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Application of Target Value Design to Energy Efficiency Investments

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Application of Target Value Design to Energy Efficiency Investments

by

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Professor Iris D. Tommelein, Co-Chair

Professor Glenn Ballard, Co-Chair

Professor Ray Larson

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ABSTRACT

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Inherent to energy efficiency (EE) investments are various uncertainties. These can be managed and reduced by an application of Life Cycle Cost Analysis (LCCA) and simulation model. However, current practices in project development and the underwriting process of EE investments in the commercial building sector appear to lack uniform processes to accommodate an effective use of LCCA. Accordingly they do not address to the extent they could energy-related uncertainties, and this deficiency appears to result in financial barriers that hinder project realization.

Target Value Design (TVD) is a management practice that make possible for customers' needs to dictate the development of project designs, and designs are steered to deliver intended customer values within project and financial constraints. TVD has proven effective in managing project cost uncertainty by providing a structured process. It helps achieve a high level of integration and collaboration among project stakeholders. In order to expand the application of TVD to include life cycle performance of buildings, the objective of this dissertation is to investigate a standard process and protocol for applying TVD to EE investments to manage three types of energy-related uncertainties: those related to (1) project cost, (2) operational practice, and (3) system performance.

This dissertation involves interviews to develop a theoretical understanding of EE investments and to argue for the use of TVD during preconstruction phases. To effectively implement TVD, the following processes are suggested: (1) the TVD protocol that the lender and borrower can follow to achieve effective underwriting in energy retrofit investments, and (2) a standard TVD decision-making process (TVD-DMP) for the delivery of new energy efficient commercial buildings.

This dissertation explores the development of a simulation model, Energy Retrofit Loan Analysis Model (ERLAM) to support Step 4 of the TVD protocol. ERLAM is tested with a case study of an energy retrofit loan in Northern California. The goals of ERLAM are (1) to determine the impacts of the energy-related uncertainties on the financial

performance of the loan, and (2) to support the overall TVD process by determining the target building performance and allowable cost.

This dissertation delivers a proof of concept for TVD in EE investments through a case study. The case study analyzes a San Francisco hospital project where the project team had challenges with a heat recovery system. To overcome the challenges, the team implemented TVD, which resulted in reducing energy-related uncertainties, system complexity, and overdesign.

Research findings illustrate that, when applied to EE investments, TVD can reduce energy-related uncertainties, enhance the predictability of achieving financial goals, and consequently lower financial barriers. Future case studies and surveys can help further validate the effects of TVD on EE investments. Future research is also needed to refine steps of the TVD protocol and TVD-DMP and to enhance the applicability of ERLAM on more and different types of projects.

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ACRONYMS

A/E/C	Architecture/Engineering/Construction
AHU	Air Handling Unit
AIA	The American Institute of Architects
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
BEPA	Building Energy Performance Assessment
BIM	Building Information Modeling
BSF	Billion Square Feet
CBA	Choosing by Advantages
CFM	Cubic Feet per Minute
CHH	Cathedral Hill Hospital
CM/GC	Construction Manager/General Contractor
CPMC	California Pacific Medical Center
DB	Design-Build
DBB	Design-Bid-Build
DCF	Discounted Cash Flow
DOE	US Department of Energy
DSCR	Debt Service Coverage Ratio
DSM	Design Structure Matrix
EE	Energy Efficiency
EECB	Energy Efficient Commercial Building
EEM	Energy Efficiency Measure
EMCS	Energy Management Control System
EPA	US Environmental Protection Agency
ERLAM	Energy Retrofit Loan Analysis Model
ESCO	Energy Service Company
GSA	US General Service Administration
HR	Heat Recovery
HRC	Heat Recovery Coil
HVAC	Heating, Ventilation, and Air Conditioning

IECC	International Energy Conservation Code
IFOA	Integrated Form of Agreement
IGLC	International Group for Lean Construction
IPD	Integrated Project Delivery
IPDT	Integrated Project Delivery Team
IRR	Internal Rate of Return
LBNL	Lawrence Berkeley National Laboratory
LCCA	Life Cycle Cost Analysis
LEED	Leadership in Energy and Environmental Design
LPDS™	Lean Project Delivery System™
LPS®	Last Planner System®
LTVR	Loan to Value Ratio
MARR	Minimum Acceptable Rate of Return
MBH	Thousands of British Thermal Units per hour
MCS	Monte Carlo Simulation
NOI	Net Operating Income
NPV	Net Present Value
O&M	Operation and Maintenance
OSHPD	California Office of Statewide Health Planning and Development
P2SL	Project Production Systems Laboratory
PBD	Point-based Design
PCA	Property Condition Assessment
PD	Product Development
PDF	Probability Density Function
PPR	Phased Plan Review
PV	Present Value
RFP	Request for Proposal
ROI	Return on Investment
TMY	Typical Meteorological Year
TVD	Target Value Design
TVD-DMP	Standard Target Value Design Decision-making Process
USGBC	US Green Building Council

SBD	Set-based Design
SP	Simple Payback
SSC	Special Seismic Certification

CHAPTER 1. INTRODUCTION

Chapter 1 provides an overview of the research conducted on "Application of Target Value Design to Energy Efficiency Investments." It presents the background and motivation of the study. This chapter also addresses research objectives, questions, and scope based on identified knowledge gaps in the domain of project development for energy efficiency (EE) investments. It concludes with a description of the dissertation structure.

1.1 BACKGROUND

According to multiple surveys about the US commercial building sector, EE implementation can be hampered by a number of barriers, including inadequate access to capital, short payback expectation, and uncertainty in energy performance (e.g., BD+C 2007; IBEF 2011; MARSH 2009). The biggest barriers are those that are related to financing the project (i.e., financial barriers). In particular, inherent to EE investments are numerous uncertainties. Unmanaged uncertainties may make it difficult to obtain project funding, and increase the cost of borrowing. As investors and developers look for attractive returns on their investments, overcoming the financial barriers and designing EE improvements with this in mind involves Life Cycle Cost Analyses (LCCA) that address risks and returns. These types of analyses are used to develop and underwrite business cases for EE investments.

LCCA is most effective when applied in the early phases of project delivery. However, developing energy efficient commercial buildings (EECB) involves managing complex commercial relationships between parties, which often result in fragmented processes. In turn, this fragmentation makes it hard to use LCCA to evaluate feasible design alternatives in early design phases.

This study investigates deficiencies in current practices in the delivery of EECB, with a focus on practices in preconstruction phases. Based on deficiencies identified, the study explores how Target Value Design (TVD) can provide an 'integrated' method to facilitate a collaborative LCCA process by (1) increasing the level of shared understanding and communication among stakeholders and (2) managing specific uncertainties during EE design decision making. The study is intended to contribute to improving uncertainty management practices in these types of investments in order to effectively overcome or at least lower the financial barriers.

An industry precedent exists for using the TVD methodology to achieve a high level of integration among team members' efforts from the start of the project and throughout project delivery. TVD has been effective in the development of fast, dynamic, and complex projects (e.g., Ballard 2008; Ballard and Reiser 2004; Ballard and Rybkowski 2009). However, the initial application of TVD to projects was limited to considering only the capital cost—'first' cost—of the facilities. Efforts have been initiated to broaden its application toward analyzing business operating costs and user costs with the consideration of whole-life cost concerns (Ballard 2008). To support the expanded use of TVD, a research opportunity, therefore, exists to investigate how TVD can systematically be applied to EE investments.

1.2 CONCEPTS AND TERMINOLOGY

Listed in alphabetical order, this section defines the key concepts and terminology used in this study.

Appraisal: "An opinion of value supported by market research. It is an attempt to establish a probable sales price or "market value" for an existing or proposed facility" (Collier et al. 2008). Appraisal in the US commercial building industry employs one of three approaches: (1) the cost approach, (2) the income approach, and (3) the market approach.

Business Case: "A business case is a key form of advice used by executive decision-makers. It is a key element in the decision-making and budgeting process, providing a commercial assessment for a project, policy or program proposal requiring a commitment of financial or human resources. A business case should present a detailed summary of the business benefits, market impact, financial benefits and potential risks of undertaking a new venture" (Wasiluk and Horne 2009).

Capitalization (Cap) Rate: A conversion factor used to determine the appraised value of a property.

$$Cap\ Rate\ [\%] = \frac{Net\ Operating\ Income\ [\$/year]}{Appraised\ Value\ of\ Property\ [\$]} \qquad \text{Equation 1-1}$$

Commercial Buildings: Buildings designed and constructed for business use, as opposed to use for housing.

Choosing by Advantages (CBA): Decision-making system that anchors decision making to the relevant facts and the importance of advantages of the different alternatives being considered (Suhr 1999).

Debt Service Coverage Ratio (DSCR): A ratio of annual net operating income to annual loan payment. DSCR is an indicator of the likelihood of default. Borrowers are assumed to be increasingly likely to default on their mortgage payments as the DSCR approaches 1 from above.

$$DSCR = \frac{Net\ Operating\ Income\ [\$/year]}{Loan\ Payment\ [\$/year]} \qquad \text{Equation 1-2}$$

Design Process: "Systematic, intelligent generation and evaluation of specifications for artifacts whose form and function achieve stated objectives and satisfy stated constraints" (Dym and Levitt 1991).

Energy Efficiency (EE): In contrast to energy conservation that refers to reducing a service to save energy, EE refers to reducing energy required to provide the same service (LBNL 2012).

Energy Efficiency Measures (EEMs): Material, devices, designs, or practices used to improve EE of building systems.

Energy Efficient Building: A building designed and constructed to increase the efficiency of resource use, such as electricity and natural gas, over its lifecycle. As a result, it consumes significantly less energy than a conventional building presumably designed and built to meet minimum building codes such as local building codes or ASHRAE 90.1-2004.

ENERGY STAR: An EE rating system for buildings that was developed by the US Environmental Protection Agency (EPA) and the US Department of Energy (DOE). Buildings are rated on a scale of 1 to 100, where 50 indicates 'average' energy performance. Buildings of 75 or above can qualify for an ENERGY STAR certification.

Exchange Value: A building's exchange value is "the price the market is willing to pay. For the owner, this is the book value; for the developer, this is the return on capital and profitability" (Macmillan 2006).

First Cost: An amount of money spent to design and construct a facility before its occupancy. It includes soft cost (e.g., designing) and hard cost (e.g., construction).

Integrated Form of Agreement (IFOA): A type of relational contract. The IFOA differs from other relational contracts by explicitly requiring the use of lean methods such as TVD and Last Planner® (Lichtig 2005).

Integrated Project Delivery (IPD): "IPD is a Relational Contracting approach that aligns project objectives with the interests of key participants. It creates an organization able to apply the principles and practices of the Lean Project Delivery System" (Matthews and Howell 2005).

Integrated Design: "A collaborative process that can achieve high-performance, low-energy, sustainable buildings by considering all design variables together. It looks beyond the immediate building to how the building and its systems can be integrated with supporting systems, and at how materials, systems, and products connect, interact, and affect one another" (Peterson 2007).

Last Responsible Moment: "The latest moment for starting an activity without compromising cost or program whilst maintaining maximum flexibility for the Business" (Lane and Woodman 2000).

Lean Project Delivery System™ (LPDS™): The LPDS™ is a "production management-based approach to designing and building capital facilities in which the project is structured and managed as a value generating process" (Ballard 2000a). It consists of five overlapping project phases: the (1) project definition, (2) lean design, (3) lean supply, (4) lean assembly, and (5) use phases. The LPDS™ suggests an integrated way to design and build facilities.

Leadership in Energy and Environmental Design (LEED): A third-party rating system developed by the US Green Building Council (USGBC). LEED includes a variety of rating systems such as New Construction, Existing Buildings: Operations & Maintenance, Commercial Interiors, Core & Shell, Schools, Retail, Healthcare, Homes, and Neighborhood Development. LEED evaluation measures the greenness of a building in six key respects:

1. Sustainable Sites
2. Water Efficiency
3. Energy and Atmosphere
4. Materials and Resources
5. Indoor Environmental Quality
6. Innovation and Design Process

Life Cycle Cost Analysis (LCCA): A holistic method to support decision-making processes by comparatively assessing cost impacts of solutions over a specified period. With respect to the built environment, LCCA involves calculation of the total cost of ownership, including initial capital costs, building O&M costs, and asset replacement costs (Boussabaine and Kirkham 2004; Bull 1993; Langston 2002).

Loan to Value Ratio (LTVR): The ratio of the loan balance to the appraised value of the property. LTVR is an indicator of the potential severity of a lender's losses in the event of default. Borrowers are assumed to be increasingly likely to default on their mortgage payments as the LTVR approaches 1 from below.

$$LTVR\ [\%] = \frac{Loan\ Balance\ [\$]}{Appraised\ Value\ of\ Property\ [\$]} \qquad \text{Equation 1-3}$$

Monte Carlo Simulation (MCS): A stochastic simulation method used to generate a set of random numbers for input variables. It has become a popular method for probabilistic risk analysis (Smith et al. 2006). MCS can be applied to a variety of quantitative analyses ranging from finance to traffic management (Boussabaine and Kirkham 2004).

Net Operating Income (NOI): Operating income of a property after deducting operating expenses such as taxes, loan payments, and utility costs.

Set-based Design (SBD): A design methodology promoting (1) simultaneous application of all relevant design criteria; (2) exploration and evaluation of many feasible and integrated design solutions within a given schedule and budget; (3) delaying design decisions until the 'last responsible moment' (Lane and Woodman 2000).

Target Costing: "A structured approach to determine the life-cycle cost at which a proposed product with specified functionality and quality must be produced to generate the desired level of profitability over its life cycle when sold at its anticipated selling price" (Cooper and Slagmulder 1997). As for commercial buildings, target costing is anchored to the price a buyer is willing to pay to get use of the constructed asset (Ballard 2008).

Target Value Design (TVD): An adaptation of target costing in the construction industry to strive for 'design to cost.' TVD is a management method used in the project definition phase and the lean design phase. To implement 'design to cost,' TVD focuses on improving assessment of a projects feasibility and maximizing customer values within project constraints including financial constraints (Ballard 2008).

Whole-life TVD: A broad application of TVD to facility operation and user costs beyond the first cost of design and construction.

1.3 NEED FOR RESEARCH

The need for research addressed in this dissertation stems from my interest in:

1. Identifying deficiencies of current commercial loan underwriting
2. Identifying the need for a standard process and protocol
3. Identifying the need for an LCCA method to support the standard process and protocol

1.3.1 Limitations of Current Commercial Loan Underwriting

A number of studies (e.g., Galuppo and Tu 2010; Jackson 2009; MARSH 2009) discussed risks in EE investments, which suggest that the main drivers for EE investments are financial risks and returns, not 'green ideology' (Muldavin 2010). Accordingly, the ways in which investments will yield added value must be made explicit so that project stakeholders will favor designing for and adequately funding EE installments (Wasiluk and Horne 2009).

However, current commercial investment practices in EE show low levels of effectiveness in assessing investments due to the complex value chains involved in project deliveries (Van Nederveen and Gielingh 2009). In particular, current loan underwriting practices are neither capable of effectively underwriting risks and returns of EE investments, nor connecting them to business cases. Consequently, lenders perceive risks to be relatively high with such investments (Muldavin 2010; NEEA 2010). Inadequate access to financing (i.e., financial barriers) is typically the result.

In order to verify this view articulated in the literature, I interviewed a variety of companies and organizations involved in the development of commercial buildings. The investigation revealed that current loan underwriting practices are indeed ineffective at evaluating risks and returns of EE investments during the process. Loan underwriters' analyses of the risks of EE investments appear to lack depth, which increases financial barriers. Unmanaged energy-related uncertainties appear to result in increased difficulty of financing, and higher cost of borrowing (e.g., higher interest rates and higher cap rates). The investigation also found that the current underwriting process requires a complete design before funding decisions are made. A project team is not assured funding for its EE investments until the lender completes the underwriting process.

1.3.2 Need for a Standard Process and Protocol

In order to improve on current practices, a better process and protocol is needed and standardized for EE investments. Standardization of these is key to achieving consistent performance, because variation due to lack of standardization results in random activities and inconsistent results (waste) (Liker and Meier 2005).

The standard process and protocol is intended to help project stakeholders achieve the process integration to benefit the delivery of EECBs. In particular, this research develops a TVD protocol that enables borrowers and lenders to achieve more effective underwriting in EE investments. I developed the protocol by adapting the existing TVD methodology to the specific conditions and requirements of energy retrofit project development. The TVD protocol allows for the required integration of the project development process and the loan underwriting process. Previous studies have argued that such enhanced coordination between borrowers and lenders in the underwriting process is crucial to increase the fundability of EE investments (e.g., Muldavin 2010; NEEA 2010; ULI 2010).

1.3.3 Need for a Life Cycle Cost Analysis Method that Supports the Standard Process and Protocol

While the early applications of TVD have been limited to considering only the first cost of the facilities, greater efforts have been initiated to broaden its application toward analyzing business operating costs (including energy costs) and user costs with the consideration of whole-life cost concerns. 'Whole-life TVD' compares whole-life cost impacts of design alternatives in early phases of the design process. Teams that use Whole-life TVD make design decisions based not only on first cost, but also on whole-life costs of each alternative.

For Whole-life TVD to succeed, using an LCCA method is important to effectively compare whole-life cost implications of each alternative. In particular, inherent to the risks of EE investments are numerous uncertainties that have to be modeled into the LCCA method. Therefore, this research seeks to develop an LCCA method integrated with a model based on Monte Carlo Simulation (MCS) to support TVD in EE investments. The model can accommodate a stochastic analysis to address and determine the impacts of uncertainties, for example, on the financial performance of the target property and the loan.

Establishing the allowable cost based on a target return on the EE investment is critical to the TVD process: "The business case is based on a forecast of facility life cycle costs and benefits, preferably derived from an operations model; and includes specification of an allowable cost. Financing constraints are specified in the business case; limitations on the customer's ability to fund the investment required to obtain life cycle benefits" (Ballard 2009a). Therefore, to support TVD, the LCCA method must be able to specify the two financial constraints that drive a business case during the TVD process: (1) target building performance and (2) allowable cost. In addition, the method must be analytical and systematic such that project teams can collaborate and commit to the TVD process based on estimates obtained using the method.

1.3.3.1 Setting the Target Building Performance

The target building performance refers to a 'target value' in TVD for EE investments. The building will have to achieve the target value for the business case to be viable, because—by definition—the target value determines energy savings used to make loan payments. Therefore, critical in the TVD process for EE investments are setting the target building performance and then having the project team 'design to target value.'

1.3.3.2 Setting the Allowable Cost

Setting the target building performance leads to setting the allowable cost. In the case of construction financing of EE investments, the feasible loan size determines the 'allowable cost'; this allowable cost is mostly driven by a net operating income increase from energy savings. Setting a reasonable allowable cost early in the TVD process is critical for the success of the overall process, because it determines whether or not to fund a validation study and it serves as a basis for setting the target cost for 'designing to target cost.'

1.4 RESEARCH OBJECTIVES

This research has four objectives:

1. Develop a TVD protocol to support an application of TVD to EE investments
2. Develop a simulation model to set the target building performance and the allowable cost in the TVD protocol
3. Provide a proof of concept for the application of TVD to EE investments
4. Standardize the TVD decision-making process

1.5 RESEARCH QUESTIONS

Based on these objectives, I pose the following research questions:

1. What types of uncertainties and barriers exist in commercial EE improvement projects, specifically energy retrofits?
2. By adapting the existing TVD methodology, how can a TVD protocol be developed to improve the current commercial loan underwriting practices?
3. Can the target building performance and the allowable cost be estimated to support the TVD protocol considering uncertainties related to EE investments specifically:
    a. Project cost uncertainty;
    b. Operational practice uncertainty; and
    c. System performance uncertainty?
4. How can TVD in an Integrated Project Delivery environment help reduce these specific uncertainties?
5. Can a TVD decision-making process for EE investments be standardized?

1.6 RESEARCH SCOPE

The research focuses on developing processes to support the preconstruction phases of EECB delivery: project development and design development. The scope of this research is further developed as follows:

1.6.1 Energy Efficiency for Financial Motivations

The focus is on identifying financial motivations for EE inside the industry and not those generated from public policies or government regulations. EECBs can also bring indirect financial benefits (e.g., enhanced productivity, increased sales, etc.). Although significant, these indirect benefits will not be studied within this research. Thus, this research assumes that building owners develop a business case for direct financial benefits from utility savings.

1.6.2 Commercial Building Sector

This research focuses on the commercial building sector because commercial building owners seek to develop a sophisticated business case to increase EE for financial motivations and business purposes. Residential buildings involve more qualitative evaluations of their occupants due to their varying living styles, which can hardly be explained by a business case.

Commercial buildings are typically delivered through traditional project delivery methods such as Design-Bid-Build (DBB) or Construction Manager-at-risk. However, TVD requires a high level of integration and collaboration of project stakeholders in the process. This is hard to achieve in the fragmented environment all too often resulting from the use of DBB. Therefore, I assumed the use of an integrated form of project delivery for TVD applications—represented by Integrated Project Delivery (IPD) in this research. Discussion of contractual and legal issues associated with IPD is not part of the research scope.

1.7 DISSERTATION STRUCTURE

Chapter 2 titled “Literature Review” surveys the literature that influenced this research. It consists of two main sections. The first section contains literature on target costing, TVD, lean design management, and IPD. The second section summarizes current practices in EE investments, introducing value and market barriers to EE, risks related to EE, and ‘Integrated Design.’ The chapter highlights the need for an integrated approach to EE investments in order to identify, manage, and reduce energy-related risks, so that financial barriers can be overcome.

Chapter 3 titled “Research Approach” presents the research methodology and process. This research employs a combination of qualitative and quantitative approaches. The qualitative research methods include interviews and case study, whereas the quantitative research methods include an LCCA method with a simulation model.

Chapter 4 titled “Current Practices in Applying Commercial Loans for Energy Retrofits” analyzes current practices of the commercial lending industry that are related to commercial energy retrofits. It summarizes the findings of interviews to show (1) how commercial loans are currently underwritten for EE investments in commercial building developments and retrofits, how EE is benchmarked, and how risks drive the process, and (2) what deficiencies exist in current practices.

Chapter 5 titled "Target Value Design Protocol" presents a TVD-based process protocol with eight key steps that borrowers and lenders can follow to achieve more effective underwriting in EE investments. The presentation includes the background, key steps, key participants, and key inputs/outputs of the TVD protocol. The protocol redefines for key decisions the parties that are involved, when certain steps are taken, and how decisions are made. Chapter 5 closes with summarizing feedback I received from three commercial banks when seeking validation of my work.

Chapter 6 titled "Setting Target Building Performance and Allowable Cost to Support Target Value Design" illustrates the process of an LCCA method using a simulation model to support Step 4 of the TVD protocol. To test the model, the analysis involves a case study of a Northern California office building. It demonstrates how the model helps set the target building performance and allowable cost for a given loan period. It serves as a proof of concept for the applicability of Step 4 of the TVD protocol during the commercial loan underwriting process.

Chapter 7 titled "Heat Recovery (HR) System Case Study" presents a study conducted in the course of designing the Cathedral Hill Hospital (CHH) project where the project team encountered a number of challenges regarding the heat recovery system. Through the TVD process applied in an IPD environment, the project team was able to manage and reduce uncertainties. The chapter illustrates their design decision-making process: the team explicitly used TVD to achieve a cost-effective solution that delivered greater EE value to the owner and end users. This case study serves as a proof of concept for the application of TVD to EE investments.

Chapter 8 titled "Standard Target Value Design Decision-making Process (TVD-DMP)" presents a standard TVD decision process in EE investments. The development is the result of the learning from the case studies, literature review, and interviews. The decision process includes four key steps and three workshops.

Chapter 9 titled "Conclusions" summarizes the research findings by presenting detailed responses to the research questions. The chapter presents the contributions to knowledge of the research I conducted, and poses questions for future research.

CHAPTER 2. LITERATURE REVIEW

Chapter 2 surveys the literature that influenced this research. It serves two purposes: (1) to summarize the state of knowledge in industry and academia; and (2) to provide context for the original contribution of this research.

The chapter consists of two main parts. The first part summarizes literature on Target Costing, TVD, lean design management, and IPD. The second part summarizes current practices in EE investments, introducing value and market barriers of EE, risks related to EE, LCCA and 'Integrated Design.' The chapter highlights the need for an integrated approach to EE investments in order to identify/manage/reduce energy-related risks so that financial barriers can be overcome.

Sections 2.1 through 2.3 present the literature that influenced the development of TVD and IPD.

2.1 TARGET COSTING AND TARGET VALUE DESIGN

2.1.1 Target Costing

Target costing has been a major contributor to the superior market competitiveness of Japanese products. Target costing is believed to originate from Japan, although earlier similar efforts were found to be used at Ford or Volkswagen (Feil et al. 2004).

Target costing is defined as "a structured approach to determine the life-cycle cost at which a proposed product with specified functionality and quality must be produced to generate the desired level of profitability over its life cycle when sold at its anticipated selling price" (Cooper and Slagmulder 1997).

The target costing process begins by determining, with an expected functionality (value for customers), how much a customer is willing to pay for a product. With a rigorous market analysis, a company sets the sales price of the new product. Then, it determines the target cost by deducting the target profit margin from the sales price (Equation 2-1). This calculation can be made prior to designing the product.

$$Sale\ Price - Target\ Profit = Target\ Cost \qquad \text{Equation 2-1}$$

Cooper and Slagmulder (1997) stated, based on the Japanese practices, that target costing's goal of effectively managing profit margins can be achieved by creating pressure for cost reductions in three ways (Figure 2-1):

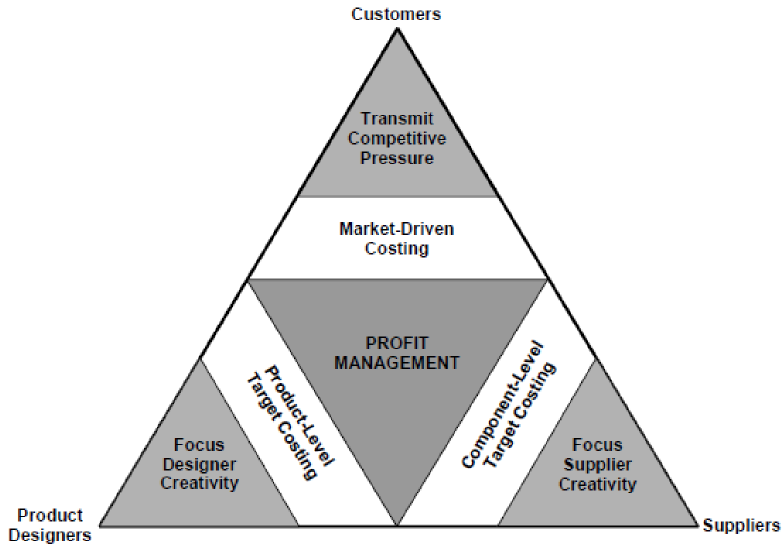

Figure 2-1: Target Costing Triangle (Figure 3 in Cooper and Slagmulder 1997)

1. Market-driven costing: determining the product's allowable cost by deducting the target profit margin from the target selling price
2. Product-level target costing: setting the product-level target cost lower than the allowable cost, promoting designers' creativity to design to target cost
3. Component-level target costing: setting component-level target cost based on the firm's willingness to pay for each of the components that suppliers provide.

These three specific cost management techniques that Japanese manufacturing firms have developed and implemented in their new product development processes have proven their effectiveness for decades.

Further, Cooper and Slagmulder (1999) discussed how to distribute cost reduction pressures across the supply chain. They argued that "blurring" organizational boundaries helps achieve an effective lean supply chain system and target costing, enabling the whole process to become more efficient.

Such interorganizational cost management appears applicable to the construction industry, because most projects are performed by groups of firms. Its benefits have been noted and used to establish new forms of contractual relationships in the industry, such as IPD or the Integrated Form of Agreement, which will be discussed in Section 2.4.

2.1.2 Target Costing in the Construction Industry

Since the first successful implementation of target costing to a building project (Ballard and Reiser 2004), interest has grown in the construction industry, particularly in the private sector, in using target costing methods.

Traditional design and estimating process approaches in the construction industry are sequential in nature; first design and estimate the design later, which results in non-value-adding design iterations (referred to as 'negative iterations' in Ballard 2000b). All too often, the project scope has to be altered to meet the project's budget. These iterations keep designers from delivering items of true value to the customer, and furthermore, they create significant delay and waste. As Ballard and Reiser (2004) pointed out, even a contract form of Design-Build (DB) with a guaranteed maximum price may not be effective enough to prevent the waste and rework in this so-called design/estimate/redesign process.

In contrast, the application of 'design to target cost' in target costing enables a project team in the early phases of a project to achieve a design that meets the project's budget ('allowable cost'). Designing to target cost therefore helps a team avoid going over budget while delivering features of a building that provide value to the owner.

2.1.3 Target Value Design

As an adaptation of target costing in the A/E/C industry, TVD strives for 'design to cost' rather than 'design and then estimate.' TVD is a management method to be used in the project definition phase and the lean design phase. To implement 'design to cost,' TVD focuses on improving assessment of a project's feasibility and maximizing customer values within the project's constraints including financial constraints (Ballard 2008).

TVD encourages concurrent and interorganizational collaboration in the design and estimating processes, inviting project stakeholders to participate early in the process, including those who will construct the physical structure, such as general contractors and subcontractors.

Macomber et al. (2007) defined TVD as:

- "Rather than estimate based on a detailed design, design based on a detailed estimate;
- Rather than evaluate the constructability of a design, design for what is constructable;
- Rather than design alone and then come together for group reviews and decisions, work together to define the issues and produce decisions then design to those decisions;
- Rather than narrow choices to proceed with design, carry solution sets far into the design process; and
- Rather than work alone in separate rooms, work in pairs or a larger group, face to face"

In TVD, clients are recognized as key players. They generate mission statements of values expected from the new built environment, define project constraints, and eventually make timely key design decisions for the team.

With TVD, project members get incentives to participate in aligning their work processes. Such alignment can lead to (1) reduced contingency funding, (2) reduced cost and duration of projects while delivering a structure that meets a customer's needs, and (3) increased profitability of project members.

Since 2002, TVD has allowed multiple institutional projects to be completed on or below budget and on or ahead of schedule, all while ensuring value delivery to the customer (e.g., Ballard 2008; Ballard and Reiser 2004; Ballard and Rybkowski 2009). As for their cost performance, a number of projects where TVD was explicitly applied have reported two consistent outcomes:

- The project initial scope is completed below market cost[1]
- Cost estimates fall as designs become more developed

TVD begins with project business planning, in which the owner prepares a business case and explicitly defines how the to-be-built structure needs to perform. Then the business case is validated by working with a project delivery team, appointed earlier than on a traditional project. The validation is done before the client's funding decision, and is done by the key members of the team that will deliver the project if funded.

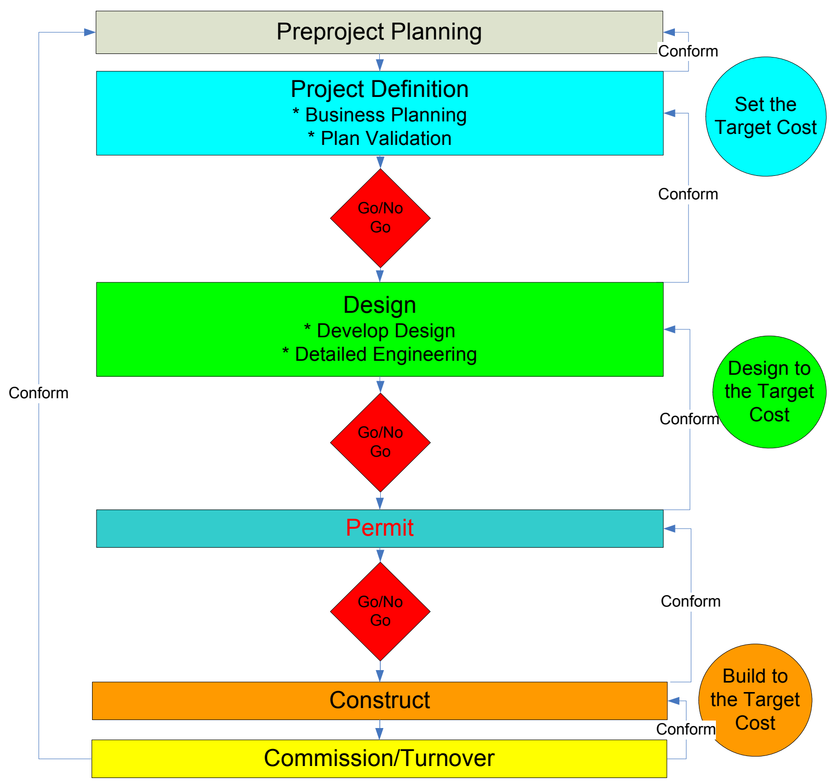

Figure 2-2: TVD Process (Figure 5 in Ballard 2008)

A contract may specify that portions of the project team members' profits are to be put in an 'at-risk pool' that will help pay for any cost overruns. This arrangement motivates the cross-functional project team to assess a design's feasibility more accurately than they might otherwise. After a business case is validated, target costs are allocated to building

[1] Appendix A lists 16 TVD projects that used TVD explicitly for design and estimating management. The outturn costs of the TVD projects are significantly lower than (15% below) those in the market.

system categories; the general contractor and subcontractors once again confirm such systems are constructable as designed. The team then proceeds designing to target, while allowing for target costs to be adjusted between categories when the whole project benefits from doing so (Ballard 2008).

2.1.4 Whole-life Target Value Design

Whole-life TVD is a broad application of TVD involving facility operation and user costs beyond first costs (such as design and construction costs). While the initial application of TVD to projects considered only the initial costs of facilities, greater efforts have been initiated to broaden its application toward analyzing business operating costs and user costs, while considering whole-life costs. Ballard (2008) argued that more attention ought to be paid to making facilities better fit for use, because user costs appear to be much more significant than first costs when whole-life costs of the buildings are considered.

For example, multiple studies investigated the ratio of relative costs in owning and using a commercial office building. Table 2-1 summarizes their ratios. How ever different, they shared the same view on the importance of shifting focus from first costs to whole-life costs.

Table 2-1: Ratios of Relative Costs in Owning and Using a Commercial Office Building

	Evans et al. (1998)	Hughes et al. (2004)	Ive (2006)
Construction cost	1	1	1
Building O&M costs	5	0.4	1.5
Business operating costs	200	12	15

Whole-life TVD provides an integrated approach to compare, in the early stages of the design process, whole-life impacts of design alternatives. This enables teams to make design decisions that optimize whole-life values of target properties. These impacts are based not only on first costs, but also on whole-life costs. Particularly in hospital design, Whole-life TVD promotes an in-depth consideration of design alternatives to improve users' productivity and safety in a given facility.

Part of whole-life costs is an energy cost. To enhance applicability of Whole-life TVD, this dissertation attempts to investigate how TVD can systematically be applied to EE investments, so similar attempts can be made toward including user costs.

2.2 LEAN PROJECT DELIVERY SYSTEM™

This research assumes the implementation of TVD can be most effective within the Lean Project Delivery System™ (LPDS™) that involves applying lean design management and IPD. Sections 2.2 to 2.4 summarize the relevant literature.

The LPDS™ is a "production management-based approach to designing and building capital facilities in which the project is structured and managed as a value generating process" (Ballard 2000a). It consists of five overlapping project phases: (1) the project definition phase, (2) the lean design phase, (3) the lean supply phase, (4) the lean assembly phase, and (5) the use phase (Figure 2-3). The LPDS™ suggests an integrated way to design and build facilities.

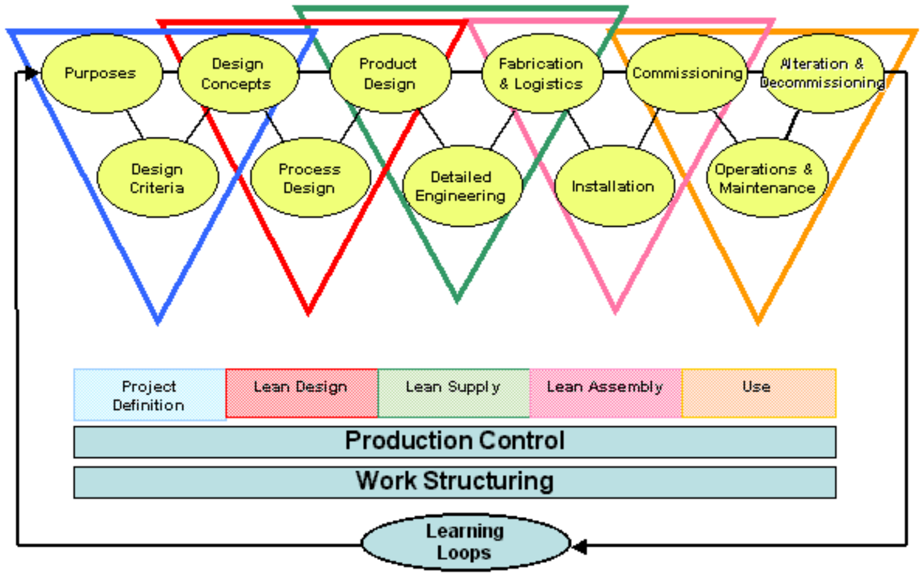

Figure 2-3: Lean Project Delivery System™ (Figure 3 in Ballard 2008)

As shown in Figure 2-3, Work Structuring and Production Control are interwoven with the five phases to support the 'project-based production system.' Ballard (2000a) describes them as:

- "Work structuring indicates the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources, and design-for-assembly efforts. The purpose of work structuring is to make work flow more reliable and quick while delivering value to the customer."
- "Production control governs execution of plans and extends throughout a project. 'Control' first of all means causing a desired future rather than identifying variances between plan and actual. Production control consists of work flow control and production unit control. Work flow control is accomplished primarily through the lookahead process. Production unit control is accomplished primarily through weekly work planning."

This research focuses on two phases of the LPDS™, namely project definition and lean design, where TVD is a primary management method.

Project definition aligns ends, means, and constraints before the lean design phase is initiated (Ballard 2006). Ballard (2006) suggests the following project definition process:

- Step 1: Capture customer purposes and conditions of satisfaction (values)
- Step 2: Design means for achieving purposes within conditions of satisfaction
- Step 3: Translate values into technical specifications, i.e., translate from the language of the customer to the language of the designer

The project definition phase can employ a structured process to support the concept of target costing. A project team engages in business planning and plan validation. The customer then decides whether or not to fund the project. If during design development, the team is unable to design the structure that can deliver what the client needs, the project's definition is reevaluated. Aligning ends, means, and constraints plays a pivotal role throughout the process (Ballard 2006; 2008). At the end of the project definition phase, design criteria are established for lean design. Setting target cost for TVD happens after this phase.

The lean design phase starts with developing a conceptual design based on the design criteria, and proceeds to design development while integrating product and process design (aka. Work Structuring). Using a set-based design (SBD) approach, a design team considers a set of design alternatives, and defers design decisions to 'last responsible moments' (Ballard 2000a; Lane and Woodman 2000). The lean design phase encourages the use of various management tools and techniques, such as Building Information Modeling and Choosing by Advantages (Suhr 1999). Based on the target cost, set after the project definition, lean design can accommodate efforts to 'design to target.' Its management methods are presented in the following section.

2.3 LEAN DESIGN MANAGEMENT

TVD is a lean design management method. In lean design, conceptualizations of design processes have reflected three different views: (1) a transformation of inputs into outputs; (2) a flow of information through time and space; and (3) the generation of value for customers. Traditional A/E/C design processes appear to be mainly based on the transformation view, focusing on completing individual tasks, while neglecting flow and value generation (Ballard and Koskela 1998; Koskela 1992; Koskela et al. 2002). Design management for TVD requires that more attention be paid to the flow and value views.

The flow view emphasizes short lead times, elimination of waste, including reduction of rework, use of team-based approaches to avoid time-consuming iterations, and release of information in small batches to allow for rapid feedback from team members. Koskela et al. (1997) showed how use of the design structure matrix (DSM) supports the flow view in design management. Mathematical operations performed on the DSM can lead to more optimal sequencing of design tasks. Subsequent studies involving the use of DSM have proven the value of using this tool (e.g., Choo et al. 2004; Hammond et al. 2000; Tuholski and Tommelein 2010).

The value view stresses the use of analysis of requirements and constraints to deliver what matters to the customer (Ballard and Koskela 1998). This view may be pursued using a 'workshop model' (e.g., Thyssen et al. 2010) and TVD (Ballard 2006). The workshop model involves a series of workshops to shape the lean design management process (Emmitt et al. 2004; 2005). The workshop model can increase the effectiveness of cooperation, communication, experience, and group learning in design problem solving. Hence, it increases the likelihood that value will be delivered in the design phase.

2.3.1 Point-based Design (PBD)

Ward et al. (1995) characterized 'traditional' design methodology (albeit in product development, not in the A/E/C industry) as being 'point-based.' Point-based design (PBD) follows the model of sequential processing. Participants in the project are engaged only when their specific work product is scheduled to be produced. Successive design specialists—each within his/her field of specialization—generate, evaluate, and select from alternatives available in the design space they are exploring. Any consideration of design criteria of later specialists is made speculative, because those later specialists are not yet engaged. The selected design option is then passed on to the next design specialist. Ward et al. (1995) characterized this PBD process as linearly spiraling from one specialist to the next. Quite often, when feedback from later design specialists is considered, a design decision made earlier proves to be infeasible or no longer desirable. This results in designers having to explore those earlier alternatives again (e.g., using dependency-directed backtracking or other means to iterate). Such 'negative iteration' is wasteful (Ballard 2000b).

2.3.2 Set-based Design (SBD)

In contrast to PBD, in set-based design (SBD):

- Design decisions get delayed until the 'last responsible moment' (Lane and Woodman 2000), and
- All relevant design criteria are applied simultaneously.

This methodology enables a team of specialists to explore and evaluate many feasible and integrated design solutions within a given schedule and budget. At the time the SBD team is to select an alternative, the team applies the assessment factors and criteria from all their specialties to all alternatives deemed viable at that time. Although SBD may begin with the same 'problem definition' phase as does PBD, it urges designers to carry forward a set of design alternatives and only gradually narrow down the set as they converse with other designers. The design team performs set-narrowing by eliminating non-viable alternatives over time in order to single out a solution (Liker et al. 1996). Ward et al. (1995) characterized this SBD process by means of parallel funnels that converge towards a design solution. It may be feasible and desirable to develop or identify an acceptable, if not optimal, alternative early in each search, so the project is not delayed when the 'last responsible moment' arrives before a 'best' alternative is agreed.

Though SBD may appear inefficient, Ward et al. (1995) found that Toyota's practices tell a different story. Keeping alternatives open until the 'last responsible moment' helps superior outcomes to emerge. SBD supports design creativity, because the practice encourages designers to develop and study a wide range of alternatives. SBD is a methodology that could be well suited to deliver Design-Build (DB) projects, because such projects offer the opportunity for designers and builders to jointly generate, explore, and assess alternatives, rather than having to make sequential design decisions and iterating between specialists, as is necessary in Design-Bid-Build (DBB).

SBD has been applied in a variety of design domains. A number of lean design studies in various areas of the A/E/C industry are rooted in the SBD approach and have elaborated upon how delaying design decisions can lead to better design solutions. Such studies include construction site layout (Tommelein et al. 1991), HVAC and structural design (Lottaz et al. 1999), design of rebar in reinforced concrete (Parrish et al. 2007), hospital design (Parrish et al. 2008), and design of seismic retrofits (Tuholski and Tommelein 2010).

2.3.3 Choosing by Advantages (CBA)

SBD used in the context of TVD often involves Choosing by Advantages (CBA) (Suhr 1999) so as to better analyze value implications of design alternatives.

In the process of generating, evaluating, and selecting from alternatives, design team members will articulate judgments based on their interpretation of project requirements, their expertise, and their preferences. In order to come up with a selection that best suits the project overall, while recognizing that all decision making is subjective, the design team must use a decision-making system that encourages everyone to share their expertise. The system for decision making called CBA suits the process of lean design management (e.g., Parrish and Tommelein 2009).

The CBA system emphasizes that decision making must be anchored to the relevant facts and based on the 'importance of advantages' of different alternatives being considered. CBA defines its own terminology, urging people who use the system to all speak in the language in order to foster clarity. Suhr (1999) used the following:

- Alternative: possible decision or choice
- Factor: container for criteria, attributes, advantages, importances, and other types of data
- Criterion: decision rule or guideline established by the decision maker. It can be indicated as a 'must' criterion (mandatory) or a 'want' criterion (desirable)
- Attribute: a characteristic, quality, or consequence of one alternative
- Advantage: beneficial difference between two and only two attributes

To begin the CBA process, the team defines design alternatives, as well as factors and criteria for decision making that reflect values the team wants to realize in their design solutions. A table can show 'must' criteria and 'want' criteria.

The next step is for the team to collect data in order to describe the attributes of each alternative, corresponding to the factors and criteria shown. Repeating row by row, for each 'want' criterion, the team then determines which alternative has the least preferred attribute and underlines it. This attribute defines the baseline against which the design team must gauge the advantage of each other alternative according to that 'want' criterion. In the same row, the team then looks for the attribute that is most favorable relative to the baseline and highlights that.

In order to define a scale by which to gauge importances of advantages for use in the entire table, the team looks at each row in the table and assesses the difference between the underlined attribute and the highlighted attribute according to what they value. Across all rows, the team then chooses which one of those differences is the so-called 'paramount' advantage. That paramount advantage (circled) gets assigned 100 points on the importance of advantages scale, relative to the underlined attributes, each of which get assigned 0 points. Using that scale, the team then gauges the importance of each other advantage relative to the baseline. To conclude the process, the team adds up the importance of advantages for each alternative. The design alternative with the greatest total importance of advantages represents the best value solution. Table 2-2 presents an example of a CBA table.

