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BUILDING ENERGY LABELING: A PATH TO IMPROVED ENERGY PERFORMANCE FOR COMMERCIAL BUILDINGS

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BY

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THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF ARCHITECTURE

The University of New Mexico
Albuquerque, New Mexico

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Abstract

Architects, engineers, and builders have a unique opportunity to lead society and the economy through the current difficult times. Since studies show that buildings account for nearly half the nation's energy consumption, our power derives from our ability to dramatically cut the energy consumption through energy efficient refurbishment of the vast existing building inventory and through energy efficient designs for new construction. This conservation has an amazing threefold benefit: through reduced consumption we extend the life of our limited natural resources; through reduced consumption we reduce our emission of greenhouse gases and thus reduce the threat of climate change; and through reduced consumption we save enough money to pay for refurbishment of existing buildings and energy efficiency enhancements built into new designs. The combination of inertia and barriers in the marketplace has stalled attempts to harvest these economic rewards from the last benefit. Now the urgency of limited resources and greenhouse gas emissions compels architects, engineers, and builders to advocate for informed policy that nurtures or mandates energy efficiency in buildings. In particular, now is the time for the adoption of a national building energy labeling scheme to replace the jumble of approaches currently in place and to ensure nationwide coverage. This thesis establishes that building energy labeling can promote greater energy

efficiency in an economically attractive manner and identifies how architects, engineers, and builders can lead the charge toward energy security and economic stability.

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Preface

In March 2008 I was one of 15 graduate students in an architecture studio at the University of New South Wales (UNSW, Sydney, Australia) that focused on the design of a sustainable high-rise. I thought the topic was most intriguing since I felt “sustainable high-rise” a bit of an oxymoron. To get the semester started each of us picked a sustainability topic from the tutor’s list and developed a presentation for the following week. I picked energy, and my life hasn’t been the same since.

After Al Gore’s “An Inconvenient Truth” made the rounds in 2006, no one could plead ignorance of the consequences of global warming. Yet there was a persistent group of doubters who point out perceived or contrived weaknesses in the research and even went so far as to suggest that climate-change researchers were simply exploiting easy research funding aligned with the climate-change ideology. Following my energy presentation at UNSW, I wanted to sort out the argument to my own satisfaction. I looked into the data sources for CO_2 concentrations in the atmosphere to understand the measurement techniques and the possible source for errors. I read about the difficulties in the climate modeling codes. I examined the case for solar cycles driving the CO_2 concentration cycles over the past 600,000 years. In the end I concluded the case for anthropogenic emissions of CO_2, while not proven, was compelling, and we as inhabitants of Earth ought not to bet the future of the planet on some elusive “natural” explanation.

The consequences of climate change really worried me. Many environmentalists preached doom and gloom and I found it depressing. Then it dawned on me that my response could be different—I would emphasize the positive possibilities and work towards solutions. Surely there were others working to make a positive difference. And viola! I found them working across a broad multi-disciplinary front. It’s great to awaken from a bad dream and fine new friends and intellectual leaders that have been working while I dreamt.

I returned from my two years in Australia keen on completing my architecture studies and finding a place to make my contribution. I had developed the notion that policy-based understanding of climate change, economics, architecture, and psychology offered the best hope for brightening the future. Clearly this work is ideally suited for multidisciplinary teams. The faculty of UNM played a decisive role in my journey with their suggestion that I write a thesis addressing my interests in energy policies and architecture rather than pursuing the traditional path at UNM, the Master's Studio.

Thus during this last semester I worked to sharpen my understanding of policies, how they relate to architecture, and develop a strategy for my thesis. Using new skills and interests born from studies of architecture and combining them with the familiar tools of an experimental physicist, I have pursed current literature and sought insights as to options for mitigating harm to the environment. Conservation is the clear winner especially in the near-term. Due to our dependence on an energy-driven economy and our typically inefficient use of that energy, conservation stands out as a particularly significant opportunity. Analysis of the end-use of energy reveals that our building sector consumes approximately half the energy used in the US for construction and operation. Since the commercial inventory within the building sector is failing to evolve towards improved energy efficiency and since the residential and industrial inventory continues a trend of energy consumption reductions over the past three decades, I see commercial buildings as a strategic target of opportunity for enhanced efficiency.

Governments, nonprofits, and various building organizations have all promoted energy efficiency programs and policies, and many have enjoyed success. Yet there remains a persistent failure to transform the commercial building sector that demands renewed attention from those who can see the possibilities for economic savings and concurrent environmental savings. Thus the solution requires political action, but what policies would be most effective in promoting energy efficiency? This makes a great thesis topic!

After significant reading, the topic of building energy labeling emerged as the frontrunner from a field of a roughly 20 policy options. While my thesis introduces the gamut of these related policies and their context, I limited my detailed research to building energy labeling. Note that this research restricts its arguments to qualitative feasibility and avoids quantitative assessments. Furthermore, while presenting a strong case for the efficacy of building energy labeling in the quest to reduce energy consumption, there is no attempt to formally prove that building energy labeling is the optimum policy intervention or even to prove that it is effective. Such proofs are well beyond the scope of this thesis, which was limited to a six-month effort.

A summary of the thesis follows in two forms: a one-page synopsis of bullet points and an executive summary, a six-page narrative.

Synopsis

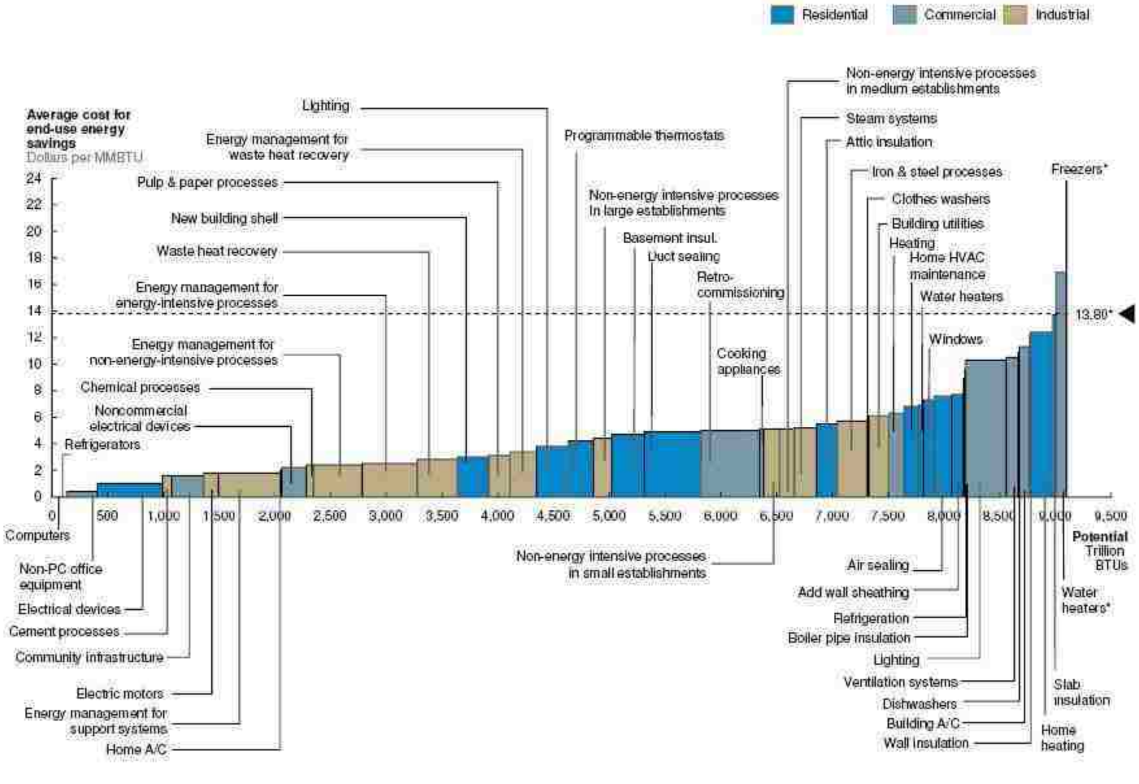
This thesis:

- Seeks to identify the policy most likely to break through the market barriers and failures that currently prevent markets from realizing the potential energy savings available through refurbishment of the existing building inventory—especially the commercial stock.
- Establishes the viability of building energy labeling as the flagship policy for initiating the market transition that captures these potential savings through
    - Use of an intuitive building energy savings scale that provides the essential information required for building owners, tenants, realtors, and financiers to make appropriate market evaluations and decisions
    - Enhancement of values and rents for rated buildings
    - Effective and cost-effective government intervention established by international precedents.
- Explains the relationship of building energy labeling and building energy codes.
- Identifies the impacts upon the profession of architecture including
    - Integrated design process that employs a multi-disciplinary team from the earliest stages of conceptualization to completion with commissioning
    - Emphasis on the passive performance of the design
    - Goal of net zero energy building design for 2030 or earlier
    - Requirements for high-performance material systems for components of net zero energy buildings
    - Challenge to continuously educate architects, engineers, and builders regarding new techniques and materials for designs.
- Recommends adoption of
    - National policy to implement voluntary building energy labeling using the building energy saving scale
    - Integrated design process for architects, engineers and builders.
- Recognizes that business-as-usual interests will resist these changes, e.g. realtors and builders who see this as interfering with customary business practice.

Executive Summary

In the US, our building inventory consumes nearly half of the energy used during construction and normal buildings operations. As a consequence of this economic activity and embodied energy in materials, our buildings are responsible for 39 percent of the nationwide CO_2 emissions. Studies have shown that energy conservation in these buildings can mitigate these deleterious emissions and enhance our national security through energy independence while actually stimulating our economy through life-cycle cost *savings* and creating jobs.

In a recent study published in July 2009, McKinsey & Company evaluated over 600 efficiency measures in market sectors other than transportation[1]. A vast number of these would not only reduce energy consumption but also produce life-cycle savings by



* Average price of avoided energy consumption at the industrial price; $35.60/MMBTU represents the highest regional electricity price used; new build cost based on AEO 2008 future construction costs

Source: EIA AEO 2008, McKinsey analysis

Figure ES1. Efficiency measures in the US producing a net savings by 2020.

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[1] Hannah Granade, Jon Creyts, Anton Derkach, Philip Farese, Scott Nyquist, Ken Ostrowski, *Unlocking Energy Efficiency in the U.S. Economy*, McKinsey & Company, July 2009, piv.

2020. Today's capital costs and the interest expenses to implement many of the efficiency measures are fully recovered in ten years through savings in operational costs. Their study further considers the economic and environmental consequences if only the measures producing savings were implemented. Figure ES1 shows these cost avoidance, money saving, efficiency measures.

Ideally market forces would induce owners, architects, and builders to harvest these savings, but barriers persistently thwart this behavior. Nowhere is the failure of the market more apparent than in the commercial sector where the energy use intensity (EUI) index—the total energy consumed in the sector divided by the total floor area of the sector—has been steadily rising for decades although a leveling trend seems to be emerging in recent years. In contrast the other sectors have seen reduced indices throughout the period as shown in Figure ES2[2]. In the commercial sector, split incentives present significant barriers to efficiency innovations—typically neither landlords nor tenants are willing to make investments that unduly benefit the other.

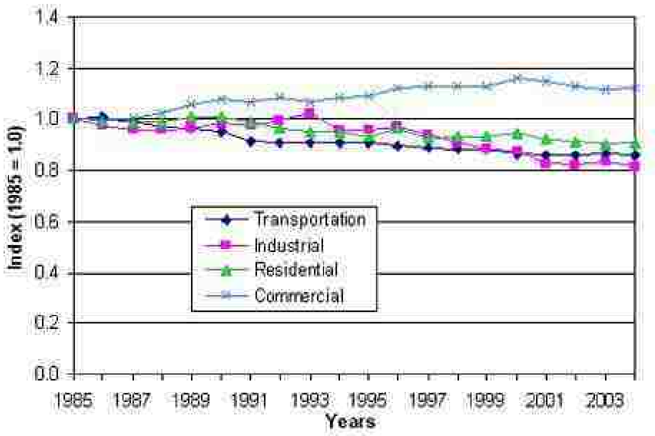

Figure ES2. Trends in the energy intensity use during the last 30 years for the four economic sectors.

