reasons for early involvement of the project team bear re-mentioning. Specifically, designers and contractors should support owners. Designers and contractors should share their expertise to help the owner make the right decision. Contractors and subcontractors in particular can drive the project and prevent rework if they provide constructability input and allow the project to benefit from their experience and lessons learned from previous projects. Further, the project team can examine design assumptions and adjust them as appropriate to meet the project's needs.

6. Lean Principles as a Foundation for Management

DPR implemented management methods on this project that ensured the team was aware of the whole project, rather than simply a specific trade. Thus, team members were able to understand how their work fit in to the entire project and how their individual work integrated and interfaced with that of other contractors. DPR pursued lean principles and adopted lean tools, like Last Planner (Ballard 2000), map-days and just in time delivery. These lean principles fostered communication and shared understanding amongst team members. Last Planner and map-day scheduling (or reverse phase scheduling) continually reinforced the role of each subcontractor, as well as DPR, on the project, resulting in a more coordinated schedule and project approach. Finally, practices like just in time delivery resulted in a clean site, promoting productivity, safety and efficiency.

7. Involve an Energy Consultant

To achieve deep energy savings, an energy consultant should be a member of the project team. Early involvement gives the energy consultant time to understand the project and suggest and design appropriate energy efficiency measures. Though the owner provides the project goal, the energy consultant and the contractor assume the responsibility for operationalizing the goal. We argue this is not only appropriate, but a best practice, as the energy consultant and contractor each have expertise that allows them to achieve the owner's goal. Typically, the energy consultant develops several alternative suites of EEMs and presents them to the owner and contractor. This presentation provides the owner the information required to select the best suite of EEMs based on benefits, lifecycle cost, payback period, constructability, or a combination thereof.

8. Challenge Engineering Design Assumptions

Design teams make assumptions on most projects. These assumptions often reflect the design team's experience, understanding of the project, and industry norms. Whatever the basis, engineering assumptions often pertain to worst-case scenarios. However, in the case of energy performance, the worst-case scenario (all loads in the building achieving maximum at the same time), is highly unlikely and may not be detrimental to business practices enough to warrant the cost of prevention. If a project team can articulate an acceptable level of risk, the owner, design team, and contractor team can "right size" building systems and significantly reduce energy consumption.

CONCLUSIONS

This paper is based on a case study of a net-zero office building, located in Phoenix, Arizona. The owner and the contractor were the same on this project and the contractor drove the project right from the beginning. Though not typical, this case study reveals several elements that were critical to the project's success, i.e., achieving the goal of net-zero, that could be implemented on other IPD projects. Based on this case study, we developed recommendations for future goal of deep energy retrofit projects. We summarize these here:

- The contractor should support the owner and drive the project. The owner provides the project goal, and the contractor instantiates it.
- The contractor should analyze various design and construction options available for the project.
- The design and contractor teams should educate the owner about the benefits of EEMs compared to their payback period and lifecycle cost.
- Designers and contractors should study the existing facility thoroughly and make recommendations to owner based on this understanding.
- The contractor may help the owner choose the right designers and sub-contractors for their deep energy retrofit projects, including an energy consultant.
- It is the contractor's responsibility to make sure that everyone has all the project information they require to plan and complete their work and ensure the project team is aware of the owner's goals for the project.
- Contractors should implement communication and collaboration protocols that promote optimizing the project as a whole.
- Contractors should utilize their expertise and apply lessons learned from previous projects. If the contractor does not have previous deep energy retrofit experience, contractors should study similar projects.
- Contractors should determine the suitable payback period for the project; we suggest eight to ten years.

ACKNOWLEDGEMENT

We would like to extend a deep sense of gratitude to Cassie Robertson, LEED AP: BD+C, of DPR Construction Phoenix, for taking the time to discuss the project with us, which helped us develop and compile this paper. We also thank DPR Construction Phoenix for giving us the opportunity to study their office building and for their cooperation throughout this study.

REFERENCES

Ahn, Yong Han and Annie R. Pearce, (*2007*) Green Construction: Contractor Experiences, Expectations, and Perceptions. Journal of Green Building: Summer 2007, 2(3), 106-122.

Alarcon, I. D. C. (2011). "Collaborating with a permitting agency to deliver a healthcare project: case study of the Sutter medical center Castro valley (SMCCV)." Proc. 19th Annual Conf. Int'l Group for Lean Construction(*IGLC 19*). Lima, Peru, 13-15 July, 402-415.

Ballard, G. (2000). *The Last Planner System of Production Control.* Doctoral Dissertation, Civil Engineering, The University of Birmingham, Birmingham, UK, 192 pp.

Blair, S (2012). "Project of the year: Net-zero office building a living lab for DPR". ENRSouthwest. < http://southwest.construction.com/southwest_construction_projects/2012/1112-net-zero-office-building-a-living-lab-for-dpr.asp > (Nov. 25, 2012).

DPR Construction, (2012). "DPR Phoenix building dash board." < http://www.buildingdashboard.com/clients/dpr/phoenix/> (Nov, 2. 2012).

DPR Construction (2011)."The Path to Zero." *DPR Review*, Fall/Winter, 2011. < http://dpr-review.com/fall-2011-winter-2012/story/the-path-to-zero> (Dec. 5, 2012).

Drury Crawley, S. P. (2009). "Getting To Net zero." *ASHRAE Journal*. 51(9), 18-25.

Gibson Jr., G. E., Kaczmarowski, J. H., and Lore Jr., H. E. (1995). "Preproject-Planning Process for Capital Facilities." *Journal of Construction Engineering and Management*, 121(3), 312-318.

Miller, N.G. and D. Pogue. Do Green Buildings Make Dollars and Sense. University of San Diego, 2009. <http://catcher.sandiego.edu/items/business/Do_Green_Buildings_Make_Dollars_and_Sense_draft_Nov_6_2009.pdf> (Dec. 20, 2012).

Parrish, K., Wong, J.-M., Tommelein, I., and Stojadinovic, B. (2007). "Exploration of Set-Based Design for Reinforced Concrete Structures." In C. Pasquire and P. Tzortzopoulos (Eds.) *Proc. 15th Annual Conference of the International Group for Lean Construction* East Lansing, Michigan, 213 - 222.

Roth, K. W., Llana, P., Westphalen, D., Quartararo, L., and Feng, M. Y. (2006). "Advanced Controls for Commercial Buildings: Barriers and Energy Savings Potential." *Energy Engineering*, 103(6), 3-36.

U.S. DOE (2012). "Superior Energy Performance". U.S. Department of Energy. Available at http://www1.eere.energy.gov/manufacturing/tech_deployment/sep.html. Accessed 12 Dec, 2012.