Table 2-2: CBA Table for Girder Design (Table 1 in Lee et al. 2010)

Superstructure on Busy Streets	Alternative 1 **CIP Box Girder**		Alternative 2 **Steel Beam**		Alternative 3 **I-Girder**		Alternative 4 **Bulb-T**		Alternative 5 **U Segmental**		Alternative 6 **U-Section**	
Factor: Speed of Construction Criterion: Faster is better	100% on-site operation		Prefabrication Much faster	60	Prefabrication Much faster	60	Prefabrication Much faster	60	Prefabrication but much on-site operation needed Faster	40	Prefabrication Much faster	60
Factor: Ease of Construction Criterion: More is better	100% on-site forming/pouring/stripping		On-Site Installation only Much Easier	30	On-Site Installation only Much Easier	30	On-Site Installation only Much Easier	30	More Installation needed with more pieces Easier	10	On-Site Installation only Much Easier	30
Factor: Falsework Requirement Criterion: Less is better	Due to falsework, involves traffic lane shutdowns		Installation will be done at night time Many fewer shutdowns	100	More night time shutdowns wth more pieces Fewer shutdowns	70	Installation will be done at night time Many fewer shutdowns	100	More night time shutdowns wth more pieces Fewer shutdowns	70	Installation will be done at night time Many fewer shutdowns	100
Factor: Aesthetics Criterion: Closed bottom is better	Closed bottom Much more closed	80	Many openings		Open bottom More closed	20	Open bottom More closed	20	Closed bottom Much more closed	80	Closed bottom Much more closed	80
Factor: Span Length Criterion: Longer is better as fewer columns will be needed	Span more than 120 feet (± 37 meter) Much longer span	80	Span more than 120 feet (± 37 meter) Much longer span	80	Max Span at ± 100 feet (± 30 meter) Longer span	30	Max Span at ± 125 feet (± 38 meter) Much longer span	80	Max Span at ± 80 feet (± 24 meter)		Max Span at ± 125 feet (± 38 meter) Much longer span	80
Factor: Maintenance Criterion: Less is better	Little maintenance Much less maintenance	50	Periodic steel coating		Little maintenance Much less maintenance	50	Little maintenance Much less maintenance	50	Little maintenance Much less maintenance	50	Little maintenance Much less maintenance	50
		210		**270**		**260**		**340**		**250**		**400**

CBA deals with money separately, when the alternative that has the highest total importance of advantages is not cheapest. 'Money decisions' involve evaluating 'increments' between alternatives—an increase or decrease in cost from one alternative to another. For example, Figure 2-4 suggests that an increase in cost from Alternative A to B may be a desirable investment because the increment adds more importance of advantages. Meanwhile, an increase in cost from Alternative B to C is not desirable because Alternative C has a lower total importance.

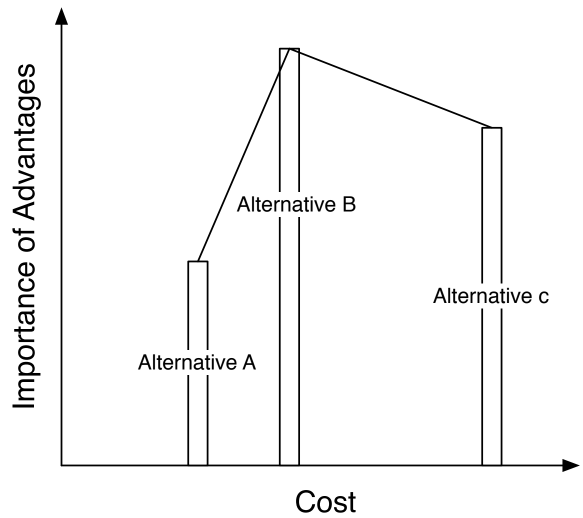

Figure 2-4: Cost vs Importance of Advantages Chart

2.4 INTEGRATED PROJECT DELIVERY (IPD)

Integrated Project Delivery (IPD[2]) is developed as an integrated form of project delivery that establishes the notion of aligning interests, objectives and practices, and it promotes complete sharing of the risk and profit, the amounts of which are made contingent on the performance of the total project (Matthews and Howell 2005).

AIA (2007b) defined IPD as "a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction."

In IPD, the primary team members—'key participants'—consist of the architect, general contractor, key subcontractors, and key design consultants. This IPD team, as a single entity, is bound by a single contract to the client, defining the scope, schedule, and cost of the project. The single contract defines the shared risk and reward structure, promoting the common goal of delivering a project within budget. Among others, IPD has the following characteristics (Cohen 2010):

- Early involvement of key participants
- Shared risk and reward
- Multi-party contract
- Collaborative decision making and control
- Liability waivers among key participants
- Jointly developed and validated project goals

Thomsen et al. (2009) analyzed the structure of IPD from the three basic domains, namely (1) project organization—how the parties participating in the contract are

[2] IPD is a trademark of Westbrook Air Conditioning in Orlando, FL.

organized, (2) project operating system—how the project is managed on an overall and down to day-to-day basis, and (3) project commercial terms—the contractual responsibilities and associated compensation. They summarize the characteristics of IPD from the three domains as follows (Thomsen et al. 2009):

1. Project organization
    a. Integrated teams/governance
    b. High performing teams
2. Project operating system
    a. Lean construction and LPDS™
    b. TVD
    c. Last Planner System®
3. Project commercial terms
    a. Collective risk management
    b. Painsharing and gainsharing
    c. Profit pooling
    d. Contingency sharing
    e. Incentives and goal definition

TVD is a management method that defines design strategy and process, and therefore belongs to the project operating system. Meanwhile, the project's commercial terms are supported by appropriate contractual provisions, most of which relate to establishing a relational contract for the shared risk and reward system.

2.4.1 Integrated Form of Agreement (IFOA)

The construction industry is well-known for its adversarial contracting practices where owners transfer risk through contract clauses to prime contractors, and prime contractors further pass down the risk onto the smaller subcontractors who are often incapable of taking it (Sakal 2005). While traditional contracting focuses on risk transfer, relational contracting focuses on risk and reward sharing for team collaborations.

Relational contracting is a contracting mechanism that emphasizes the commercial 'relationship' among contracting parties (Colledge 2005; Macneil 1978). Relational contracting emphasizes shared responsibility for project management and collective risk management of incentives/disincentives, which are based on the value delivered to the customer.

Will Lichtig created the Integrated Form of Agreement (IFOA), a type of relational contract (Lichtig 2005b; 2006). IFOA differs from other relational contracts by explicitly requiring the use of lean methods such as TVD and LPDS™ (Smith et al. 2011). The IFOA also requires the IPD team to break the whole project into a series of cross-functional subgroups called 'clusters.' Clusters are usually organized by building systems, such as structural, mechanical, electrical, plumbing, exterior skin, interiors, project requirements, site work, and conveying systems (Ballard and Rybkowski 2009). The IFOA explicitly requires use of Building Information Modeling as a design tool.

2.4.2 Building Information Modeling

Full-scale implementation of Building Information Modeling (BIM) appears to require changes to existing project delivery methods, and IPD can provide the collaborative working environment required for BIM implementation. In the same regard, AIA (2007) stated that, "BIM is a tool, not a project delivery method, but IPD process methods work hand in hand with BIM and leverage the tool's capabilities."

With regards to energy systems, using BIM can be important in designing and estimating processes used in IPD. With the recent advancement of technology, energy simulations for decision making can be conveniently generated with BIM. The design process for an EECB requires a high level of communication and commitment between all project participants toward integration of building systems. Various design options need to be studied, and their cost and energy impacts need to be assessed. BIM used with IPD supports design optimization by allowing designers the ability to toggle building features on and off, which helps easily visualize different project conditions. These 'what-if' analyses can accommodate easily evaluating design options to achieve their target performance within project constraints (Autodesk 2005).

Sections 2.5 through 2.8 provide literature reviews on current practices in EE investments, introducing value and market barriers of EE in commercial buildings, EE building certifications and uncertainty and risks related to EE investments.

2.5 ENERGY EFFICIENCY IN COMMERCIAL BUILDINGS

This section summarizes the literature related to building owners' motivations for developing EECBs. EECBs consume significantly less energy than conventional commercial buildings, buildings designed and built to meet minimum building codes such as local codes (e.g., Title 24 in California) or ASHRAE[3] 90.1-2010. Owners invest in EECBs for multiple reasons including the economic incentive of reduced O&M costs. EECBs are commonly LEED (Leadership in Energy & Environmental Design) and/or ENERGY STAR certified.

2.5.1 Definition of Energy Efficiency in Commercial Buildings

The US Department of Energy (2009) reported that in 2006 energy consumption in buildings was responsible for 39% of the US primary energy consumption, and of that, electricity accounted for 74% of building energy consumption (Figure 2-5). Among various building types, commercial buildings accounted for nearly 50% of the total energy consumption of the building sector (Figure 2-5). The Commercial Buildings Energy Consumption Survey (CBECS) reported that in 2003, the US building stock included nearly 4.9 million commercial buildings, comprising more than 71.6 billon square feet (BSF) of floor space. Commercial buildings consumed more than 6.5 quadrillion Btu of energy, 55% of which was electricity and 32% of which was natural gas. Of this energy, 36% was consumed for space heating and 21% for lighting (Diamond

[3] American Society of Heating, Refrigerating and Air-Conditioning Engineers

2001; EIA 2003). Thus, energy savings within the commercial building sector can significantly reduce energy consumption in the US.

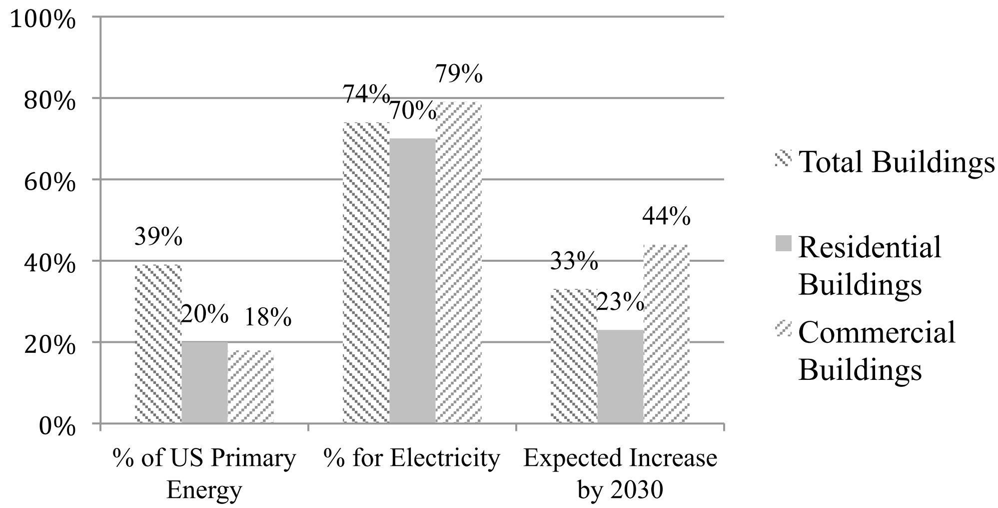

Figure 2-5: Energy Consumption within the US Building Sector in 2006 (DOE 2009)

Given the significant potential benefits of EE in commercial buildings to the US economy, the President of the US, Barack Obama, announced on February 2011 the 'Better Building Initiatives' targeting to improve EE in commercial buildings by 20 percent by 2020. The initiative includes nearly $4 billion investments in the public and private sector (The White House 2011). Similarly, the US Department of Energy (DOE) recently launched its 'Net-Zero Energy Commercial Building Initiative' to develop marketable commercial buildings that produce as much energy as they consume over their entire lifecycle (DOE 2010b). These initiatives indicate the current demand for EECBs. Interest appears to be rising both in the public- and private sectors in developing EECBs in light of their long-term benefits.

EECBs are believed to deliver direct and indirect financial benefits to their owners and tenants as summarized in Table 2-3.

Table 2-3: Benefits from EE and Beneficiary of Each Benefit
(Adapted from Tobias 2010; Yudelson 2010)

Direct/Indirect	Description of Benefit	Owners	Tenants
Direct benefit	Reduced operation cost	✓	✓
	Reduced maintenance cost	✓	✓
Indirect benefit	Higher rent and greater occupancy	✓	
	Greater resale value	✓	
	Reduced cost of commercial insurance	✓	
	Tax benefits	✓	
	Meeting tenant demand	✓	✓
	Mitigating risk of environmental regulation	✓	
	Mitigating risk of energy price	✓	✓
	Brand image by corporate sustainability	✓	✓
	Public relations and marketing	✓	✓
	Increased sales (for retail buildings)		✓
	Increased productivity (for office buildings)		✓

2.5.2 Business Case for Enhancing Energy Efficiency

Establishing a business case is a key element during the decision-making- and budgeting processes for EE investments. A developer planning to design and construct an EECB must include, in its business case, a detailed financial summary of costs, benefits, and risks associated with the business case. The link between investment and the added value must be made explicit so that project stakeholders make design decisions in favor of EECBs (Wasiluk and Horne 2009). Business cases for enhancing EE in commercial buildings can fall into two areas: (1) new EECB projects and (2) energy retrofits of existing buildings.

Turner Construction (2008) reported that 83% of commercial real estate executives would be ‘extremely’ or ‘very’ likely to pursue EECBs. Given that the commercial real estate market is driven by financial parameters such as return on investment (ROI), this implies that commercial building owners/investors have begun to recognize that the financial benefits of EECBs are significant enough to justify investments.

The US Green Building Council (2009) reported a nearly 10% growth in energy efficient building construction projects in the non-residential building market from 2005 to 2008, and it expects this growth to increase another 20-25% by 2013. This growth coincides with the recent proliferation of energy saving materials and systems available on the market (Frej 2005).

Applying energy efficiency measures (EEMs) to new construction projects is less complex than applying them to existing buildings, because improvements of the latter are limited by existing building conditions and tenant demands/relocations. Thus, enhancing EE in new buildings is often most efficient and effective (Yudelson 2010).

Nevertheless, retrofitting also provides ample opportunity for EE investment. This is so particularly for commercial properties in the dynamic US building sector because they turn over frequently. Every year, the US renovates approximately 1 to 2 BSF of commercial space. The roughly 69 BSF of existing buildings being more than 10 year old, will be due for major retrofits in the near future (Pike Research 2010). Thus, if energy retrofits are properly coordinated, the commercial building sector alone will be able to significantly reduce the total energy consumption in the US.

EE investments can enhance many qualities of a building; this study deals only with the direct value enhancement from such investments, namely a building's 'exchange value.' According to the terminology from Macmillan (2006), the exchange value refers to "[the] building as a commodity to be traded, whose commercial value is measured by the price the market is willing to pay. For the owner, this is the book value; for the developer, this is the return on capital and profitability." The exchange value includes ownership, rental, and sale of the property. The value is measured by direct economic metrics such as book value, rental rates, ROI, and net operating income (Macmillan 2006).

EE investments are believed to enhance the exchange value of a commercial building primarily in three respects: (1) reducing energy costs, (2) enhancing the appraised value, and (3) enhancing rental rates. The following sections deal with only the first two, because the notion of enhanced rental rates is still being studied. Nevertheless, findings of recent studies claim a positive statistical relationship exists between ENERGY STAR or LEED certification and rental rates (e.g., Kats 2003).

2.5.3 Reducing Energy Costs

Energy costs account for a significant portion of business expenses—approximately 30 to 35% of a typical commercial building's operating cost. Furthermore, saving energy costs becomes important, because energy costs are regarded as uncontrollable costs due to (1) the price of energy being controlled by utility companies; (2) the rise of energy prices; and (3) the volatility of energy prices (Jaffee et al. 2011; Yudelson 2010). EECBs are also known to achieve additional 10 to 15% savings in maintenance costs, because they tend to implement proper commissioning processes (USGBC 2009; Yudelson 2008).

2.5.4 Enhancing the Appraised Value

Enhancing EE and reducing energy costs can increase the value of the target property. Measuring the property value is commonly done through a structured process called 'appraisal.' Appraisal in the US commercial building industry employs any one or several of the following three approaches: the (1) cost, (2) income, and (3) market approaches (Collier et al. 2008):

2.5.4.1 Cost Approach for Appraisal

The cost approach for appraisal assumes that the value of the property can be determined by the cost to duplicate the project less depreciation, based on Equation 2-2 (Collier et al. 2008):

$$Appraised\ Value = \\ Current\ Land\ Value + (Cost\ of\ Improvement - Depreciation) \quad \text{Equation 2-2}$$

2.5.4.2 Market Approach for Appraisal

The market approach for appraisal uses recent open-market sales of similar properties as 'comparables' for the valuation (Collier et al. 2008). This approach is preferred in the residential sector.

2.5.4.3 Income Approach for Appraisal

The income approach for appraisal assumes that "the value of a commercial real estate property lies in the income stream it generates" (Collier et al. 2008). This approach is preferred for income-generating properties in the commercial sector.

A key metric in this approach is net operating income (NOI), which is the operating income of a property after deducting operating expenses, including taxes, loan payments, and utility costs. In this approach, using a pre-determined capitalization (cap) rate, the appraised value of the property is determined by Equation 2-3:

$$Appraised\ Value = \frac{Net\ Operating\ Income}{Cap\ Rate} \qquad \text{Equation 2-3}$$

In measuring the impacts of EE investments on the property value, the income method is applicable. For example, applying the cap rate of 8%, a $50,000 of utility saving (NOI increase) can increase the value of the property by $50,000/8% or $625,000, which eventually reduces the loan to value ratio (explained later in this chapter). That is, the investment not only produces $50,000 in extra income, it also increases the property's appraised value by $625,000.

An enhancement of a property's appraised value through improved EE contributes to making a business case for EE more viable, and has to be explicitly evaluated during financial underwriting. Third party certifications can give underwriters more confidence in the enhanced value of the property, which is discussed in the following section.

2.6 ENERGY EFFICIENCY CERTIFICATIONS FOR COMMERCIAL BUILDINGS

EECBs are commonly LEED and/or ENERGY STAR certified. LEED and ENERGY STAR will be frequently referred to throughout this dissertation, because most business cases for EE require them.

2.6.1 LEED

Bayraktar and Owners (2009) defined 'green building' as a philosophy and management practice designed to achieve minimum environmental impacts, enhance the health and productivity of users, provide financial returns on investment, and apply life-cycle oriented approaches. Developing green buildings contributes to a movement to provide socially and environmentally responsible spaces for users. Along with various societal benefits, green buildings equip owners to deal with uncertain economic situations (e.g., increased costs of energy and building materials) and regulatory disincentives.

LEED is the most widely used green building certification in the US industry and worldwide. LEED is a third-party rating system developed by the US Green Building Council (USGBC). Developing an EECB typically involves obtaining LEED certification, although LEED addresses wider sustaintaiblity issues, including EE. LEED is applicable to new construction, existing buildings, core and shell, schools, retail, and healthcare. LEED evaluation measures the greenness of a building in six key respects:

1. Sustainable Sites
2. Water Efficiency
3. Energy and Atmosphere
4. Materials and Resources
5. Indoor Environmental Quality
6. Innovation and Design Process

2.6.2 ENERGY STAR

ENERGY STAR is an energy efficiency rating system for buildings, developed by the US Environmental Protection Agency (EPA) and the US Department of Energy (DOE). Buildings are rated on a scale of 1 to 100, where 50 indicates 'average' energy performance. Buildings of 75 or above qualify for an ENERGY STAR certification. In other words, a certification is awarded if a building's energy use is in the top quartile of ratings in its business category.[4]

Obtaining LEED and/or ENERGY STAR certification is commonly a project requirement in EE investments. However, when investing in EE improvements, project stakeholders face various types of 'market barriers' that have to be overcome for project realization.

2.7 MARKET BARRIERS TO ENERGY EFFICIENCY

Market barriers to EE can be understood from the perspective of the so-called 'efficiency gap'—the difference between the actual energy use and the optimal energy use during the use phase of a building. The gap results from market failures (e.g., 'misplaced' incentives and 'unpriced' costs and benefits) and market barriers (e.g., low prioritization of energy issues and capital market barriers) (Goldman et al. 2005; Jaffe and Stavins 1994). For the purposes of this study, attention is primarily given to capital market barriers (financial barriers) for energy retrofits in the private sector.

A recent survey done by IBEF (2011) revealed that in the US, inadequate access to capital accounted for 38% of market barriers to energy investments, followed by short payback standard at 21%, and uncertainty of benefits at 10% (Figure 2-6). The survey

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[4] For ENERGY STAR in the commercial building sector, see

http://www.energystar.gov/index.cfm?c=business.bus_index indicated that US-based organizations, more than other countries, notably pointed out ‘inadequate access to capital’ as the biggest barrier.

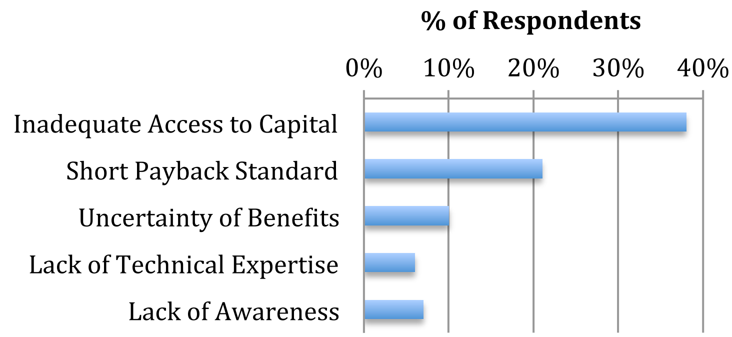


Figure 2-6: Market Barriers to EE (Adapted from IBEF 2011)

An owner’s desire to deliver an EECB project is often constrained by their fear of high ‘first’ costs, despite the potential returns that EE can provide (Ashworth 1993; Cole and Sterner 2000). The first cost of a project can make it difficult to validate a project business case, regardless of the long-term benefits of a high value design (Ballard and Rybkowski 2009).

Ryghaug and Sørensen (2009) argue that issues around EE in the building industry can be explained from the perspective of a “complex sociotechnical system where diverse actors act at the intersection of industry and market structures, institutions of governance, innovation systems, evaluation practices, supplier-user chains, designer and engineering practices, etc.”

Table 2-4 summarizes the commonly-observed contributors to financial barriers in the US capital market in the case of energy retrofits.

Table 2-4: Contributors to Financial Barriers in Commercial Energy Retrofits (Adapted from ISC 2009; Pike Research 2010)

Areas	Description
Lien	Energy retrofits often involve putting additional liens on the property, which requires the unlikely consent from the first lien-holder.
Premium	The lending industry currently exhibits no standard practice to properly underwrite energy investments due to unproven premium value of energy efficient buildings.
Credit	Shell LLCs (limited liability companies that building owners create for owning and managing individual buildings) have not enough credit-worthiness.
Debt	Due to a hard cap on debt, it is difficult to have additional energy project debt on the balance sheet
Turnaround	Quick turnaround in private building ownerships makes long-term capital investments impossible.
Guarantee	Buildings owners can hardly guarantee that energy savings will be used to pay off the loan.

2.8 RISK IN ENERGY EFFICIENCY INVESTMENTS

Multiple studies (e.g., IBEF 2011; MARSH 2009) indicate that inadequate access to capital, short payback standard, and uncertainty in energy performance are the major barriers to investing in energy retrofits. Inherent in the risks of EE investments are the numerous uncertainties, which often make it difficult for developers to obtain viable loans for their projects (financial barriers).

Many project stakeholders are responsible for decisions that affect EE investments and the terms of the commercial loans that are used to finance such projects. Literature reviews (e.g., 7group 2009; BC Green Building Roundtable 2007; Van Nederveen and Gielingh 2009) indicate that in traditional project delivery methods, EE design decisions are often made through fragmented processes with non-iterative handovers between project stakeholders. These fragmented processes do not support the integration of team members' efforts that is required to properly evaluate benefits and risks of EE investments. Consequently, lenders may tend to view EE investments as relatively high risk projects and therefore make it difficult for developers to attain favorable loans (NEEA 2010).

Risk in EE investments are discussed in a number of studies (e.g., Galuppo and Tu 2010; Jackson 2009; MARSH 2009), which suggest that the main driver for EE investments are its financial risks and returns, not green ideology (Muldavin 2010). EE investments need to be understood from the perspective of investors and developers who are looking for an attractive ROI (Melaver and Mueller 2008).

The commercial building industry appears to see risk of energy retrofit investments in two ways:

1. The level of investment needed to fund the design and construction of the project (project cost risk), and
2. The level of performance during the building's operation required to yield a positive ROI (performance risk).

Performance risk and project cost risk are closely related, because cost-cutting value engineering in the late stage of design development or construction affects a building's operational performance. Fowler and Raucha (2007) investigated why multiple intended EECBs didn't reach target performance levels during operation, and revealed that the EE technologies included in the original design had been cut due to their implementation costs.

Volatility around market-determined rents and around occupancy premiums is another interesting area in risks of EE investments (e.g., Kats 2003; Jackson 2009), but they are beyond the scope of this dissertation.

The following two sections will expand on the nature of project cost risk and operational practice risk. The types of energy-related risks studied in this research are:

1. Project cost risk
    a. Cost of uncertainty
    b. Risk of cost overruns
2. Performance risk
    a. Operational practice risk
    b. System performance risk

2.8.1 Project Cost Risk

Though LEED standards encompass more than just EE, the rating system provides an indication of how much more so-called high performance buildings cost than conventional buildings. In his seminal work, Kats (2003) surveyed the cost premiums associated with different LEED certification levels based on 33 buildings in California. Later, the General Services Administration (GSA) (2004) performed a LEED incremental cost study using two prototypical buildings: a mid-rise federal courthouse and a mid-rise federal office building. Table 2-5 compares the findings of the two studies.

Table 2-5: Cost Premiums for LEED Certifications

LEED Certification Level	Cost Premium as a Percentage Increase from Baseline Building Cost	
	Kats (2003)	GSA (2004)
LEED Certified	0.66%	0.03 to 1.45%
LEED Silver	2.11%	0.14 to 4.94%
LEED Gold	1.82%	1.96 to 8.83%
LEED Platinum	6.5%	N/A

Similarly, a survey done by BD+C (2007) reported the following:

- 94% of respondents said the trend of making building projects sustainable is ‘growing.’
- 78% thought sustainable design added ‘significantly to first costs.’
- 86% of respondents said they thought green buildings were more costly to build than conventional buildings.
- 31% said they had trouble sourcing green products. There is still uncertainty in the marketplace as to what constitutes ‘green.’
- 32% of respondents said green buildings would cost from 6% to 10% more, while 41% said the cost increase would be 11% or greater.

While a number of studies have focused on incremental LEED costs and their financial benefits (e.g., Kats 2003), some studies reported incremental costs related to ENERGY STAR. By combining multiple sources, Jackson (2009) investigated cost premiums perceived by the industry when developing LEED or ENERGY STAR-certified commercial buildings. Table 2-6 summarizes Jackson’s findings on cost premiums.

Table 2-6: Cost Premiums of LEED and ENERGY STAR Certifications
(Adapted from Jackson 2009)

Certification Type	Qualitative Perception of Premium Amount		
	Low	Mean	High
LEED	1%	3%	5%
ENERGY STAR	0.5%	1.5%	2.5%

Despite the common perception on the cost premiums, advocates for 'Integrated Design' (explained in Section 2.11) argue that they can deliver an EECB at no significant cost increase over a baseline building. Matthiessen and Morris (2007), in their frequently-cited study, found no statistically significant cost differentials (1) between LEED-seeking buildings and non-LEED-seeking buildings, or (2) between different LEED certifications.

Evaluating cost premiums associated with EE improvements is a critical step to successfully delivering EECBs. As stated earlier, Fowler and Raucha (2007) revealed that in order to reduce construction costs, EEMs in multiple EECB projects were not included in many final designs. In spite of their long term benefits, 'first cost' barriers were significant to implementing EEMs.

Project cost risk in EE project developments can be understood in two respects: (1) the cost of uncertainty and (2) the risk of cost overruns.

2.8.1.1 Cost of Uncertainty

The cost of uncertainty contributes to the project cost risk. In a study on product development (PD), Browning et al. (2002) stated that, "Uncertainty has many costs during PD (e.g., costs of resource buffers and options) and these costs are passed along to the customer as higher acquisition costs. Whether the customer considers certainty explicitly or not, product costs reflect the costs of uncertainty. Reducing uncertainty in PD increases customer value by improving affordability."

Unmanaged uncertainty can result in excessive contingencies in programs and/or designs. That in turn leads to 'overspecification' and 'overdesign.' Ronen and Pass (2007) define overspecification as "defining product or service specifications beyond the actual needs of the customer or the market" and overdesign as "designing and developing products or services beyond what is required by the specification and/or requirements of the customer or the market."

The following scenarios exemplify the issues in overspecification and overdesign:

- Flyvbjerg et al. (2003) found that dozens of mega infrastructure projects suffered from overestimation of demand and underestimation of cost.
- Levitt et al. (1980) reported a tunnel project with specifications that called for zero leakage and no pumping in the tunnel. To meet these (unrealistically demanding) specifications, the engineer included 12-inch thick concrete lining. Had the specifications been less restrictive, the lining could have been replaced

with a simple pumping system. The overspecification resulted in additional millions of dollars per mile.
- Levitt et al. (1984) argued that designers plan for the least skillful contractor that might win the contract in the delivery of DBB projects. Consequently, they are often wary of designing aggressively to reduce construction costs.

When it comes specifically to EE investments, overspecification and overdesign can be detrimental, because they both can increase first costs as well as energy costs. For example, multiple studies have identified persistent issues with HVAC oversizing:

- Knight and Dunn (2004) surveyed over 30 air conditioning systems in office buildings in the UK, and revealed that all the systems were oversized for the loads they actually encountered during operation.
- Crozier (2000) surveyed 50 HVAC systems in the UK, and reported that approximately 30% of the systems had more than twice the required capacity.
- Deng (2002) presented a case study from Hong Kong where the original design included four chillers that provided a total capacity of 8,000kW, but the highest cooling load observed was only 3,516 kW.
- PIER (2005) reported that about 60% of residential HVAC subcontractors in California still calculate the size of HVAC systems by heavily relying on the 'square feet per ton' rule. However, recently built houses with good envelope designs can be served by HVAC systems of 40% less in size.

Overspecification and overdesign are indeed passive ways to manage uncertainty. They involve having buffers to absorb the impact of uncertainty. However, this can lead to the following undesirable results:

- Increased first costs as well as O&M costs
- Reduced affordability and fundability
- Raised financial barriers

2.8.1.2 Risk of Cost Overruns

In ways similar to the cost of uncertainty, the potential for cost overruns also contributes to project cost risk. Compared to new EECB projects, energy retrofit projects pose greater challenges to containing costs due to unknowns and high complexity inherent to retrofits. Mitigating the risk of cost overruns in retrofit projects becomes a large challenge for project stakeholders, especially lenders who are providing a construction loan for projects. McKim et al. (2000) reported from their survey of 25 retrofit projects the cost overruns of 19.9% on average—five times higher than overruns of the new construction projects they surveyed.

Following this expansion on project cost risk, the next section expands on performance risk.

2.8.2 Performance Risk

Torcellini et al. (2004) measured the actual energy savings achieved by six intended high performance buildings and compared these operational savings to their corresponding design goals. They found that in every building, energy savings fell short of their targets (Figure 2-7). In particular, one building reported an actual energy use of 16.4 kBtu/ft^2, while its design goal had been set to net-zero, i.e., 0 kBtu/ft^2 (not included in Figure 2-7). The subpar performance appeared to be mainly due to "higher than expected occupant loads and systems not performing together in an ideal fashion" (Torcellini et al. 2004). Torcellini et al.'s investigation suggests the need for carefully measuring and reducing performance risks when aiming at achieving EE goals.

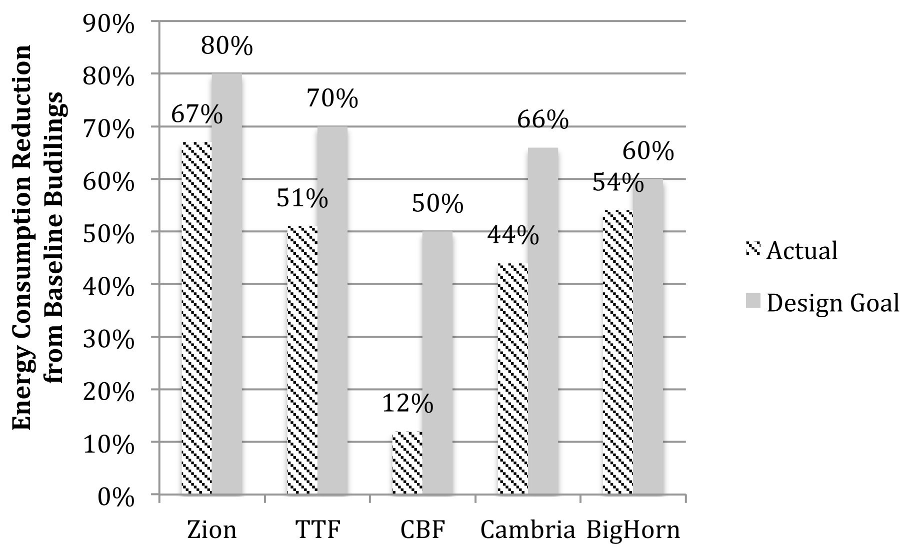


Figure 2-7: Lower Performance Observed from Five DOE High-performance Buildings (Adapted from Torcellini et al. 2004).

Choi (2009) discussed "the need for reliable performance, cost, and benefit information of green features." Current gaps in knowledge about EEMs cause building owners to question whether implemented EEMs will perform as intended and whether users/staff will be able to operate and maintain EEMs. This questioning makes it difficult for owners to justify upfront investments required for achieving aggressive sustainability goals (Choi 2009).

MARSH (2008) expressed concern about the performance risk of improper installation or faulty designs causing buildings to not see intended energy savings. With the recent high demand for EE and LEED, insurance companies are looking to provide coverage for these performance issues.

Based on the literature reviews, I categorize the performance risk into two types of risk:

1. **Operational practice risk**: Buildings with similar energy-related structures, such as lighting elements, envelopes, and HVAC equipment, can nevertheless have significantly different energy consumption levels, depending on different

operational practices being applied. Such variable operational practices are heavily related to how facilities' staff and occupants operate/control their buildings.

2. **System performance risk**: The system performance risk involves two issues:
    a. The built-in quality of EE-related systems (e.g., building envelopes and HVAC systems) has a significant impact on the building performance. In particular, low quality construction of HVAC systems and distribution systems can harm energy performance. Commonly observed quality issues (called 'faults') include issues with duct leakage, lack of airtightness of the building envelope, low-quality duct insulation, etc.
    b. Variability in climate can significantly impact the performance of target buildings. DOE (2010a) established eight climate zones. A certain EEM that performs well in one zone can show performance below par in another zone.

2.8.3 Managing Risk from a Project Management Perspective

Browning et al. (2002) argued that risk associated with product development (PD) activities decreases with availability of information (Figure 2-8). They stated that, "Making progress and adding customer value in product development equate with producing useful information that reduces performance risk." This suggests the importance of having reliable information flows and feedback systems in design development as a means to reduce risks.

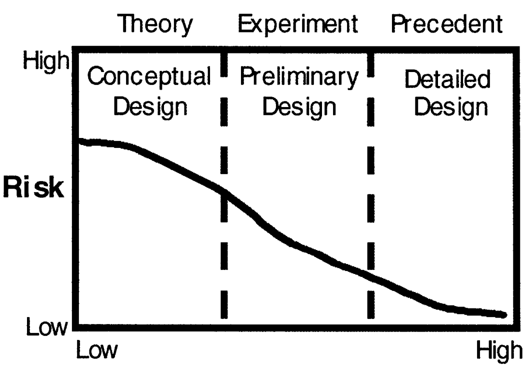


Figure 2-8: Risk vs. Availability of Useful Information through Design Development (Figure 1 in Browning et al. 2002)

Useful information can be made more readily available by preventing design processes from being sequential and fragmented. The fragmented design approach is commonly observed in traditional DBB project delivery. In contrast, the recent development of IPD allows early involvement of key participants, which can drastically increase the availability of design information provided by design specialists (Figure 2-9) (AIA 2007b; Matthews and Howell 2005).

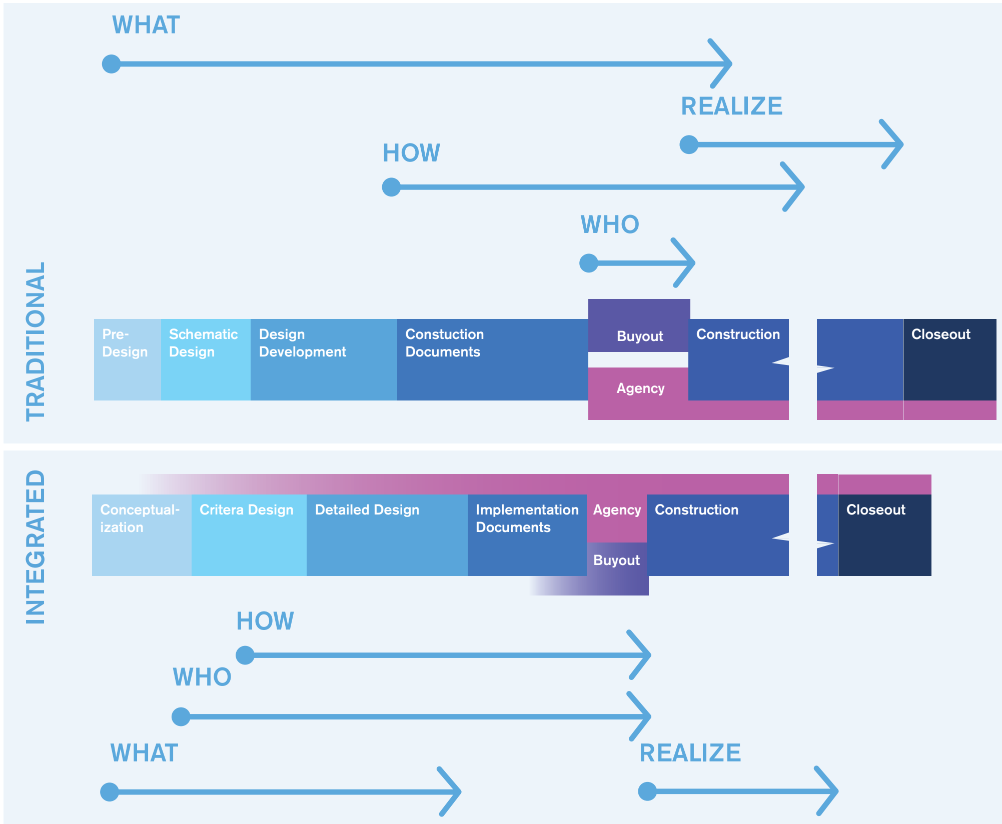


Figure 2-9: IPD vs Traditional Delivery (Image on Page 4 of AIA 2007a)

The fragmented design process ('design-in-silos') prevents design specialists from effectively sharing information, which can result in oversizing. For example, Moller and Thomas (2009) demonstrated a scenario in which an HVAC designer assumed overly conservative glazing characteristics early in the process and developed high cooling load estimates. Without verifying this design later in the delivery process due to the fragmented process, the installed HVAC system will likely be oversized.

Smith et al. (2006) suggested that establishing a single project entity contributes to "reducing capital costs by reducing the incidence of overspecification and overdesign which prevents achieving right-sizing and by reducing conflict between the various parties to the project."

Vaidya et al. (2009) emphasized the importance of "increased trust between different design disciplines and a continuous check through the design and construction process." Such enhanced coordination is required to achieve rightsizing by preventing use of rule-of-thumb calculations and traditional safety factors. They further suggested that rightsizing or downsizing could be achieved by the method of 'Integrated Design' (Integrated Design will be explained in Section 2.10).

Moller and Thomas (2009) emphasized the importance of Integrated Design in whole-building simulation programs for evaluating design alternatives in a comprehensive manner. A single entity in alternative project delivery methods (e.g., IPD) can help achieve Integrated Design that provides an opportunity to rethink who is responsible for design of all major energy subsystems. In contrast to the traditional fragmented process, Integrated Design can help achieve right-sizing of HVAC (Moller and Thomas 2009).

Specifically discussing retrofit projects (such as energy retrofits), McKim et al. (2000) suggested key factors to manage risks in retrofits, including: (1) communication control, (2) proactive involvement of cross-disciplinary team members, and (3) clear scope definition.

By surveying 33 retrofit projects, Sanvido and Riggs (1991) found that, "the project team was the single most dominant factor that influenced the outcome of a project." Specifically, the most important team characteristics that determined the success of the retrofit projects included (1) cohesiveness, (2) chemistry, (3) flexibility, and (4) early involvement.

Sections 2.9 and 2.10 present the literature that influenced the development of the TVD protocol (Chapter 5), the process of Energy Retrofit Loan Analysis Model (Chapter 6), and the development of the standard TVD decision-making process (Chapter 8).

2.9 LIFE CYCLE COST ANALYSIS

LCCA is a holistic method to support decision-making processes by comparatively assessing cost impacts of solutions over a specified period of time. With respect to the built environment, LCCA involves calculation of the total cost of ownership, including initial capital costs, building O&M costs, and asset replacement costs. In the building industry, LCCA has been recognized as a valuable method to help project teams discuss options/alternatives and their benefits and compare cost implications of choices (Boussabaine and Kirkham 2004; Bull 1993; Langston 2002).

The LCCA process often involves "high-quality professional judgment, forecasting, and insight" (Ashworth 1993). Therefore, to address the issues of life cycle costs in a commercial building project, the project owner must collaborate early with specialists, such as designers, engineering consultants, and contractors who are capable of forecasting the future state of the given facility (Cole and Sterner 2000; Keeler and Burke 2009).

LCCA is most effective when applied in the early stages of project delivery (Keeler and Burke 2009; Langston 2002). However, the commercial building sector has a complex value chain in project delivery. It involves complicated commercial relationships between parties, which too often results in a fragmented process (Van Nederveen and Gielingh 2009). The fragmented process makes it hard to accommodate LCCA to evaluate feasible design alternatives in early design phases (Lutzenhiser and Biggart 2001; WBCSD 2007).

2.9.1 Economic Analysis

In quantifying the benefits of EE improvement investments, practitioners often use simple payback (SP), net present value (NPV), and internal rate of return (IRR) (Martinaitis et al. 2007). Each of these will be explained next. Selecting specifically which method to use depends on the level of sophistication of users and the amount of time allowed for analysis.

2.9.1.1 Simple Payback (SP)

SP is defined as the period, usually measured in years, taken for the return to repay the initial investment (Boussabaine and Kirkham 2004; Bull 1993). This method is simplistic because it is based on assuming no discounting factor, yet it is a widely-used metric for testing the viability of EE investments, enabling project teams to screen out solutions at early stages. SP allows the quick elimination of unrealistic options without involving complex computations (Bull 1993). In this study, SP is measured Equation 2-4:

$$SP = \frac{EE\ Investment}{First\ Year\ Energy\ Cost\ Saving} \quad \text{Equation 2-4}$$

The commercial sector is known to generally accept a very short SP—as short as three to five years—while those in the residential sector generally accept a relatively long SP, over ten years. Kulakowski (2009) interviewed a facilities engineer and business manager. He found that they both agreed the SP of three to five years in the commercial sector is largely based on the fact that the current US commercial building lease contracts typically run between three and five years in length.

Goldman et al.'s (2005) study of the ESCO[5] industry, found that lighting improvement is the most frequently implemented EEM, followed by HVAC improvement. Lighting improvement is believed to guarantee a relatively short SP period (low capital investment but high energy savings). The survey also found that institutional sectors target more comprehensive retrofits (an average of 2.2 measures per project) than the private sector (an average of 1.6 per project). This makes sense, because private projects are commonly done in phases, and the extensions of ESCO contracts depend on the performance of these initial phases, where developers elect to implement relatively 'safe' measures such as lighting improvement (Goldman et al. 2005). Additionally, Goldman et al. (2005) found that this disparity occurs partially because the private sector has stringent standards for determining maximum SP periods. More capital-intensive investments are often made in later phases.

Concurring with the study of Goldman et al. (2005), a recent survey done by IBEF (2011) on "Which of the following energy efficiency measures has your company/organization adopted in the last 12 months?" revealed that lighting improvements are the most popular options implemented (Figure 2-10).

[5] ESCOs (Energy Service Companies) provide a type of performance contracting method, distinct from other service providers mainly by the use of performance-based contracting and services. It means that ESCOs attempt to deliver additional assurance regarding the inherent risks of energy retrofits, which include the probabilities of failing to meet expected energy- and project performances.

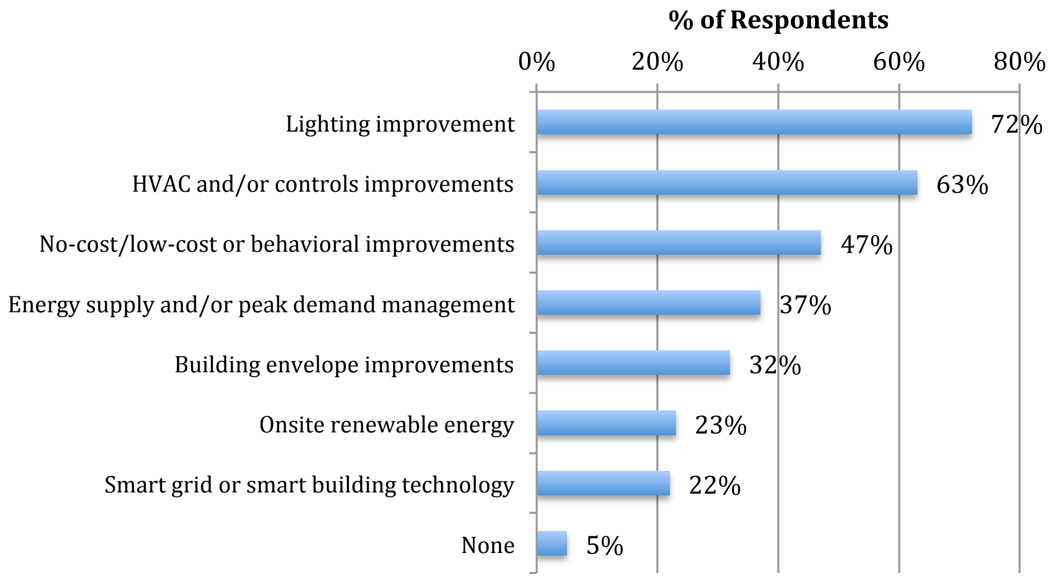


Figure 2-10: Frequency of Different EE Improvements Considered
(Figure 8 in IBEF 2011)

Kulakowski (1999) reported the predominance of using SP during the financial decision-making process in the building industry. As stated, a SP of two or three years serves as a threshold for go/no-go decisions in the commercial sector. Bull (1993) stated that the requirement for a short SP is partially due to its incapability of addressing the following factors:

- The time value of money, involving inflation and interest
- Positively and negatively varying cash flow
- Tax benefits

In addition, the SP method disregards positive cash flows that occur after the investment has paid for itself. This can cause underinvestment in projects whose benefits would accrue later and grow over time (Kulakowski 2009). To overcome the shortcomings of SP, developing business cases for EE investments requires more considerations on long-term savings.

2.9.1.2 Net Present Value (NPV)

Bull (1993) defined NPV as "the sum of money that needs to be invested today to meet all future financial requirements as they arise throughout the life of the investment." SP and NPV are the most frequently used methods in economic analyses in the building industry (Bull 1993). NPV is calculated by totaling the present value (PV) of all cash flow events being considered; the PV of a cash flow event is calculated by using an appropriate discount rate—rate used for discounting the future value to PV. A NPV calculation is the most basic indicator that measures the economic performance of an investment—determining whether NPV is over zero or below zero. NPV is calculated by Equation 2-5 at the discount rate of r:

$$NPV = A_0 + \frac{A_1}{(1+r)} + \frac{A_2}{(1+r)^2} + \cdots + \frac{A_N}{(1+r)^N} = \sum_{t=0}^{N} \frac{A_t}{(1+r)^t} \qquad \text{Equation 2-5}$$

Where A_t refers to a cash flow at time t, and N is the length of the study period. In the case of an EE investment, A_0 is typically the initial investment required for enhancing EE in a building (negative), and the following cash flows (A_1 to A_N) are the energy cost savings that the enhanced EE of the building provides (positive).