To transform the building market, governments worldwide are endeavoring to adopt policies to penetrate these barriers. Generally these policies fall into one of three categories: mandatory regulatory interventions, voluntary economic interventions, and either mandatory or voluntary information tools. Mandatory building energy codes are widely used but in the US generally are not stringent enough to produce effective results. The notable exception is in California where regulation has held the per capita energy

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[2] Economy-Wide Total Energy Consumption, http://www1.eere.energy.gov/ba/pba/intensityindicators/total_energy.html, Sept 27, 2009.

consumption flat for 30 years. Despite federal law that mandates each state adopt a building energy efficiency code, not all have done so.

Tax deductions and tax incentives are popular economic interventions. Both federal and state governments offer a myriad of options to incentivize energy efficiency enhancements, and they apply to existing buildings and new construction alike. These interventions effectively save energy but are less cost effective than alternative policy options[3] such as building energy labeling and building energy codes.

Voluntary building energy labeling systems are becoming popular information tools in the US. The Environmental Protection Agency's Energy Star is strong on rating energy efficiency and the US Green Building Council's LEED stresses the broader set of sustainability metrics that includes a lightly weighted energy component. The label seeks to provide the market with information to differentiate between buildings with different energy-performance characteristics. A recent study of market transactions involving labeled buildings in the US reveals that the energy labeling of Energy Star commands enhanced market values for property sales or rents whereas the sustainability rating from LEED carries no such premium. The European Union is currently launching its mandatory building energy labeling scheme, but it is too early for any systematic results.

The US currently has a jumble of building energy labeling schemes. The Energy Star label exists for both commercial and residential buildings but the two schemes are very different. In fact the Energy Star rating for residences is more similar to Residential Energy Services Network's Home Energy Rating System (HERS) than it is to the commercial Energy Star system. Adding to the confusion, LEED is not alone in the business of sustainability labeling, but has competition from the Green Building Institute's Green Globe label. In addition to these national labeling schemes, there are numerous regional and local rating systems. Each of these utilizes a different methodology to rate building energy efficiency although each has similarities with either the commercial Energy Star system or the computational method defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

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[3] Diana Urge-Vorsatz1, Sonja Koeppel1, and Sebastian Mirasgedis, "Appraisal of Policy Instruments for Reducing Buildings' CO_2 Emissions," *Building Research & Information*, 35(4), 2007, pp458–477.

This thesis proposes a national building energy labeling policy and process comprised of features selected from the various systems currently in use. It is similar to the labeling system that ASHRAE prototyped mid-year in 2009. Both schemes promote labels for “as designed” and “as operated” buildings to bring more information to market. The “as designed” rating indicates the expected energy consumption of the design and construction effort and is an important factor in establishing the market value of the building for mortgage or sales purposes. Once the building has an established track record, the “as operated” label characterizes actual building energy efficiency performance.

This thesis defines an innovative building energy savings (BES) scale based on 0-100 points with extra credit granted to buildings that produce more energy than they consume. As shown on the right in Figure ES3, for the BES label net zero energy buildings score 100 and buildings with average energy use intensity score zero. With the

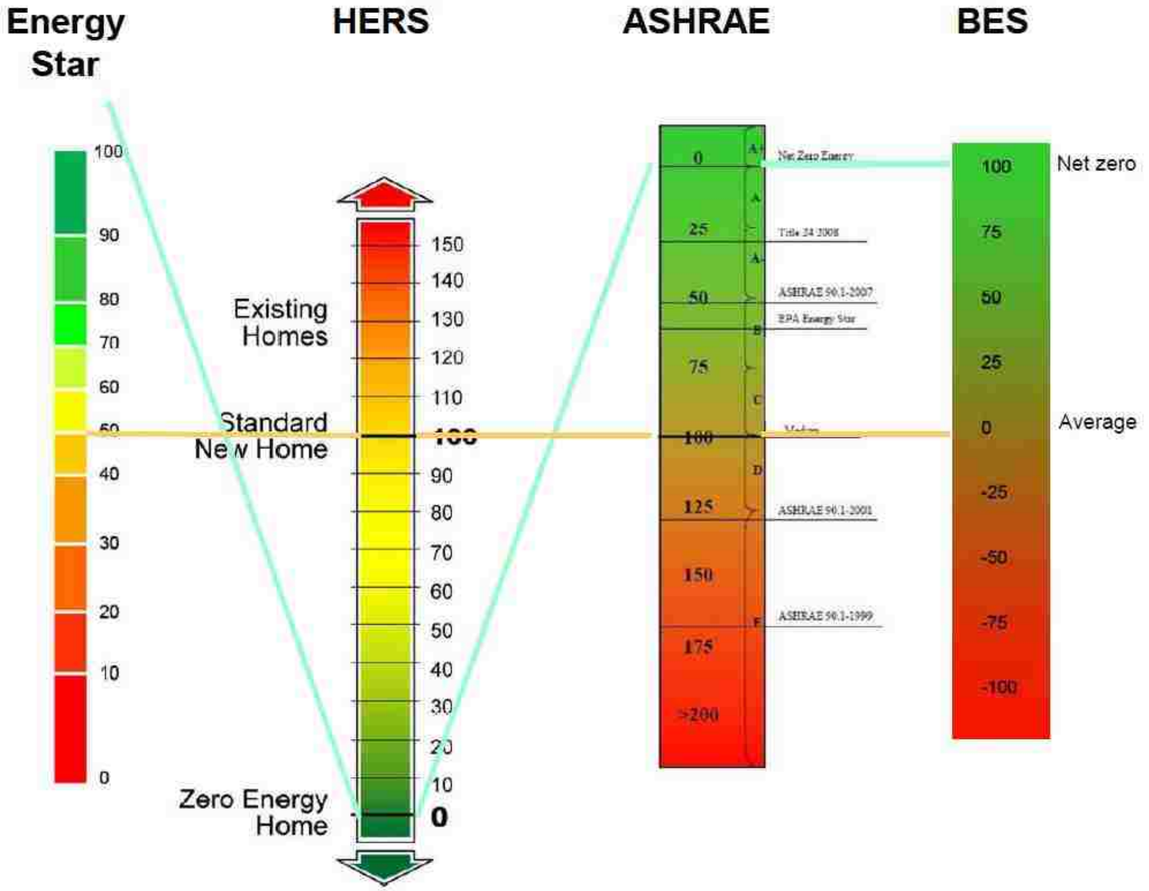

Figure ES3 The proposed building energy savings scale is shown on the right and compared with the two other schemes used nationally and the ASHRAE proposal.

linear mapping of EUI indices onto the BES scale, buildings consuming more than the average will have negative scores.

Such a building energy labeling policy will initiate the market transformation illustrated in Figure ES4 by providing information that enables buyers and tenants to differentiate between energy "hogs" and high-performance buildings. Through voluntary building energy labeling, early adopters of high-performance buildings will have the incentive to differentiate their buildings from the business-as-usual designs. Not only will their buildings have premium values in the market, but owners can advertise their environmental stewardship to clients with similar ideals. In addition to the market forces, social marketing touting the benefits to society can enhance the spread of building energy labeling. As the penetration of high-performance buildings increases in the market, mandatory building energy labeling and, finally, stringent mandatory building energy codes should be introduced.

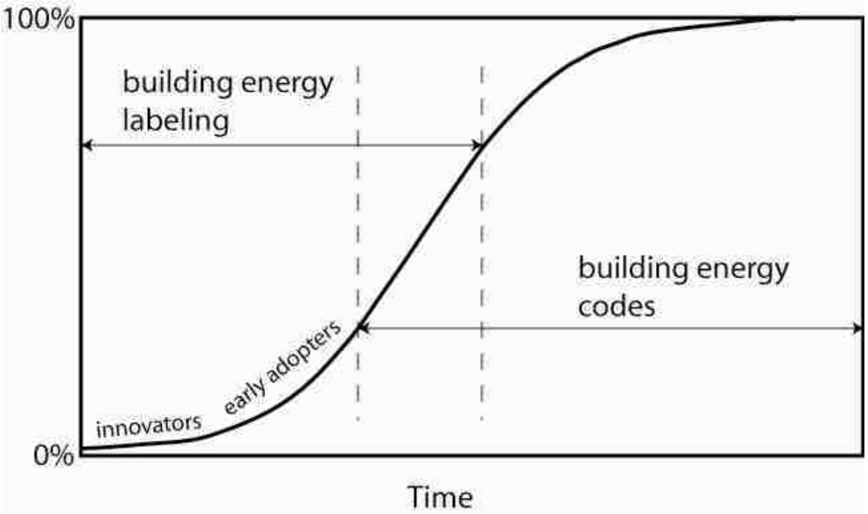

Figure ES4. Market penetration for life cycle of building energy efficiency as proposed in this thesis. Mandatory follows voluntary building energy labeling. Finally building codes mandate energy efficiency in buildings.

As the market transitions, we will reap economic savings from energy expenses and environmental savings from reduced CO_2 emissions. Due to the slow turnover of our building inventory, initially the savings will come from refurbishment of existing buildings followed by incremental savings from new buildings that avoid the energy-squandering inefficiencies.

Architects, engineers, and builders must adapt to the changes driven by this market transition. Realizing the goal of net zero energy buildings by year 2030, as required in proposed federal legislation, demands changes to building practices as well as changes in technologies and materials. No longer can the architect guide the process from conceptual design to construction singlehandedly—the process demands the efforts of a team of consultants from the earliest phases of conceptual design. This “frontloaded” integrated design process optimizes the design through short iterations of the design using shared tools and a building information modeling database. Once established early, the framework of the design guides the elaboration of the details across the diverse disciplines of the project.

Additional changes are expected in materials, techniques, and business environments: dynamic fenestration for the building envelope, photovoltaics, smart electrical grids, time-dependent value for energy, sub-metering for diagnostic analysis, and the labeling of material for embodied energy and chemical content. However, some things should not change—the energy conservation features must maintain or enhance the aesthetic quality of the building.

We can not ask for more interesting and challenging times. We must banish the business-as-usual mentality reaching back to the industrial revolution and embrace an environmental design philosophy that secures energy conservation and sustainability for our buildings. We have the tools, the technology, and the opportunity. Propelled by savings from environmentally friendly energy efficiency refurbishment, we can launch our journey toward net zero energy buildings facilitated by the BES labeling and other informed policies that overcome the economic barriers currently in place. Architects, engineers, and builders are critical stakeholders in this unconventional challenge and have the responsibility to educate and advocate as well as learn, design, and build.

Acronyms

ABEL	Advanced Building Energy Labeling
AC	alternating current
ACH	air changes per hour
AEO	Annual Energy Outlook, from EIA
ALP	Advanced Lighting Package
AIA	American Institute of Architects
ANSI	American National Standards Institute
APS	Albuquerque Public Schools
APS	American Physical Society
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
bEQ	Building Energy Quotient
BER	building energy rating
BIM	building information modeling
BOMA	Building Owners and Managers Association
BREEAM	Building research Establishment Environmental Assessment Method
BSR	ANSI Board of Standards Review (indicates draft standard prior to ANSI approval)
BT	Building Technologies Program within DOE/EERE
BTU	British thermal unit
CBECS	Commercial Buildings Energy Consumption Survey
CDD	cooling degree day
CEC	California Energy Commission
CEN	European Committee for Standardization
CFL	compact florescent lamp
CH4	methane
CHP	combined heat and power
CIBSE	Chartered Institution of Building Services Engineers
CO_2	carbon dioxide
COMNET	Commercial Energy Services Network

COP	coefficient of performance
DC	direct current
DOE	US Department of Energy
DSM	Demand side management
DX	direct expansion
EERE	Energy Efficiency and Renewable Energy within DOE
EIA	Energy Information Administration within DOE
EP	EnergyPlus
EPA	US Environmental Protection Agency
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Contracting
ERHA	Energy Rated Homes of America
ESCO	Energy Service Companies
EU	European Union
EUI	energy use intensity
FHA	Federal Housing Administration
FY	fiscal year
GBI	Green Building Institute
GDP	gross domestic product
GDP	gross domestic product
GHG	green-house gas
HERS	Home Efficiency Rating System
HUD	Housing and Urban Development
HVAC	heating, ventilating, and air-conditioning
IBC	International Building Code
ICC	International Code Council
IDF	input data file
IDP	integrated design process
IECC	International Energy Conservation Code
IESNA	Illuminating Engineering Society of North America
IMT	Institute for Market Transformation
IPD	integrated project delivery
IRC	International Residential Code

JPEG	Joint Photographic Experts Group who created the file compression standard for images
LBNL	Lawrence Berkeley National Laboratory
LEED	Leadership in Energy and Efficiency Design
LPD	lighting power density
NASEO	National Association of State Energy Officials
NBA	National Builders Association
NBI	New Buildings Institute
NECPA	National Energy Conservation Policy Act
NEEP	Northeast Energy Efficiency Partnerships
NEPS	National Energy Protocol Specification
NPV	net present value
NREL	National Renewable Energy Laboratory
NZEB	Net zero energy building. A building with net-zero energy consumption over one year. Assumed to be based on net site energy use.
OECD	Organization for Economic Cooperation and Development
PBA	principal building activity
PC	Personal computer
PDF	probability density function
PG&E	Pacific Gas and Electric
PURPA	Public Utilities Regulatory Policies Act
PV	photovoltaic
R&D	research and development
RESNET	Residential Energy Services Network
SAF	size adjustment factor
SHGC	solar heat gain coefficient
TBC	Thermal Bypass Checklist
TDD	tubular daylighting device
TDV	time dependent valuation
TOU	Time of Use
UK	United Kingdom
UL	Underwriters Laboratory
US	United States

USGBC	US Green Builders Council
VA	Veteran's Administration

1 Introduction

Throughout history around the world people have been busy living in their societies and working in their economies to meet their personal needs and the needs of their families. Through man's ingenuity, he has been able to harness energy to leverage his productivity and thus increasingly satisfy his needs and increase his wealth. At the same time he has become enslaved—an addict totally reliant on this energy "genie" who grants him his wishes.

Only a few decades ago people believed that in the fullness of time the planet's population would emerge from the bonds of poverty, and all of us would enjoy basic human comforts in a world of cheap energy. On our way to this utopian destination, we encountered a detour followed by a hijacking! We found our energy resources more limited and expensive than expected and, worse yet, their use produced adverse environmental consequences—climate change. Continued business-as-usual behavior threatens the very health of our planet.

However, many of us see an opportunity to regain control of our travel toward global prosperity. The path requires changes in our behavior as residents of the globe, and as architects, engineers, and builders it requires prompt attention to the possibilities that energy conservation in building offers. This thesis will briefly review the circumstances of our detour and hijacking, and then characterize the solutions that architects, engineers, and builders hold in their hands. Since these solutions apparently need a catalytic boost from informed policy to flourish, policy considerations will be emphasized as well as.

1.1 *Energy and growth*

From the start of the 20th century the US economy grew vigorously fueled first by cheap domestic oil and then by increasingly expensive oil as our dependence on foreign oil grew. While oil was the source fuel of choice for economic growth, the other fossil fuels, coal and natural gas, also fed our energy consumption. Plotted on a logarithmic scale, data in Figure 1 show annual national costs for energy after 1970, and, to illustrate some of the drivers for energy cost, also show the US population and US appetite for energy measured in quadrillion BTUs (quad) or 10^{15} BTUs. The population follows an exponential growth pattern (linear on the logarithmic scale), and energy consumption tends to follow. The total energy costs exhibit significant volatility especially after the first energy crisis in 1973 and then again in recent years. To control or at least influence energy cost we must understand the cost drivers, which are[4]:

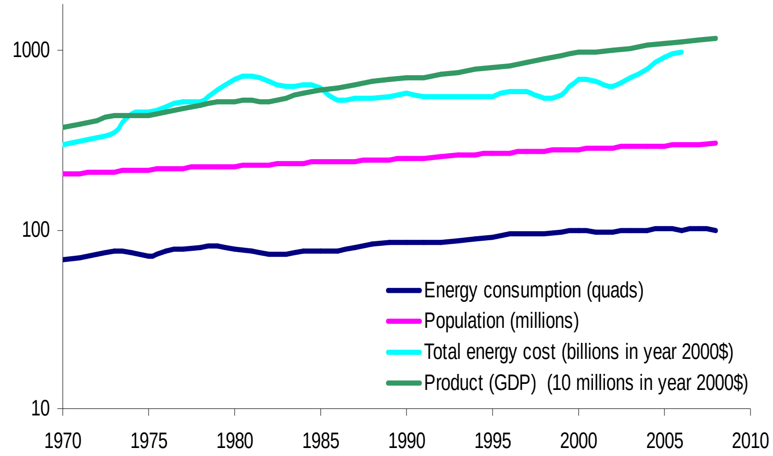

Figure 1. US trends for gross domestic product (GDP), energy costs, population, and total consumption on a logarithmic scale. Dollar values are normalized to year 2000. Data source: EIA http://www.eia.doe.gov/emeu/aer/txt/ptb0105.html, Sept 26, 2009. Data are displayed on a logarithmic scale to facilitate comparisons.

- Market prices for energy
- Population, which drives the number of homes, schools, and other community buildings
- Economic growth (real GDP), which is a major driver of new floorspace in offices and retail buildings
- Building size distribution (the amount of commercial floorspace and the size of homes)
- Service demands (lighting and space conditioning, electronics, process loads)
- The *efficiency* with which energy service demands are met

The first five drivers are well beyond the control of architects, engineers, and builders. Building sizes and services are largely defined by owners and operators of buildings. So the only hope to lower energy costs is the last point, efficiency, the focus of this thesis. During the past 35 years considerable progress has been made in materials, powered systems, and design processes such that the technologies in lighting fixtures,

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[4] Office of Energy Efficiency and Renewable Energy, *Energy Efficiency Trends in Residential and Commercial Buildings*, US Department of Energy, October 2008, p4.

building envelopes, windows, HVAC systems, appliances, building sensors and controls as well as integrated design processes have made it possible to build high-performance buildings. It remains first to educate the uninitiated architects, engineers, and builders, and then to transform both new designs and existing buildings.

As energy resources are inevitably depleted, their costs can be expected to skyrocket. Experts from the oil industry point out that over the last 30 years there have been very limited discoveries of new fields and the globe is approaching "peak oil"—the point at which half the economically viable oil has been extracted and after which the oil supply declines. Consequently efficiency will acquire even greater significance in the quest to achieve energy security and economic stability.

1.2 Energy and environment

When our energy journey detoured thirty-five years ago with the first oil crisis signaling resource depletion, few of us could image the impending hijacking that laid ahead—global warming and its potential for causing major disruptions to the Earth's climate. While mankind used some renewable energy sources to grow his economy, most of the energy came from the combustion of fossil fuels, which releases CO_2 into the atmosphere. Although the oceans dissolve some of this gas, most remains in the atmosphere, and the measured CO_2 concentrations are on the increase. Though some quarters are still skeptical, the preponderance of researchers consider global warming and its potential threats to be scientific realities[5]. The extent of the anthropogenic contribution to global warming needs deeper understanding, but "there is virtually no disagreement among scientists that it is real and substantial."[6]

Modeling the climate has proven to be a complex scientific challenge. There are so many interactive systems: solar cycles with different periods, precession of the Earth's axis of rotation, variations of the Earth's solar orbit, chemistry of the atmosphere, CO_2 solubility in sea water, water cycles, cloud reflectance, and the list goes on. While the climate models are constantly improving, already they successfully predict the observed

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[5] Intergovernmental Panel on Climate Change, *Climate Change 2007: Synthesis Report*, November 2007.

[6] American Physical Society, *Energy Future**:** Think Efficiency*, September 2008, p7.

long-term climate patterns of the past million years inferred from ice core, tree ring, and coral data. Models fail to predict any abrupt increases in atmospheric CO_2 concentrations from natural processes or levels as high as we currently observe. Therefore science has established an “overwhelming consensus that the increase in greenhouse gases is largely of human origin, tracing back to the Industrial Revolution and accelerating in recent years, as carbon dioxide and methane—the products of fossil fuel use—have entered the atmosphere in increasing quantities.”[7]

Can these models predict what going to happen in the future? No, since each scenario depends on assumptions about what sort of emissions we generate in the future. Can we explore the alternative assumptions and develop an understanding of the boundaries of the possibilities? Yes, and the extremes are quite alarming while perhaps unlikely. Those of us who believe that these forecasts are meaningful warnings and who are also somewhat risk adverse seek to influence the outcome with personal changes in behavior as well as advocating policymaking to influence the nonbelievers and risk takers.

The challenge is enormous. In the best of economic times reducing global carbon emissions while continuing global economic growth would not be easy. Architects, engineers, and builders wield incredible power in this challenge since our products are the single largest sink of energy in the US. Building science and building technology, coupled with intelligent policymaking, can provide the US with the tools needed to conquer this energy and climate challenge at home and stimulate success in other parts of the world.

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[7] Ibid, p20.