2.9.1.3 Internal Rate of Return (IRR)

IRR is defined as the discount rate that produces a zero NPV (Boussabaine and Kirkham 2004). IRR refers to the value of r that satisfies Equation 2-6:

$$NPV = \sum_{t=0}^{N} \frac{A_t}{(1+r)^t} = 0 \qquad \text{Equation 2-6}$$

An IRR is commonly measured against a minimum acceptable rate of return (MARR), which is the hurdle rate considered viable for an organization. In other words, a project with an IRR greater than the MARR is presumed to be economically acceptable, else the project is deemed unworthy of investment (Boussabaine and Kirkham 2004). In reality, there is always a 'do nothing' option, against which an IRR will also be compared (Bull 1993).

IRR has multiple shortcomings, including (1) simplistic or no assumption on reinvestment of interim cash flows in projects, and (2) issue of having multiple IRRs in the case of cash flows changing from positive to negative, and then back to positive.

2.9.1.4 Discounted Cash Flow (DCF)

Expanding on NPV and IRR, Muldavin (2010) argued for a more sophisticated use of discounted cash flow (DCF) in the lending industry. DCF is a standard approach used by commercial real estate investors to value commercial property and financial potential, and it is commonly required to understand the financial implications of options for underwriting EE investments.

Though a complex DCF is not very practical in real-life investments, DCF is still preferred, because it can provide an intelligently organized assessment of revenue and risk, and provides rich details to assist decision making in the capital market (Muldavin 2010).

2.9.2 Monte Carlo Simulation (MCS)

Monte Carlo Simulation (MCS) is a stochastic method used to generate a set of random numbers for input variables of a model. It has become a popular method for probabilistic risk analysis (Smith et al. 2006). MCS can be applied to a variety of quantitative analyses ranging from finance to traffic management (Boussabaine and Kirkham 2004).

One must define/assume probability density functions (PDF) for each of the random variables in the model. The appropriate distribution can be decided upon from past experience, judgment of the analyst, or market research. Using a computational process or software (e.g., @Risk or MATLAB), random numbers for each variable are generated and put into the pre-defined formula/model, which in turn produces output values. By repeating the process a large number of times, the outputs of the model can be analyzed to identify the statistical conclusions they imply. The number of repetitions—also called iterations or runs—is important because it determines the standard error of the mean (i.e., the margin of error) statistic from the perspective of random sampling (by Equation 2-7).

$$Standard\ Error\ of\ Mean = \frac{Standard\ Deviation\ of\ Outcomes}{\sqrt{Number\ of\ Interations}}$$ Equation 2-7

One often has to decide on the number of iterations to run MCS in order to have a desired statistical confidence in simulation results. The decision can be in the function of 'confidence interval' and 'confidence level' that a user wants to have. For example, if a user desires MCS to produce an estimate that is accurate to within 3% of confidence interval, with a 95% confidence level, s/he can compute the number of iterations using Equation 2-7. However, the rule of thumb is that the more iterations, the narrower confidence internal the MCS results produce (Boussabaine and Kirkham 2004; Smith et al. 2006).

MCS is subject to the following two concerns (Boussabaine and Kirkham 2004; Smith et al. 2006):

- One assumes that the random valuables in the model are independent of each other. However, for most engineering problems, variables are interdependent. Ignoring correlations can bias the MCS and can lead to significant misinterpretation of the results (Boussabaine and Kirkham 2004). When expecting interdependence between input variables of MCS, use of correlation coefficients is suggested to reflect how strongly positive or negative the relationships are.
- In an ideal situation, PDFs of random variables are determined from historical data/observations. However, it is common for data to be lacking to determine the type and parameters of the PDF. In that case, "It is left to the project modeler and those associated with the project to decide on the probability distribution shape… Utilization of the experience of members of the organization, from previous similar projects, might assist in the decision as to which probability distribution is most appropriate for a particular variable" (Smith et al. 2006).

Sensitivity analysis in MCS is a technique to "measure the impact on project outcomes of changing one or more key input values (assumptions) about which there is uncertainty" (Boussabaine and Kirkham 2004). By changing one assumption at a time, a researcher can use sensitivity analysis to determine the sensitivity of an output variable to the change in the input variable. It is also possible to adjust multiple input variables at the same time (Boussabaine and Kirkham 2004; Emblemsvåg 2003).

A sensitivity analysis technique is commonly based on what-if scenarios and serves to measure the impact of associated uncertainties (Emblemsvåg 2003). Sensitivity analysis of MCS methods helps provide reliable financial impacts of selected options for the study period and provides insight into the inadequacies of parameter estimation (Boussabaine and Kirkham 2004).

Emblemsvåg (2003) stated that in MCS, sensitivity analysis deals with the uncertainty. The MCS applies the sensitivity analysis' attempts to statistically measure the impact that the uncertainty of a certain input variable has on the output variables. In doing so, one can accurately measure the output's sensitivity to the input, given that the uncertainty is properly modeled. So by adding uncertainty to the model, the risk is actually better addressed and managed.

2.10 INTEGRATED DESIGN

'Integrated Design' is defined as, "A discovery process optimizing the elements that comprise all building projects and their interrelationships across increasingly larger fields in the service of efficient and effective use of resources" (MTS 2006). It represents a series of efforts to accommodate the "Four E's – *Everybody Engaging Everything Early* in the project" (7group and Reed 2009).

Peterson (2007) defined Integrated Design similarly as, "a collaborative process that can achieve high-performance, low-energy, sustainable buildings by considering all design variables together. It looks beyond the immediate building to how the building and its systems can be integrated with supporting systems, and at how materials, systems, and products connect, interact, and affect one another."

EECB development requires highly complex design analysis, careful system selection, and a rigorous optimization process, which are enabled by Integrated Design guided by engineering exptertise (Lapinski et al. 2006). Traditional approaches prevent project from properly addressing issues such as value tradeoffs, system optimization, and evaluating design alternatives.

As discussed earlier, the construction industry often anticipates upfront cost premiums for EECBs or LEED-certified buildings. However, recent studies of Vaidya et al. (2009), Harvey (2009) and 7group and Reed (2009) suggested that improved energy performance can be achieved at no significant increase in first cost and, further, high energy performance can be achieved by improved optimization and integration levels.

The literature review identifies Integrated Design as an enabler for cost-effectiveness and integration in the EECB delivery (e.g., 7group and Reed 2009; Horman et al. 2006; Keeler and Burke 2009; Vaidya et al. 2009; Yudelson 2008). For example, the US Green Building Council (2003) articulated how Integrated Design can benefit the cost-effective delivery of EECBs:

> *"Asking if a high performance green building costs more than a conventional alternative is a little like asking which is more expensive, an efficient car or an inefficient one? The answer, of course, is that it depends on factors such as the make and model, features and driving preferences. Many green buildings cost no more to build – or even less than the alternatives – because resource-efficient strategies often allow*

downsizing of more costly mechanical, electrical and structural systems. The key is integrated design."

Integrated Design for EECBs requires a different approach to building systems than traditional approaches. Integrated Design regards building systems as complex and integrated, and accordingly, understanding relationships between building elements is necessary for a successful Integrated Design. For instance, multiple efficiency and cost relationships between HVAC and building envelope systems have to be understood to optimize building systems in terms of life cycle costs (MTS 2006).

Bors (2009) stated that, "The core of integrated design is the search for synergies: i.e., strategies with resultant benefits greater than the sum of individual design decisions." He suggested that Integrated Design for EECBs be a two-step process. First, reduce building loads by considering design aspects such as daylight, site orientation, occupancy, and building envelope. These efforts can result in significant load reductions of HVAC systems. Second, design more efficient HVAC systems to reduce energy usage to a further degree. This two-step process can result in significant reductions both in first costs and in energy use, and it often even results in eliminating a mechanical system component (Bors 2009).

7group and Reed (2009) suggested similar steps in designing EECBs:

1. Determine baseline (one designed to meet minimum building codes)
2. Develop EEMs from baseline
3. Focus on load-reduction strategies
4. Develop combinations of EEMs to evaluate optimal synergy between cost, savings, and load reduction.
5. Evaluate HVAC system options only after all loads have been reduced as much as possible

Both approaches ensure that a right combination—also known as 'bundling'—of building components will be achieved to produce the best value design solution that lowers not only life cycle costs, but also first costs. Multiple case studies reported that when using Integrated Design, improved energy performance has no apparent linear relationship with first costs and that higher energy efficiency can actually cost less:

- Harvey (2009) argued that it is feasible to offset the cost of a high-performance building envelope with lower costs of mechanical systems. The system tradeoff can work better for commercial buildings as the mechanical systems usually account for a bigger fraction of the first cost. Thus, an optimum tradeoff helps achieve lower life cycle costs and lower first costs at the same time. A case study in Canada showed that an EECB cost 9% less to build than a comparable conventional building, while consuming about half the energy during its use phase.
- A design team considered 13 EEMs in a school building and experimented with various combinations of them. When each EEM was implemented individually, it resulted in an increase in first costs. However, after the team rigorously searched for an optimized bundling of EEMs, they reduced the HVAC system load by 40%

with the optimized whole building system. The efforts for Integrated Design resulted in $275,550 first-cost reduction while the optimized building system yielding $80,166 in annual energy cost savings (7group and Reed 2009).

- Vaidya et al. (2009) articulated through energy simulation that energy performance in an office building has no apparent relationship with first costs, and high energy performance can be achieved by improved bundling levels with no significant increase in first costs.

The illustrated cases indicate that Integrated Design can help a project team overcome financial barriers while delivering significant energy savings. This is possible through Integrated Design by integrating cost and design with the intent to optimize the whole building, as opposed to local optimization that relies on individually implemented EEMs.

The principles of Integrated Design contribute to the development of a standard TVD decision-making process (Chapter 8).

This literature review provided a context for my research and contributions. It also highlighted the need for an application of TVD to EE investments in order to identify/manage/reduce energy-related risks so that financial barriers can be overcome.

CHAPTER 3. RESEARCH APPROACH

Chapter 3 presents the research methodology and research process used to develop the research. A combination of qualitative and quantitative approaches is used. The qualitative research methods include interviews and case study, while the quantitative research methods include an LCCA method with a simulation model based on MCS.

3.1 RESEARCH METHODOLOGY

A combination of quantitative and qualitative approaches develops this research and documents an application of TVD to EE investments. This mixed method approach is expected to enhance the theoretical understanding of project development and loan underwriting for EE investments and expand the body of knowledge about EE design decision-making processes.

Figure 3-1 summarizes the research framework that is used to achieve the objectives of this research, and the deliverables as contributions to knowledge.

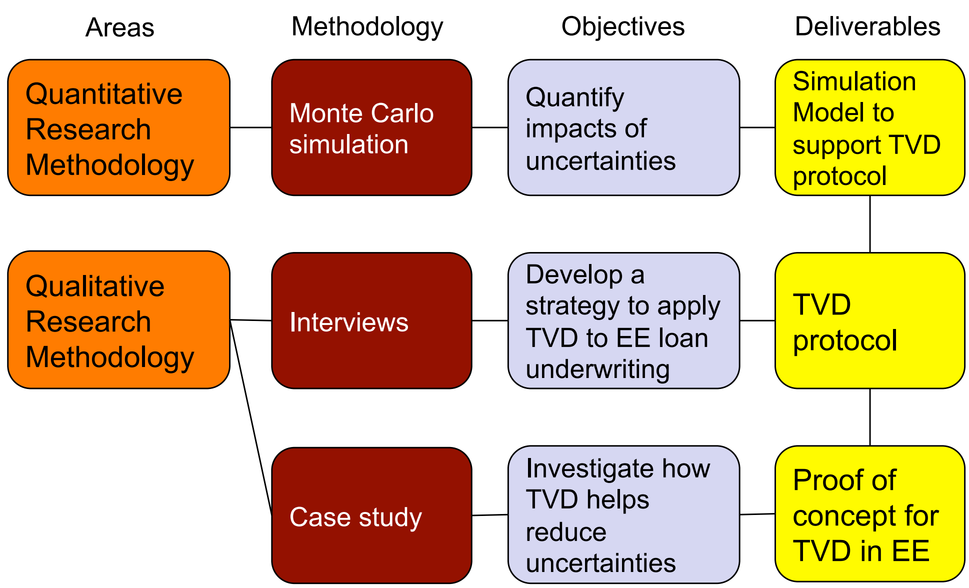


Figure 3-1: Research Framework

The part of the qualitative approach that is based on interviews provides the background of the research and answers the research question, "What types of uncertainties and barriers exist in commercial EE improvement projects, especially energy retrofits?" The interviews identified opportunities for improvements in current practices in EE investments and commercial loan underwriting. This led to the development of the TVD protocol that provides a guideline for an application of TVD to the commercial loan underwriting.

The quantitative approach uses MCS for developing a simulation model in order to answer the research question, “Can the allowable cost and target building performance be estimated to support TVD in EE investments?” The approach also employs a case study research investigating an energy retrofit project in a Northern California office building.

Another qualitative approach, based on case study research, answers the research question, “How can TVD in IPD environment help reduce the specific uncertainties?” The case study follows the application of TVD to EE design decision-making process at the Cathedral Hill Hospital (CHH) project. It provides a proof of concept for the use of TVD in EE investments.

3.1.1 Life Cycle Cost Analysis and Monte Carlo Simulation

This research involves a systematic LCCA method for evaluating feasible EE design alternatives in early stages of the commercial loan underwriting process. For that, it employs a quantitative research approach of MCS for developing a simulation model. As a result, Energy Retrofit Loan Analysis Model (ERLAM) is introduced to determine the impacts of energy-related risks on the financial performance of target buildings. ERLAM is capable of determining the target building performance and the allowable cost to support the TVD process in energy retrofit projects.

Also, the case study of CHH uses an LCCA as the economic analysis of design alternatives, while revalidating the basis of design established during the validation process of TVD.

3.1.2 Interviews

Interviewing industry practitioners was an integral part of the research investigation. The study conducted semi-structured interviews with a number of industry practitioners in EE loan underwriting, energy risk evaluation in current practices, and existing financing methods.

About 30 semi-structured phone interviews (30 minutes to 2 hours long) were conducted with a wide range of companies and organizations involved in the development of commercial buildings. The interviews were transcribed and summarized. The objective of the interviews was to learn how EE investments are incorporated into commercial building developments, retrofits, and operations, how they are funded, and what barriers/risks to financing exist. After the TVD protocol was established for loan applications, additional interviews were conducted with three senior vice presidents of banks of different sizes to get feedback on the TVD protocol’s applicability; this serves as an initial validation of the protocol.

To recap, interviews offer opportunities for (1) investigating current industry practices, (2) identifying opportunities for improvements, (3) providing a theoretical background to formulate research questions, (4) developing a TVD-based process protocol, TVD protocol, and (5) receiving feedback from commercial banks about the applicability of the TVD protocol.

3.1.3 Case Study Research

An application of TVD to EE investments involves extending the applicability of TVD methodology to EE improvement projects. This is analyzed using a case study to develop details of the application process.

Yin (2003) stated that case studies are the preferred research technique to answer questions of 'how' and 'why.' Yin defined case study research as "an empirical inquiry that investigates a contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not clearly evident." Case study research is commonly used when researchers want to understand a contemporary phenomenon within contextual conditions and when they have little control over events.

A case study develops practical and context-dependent knowledge that cannot be obtained from conventional wisdom (Flyvbjerg 2006). While some may critique the use of a single case study as the basis from which to induce a theory, Davies et al. (2009) emphasized the significance of conducting a single case study when it presents an opportunity for "unusual research access to explore a significant phenomenon."

3.1.4 Use of Process Mapping

In order to maximize the effectiveness of TVD applications to EE investments, one of the objectives of this study is to develop a standard TVD design-making process that will guide project stakeholders through EE building delivery in accordance to their value expectations. The standard process is expected to achieve an integrated method for establishing and validating energy efficiency business cases, setting project targets, and steering design to target. An integrated team building process and formation based on the process map will help to achieve the project target by sharing key information effectively throughout the team.

A process map supports an application of TVD in EECB development, because process mapping is an analytical and communication tool. It helps people to gain a better understanding of the process, seek improvement opportunities, re-engineer existing processes, and then implement new process-driven structures (Hunt 1996; Jacka and Keller 2009).

Many studies have used process mapping to describe a variety of current practices in the A/E/C industry, determine problems, and suggest opportunities for improvement. Tommelein and Li (1999) developed a process map to describe alternatives for ready-mix concrete supply chain integration. Arbulu et al. (2003) used this technique to map the supply chain of pipe supports used in power plants. They used these maps to identify non-value-adding activities (wastes that are embedded in a process) and then re-engineer the supply chain. Tuholski et al. (2009) used process mapping to compare and contrast alternative ways to execute a complex seismic retrofit process and demonstrated the effectiveness of the selected process.

In general, developing a cross-functional process map is useful in representing a complex process where multiple parties are involved. A cross-functional process map (aka. a swim-lane diagram) is a type of flowchart and a mapping method suitable to show the distribution of work amongst multiple organizations. It provides a visualized map to show a sequence of steps, inputs and outputs of steps, and the party responsible for each step (Damelio 1996).

3.2 RESEARCH PROCESS

This section presents the research process that I have followed in order to achieve the research objectives. Figure 3-2 illustrates the overall research process.

Funded by the US Department of Energy (DOE), a group of multidisciplinary researchers studied how to identify, analyze, and manage risks in commercial loans given for EE investments. The multidisciplinary research (the DOE research, hereinafter) is an integral part of this research, interwoven with every phase of the research process. The details and results of the DOE research are presented in Chapters 4, 5, and 6.

Figure 3-2 illustrates the four main phases of the research process, namely Background, Development, Application, and Understanding.

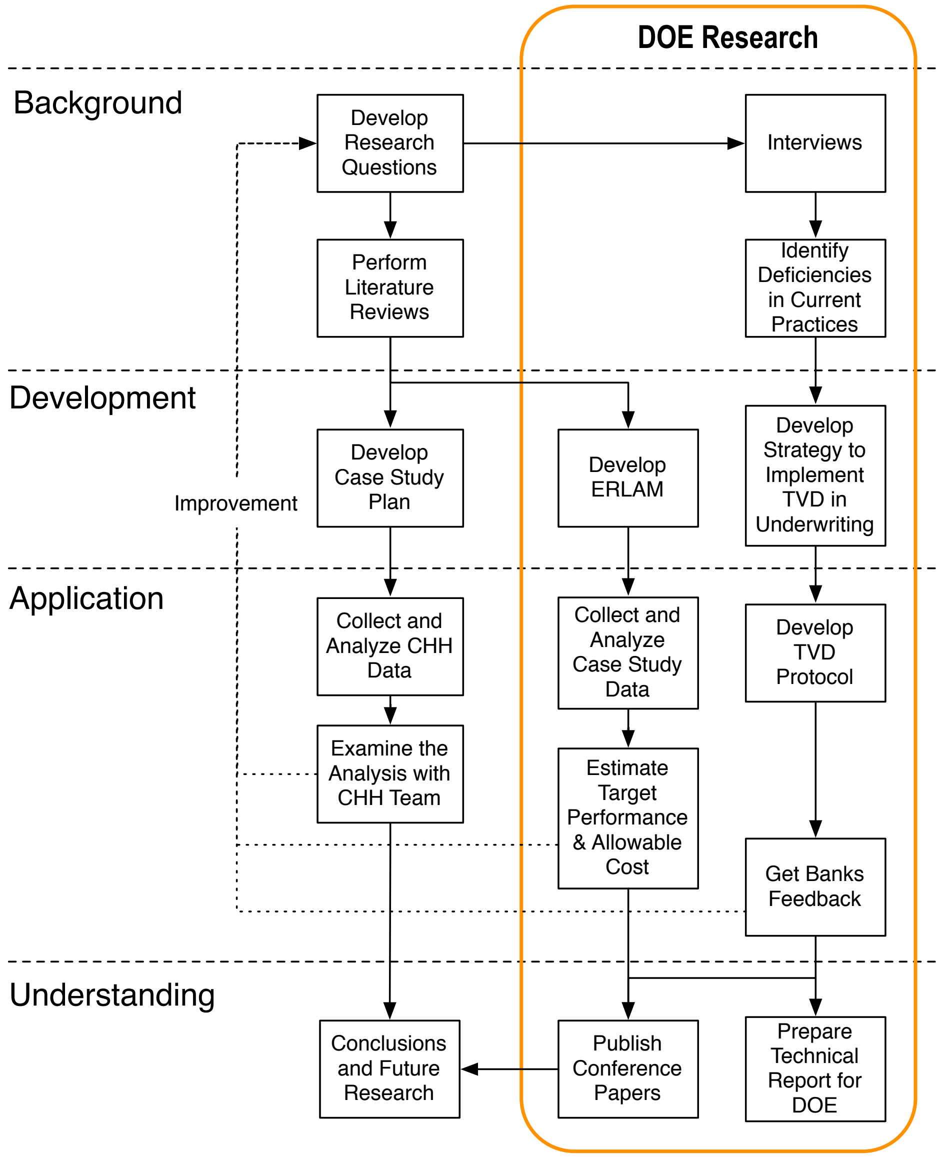


Figure 3-2: Research Process

3.2.1 Background Phase

During the background phase, I performed literature reviews to develop the knowledge background of the research. In addition, as part of the DOE research, a number of semi-structured interviews with a variety of industry practitioners helped identify deficiencies in current practices in (1) EE improvement project development and (2) commercial loan underwriting. Since the background phase identified financial barriers as the biggest barrier to EE investments, it provided a comprehensive understanding on what research questions would have to be answered to overcome the barriers, which led to the next phase, the development phase.

3.2.2 Development Phase

The objectives of the development phases are three-fold: (1) develop a strategy to implement TVD in commercial loan underwriting, (2) develop ERLAM, and (3) develop a case study plan.

First, developing a strategy to implement TVD in commercial loan underwriting was based on the deficiencies identified in the current commercial loan underwriting. I used interviews and documented the process and information flow of the current practices. The documentation identified opportunities for improvement and preparing guideline for implementing TVD in underwriting.

Second, developing ERLAM required learning how to use LCCA and MCS. Then, investigating current practices in commercial loan underwriting led to proposing use of ERLAM to better estimate the financial performance of target properties while better quantifying the impacts of uncertainties. ERLAM is intended to support the TVD protocol during commercial loan underwriting, especially its Step 4.

Last, developing a case study plan involved examining a number of projects for their EE design decision-making processes and associated challenges. The plan was to identify a project where TVD was explicitly implemented to help a project team to manage and reduce specific uncertainties regarding their EE design challenges. The case study disseminates the learning to expand the body of knowledge about EE design decision making.

3.2.3 Application Phase

In the application phase, an application of TVD in EE investments was documented. The documentation involved different levels of TVD application in the following areas:

1. Developing the TVD protocol's eight key steps used during EE loan underwriting
2. Collecting data on and analyzing an EE improvement at a Northern California energy retrofit; using HVAC upgrade project data, economic analysis data, and loan data
3. Collecting and analyzing the heat recovery system case at CHH about its challenges, uncertainties, and design-decision making process; using project data including drawings, diagrams, A3 reports, and CBA

Further, each of the areas was validated through the following approaches, respectively:

1. Obtaining feedback from three commercial banks ranging from small (local), medium (California-based), to large in size (top three, nationwide)
2. Applying ERLAM to estimate the target building performance and the allowable cost in a 15-year loan for the HVAC upgrade, and to support Step 4 of the TVD protocol
3. Having the CHH project team review the analysis of the effects of TVD application to managing and reducing risks and uncertainties related to the heat recovery system

3.2.4 Understanding Phase

During the understanding phase, I processed the results from the qualitative and quantitative approaches, synthesized conclusions, and addressed additional research questions that surfaced while carrying out this research. Most importantly, the research findings established a basis for developing a standard TVD decision-making process to answer the research question, "Can a TVD decision making process for EE investments be standardized?" The standard process is presented in Chapter 8.

In addition, the research findings have been disseminated through multiple publications including:

- Two conference papers to be presented at the 2012 Construction Research Congress conference from the 21st to 23rd of May 2012 at Purdue University
- A technical report submitted to DOE in September 2011

CHAPTER 4. CURRENT PRACTICES IN APPLYING COMMERCIAL LOANS FOR ENERGY RETROFITS

This investigation was funded by DOE, and performing interviews with industry practitioners was an integral part of the investigation. Over 30 semi-structured interviews (30 minutes to 2 hours long) were arranged with a wide range of US-based companies and organizations involved in the development of commercial buildings, as shown in Table 4-1. The main objective of the interviews was to learn how current commercial loan underwriting is done for EE investments in commercial building developments, retrofits, and operations, and how EE is benchmarked.

Chapter 4 is a result of the interviews during the DOE research. Due to confidentiality issues, interviewees' identities will not be mentioned.

Table 4-1: List of Interviewees

Types of Company	Counts
Development companies	5
Utility providers	1
Property management firms	2
Banks	10
Consulting groups	6
3rd party inspection companies (PCA)	3
Architects/Engineers	2
Contractors	3
Energy service companies	2
Alternative lenders	1
Nonprofit organizations	2
Total	**37**

4.1 PROJECT DELIVERY OF ENERGY RETROFITS

As with any significant investment decision, EE investments through commercial loans involve many project stakeholders in the decision-making process. The investigation reveals that the current decision-making process in energy investments happens sequentially, which does not allow for the use of feedback from lenders. Most importantly, the current underwriting process requires design completion before funding decisions are made (see Section 4.2.3 for more information). As with other capital projects, energy retrofit investments are driven by business cases that require assurances of availability of funding and acceptable ROI. With the current process however, building owners do not know if they are able to fund the project until the underwriting process is completed by the lender.

The investigation also reveals that commercial building owners can use two types of contract structures—Design-Bid-Build (DBB) and Design-Build (DB)—in their energy retrofit projects. In either case, the lender typically requires that the complete design and bid price from a contractor be included in the loan application package—which may be submitted by the borrower to multiple lenders. If the lenders conclude that benefits are acceptable by their loan evaluation criteria, they make an offer. Unless there is an established relationship with a lender, the borrower will likely choose the lender that offers the lowest cost of borrowing, and the project proceeds to construction.

4.1.1 Design-Bid-Build (DBB) Approach

In the case of DBB, the borrower hires a designer that works with an energy consultant to incorporate EEMs into the design process. After this process is complete, the borrower publishes a request-for-bidding to solicit interested and presumably qualified contractors. Through the competitive bidding process, the lowest-bidder is selected (Figure 4-1).

In this approach, the verification of cost estimates through bid pricing from a contractor happens late in the process. Quite often, bid prices exceed the budget, leading to late design changes and possible low performance. Late design changes triggered by cost overruns often include the removal of EEMs included in the original design with no consideration on how such changes will affect the building system as a whole.

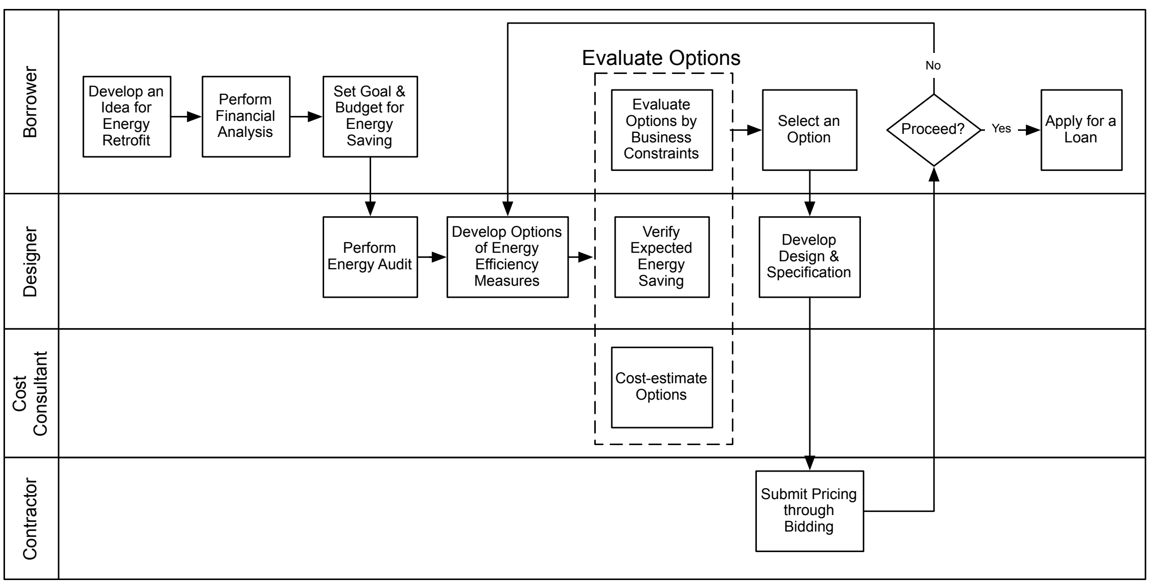


Figure 4-1: Typical DBB Process for Energy Retrofits

4.1.2 Design-Build (DB) Approach

The DBB approach requires the borrower to have particular engineering knowledge and to invest a significant amount of time to closely manage the project development process. For that reason, borrowers often select the DB approach for their energy retrofit projects. The DB approach involves preparing requests for proposals (RFPs) from design-builders such as ESCOs. Proposals include designs and guarantees of construction costs (Figure 4-

2). Though more integrated than DBB, success depends on how well the RFP defines values, requirements, and constraints. Lack of a clear definition can lead to a different, unexpected design.

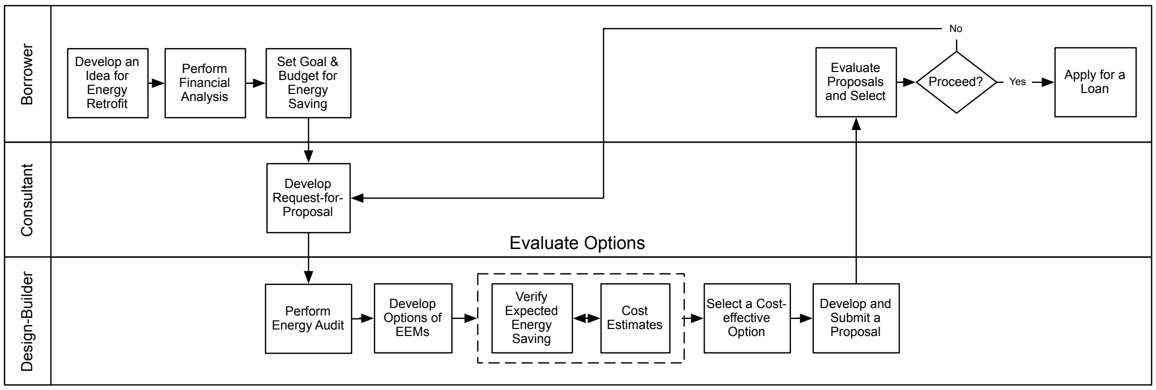


Figure 4-2: Typical DB Process for Energy Retrofits

4.2 COMMERCIAL LOAN FOR FINANCING ENERGY RETROFITS

A number of conventional ways to finance energy retrofit projects exist in the commercial building sector, namely (ENERGY STAR 2008):

- Internal capital
- Loan as debt capital
- Bond
- Leasing (operating, capital, municipal, etc.)
- Performance contracting (i.e., ESCO)

As for capital improvements in the commercial sector, including energy retrofits, a loan as debt capital has been the most conventional method of commercial lending to get initial capital for the improvements. Loan payments are made over time with increased net operating incomes (NOI) realized by lower expenses (lower utility bills) and/or higher income (higher rents).

In underwriting loans, cost-effectiveness analyses of EE improvements involve evaluating two major costs over the life cycle of buildings: (1) the first cost and (2) O&M costs:

- The first cost refers to the initial investments commonly expressed as incremental costs compared to baselines (minimum code requirements)
- O&M costs include energy costs over a target period

The initial investment to enhance EE in a commercial building is usually incorporated into a long-term commercial loan, with a typical loan period of 10 or 15 years in commercial real estate loans.

4.2.1 Major Risks in Construction Loans for Energy Retrofits

In the case of a construction loan for energy retrofits, the lender faces a greater challenge than with a conventional loan, due to higher uncertainty inherent in construction work. Therefore, in order to successfully underwrite energy retrofit investments, risk types at each project phase must be carefully categorized, evaluated, and mitigated. Figure 4-3 summarizes risk drivers that exist at each project phase of an energy retrofit. These risks are (1) construction risk, (2) carry risk, (3) take-out risk, and (4) real estate risk (Collier et al. 2008; Muldavin 2010).

- Construction risk is the risk that a project will not be completed on time or on budget, or not be of the anticipated quality.
- Carry risk is the risk that the project will fail to carry construction loan interests during the lease-up period.
- Take-out risk is the risk that the project will fail to achieve the market acceptance for the permanent lender to be able to take-out the construction loan.
- Real estate risk is the risk that the (energy) performance of the retrofitted building will fail to meet expectations and accordingly undermine the property value and NOI.

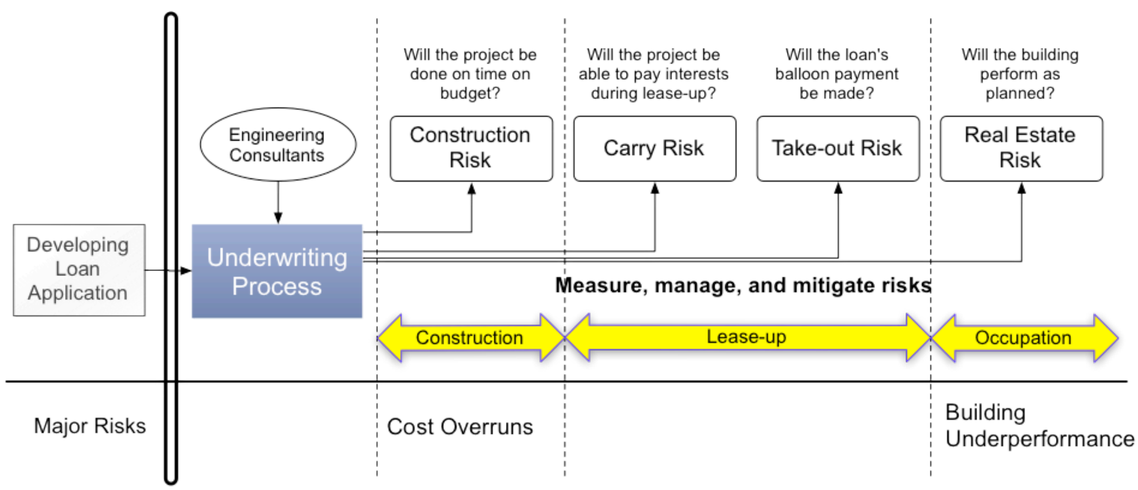


Figure 4-3: Risks in Construction Loan for Energy Retrofits

4.2.2 Commercial Loan Underwriting

The loan underwriting process consists of lenders preparing documents in order to determine if a specific loan meets their investment and risk criteria. Underwriters are vetting two key decisions: (1) whether or not to make a loan, and (2) the cost of borrowing based on risk evaluations.

It is viewed that underwriting is the process of integrating the standard protocol of the lender with the project-specific context of the target property (Figure 4-4). The lender's loan evaluation and risk criteria govern the standard protocol, while the project-specific context is determined by evaluating the property's physical and financial conditions (by means of third-party reports). Third-party reports commonly include appraisals, Property Condition Assessment (PCA) reports, and environmental reports. Since lenders are not experts in evaluating engineering data (e.g., EE), they typically rely on PCA reports in order to acquire engineering information about the specific project.

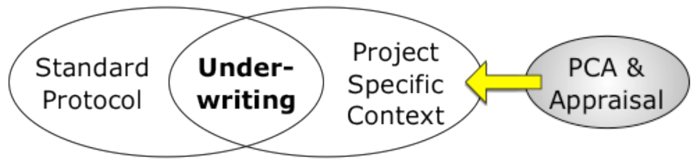


Figure 4-4: Standard Protocol vs. Project Specific Context

Lenders mainly focus on assessing risks. They extensively evaluate risks and the key metric used in commercial loan underwriting is NOI of the property. NOI is calculated as gross revenue minus operating expenses, which includes energy costs. With NOI as the key metric, the underwriting mostly involves evaluating two key ratios: debt service coverage ratio (DSCR) and loan to value ratio (LTVR) (Muldavin 2010). These ratios are important in assessing risks of a deal, because borrowers are assumed to be increasingly likely to default on their mortgage payments as the DSCR and LTVR approach 1.

- The probability of default indicated by DSCR:

$$DSCR = \frac{Net\ Operating\ Income\ [\$/year]}{Loan\ Payment\ [\$/year]} \qquad \text{Equation 4-1}$$

- The severity of losses in the event of default indicated by LTVR:

$$LTVR\ [\%] = \frac{Loan\ Balance\ [\$]}{Appraised\ Value\ of\ Property\ [\$]} \qquad \text{Equation 4-2}$$

The DSCR is especially important in underwriting EE investments, because the net savings (the buffer in Figure 4-5) of such investments are realized by the difference between NOI increase and loan payments. The buffer absorbs variations (uncertainty), and drives the risk perception for underwriters to make loan decisions. In case the target NOI increase is underachieved, the buffer acts to absorb its impact so the borrower can continue to make loan payments. If the NOI increase is a smaller than loan payment (i.e., using up the buffer), it makes increasingly difficult for the borrower to make loan payments).

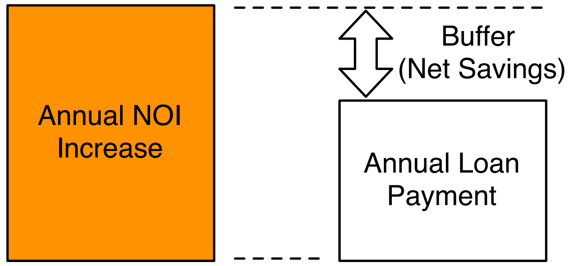


Figure 4-5: Net Savings as Financial Buffer

Banks have risk rating systems that use both DSCR and LTVR. The risk rating is one of the most important indicators that underwriters have to determine, and it is shown on the front page of the proposal presented to the credit committee that makes a final decision on the loan application.

Table 4-2 shows how one lender I interviewed decides interest rates and cap rates based on different risk ratings. Using a rating system with a scale of 1 to 7, "3" represents strong and attractive deals while "4" represents acceptable deals.

Table 4-2: Effects of Risk Ratings on Interest Rates and Cap Rates

Risk Rating	LTVR of Deal	DSCR of Deal	Interest Rate Offered	Cap Rate Applied
3 (strong)	30%	1.8 to 3	5.75%	6%
4 (acceptable)	60%	1.25 to 1.5	6.25 to 6.5%	8.5%

Nonetheless, the investigation indicates that even with quantifiable LTVR and DSCR, a subjective evaluation is still required from the underwriter to decide the risk rating of the target property. It requires an underwriter's "judgment call" to decide the risk rating.

Collier et al. (2008) pointed out that judgment calls are usually driven by the thoroughness (quality) of a loan application and whether it conforms to the lender's protocol. A well thought out and well-documented business case has a better chance to get approved. Every lender has slightly different formats for loan applications. Thoroughly prepared applications that follow the targeted lender's protocol can influence underwriters to approve a deal; i.e., if the application does not follow their protocol, a lender sees greater uncertainty associated with the project and is more inclined to decline the loan (Collier et al. 2008). Therefore, the quality of loan applications makes a significant impact on the fundability of energy retrofits.

4.2.3 Current Commercial Loan Underwriting Process

The interviews and literature reviews agree that current underwriting practices in energy investments show a low level of understanding shared between borrowers and lenders. This gap in shared understanding of projects and features of systems appears to lead to lenders perceiving risks to be relatively high (Muldavin 2010; NEEA 2010). That can eventually result in offerings of undesirable loan terms (i.e., a higher cost of borrowing—

higher interests and/or higher cap rates—and increased contingency funding) or rejected applications (Figure 4-6).

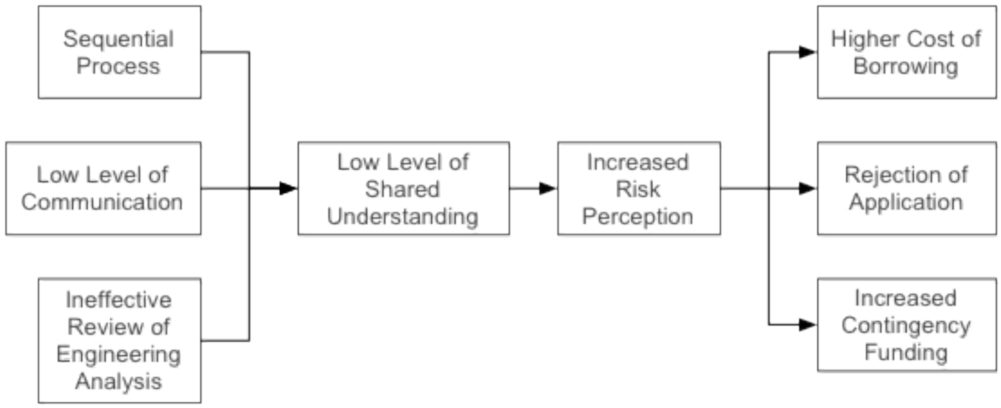


Figure 4-6: Causes and Effects of Low Level of Shared Understanding

Based on the interviews with four banks (ranging from small to large/nationwide banks), Figure 4-7 depicts the current loan underwriting process. It starts with the submission of the complete loan package that includes complete design, engineering, and bid pricing from a contractor. The first step is to determine the financial viability of the project by validating key assumptions of the business case. The underwriter performs a preliminary validation to see that a completed project will indeed enhance NOI, DSCR and, presumably, value of the property.

During the validation process, the engineering consultant[1] reviews the submitted engineering designs and construction budget. The plan review involves determining if the budget and schedule are reasonable, design quality, and most importantly, the risk of cost overruns during construction. Based on these findings, the reviewer makes a recommendation, which plays an important role in the lender deciding whether to approve a loan.

At the same time, the loan officer obtains credit reports to check if the owner has maintained a healthy credit record both on the business and on the personal side. The general contractor also likely needs to be vetted and approved by the lender in the process.

Once the package is deemed viable, an appraisal is ordered. Commercial appraisals are expensive and they are not worthwhile doing if the most basic requirements for a loan are not satisfied in the initial check. An appraiser valuates the financial state of the property with regards to the market conditions. This assessment provides the most significant financial data used by the underwriter in the loan valuation and underwriting process. The

[1] It appears that some lenders have in-house engineers for plan review and inspection during construction, but most lenders contract with third party inspection companies for this engineering service. Either way, the owner is required to pay for it.

assessed value of the development forms the foundation for determining the capital that the bank will lend for construction. The assessment data includes (Collier et al. 2008):

- Current value of the property
- Prospective market value 'upon completion'[2]
- Current rental and occupancy rates
- Market rent rates and market conditions
- Expiration info about the current rental agreements
- Whether the retrofit will improve the property's marketability and bring additional rent

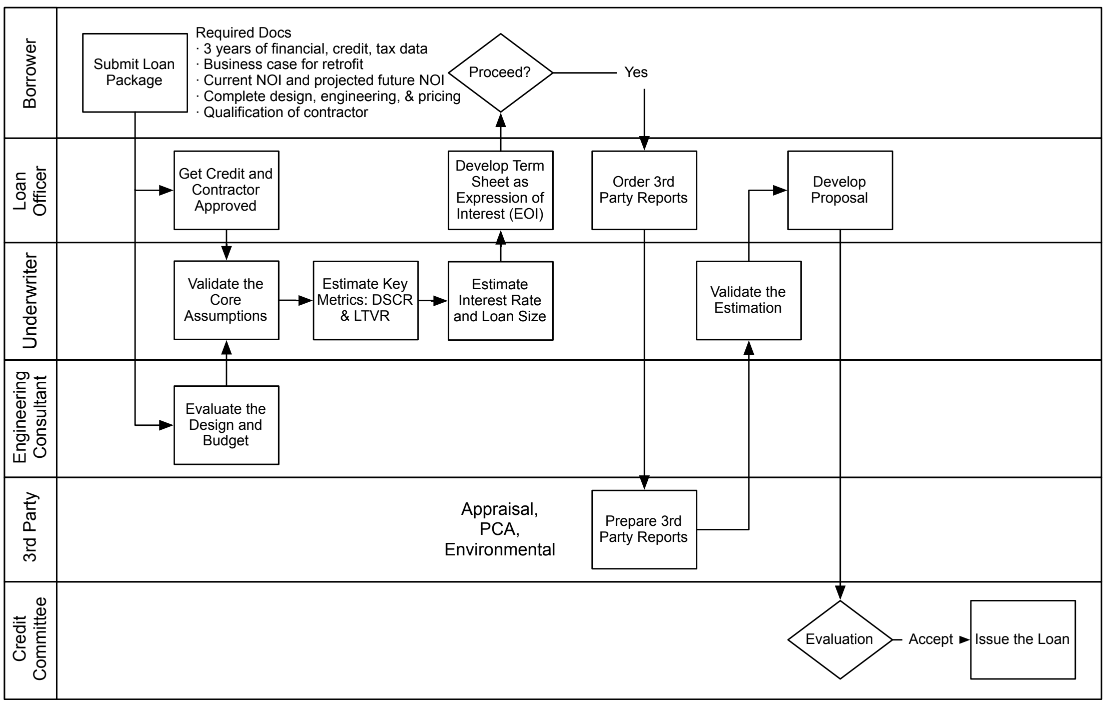


Figure 4-7: Current Retrofit Loan Underwriting

In conclusion, the investigation reveals that the current loan underwriting process and project development process are not integrated well. The current sequential process appears to slow learning between lenders and borrowers. For example, borrowers are often not familiar with lenders' standard protocols, such as loan evaluation and risk criteria. Likewise, lenders often do not pay enough attention to the project's specific context.

In the case of energy retrofits, this gap can be detrimental. Typically, engineering knowledge is required to gauge the benefits and risks of energy efficiency improvements. Therefore, reviewing project-specific energy measures can be challenging for

[2] Prospective market value 'upon completion' refers to an appraisal of proposed new construction that is to be completed at a later date. The value estimated is the current value of the completed improvements. Thus, the appraisal is made subject to the completion of the improvements as described in a loan package.

underwriters, and accordingly they heavily depend on third-party reports (appraisals and PCAs). However, interviews indicated that given current practices, neither appraisals nor PCAs adequately assess the values of EE improvement projects.

In addition, unfamiliarity with energy projects is worsened by frequent handovers among decision makers. It was learned that within large lenders, different departments have little to no coordination in sharing relevant engineering information about the property. Too often, third-party reports are not reviewed, which leaves underwriters no other evaluation criteria other than credit worthiness (e.g., reputation and track record) of the borrower. Underwriters also have to rely more on collateral and guarantors for shifting risks to the borrower.

4.2.3.1 Contingency Funding

Contingency funding is defined as "an amount added to an estimate to allow for items, conditions, or events for which the state, occurrence, or effect is uncertain and that experience shows will likely result, in aggregate, in additional costs" (AACE International 2007). In particular, contingency in construction loans is a reserve to pay for changes triggered by any risks in the design, cost estimate, bid environment, and labor and material prices fluctuating with the open market during construction.