1.3 Energy sources and flows

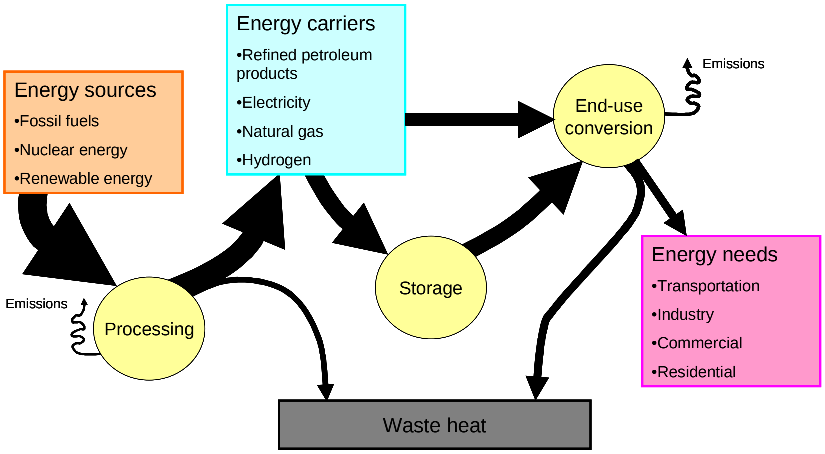
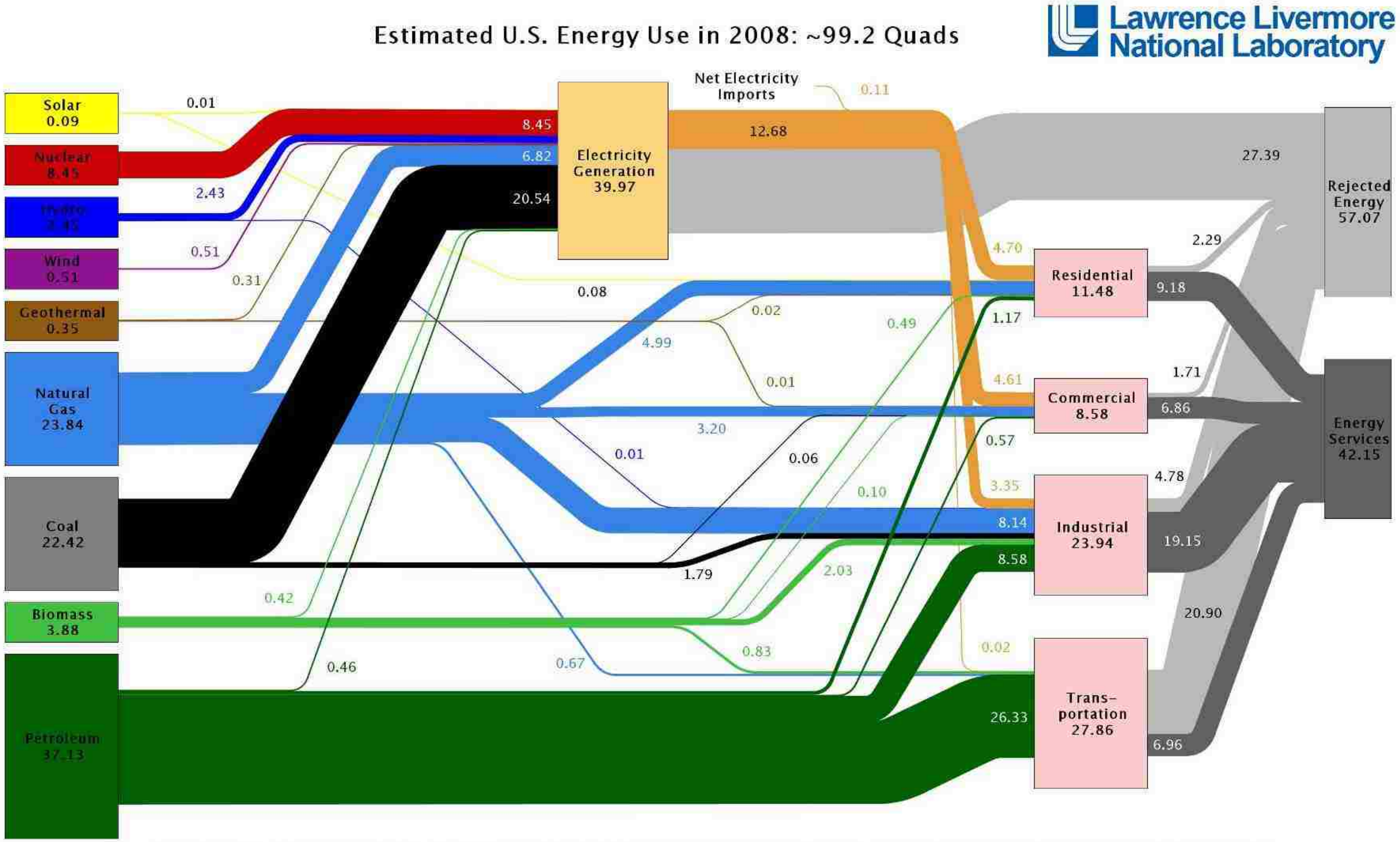


Figure 2. Simplified energy flows.

For an effective response to the energy and climate challenge, we must first understand the flow of energy in our economy and its side effects. A very simplified picture of this flow is presented in Figure 2. It stresses the three categories of energy sources, processes to produce energy carriers, optional storage, and finally end-use applications where society receives a benefit. At each step conversion yields undesired waste heat and emissions. Finally a fraction of the initial energy performs work in the intended application.

Although the Sankey diagram in Figure 3 may seem excessively complex at first glance, it condenses numerous pie charts and tables into a single comprehensible chart. First it shows schematically the flow of energy from sources on the left into various sectors of the economy (residential, commercial, industrial, and transportation), and finally into two categories, rejected energy (energy wasted as heat) and energy services that are desired. The sources on the left are comprehensive ranging from solar on the top to petroleum on the bottom. Each energy source then “flows” to the right into economic sectors or into electricity generation. The diagram also indicates that electrical generation transforms energy from one form of energy to another, e.g. coal to electricity.



Source: LLNL 2009. Data is based on DOE/EIA-0384(2008), June 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Figure 3. The estimated US energy flow for 2008 shown as Sankey diagram. Sources are located to the left, the four economic sectors in the middle-right, and wasted energy (rejected) or useful energy (services) are located to the right. Power generation is located to the middle-left. All energies are shown in quads (10^{15} BTU).

The process is highly inefficient and produces a significant amount of waste heat that flows into rejected energy. Downstream from the “electricity generation” box, the diagram shows a small flow colored orange (12.68 quads) into various economic sectors and a large flow colored gray (27.39 quads) to waste. Note that these two flows add to the 39.97 quads that is equal to the sum of the energy inputs into electricity generation from solar, nuclear, hydro, wind, geothermal, natural gas, coal, biomass, and petroleum. The energy flow diagram not only tells us about the energy source and its application, but it quantifies the waste at each step along the way. On average electricity generation is 12.68/39.97 = 0.317 = 31.7% efficient.

Thus to deliver 1 unit of electrical energy to a commercial building it takes 1/0.317 units—more than 3.1 units—at the source power on average. The specific efficiency for electrical power conversion of each fuel type varies and for that matter depends upon the specific power plant. The point to remember is not all energy delivered to the building in transmission lines, steam lines, or gas pipes is the same when traced back to the source. Thus metrics for building energy use intensity (EUI) generally are calculated with the source energy, i.e. the total energy corrected for any fuel-type conversion and for any transmission losses to the building, divided by the building floor area. Furthermore, source energy consumption more appropriately relates to the environmental impact.

1.4 *Energy and buildings*

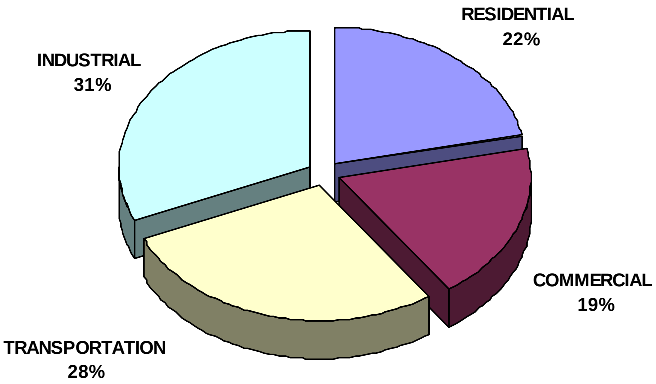


Figure 4. Source energy consumption by sector for year 2008 as derived from Figure 3.

An inspection of Figure 3 shows that of the four economic sectors, *transportation* is the largest energy consumer. In fact it is significantly larger than the residential and commercial sectors combined. But when you examine where the electricity goes and account for the 69% of energy wasted at generation, then the energy consumption of the residential and commercial sectors approximately doubles. When corrected for source energy, the relative size of each sector dramatically changes to produce the result shown in Figure 4. This derivation demonstrates the importance of using source energies to avoid distortions.

After performing a different energy-accounting analysis, Ed Mazria found another distortion derailing effective conservation. Pie charts, which had long portrayed the transportation and industry as the targets for efficiency programs, had in fact literally missed the biggest opportunity. Mazria, author of *The Passive Solar Energy Book* and an internationally respected environmental designer, discovered that combining all building construction and operating costs into a single sector revealed that buildings were in fact the correct target (see Figure 5)[8]. Since buildings account for about half the energy consumption in the US, in 2006 Mazria launched the 2030 Challenge that specifically targets increases in building energy efficiency.

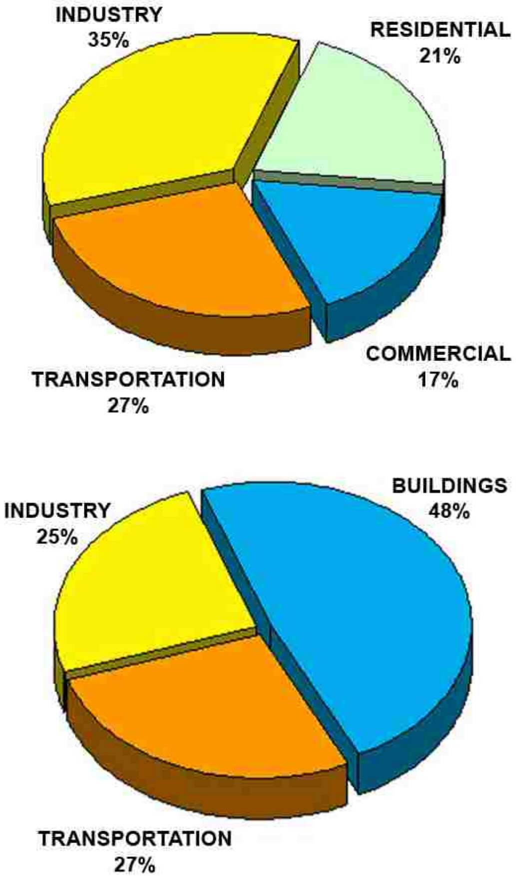


Figure 5. The US energy consumption by sector for year 2000. The upper pie chart depicts the standard grouping by economic sectors prior to the 2030 Challenge. The lower chart assigns energy associated with construction and operation of buildings into a single sector including a fraction of the industrial sector that contributes to buildings. The data are from year 2000.

1.4.1 Building energy efficiency opportunity

Considering 250 CO_2 abatement strategies that spanned all segments of the economy, McKinsey and Company published

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[8] Architecture 2030, http://www.architecture2030.org/current_situation/building_sector.html, Sept 28, 2009.

in 2007 a detailed analysis that estimated costs to mitigate CO_2 emission sources in the US[9]. Interestingly those that were the most cost effective were largely within the building sector. The results of the study summarized in Figure 6 indicate the costs to abate one ton of CO_2 emissions for each of the 250 options. The options are sorted from the least expensive displayed at the left and progressively work through the options toward the more costly shown on the right. The most expensive options are simply not shown. Negative cost options actually save money while those that are positive indicate true costs. Inspection of Figure 6 reveals that many of the money savings options involve buildings (the building mitigations are highlighted in dark blue).

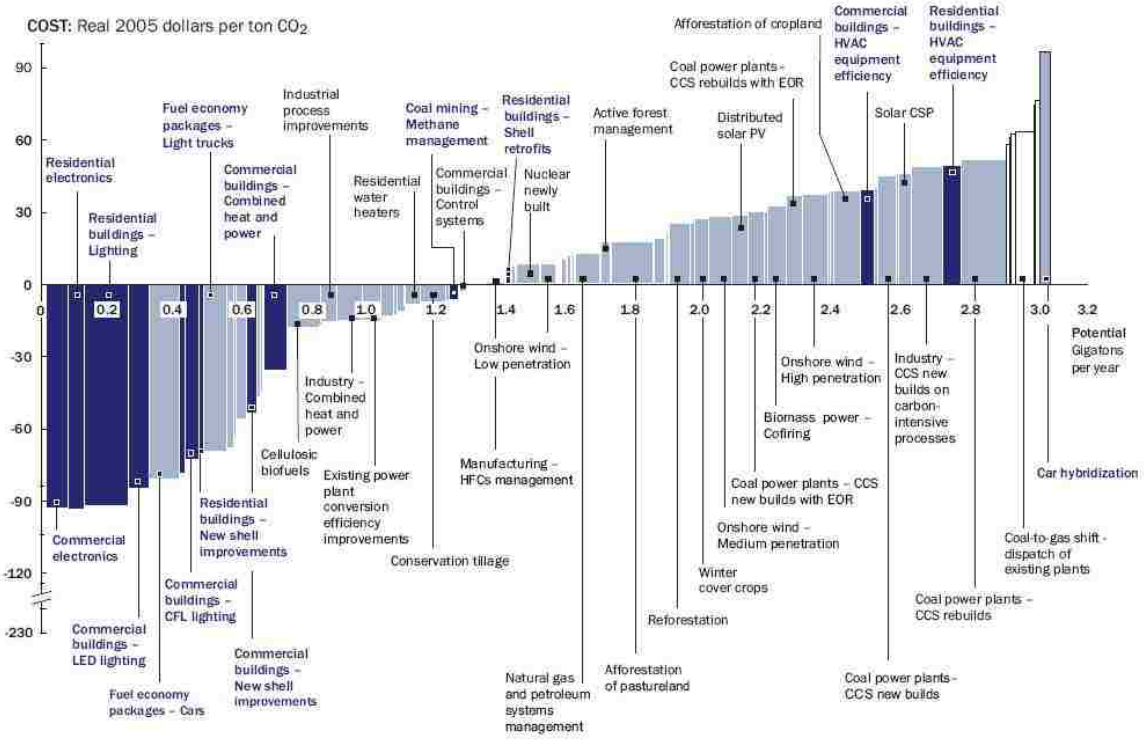

Figure 6. Marginal abatement curve from McKinsey and Company.