It is viewed that contingency funding represents the level of cost risks that lenders see in a deal. Most lenders require an additional 5% to 10% contingency of the project cost be added to the loan amount. One lender interviewed indicated that they would put an arbitrary 7% contingency on a loan application they feel comfortable with. However, if they see more risks than ordinary (e.g., unproven track record of borrowers or contractors, unclear presentation of business cases, new and unproven technology for energy saving, etc.), they would allocate more contingency—over 10%.

Borrowers are often the ones that ask for contingency funding in order to mitigate default risks. In the event of cost overruns, the borrower can benefit from the contingency funding. Since the contingency is allocated in an escrow account, if the contingency is not used, then it will not be added to the term loan upon completion of the improvement. In the case that the cost overruns are not accounted for in the contingency fund, the lender can withhold further funding until the borrower gets the process back on schedule through any necessary recovery actions.

4.3 ENERGY EFFICIENCY BENCHMARKING

Many of the interviewees stated that lenders would likely be more interested in EE benchmarking over time, because EE in buildings can affect the borrowers' ability to pay loan payments, and accordingly, default rates. Therefore, lenders can ask for the benchmarking data during loan applications to evaluate how the target property performs or will perform compared to other similar buildings in the market.

There are several benchmark data sources available, including the Commercial Building Energy Consumption Survey (CBECS) and the California Commercial End Use Survey (CEUS). ENERGY STAR's Portfolio Manager is a commonly used tool for EE benchmarking, based on CBECS. Portfolio Manager applies regression analysis, with normalization for building size, weather, operation schedules, and many other specific characteristics (e.g., number of computers). Part of Portfolio Manger is Target Finder. It allows users to identify energy performance ratings of building projects in comparison to existing buildings, so that users set energy performance targets to achieving ENERGY STAR certifications (ENERGY STAR 2011).

When investing in energy retrofits, EE benchmarking can include a number of metrics, such as energy intensity by area (kWh/ft^2), for primarily assessing the existing performance and for setting post-improvement target performance goals. While EE benchmarking can be resource for stakeholders to identify potential efficiency opportunities in energy retrofits, it must be used with caution. Benchmarking compares a building's performance to its peer group, but does not actually estimate the energy performance based on historical data of usages or energy simulations. However, if there are enough peer buildings with similar characteristics, benchmarking against them can still be resource for developing a business case for energy retrofits.

Interviewees agreed that PCAs would be a platform for EE benchmarking, because PCAs are the only form of third-party investigation to assess EE of the same equipment and building components. The following sections summarize the current practice in performing PCAs and their potential for EE benchmarking in energy retrofit investments:

4.3.1 Property Condition Assessment (PCA)

Figure 4-8 shows the standard PCA process that the building industry currently accepts.

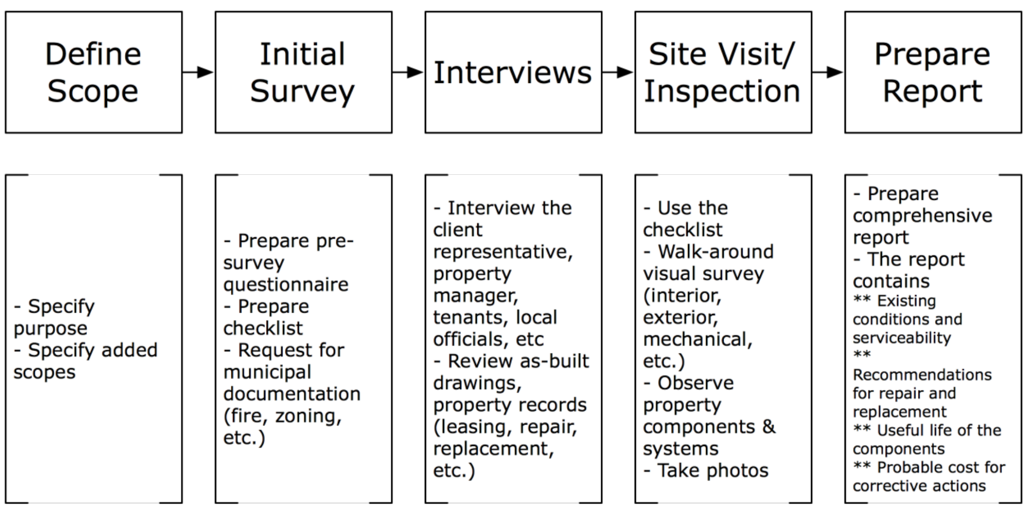


Figure 4-8: Standard PCA Process (Adapted from Kubba 2007; S&P 1995)

A qualified inspector performs PCA and the inspector investigates the current state of building systems to determine the following (Tobias 2010):

- Existing conditions and serviceability of the property
- Recommendations for repair and replacement
- Useful life of the building components

- Probable cost of corrective actions

4.3.2 Current Practices

Three current major types of PCAs are identified from the interviews (Table 4-3). Scopes and details of a PCA vary widely based on its purpose and who commissions the study. Most PCAs are developed based on minimum standards outlined by ASTM E2018 – 08, *Standard Guide for Property Condition Assessments: Baseline Property Condition Assessment Process* (ASTM International 2011a).

Table 4-3: Types of PCAs

Types	Financing	Acquisition	Owner Review
Who commissions	Lender	Buyer (e.g. equity investor)	Owner
Level of detail	Least	Most	Most
Level of risk for the commissioner	Least	Most	Moderate
Purpose	Due diligence for transaction	Assessment for capital investment	Assessment for capital investment

Lenders involved in the security markets (e.g., selling loan products to Commercial Backed Mortgage Securities) require PCAs along with other third-party reports (appraisals and environmental reports) as part of their due-diligence practices for commercial transactions. However, PCAs are not ordered until the later stages of transactions, because those expenses are unrecoverable if the deal does not happen. In addition, in large banks, different lending departments appear to have little to no coordination sharing relevant engineering information of the property, which often leads to inadequate PCA reviews. If a lender looks to securitize the deal to the security market, they only hold it on their books for a short period of time, meaning they have no real motivation to thoroughly review PCAs. It is because the risk with a few of low-quality loans will be diluted with a large number of other good-quality loans.

PCAs are also useful for lenders to figure how much reserve needs to be allocated for deficiencies of the property of the loan period (usually ten or fifteen years for commercial real estate loans). However, if the borrower is acquiring the property, he or she will want to minimize the reserve while demanding a detailed investigation of the property for investment purposes. Interviews revealed that this conflict-of-views between lenders and borrowers often results in two different versions of PCAs. In other words, the borrower sometimes has their own report (more detailed) that they do not necessarily share with the lender.

4.3.3 New ASTM BEPA Standard

The existing ASTM E2018 – 08 standard does not appear to speak to EE. As a result, EE is currently not part of regular PCA scopes, which are simply more focused on equipment replacement risks rather than its efficiency issues. Subsequently, current PCA practices capture neither the operation side of the property nor volatility issues.

In order to improve the current practice, ASTM has been developing standards for assessing building energy performance. A new ASTM standard has just been published in January 2011: ASTM E2797 – 11 *Standard Practice for Building Energy Performance Assessment for a Building Involved in a Real Estate Transaction* (BEPA) (ASTM International 2011b). Interviewees seem to agree that this new ASTM BEPA standard would be a good supplement to the existing standard for capturing energy efficiency of the property. It guides how to collect, disclose, and report building energy use information for transactional purpose. It involves benchmarking the property to other buildings through its data collection practice.

However, the interviewees indicated that the ASTM BEPA standard appears have a labor-intensive data collection requirement. In addition, one interviewee questioned its impact on the whole industry, because the adoption of the new standard will depend on whether the regulation would be required by state and federal legislations. Therefore, how the measurement through the ASTM BEPA standard will be applied and evaluated remains unresolved. Nevertheless, the interviewees still agreed that in the near future, PCAs would address EE benchmarking through the ASTM BEPA standard, because PCAs are the only third-party investigation to assess the building's physical components with regards to EE.

It is still recommended to use the new ASTM E2797 – 11 for benchmarking property to other buildings. Such benchmarking can be beneficial for identifying potential savings in an attempt to improve the financial performance of a property. Combined with the ASTM standard, PCAs can provide a guideline that helps project stakeholders narrow their focus areas in order to analyze risks and opportunities of alternative energy investments.

4.3.4 Property Condition Assessment as Risk Assessment Tool

From the perspective of lenders, PCAs can also be a risk assessment tool for real estate investments by providing estimates of the cost per year for maintaining the asset over the loan period. PCAs help lenders calculate the necessary reserve with an inflation factor (commonly 3%). Also, lenders will use PCAs to obtain information on immediate repairs and life safety issues.

Compared to other expensive special inspections, PCAs provide the client with relatively cost-effective risk assessments. Therefore, PCAs help stakeholders determine which building components appear to be in satisfactory condition. By doing so, stakeholders can focus on the areas that are more at risk and initiate an in-depth inspection of those items. Similarly, PCAs can be an effective risk assessment tool in early decision-making processes of energy retrofits, for analyzing risks and opportunities in terms of alternative investments.

PCA companies commonly offer investment-grade audits to those who are interested in making their properties green or energy efficient (mostly requested by equity investors or building owners). It often involves a 'gap analysis' that tells building owners what to target to get LEED certification, and establishes a guideline for further design studies and development.

CHAPTER 5. TARGET VALUE DESIGN PROTOCOL

As mentioned in Chapter 4, this investigation was initiated as part of the research, funded by DOE. A group of multidisciplinary researchers—including the Haas School of Business, and Lawrence Berkeley National Lab (LBNL)—studied how to identify, analyze, and manage risks in commercial loans given for EE investments. Loan underwriters' analyses of the risks of EE investments are found to lack depth, which causes developers to encounter financial barriers when applying for such loans. In order to remedy this situation, on September 2011, researchers compiled a series of technical reports for DOE that included a TVD protocol with eight key steps that borrowers and lenders can follow to achieve more effective underwriting in EE investments. The protocol redefines for key decisions the parties that are involved, when certain steps are taken, and how such decisions are made. The goal of the protocol is to increase shared understanding between parties involved on an EE improvement project and achieve aggressive energy savings, while reducing risks and uncertainties in such investments.

5.1 NEED FOR A PROTOCOL

5.1.1 Problem Statement and Suggestions

As discussed in Chapter 4, risks and uncertainty that can be eliminated or reduced by an integrated approach are not properly managed with current practices. A lack of 'shared understanding' contributes to this mismanagement. A number of previous studies argued that enhanced coordination between borrowers and lenders in the underwriting process is crucial for preventing such deficiencies to increase the fundability of EE investments (e.g., Muldavin 2010; NEEA 2010; ULI 2010).

The purpose of Chapter 5 is to adapt the existing TVD methodology to the specific conditions and requirements of the energy retrofit process so that it can allow the required integration of project development process and loan underwriting process. Based on the findings from the existing TVD projects, I expect that the efforts can help reduce the cost of borrowing and the difficulty of financing, while enhancing shared understanding between lenders and borrowers. It is suggested that lenders recommend and reward the use of the TVD protocol so they can better measure, manage, and mitigate specific types of uncertainty—reducing energy-related financial risks.

5.1.2 Expected Benefits

Interviews indicated that commercial (large) lenders have maintained an overly conservative view on EE investments in the commercial building sector, thus have not been active in this fast emerging market. The market growth for energy retrofits in the commercial sector is estimated to be as high as many billions of dollars annually over the next decade.

The interviews tell that the lending market is so competitive that lenders are under pressure from borrowers to lower fees and costs of capital. Therefore, efforts to lower borrowers' cost of capital and increase the capital available for lending can result in increasing their market competitiveness, especially in the fast-growing commercial energy retrofit market.

From the borrowers' perspective, an alternative investment strategy for energy retrofits is to reduce energy-related risks in an attempt to improve their loan contracting terms. Borrowers can use the TVD protocol to reduce LTVR by better managing construction costs and uncertainty than with conventional practices. Meanwhile, from the lenders' perspective, using TVD can effectively reduce defaults rates so more loan applications can be accommodated. Therefore, this study argues that an application of the TVD protocol is beneficial for both lenders and borrowers.

5.2 TARGET VALUE DESIGN PROTOCOL

Chapter 5 describes a TVD protocol that adapts the TVD methodology used in new construction to the specific conditions and requirements of energy retrofit projects. It can thereby facilitate the integration of the project development and loan underwriting processes. The findings from 16 previous projects (see Appendix A) suggest that the application of TVD can help achieve the following advantages in the underwriting process:

- Reduce the cost of borrowing and the difficulty of financing
- Increase shared understanding between lenders and borrowers

Acknowledging the expected benefits, lenders are advised to recommend and reward the use of the TVD protocol so they can better measure, manage, and mitigate uncertainties in the competitive commercial lending market.

The TVD protocol suggests allowing the borrower and the lender to start coordinating from the early stages of project development. Early feedback from the lender can be used to balance allowable investment with the energy retrofit business case. It can be beneficial for determining the allowable cost from the available loan size based on the lender's criteria. Setting the target building performance and the allowable cost will be further discussed in Chapter 6.

The TVD protocol also suggests bringing underwriters and appraisers to the discussion early. By doing so, they can be better informed and educated on benefits and risks of specific EEMs that are feasible in the project-specific context. To achieve the goal, the TVD protocol suggests an alignment of work processes of various stakeholders. The protocol redefines how, when, and who is involved on key decisions, to increase shared understanding and achieve aggressive energy savings.

The TVD protocol advocates the use of the new ASTM E2797 – 11 for benchmarking the property to other buildings. Such benchmarking can be beneficial for identifying potential savings as an attempt to improve the financial performance of the property. PCAs provide a guideline that helps the client narrow down their focus areas in order to analyze risks and opportunities of alternative EE investments.

To achieve effective applications of the TVD protocol, Chapter 5 presents a flowchart and guideline of the TVD protocol by laying out its eight key steps. Figure 5-1 illustrates how the TVD protocol adapts the existing methodology, and how the energy retrofit project development and loan underwriting process can intersect. This is an abridged version of the full guideline presented in Section 5.3.

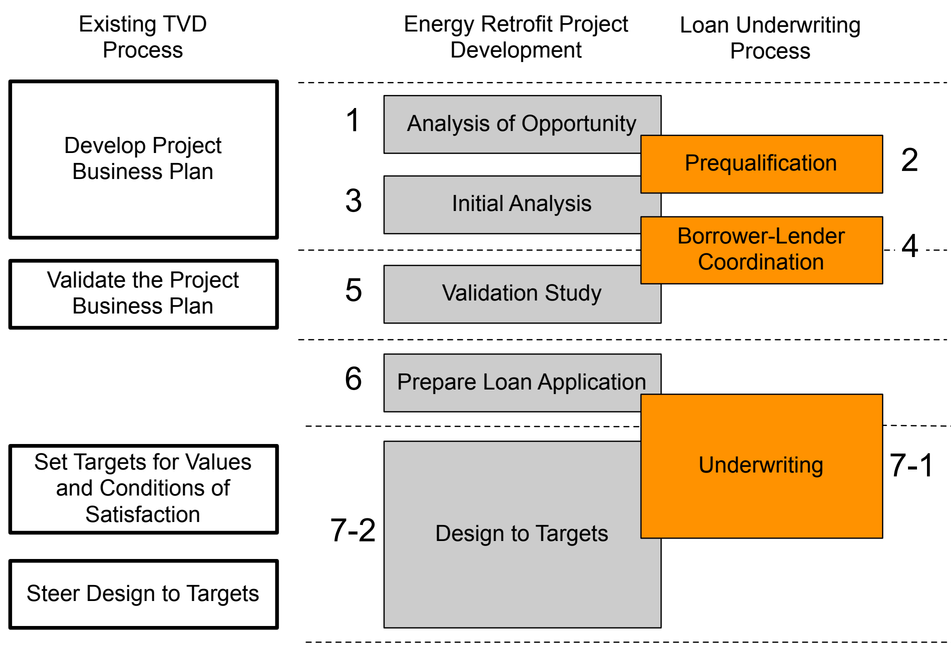


Figure 5-1: Key Steps of TVD Protocol

5.2.1 Target Value Design Protocol Steps

The TVD protocol involves aligning processes of stakeholders. Chapter 5 presents generic flowcharts and guidelines. Figure 5-2 illustrates the key steps of the protocol and participants involved during each step. Detailed flowcharts are presented in the following sections.

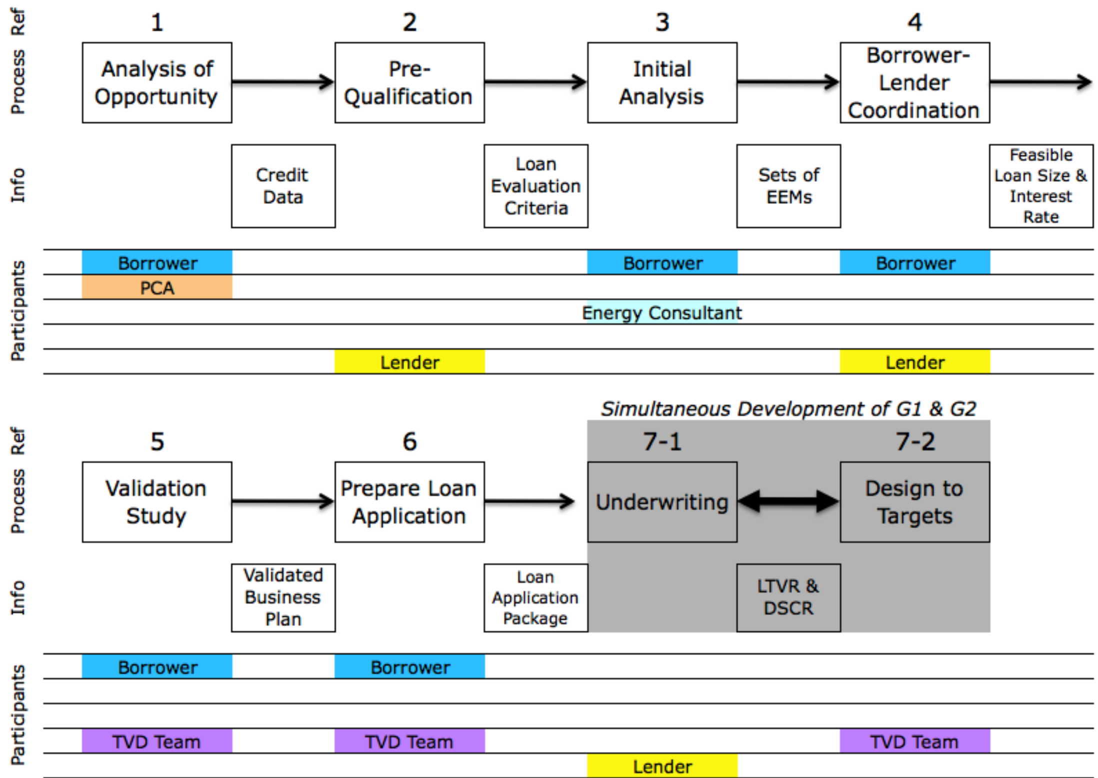


Figure 5-2: Inputs/Outputs/Participants of Key Steps

Table 5-1 summarizes the key steps in the TVD protocol, the responsible/cooperating parties in each key step, the key questions to ask during the process, and key input and output data. The full guideline is given in the following sections.

Table 5-1: Inputs and Outputs for Key Steps of TVD Protocol

Key Steps	Key Questions	Key Inputs	Key Outputs
Analysis of Opportunity	What are the opportunity and key risk factors?	• Demands for EE • PCA • Baseline estimates	• Project opportunity
Pre-Qualification	Is the borrower credit worthy for consideration?	• Credit data	• Credit approval • Loan evaluation criteria (incl. LTVR & DSCR)
Initial Analysis	What design alternatives are feasible?	• Investment criteria • Loan evaluation criteria	• Sets of EEMs • Risk factors
Borrower-Lender Coordination	What are the feasible loan size and interest rate?	• Sets of EEMs • Risk factors	• Feasible loan size and interest rate • Cost-effective EEMs
Validation Study	What will it cost?	• Cost-effective EEMs	• Validated business case • Basis of design/estimate
Prepare Loan Application	What are the loan application requirements?	• Validated business case	• Loan application package
Underwriting	Is this investment worth making?	• Loan application package	• LTVR and DSCR • Loan size and interest rate
Design to Targets	How best to steer design to targets?	• Target cost • Target energy saving	• Construction documents

5.2.1.1 Step 1: Analysis of opportunity

The TVD protocol suggests capturing the opportunity for energy retrofits, usually triggered by "compelling events" such as planned replacement of major components, acquisition, and refinance. Situational analysis can involve extensively using PCAs, earlier than with conventional methods, as an assessment tool for benchmarking the property to other buildings. Such benchmarking can be beneficial for identifying potential savings to improve the property's financial performance. PCAs can also provide a guideline that helps the borrower narrow their focus areas in order to cost-effectively analyze risks and opportunities of alternative EE investments.

5.2.1.2 Step 2: Prequalification

Prequalification allows the lender to be proactively involved in the project development process. This provides an opportunity (1) for the lender to offer their loan evaluation and risk criteria prior to design development, (2) for the borrower to develop the project according to the protocol, and (3) for the borrower to have a preliminary assurance of fundability by prequalifying the target property and his/her credit record.

5.2.1.3 Step 3: Initial analysis

Once prequalified, the borrower hires an energy consultant to conduct an investment-grade energy audit. The consultant develops EEMs by evaluating the borrower's investment criteria, such as payback period. The consultant also performs conceptual cost estimating and calculates conceptual energy savings, both of which are used in Step 4.

5.2.1.4 Step 4: Borrower-lender coordination

Borrower-lender coordination refers to a rapid analytical exercise that evaluates the cost impacts of alternative investments—represented by 'sets' of EEMs developed in Step 3. This practice is expected to produce estimates of the relative cost effectiveness of differing sets of EEMs while evaluating specific uncertainties of the target project. This early evaluation of energy retrofits' contributions to enhanced financial performance can give underwriters and appraisers useful information. This allows them to be more confident of their later loan decisions so they can make informed, situational decisions, with the business case developed by the lender's evaluation and risk criteria. This exercise is expected to enable a collaborative process between borrower and lender to help parties better manage the identified uncertainties and accordingly agree on better loan contracting terms. Chapter 7 presents a simulation model to support Step 4.

5.2.1.5 Step 5: Validation study

Validation study refers to a cross-disciplinary process for validating sets of EEMs, shortlisted during Step 4. It acts as an advanced feasibility test that delivers enhanced predictability of project performance. The cross-disciplinary TVD team is motivated to assess feasibility accurately, by having their fees in an 'at risk pool' and partially dependent on the project's success (through incentive/disincentive contracts). The study is an essential step for establishing shared understanding among the team members about design, budget, and schedule.

5.2.1.6 Step 6: Prepare loan application

Based on the lender's protocol obtained from Step 2, the borrower and TVD team together develop a loan application package to the level of detail that the lender requires by their standard protocol. Every lender has slightly different formats for loan applications, so applications thoroughly prepared using the targeted lender's protocol as a guide can influence the underwriter to approve the deal (i.e., increasing the fundability).

5.2.1.7 Step 7-1: Underwriting

Upon the submission of the loan application, the lender commences the regular underwriting process, with the due diligence required by the federal regulations. This step includes ordering third-party reports, including an appraisal, PCA, and environmental report. The TVD protocol suggests that the lender can perform effective underwriting by acknowledging (1) better-managed uncertainty from the validated business plan, and (2) increased shared understanding from the early coordination.

5.2.1.8 Step 7-2: Design to targets

Simultaneously with Step 7-1, the increased confidence about the fundability leads the borrower to set the target cost and target energy savings as the project goals and distribute the target cost across the building's system categories. Then the TVD team begins designing to targets, while allowing for target costs to be adjusted between categories, provided that the whole project can benefit from doing so. The process is achieved by doing (1) continuous scope control, (2) continuous scope refinement, and (3) proactive value engineering.

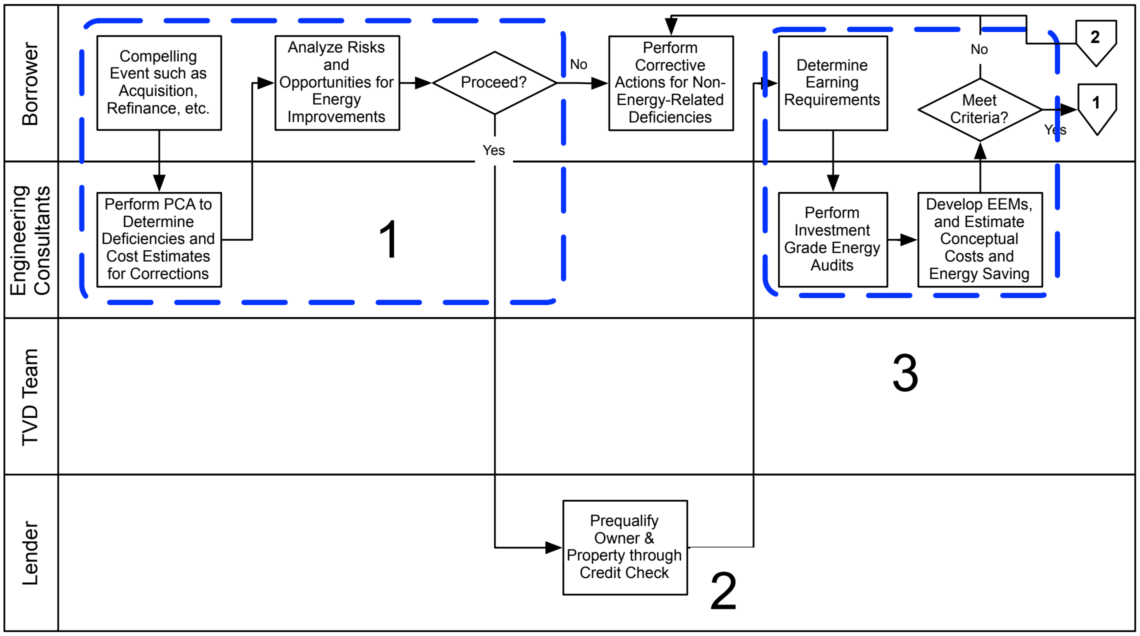
5.3 GUIDELINE AND FLOWCHARTS OF TARGET VALUE DESIGN PROTOCOL

Section 5.3 presents detailed flowcharts and guidelines by the key steps that were summarized in Section 5.2. Table 5-2 gives descriptions for the callouts used in the guidelines.

Table 5-2: Legend in Tables

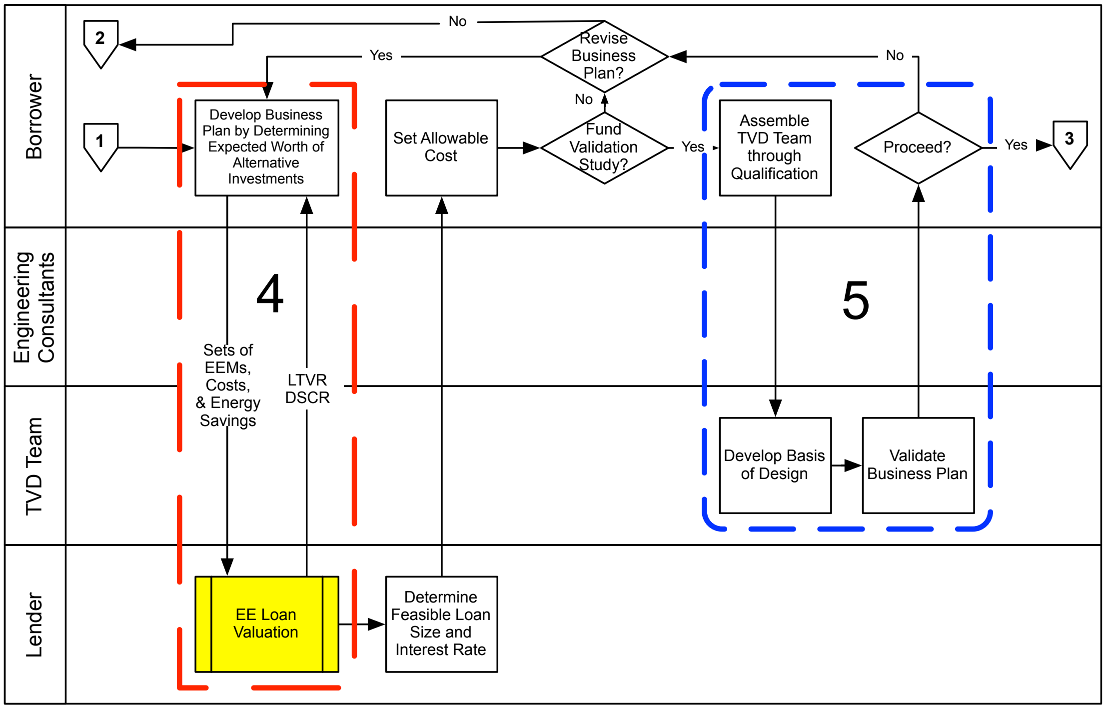
Callouts	Descriptions
R	Responsible party
C	Cooperating party
B	Borrower
L	Lender
E	Energy consultant
P	PCA company
T	TVD team

5.3.1 Steps 1, 2, and 3



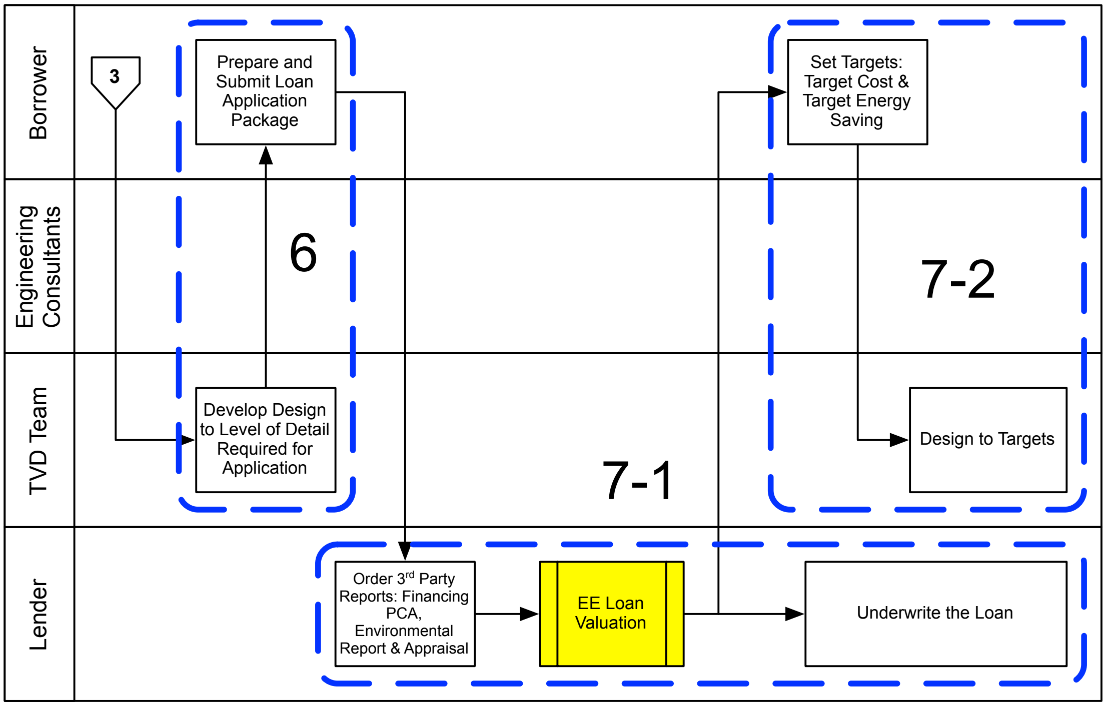
Ref	Key Steps	R	C	Activities	Inputs	Outputs
1	Analysis of Opportunity	B		Analyze compelling event	• Expected change in business	• Demand for capital improvement
		P	B	Perform PCA to determine deficiencies	• Compelling event	• PCA • Baseline cost estimates
		B		Analyze risks and opportunities	• PCA • Baseline cost estimates	• Cost benefit analysis
		B		Proceed?	• Cost benefit analysis	• Analysis of opportunity
2	Pre-Qualification	L	B	Prequalify the owner and the property through credit check	• Credit records	• Credit approval • Loan evaluation criteria • LTVR & DSCR
3	Initial Analysis	B		Determine earning requirements	• Owner's investment criteria • Lender's loan evaluation and risk criteria	• ROI • Payback period • Minimum NOI increase
		E	B	Perform investment grade energy audit	• PCA • Utility bills	• Achievable energy saving
		E		Develop EEMs and associated costs and energy savings	• Current-state building • Future-state building	• Feasible EEMs • Conceptual cost estimates of EEM • Estimated energy savings of EEM
		B		Meet criteria?	• Feasible EEMs • Conceptual cost estimates of each EEM • Estimated energy savings of each EEM	• Investment idea that meets the criteria

5.3.2 Steps 4 and 5



Ref	Key Steps	R	C	Activities	Inputs	Outputs
4	Borrower-Lender Coordination	B	L	Develop business plan by determining expected worth of alternative investments	• Feasible EEMs • Conceptual cost estimates of each EEM • Estimated energy savings of each EEM	• Business plan with sets of EEMs
		L	B	EE loan valuation	• Business plan with sets of EEMs	• LTVR • DSCR
			L	Determine feasible loan size and interest rate	• LTVR • DSCR	• Feasible loan size and interest rate
		B		Set allowable cost	• Warranted investment	• Allowable cost
		B		Fund validation study?	• Allowable cost	• Decision to do validation study
5	Validation Study	B	T	Assemble TVD team through qualification	• Qualification-based selection	• TVD team
		T	B	Develop basis of design	• Project business model	• Basis of design for validation
		T	B	Validate business plan	• Basis of design	• Expected cost
		B		Fund project?	• Assurance that expected cost ≤ allowable cost	• Decision to apply for a loan

5.3.3 Steps 6, 7-1, and 7-2



Ref	Key Steps	R	C	Activities	Inputs	Outputs
6	Prepare Loan Application	T		Develop design to level of detail required for application	• Validated business case	• Engineering design • Specification • Cost estimates
		B	T	Prepare and submit loan application package	• Financial data • Engineering design • Specification • Cost estimates	• Loan application package
7-1	Underwriting	L		Order 3rd party reports: PCA, appraisal, and environmental report	• Decision to order 3rd party reports	• PCA • Appraisal • Environmental report
		L		EE loan valuation	• Loan application package • 3rd party reports	• LTVR • DSCR
		L		Underwrite the loan	• Loan application package • 3rd party reports	• Loan size • The cost of capital
7-2	Design to Targets	B	T	Set targets	• LTVR • DSCR	• Target cost • Target energy saving
		T	B	Design to targets	• Target cost • Target energy saving	• Construction documents

5.4 FEEDBACK FROM BANKS

As an initial validation before a full-scale implementation of the TVD protocol, following the release of the technical report, I attempted to get feedback from three commercial banks ranging in size from small (local), medium (California-based), to large (top three nationwide). The senior vice presidents in charge of commercial real estate loan underwriting in each organization was selected for the survey. They were requested to review the full technical report of the TVD protocol. Table 5-3 presents their responses to three simple statements based on a five-point Likert scale, followed by their key comments.

Table 5-3. Survey Results Showing How Banks Accept the TVD Protocol

Statements	Small Bank	Medium Bank	Large Bank
The argument is sound.	Agree	Agree	Agree
The lending industry can benefit from the TVD protocol.	Agree	Agree	Strongly Agree
My organization can benefit from the TVD protocol.	Neutral	Neutral	Agree

5.4.1 Small Bank

"Portions about the bank being more involved in the energy efficiency evaluation is quite good…A discussion of specific EE upgrades, and average costs and paybacks might make an useful real world example."

5.4.2 Medium Bank

"I certainly agree with your conclusions about current state underwriting and the issues you raise around that. Your proposal seems compelling and is certainly interesting…If what you say is proven this could be a good business opportunity to pursue for our bank and others as well."

5.4.3 Large Bank

"The study needs to be focused on specifics. It only has 'part' of answers, but it still did a good job laying out a lot of procedural relationships and it is very detailed…The industry can certainly benefit from a better risk control, identifying and mitigating, and we are already doing some of the features discussed in the protocol."

CHAPTER 6. SETTING TARGET BUILDING PERFORMANCE AND ALLOWABLE COST TO SUPPORT TARGET VALUE DESIGN

Current practices in commercial loan underwriting do not appear capable of evaluating energy-related risks inherent in EE investments and consequently may not help overcome financial barriers. In response, Chapter 5 presented the TVD protocol to improve the current underwriting practices. This chapter focuses on Step 4 of the protocol, namely borrower-lender coordination, which is a key part of successfully applying the TVD process. In Step 4, the borrower and lender are encouraged to collaborate early on, in order to determine the loan size and loan terms, while evaluating various types of uncertainty in a specific EE investment.

To support Step 4, Chapter 6 introduces a simulation model, Energy Retrofit Loan Analysis Model (ERLAM), based on Life Cycle Cost Analysis (LCCA) and Monte Carlo Simulation (MCS). ERLAM uses findings from the DOE research in determining its input variables and parameters.

To test ERLAM, this chapter uses data from a case study of an energy retrofit project in a Northern California office building that was funded by a construction loan and completed in 2011. At completion, the building owner settled on a 15-year loan with a local commercial lender to 'take out' the construction loan.

ERLAM uses two reducible uncertainties associated with the case project: (1) the project cost uncertainty and (2) the operational practice uncertainty. Then, to support Step 4, ERLAM quantifies their impacts on the financial performance of the given 15-year loan, and then determines:

1. The target building performance of the building; and
2. The allowable cost of the project based on the target.

6.1 STEP 4: BORROWER-LENDER COORDINATION

The TVD protocol suggests having the borrower and the lender to start collaborating during the early stages of a project, before design development, to increase their joint understanding about feasible loan sizes and loan terms. To achieve this, Step 4 includes an analytical exercise to evaluate the financial impacts of alternative investments while considering their risk factors and specific uncertainties.

Early collaboration allows underwriters and appraisers to develop confidence needed to determine the terms of their loans. Loan terms are generated based on project-specific contextual factors, with a business case developed using the lender's risk criteria. Borrowers can then use the early feedback from lenders to determine their allowable cost based on the available loan size. This is a key step of the TVD process for energy retrofits.

EE investments are subject to various uncertainties that must be considered during the analytical exercise of Step 4. Energy-related uncertainties fall into two categories: (1) reducible uncertainties and (2) irreducible uncertainties. Both of the categories can be simulated to determine their impacts on the financial performance of the investments using a stochastic model.

Typically in project development, buffers can be allocated in the process of designing and estimating to absorb the impacts of the uncertainties (Table 6-1). Failure to manage the uncertainties can result in a greater contingency used by estimators, and/or greater than necessary safety factors used in design. This contributes to financial barriers by producing overly conservative designs and estimates when applying for a construction loan.

Table 6-1: Types of Uncertainty vs Buffer in EE Investments

Uncertainty	Buffer
Reducible Uncertainty	
Project cost	Cost contingency in construction cost estimate
System performance	Safety factor in design
Operational practice	Safety factor in design (commonly ignored)
Irreducible Uncertainty	
Weather	Safety factor in design (commonly ignored)
Energy price	No buffer assumed in design or construction cost estimate
Vacancy rate	No buffer assumed in design or construction cost estimate

6.2 DESCRIPTION OF ENERGY RETROFIT LOAN ANALYSIS MODEL (ERLAM)

ERLAM uses two types of reducible uncertainties as input variables: (1) the project cost uncertainty and (2) the operational practice uncertainty (Figure 6-1). For simplicity, the two variables are assumed to be independent of each other.

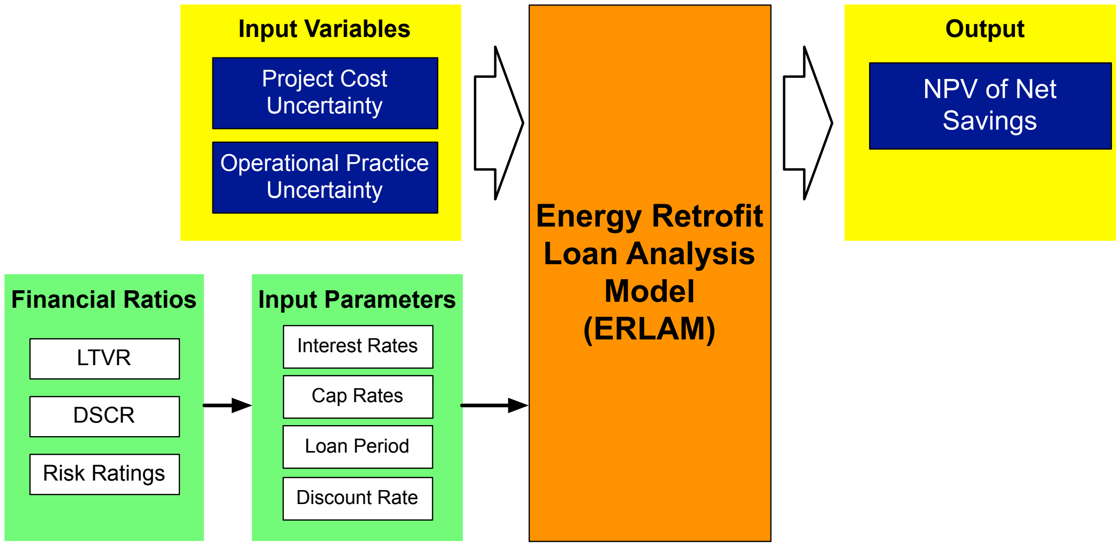


Figure 6-1: Outline of ERLAM[1]

Input parameters for ERLAM include interest rates, cap rates, a loan period, and a discount rate. For the case project, ERLAM uses the loan period of 15 years that is typical for commercial loans, and assumes the discount rate of 5% for its NPV calculations. Risk ratings that involve evaluating LTVR and DSCR determine interest rates and cap rates.

I determined to run ERLAM a large number of times in order for its simulation results to have statistically meaningful confidence intervals. Learning from a few trials that 5,000 runs would produce narrow confidence intervals for the simulation, I decided to have ERLAM set to run 5,000 samples.

The output of ERLAM is the NPV of realized net savings from the investment, and its sensitivity to the input variables. The net savings represent the impact of the two uncertainties on the building owner's ability to make loan payments, and accordingly determine the viability of the investment. In other words, when the NOI increase falls short of what is expected, the net savings must absorb its impact so the borrower can continue to make loan payments.

6.3 CASE DATA OF AN ENERGY RETROFIT PROJECT

To illustrate and test the use of ERLAM, Chapter 6 uses an energy retrofit completed in 2011. The owner of a Northern California office building (the Owner, hereinafter) developed their business case, based on an energy audit they had performed in 2008. The audit recommended the following four potential EEMs:

[1] Appendix C presents algorithm flowcharts of ERLAM.

1. Improve lighting fixture efficiency
2. Install lighting controls
3. Upgrade rooftop HVAC units
4. Convert to central chilled water plant

Table 6-2 summarizes costs and benefits of these four EEMs. The audit did not consider measures to save on gas consumption, because their buildings use gas only for space heating from rooftop packaged units, and the existing space heating was already highly efficient.

Table 6-2: Recommended EEMs (Adapted from the 2008 Audit Report)

Energy Efficiency Measures	Energy Savings and Cost Savings			Implementation Costs				CO2 savings (tons of CO2 per year)
	Estimated Demand Savings (kW)	Esitmated Energy Saving (kWh)	Estimated Annual Utility Savings	Estimated Construction Costs	Estimated Potential Municipal Incentives	Estimated Net Costs after Incentives	Simple Payback Period (yrs)	
Improve lighting fixture efficiency	61.2	230,808	$32,775	$110,489	$11,540	$98,948	3.0	60.5
Install lighting controls	0.0	84505	$12,000	$36,176	$5,334	$30,842	2.6	22.1
Upgrade rooftop HVAC units	226.0	241,000	$34,235	$424,450	$2,320	$422,130	12.3	63.1
Convert to central chilled water plant	507.8	1,063,000	$151,005	$1,868,762	$68,000	$1,800,762	11.9	278.5

The measure 'upgrade rooftop HVAC units' refers to the full replacement of the rooftop packaged air-conditioning units with higher-efficiency units. It was eventually selected for implementation on a total of seven buildings.

The case study in this chapter uses data from one of the seven buildings, Building A, for the simulation. Table 6-3 summarizes Building A's features.

Table 6-3: Case Project Features of Building A

Building type	Commercial office and lab
Size	30,651 square feet
Initial project cost estimate	$160,330
Final project cost at completion	$239,502
Expected annual NOI increase	$29,402
Annual loan payment based on a 15-year loan at an interest rate of 6.5%	$25,032
Net saving (NOI increase minus loan payment)	$4,370

The expected annual NOI increase stems from utility and maintenance savings, expected after the upgrade of Building A. The net saving of $4,370 (NOI increase minus loan payments) is a buffer to absorb impacts of variation (uncertainty) especially when the NOI increase were to fall short of what is expected. It also drives the calculation of DSCR.

6.3.1 Project Cost Uncertainty

I assumed PERT-Beta as the probability density function (PDF) for the project cost uncertainty[2]. The range of the project cost uncertainty is set as shown in Table 6-4. I considered the initial project cost to be the mode. I set the high end of the range to be +50%, and the low end of the range to be -20% (I rationalize this selection of -20% based on the finding of an average 15% below-market benchmark cost from the 16 projects where TVD was applied (see Appendix A)). This range from -20% to +50% is wide enough to conduct a sensitivity analysis of the project cost uncertainty.

Table 6-4: Project Cost Uncertainty Modeled with PERT-Beta Probability Distribution

Min (20% cost underrun)	$128,264
Mode (initial cost estimate)	$160,330
Max (50% cost overrun)	$240,495

ERLAM uses a total of 8 scenarios (from -20% to +50%, in 10% increments) to conduct a sensitivity analysis of the project cost uncertainty on the NPV of the net savings. Each scenario has different loan sizes. They subsequently lead to different LTVRs and DSCRs, because the formula for LTVR contains the loan size in the numerator, whereas the formula for DSCR contains loan payments in the denominator.

6.3.2 Operational Practice Uncertainty

The operational practice uncertainty is based on findings from the DOE research. One of the objectives of the DOE research was to determine the ranges of the operational practice uncertainty of different individual operational measures. The DOE research developed a total of 13 operational measures based on three DOE commercial building benchmark models[3] (large, medium, small) for major cities in the US. Using the EnergyPlus[4] energy simulation software, the DOE research collaborators calculated the upper and lower boundaries of the operational practice uncertainty. Based on the characteristics of Building A, and results of the medium benchmark model (53,625 square feet) in the climate of Northern California, I selected 5 individual measures out of the 13 measures (Table 6-5).

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[2] PERT-Beta is a distribution used for probabilistic project cost estimating. It is a predefined function in software such as MATLAB, which I used to program ERLAM. Although some studies suggested alternatives to PERT-Beta to improve its accuracy (e.g., Perry and Greig 1975), this study employs the original PERT-Beta distribution for ERLAM.

[3] Refer to http://www1.eere.energy.gov/buildings/commercial_initiative/

[4] See http://apps1.eere.energy.gov/buildings/energyplus/

Table 6-5: Operational Practice Uncertainties of Selected Operation Measures (Adapted from the DOE Research)

Operational Practice Measures	**Good Practice vs Average Practice**	**Poor Practice vs Average Practice**
HVAC equipment operation schedule	-0.08%	0.23%
Night setback	-0.51%	0.04%
Room setpoints for occupied hour	-3.41%	7.51%
Lighting load control	-6.09%	9.08%
Supply air temperature reset	-0.18%	9.76%
Total	-10.27%	26.62%

Based on the simulation data in Table 6-5, I assumed that the operational practice uncertainty has the following range:

- 15% less consumption as 'good practice'
- 0% (no deviation from the intended energy saving) as 'average practice'
- 25% more consumption as 'poor practice'

'Good practice' represents an optimal performance of the building. For 'average practice' and 'poor practice,' the building has the capability to run at a 'good practice' level, but runs less efficiently due to poorer facility management.

Per the recommendation of building technology researchers working with me on the DOE research, I used lognormal as the PDF for the operational practice uncertainty. I considered 'good practice' to be the 5th percentile, 'average practice' to be the mean, and 'poor' practice to be the 95th percentile (Table 6-6). PERT-Beta might have been another choice to model this PDF, but I did not investigate this further.

Table 6-6: Operational Practice Uncertainty Modeled with Lognormal Probability Distribution

5^{th} percentile (good practice)	15% less consumption
Mean (average practice)	0% (intended energy consumption)
95^{th} percentile (poor practice)	25% more consumption

ERLAM uses a total of 9 scenarios (from -15% to +25%, in 5% increments) to conduct a sensitivity analysis of the operational practice uncertainty on the NPV of the net savings.

6.3.3 Interest Rates and Cap Rates

I was able to obtain one lender's risk ratings that govern their interest rates and cap rates. Based on the lender's rating system with a scale of 1 to 7, '3' represents a strong and attractive deal while '4' represents an acceptable deal (Table 6-7). To represent the impacts of risk ratings, I assumed the rating of '3.5' as input to ERLAM. Table 6-7 shows interest rates and cap rates in accordance with given risk ratings.

Table 6-7: Interest Rates and Cap Rates by Risk Ratings[5]

LTVR of Deal	DSCR of Deal	Risk Rating	Interest Rate Offered (15-year Loan)	Cap Rate Applied
30% to 40%	1.8 to 3	3 (strong)	5.5%	6%
40% to 50%	1.5 to 1.8	3.5	6.0%	7%
50% to 60%	1.25 to 1.5	4 (acceptable)	6.5%	8%

Table 6-8 tabulates LTVRs, DSCRs, interest rates, and cap rates based on the 8 scenarios of the project cost uncertainty and their risk ratings.

An example computation follows (for the scenario of Column -20%); the steps are:

1. Using the expected loan size = (1 – 20%) × \$160,330 = \$128,264, and the NOI increase from Table 6-3 of \$29,402
2. Assume a risk rating of 3 as the starting point for iteration and look up the corresponding values in Table 6-7 for the interest rate = 5.5% and cap rate = 6%
3. Compute the annual loan payment:
   - A = P (A/P, i, n) = \$128,264 × (A/P, 5.5%, 15 years) = \$128,264 × 0.09805 = \$12,576
4. Compute the appraised value of Building A:
   - Appraised value = NOI increase / cap rate = \$29,402 / 6% = \$490,033
5. Accordingly the LTVR = loan size / appraised value = \$128,264 / \$490,033 = 26.17%
6. And, the DSCR = NOI increase / annual loan payment = \$29,406 / \$12,576 = 2.34
7. Use Table 6-7 for the computed LTVR and the DSCR to look up the risk rating and the corresponding interest rate offered and the cap rate applied. Based on the LTVR of 26.17% and the DSCR of 2.34, the risk rating of '3' is selected, and the interest rate of 5.5% and the cap rate of 6%, which are assumed (step 2), are now confirmed.

One can perform the same computation for the other scenarios. If the computed LTVR (step 5) and the DSCR (step 6) lead to a different risk rating (step 7) than the one assumed (step 2), then look up the new risk rating in Table 6-7 and corresponding interest rate offered and the cap rate applied. One then repeats the computation to confirm the selected interest and cap rate.

[5] The lender's name may not be disclosed for confidentiality.

Table 6-8: Tabulation by Risk Ratings

Cost overrun/underrun	-20%	-10%	0%	10%	20%	30%	40%	50%
Loan size (project cost)	$128,264	$144,297	$160,330	$176,363	$192,396	$208,462	$224,462	$240,495
LTVR	26.17%	29.45%	32.72%	41.99%	45.81%	56.72%	61.07%	65.44%
DSCR	2.34	2.08	1.87	1.65	1.51	1.35	1.25	1.17
Interest rate offered	5.5%	5.5%	5.5%	6.0%	6.0%	6.5%	6.5%	6.5%
Cap rate applied	6.0%	6.0%	6.0%	7.0%	7.0%	8.0%	8.0%	8.0%
Risk ratings	**3**	**3**	**3**	**3.5**	**3.5**	**4**	**4**	**4**

Figure 6-2 plots the data shown in Table 6-8. Figure 6-2 shows that as the project cost increases, the lender will increase its cap rate and interest rate. This means that project cost overruns not only increase the required loan size, but also increase the cost of borrowing. Thus, the increased likelihood of project cost overruns will make the business case for the HVAC upgrade increasingly less attractive.

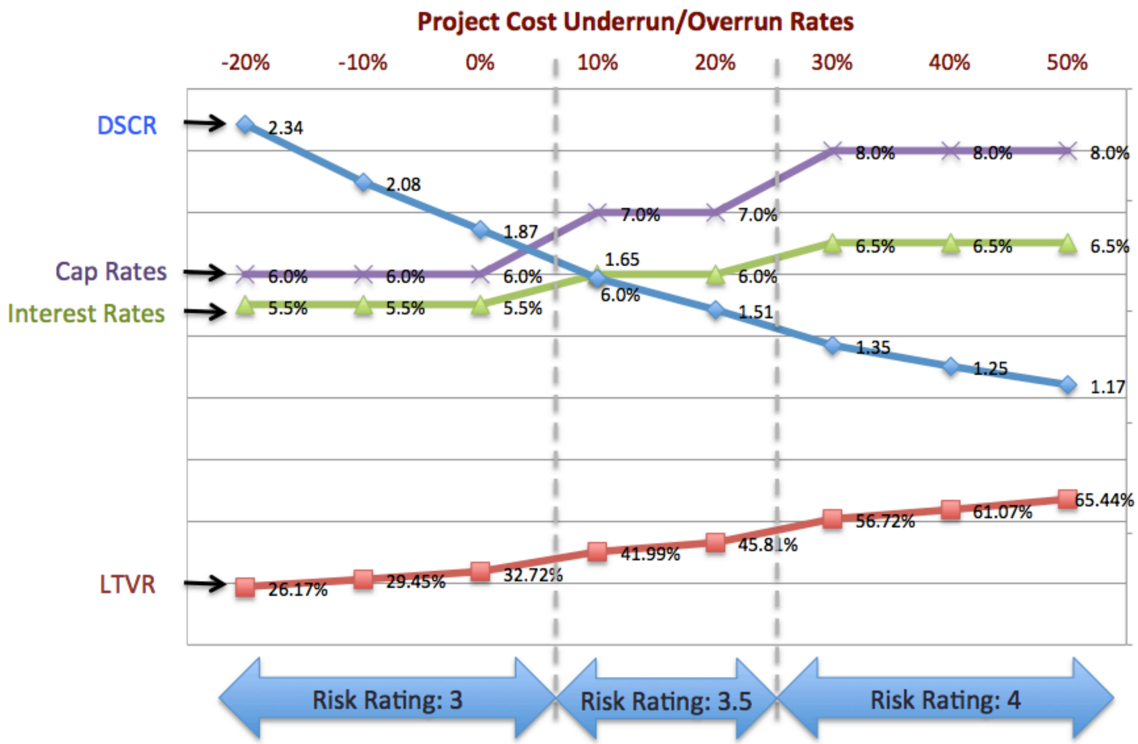


Figure 6-2: Trends of Key Financial Ratios

6.4 SIMULATION RESULTS

This section summarizes the simulation results from ERLAM in terms of sensitivity analysis of the two input variables to the output, i.e., the NPV of the net savings. It also demonstrates how the sensitivity analysis can be translated to determine the target building performance and the allowable cost in order to support Step 4 of the TVD protocol.

6.4.1 Sensitivity Analysis of Project Cost Uncertainty to Net Present Value (NPV) of Net Savings

Figure 6-3 presents the simulation result of 5,000 runs to analyze the sensitivity of the project cost variable on NPV. It shows that as the project cost increases, the NPV of the net savings decreases. At the same time, the loan default rate increases: smaller net savings make it increasingly difficult for the borrower to make loan payments. For example, a 20% cost underrun implies a 1.5% default rate. This 1.5% is the area under the PDF that represents the NPV of the net savings for the values smaller than $0 in Figure 6-3. Indeed, the loan default rate is defined as the likelihood that the Owner cannot make loan payments with realized energy savings (i.e., likelihood that NPV of net savings is negative). Likewise, a 50% cost overrun implies a significantly increased default rate of 23.7%.

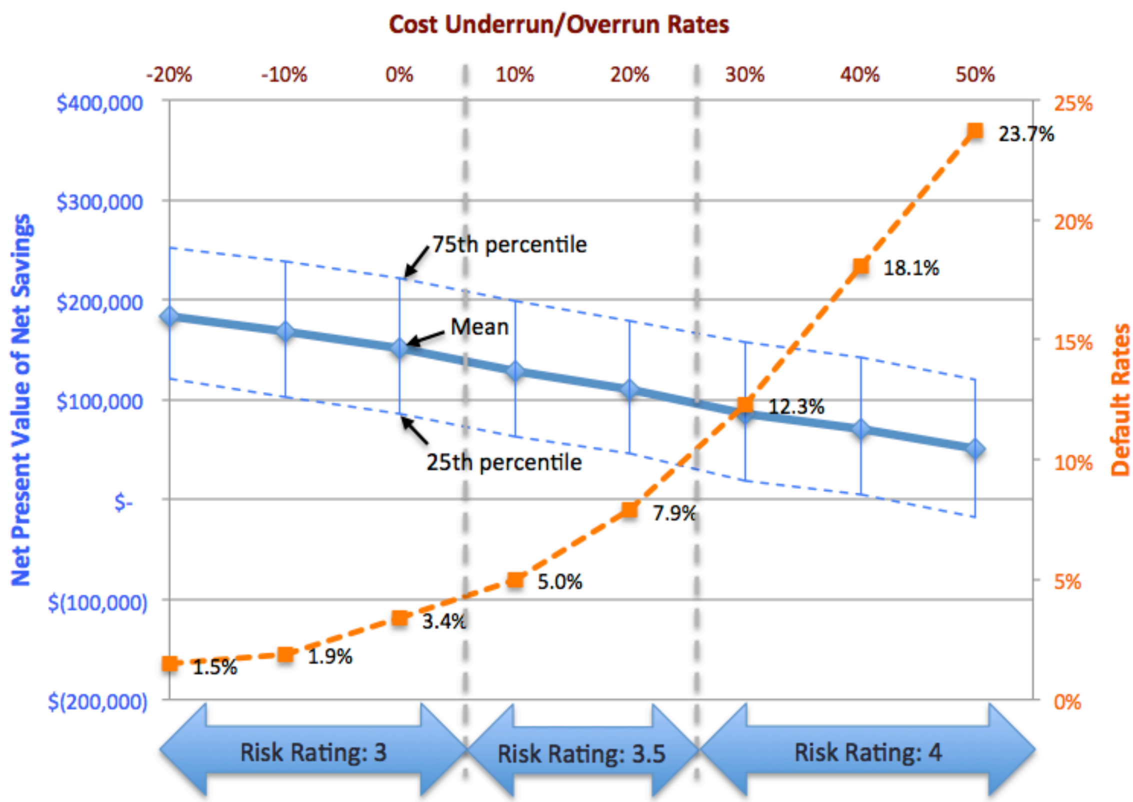


Figure 6-3: Sensitivity Analysis of Project Cost Uncertainty on NPV of Net Savings

6.4.2 Sensitivity Analysis of Operational Practice Uncertainty to Net Present Value of Net Savings

Figure 6-4 presents the simulation result of 5,000 runs to analyze the sensitivity of the operational practice on the NPV. It shows that the default rate can remain around 0% as long as Building A consumes less than 5% over the anticipated consumption. However, a default rate of around 100% occurs should Building A consume 15% or more of the anticipated consumption.

The sensitivity analysis of the operational practice uncertainty shows a significantly steeper decrease of the NPV and much narrower spread than the project cost uncertainty. Thus, from Figures 6-3 and 6-4, one can conclude that the NPV of the net savings is more sensitive to the operational practice uncertainty than to the project cost uncertainty.

In retrospect, it is logical that the operational practice uncertainty has more impact on the NPV. In a commercial office building, the operation and maintenance costs for the life of the building is estimated to be about five times greater than the design and construction costs (Evans et al. 1998). This finding emphasizes the importance of shifting the industry's focus from project cost management to building performance management.

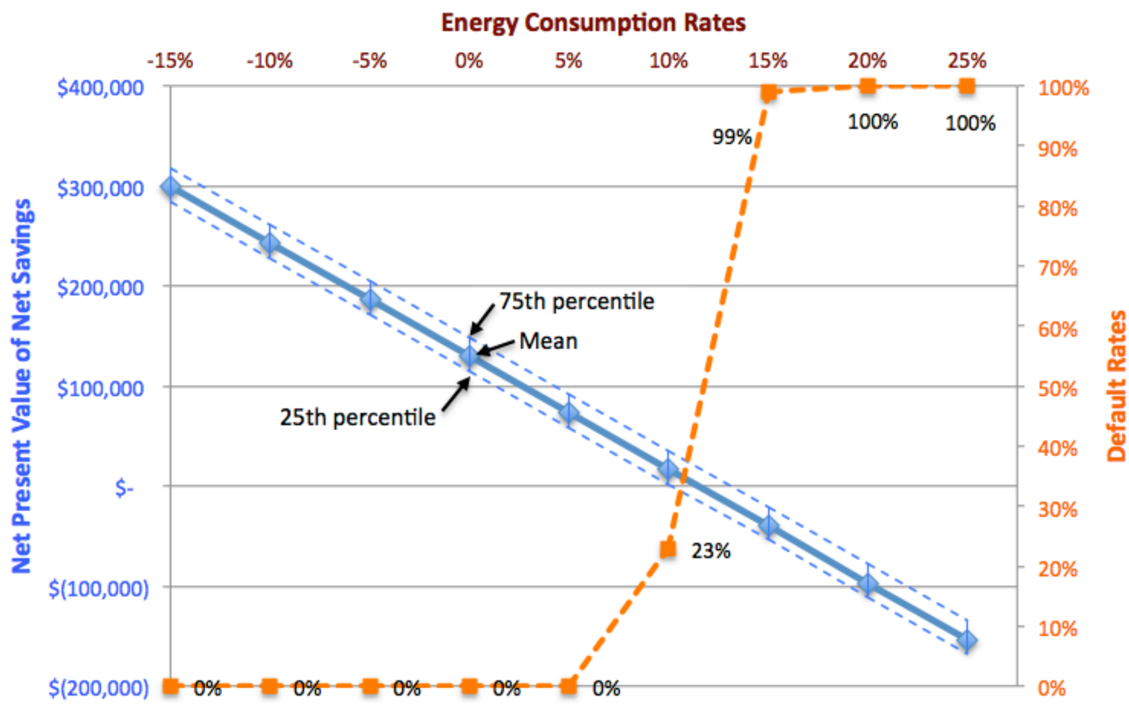


Figure 6-4: Sensitivity Analysis of Operational Practice Uncertainty on NPV of Net Savings

6.4.3 Determining the Target Building Performance

The findings from the sensitivity analysis lead to setting the target building performance. If one assumes that the borrower and lender want a low default risk[6], then the target building performance has to be set at 5% of the energy consumption rate (the abscissa of Figure 6-4), because the default rate there no longer is around 0% (as it was for energy consumption rate up to 5%), but begins to increase (± some variation that is not shown here). Given the parameters of the lognormal distribution I used to characterize the operational practice uncertainty, the 5% mark falls at the 75th percentile of the distribution (Figure 6-5).

[6] Different banks have different risk evaluation criteria in EE improvement loans.

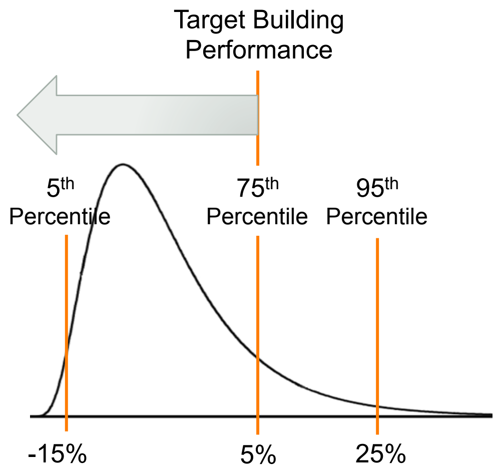


Figure 6-5: Target Building Performance Set at 5% on the Lognormal Distribution that Characterizes the Operational Practice Uncertainty

6.4.4 Determining the Allowable Cost

Setting the allowable cost involves translating the target building performance, as set in Figure 6-5, to NPV calculations. When the energy consumption rate in the operational practice uncertainty increases, the NPV of the net savings decreases.

Setting the target building performance at 5% in Figure 6-5 means that performance at the upper 25% is inacceptable. Accordingly, the lower 25^{th} percentile of the distribution of the NPV of the net savings (Figure 6-3) should be inacceptable as well. Therefore, the analysis sets the allowable cost boundary at that very 25^{th} percentile of the NPV calculations (see Figure 6-6, adapted from Figure 6-3).

If Building A performs better than the target building performance of 5%, the lender has the assurance that the Owner will have sufficient net savings to make loan payments (‘viability zone’ in Figure 6-6). That is true up to the point where the project cost reaches $225,000, where the allowable cost boundary line crosses the zero NPV line. So, the analysis concludes that the allowable cost should be set at $225,000.

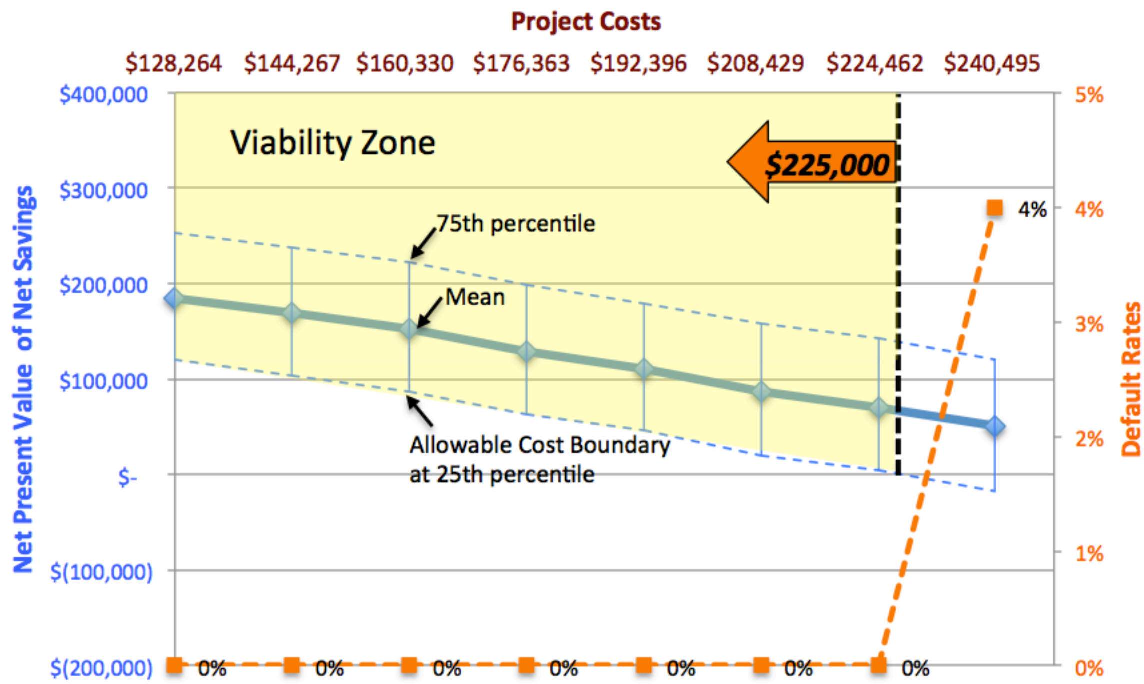


Figure 6-6: Setting the Allowable Cost based on the Target Building Performance

Returning to the fact of the case study on which I based this simulation, the Owner was granted a loan of $239,502 for its HVAC upgrade of Building A. Had the energy-related uncertainties been assumed and tested, and the findings from the DOE research applied, the results from ERLAM could be interpreted to challenge the viability of the original loan. To make the business case more viable, the project cost could also have been more carefully managed.

6.5 INTERNAL RATE OF RETURN (IRR) ANALYSIS

In addition to the NPV simulation to support Step 4 of the TVD protocol in Building A, this section presents the results of another application of ERLAM to analyze the IRR of the investment.

With 5,000 simulation runs, Table 6-9 and Figure 6-7 summarize a sensitivity analysis of the project cost uncertainty on the IRR for each of the 8 corresponding scenarios. As the project cost increases, both the mean and the standard deviation of the IRR decrease. The analysis shows that at -20%, the IRR can be estimated with 95% confidence to be between 21.8% and 22.2%. The 5,000 runs make the confidence intervals narrow as seen in Table 6-9.

Table 6-9: Summary of Sensitivity Analysis of Project Cost Uncertainty on IRR

Cost Underrun/ Overrun Rates	**-20%**	**-10%**	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**
IRR mean	22.0%	19.0%	16.4%	14.6%	12.9%	11.5%	10.0%	8.7%
IRR standard deviation	8.9%	8.2%	7.6%	7.2%	6.5%	6.3%	6.2%	6.0%
95% confidence interval	21.8% to 22.2%	18.8% to 19.2%	16.2% to 16.6%	14.4% to 14.8%	12.7% to 13.1%	11.3% to 11.7%	9.8% to 10.2%	8.5% to 8.9%
Likelihood of breakeven	94.9%	93.1%	90.0%	88.1%	85.2%	81.0%	75.6%	68.6%
Likelihood of achieving 30% MARR	18.0%	7.2%	1.7%	0.2%	0.0%	0.0%	0.0%	0.0%

Figure 6-7 plots the data in Table 6-9. As explained in Chapter 2, IRR is commonly measured against the minimum acceptable rate of return (MARR). MARR is the 'hurdle rate' at which the investment is considered viable for an organization. If the Owner sets their MARR at 30% (which is common in the commercial sector), the project is relatively unlikely to achieve the MARR. In this example, the project is unlikely to meet the MARR should the cost overrun be 10% or greater.

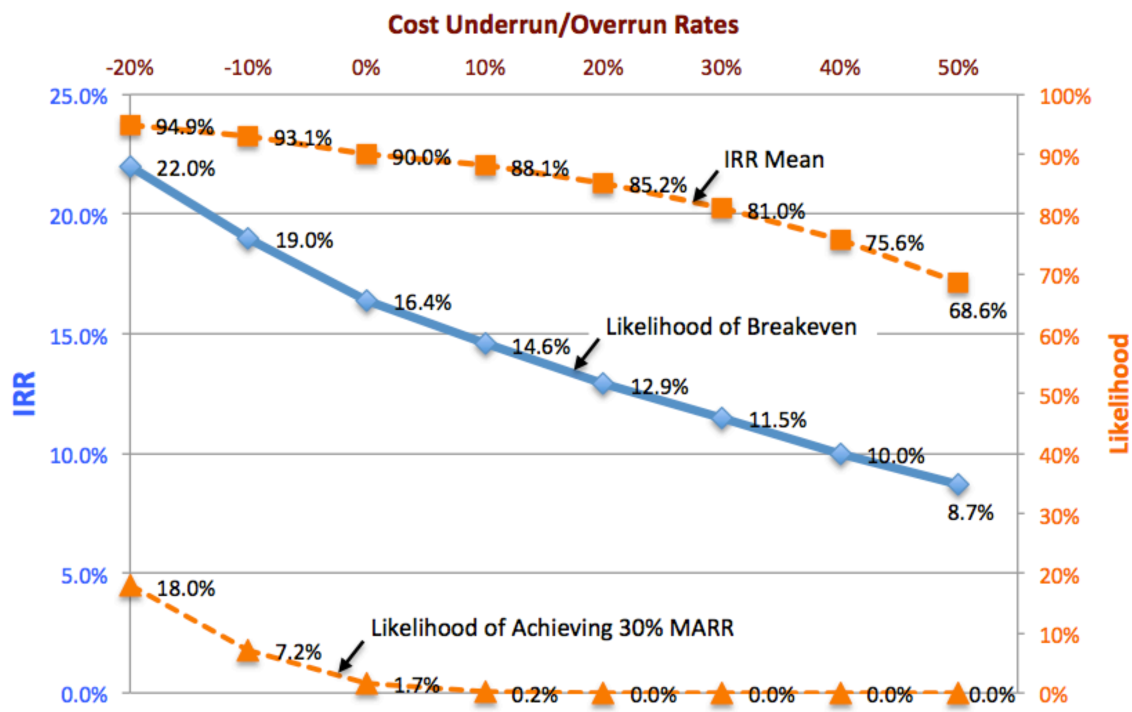


Figure 6-7: Summary of Sensitivity Analysis of Project Cost Uncertainty on IRR

However, if the Owner sets the project goal lower (i.e., the MARR = 6.5%), hoping that the investment will only break even against the interest rate of the given 15-year loan, it is much more likely that the project will achieve its goal in every scenario. Figure 6-8 illustrates the breakeven point in the case of 0% cost overrun with 5,000 runs of the simulation.

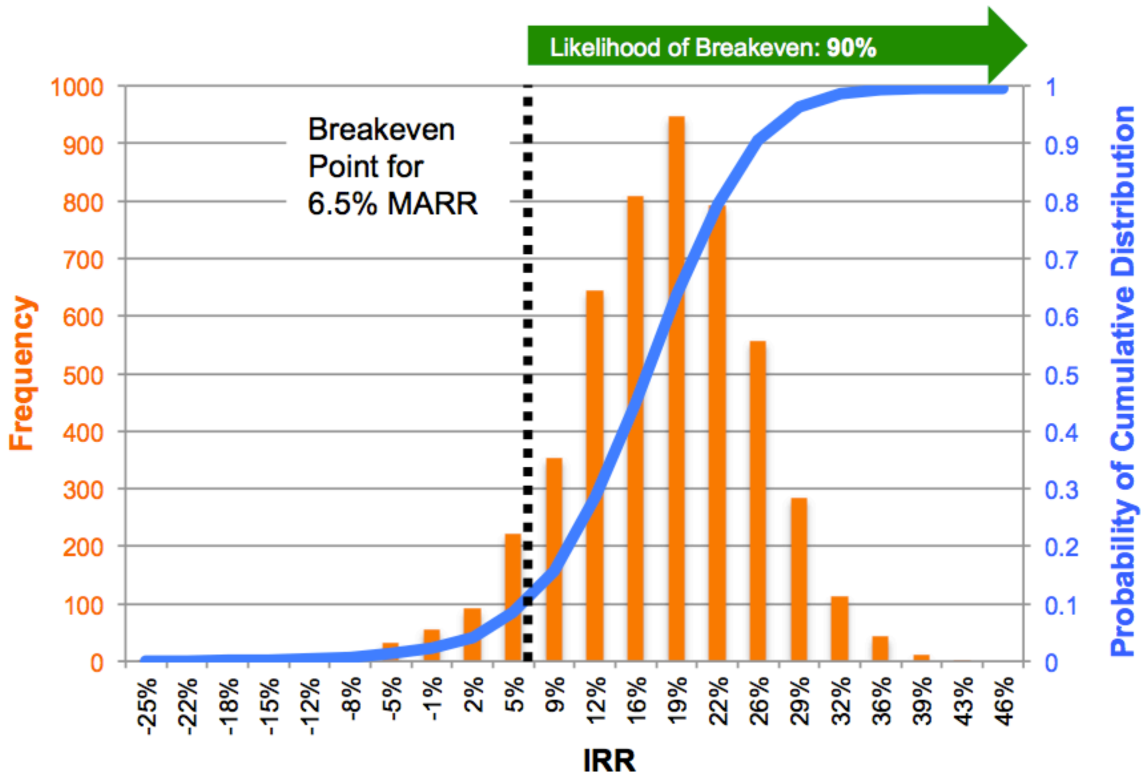


Figure 6-8: Histogram and Cumulative Distribution of 0% Cost Overrun Scenario

Using the same data, Figure 6-9 plots the 50% boundary (from the 25th percentile to the 75th percentile) of the IRR for the 8 scenarios. As mentioned, both the mean and the standard deviation of the IRR decrease when the cost overrun rate increases (from left to right). So, the 50% boundary plot of the IRR converges and decreases as the cost overrun rate increases.

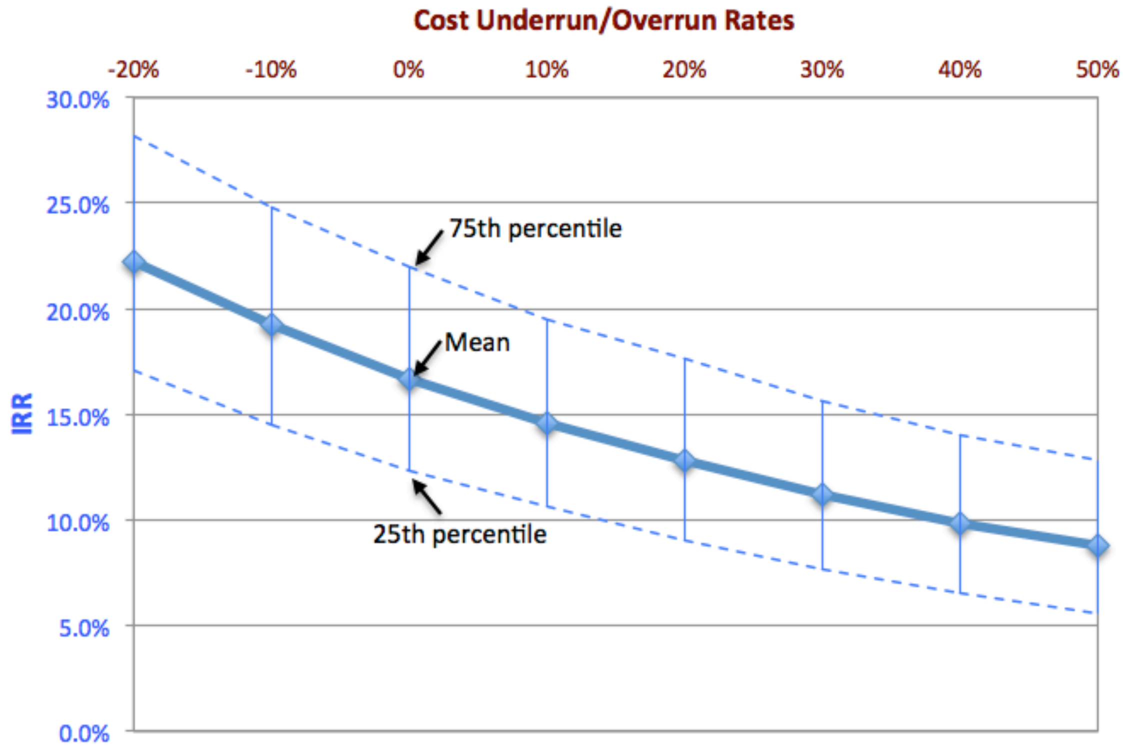


Figure 6-9: 50% Boundary Plot of IRR

Figure 6-9 confirms that as the cost overrun rate increases:

1. The IRR of the investment decreases (the mean decreases); and
2. The impact of the project cost uncertainty on the IRR increases (the standard deviation decreases).

6.6 SUMMARY

Current practices in commercial loan underwriting—to the best of my knowledge—lack depth in analysis, and consequently appear incapable of evaluating energy-related uncertainties. I developed the TVD protocol and ERLAM to improve current practices.

Using an energy retrofit case in a Northern California office building, Chapter 6 demonstrated use of ERLAM to determine the impacts of two energy-related uncertainties on the financial performance (NPV and IRR) of the investment:

- Project cost uncertainty
- Operational practice uncertainty

The objective of the analysis is to support Step 4 of the TVD protocol by showing that ERLAM can help determine the target building performance and the allowable cost.

CHAPTER 7. HEAT RECOVERY (HR) SYSTEM CASE STUDY

Chapter 7 presents a case study of the Cathedral Hill Hospital (CHH) project where the project team encountered several challenges with one of their EEMs—heat recovery system. Through the TVD process, applied in an IPD environment, the project team was able to manage and reduce specific uncertainties related to a set of heat recovery coils (HRCs) in rooftop air handling units, namely:

- Project cost uncertainty
- Operational practice uncertainty
- System performance uncertainty

Chapter 7 illustrates the design decision-making process that led to achieving a cost-effective solution that delivered greater EE value to the owner and the end users. The development of this process serves as proof of concept for the application of TVD to EE investments.

The following types of project data were used to illustrate this process and the concepts behind it:

- Interviews
- A3 reports
- TVD update charts
- Emails circulated amongst the IPD team (the IPDT, hereinafter)
- Sketches
- Project drawings
- Proposals
- System schematics
- *Choosing by Advantages* tables and charts

7.1 PROJECT BACKGROUND – CATHEDRAL HILL HOSPITAL (CHH)

Covering one city block and replacing the Cathedral Hill Hotel located at the corner of Geary Boulevard and Van Ness Avenue in San Francisco, California, CHH has been designed to become a new acute care and women's and children's hospital of the California Pacific Medical Center (CPMC).

Backed by a budget of $1.7 billon, this 1-million square foot hospital will stand fifteen stories tall with two parking levels below grade and house 555 patient beds. The project includes over 250,000 square feet of below grade parking. Design development commenced in 2005, and the project team expects to complete construction in 2015.

Based on the California hospital seismic safety law (SB 1953) passed in 1994, OSHPD (Office of Statewide Health Planning and Development) regulates seismic requirements for new hospital construction in the San Francisco Bay Area. This presented major challenges to the CHH project. OSHPD seismic requirements have certain impacts on EE design decision-making, as will discussed in detail in this chapter.

7.1.1 CPMC, Sutter, and Five Big Ideas

CPMC is one of the largest private, non-profit medical centers in California. It is an affiliate of Sutter Health, a major non-profit health care provider in California, headquartered in Sacramento.

Sutter Health (Sutter, hereinafter) is a long time partner of the Lean Construction Institute and has been committed to applying the Lean Project Delivery System™ (LPDS™) to their healthcare facility projects. In 2004, Sutter announced their 'Five Big Ideas' to the construction community in an effort to develop a new foundation for project-based collaboration:

1. Collaborate; really collaborate, throughout design, planning, and execution
2. Increase relatedness among all project participants
3. Projects are networks of commitments
4. Optimize the project not the pieces
5. Tightly couple action with learning

Sutter had observed many inefficiencies with conventional processes, such as low reliability of project outcomes, high numbers of claims and lawsuits, and prolific change orders. In response, Sutter sought to develop a better form of contract to help ensure successful use of the LPDS™ (Lichtig 2005a), and led to the development of the *Integrated Form of Agreement* (IFOA), first authored by Will Lichtig (Lichtig 2005b; 2006).

7.1.2 Integrated Form of Agreement

As stated in Chapter 2, relational contracting has proven effective for IPD by utilizing a single agreement signed by the owner, designers, contractors, trade partners, and major consultants to share risks and rewards. This alternative way of contracting has shaped Sutter's IFOA, with which Sutter strives to assure a successful IPD process. Along with the use of the IFOA, the use of TVD plays a pivotal role to guarantee the delivery of values to the customer (Lichtig 2005).

IFOA includes various commercial terms to support LPDS™:

- Team Selection – an IPD team is established where each party is an equal participant, and accordingly called a 'trade partner.' A quality-based evaluation is applied to selecting core team members, including architects, construction managers/general contractors (CM/GC), and major trade partners.
- Creating a collaborative design environment – IFOA suggests that all trade partners participate in the design process so that constructability issues are addressed throughout design. To enhance the quality of design, Sutter agrees to pay for the early involvement of the project team.
- Joint management of financial risk – IFOA promotes a system of shared risk rather than transferred risk. It also calls for joint management of the contingency

funds available to buffer unavoidable risks. Furthermore, a better quality design allows the team members to minimize change orders.

- Joint management of disputes – IFOA promotes party-controlled dispute resolution, where a series of meetings, such as project managers meetings, representatives meetings, and senior executives meetings, are arranged to resolve issues. If the meeting does not resolve the dispute, an independent expert review is conducted. The final option is mandatory mediation, the cost of which is shared equally by the parties. This manner of handling disputes maintains relationships between parties.
- Developing an incentive program – the incentive program in IFOA encourages superior performance and rewards the team for a successful project. The evaluation is based on the overall project performance, and all IPDT members' contributions to cost savings below the allowable cost. If project costs exceed the allowable cost, IPDT members cover the loss up to the negotiated fee at risk.

At CHH, CPMC/Sutter (the owner), SmithGroup (the architect), HerreroBoldt (the CM/GC), the major trade partners, and the major consulting engineers signed the IFOA to form the IPDT. The primary contract was established between CPMC, HerreroBoldt, and SmithGroup (Figure 7-1).

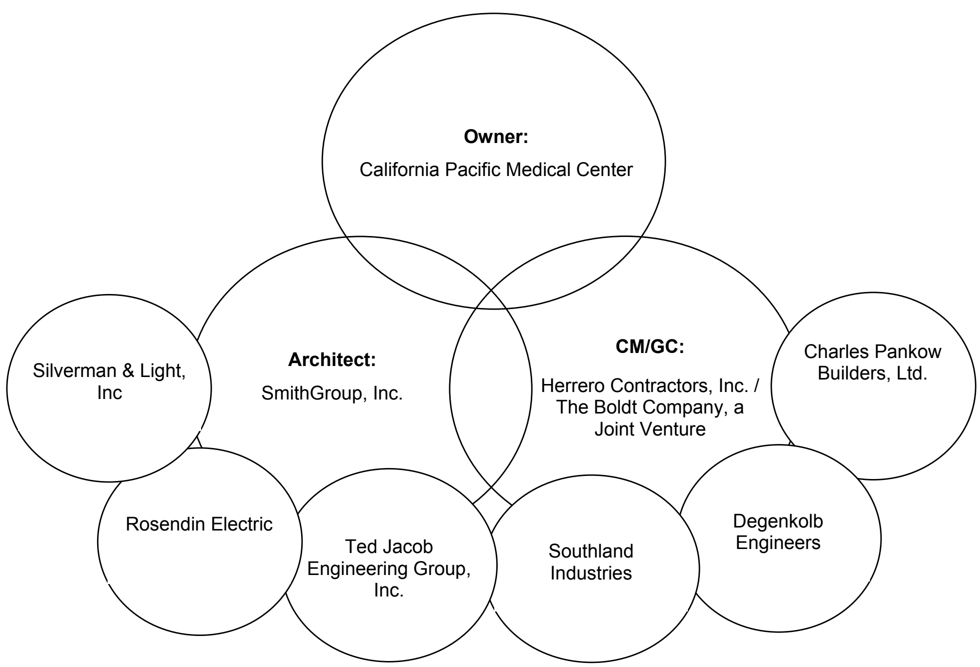


Figure 7-1: CHH IPD Team Structure per IFOA
(Image on Page 1 of CHH's IFOA Dated August 01, 2007)

The *Core Group* includes executive representatives from CPMC/Sutter, SmithGroup, HerreroBoldt, and Pankow (the concrete trade partner) (Ballard and Rybkowski 2009). The Core Group met every two weeks. During the meetings, the group made project-level decisions, reviewed the progress of the project, and discussed budget updates. For major decisions, the Core Group required A3 reports from the 'clusters.'

7.1.3 A3 Reports

At CHH, generating and sharing A3 reports for design decision-making played a pivotal role in the TVD process. The IPDT diligently produced A3 reports to support their recommendations to the Core Group. In particular, A3 reports helped SBD by allowing the team to evaluate and narrow the set of design alternatives based on their value propositions and cost implications.

A3 reports have "a description of the current condition, root cause analysis, target condition, implementation plan, follow-up plan and result report" (Ballard et al. 2008). A3 reports serve multiple purposes, including (1) the flow and analysis of information, (2) design decision-making, (3) diligent documentation of analysis and decisions, and (4) structured process to discussing and resolving conflicting issues. Figure 7-2 illustrates a typical format of an A3 report used at CHH.

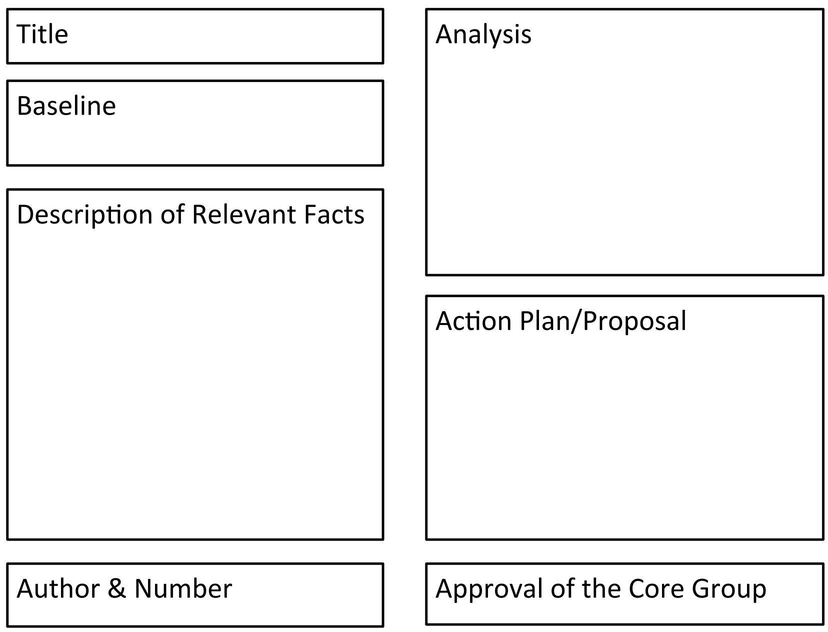


Figure 7-2: Typical A3 Report Format at CHH

7.1.4 Clusters

Clusters performed design and estimating for CHH by as functional groups. They were organized by major components and systems of the building. Each cluster consists of architects, engineers, and trade partners, usually led by a HerreroBoldt representative. The clusters are particularly important for TVD and IPD because:

1. Clusters are used to localize the design and estimating discussions; and
2. The target cost and the budget are broken down and tracked within clusters.

The clusters at CHH were organized as follows (Ballard and Rybkowski 2009):

- Structural
- Mechanical
- Electrical
- Plumbing
- Exterior skin
- Interiors
- Project requirements
- Site work
- Conveying systems

Each cluster group was responsible for tracking the trend of their estimate, which was compared against their target cost. Cluster groups therefore had greater accountability for assigned cost reduction goals. A cluster was not rewarded for its individual success (i.e., successfully reaching its target).

'Commitment to the process as a whole' is essential for TVD in such a way that TVD works as intended if everyone is committed to the process, including the owner and the end users. The commitment encourages collaborative and concise efforts to complete the project in the most economic/efficient manner; individual companies or clusters do not have as much incentive to look out only for their own welfare. In short, TVD requires high levels of collaboration for optimizing the whole project delivery process.

In addition, TVD brings to the team a sense of ownership of the project by establishing clusters, which requires all partners to take on responsibility and accountability. Each cluster is responsible in its own way for the project's overall success. This enables the IPDT to be a true project-based organization. Each team member is dedicated to the common goal of helping develop a design that meets the program and budget.

7.1.5 Co-location

When developing its Prius model, Toyota used a concept called "obeya" (aka. Big Room) where the cross-functional team works together on a daily basis. It was found that the use of the Big Room facilitates fast and accurate decision-making, improves communication, maintains alignment, speeds information gathering, and creates a sense of team membership (Liker 2004).

The Big Room is a place where visual management tools are displayed and maintained. These tools include schedules, drawings, quality information, manpower charts, financial status reports, and other important performance indicators. Liker (2004) emphasizes that with such visual controls, the Big Room serves two purposes: (1) real-time information sharing, and (2) timely decision-making by having the right players there to make decisions on the spot.

Pursuing the eighth principle of TVD (see Chapter 2), a Big Room was established at CHH on 6th floor at 633 Folsom Street, San Francisco, CA to facilitate collaboration. Each cluster was physically co-located on the same floor. As the TVD process is meeting-intensive, it would have been difficult to operate without co-location.

Throughout the design development process, more than ten different trade partners and consulting engineers were co-located in the Big Room (Figure 7-3).

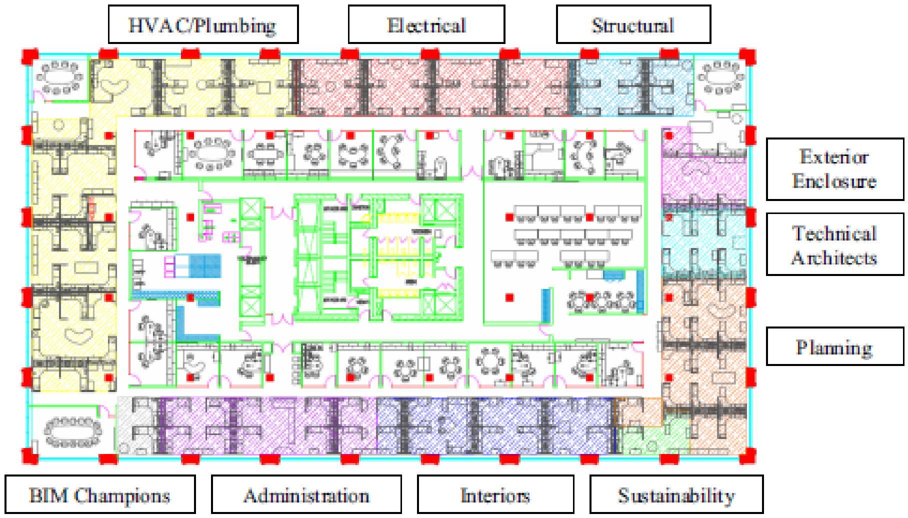


Figure 7-3: Big Room of CHH (Figure 1 in Ballard and Rybkowski 2009)

7.1.6 Target Value Design Process

TVD is "a management practice that seeks to make customer constraints drivers of design for the sake of value delivery" (Ballard 2011). TVD has a number of key features including target costing, validation study, set-based design (SBD), work structuring, collaboration, and co-location (Ballard 2009a; Macomber et al. 2007).