It is ironic that these measures, which actually decrease energy usage and decrease CO_2 emissions, also save money. How is it that these opportunities have been systematically bypassed for years? It would seem that either the analysis is wrong or the

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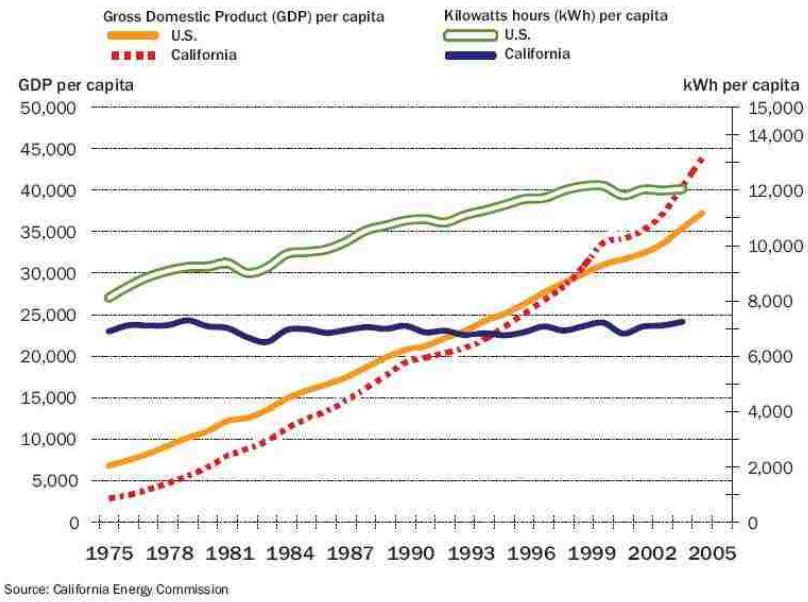
[9] Jon Crets, Anton Derkach, Scott Nyquist, Ken Ostrowski, Jack Stephenson, Reducing US greenhouse Gas Emissions: How Much at What Cost?, McKinsey and Company, December, 2007, p33.

market has failed to minimize resource consumption. Fortunately the California experience offers some clues.



Source: California Energy Commission

Figure 7. Electricity usage and economic growth for California and the United States.

Two years after the first energy crisis in 1973 California instituted a program to improve electrical energy efficiency. California's policies, including regulations and incentives, have helped hold the state's per capita electricity use constant for the past 30 years while allowing its economy to flourish (see Figure 7)[10]. Note that the data is reported on a per capita basis to eliminate the growth factor due to expansion in the population.

While a shift towards a service economy may partially explain how California maintained a level per capita energy consumption during this 30-year period, no comparable effect appeared in the US economy where consumption increased by 50%. Furthermore the California economy grew faster than in the US, so Californians were more productive without increasing their energy consumption. Apparently the McKinsey analysis is correct—efficiency improvements actually save money while lowering energy consumption and lowering the corresponding emissions. Then it follows that there must be market failures, and California's policies addressed some of the market barriers and failures that persist in the balance of the US.

In its analysis the American Physical Society (APS) concludes that the time horizon for business is problematic. Business avoids the first costs that would otherwise

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[10] Op cit, American Physical Society, p23.

improve building performance. Furthermore business leaves long-term research in the hands of the government. The APS notes that[11]:

> Notwithstanding the positive California experience, in which the state intervened with regulations and incentives to achieve energy efficiencies, some analysts argue that markets ultimately are efficient and will provide the most beneficial outcomes if left unregulated. Government intervention, they say, is unnecessary and potentially harmful. But in the case of energy efficiency, market imperfections exist and must be remedied if progress is to occur. …. Experience of the past few decades has shown that such [long] time horizons are incompatible with the parameters established by financial markets, which require companies to demonstrate performance every quarter or every year. Money may be patient to some degree, but certainly not for a decade or more.

1.4.2 Building energy efficiency metrics

The EUI for a building is the most common metric of a building's energy performance and is calculated as the building's annual source energy consumption divided by its gross floor area. Thus the units for EUI can be BTU/ft^2/yr or kWh/m^2/yr—a measure of average power per unit area. A net zero energy building (NZEB) is the "efficiency ideal" for every building—the case where the "net" EUI is zero. Since every realistic building uses energy, "net" zero energy can only be achieved if the building supplies itself with some renewable internal power, typically from photovoltaic panels. The concept of the NZEB implies only that the average yearly power from off-site is zero, not that power consumption from the grid is continuously zero. Therefore an NZEB can consume as much electrical power as it produces *on average*.

The notion of using an EUI to characterize building energy efficiency is fundamentally sound. However without "corrections," buildings in cold climates, buildings with unusually high occupancy, buildings with extra plug loads from computers and printers, etc, bear an unfair disadvantage. Later in Section 4.1 corrections will be introduced that attempt to level these distortions.

Energy use intensities are used to compare energy use in buildings through time. These intensities are used to examine energy-use trends in the diverse building stocks that

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[11] Ibid, p23-24.

make up the residential and commercial sectors. Since EUIs are intended to show trends in energy use, a year-to-year weather factor is used to take into account the impacts of annual weather variation on energy consumption. In applications other than buildings, e.g. transportation, analogous energy use indicators show how the amount of energy used per unit of output or activity has changed over time. Using less energy per unit of output reduces the energy intensity; using more energy per unit increases the energy intensity.

Using the various EUI metrics we can now examine the efficiency trends in each of the economic sectors. These sector-wide averages[12] shown in Figure 8 are arbitrarily normalized to 1 in 1985 so that these unit-less ratios can easily compare the changes in efficiency that follow. Notice that all sectors have been steadily decreasing energy use during the period *except* for commercial buildings, although after year 2000 its EUI declines slightly. This anomalous behavior emphasizes the point that the commercial sector is a large target of opportunity and warrants particular scrutiny. Thus this thesis is interested in *commercial* building energy efficiency in particular but the broader context of efficiency is essential.

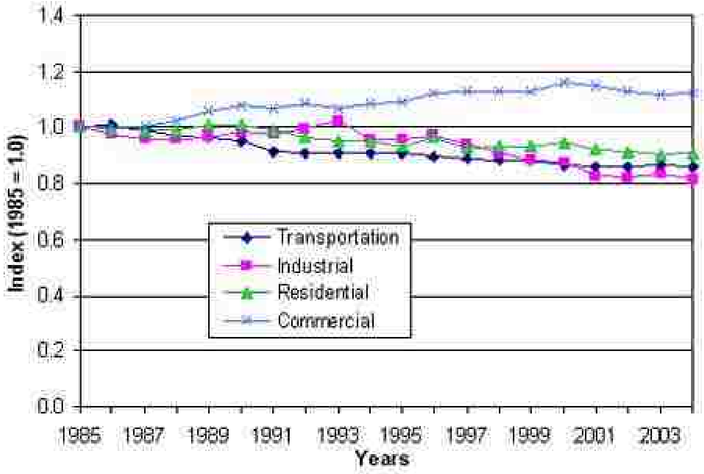

Figure 8. Trends in relative EUIs for the four end-use sectors, 1985-2004.

Our understanding of the EUIs in Figure 8 can be improved with additional data as shown in Figure 9 and Figure 10. For the residential sector in Figure 9 we see that in response to the growth of the population, the number of households increased thereby tending to increase the total energy used. In addition the relative housing size also increased thereby compounding the effect. But overall the total area of residences (the

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[12] Economy-Wide Total Energy Consumption, http://www1.eere.energy.gov/ba/pba/intensityindicators/total_energy.html, Sept 27, 2009.

product of the number of households and housing size, which is not shown) grew faster than the consumption, so the average EUI actually decreased.

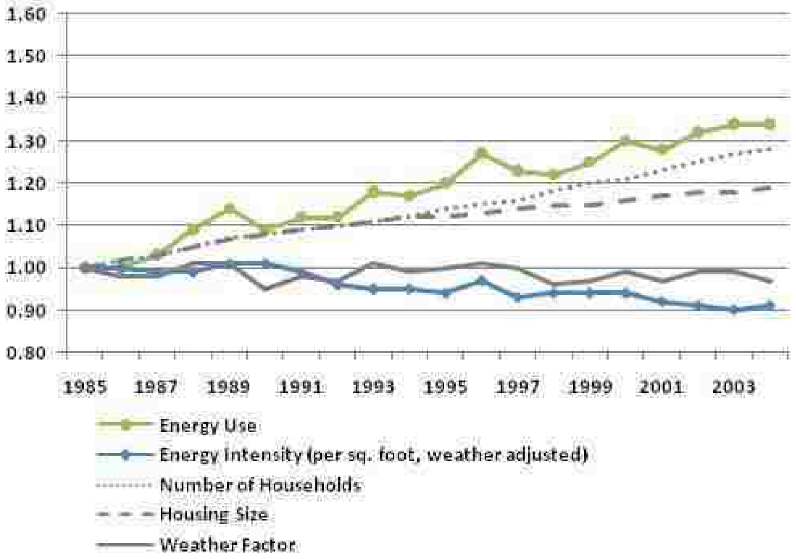

Figure 9. Performance data for the residential sector.

In contrast with the residential sector, in the commercial sector the total area and energy consumption both grew, but in this case the energy consumption grew faster than the total floor area, so the EUI increased as shown in Figure 10. The fact that building energy efficiency, which offers the possibility of substantial emission reductions in conjunction with life-cycle savings, fails to progress in the marketplace is vexing. Coupled with this unfavorable trend of increased energy consumption in commercial buildings, it makes the situation even more alarming. Why are *commercial* buildings gobbling up more energy than other building types, which apparently use viable alternatives?

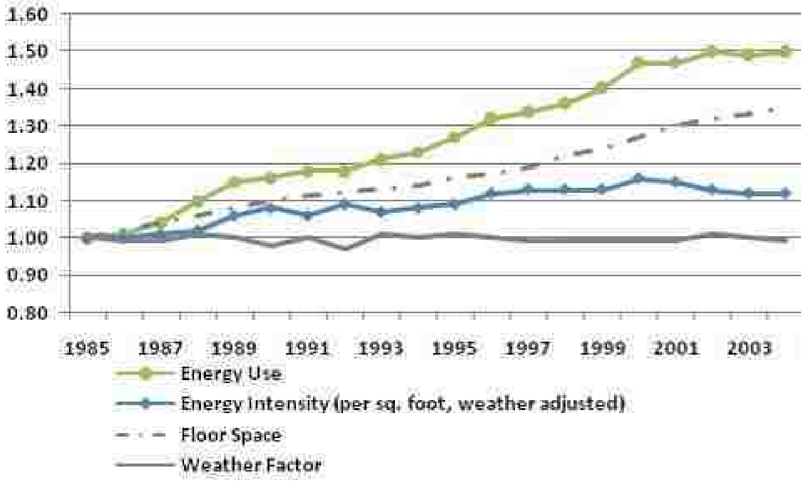

Figure 10. Performance data for the commercial sector.