To implement TVD, the project team can follow suggest a structured process for its implementation. TVD starts with project business planning where the owner prepares a business case that describes the value they expect to receive from the building. The owner defines the allowable cost based on desired minimum acceptable ROI or maximum available funds. Clients must specify how much money and time they are able and willing to spend in order to achieve their desired final product, or more exactly, their objectives for the project.

$$Allowable\ Cost \geq Expected\ Cost \geq Target\ Cost \qquad \text{Equation 7-1}$$

The business case and the allowable cost are then validated by a project delivery team appointed early on. During the validation, the team calculates the expected cost as the estimated cost of the project based on current best practices, typically determined by market conditions. The expected cost should not exceed the allowable cost. If it does, the business case has to be either revised or abandoned (Ballard 2008; Ballard 2009a).

After validating the business case, the client sets the target cost below the expected cost to spur design innovation. Target costs are assigned to each cluster. The team proceeds to design to targets, applying lean design management practices such as SBD, A3, Choosing by Advantages (CBA), and Last Planner System® (LPS®) (Ballard 2008).

At CHH, the validation process started in March 2007 and finished in July 2007. The project funding decision was made after the validation study report recommendations were presented to CPMC/Sutter. The validation was completed with establishing the project team including SmithGroup, HerreroBoldt, Degenkolb (structural engineer), Pankow, Herrick (steel fabricator/contractor), Southland (mechanical contractor), and other key engineers and trade partners. The team benchmarked the costs of comparable healthcare facilities in order to produce their estimated cost for CHH. CPMC/Sutter set the allowable cost at 13% below the market benchmark. The team then set the target cost $70 million below the allowable cost as this appeared to be a reachable goal.

During design development, cluster groups held weekly meetings for design coordination and estimate updates. To track the TVD progress, a designated 'TVD manager' compiled from each cluster the evolution of their estimates, and then reported them during the weekly meetings.

As part of its commitment to the TVD process as a whole, each cluster was responsible for the following (Nguyen 2010):

- Developing design innovations to meet the cluster's target cost
- Employing value analysis to identify constraints and value gaps
- Tracking the impacts of design iterations on costs
- Preparing A3 recommendations for the Core Group's consideration and approval
- Communicating with other clusters and keeping the IPDT informed about areas of concerns

The TVD progress was rigorously updated every three weeks against the target costs. Through TVD from September 2007 to December 2009, and measuring from the highest point, the IPDT achieved a total cost reduction of $106 million (Figure 7-4).

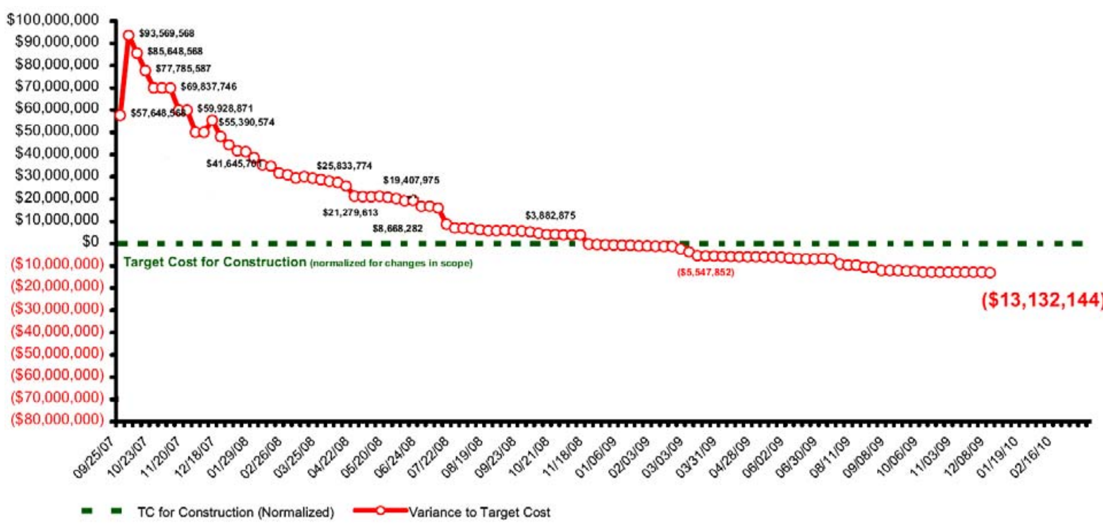


Figure 7-4: Evolution of Cost Estimates at CHH (Figure 4.2 in Nguyen 2010)

7.1.7 Office of Statewide Health Planning and Development (OSHPD) Increments

OSHPD is a California state office that is responsible for overseeing construction of California health care facilities. Their major responsibilities include reviewing initial construction plans and approving for construction.

At CHH, OSHPD agreed to perform incremental reviews called Phased Plan Reviews (PPR) with the IPDT. PPR was conceived to reduce the length of time required for review of OSHPD submittals and accordingly reduce the overall duration of the project. The increments were organized as follows:

- Increment 1: Site Development
- Increment 2: Structural Systems
- Increment 3: Exterior Wall Systems
- Increment 4: Architectural & MEP Systems and Anchorage
- Increment 5: Anchorage of Architectural Accessories and Medical Equipment
- Increment 6: Interior Construction

Design packages of increments and sub-increments were to be submitted based on a pre-agreed schedule that determined milestones in the design development process of CHH. To stay on schedule, the whole team had to be involved and committed to the PPR process.

From the OSHPD submittal dates, the IPDT developed a master schedule using reverse ('pull') scheduling. LPS® enabled the pull scheduling by which the IPDT could plan and track their design development progress. The IPDT held comprehensive meetings every week to review the progress of OSHPD increments and identify project constraints.

7.2 CASE DESCRIPTION – HEAT RECOVERY SYSTEM

The IPDT on CHH applied TVD to manage and reduce types of uncertainties for its specific EE investments. The focus here is on heat recovery coils (HRCs) located inside of the rooftop air handling units (AHU). The application of TVD resulted in the following benefits:

- Increasing the predictability of the financial performance of the facility;
- Reducing complexity and overdesign; and
- Enhancing the value delivered to the customer.

7.2.1 Original Structure of Ventilation System

During validation, the IPDT developed a validation report based on values specified by CPMC. The design of the HVAC system included the following options:

- Use of 100% outside air as supply air
- Provision of coils for HR

To maintain pressure balance in the building, an equal amount of ventilation air had to be introduced and exhausted. Ted Jacob Engineering (the mechanical engineer in the IPDT;

Ted Jacob, hereinafter) calculated that approximately 1 million CFM (cubic feet per minute) of air would be supplied through a total of seventeen AHUs and then an equal amount exhausted at CHH. Their design specified that the supply air would cool down (or heat up) to 53°F, and then warm up to 78.5°F by the internal heat loads.

Figure 7-5 illustrates the schematic of the HR system designed per the validation report. Situated inside of each AHU are eight rows of HRCs working as heat exchangers in each air stream, devices to filter the exhaust air before it passed through HRCs, a pumped run-around loop, and automation controls.

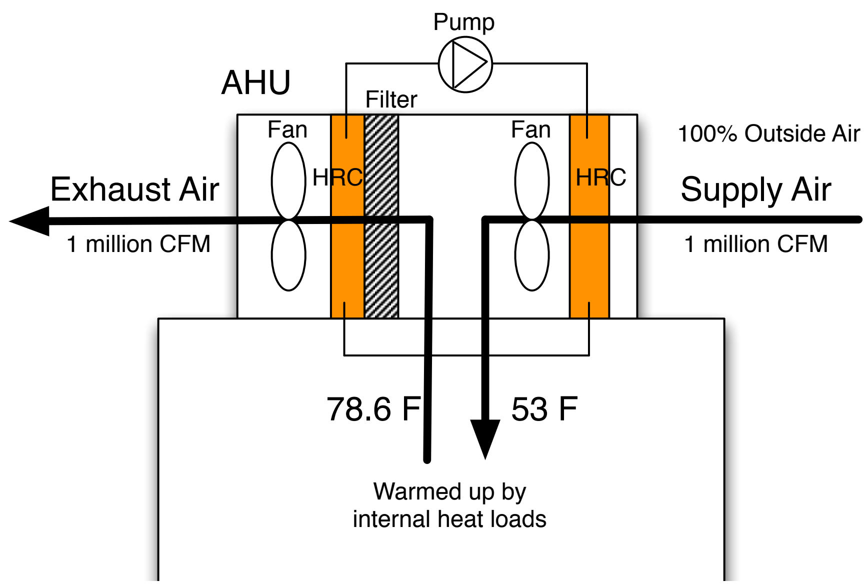


Figure 7-5: Schematic of Original HR System in Double-staked Rooftop AHUs with Run-around Loop

7.2.2 Energy Saving Scheme

HRCs would be installed both in the supply air stream and exhaust air stream and connected through piping with internal pumps. HRCs preheat or precool the air depending on outside environmental conditions:

- During wintertime, the HR system is in heating mode, *capturing* heat from HRCs in the exhaust air stream so as to preheat the air through HRCs in the supply air stream.
- During summertime, the HR system is in cooling mode, *releasing* heat to HRCs in the exhaust air stream so as to precool the air through HRCs in the supply air stream.

The HR system is designed to save energy by reducing the overall size of the building's central plant. Saving energy was the primary reason listed for inclusion of a HR system.

7.2.3 Sustainable Building Certifications

CHH sought to acquire multiple green building certifications, including LEED for Healthcare[1], Green Guide for Healthcare[2], LEED NC 2.2[3], and Savings by Design[4]. Guttmann & Blaevoet (an engineering consultant; G&B, hereinafter) prepared action plans for these certifications, particularly for LEED. Based on the plans, the building would have to use a minimum of 14% less energy compared to the baseline usage specified in ASHRAE 90.1-2004. To achieve this goal, the HVAC system would include provisions for displaced ventilation and variable air volume, in addition to having a HR system.

7.3 DYNAMIC PROJECT ENVIRONMENT

During the design development of the HR system, IPDT faced two unexpected challenges: (1) bankruptcy of the AHU trade partner, and (2) evolution of OSHPD's seismic requirements. The application of TVD in an IPD environment helped the team to handle the fast-changing, dynamic megaproject environment.

7.3.1 Bankruptcy of Air Handling Unit (AHU) Trade Partner

M&I Air Systems Engineering West Inc. (M&I, hereinafter) was a HVAC systems manufacturer based in Tualatin, Oregon. M&I proposed to the IPDT a unique AHU design using a 'vane axial fan.' Following a CBA process, M&I was selected in mid-2009 to be the AHU trade partner. On an A3, the IPDT recommended M&I to the Core Group that approved. The selection resulted in a reduction of $1,714,716 ($1.6 million saving for the mechanical cluster and $114,716 saving for the electrical cluster) in the cost estimate.

On February 5, 2010, M&I filed for Chapter 11 Bankruptcy. A company called Engineered Air acquired M&I's patents and technical information. Southland Industries (the mechanical contractor in IPDT; Southland, hereinafter) received a letter from Engineered Air stating that they would not honor the price M&I previously provided to the IPDT, and provided a new estimate at $10.2 million on March 10, 2010. Table 7-1 summarizes the cost differences needed for the new estimate from Engineered Air.

Table 7-1: Cost Differences as of May 18, 2010

Total TVD Budget for Mechanical Cluster	Engineered Air Estimate	TVD Budget Risk with Engineered Air
$8,209,999	$10,190,001	$1,990,002

[1] http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1765

[2] http://www.gghc.org/

[3] http://www.usgbc.org/DisplayPage.aspx?CMSPageID=2464

[4] http://www.savingsbydesign.com/

M&I's bankruptcy resulted in risk of a cluster budget cost overrun of $1,990,001. What was worse, design changes in the AHUs were inevitable and provided the IPDT with the following challenges:

- Changes required to the central chiller plant size
- Changes required to the OSHPD increment 4 submittal

At the time of the bankruptcy, the IPDT was well into the construction document phase. The drawings for the AHUs had already been submitted to OSHPD. Consequently, any design changes would be subject to space and electrical power constraints. For example, the weights of the chillers could not be substantially changed. The size of the central chiller could not exceed the power requirement submitted to OSHPD; the size had to be kept within the power already designed.

Table 7-2[5] summarizes the IPDT's description of its current state and the suggested action plans to the Core Group, as they related to the OSHPD submittal.

[5] For confidentiality reasons, the complete A3 may not be presented.

Table 7-2: Summary of the Current State and Suggestions of IPD Team
(Excerpted from A3 Dated May 18, 2010)

Trade Partner Affected	**Design Requirements of AHU that inform other Trade Partners**	**Current State**	**Future State/Action Plan/Path Forward**
Structural Design	Change in AHU weights that would require structural redesign	OSHPD submittal includes weight provided by M&I – approximately 220,000 lb calculations	
Architectural Design	Change in AHU size/configuration that would require architectural redesign	Spatial design criteria of 44'- 6" max length and 38' max width applies. M&I met these criteria.	
Exterior Cluster – Exterior Screen Wall Design	Structural screen wall attachments are included as part of the AHU structural design	Architectural screen connections will be attached to AHU and the structural element on and within the AHU. Structural elements on and within the AHU for the screen to be engineered and fabricated by the AHU vendor.	
Mechanical Engineer – Basis of Design of Equipment Schedules	Information included on the current OSHPD submittal drawings schedule for submission in July 2010, may not be accurate	Equipment schedules reflect the single fan vane axial design for the air handling units	Revise mechanical equipment schedules to reflect the original basis of design, fan wall system, without identifying a specific manufacturer. A Fan Wall system will be required due to the physical limitations on the roof – the roof does not have sufficient length for the vane axial design approach.
Electrical Engineer	Electrical drawings will need to be updated to match mechanical drawings for submission to OSHPD	Electrical circuiting is shown as the single vane axial fan	Revise electrical circuiting based on the fan wall system

7.3.2 Seismic Requirements

OSHPD imposes a seismic requirement for equipment. Their requirements have evolved over the past ten years. As written in the 2007 code, the requirement was intended to make California hospitals seismically safe. Interpretation of the code suggested that equipment should be anchored sufficiently so as not to overturn during a seismic event.

However, the requirement had evolved to now demand that equipment be certified to remain operational after an earthquake. Therefore, anchors must not only be designed and installed properly, but also pass a special test to ensure that after an earthquake, the equipment would still be functional.

Due to limited rooftop space, the initial design specified that the AHUs be double-stacked, measuring 24 feet high, 40 feet wide, and 40 feet deep. Each AHU would weigh about 120,000 lb, and the double stack would weigh about 300,000 lb total (including the additional 55,000 lb structure required to support the weight of the upper unit) (Figure 7-6). While dealing with the bankruptcy of M&I, the IPDT became aware of another serious challenge to certify these double-stacked rooftop units.

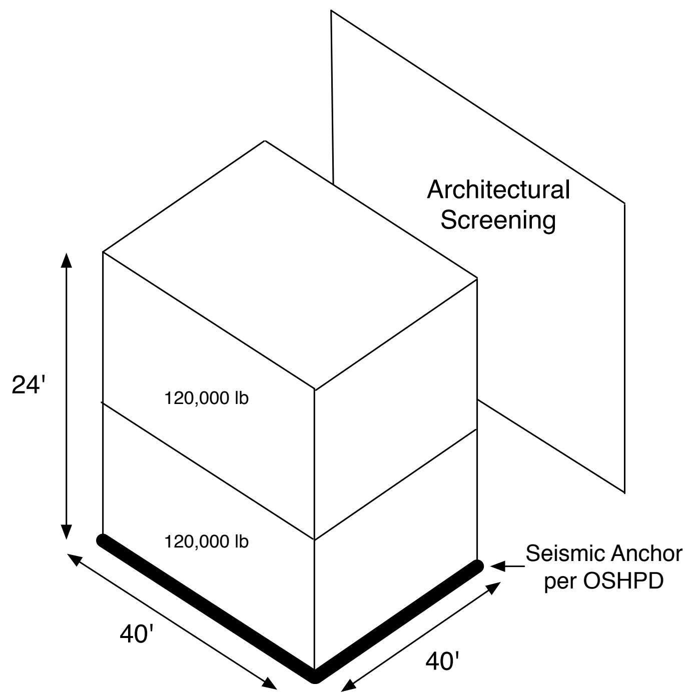


Figure 7-6: Initial Configuration of Rooftop AHUs

The IPDT learned that the Kaiser Permanente Oakland Medical Center Replacement Project (also delivered using a form of IPD) had rooftop units designed very similarly to CHH's double-stacked AHUs. Because the double-stacked units could not be easily shake tested, the Kaiser project team experienced a large cost increase and delay in their schedule to make those units comply with the seismic certification (as of May 2011, the double-stacked design at Kaiser had still not been approved by OSHPD).

Based on the lessons learned, the IPDT estimated these risks to add $9 million to the current TVD budget. CPMC also acknowledged that due to the budget constraints and the seismic requirements, there was a high project cost uncertainty with the double-stacked units.

7.4 DESIGN DECISION MAKINGS DURING TARGET VALUE DESIGN

With these two unexpected challenges, the IPDT held a series of rigorous TVD discussions to identify, manage, and reduce uncertainties related to the AHUs. Using the TVD process, the IPDT evaluated numerous scenarios in order to recommend to the Core Group a comprehensive solution that could bring the cost of the AHUs back within the constraints of the cluster's budget. The team's evaluations were focused on:

- Alternate AHU manufacturers;
- Alternate configurations that have OSHPD pre-approval; and
- Alternate design options for the HVAC system.

This section presents the design decision-making process of the IPDT.

7.4.1 Evolution of Target Value Design Budget Gaps

Figure 7-7 illustrates the evolution of the cost estimates from five AHU manufacturers and their associated 'TVD budget gaps' before the IPDT successfully closed the gap. The IPDT clearly documented their TVD diligently. Such diligent documentation of events that are related to a target goal is important for TVD implementation, because it helps the team build shared accountability and reliable commitments to the TVD process.

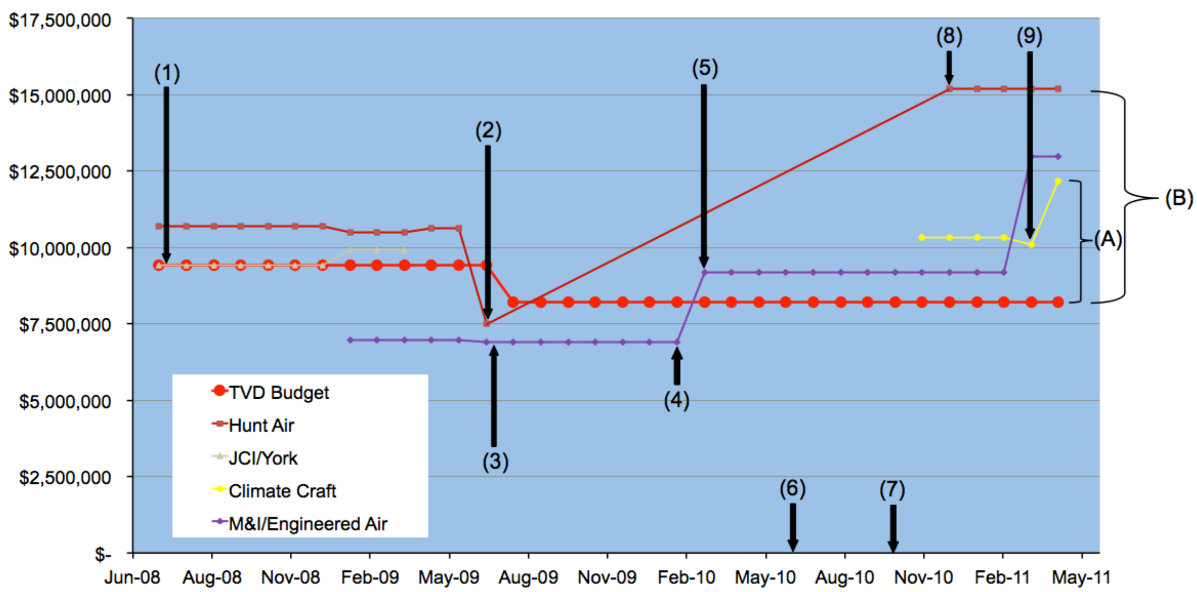


Figure 7-7: Evolution of TVD Budget Gaps
(Adapted from Southland Industry's Analysis)

The numbers in Figure 7-7 refer to the following events:

1. The initial TVD budget carried JCI/York.
2. July 2009 NSW/Hunt Air provided last minute updated pricing for AHUs to match M&I Pricing the day before the A3 was presented to the Core Group

3. July 2009 — The Core Group approved the IPDT's A3 recommendation for M&I AHUs.
4. February 2010 — M&I filed for bankruptcy.
5. May 2010 — Engineered Air acquired all M&I assets and factories, and provided an updated budget for the project.
6. June 2010 — Path Forward A3 for AHUs was presented to the Core Group
7. October 2010 — Lessons about the special seismic certification for NSW/Hunt Air units learned from the Kaiser Oakland project. Accordingly, Southland requested new pricing from NSW/Hunt Air and Climate Craft.
8. December 2010 — NSW/Hunt Air provided updated project pricing based on the Kaiser Oakland lessons learned, and that resulted in a 102% Increase.
9. March 2011 — Climate Craft provided a budget reduction, while NSW/Hunt Air refused to provide updated budgets when requested.

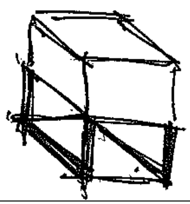
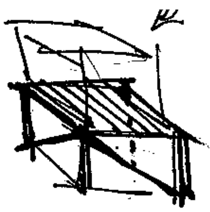
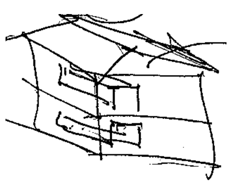
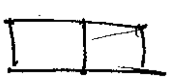
In Figure 7-7, (A) refers to the total gap of $3.96 million relative to Climate Craft's estimate and the TVD budget, while (B) refers to the total gap of $6.97 million compared to NSW/Hunt Air.

The TVD budget gaps evaluated in May 2011 still indicated a high cost uncertainty. Consequently the IPDT had to work together to validate the basis of design for the HR system. That led to the team suggesting a solution to remove the HR system for better managing and reducing uncertainties related to the system. With the solution, the IPDT succeeded 'design to target' while making "customer constraints drivers of design for the sake of value delivery" (Ballard 2011).

7.4.2 Set-based Design

In response to the issues related to OSHPD's seismic requirement, the IPDT evaluated several structural design options for AHUs during their TVD process (Table 7-3). The team narrowed their consideration to four structural design options. Note that no one manufacturer can deliver every design.

Table 7-3: AHU Structural Design Options Considered as SBD
(Images Courtesy of St. Clair)

Options	Features	Pros & Cons	Costs
Double-stacked AHU 	• Two individual units, one stacked on top of the other with additional support	• Basis of design • Does not require design changes • No manufacturer that have achieved OSHPD preapproval	• $6 million to $11.4 million over the TVD budget
Exoskeleton 	• A licensed structural engineer designs additional external frame. • The lower frame is part of AHU, but units would be separated with a structural platform.	• Designs of the structural frame by Degenkolb • Significant waterproofing issues to be resolved	• Costs were not estimated.
IPDT-built penthouse with indoor AHUs 	• Degenkolb designs and Herrick provides a two story structure for AHUs. The IPDT provides enclosure and systems • AHU will be indoor units	• Higher confidence in obtaining OSHPD approval with Degenkolb designing	• $1.5 million (without HR) to $6 million (with HR) over the TVD budget
Single story AHUs (without HR) 	• With the HR removed, two AHUs can be placed side-by-side in a smaller footprint	• Central plant increases in capacity	• Meets the TVD budget

The IPDT considered the four design options with and without the HR system to evaluate their value propositions to CPMC and impacts to the TVD budget. However, an energy saving estimate from G&B turned out significantly lower than expected, triggering additional significant design decisions to be made during the TVD process. The following sections compare the energy saving analysis from G&B, Ted Jacob, and Southland, which led to constructive design discussions, as part of the TVD decision-making process.

7.4.3 Energy Saving Analysis

G&B distributed a report to the IPDT on June 14, 2011 that provided the LEED Energy and Atmosphere Credit #1 calculations for energy savings as compared to ASHRAE

90.1-2004. Their first forecast of savings from the HR system was estimated at $34,000 per year. The IPDT was surprised to learn that a $5 million[6] investment in a HR system would only yield $34,000 in annual savings, i.e., have a simple payback period of almost 150 years.

Ted Jacob, a designer of the HR system, subsequently conducted their own energy simulation using 100% outside air as the basis of design. They concluded that without the HR system, the building would require (1) an additional 402 tons of mechanical cooling at peak design and (2) 16,375 MBH (thousands Btu per hour) of added heating capacity. Their investigation estimated the energy savings from the HR system to be $264,327[7], which still resulted in a 19-year simple payback period if using the $5 million investment. Table 7-4 summarizes the results from Ted Jacob's analysis.

Table 7-4: Summary of Analysis Results from Ted Jacob Engineering

	Cooling Demand at Design Condition Tons	**Heating Demand at Design Condition** MBH	**Total Electrical Energy** kWh/yr	**Total Gas** therms/yr	**Annual Cost of Total Utilities** **$/yr**
Without HR	2,824	20,139	11,734,739	721,048	**$2,222,662**
With HR	2,422	3,764	12,353,409	294,648	**$1,958,335**
Difference	402	16,375	(618,670)	(426,400)	**$264,327**

7.4.3.1 Uncertainty with CPMC's Operational Practice

Along the energy saving analysis of Ted Jacob, Southland performed an additional investigation to characterize CPMC's practices in their O&M. If CPMC would have additional O&M costs for the HR system, that would offset any energy savings. The investigation specifically focused on replacing filters of the HR system. It is a big advantage that with the TVD-IPD environment, "the customer is an active and permanent member of the project delivery team" (Ballard 2009a). Therefore, the team can easily get feedback on their O&M practices, so that the design can accommodate such practices.

In order for the HR system to work properly, the system would need to be equipped with a set of filters (not needed in the design without the HR system) just to protect the HRCs in the exhaust air steam (see the schematic of the system in Figure 7-5). The filters would add a significant amount of 'static pressure' for fans to overcome. The increase in the static pressure is proportional to the increase in a horsepower of fans, and horsepower is proportional to electrical energy consumed to run fans. Therefore, the higher the static pressure, the more energy fans need to consume to overcome the pressure, and the larger the fan sizes become.

[6] The difference between with HR and without HR for the option of 'penthouse' in Table 7-3

[7] Later, G&B agreed with the estimate of Ted Jacob

In addition, filters in the exhaust air stream of AHUs would load up with dust, and need to be replaced periodically. Southland attempted to get CPMC's feedback on how they would operate the HR system and maintain the filters. The feedback was not promising. Based on their previous experience with HR systems in other facilities, CPMC stated, "We are not going to change those filters very often. Maybe once a year." However, to achieve the intended energy savings, the filters would have to be replaced twice a year at least. Therefore, Southland' energy saving assessment (Table 7-5) accounted for the following:

- CPMC's O&M practices in replacing filters
- Additional electrical costs to overcome static pressure
- Electrical costs to run HR pumps

In addition, an analysis of San Francisco weather data revealed that the typical meteorological year[8] (TMY) of San Francisco sees only 71 hours in which temperatures exceed 78.5°F, the temperature at which the HR system can save energy by pre-cooling. Therefore, energy savings in summer time were not considered. Discussions about the weather data will be discussed in the following section.

Table 7-5: Summary of Energy Saving Analysis from Southland Industry

	Energy	**Unit Costs**	**Total Savings**
Annual gas savings in wintertime	226,629 therms	$0.7 per therm	$158,640
Additional electrical cost for supply air fans to overcome the incremental static pressure due to HRCs	308,626 kWh	$0.13 per kWh	($40,121)
Additional electrical cost for exhaust air fans to overcome the incremental static pressure due to HRCs	463,751 kWh	$0.13 per kWh	($60,288)
Electrical cost for HR pumps	124,377 kWh	$0.13 per kWh	($16,169)
Filter replacement (2 times per year)		($139,512) per replacement	($279,024)
Net savings			($236,962)

Southland concluded that the design with HR system would have a high system performance uncertainty, and in fact would cost more to maintain, given the O&M costs to replace filters.

7.4.4 Weather Data Analysis

U.S. DOE (2010a) recently established eight climate zones based on the climate designations used by the International Energy Conservation Code (IECC) and ASHRAE

[8] A selected set of weather data for a specific location. It represents the typical weather phenomena for the location. The TMY data of the US can be downloaded from http://doe2.com/Download/Weather/. US DOE provides three versions of TMYs, namely TMY, TMY2, and TMY3, based on the different ranges of years.

(Figure 7-8). The zoning designates the mild climate in the San Francisco Bay Area as 'Marine'; a marine environment meets all of the following criteria (DOE 2010a):

- A coldest month mean temperature between 27°F and 65°F
- A warmest month mean temperature less than 72°F
- At least four months with mean temperatures higher than 50°F
- A dry season in summer

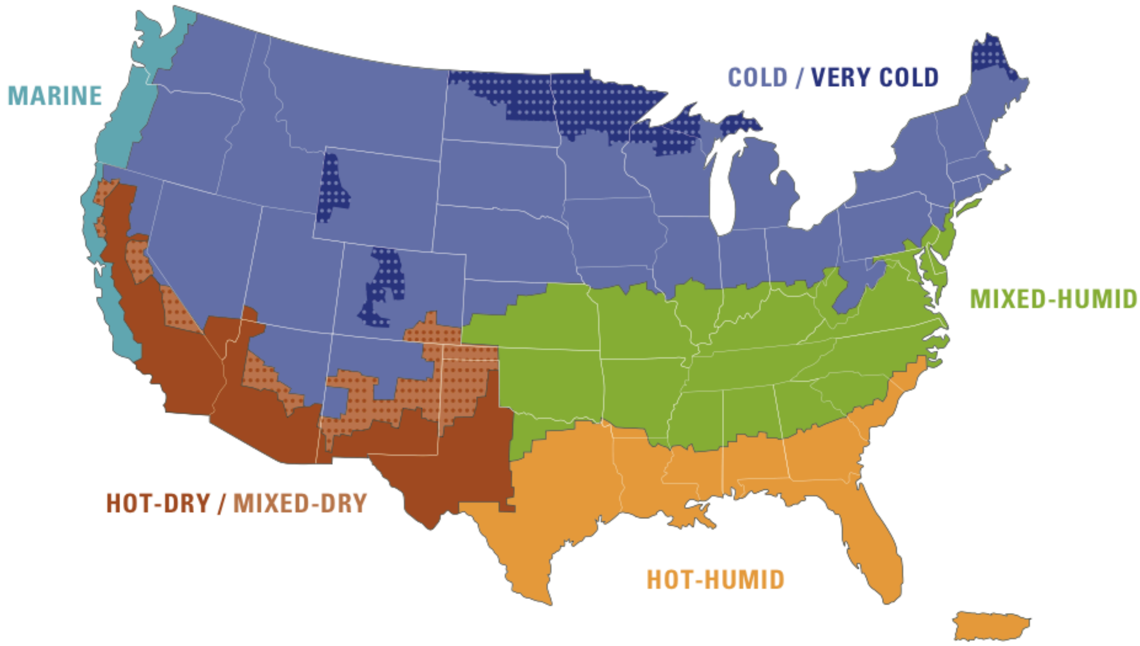


Figure 7-8: Eight US Climate Zones (Figure 1 from DOE 2010a)

When it comes to energy saving analysis, a mild climate offsets benefits of EEMs and this of affects EE design decision-making. The HR system at CHH was intended to achieve energy savings through:

1. Pre-cooling only when outside temperatures are over 78.5°F in summertime
2. Pre-heating only when outside temperatures are below 53°F in wintertime

Figure 7-9 plots the distribution of the TMY of San Francisco (measured at the San Francisco International Airport) and percentages of hours for which the temperature was over 78.5°F or below 53°F. The distribution indicates that pre-cooling would be beneficial for less than 1% of a typical year, while pre-heating would be beneficial for 42% of time. The results can be interpreted to illustrate that the HR system at CHH adds no value, in terms of financial performance, for 57% of a typical year. Yet, the HR system results in high risk and uncertainty due to O&M costs related to the filters (Table 7-5).

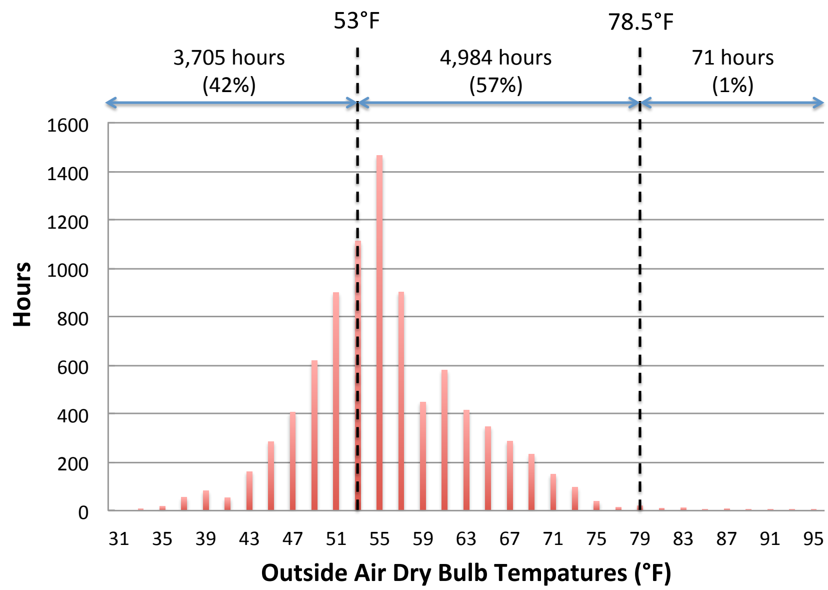


Figure 7-9: Energy Saving Hours Relative to Typical Meteorological Year at San Francisco

7.4.5 A3 Reports and Choosing by Advantages

Three major A3 reports related to the HR system were issued:

1. July 2009 — A3-2374-00178: Custom Air Handling Unit Design / Manufacturing Source
2. May 18, 2010 — A3-2374-00223: Custom Air Handling Unit Trade Partner – Current State and IPDT Path Forward
3. October 12, 2011 — A3-2300-00259: Air Handling Unit Configuration and Run-Around Heat Recovery – Capital Cost Reduction Consideration

The first A3 report resulted in selecting M&I as the AHU trade partner. The third A3 resulted in removing the HR system except for AHUs #1 & #2.

Drafting A3 reports often involves a process called *Choosing by Advantages* (CBA). For HR system issues, CBA was used to study four alternative AHU manufacturers by initially asking for their estimates. Through the CBA process, the IPDT attempted to decide upon a manufacturer through a sound decision-making process.

The manufacturers considered were Climate Craft, Energy Labs, Engineered Air and Hunt Air. The CBA table is not presented for confidentiality reasons. However, I can mention that the team established 33 factors including:

- AHU weight
- Noise radiated
- Approved OSHPD special seismic certification (SSC)
- Overall AHU footprint
- Overall AHU height
- AHU fan vibration
- Leakage guarantee
- Manufacturer experience
- Vendor reputation
- Fan energy load
- Proven technology
- Factory testing
- Serviceability
- Commissioning assistance & start up
- Onsite assembly time
- Warranty
- Opportunity for early commitment
- Cost escalation plan

The IPDT selected "Large difference in SSC for units" as the 'paramount' advantage in the factor of "Approved OSHPD SSC." They assigned it 100 points on the importance of advantages scale. Using this scale of 0 to 100, the team then deliberated on the degree of importance of each other advantage relative to the paramount advantage. To conclude the process, the team added up the importance of advantages for each manufacturer option. Figure 7-10 illustrates total importance of advantages for each AHU manufacturer relative to initial cost impact.

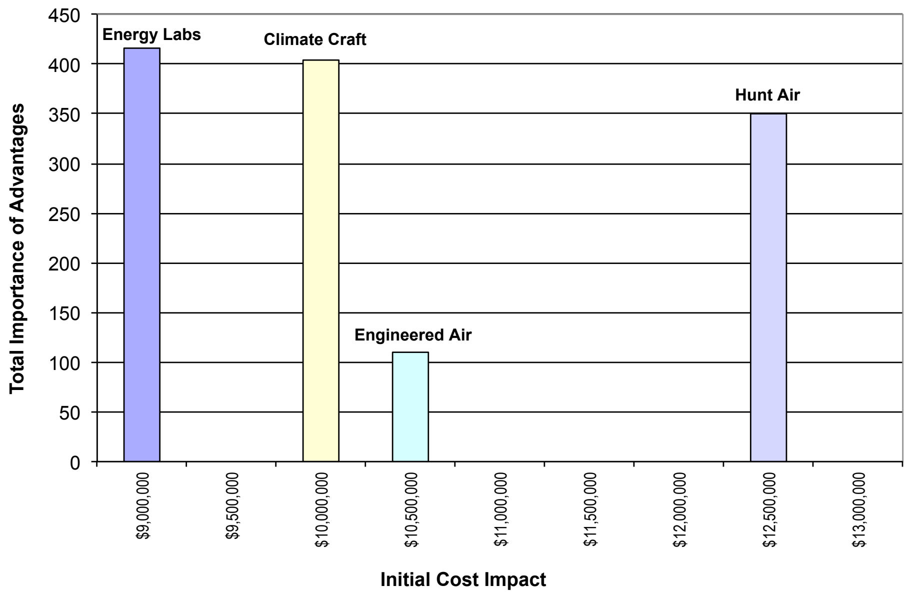


Figure 7-10: CBA Chart for Total Importance of Advantages Relative to Initial Cost Impact (Adapted from CBA in Courtesy of St. Clair)

Unfortunately, the participants involved in the CBA process were not able to reach a consensus at the end of the session. Nevertheless, the CBA session helped the IPDT articulate arguments based on its interpretation of project requirements and preferences. The process ultimately aided the team in selecting Hunt Air as the AHU trade partner.

7.5 DESIGN DECISIONS ON HEAT RECOVERY SYSTEM

The two unexpected challenges from the bankruptcy of M&I and the tightened OSHPD requirement presented additional risks that the project would significantly run over budget. In response, the IPDT held a series of rigorous design discussions. The application of TVD to the design process, the IPD environment, and co-location enabled the team to effectively evaluate design options in a timely manner. This allowed a better value solution to be recommended to the Core Group. During the TVD process, SBD supported by A3 reports played a pivotal role in assessing the value of design alternatives and comparing their cost impacts.

The IPDT concluded that eliminating the HR system for all AHUs except #1 and #2 would maximize value to the customer and increase the predictability of the financial performance of the facility. Two AHUs with HRCs were kept, because they would prevent the changed equipment size and central plant size from becoming problematic. In other words, the design decisions were based on all issues concerning the HR system, not simply on the TVD target.

Figure 7-11 summarizes the design alternatives and their initial costs considered by the IPDT.

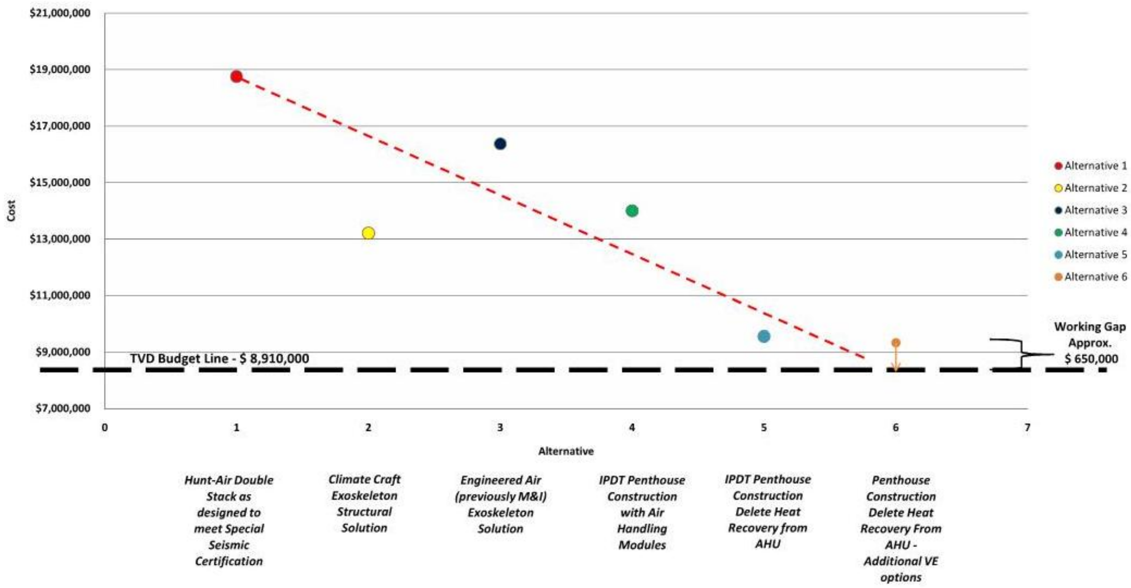


Figure 7-11: Cost Analysis of Design Alternatives in Terms of TVD Budget Gaps
(Image Courtesy of St. Clair)

The IPDT formally submitted an A3 report with their recommendation to the Core Group on October 12, 2011, and subsequently the removal of the HR system was approved. It was the better value solution given the following project constraints:

- Constraints due to dynamic project environment
  - Bankruptcy of M&I
  - OSHPD requirement for special seismic certification of double-stacked AHUs
- Constraints due to CPMC's value definitions
  - TVD budgets for AHUs
  - O&M practices in replacing filters
- Constraints due to physical conditions
  - Mild climate of San Francisco
  - Limited rooftop space

As stated, the removal of the HR system would increase the cooling demands on the central chilled water equipment by 391 tons from 2,554 tons to 2,974 tons. As a result, the size of three chillers increased from 900 tons to 1,000 tons. The increase of the chiller size also required changes to water pumps and the condenser water piping distribution; the chilled water piping distribution was not affected.

Similarly, removing the HR system would increase heating demands on the central heating plant by 17,388 MBH. Consequently, the current four 12,400 MBH boilers would have to be replaced with four 18,600 MBH boilers. The boilers would operate with the increased load for 3,705 hours per year. The increase in the boiler size would also increase the number of water pumps and water pipes.

Per the A3 report dated October 12, 2011, the larger chillers, boilers, water pumps, and piping would result in a cost increase estimated at $512,000. As a tradeoff, the following financial benefits were expected (whether quantifiable or not), explained in detail in the following section:

- Single-story AHUs designed with a smaller footprint than would be needed for AHUs with HRCs
- The project cost uncertainty reduced so that the IPDT would stay within the TVD budget
- The operational practice uncertainty reduced
- The system performance uncertainty reduced
- The complexity of the building system reduced
- Overdesign of AHUs prevented
- AHU weights significantly reduced:
    - Reduced weight of each unit to 51,166 lb and a total weight reduction for the 15 AHUs at 767,490 lb (384 tons).
    - Significantly increased structural performance of the building and accordingly increased chances of getting OSHPD approval on the structural-related increment submittals.

7.6 EFFECTS OF TARGET VALUE DESIGN PROCESS ON ENERGY EFFICIENCY INVESTMENTS AT CATHEDRAL HILL HOSPITAL

The IPD environment and co-location at CHH allowed the IPDT to accelerate design iterations, which brought the TVD process to a high-level implementation. In addition, resolution of issues could have been much more difficult without the IPD environment.

Figure 7-12 summarizes how the TVD process was applied to the design decision-making process for the HR system. Having used the CHH case study as proof of concept, I articulate the explicit benefits of the application of TVD to EE improvement investments in the following respects:

- Managing complexity
- Preventing overdesign
- Maximizing value delivered to the customer
- Reducing three types of uncertainties
    - Project cost uncertainty
    - Operational practice uncertainty
    - System performance uncertainty

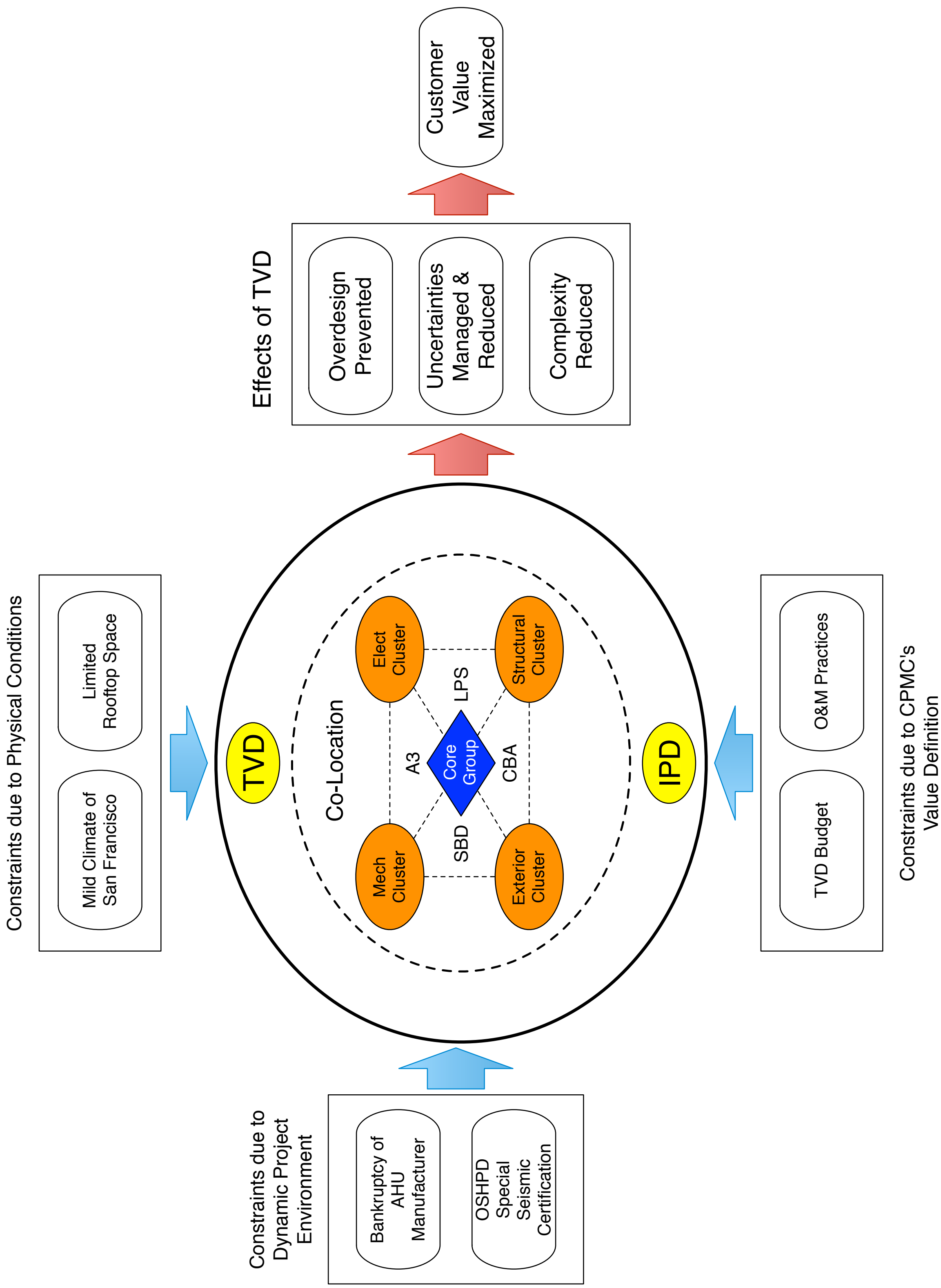


Figure 7-12: Effects of TVD about the HR System

7.6.1 Managing Complexity

Addressing and managing complexity and uncertainty are essential to modern day project management. For complex and uncertain projects, lean project management can be better suited than traditional project management which tends to use buffering to mitigate the impacts of uncertainty "by adding time to schedules and money to budgets" (Ballard and Tommelein 2012). TVD suggests that "setting stretch goals can improve performance, but these stretch goals reduce buffers previously needed for successful performance" (Ballard 2009b). Reducing complexity can contribute to the success of the TVD process.