1.5 Energy efficiency barriers

Although the building sector holds the potential for simultaneously reducing emissions and saving money, we saw that the market can fail to seize these opportunities due to various barriers and failures. Since we seek polices that will break through this paralysis, we should briefly identify these problems.

In the case of commercial buildings, for example, tenants are often responsible for paying for utilities and maintenance. Therefore, builders and landlords have little incentive to spend extra money to achieve energy efficiencies in lighting, heating, cooling and structural design. Similarly, in the case of residences, developers want to minimize the “sticker shock” of a home. Since they will be making no utility payments, there is little motivation to invest in energy saving measures that increase the price they must charge, which could reduce sales. Few residential consumers have the knowledge, time, or inclination to seek energy efficient products. Without government energy labels, codes and standards, market forces alone will not encourage such investments.

Ironically the government itself has fiscal practices that produce similar consequences. By separating capital projects from operating funds the government unwittingly inserts an incentive to trade energy efficiency features for other building features such as more space. Managers for the capital projects care little about the cost implications that the operating managers will face. Some businesses suffer from the same dilemma.

Architects, engineers, and builders may resist changes. The practices to optimize building performance are not the business-as-usual procedures that have been in place for decades. Optimized design demands a team with diverse skills working iteratively early in the project. Construction demands the use of new systems and new techniques unfamiliar to many builders. Education is essential to facilitate these changes. Some organizations and individuals may ignore this challenge and continue with current practice.

Markets can also suffer deadlocks from stalled demand for innovation. Perhaps a designer would like to install fenestration with variable transparency that doubles as a photovoltaic energy source. In this conceptual innovation electricity production increases as light transmission decreases. The designer chooses to delete this innovation from his design because he can find no source. The semiconductor manufacturer chooses not to produce this product since he sees no demand for it. Of course deadlocks are more likely when financial barriers such as research and development costs or initial capitalization costs are high.

Since the utilities providing energy have profits tied to sales, they have a significant and natural financial disincentive to promote efficiency. As regulated monopolies, the governing utility commissions must create innovative policies to combine profit motive with conservation motives. The California Energy Commission (CEC) has a successful track record in this endeavor.

In summary we have identified a list of market barriers and failures that include:

- Split incentives for owners and tenants, developers and buyers
- First costs vs. life-cycle costs
- Not knowing
- Not caring
- Financial practice—capital vs. operating expense
- Resistance to change
- Stalled demand for innovation
- Utility profits based on sales

In the next chapter we discuss what policy interventions have been applied to these market problems. Each has either direct or indirect implications for architects, engineers, and builders since they impose requirements through mandatory codes or incentivize voluntary performance through labeling, tax credits, and tax deductions for owners. Consequently it is appropriate and essential that architects, engineers, and builders engage in the process of establishing the mix of policies that will facilitate changes in building design and construction needed to promote energy efficiency. Global economic and environmental viability demand it.

2 Policy interventions

This chapter surveys the policy scene as it relates to promoting energy efficiency in buildings. In passing we glean insights into the skills and knowledge of processes and technologies that architects, engineers, and builders must have to design and build in our changing environment.

Since the “oil Crisis” of 1973 many types of policy tools have been implemented to reduce the impact that the building sector has on the depletion of energy resources and on the environment, but few studies have reviewed such policy interventions. The Organization for Economic Cooperation and Development (OECD) sought to address this dearth of information and initiated a four-year study in 1998. To analyze the progress of policy design for building energy efficiency, the OECD conducted a survey of member countries, received 20 responses, and then extended this data with its own research of the literature. Among various kinds of policy instruments, three principal categories were apparent: regulatory instruments, economic instruments, and information tools[13].

Each of the policy categories has a different connotation as regards compliance. The regulatory measures are mandatory whereas the economic measures are voluntary incentives, i.e. sticks and carrots, that control or impact what is built. The information tools may be either mandatory or voluntary, but the essential feature is that they provide information to some audience.

To ensure effective policy, the measures target a building end-use that is a significant consumer of energy. Figure 11 shows the source energy usage in commercial (top chart) and residential (bottom chart) buildings from year 2006. While these two sectors differ somewhat, space conditioning, lighting, and water heating stand out as ideal targets for energy efficiency.

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[13] OECD, *Environmentally Sustainable Buildings: Challenges and Policies*, OECD, 2003, p32.

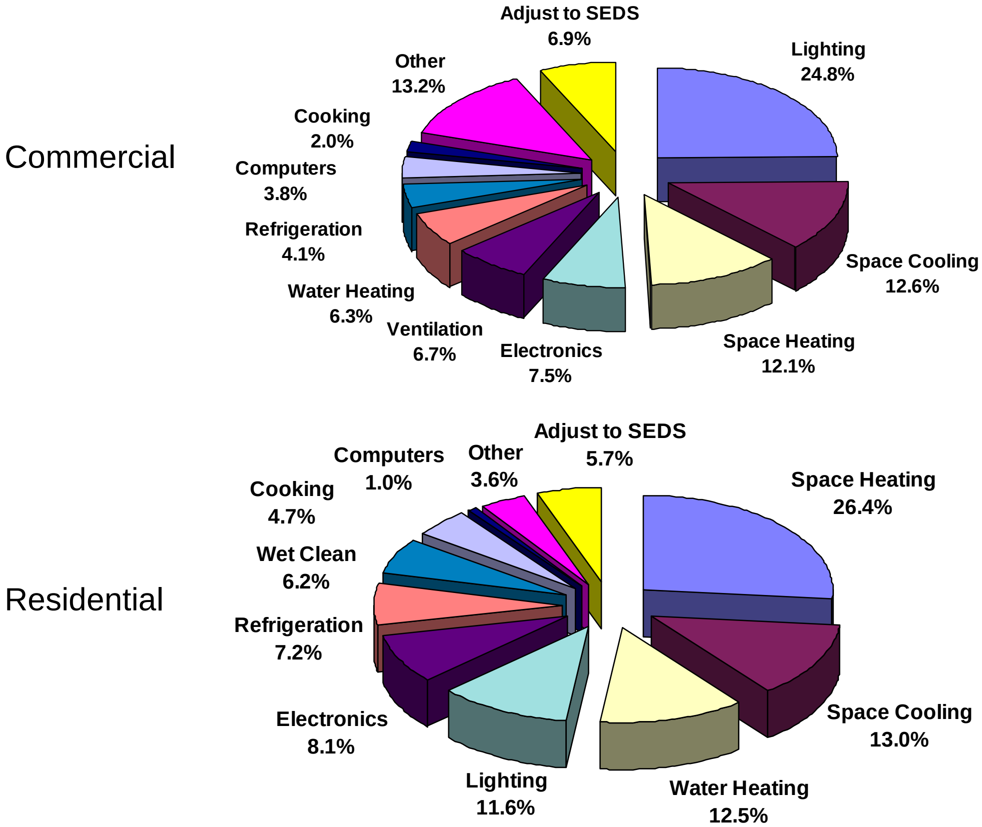

Figure 11. 2006 commercial (above) and residential (below) source energy end-use splits. The EIA makes an adjustment to State Energy Data System (SEDS) to absorb discrepancies between data sources. Data from http://buildingsdatabook.eren.doe.gov

2.1 Regulatory instruments

Primarily the OECD study found that countries extended their conventional life-safety codes' approach to an analogous approach for building energy codes. These measures are mandatory and establish a minimum level of performance for the buildings. We have three major building energy codes in the US: two used in the majority of the US, which are considered equivalent to one another, and one used exclusively in California. These codes are discussed in the next sections.

In addition I discuss energy metering and Demand Side Management (DSM)—a regulatory policy intervention to enable energy service providers an opportunity to be profitable while at the same time not seeking to increase energy consumption through additional sales.

2.1.1 Building energy codes

The first energy efficiency code for buildings was established in 1975 through the efforts of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) as a response to the first energy "crisis" in 1973. The initial Standard 90-1975 covered both residential and commercial buildings, but evolved into Standard 90.1 for commercial buildings and Standard 90.2 for residences.

Concurrently California passed the Warren-Alquist State Energy Resources Conservation and Development Act that created the California Energy Commission (CEC) in 1975. Based largely on ASHRAE Standard 90-1975, the CEC developed its first version of Title 24, Part 6, of the California Code of Regulations: California's Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24)[14].

While the code development efforts for Standard 90.1 and Title 24 shared common goals and techniques as well as engineers who worked on both code development projects, the two are not equivalent. Since the ASHRAE approval process operates on a consensus basis and has a nationwide constituency including equipment vendors, it moves more slowly than the CEC, which after periods of public comment from Californians, votes on adoption. Thus Title 24 consistently has been more agile in its evolution and more aggressive in its conservation, and has provided lessons to the nation on the potential for energy efficiency.

While some states had already adopted energy efficiency codes before the Federal government required them, the impetus for most states was the passage of the US Energy Policy Act of 1992. With this legislation, the Standard 90.1-1989 (*Energy Standard for Buildings Except Low-Rise Residential Buildings*), jointly developed by ASHRAE and the Illuminating Engineering Society of North America (IESNA), became the base efficiency standard for nonresidential building codes across the US. Under this act, each state had until October 1994 to certify to the Department of Energy (DOE) that it had a

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[14] Mark Hydeman, "A Tale of Two Codes," *ASHRAE Journal*, Vol. 48, April 2006, p50.

building code as stringent as Standard 90.1-1989[15]. States responded with an assortment of building energy codes.

In response to the proliferation of building codes for life safety and energy efficiency, in 1994 the International Code Council (ICC) was established as a nonprofit organization dedicated to developing a single set of comprehensive and coordinated national model construction codes[16]. The ICC sought to combine the efforts of the existing code organizations to produce a single set of codes so that code enforcement officials, architects, engineers, designers and contractors could work with a consistent set of requirements throughout the US. Furthermore this uniform adoption would enable code organizations to direct their collective energies toward wider code adoption by the states, better code enforcement, and services to communities. One of the products of this endeavor, the International Energy Conservation Code (IECC) is an off-the-shelf model energy code that many cities and states have adopted. It applies to both residential and non-residential construction.

As a result of this evolution, the two most commonly used national model energy codes or standards for commercial buildings in the US today are the IECC and the ASHRAE Standard 90.1. Most commercial structures built in the last 30 years have been designed to meet the requirements of one of these documents, their predecessors, or related state codes that draw on these documents. Standard 90.1 and the IECC are "rarely identical, usually equivalent, and typically similar in how they approach a particular code requirement."[17]

The discussion of codes in the next sections will combine the "equivalent" ASHRAE Standard 90.1 and IECC and compare and contrast them with Title 24.

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[15] Ibid, p46.

[16] About ICC: Introduction to the ICC http://www.iccsafe.org/news/about, International Code Council, Oct 4, 2009.

[17] Building Energy Code research Center, "Relationship Between Standard 90.1 and the IECC", http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article//1567, Oct 3, 2009.

2.1.1.1 Standard 90.1 and IECC

Since the birth of the ICC, ASHRAE Standard 90.1 and the IECC share a history of development. Both documents are currently on 3-year development cycles, with development following the rules and procedures of their parent organizations. The building science community, including industry representatives, code officials, building owners and operators, architects, mechanical engineers, and lighting designers, contribute input and suggestions for both documents. Every IECC document contains both a set of commercial building requirements and a reference to Standard 90.1, giving IECC users flexibility. Both documents have two compliance paths: a prescriptive approach and a performance approach. The current documents are the 2009 IECC and Standard 90.1-2007.

Using the prescriptive approach involves working with three construction categories that are consistent with the largest opportunities shown in Figure 11:

- Building envelope
- Interior/exterior lighting
- Space conditioning systems

Each category must meet the required minimum standards for the climate zone where the project is located. Tradeoffs between categories are not allowed. For example, if the design produces extra energy savings on lighting, these savings can not be used to cover deficiencies of the building envelope. Each category must comply independently.

Using the performance approach requires simulations for two buildings—the proposed building and a baseline standard building derived from the proposed building. The software ensures that the baseline standard meets the *prescriptive* requirements for that climate zone and separately satisfies the requirements for each prescriptive category. Then the second simulation must show that the designed building uses no more *total* energy annually than the baseline standard building. Thus the performance approach allows tradeoffs between all aspects of the building's design. As long as the total energy consumed by the entire proposed building is equal to or less than the total energy consumed by the baseline standard building, then it complies. Although this path with its simulations is more complex than the prescriptive approach, it offers a tremendous amount of flexibility in the design and thus is often justified.

2.1.1.2 California's Title-24 Building Energy Standards Part 6

The energy conservation potential for building energy codes is clearly demonstrated in California. California initiated its first response to the energy crisis with code changes in 1978 and has continued to raise the standard of performance over the next thirty years while the rest of the US lagged behind.

Like Standard 90.1 and the IECC, an optional prescriptive path for Title 24 can be satisfied by adhering to sets of rules defined for construction in three categories similar to ASHRAE and IECC:

- Building envelope/HVAC systems
- Indoor lighting efficiency
- Water heating

While the categories for Standard 90.1 and the IECC are slightly different from Title 24, the procedure is essentially identical. The alternative performance approach requires energy simulations for two buildings as described above. The derived standard baseline building defines the energy budget, and the whole building must satisfy the energy budget. Each category need not pass separately. Thus the performance track enables a good deal of flexibility not available to the prescriptive approach.

In the required simulations for the performance option, Title 24 takes the cost of energy a step beyond the concept of source energy of the last chapter with the introduction of time dependent valuation (TDV). The application of the TDV factor primarily intends to allocate economic resources equitably—not simply to conserve energy or to mitigate climate. Nevertheless, TDV may produce desirable outcomes for both, in particular renewable energy. Title 24 requires TDV energy be used to compare proposed designs to the energy budget. TDV energy is calculated by multiplying the site energy use (kWh of electricity, therms of natural gas, or gallons of fuel oil or LPG) for each energy type times the applicable TDV multiplier[18]. TDV multipliers vary for each hour of the year and by energy type (electricity, natural gas or propane), by climate zone and by building type (low-rise residential or nonresidential, high-rise residential or hotel/motel). TDV multipliers are summarized in Joint Appendix JA3—2008[19].

Figure 12 shows the TDV multipliers for commercial buildings in climate zone 12 (Sacramento) for a typical year and for the month of July. These multipliers include the conversions to source energy as well as the time-dependent values of the electricity. To provide the electricity needed for air conditioning on hot summer afternoons, the utility must invest in peak-power capacity that sits idle most of the year. Rates that are 10 times higher during these peak periods compensate the utilities for investing in and maintaining this infrastructure, and thus reflect the true economic cost of the resource as a function of time.

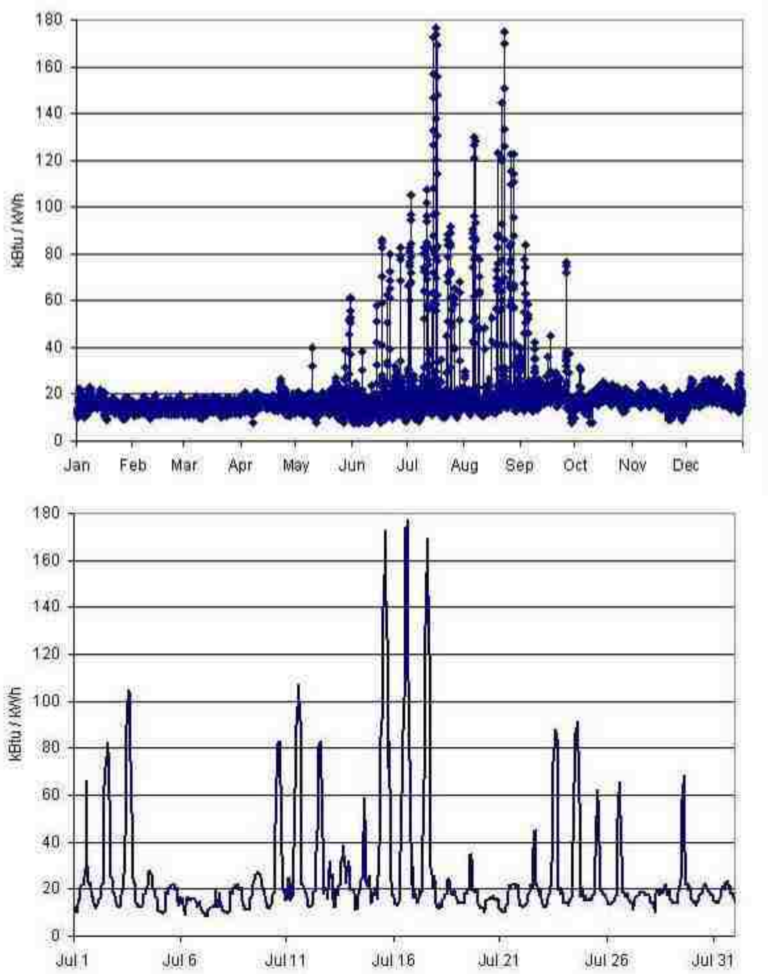

Figure 12. The hourly TDV conversion factors for climate zone 12 (Sacramento) for commercial electrical power during the year and the month of July.

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[18] California Energy Commission, *2008 Building Energy Efficiency Standards for residential and Nonresidential Buildings*, CEC-400-2008-001-CMF, December 2008, p48.

[19] California Energy Commission, "Appendix JA3 – Time Dependent Valuation (TDV)," http://www.energy.ca.gov/title24/2008standards/rulemaking/documents/pre-15-day_language/appendices/joint_appendices/JA%203%20-%20TDV%20-%20Rev5-15-day.pdf, Oct 3, 2009.

The use of the variable TDV incentivizes architects to design the buildings to avoid using power during peak periods. Since electrical power can not be stored, some designs have resorted to freezing ice during the night when power is affordable and then chilling the circulated air with the ice during the day. This thermal energy storage (TES) is an untended consequence of Title 24 since it may cost energy (BTUs) while saving dollars. However, if *renewable* energy is “stored” as ice, then source energy and emissions may be reduced and construction of new power plants and transmission lines may be delayed or eliminated[20]. If properly engineered, TES techniques can store energy at night with lower outdoor temperatures, and literally save energy[21].

Another significant difference between Title 24 and the Standard 90.1 deals with acceptance testing. Title 24 is quite detailed requiring functional performance tests that take place after the completion of construction and the documentation of the acceptance tests required for the certificate of occupancy. In contrast Standard 90.1 requires verification tests, but “doesn’t provide any guidance on how to specify these tests.”[22]

2.1.2 Metering

In searching for additional energy efficiency regulations that impose requirements upon the building design and performance, it was difficult to find much beyond building codes. However, there seemed to be a tide of interest in two aspects of energy consumption metering: sub-meters and smart meters. This interface between the building and its energy sources is becoming a focus of attention and offers a lever to move the industry towards more energy efficient behavior.

Sub-meters are relevant to buildings shared among a group of tenants. Typically a building has a single meter, and the landlord includes the average utility costs in the lease agreement, thereby removing any incentive for tenants to conserve energy. Various

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[20] CALMAC--Thermal Energy Storage, Off-Peak Cooling, Ice Rink http://www.calmac.com/, Oct 3, 2009.

[21] D.P Fiorino, “Energy conservation with thermally stratified chilled-water storage,” *ASHRAE Transactions*, v 100, n 1, 1994, p 1754-1766.

[22] Op cit, Mark Hydeman, p51.

jurisdictions around the country (New York City[23], Massachusetts[24], etc) are considering requiring sub-meters for all multi-tenant buildings whether residential or commercial to eliminate this market failure.

Smart meters address a different market problem. The time dependent valuation of energy acknowledges the capital investment committed by utilities to meet peak demands. Unfortunately the common meters in use today provide no feedback to customers and no warnings to indicate it would be cost effective for them to shed some of their load during these peak periods. Furthermore there is no mechanism to program automatic load shedding. Smart meters and their accompanying software address both of these issues. Smart meters will be essential components for smart electrical grids that seek to use intermittent renewable energy sources like wind and solar to provide a significant fraction, 20% to 50%, of the aggregate power for the grid. While in most jurisdictions there are no requirements for smart meters, Texas passed legislation requiring their use[25].

2.1.3 Demand side management (DSM)

In this section, the focus changes from the energy consumption of our buildings to their energy sources—the utilities. The discussion of the regulation of energy suppliers acknowledges the interaction of the supply and demand sides of the energy business and is unique in this thesis. While all the other interventions discussed here target the designer, builder, and owner directly, the indirect implications of photovoltaic installations on our buildings and the broad role of the electrical power utilities with buildings require knowledge of utility operation and regulation.

The initial model for energy utilities was that of natural monopolies. Either energy service would be provided by a utility owned by a governmental jurisdiction or the utility would be privately owned and regulated by a public utility commission. In the

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[23] Jennifer V. Hughes, Electricity: Saving by Submetering, http://www.habitatmag.com/publication_content/save_the_environment_save_the_world/electricity_submetering, Oct 5, 2009.

[24] Getting to Zero, Massachusetts Zero Net Energy Buildings Task Force, March 11, 2009, p14.

[25] Rebecca Smith, Smart Meter, Dumb Idea? April 27, 2009, http://online.wsj.com/article/SB124050416142448555.html#printMode,.

latter case the rates for energy sales were negotiated to provide an established rate of return on the utilities' undepreciated investments. This model resulted in highly leveraged utilities that sought to increase energy sales. Prior to the first oil crisis in 1973, this was a viable model.

However, subsequent to the crisis, two laws passed by the federal government permanently changed the electric utility industry. The first, called the Public Utilities Regulatory Policies Act of 1978 (PURPA), required utilities to purchase power from nonutility generators at posted prices equivalent to the cost of power that the utility would otherwise generate. This law acknowledged that the economies of scale underlying the natural monopoly in electricity generation were exhausted and that utilities' power to limit competition in the market was not in the public interest. The second law, the National Energy Conservation Policy Act of 1978 (NECPA) required utilities to provide an energy audit service to residential customers. This law recognized that saving energy was cheaper than producing it. Although this program was not called demand side management (DSM), it gave birth to the concept, which grew in subsequent years.

Energy efficiency advocates introduced the term "least-cost planning" to describe a new planning process. Whereas in the initial model utilities made capital investments without prior approval from regulators, least-cost planning was based on the notion that alternatives to new power plant construction—especially those available from managing customers' energy demands—could meet customers' energy service needs at lower cost. At a minimum least-cost planning required utilities to review their planned resource investments with regulators and the public in advance and to obtain prior approval for their acquisitions. Conceptually, least-cost planning differed from traditional planning by treating future load growth as an outcome of a planning process rather than the default assumption. Consequently, utility planners had to give equal consideration to both supply and demand-side options.

As a result of this energy efficiency advocacy, DSM programs grew significantly in the '80s and early '90s as shown in Figure 13.