The IPDT viewed that the HR system added unnecessary complexity and uncertainty to the building system. Figure 7-13 illustrates the interconnectivity of the HR system components with other building components before and after the TVD process reduced its complexity. Managing and reducing the complexity of the HR system contributed to the 'design to target,' while reducing energy-related risks. The sizes of the boxes and arrows represent relative sizes of associated components (e.g., the size of the fan is reduced).

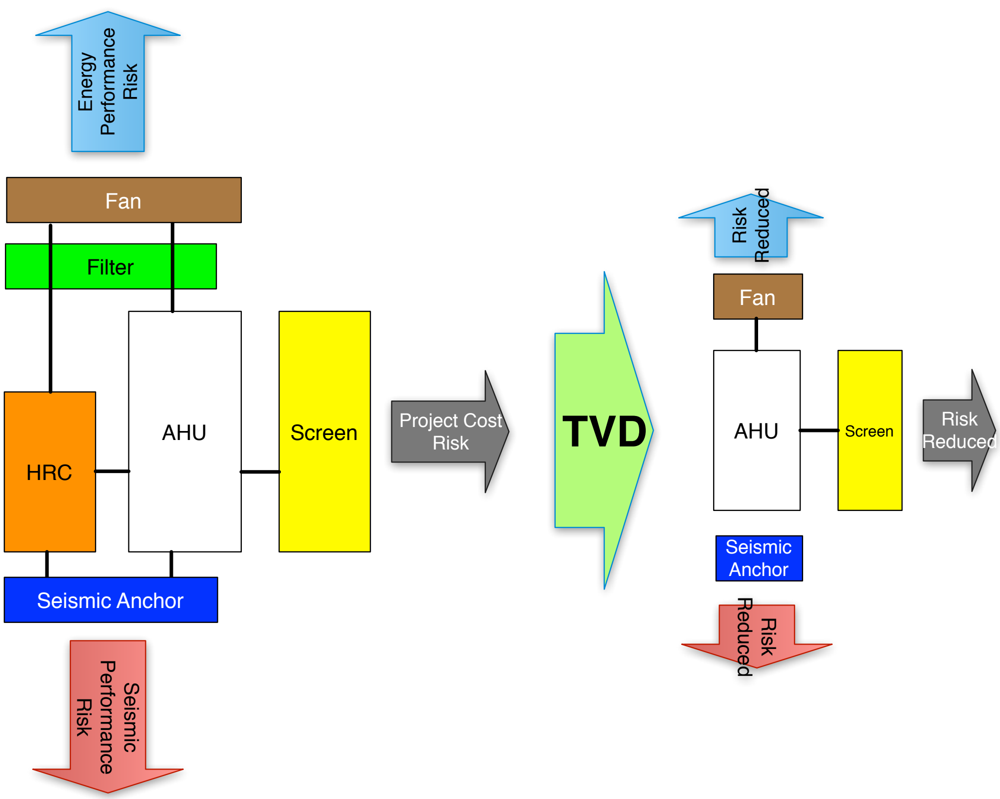


Figure 7-13: Complexity and Risk Reduced through TVD

The complexity of field installation tasks is also reduced. AHUs at CHH are engineered-to-order units, to be delivered in pre-fabricated components from the factory. Southland will set each component and connect them in the field. A factory representative will observe and advise Southland to ensure proper seals between the units.

Without the HR system, AHUs would only require three or four pre-fabricated components. With the HR system, twelve components would be needed. Inclusion of the HR system would require additional field assembly, including assembly of additional pumps, connection components, and run-around loops between HRCs. Much more electrical work and fieldwork would have to be done. Therefore, the elimination of the HR system greatly reduced the amount of field build-up requirements and field labor; accordingly the difficulty of field quality control was reduced.

7.6.2 Preventing Overdesign

Although overdesign can provide product and process flexibility to deal with challenging project deliveries (Gil et al. 2005), overdesign and overspecification have to be carefully addressed and managed for the TVD process to be successful. As noted in Chapter 2, overdesign and overspecification can be detrimental to EE investments, because they can increase first costs as well as energy costs. Overdesign and overspecification are passive ways to manage uncertainty. They add (unnecessary) buffers to absorb the impact of uncertainty.

Due to two unexpected two challenges, the IPDT had a chance to revalidate the basis of design that had been established during the original validation process. The revalidation was made possible by the TVD process that enabled "double-loop learning", a process used to determine if overdesign occurs. The double-loop learning helped the IPDT revalidate "how the original project goals and design criteria were set and established" (Whelton et al. 2002). From this, the team questioned what value the HR system would ultimately deliver to CPMC and what risks the HR system would contribute.

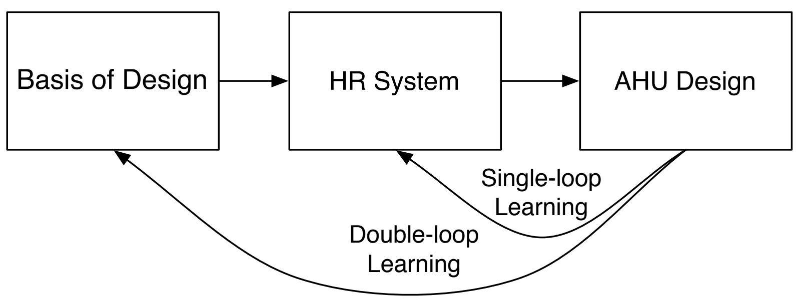


Figure 7-14: Double-loop Learning through TVD

Through the TVD process, the IPDT concluded that the HR system would not only be of no value for 57% of a typical year, but also result in consuming more electricity. In addition, the HR system on the rooftop added a significant additional load to the building's structure. Thus, the HR system appeared to be a case of overdesign. Through the TVD process, the IPDT could determine and make necessary design decisions to prevent the overdesign, i.e., rightsizing of the HVAC system.

7.6.3 Reducing Project Cost Uncertainty

The best-known effect from the TVD application has been its effectiveness in reducing the project cost uncertainty through 'design to target costs.' The original TVD budget was set below market at $9,887,712 to spur design innovations. Before the bankruptcy of

M&I, the mechanical cluster group was on its way to achieving the target via a TVD process that had lasted more than two years. Then, the bankruptcy and the OSHPD requirement related to the HR system brought a risk of cost overrun estimated upwards of $11 million. The IPDT had to redesign the AHUs to be within the TVD target. Project cost uncertainty needed to be managed and reduced, without harming the intended value established during the validation process.

After a number of TVD sessions to evaluate alternative design options and alternative manufacturers for SBD, the IPDT came up with a better value solution, suggesting the removal of the HR system. As of December 2011, the IPDT had brought the system $1 million under the TVD budget. This difference will be added to the pool and be shared amongst project parties as per the gainsharing provision of the IFOA. The financial benefits from the design decision were as follows:

- The removal of the HR system in 15 AHUs resulted in a cost reduction estimate ranging between $4 million to $6 million
- The design of single-story AHUs eliminated an additional $9 million risk related to meeting the OSHPD seismic requirement, because that design was preapproved by OSHPD.
- The single-story AHUs reduced the size of the architectural screens, which resulted in another significant cost saving (see Figure 7-6). The exterior skin cluster group was still estimating the savings as of December 2011.

7.6.4 Reducing Operational Practice Uncertainty

CPMC does not have to rely on uncertain energy savings from the HR system. Consequently, they can more accurately predict their O&M costs. According to the team's analysis (Table 7-5), for the HR system to yield the intended savings, the filters would have to be replaced at least twice a year, incurring a cost of over $270,000 a year. Those O&M costs would offset any energy savings.

In addition, to reduce the uncertainty of the financial analysis, the team studied the O&M practices of CPMC, and learned that the facility management of CPMC would not change the filters very often. That meant a significant reduction in energy savings. Learning from CPMC's experience with the HR system in other facilities led to managing and reducing the operational practice uncertainty in the economic analysis of the HR system.

7.6.5 Reducing System Performance Uncertainty

The HR system would yield greater energy savings in extreme conditions, such as hot summers and cold winters. The San Francisco Bay Area's mild climate hence would reduce the cost effectiveness of the HR system. According to the basis of design, energy savings could be claimed only 57% of a typical year. The HR system would cost more to keep it (on top of the filter replacement costs), because the larger fans would cancel any energy savings that the HR system would provide.

As stated in Chapter 2, Torcellini et al. (2004) reported that the actual energy savings from six 'high performance' buildings fell short of their targets. The subpar performance appeared to be partially due to "systems not performing together in an ideal fashion" (Torcellini et al. 2004). In order to reduce such system performance uncertainty related to the HR system, the IPDT attempted to address every facet of the issues around the HR system. A time consuming process, filled with discussions and design iterations resulted. However, the team acknowledged that this was required to 'design to target value,' to increase certainty of the financial performance of the facility, and to reduce the system performance uncertainty.

7.6.5.1 Energy Cost Risks Related to HR System

In the A3 report dated October 12, 2011, Ted Jacob acknowledged that the HR system analysis had been dramatically complicated over recent years by the two economic factors:

1. Steep declines in natural gas prices
2. Increases in copper prices

In other words, the validity of the better value decision of not having the HR system is impacted by electricity price drops and gas price increases. This was due to the fact that the majority of savings from the HR system was based on gas savings in wintertime. However, the IPDT was not in the position to predict the macroeconomic changes in utility rates, so these were not factored into the design decisions.

CHAPTER 8. STANDARD TARGET VALUE DESIGN DECISION-MAKING PROCESS (TVD-DMP)

EECB development involves performing tasks such as value tradeoffs, system optimization, and evaluations of design alternatives. It requires highly complex design analysis, careful system selection, and a rigorous optimization process (Lapinski et al. 2006). Chapter 8 presents a standard TVD decision-making process (TVD-DMP, hereinafter), which is designed to support all these tasks. I developed TVD-DMP based on the following research findings:

- Literature reviews about 'creative workshop model' and 'Integrated Design' (Chapter 2)
- The DOE research – interviews (Chapter 4)
- The DOE research – the TVD protocol (Chapter 5)
- The DOE research – ERLAM (Chapter 6)
- Case studies (Chapters 6 and 7).

TVD-DMP is not a project delivery method, but rather should serve as a supplement to support preconstruction phases of the EECB delivery. I expect that an application of TVD-DMP will be most effective with an integrated form of project delivery method such as IPD, because such methods have most of the characteristics required for successful TVD implementation. Accordingly, when discussing TVD-DMP in this chapter, I assume that the project team uses IPD. The contractual and legal issues associated with IPD are not part of the discussion.

TVD-DMP can guide project stakeholders through EECB development to ensure clients receive maximum value for their investments. Such EE value delivery is especially critical to maintain the viability of business cases. While quantitative analysis and energy simulation techniques employed with an LCCA are critical for estimating EE values, this chapter focuses on process management and improvement.

For TVD-DMP to yield consistent performance, project participants should follow a structured process with certain ordered steps. Such standardization is key to achieving consistent performance and preventing random actions. However, TVD-DMP is not intended to serve as a detailed step-by-step prescription that project teams have to follow. Rather, it provides a guideline that teams can adapt to the specific conditions and requirements of their projects. Therefore, TVD-DMP possesses flexibility for situational applicability.

TVD-DMP serves as a standard guideline to facilitate information flow, by which 'negative iterations' can be minimized. The process mandates collaboration of project participants. Most importantly, in order to achieve rightsizing of building components, an EE design decision-making process is to be iterative as well as rigorous to "Optimize the project not the pieces"—as stated in the 'Five Big Ideas' of Sutter Health (Chapter 7).

Therefore, TVD-DMP is structured to accommodate a project team's iterative design discussions and rigorous decision making as they pertain to EE system design decisions.

While the TVD protocol in Chapter 5 targets energy retrofit projects, TVD-DMP presented here instead considers the preconstruction phases of *new* construction projects. Enhancing EE in new construction projects is less complex and more efficient and effective than in energy retrofits (Yudelson 2010). TVD-DMP is similar to the TVD protocol. However, the difference between TVD-DMP and the TVD protocol is that the former does not necessarily assume a client has to apply for a construction loan. Therefore, TVD-DMP does not explicitly involve calculating key financial ratios such as LTVR, DSCR, or risk ratings, but it does apply economic analysis.

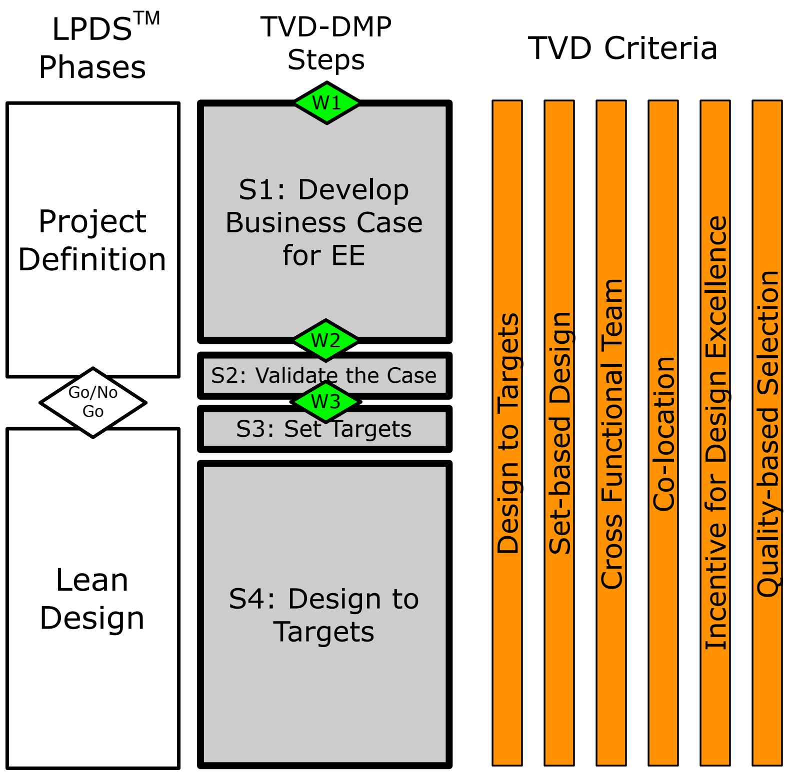


Figure 8-1: Outline of TVD-DMP

Based on the four key steps of the existing TVD methodology (Chapter 5), Figure 8-1 outlines the key steps of TVD-DMP as applied in the LPDS™. Value workshops play a pivotal role during the TVD process. Thus, TVD-DMP includes three workshops: W1, W2, and W3. Adapted from the 'creative workshop model' (Emmitt et al. 2004; 2005; Thyssen et al. 2010), these workshops have the following titles:

- W1: Initiation
- W2: Definition
- W3: Alignment

The three workshops serve as checkpoints that involve making go/no go decisions. Meanwhile, the four steps refer to prolonged development process of designs, agreements, investigations, benchmarking, estimating, and contracting.

Table 8-1 summarizes the TVD criteria, key features, and their expected benefits as applicable to TVD-DMP.

Table 8-1: TVD Criteria, Key Features and Expected Benefits

Criteria	**Key Features**	**Benefits**
Design to Targets	• Design to target costs • Design to target EE value	• Reduced project cost risk • Reduced performance risk • Promoting design innovation
	• Validation study	• Enhanced feasibility study to increase shared understanding
	• Cluster-based management	• Enhanced coordination in designing and estimating
	• Whole-system thinking	• Seeking synergies
Set-based Design	• 'Last responsible moments' • Sharing of incomplete design information	• Rigorous evaluations of design alternatives
Cross Functional Team	• Design-Build or Design-Assist • Sharing of incomplete design information	• Early involvement of all parties • Enhanced constructability
Co-location	• Weekly budget meetings • Weekly design meetings	• Enhanced communication efficiency • Reduced turnaround times of design discussions
Incentive for Design Excellence	• Shared risks and rewards	• Alignment of commercial interests • Promoting design innovation • Enhanced contingency management
Quality-based Selection	• Value-based proposals	• Selection of key players through qualification, not low bidding

Based on the steps identified in Figure 8-1, Figure 8-2 illustrates a process to integrate EEMs based on 'Integrated Design' concepts, and economic analysis process associated with EEM integration.

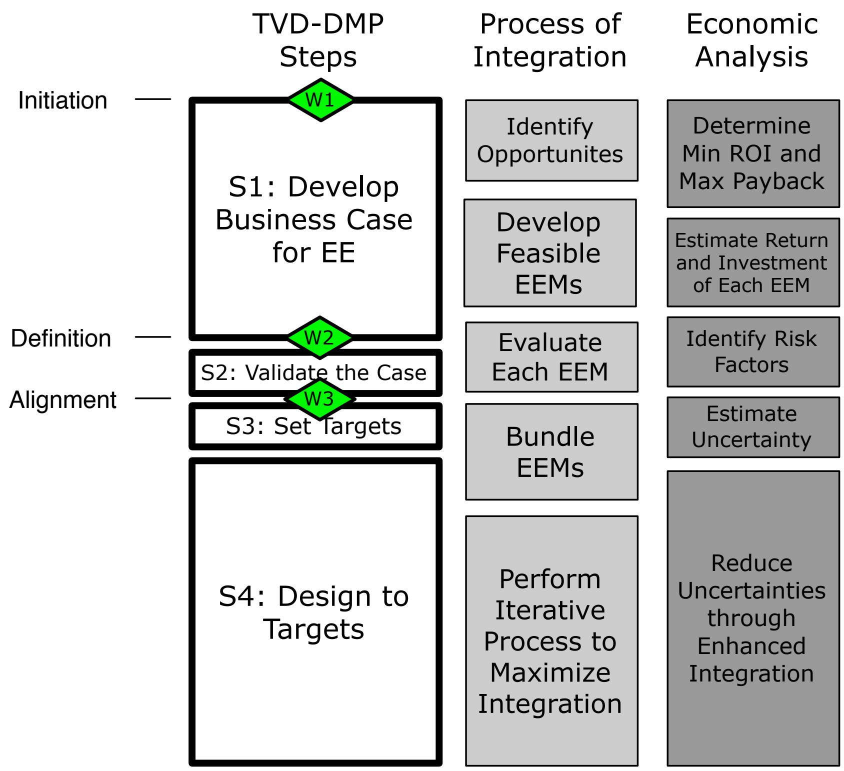


Figure 8-2: Process of Integration and Economic Analysis in TVD-DMP

8.1 WORKSHOP 1: INITIATION

Workshop 1 named "Initiation" organizes a group with project stakeholders who continue to collaborate throughout the preconstruction phase as a project team (this team can act as the Core Group throughout the project; see Section 7.1.2). This owner-initiated workshop aims to reach agreement on communication structures to achieve effective collaboration. TVD-DMP seeks to engage key specialists in developing a project business case, because "the job of the project delivery team is not only to provide what the customer wants, but to first help the customer decide what they want" (Ballard 2008).

8.1.1 Target Value Design Training

It is not unusual to have project participants who have not been exposed to TVD, IPD, or LPDS™, as these are relatively new concepts. TVD-DMP can be a difficult process for those not familiar with such concepts, and TVD-DMP therefore emphasizes a need for a formal training during Workshop 1.

8.1.2 Team Organization

TVD-DMP suggests that major players, including key designers and builders, participate in the workshop. The involvement of such specialists is especially important for developing an EECB, because the owner is likely neither an expert in evaluating EE design options nor in developing a business case for EE. Gauging the benefits and risks of EEMs when developing a business plan requires substantial engineering knowledge, which these specialists can provide.

8.1.3 Compensation

TVD-DMP suggests that the owner compensate the selected specialists using a professional service contract. Even with the service contract, the project team still has a motivation to commit to success in TVD-DMP so that they can proceed to construction. In that regard, their commercial interests are aligned. The alignment of commercial interests can be enhanced later with an agreement of shared risks and rewards during design development.

8.2 STEP 1: DEVELOP A BUSINESS CASE FOR ENERGY EFFICIENCY

While the owner is primarily responsible for developing a business case for EE, the team established during Workshop 1 supports the owner during the development. The objective of this step is to develop a business case that, based on benchmarking, clearly defines the expected financial values and constraints of the intended EE investments.

8.2.1 Identifying Opportunities

Developing a business case is a discovery process to analyze opportunities for EE investments. TVD-DMP aims to create a business case that includes a detailed financial summary of expected values, based on benchmarking.

8.2.2 Financial Value Definition

The business case must clearly state the owner's financial criteria that establish the viability of EE investments. Throughout TVD-DMP, the project team will gauge the cost-effectiveness of EEMs against the criteria. The financial criteria are often specified in the form of (minimum) ROI or (maximum) payback period.

8.2.3 Developing Feasible Energy Efficiency Measures (EEMs)

Developing feasible EEMs is a critical step for the EE business case, and can be achieved by following certain steps:

- Determine baseline buildings
- Determine target building systems
- Develop feasible EEMs in each system
- Estimate costs and benefits of each EEM

8.2.3.1 Determine Baseline Buildings

The owner is suggested to develop an operation model by benchmarking her/his portfolio of buildings, which can represent baseline buildings of different types. The baseline buildings will serve as basis for incremental costs and benefits of EEMs throughout TVD-DMP.

8.2.3.2 Determine Target Building Systems

Based on the baseline buildings, the project team can support the owner in determining target building systems. Each particular building system's needs for EEMs are unique; given any one building, investing in one particular system may make more financial sense than in another system. Based on my learning from the interviews performed as part of the DOE research, Table 8-2 orders building systems by typical simple payback periods of their EEMs.

Table 8-2: Building Systems Sorted by Simple Payback Periods

Building Systems	Simple Payback Periods
Building automation system	1 to 2 years
Lighting system	↓
Cooling system	↓
Heating system	↓
Building envelope system	↓
Photovoltaic system	Over 20 years

8.2.3.3 Develop Feasible EEMs in Each System

After selecting the target building systems based on the owner's financial criteria, the project team supports the owner in developing EEMs of each system.

8.2.3.4 Estimate Costs and Benefits of Each EEM

Based on the list of feasible EEMs, the project team estimates costs and benefits of each EEM based on historical data. Then, the owner can evaluate the cost-effectiveness of EEMs by employing simple payback calculations that can help eliminate unrealistic EEMs without much effort invested.

8.2.4 Value Analysis Tools

Even in this early phase, value analysis and management can be helpful. TVD-DMP suggests the use of formal and systematic a decision-making system (e.g., CBA) for value analysis.

8.2.5 Determining the Allowable Cost

Detailing financial constraints is a critical piece of the business case. With TVD-DMP, the owner must specify the allowable cost—an amount of money the owner is able and willing to spend in order to achieve project purposes (Ballard 2008). The allowable cost is further compared to cost benchmarking to make a go/no go decision during Workshop 2.

In contrast to the TVD protocol, TVD-DMP does not assume that the owner will have to apply for a construction loan, and consequently, the available loan size does not determine the allowable cost. Rather, TVD-DMP assumes that the owner has a budget in his financial plan specially allocated for the EE business case.

8.2.6 Benchmarking

Developing a business case requires two different types of benchmarking: EE benchmarking and cost benchmarking.

8.2.6.1 EE Benchmarking

EE benchmarking can be primarily used to compare baseline buildings to their peer groups in order to identify opportunities for EE improvements. Until energy simulations are performed for estimating a detailed energy consumption profile of the building, such benchmarking provides a rough estimation of energy savings.

If the owner does not have enough buildings in his/her portfolio, the project team can use public, available data such as the Commercial Building Energy Consumption Survey (CBECS), or ENERGY STAR's Target Finder[1].

8.2.6.2 Cost Benchmarking

Cost benchmarking is to identify the 'expected cost' by studying a peer group or using a cost model (Ballard 2008). The expected cost can then be compared to the allowable cost. When expecting higher EE than the baseline benchmark building, the allowable cost can be adjusted higher than it would have been otherwise. The relationship between EE and project cost in TVD is in the determination of worth, which in turn is built on expected net benefits in use of the constructed asset. Thus, TVD-DMP suggests that the client should be willing to spend more to get higher EE (higher life cycle value), assuming investment funds are available.

8.3 WORKSHOP 2: DEFINITION

Workshop 2, named "Definition", provides the owner an opportunity to filter out projects that do not make financial sense (e.g., the expected cost is greater than the allowable cost), before investing significant resources. During Workshop 2 the owner will decide whether or not to fund a validation study.

8.3.1 Verifying Design Inputs

Workshop 2 also provides the project team an opportunity to verify design inputs available from the owner's business case, before proceeding to the validation study. Key design inputs must include, but are not limited to:

- Financial criteria (the allowable cost, minimum ROI, maximum payback, etc.)
- LEED goal
- Must-have's and/or want-to-have's
- Facility program and operation schematic

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[1] http://www.energystar.gov/index.cfm?c=new_bldg_design.bus_target_finder

Figure 8-3 shows an example of the list of design inputs that a project team expects to get from a business case of the owner. The project team must confirm that the business case is not missing any key design inputs, so that it can maximize the effectiveness of the validation study in a given time.

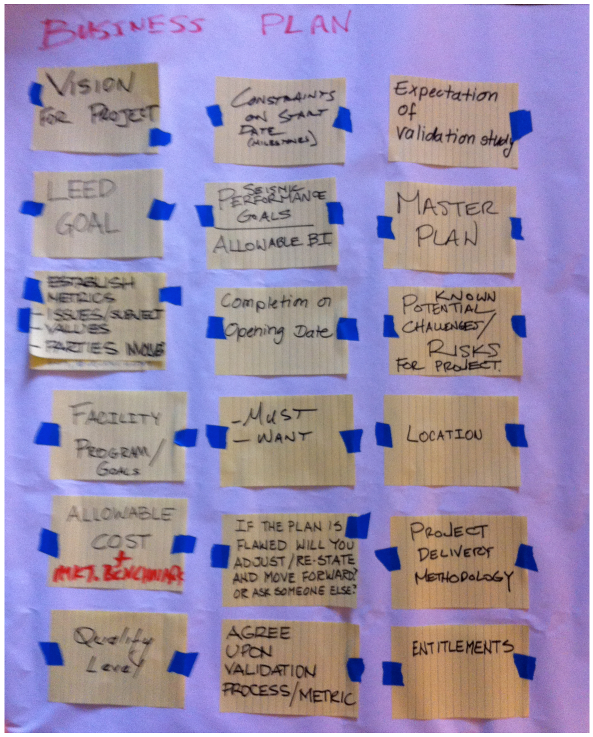

Figure 8-3: Design Inputs Expected from a Business Case
(Photo Taken by Hyun Woo Lee at a P2SL Workshop on May 25, 2011)

8.3.2 Team Organization

TVD-DMP does not dictate who and how many people are involved in the validation process, but suggests that the validation study involve major players (the Core Group), including an architect, CM/GC, MEP contractors, and major engineering consultants. These are the parties that will significantly influence EE design decision making later on.

8.3.3 Target Value Design Training

To begin Workshop 2, the project team invites more participants for the plan validation than Workshop 1. Therefore, similar to the training during Workshop 1, TVD-DMP suggests hosting another formal training to educate new participants that are unfamiliar with TVD.

8.4 STEP 2: VALIDATE THE BUSINESS CASE

The objective of this step is for the project team to perform a validation study of the business case. The cross-disciplinary team ('cross functional team') can be motivated to validate the business case by having their fees in an 'at-risk pool' in a system of shared risks and rewards. The study is essential to establishing shared understanding among the project team about basis of design, basis of budget, and basis of operation.

8.4.1 Evaluation of Each Energy Efficiency Measure for Risk Identification

Inherent in EE investments are numerous uncertainties, and TVD-DMP suggests identifying, managing, and reducing such uncertainties so the project team can increase predictability of the target property's financial performance. TVD-DMP starts with the three specific uncertainties, as discussed throughout this dissertation:

- Project cost uncertainty
- Operational practice uncertainty
- System performance uncertainty

Based on the list of EEMs developed in the business case, the project team estimates ranges of each uncertainty considered in its economic analysis. At this early phase, this task must be simple as specifying key parameters for probability density functions (PDF) of each EEM. Adapting from Chapter 6, Table 8-3 presents a sample uncertainty table. The identified uncertainties of each EEM will be gauged against their expected benefits during the validation study.

Table 8-3: Sample Uncertainty Table of EEMs

Building System	**EEM Description**	Uncertainty	**Project Cost**			**Operational Practice**		
		PDF	PERT-Beta			Lognormal		
		Parameters	Min	Mode	Max	5^{th} PT*	Mean	95^{th} PT*
HVAC	EEM1							
Lighting	EEM2							
Envelope	EEM3							

* PT: Percentile

8.4.2 Risk Analysis Tools

During the validation study, TVD-DMP suggests that the project team apply Monte Carlo Simulation (MCS) and/or discounted cash flow (DCF) to their study.

8.4.2.1 Monte Carlo Simulation

MCS is an effective method to estimate the impacts of uncertainties on the financial performance of target projects. As stated earlier, the project team must define/assume PDF of each uncertainty for its analysis. The appropriate distribution can be decided upon from past experience, judgment of the analyst, or market research. If the team decides not to define a PDF for some EEMs, they can still use some deterministic numbers while still stochastically simulating the other EEMs.

8.4.2.2 Discounted Cash Flow

DCF can provide an organized assessment of revenue and risk, and provide rich details to understand the financial implications of decision making. Although DCF is regarded as a time-consuming economic analysis method, TVD-DMP still recommends that the project team develop a DCF to the extent that the owner sees fit.

8.4.3 Developing Basis of Design, Budget, and Operation

The basis of design, budget, and operation are primary outputs of the validation study, and their purpose is to maximize shared understanding among the project team for design development.

In TVD-DMP, the basis of design provides design criteria and guidelines for energy-related building components such as HVAC, lighting, envelope, and roofing. The basis of the budget provides detailed budget items from which the project team can develop designs. In addition, the basis of operation provides the description of facility operation and plug loads (i.e., electrical demand of devices that plug into the electrical system of a building) that serves as inputs to energy modeling.

8.4.4 Pull Planning

For the validation study, information is 'pulled' from the business case to make information flow and work sequence reliable. Figure 8-4 illustrates an example of information flow and work sequence that a group of practitioners envisioned for a validation study, developed by means of pull planning, in a design workshop.

Figure 8-4: Information Flow for Pull Planning during Validation Study
(Photo Taken by Hyun Woo Lee at a P2SL Workshop on April 28, 2011)[2]

8.5 WORKSHOP 3: ALIGNMENT

Workshop 3 named "Alignment" is designed to verify the alignment of purposes, designs, and constraints in EE investments. The objective of Workshop 3 is for the owner to

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[2] Appendix D presents the detailed validation information flow.

decide whether or not to fund the project, and whether or not to proceed to design development.

8.5.1 Bundling Energy Efficiency Measures

Adapted from 'Integrated Design,' TVD-DMP has the project team develop different levels of 'bundling.' A bundle is a grouping of individual EEMs based on different optimization levels. Bundling can represent interactive effects of a group of EEMs on EE, as well as on incremental costs. A number of bundles can be developed to represent 'aggressive' savings, and one 'extreme' bundle can be also considered with state-of-the-art technology.[3]

This practice produces estimates of the relative cost effectiveness of different bundles of EEMs while evaluating the uncertainties identified during the validation study. This early evaluation of bundling to enhance the financial performance can give the owner more confidence in making informed, situational decisions.

To verify the risks and returns of different bundles, TVD-DMP has the project team performing early energy modeling, specifying options only for major design parameters, including:

- Facility operation schedule
- Plug load
- Orientation
- Glazing ratios and exposures
- Wall/roof insulation values
- HVAC systems
- Lighting and electrical systems

8.5.2 Basis for Targets

Establishing the basis for reasonable targets is important, because they establish benchmarking points for shared risks and rewards. Different levels of bundles ranging from the baseline to 'extreme' can provide bases for realistic goals that the project team can agree on.

8.6 STEP 3: SET TARGETS

The objective of this step is to set targets for design development, thereby encouraging design innovations.

8.6.1 Setting Target Building Performance

The target building performance refers to a 'target value' in TVD-DMP. The building will have to achieve the target value for the business case to be viable, because the target value determines energy savings as ROI. Therefore, setting the target building

[3] Appendix B presents examples of bundling in different levels.

performance is critical in TVD-DMP to enable the project team to 'design to target value.'

8.6.2 Setting Target Cost

Comparing the allowable cost to the expected cost during the validation study leads to setting the target cost. As it is the basis for 'designing to target cost,' setting a reasonable target cost is critical for the success of TVD-DMP.

8.6.3 Allocating Target Costs to Clusters

After the overall target cost is set for the project, the target cost is broken down and allocated to clusters. Clusters are functional groups organized by major buildings components such as electrical, HVAC, and building envelope.

8.7 STEP 4: DESIGN TO TARGETS

The objective of this step is to apply lean design management to steer design to targets—the target building performance and the target cost—established during the previous step.

8.7.1 Cluster-based Team Organization

TVD-DMP suggests that design and estimating be coordinated by clusters. Each cluster has a cross functional team including designers and builders. The clusters are particularly important for TVD-DMP, because (1) clusters localize the design and estimating discussions, and (2) each cluster group is responsible for tracking the trend of their estimate against its target cost, and it encourages collaborative efforts to complete the project as a whole.

8.7.2 Set-based Design

TVD-DMP suggests that the project team consider many design alternatives and keep them open until the 'last responsible moment.' This practice, called SBD, can promote design innovations, because it encourages the team to develop and concurrently study a wide range of alternatives.

Bundles developed during Workshop 3 contribute to SBD. TVD-DMP (as is done in parametric design) suggests that values of design parameters in the bundles must be considered in ranges rather than in deterministic figures. Table 8-4 presents sample design parameters of some building systems.

Table 8-4: Design Parameter Examples by Building Systems
(Adapted from Vaidya et al. 2009)

Building Systems	Design Parameters
Building Envelope	Glazing U-Factor
	Glazing Solar Heat Gain Coefficient
	Glazing Visible Transmittance
	Glazing Ratio
	Window Overhangs
	Wall Insulation/Mass
Lighting	Lighting Power Density
	Occupancy Sensor Control Lighting
	Daylighting Control
HVAC	Heating Plant Size
	Cooling Plant Size
	Supply Air/Duct/Fan Size
	CO_2 Control of Outdoor Air
	Occupancy Sensor Control of Air

8.7.3 Sharing of Incomplete Design Information

Sharing of incomplete design information is another critical piece of SBD and helps prevent overdesign. Overdesign often happens when design discussions are made in a fragmented manner and when design inputs are speculatively assumed. Therefore, the sharing of incomplete design information through cross-functional teaming and cluster-based teaming prevents rule-of-thumb calculations and 'design-in-silos.' The project team can rightsize building components in such a way that they not only reduce the first cost but also reduce energy costs over the lifecycle of the building.

8.7.4 Co-location

TVD-DMP urges the use of co-location during design development, because sharing of incomplete design information can be best facilitated by co-location. It contributes to real-time information sharing and timely decision-making.

8.7.5 Rapid Estimating

TVD-DMP requires rapid estimating of design changes to proactively steer designs to target costs—"Cost estimating and budgeting is done continuously through intimate collaboration between members of the project team—'over the shoulder estimating'" (Ballard 2009a). For the process to be successful, rapid estimating must produce frequent, reliable, and transparent cost estimates.

8.8 SUMMARY

TVD-DMP can help achieve a high level of collaboration and coordination that is required for EE investments. Consequently, it can provide a decision-making process to maximize integration among building systems while effectively reducing energy-related risks.

Figure 8-5 summarizes the overall process of TVD-DMP, presented in Chapter 8.

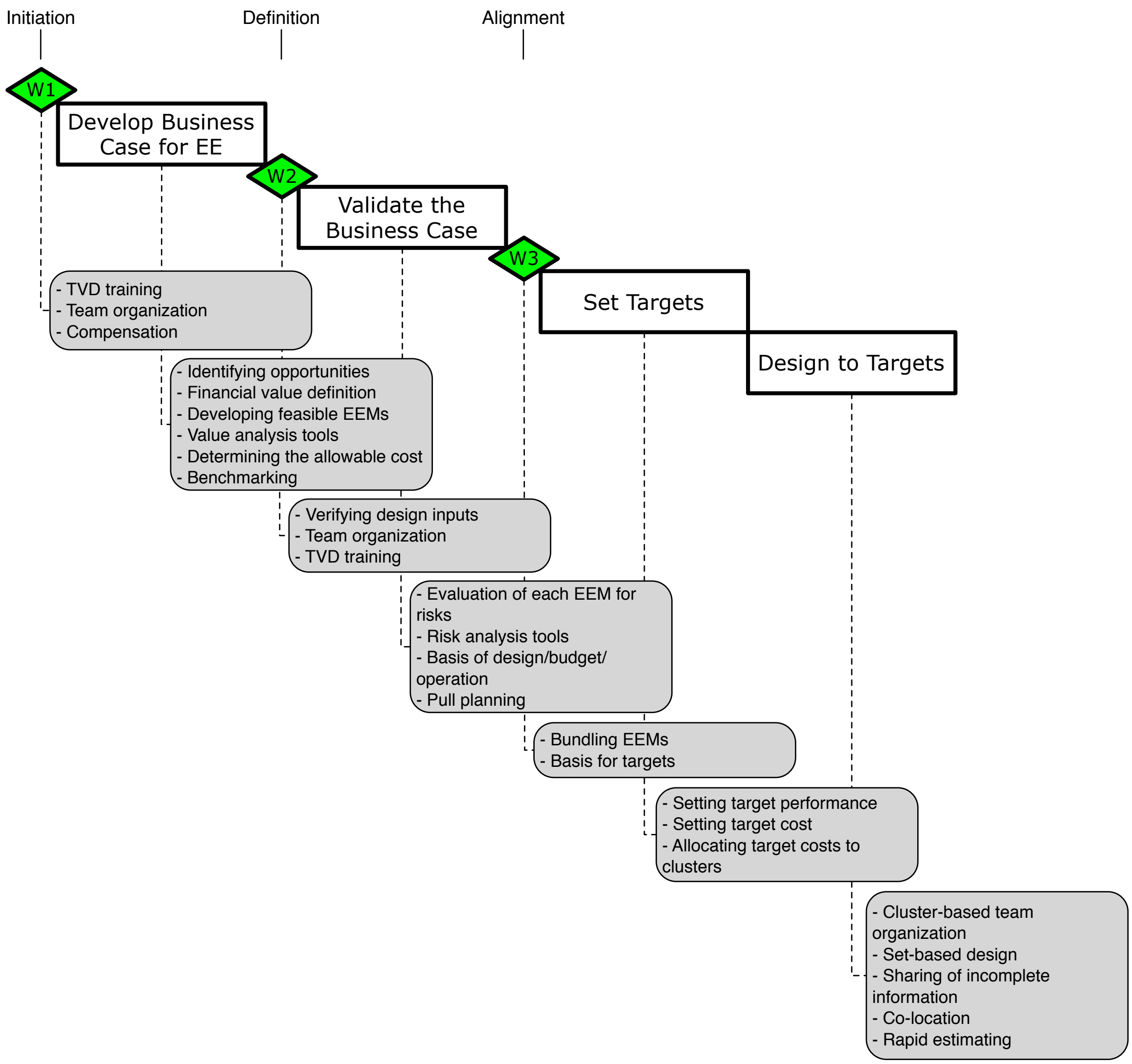

Figure 8-5: Summary of TVD-DMP

CHAPTER 9. CONCLUSIONS

This chapter presents the research findings in response to the research questions. It states the contributions to knowledge and concludes with questions for future research.

9.1 RESEARCH FINDINGS

This dissertation presented a combination of quantitative and qualitative approaches, involving literature review, case studies, interviews, and simulation model. This section presents answers to the research questions raised in Chapter 1.

9.1.1 Target Value Design Protocol and Life Cycle Cost Analysis Method

9.1.1.1 What types of uncertainties and barriers exist in commercial EE improvement projects, specifically energy retrofits?

Performing interviews with industry practitioners was an integral part of the investigation. Chapter 4 summarized over thirty semi-structured interviews conducted with people working in a wide range of US-based companies and organizations involved in the development of commercial buildings. Interviewees seemed to agree that the movement to implement EE in the commercial building sector is still hampered by various market barriers, including inadequate access to capital, short payback expectation, and uncertainty in energy performance. Among the listed barriers to EE, financial barriers appear to be the largest.

Inherent to EE investments are various risks that contribute to the financial barriers, which fall into two categories, namely project cost risk and performance risk. Given these two categories, this dissertation focused on the types of uncertainties listed below, which were the basis for the development of case studies and the TVD protocol and ERLAM:

- Project cost uncertainty
- Operational practice uncertainty
- System performance uncertainty

Unmanaged uncertainty can result in unnecessary contingencies in programs and/or designs, which in turn lead to overspecification and overdesign. Particularly with EE investments, overspecification and overdesign can be detrimental, because they can increase first costs as well as energy costs (e.g., HVAC oversizing).

Chapter 4 explained that when evaluating construction loan applications for EE improvement projects, lenders mainly focus on assessing risks through a set of financial metrics such as NOI, LTVR, and DSCR. Lenders have risk rating systems that use both DSCR and LTVR. Unmanaged uncertainties appear to result in an increased perception of risk that lenders hold during underwriting (i.e., higher risk ratings), and that most likely leads to higher interest rates and cap rates. Subsequently, loan applicants (e.g., developers and building owners) can suffer from higher cost of borrowing and increased difficulty of funding. These are the financial barriers to overcome.

The case of Building A in Chapter 6 illustrated how different risk ratings based on DSCR and LTVR would impact the cost of borrowing with differing interest rates and cap rates; as DSCR decreases and LTVR increases, risk ratings increase. That again leads to higher interest rates and cap rates. Consequently a business case for an EE investment loses its viability due to the higher cost of borrowing.

The HR system case in Chapter 7 illustrated challenges regarding a specific EEM of HRCs in rooftop AHUs. The case study described how the HRCs would affect different types of energy-related uncertainties. The chapter further showed how TVD in an IPD environment helped the project team reduce the uncertainties and incidences of the EE system complexity and overdesign.

9.1.1.2 By adapting the existing TVD methodology, how can a TVD protocol be developed to improve the current commercial loan underwriting practices?

The objective of TVD is not to minimize project cost, but to maximize the value of the project to the customer, within the project constraints including financial constraints. Maximizing value can mean increasing the predictability of project outcomes by managing and reducing uncertainties. To accomplish that, TVD focuses on improving the assessment of project feasibility through validation study and increasing shared understanding between stakeholders. TVD allows concurrent and interorganizational collaboration in the design and estimating processes that enables an effective use of LCCA for managing and reducing various uncertainties early on.

I adapted the existing TVD methodology to the specific conditions and requirements of the energy retrofit preconstruction process. As a result, I developed a TVD protocol and presented it in Chapter 5. The TVD protocol includes eight key steps that borrowers and lenders can follow to achieve more effective underwriting in EE investments. The protocol redefines for key decisions: (1) the parties that are involved, (2) when certain steps are taken, and (3) how such decisions are made.

The implementation of this protocol involves realigning the current process of loan underwriting to obtain reliable information flow to reduce specific uncertainties. Through such realignment, the TVD protocol provides borrowers opportunities to develop business cases that are based on the evaluations and risk criteria of their target lenders. The protocol also advocates for the use of the new ASTM E2797 – 11 for benchmarking the property's performance to other buildings. Such benchmarking can be beneficial to managing energy performance uncertainties.

While the TVD protocol can be readily understood on paper, some practitioners may struggle implementing it on an actual project. Thus, I developed swim-lane diagrams of and guidelines to the TVD protocol's eight key steps to make it easy to implement. The swim-lane diagrams also highlight the importance of iterations during the underwriting process.

As an initial validation of the TVD protocol, I got feedback from three commercial banks ranging in size from small, medium, to large. Their responses were positive and they appeared interested in implementing the TVD protocol in their underwriting process.

9.1.1.3 Can the target building performance and the allowable cost be estimated to support the TVD protocol considering specific uncertainties related to EE investments?

With the TVD protocol presented in Chapter 5, Chapter 6 presented a framework to support Step 4 of the protocol—'borrower-lender coordination.' This is a key part of successfully applying TVD. Step 4 allows borrowers and lenders to collaborate early to determine the feasible loan size and loan terms, and consider types of uncertainty in a specific EE investment.

Step 4 involved the development of a simulation model that can determine the impacts of energy-related uncertainties on the financial performance of target buildings, in this case, NPV of net savings. Thus, Chapter 6 described the Energy Retrofit Loan Analysis Model (ERLAM) I developed to support Step 4, determining the financial impacts of the following specific uncertainties:

- Project cost uncertainty, which represents project cost risk
- Operational practice uncertainty, which represents performance risk

With the two uncertainties as key input variables for ERLAM, using a real case in Northern California office building, Chapter 6 demonstrated how ERLAM helps determine (1) the target building performance and (2) set the allowable cost based on the said target. The case study presented in Chapter 6 revealed again that the current loan underwriting practice appears ineffective in addressing energy-related uncertainties. In response, Chapter 6 showed that ERLAM can support Step 4, by addressing specific uncertainties for determining a feasible loan size and loan terms for TVD implementation.

9.1.2 Target Value Design for Energy Efficiency in Integrated Project Delivery

9.1.2.1 How can TVD in an Integrated Project Delivery environment help reduce the uncertainties?

TVD requires collaboration and integration of project teams during its implementation. Thus, TVD is more effective when using an integrated form of project delivery, such as IPD, than it is implemented using conventional, fragmented forms of project deliveries such as DBB.

Chapter 7 presented a case study of the CHH project where the project team encountered several challenges with their HR system. Chapter 7 illustrated the details of the design decision-making process that led to achieving a solution that enhanced EE value delivered to the owner and the end users. The documentation of this process provides a proof of concept for the effectiveness and application of TVD to EE investments.

Through the TVD process, applied in the IPD environment, the project team was able to manage and reduce the following uncertainties related to the HR system:

- Project cost uncertainty
- Operational practice uncertainty
- System performance uncertainty

Project cost uncertainty: By using a SBD approach to evaluate alternative design options and alternative manufacturers, the IPDT effectively reduced the project cost uncertainty without compromising the intended value established during the validation process.

Operational practice uncertainty: With the IPD setting, the IPDT proactively engaged the owner's facility management personnel in the TVD process. Learning from the owner's experience with the HR system in other facilities led to managing and reducing the operational practice uncertainty in the economic analysis of the HR system.

System performance uncertainty: In order to reduce system performance uncertainty related to the HR system, the IPDT addressed all facets of the issues concerning the HR system. The San Francisco Bay Area's mild climate would reduce the effectiveness of the HR system. Energy savings could be claimed only 43% of time. 57% of the time the HR system would cost more to operate, because it would require larger fans that consume more energy than a system without HR. TVD facilitated this investigation and therefore effectively increased certainty of the financial performance of the facility, and reduced the system performance uncertainty.

Overdesign and overspecification have to be addressed and managed for the TVD process to be successful, because overdesign and they can not only increase capital costs but also O&M costs over the lifecycle of a building. In this specific case, the IPDT's effort to reduce uncertainties also resulted in a reduction of incidences of complexity and overdesign related to the HR system (which would have added unnecessary complexity and uncertainties to the overall building system).

The mega-project stature of CHH produced a highly dynamic environment, which triggered the IPDT to revalidate the basis of design throughout the TVD process; this enabled 'double-loop learning.' The revalidation contributed to preventing overdesign related to the HR system, and thereby increased the value delivered to the customer. The research also found that reducing the complexity of the HR system contributed to the strategy of 'designing to target,' while reducing energy-related risks. The TVD process reduced the complexity of field installation tasks.

Overall, the research found the following benefits of the application of TVD to EE investments (Figure 7-12):

- Managing complexity
- Preventing overdesign
- Maximizing value delivered to the customer
- Reducing the three types of uncertainties

9.1.2.2 Can a TVD decision-making process for EE investments be standardized?

Chapter 8 described a standard TVD decision-making process (TVD-DMP). Standardization is key to achieving consistent performance. I developed TVD-DMP by synthesizing results from the literature review, case studies, and interviews performed as part of the dissertation.

The aim of TVD-DMP is to guide project stakeholders through EECB delivery in accordance with their value expectations. TVD-DMP is expected to achieve an integrated method for establishing and validating EE business cases, setting project targets, and steering design to target. An integrated team-building process and integrated team formation based on the process map will help to achieve the project target because in such settings key information can be shared effectively throughout the team.

Like the TVD protocol, TVD-DMP includes process maps and guidelines that define how, when, and who is involved in key decision making. The process can increase shared understanding between project stakeholders while enabling team members to better understand design problems within project constraints. It systematically allows for generating/evaluating design alternatives using a SBD approach and selecting from alternatives. The systematic design decision-making process is a key to successful TVD implementation in EE investments, and TVD-DMP can help achieve consistent outcomes.

9.2 CONTRIBUTIONS TO KNOWLEDGE

The dissertation provided a theoretical understanding of three types of uncertainties and financial barriers that exist in commercial EE improvement projects, specifically energy retrofits. In order to validate the understanding, a series of interviews were performed with industry practitioners involved in the development of commercial buildings. The findings from the literature review (Chapter 2) and interviews (Chapters 4 and 5) revealed the following contributes to financial barriers:

- Lack of an integrated approach to underwriting EE investments
- Lack of understanding how to manage uncertainties related to such investments

In response, this dissertation focused on the development of a TVD protocol (Chapter 5) that lenders and borrowers can follow to achieve more effective underwriting of business cases in EE investments. Preliminary responses to the TVD protocol from the lending industry indicate a positive outlook for future full-scale implementation of the protocol.

In order to increase the applicability of the TVD protocol and support Step 4 specifically, I developed ERLAM to model the impacts of specific uncertainties on the financial performance of target buildings (Chapter 6). Based on MCS, ERLAM computes target building performance and allowable cost. These support the TVD process in both the strategies of ‘design to target value’ and ‘design to target cost.’ I used an energy retrofit investment on a Northern California office building as a case study to test the feasibility of Step 4 using ERLAM.

My research also delivered a proof of concept for TVD in EE investments and validated it through a detailed case study. The case study (Chapter 7) demonstrated that TVD in an IPD environment helped manage and reduce energy-related uncertainties to enhance the predictability of the financial performance of the target property. The IPDT could maximize the EE value delivered to the customer within various project constraints, including financial constraints.

In addition, the literature review, case studies, interviews, and ERLAM lead to defining TVD-DMP. The standard process includes generic multi-level process maps and guidelines that can be readily applied to real cases. Such standardization contributes to successful, consistent implementation of TVD in future EE improvement projects.

This dissertation contributes to the development of an integrated approach to design and estimating management required for EE investments in the A/E/C industry. It also provides the lending industry with valuable insights into how the integrated approach can contribute to risk and uncertainty management so that financial barriers can be effectively overcome.

Research findings have been disseminated in academia and industry through publications and presentations. The publications are as follows:

Hyun Woo Lee, Glenn Ballard, and Iris D. Tommelein (2012). "Developing Target Value Design Protocol for Commercial Energy Retrofits – PART 1." *2012 Construction Research Congress*. Purdue University, West Lafayette, IN, in press.

Hyun Woo Lee, Glenn Ballard, and Iris D. Tommelein (2012). "Developing Target Value Design Protocol for Commercial Energy Retrofits – PART 2." *2012 Construction Research Congress*. Purdue University, West Lafayette, IN, in press.

Hyun Woo Lee, Glenn Ballard, and Iris D. Tommelein (2011). Sections 2.3 and 3.3 of "Energy Risk Management in Commercial Mortgages: A Primer for Lenders." Practical guideline prepared for Office of Energy Efficiency and Renewable Energy at U.S. Department of Energy. University of California, Berkeley, CA.

Hyun Woo Lee, Glenn Ballard, and Iris D. Tommelein (2011). "Task 4: Target Value Design and Delivery Process to Incorporate Energy Efficiency Metrics." Technical report prepared for Office of Energy Efficiency and Renewable Energy at U.S. Department of Energy. University of California, Berkeley, CA.

The presentations are as follows:

"DOE Finance Research – Development of LCCA-MCS Method to Support TVD Protocol." *Project Production Systems Laboratory (P2SL) Annual Conference*, March 7, 2012. University of California, Berkeley, CA.

"DOE Finance Research – Development of Target Value Design Protocol." *Project Production Systems Laboratory (P2SL) Annual Conference*, April 27, 2011. University of California, Berkeley, CA.

9.3 FUTURE RESEARCH OPPORTUNITIES

The government, industry and academia have developed their interests in studying how to overcome the financial barriers to EE investments. However, how to manage and reduce uncertainties related to such investments is quite new. Accordingly, many opportunities exist for future research.

Above all, a statistical analysis is suggested to validate the effects of TVD. Efforts have been initiated to collect more project data. Sixteen projects where TVD was explicitly implemented are presented in Appendix A. The findings are promising. The sixteen TVD projects reported an average 15% lower cost than market cost, proving TVD's effectiveness in managing project cost uncertainty. Further, research is needed to formalize statistical relations between TVD and the value EE adds to properties over their life cycles. The aim of the investigation is to relate proper management of uncertainties to the financial performance of properties in terms of risk management. As the loan underwriting process is driven by risk and reward of EE investments, the results from such statistical analyses can provide lenders more confidence in underwriting EE investments, delivered with integrated approaches such as TVD in an IPD environment.

Whole-life cost benefits of TVD implementation are also worth studying. This dissertation focused on direct financial benefits from EE investments, such as energy savings. However, EE investments can yield many other indirect financial benefits, which would make business cases more viable. Some indirect financial benefits include enhanced productivity, increased sales, and reduced vacancy rates. Therefore, future research is suggested to investigate the effects of TVD implementation on whole-life costs of commercial properties by developing total value propositions of TVD (e.g., Figure 9-1).

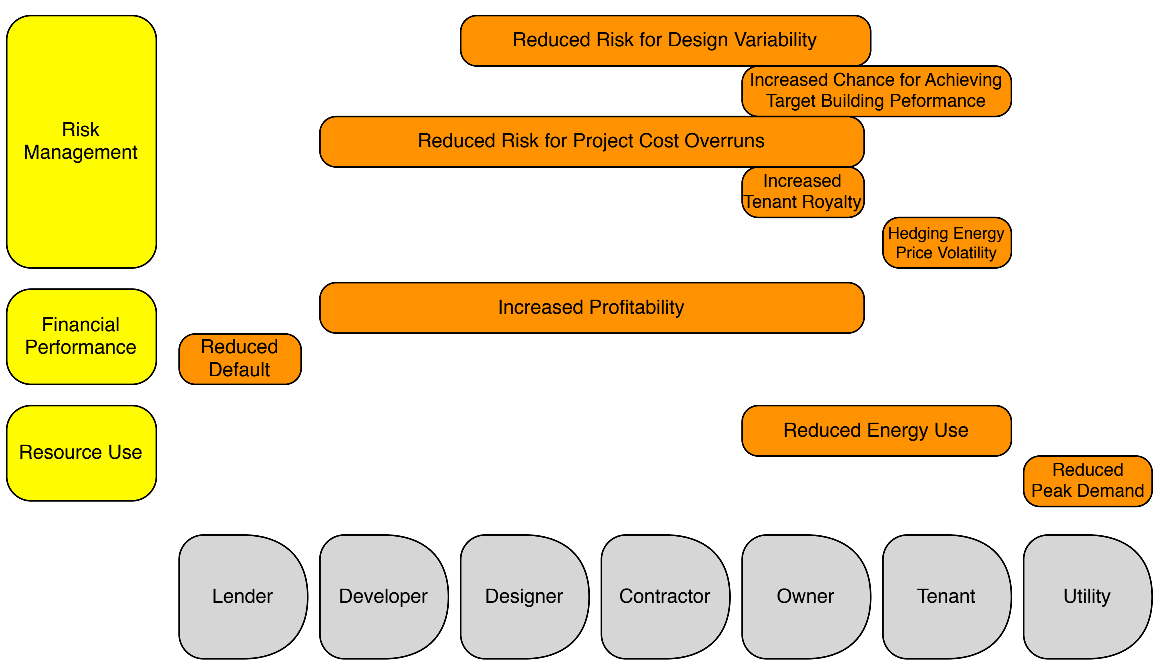

Figure 9-1: Value Propositions of TVD to EE Investments (Adapted from Pater 2006)

I sought an initial validation of the TVD protocol by surveying three lenders. TVD needs to be further implemented in real cases to test its feasibility. I plan to work with major lenders to look for opportunities. Using the value stream mapping methodology, I will implement the TVD protocol and evaluate results, so that the protocol can be further refined.

The dissertation presented a case study of CHH and documented the design decision-making process, which provided a proof of concept for an application of TVD to EE investments. To expand the case study effort, the standard TVD decision-making process is to be further tested in more case studies.

9.4 CONCLUSION

Research presented in this dissertation applied concepts of TVD—that have been applied to a number of capital projects—to EE investments. The aim of the research was to adapt the existing TVD methodology to the specific conditions and requirements of such investments to overcome financial barriers by better managing uncertainties related to EE. Using a combination of quantitative and qualitative approaches, this research demonstrated the feasibility of applying TVD to EE investments and its benefits to EE design decision-making process. Future research to implement TVD to more EE investments is needed to generate statistically meaningful performance improvement data to convince the industry of the value of TVD implementation. Significant opportunities also remain to improve the TVD protocol developed in this dissertation through analysis of additional case studies.

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APPENDIX A. LIST OF 16 TARGET VALUE DESIGN PROJECTS

Table A-1: List of 16 TVD Projects[1]

Ref	Project Size	Date Completed	Market Cost (Benchmaked or Expected)	Target Cost Set for Designing	Final Cost (or Current Estimate if below Target)	Market Unit Cost / SF	Target Unit Cost / SF	Final Unit Cost / SF	Improvement in % (Realized or Targetted)
1	114,000 SF	Aug-02	$ 13,533,179	$ 11,645,250	$ 11,716,836	$ 158		$ 103	35%
2	230,000 SF	Nov-07	$ 22,000,000	$ 18,900,000	$ 17,900,000	$ 96		$ 78	19%
3	105,230 SF	Nov-08			$ 40,887,342			$ 389	0%
4	75,362 SF	2006	$ 13,600,000	$ 13,100,000	$ 11,200,000	$ 180		$ 149	18%
5	231,966 SF	In construction	$ 309,000,000	$ 229,514,852	N/A	$ 1,332	$ 989		26%
6	925,000 SF	In construction documents	$1,109,895,176	$ 960,958,000	N/A	$ 1,200	$ 1,039		13%
7	869,000 SF	In construction documents	$1,812,000,000	$ 1,586,000,000	N/A	$ 2,085	$ 1,825		12%
8	233,050 SF	In design development	$ 312,703,815	$ 295,486,733	N/A	$ 1,342	$ 1,268		6%
9	107,000 SF	In design development	$ 281,000,000	$ 250,000,000	N/A	$ 2,626	$ 2,336		11%
10	477,000 SF	In construction documents	$ 210,000,000	$ 189,017,000	$ 187,557,000	$ 440		$ 393	11%
11	368,882 SF	Dec-09	$ 98,000,000	$ 94,000,000	$ 89,200,000	$ 266		$ 242	9%
12	101,992 SF	In construction	$ 163,294,171	$ 108,324,655	N/A	$ 1,264	$ 1,062		16%
13	430,000 SF	Mar-09			$ 153,300,000			$ 357	
14	138,000 SF								
15	220,587 SF		$ 45,500,000			$ 206			
16	30,000 SF	Oct-10	$ 14,500,000		$ 13,700,000	$ 483		$ 457	18%
								average	15%

[1] Project titles or locations may not be disclosed for confidentiality.

APPENDIX B. TARGET VALUE DESIGN COST METRICS

The DOE research (Chapters 4 and 5) had five different tasks and Task 4 was for developing the TVD protocol and TVD cost metrics. Along with the TVD protocol, the Task 4 team also developed a spreadsheet-based cost model for estimating the construction cost uncertainty for various EEMs. Figure B-1 illustrates the collaborative process between the Task 4 team and LBNL (Lawrence Berkeley National Laboratory) for developing the cost metrics.

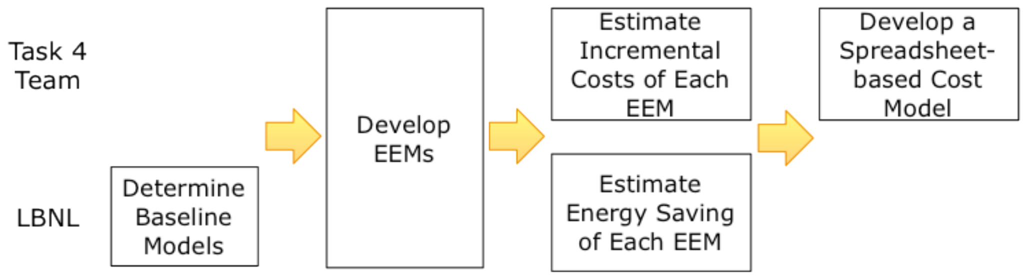

Figure B-1: Task Flow for Developing Cost Metrics

LBNL selected the three baseline models from the DOE's commercial benchmark buildings (Table B-1). Then, with a joint effort with the Task 4 team, a list of measures was developed and the full list is presented in Section B.4. The list focuses on the building systems that require capital expenditures for enhancing EE, so management and control issues are not included, except for "install EMCS[1]" as it relates to capital investment.

Table B-1: Summary of Baseline Buildings

Building size	Large	Medium	Small
Total floor area (in square foot)	498,589	53,625	5,500
Number of floors	12 + 1	3	1
Building shape	Rectangular	Rectangular	Rectangular
Shape aspect ratio	1.5	1.5	1.5

The Task 4 team selected categories of target building systems to identify focus areas and to investigate associated EEMs as parameters of a cost model. The team developed about 60 different measures, and the applicability of each measure is limited by the sizes of the baseline benchmark buildings.

In order to achieve reliable cost estimates, the Task 4 team established a strategic research partnership with Davis Langdon, one of the largest cost consulting companies in the world. Davis Langdon has maintained a high reputation in the field of sustainable

[1] Energy Management Control Systems

development such as green buildings and energy-efficient buildings, and they maintain a vast amount of relevant cost data that they continuously update with current market data.

Using the Davis Langdon's up-to-date cost database, the team developed a cost model to provide median incremental costs of each EEM, and low/high ranges of expected costs. The ranges are expected to properly represent the volatility around construction costs of energy retrofits. In addition, depending on the borrower's business case for an energy retrofit project, the cost model is capable of offering adjustable four packages ranging from shallow retrofit to deep retrofit.

B.1 GUIDELINE FOR SPECIFICATION OF COST METRICS

This section provides a how-to guideline for the use in the underwriting process. It is intended to serve as the specification of the cost metrics. The model is developed as a prototype spreadsheet-based cost model.

The spreadsheet has three parts: (1) overall cost summary, (2) base building entry, and (3) EEM selection—to serve the following functions:

1. Overall cost summary outlines the result of the cost analysis by providing the median costs of each package and associated low and high ranges.
2. Base building entry has an input screen where a user can select from the DOE's three benchmark buildings (large, medium, and small).
3. EEM selection is (1) to provide cost estimates and their uncertainty profiles of each EEM (median, low, and high), and (2) to 'bundle' them to enhance the cost-effectiveness.

The following sections provide a number of screenshots for each part assuming the scenario in which the user selects the large benchmark building.

B.2 OVERALL COST SUMMARY

Figure B-2 shows the results of the cost analysis. The screen displays median total costs and unit costs of the four packages, and their low and high ranges.

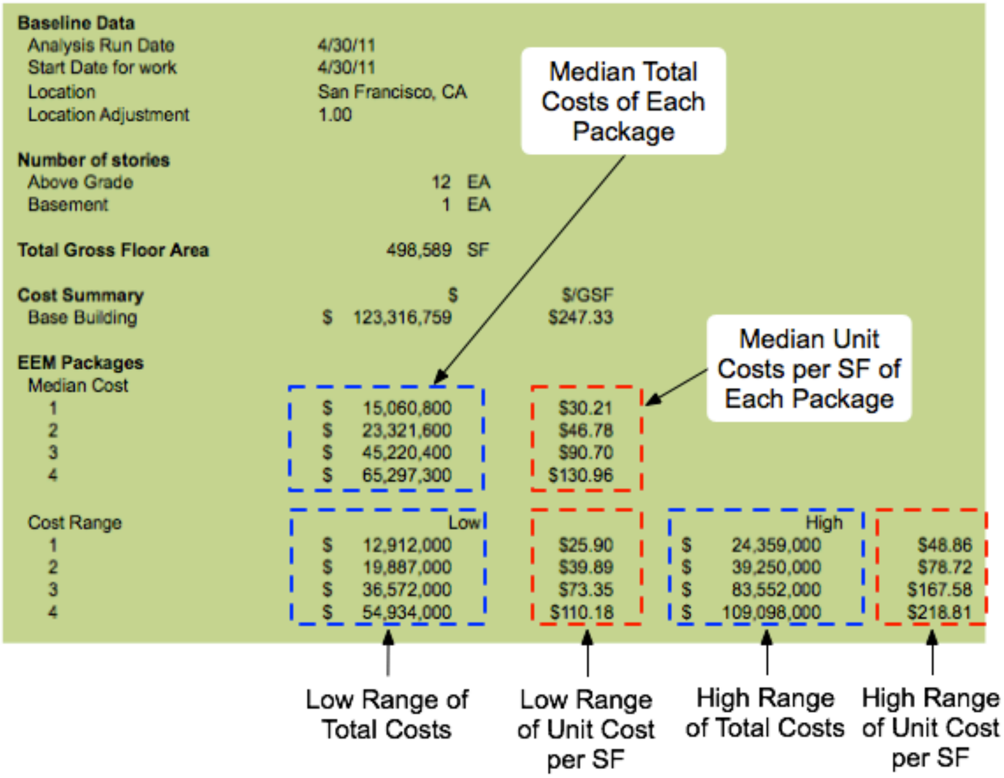

Figure B-2: Screenshot of Overall Cost Summary

B.2.1 Base Building Entry

In this step, two building geometry parameters (floor area and number of floors) are main inputs for the three benchmark buildings (Figure B-3). Other inputs include Retaining Wall Area, Finished Wall Area, Window or Glazing Area, etc. As specified in the column named "Suggested Value," pre-determined formulas automatically calculate inputs for Interior and Service Metrics, and Energy Model Options (Figure B-4).

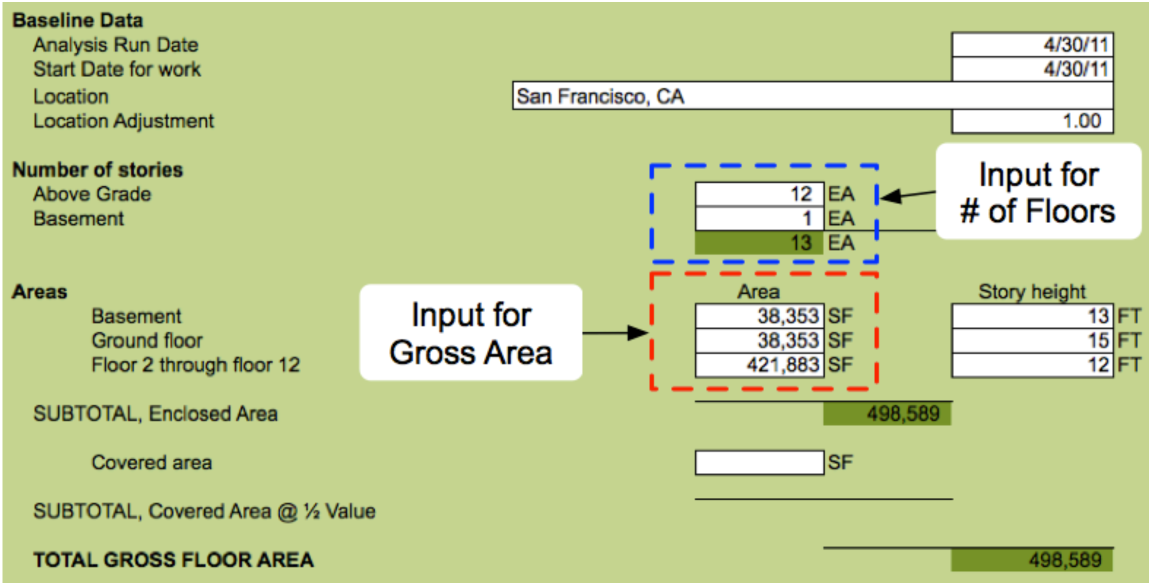

Figure B-3: Screenshot 1 of Base Building Entry

This version only supports the San Francisco area at the current time. Table B-2 summarizes what users need to input for the three benchmark buildings, and every other input will be automatically filled out.

Table B-2: Inputs for Three Benchmark Buildings

Building Size		**Large**	**Medium**	**Small**
Number of Stories	Above Grade (floors)	12	3	1
	Basement (floors)	1	0	0
Areas	Ground Floor (ft^2)	38,353	17,875	5,500
Wall Areas	Retaining Wall Area (ft^2)	10,400	0	0
	Finished Wall Area (ft^2)	124,754	21,291	3,030
	Window or Glazing Area (ft^2)	49,901	7,027	601

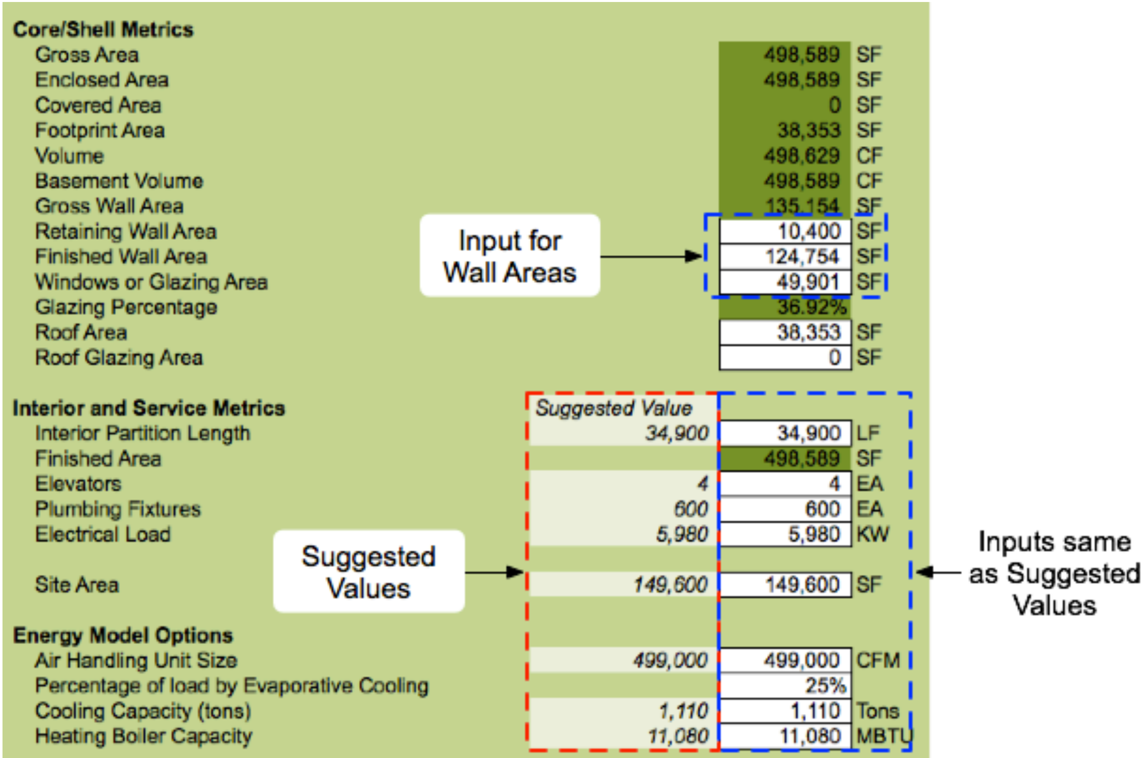

Figure B-4: Screenshot 2 of Base Building Entry

B.2.2 Energy Efficiency Measure Selection

This is the main spreadsheet that users spend most of time. With selecting EEMs from the predefined packages, users can develop their own package that delivers most financial value based on the investment criteria. The predefined packages are our suggestions intended to serve as a reliable starting point. This analytical exercise is particularly important during the process of Step 4: 'borrower-lender coordination.'

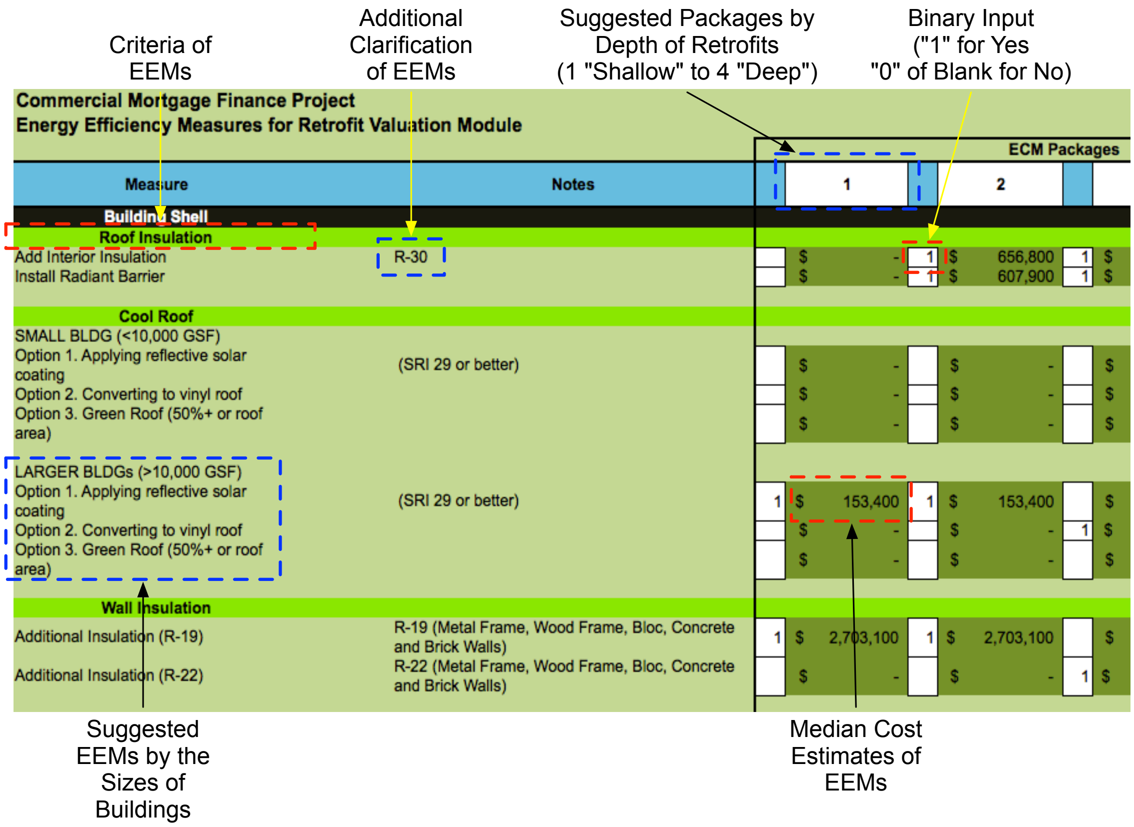

Figure B-5: Screenshot 1 of EEM Selection

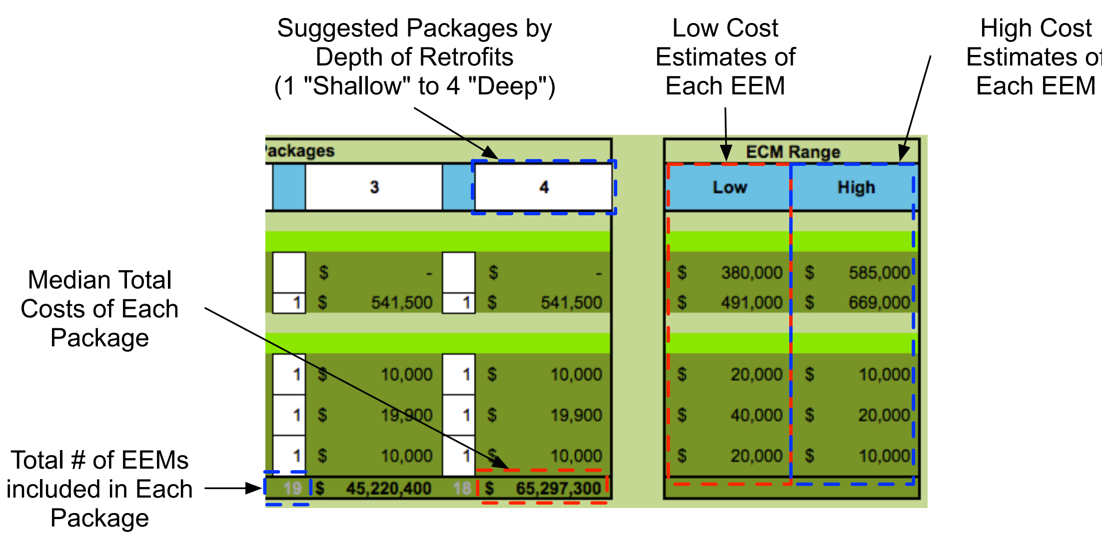

Figure B-6: Screenshot 2 of EEM Selection

B.3 APPLICATION OF COST METRICS

I view that the cost model can be used during 'borrower-lender coordination' in the underwriting process—Step 4 of the TVD protocol. The list of EEMs in the spreadsheet is intended to be an extensive benchmarking tool so that borrowers can start developing their own package from them. Based on the findings from PCA reports, borrowers elect to include or exclude certain EEMs, and thereby borrowers can have productive discussions with lenders when negotiating feasible loan sizes and interest rates. The author also expects that the results from the iterative analysis can be a guideline for designing to targets. Table B-3 summarizes the cost ranges of the four packages for the three benchmark buildings, which can be applicable to ERLAM developed in Chapter 6.

Table B-3: Cost Ranges of Three Benchmark Buildings by Packages

Building Sizes	**Packages**	**Cost Ranges**		
		Low	**Median**	**High**
Large 498,589 SF	1	$12,836,000	$15,060,800	$24,201,000
	2	$19,887,000	$23,321,600	$39,250,000
	3	$36,572,000	$45,220,400	$83,552,000
	4	$54,934,000	$65,297,300	$109,098,000
Medium 53,625 SF	1	$2,562,000	$2,871,400	$4,746,000
	2	$3,513,000	$4,188,400	$7,202,000
	3	$4,751,000	$5,900,900	$11,049,000
	4	$7,112,000	$8,472,700	$14,447,000
Small 5,500 SF	1	$36,000	$43,000	$77,000
	2	$205,000	$273,300	$605,000
	3	$244,000	$321,900	$697,000
	4	$434,000	$530,800	$960,000

I acknowledge construction costs of energy retrofits vary widely by types and sizes of buildings, and have high degree of uncertainty unless it is thoroughly planned ahead of time. Because the model is based on the hypothetical DOE's benchmark buildings, developing the cost metrics in Task 4 is, by nature, exploratory, and its applicability is limited.

B.4 LIST OF ENERGY EFFICIENCY MEASURES

Table B-4: List of EEMs

Energy Efficiency Measures	Notes
Building Shell	
Roof Insulation	
Add Interior Insulation	R-30
Install Radiant Barrier	
Cool Roof	
SMALL BLDG (<10,000 GSF)	
Option 1. Applying reflective solar coating	(SRI 29 or better)
Option 2. Converting to vinyl roof	
Option 3. Green Roof (50%+ or roof area)	
LARGER BLDGs (>10,000 GSF)	
Option 1. Applying reflective solar coating	(SRI 29 or better)
Option 2. Converting to vinyl roof	
Option 3. Green Roof (50%+ or roof area)	
Wall Insulation	
Additional Insulation (R-19)	R-19 (Metal Frame, Wood Frame, Bloc, Concrete and Brick Walls)
Additional Insulation (R-22)	R-22 (Metal Frame, Wood Frame, Bloc, Concrete and Brick Walls)
Glazing	
SMALL BLDG (<10,000 GSF)	
Single -> Double Pane	Assume Large offices already have double pane
Clear -> Tinted	
Clear -> Reflective	
Clear -> Low-e	
LARGER BLDGs (>10,000 GSF)	
Single Pane --> Double Pane	Assume Large offices already have double pane
Clear --> Tinted	
Clear --> Reflective	
Clear --> Low-e	
Add Window Film (Premium)	(Labour included)
Building Shell	
Control Type	
Install Daylight Dimming	requires dimming ballast
Install Occupancy Sensors	1. Directly attached to fixtures 2. separately attached
Lamp	
Incadescent to CFL	Cost of labor/lamp
T-12 to T-8 (includes Electronic Ballast)	From T12 to T8 - Cost of labor/tube + ballast
T-8 to T-5	From T8 to T5 - Cost of labor/fittings + tube + ballast
Change to LED lighting	
Split task-ambeint lighting	1. Assume 30% reduction to W/'/SF - no change in fixture distribution 2. Increase in task lighting cost
DHW	
Insulation	
Storage Water Heater Blanket Installation	
Pipe Insulation	
Efficiency	
HiEff Gas Storage Water Heater	
HiEff Gas Water Heater Boilers	
Instantaneous electric point-of-use heating	$1,200 installed cost each (range from $1,000-$1,500 each) for a 5kW unit
Packaget unit	
Basic PTAC	
High-efficiency packaged Water-Source Heat Pump	
High-efficiency packaged Ground-Source Heat Pump	
Variable Refrigerant Flow	

APPENDIX C. ALGORITHM FLOWCHARTS OF ERLAM

Table C-1: Descriptions of Input Parameters of Algorithm Flowcharts

Parameters	Descriptions
OldUtil	Existing utility cost
NewUtil	Expected utility cost after the energy retrofit
MaintSaving	Expected maintenance cost saving after the energy retrofit
LoanPeriod	Loan period
DiscountR	Discount rate for NPV calculations
ModeCost	Initial project cost estimate
MinCost	Lower boundary of project cost uncertainty to represent the uncertainty range calculated by assuming 20% underrun of ModeCost
MaxCost	Upper boundary of project cost uncertainty to represent the uncertainty range calculated by assuming 50% overrun of ModeCost
MeanOp	No deviation from expected utility cost
5thPT	5^{th} percentile of operational practice uncertainty to represent the uncertainty range calculated from energy simulation
95thPT	95^{th} percentile of operational practice uncertainty to represent the uncertainty range calculated from energy simulation
SimulR	Number of simulation runs
ProjectCost	Input variable for project cost uncertainty (PERT-Beta distribution)
OpPractice	Input variable for operation practice uncertainty (lognormal distribution)
InterestR	Loan interest rate
CapR	Capitalization rate
RR	Risk rating
Loan	Loan size
NOI	Net operating income
Value	Appraised value of the property
AnnualPay	Annual loan payment
RiskR	Computed risk rating based on Table 6-7 (page 80)
NetSaving	Net saving from the energy retrofit (realized savings minus loan payments)
DefaultR	Possibility that the Owner cannot make loan payments with realized energy savings (i.e., possibility that NPV of net savings is negative)

Figure C-1 describes the algorithm that I programed in MATLAB to compute NPV of net savings for sensitivity analysis of the project cost uncertainty on the NPV.

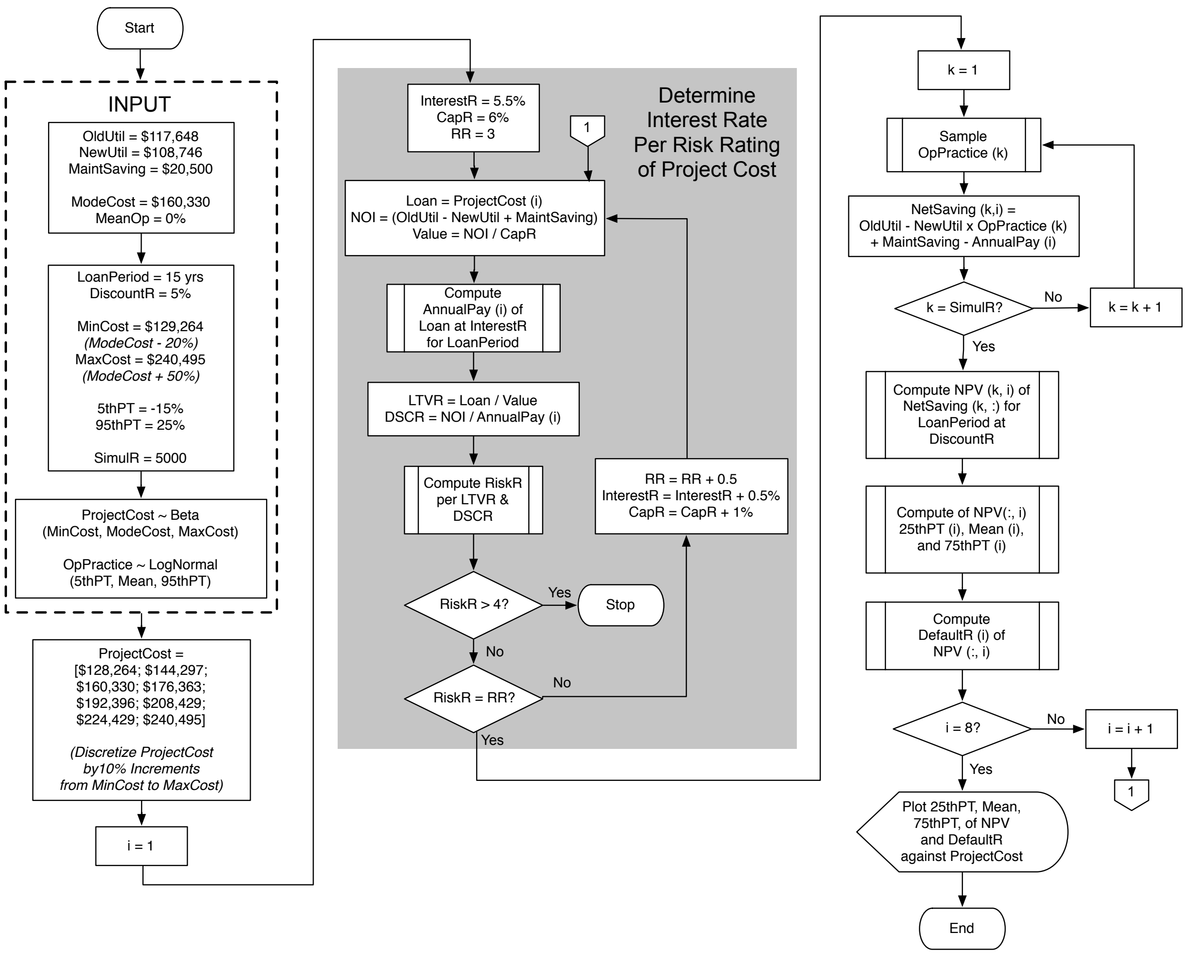

Figure C-1: Algorithm Flowchart for Sensitivity Analysis of Project Cost Uncertainty on NPV of Net Savings

Figure C-2 describes the algorithm that I programed in MATLAB to compute NPV of net savings for sensitivity analysis of the operational practice uncertainty on the NPV.

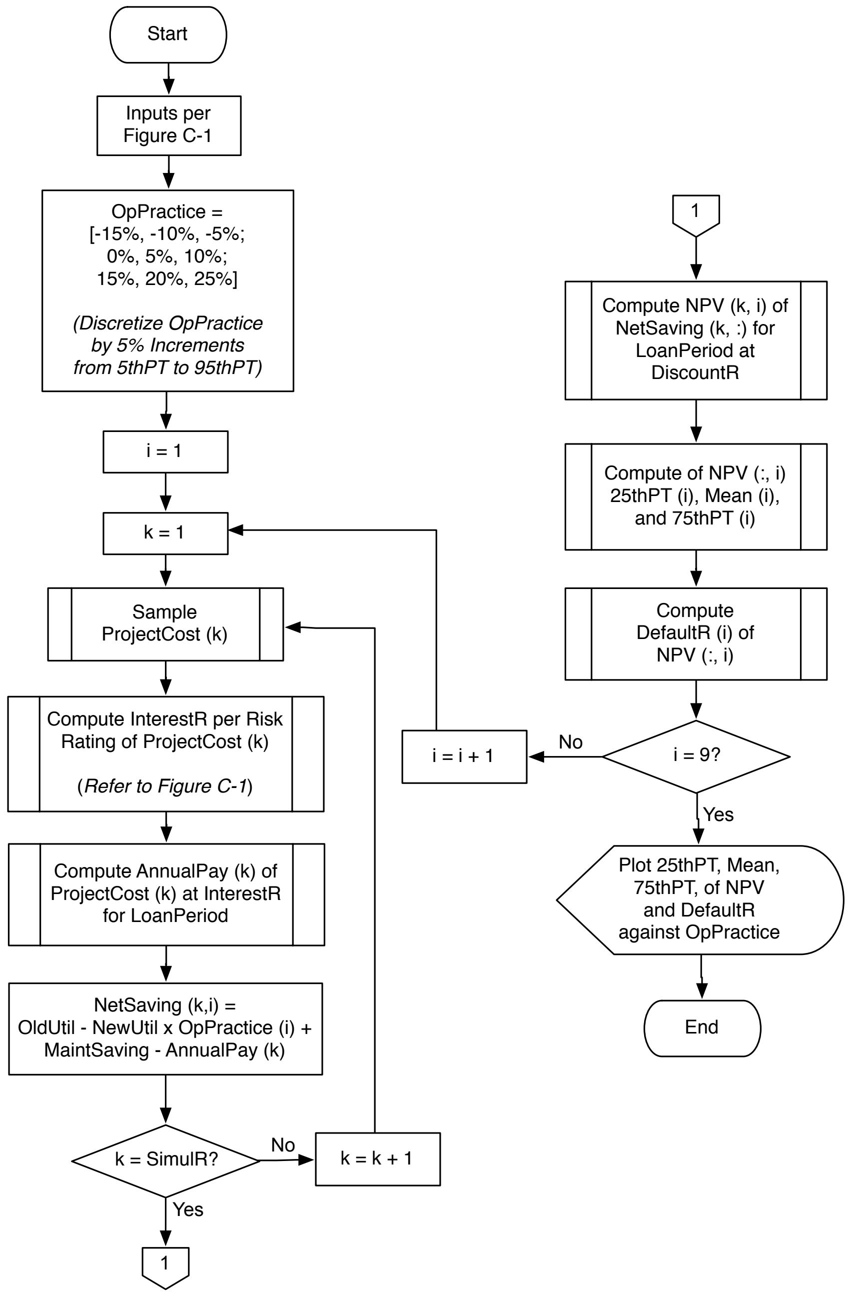

Figure C-2: Algorithm Flowchart for Sensitivity Analysis of Operational Practice Uncertainty on NPV of Net Savings

APPENDIX D. DESIGN INFORMATION FLOW EXAMPLE DURING VALIDATION STUDY OF TVD-DMP

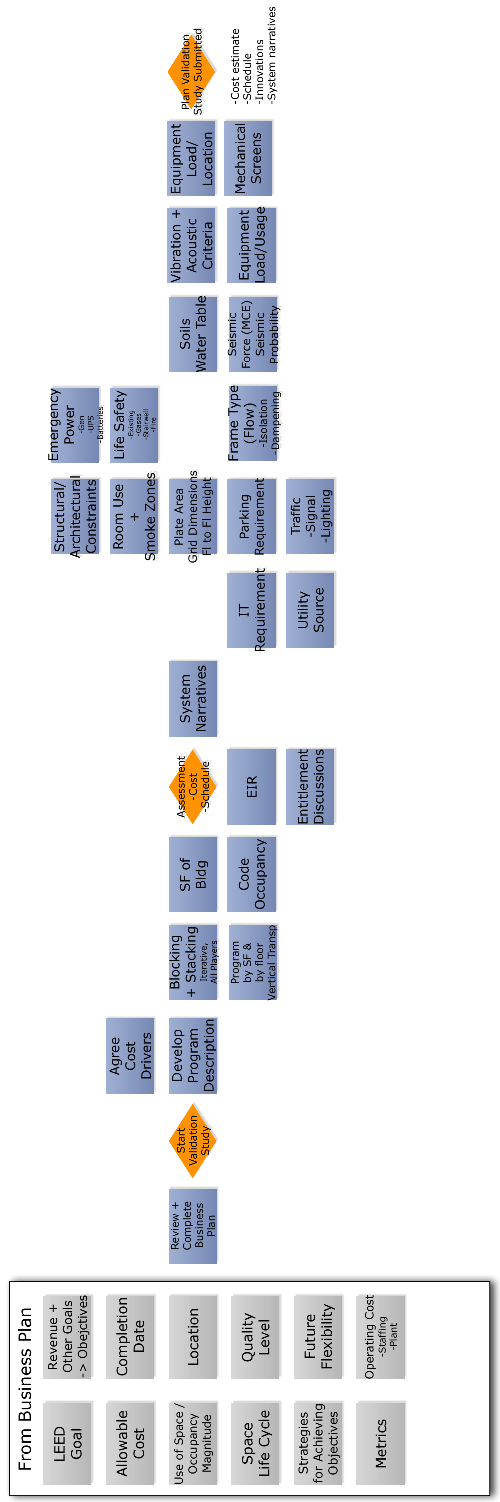

Figure D-1: Design Information Flow Example during Validation Study of TVD-DMP