Utility rates are typically set annually based on projected sales. After approval from the regulatory body, the utility has an incentive to increase sales beyond the projected sales since the marginal costs for additional production will be lower than the average costs used to establish the approved rates. Two regulatory strategies have been developed to overcome this incentive[26].

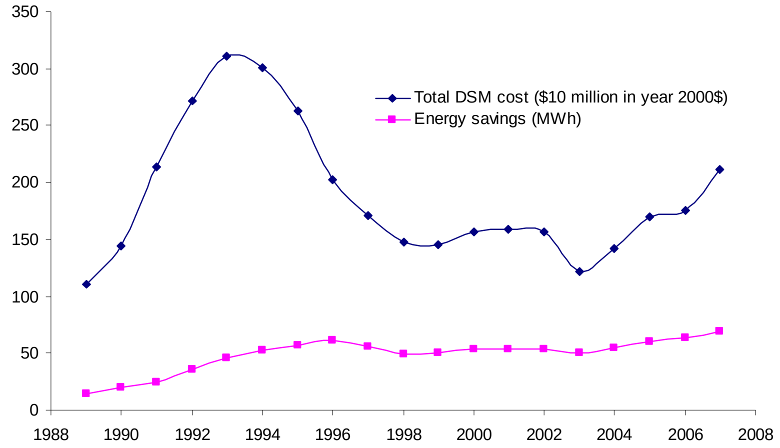

Figure 13. Electric Utility Demand-Side Management Programs, 1989-2007. See the legend for units on the vertical scale. Data source: http://www.eia.doe.gov/emeu/aer/txt/ptb0813.html

> The first compensates utilities for the margin foregone from sales "lost" as a result of cost-effective DSM programs. The second "decouples" revenue from sales. Decoupling requires establishing a revenue target that is independent of sales and creating a balancing account for the difference between revenues actually collected and the revenue target. The balance is cleared annually through either an increase or decrease in the subsequent year's revenue target. As a result, the utility has no incentive to increase loads and no disincentive to reduce loads because total revenues are independent of actual sales volumes in the short run.

Some states encourage DSM energy conservation with the creation of financial incentives for utilities. The utility may earn a[27]:

- Percentage of the money spent on DSM as an incentive
- Bonus paid in $/kWh or $/kW based on the energy or capacity saved by a DSM program
- Percentage of the net resource value of a DSM program. Net resource value is measured as the difference between the electricity system's avoided production costs and the costs required to run the program.

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[26] Joseph Eto, The Past, Present, and Future of US Utility Demand-Side Management Programs, Lawrence Berkeley National Laboratory, December 1996, p9.

[27] Ibid, p10.

Under the first two measures, the utility has an incentive to pursue DSM programs without regard to their cost effectiveness. The third measure is most popular since it directly aligns the utility’s interest with society’s interest in promoting energy efficiency only when it is cost effective. The success of these new regulatory measures appears to be a key factor in changing utilities’ perception of their role—from providing an energy commodity to one of providing energy services.

DSM does not focus exclusively on energy savings, but also considers avoidance of the expense of new plant construction. DSM measures include electricity price incentives intended to shift demand from peak periods to off-peak hours. While the shift can actually increase energy usage through thermal storage techniques that introduce inefficiencies that boost energy consumption while reducing costs to customers, well designed systems can reduce both energy consumption and costs.

As experts in energy, the utilities can continue to advance conservation. For example the smart meter program discussed in the previous section can be an innovative tool in DSM programs. In California, Pacific Gas and Electric (PG&E) notes that that the technology provides customers with detailed energy usage data to help them understand how they are using energy and reports that 87 percent of active participants in the program have been successful in saving money[28].

As architects, engineers, and builders include more on-site power generation in designs and buildings further decreasing the consumption of electrical power from the grid, the opportunity for increased sales for the utilities is further compromised. Utilities provide a backup power service that remains essential even as we pursue conservation and distributed sources of renewable energy. This backup capability need not be reinvented in our buildings. Utilities have provided power for more than 100 years, and as we move into an ever more efficient economy, polices must maintain this unique capability and ensure the viability of energy service providers.

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[28] State senator asks PG&E to prove smart meters are worthwhile, http://www.smartmeters.com/the-news/645-state-senator-asks-pgae-to-prove-smart-meters-are-worthwhile.html, 28 September 2009.

2.2 Economic instruments

The tools for economic interventions are diverse and include tax credit and tax exemption schemes, premium loan schemes, energy tax and tradable permit schemes, and capital subsidy programs.

2.2.1 Tax credit and tax exemption schemes

Governments have demonstrated a knack for innovation when it comes to economic incentives in general, and energy conservation is no exception. Most often these measures exploit tax deductions or tax credits. Due to the complexity and diversity of government incentives for building energy efficiency, I will simply identify a few federal programs, and then move to the states and municipalities.

The federal Energy Policy Act of 2005 established a tax deduction for energy efficient commercial buildings applicable to both buildings and their qualifying systems placed in service after January 1, 2006, and following several extensions, it remains in effect through 2013[29]. It covers systems such as furnaces, boilers, heat pumps, air conditioners, caulking/weather-stripping, duct/air sealing, building insulation, windows, doors, siding, roofs, and comprehensive whole-building measures. This same act also authorized individuals to receive a tax credit for energy improvements to existing residences. The residential scope includes electric heat pump water heaters, electric heat pumps, central air conditioners, water heaters and hot water boilers fired with natural gas, propane or oil, advanced main air circulating fans, and biomass stoves. The tax credit was initially limited to purchases made in 2006 and 2007, with an aggregate cap of $500 for qualifying purchases. Subsequent legislation extended the credit to include purchases made through 2010 and replaced the $500 cap with a $1,500 aggregate cap for installations made in 2009 and 2010[30].

Governments at the state or local level have developed a myriad of tax-based incentives. These jurisdictions should be regarded as experimental laboratories that are

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[29] DSIRE: Incentives/Policies by State: Federal: Incentives/Policies for Renewables & Efficiency http://www.dsireusa.org/incentives/index.cfm?state=us&re=1&EE=1, Oct 9, 2009.

[30] Ibid.

attempting to modify the behaviors of commercial and residential building owners to achieve better conservation performance. Browsing through Table 1 will give the reader a sense of the variety of legislative approaches currently in use.

Table 1. Illustrative sample of campaigns and incentive programs sponsored by state and local jurisdictions. Extracted from EPA's list of jurisdictions leveraging Energy Star tools[31].

State/Municipality	Policy	Summary
State of NM	HB 534: Sustainable Building Tax Credits	To qualify for income tax credits, applicants must demonstrate that the commercial building is 50 percent more efficient than an average building of the same type using EPA's Target Finder.
State of NJ	NJ Pay for Performance Program	Under the Pay for Performance program, commercial building owners are given technical assistance with developing and implementing an Energy Reduction Plan to reduce energy use by 15 percent or more. Participants benchmark energy use in EPA's Portfolio Manager to verify the required 15 percent threshold savings.
State of NJ	NJ Local Government Energy Audit Program	The Local Government Energy Audit Program provides local governments with cost-subsidized energy audits for municipal- and local government- owned facilities to identify cost-justified energy efficiency measures. Participants benchmark energy use in EPA's Portfolio Manager to target and verify savings.
State of PA	PA Small Business Energy Efficiency Grants	The PA Small Business Energy Efficiency Grant program makes funds available to for-profit small businesses that are completing eligible energy efficiency improvements. Applicants must benchmark in EPA's Portfolio Manager to provide projected energy savings and energy consumption data before and after the completion of the energy efficiency upgrade.

2.2.2 Premium loan schemes

Subsidized loan schemes form the second broad set of economic instruments. Often restricted to housing, the concept is that a public institution provides loans at below market rates to qualified buyers for the purchase or construction of homes that meet government efficiency standards more restrictive than current building code requirements. Advocating a variation of this concept, Architecture 2030 argues that if use of such loans were used to jumpstart the construction business in the current economy

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[31] EPA, State and local governments leveraging Energy Star, June 3, 2009, p2, http://www.energystar.gov/ia/business/government/State_Local_Govts_Leveraging_ES.pdf

through funding of efficiency upgrades, then the multiplicative effect of injected money would not only revive the economy, but the energy savings would pay off the loans[32].

2.2.3 Energy taxes and tradable permit schemes

The third approach to increase energy efficiency through economic measures is to raise the cost of energy and then allow market forces to drive efficiency improvements. Typically the cost of energy is increased by either taxing fuels or placing a value on heretofore "free" emissions. These policies are frequently termed "carbon tax" and "cap and trade," respectively, and both seek to assign a cost to the "externality" that the traditional market ignores. Economists describe externalities as those "situations in which the action of one economic agent affects the well-being or production possibilities of another in a way that is not reflected in market prices."[33] Europeans have maintained a high energy cost for decades through energy taxes, and in 2005 launched the European Union (EU) cap and trade system. Endeavoring to maintain low energy prices to encourage continued economic growth, the US has avoided carbon taxes and carbon trading schemes until 2009. The proposed Waxman-Markey Bill includes provisions to establish a cap and trade system.

By placing a "bounty" on emissions from fuel consumption, emitters have an incentive to reduce emissions. More efficient companies emit less, and can sell their emission permits to those failing to reduce. Thus the increased costs of inefficiency and emissions push companies towards efficiency measures with greater market pressure.

2.2.4 Capital subsidy programs

The US has programs for grants to assist in improving the energy efficiency of buildings. Typically such grants were reserved to low income families that received assistance through the Weatherization Assistance Program. However, with the economy in need of stimulus, grants are available through the American Recovery and

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[32] Climate Change, Global Warming, and the Built Environment - 14x Stimulus for State and Local... http://www.architecture2030.org/14x_stimulus/14x_stimulus.html, Oct 9,2009.

[33] Elise Golan, Barry Krissoff, Fred Kuchler, "Do Food Labels Make a Difference? . . . Sometimes,".*Amber Waves*, November 2007, p15.

Reinvestment Act of 2009 to mitigate energy efficiency problems in public buildings through a proposal process administered by the states, and to address efficiency improvements in the homes of low to moderate income families.

2.3 Information tools

The information tools in use by governments include mandatory or voluntary building energy labeling, environmental labeling of building materials and products, energy audit programs, green leases, and others. They share the common feature that governments consider requiring publication of information essential to the efficient operation of the marketplace whether the product is food or buildings. Unlike food packaging that has mandatory labeling, governments do not agree whether such information tools for buildings should be mandatory or voluntary.

2.3.1 Mandatory building energy labeling

Building energy labeling seeks to provide information to owners, buyers, tenants, and the public regarding the energy performance of buildings. Depending upon the labeling scheme, the building may have a wall mounted plaque or simply an undisplayed certificate. Accompanying documents may include quantitative data on the energy consumption of the buildings and its primary electrical and mechanical systems. The quantitative performance data results in the assignment of a grade to the building, for example, A-G for the EU labeling system. Some governments consider this information so critical to market transactions that they mandate such building energy labeling, e.g. the EU.

2.3.2 Voluntary building energy labeling

In the US our assorted building energy labeling schemes are generally voluntary. While the procedures of the labeling schemes are agnostic with respect to the question of voluntary or mandatory compliance, the distinction is so significant that I place these two options under separation headings to emphasize the choice. The efficacy of the intervention will vary with this degree of compulsoriness.

Today the information that would allow buyers and tenants to discriminate between apparently comparable buildings is often not available. As a first guess, the untrained public might suspect that newer buildings might be better than older ones. However, this assumption is invalid as shown in Figure 14, which plots the energy use intensity (EUI) distribution for 4,000 office buildings studied by the Environmental Protection Agency (EPA). Vertical lines at 86 and 166 kBTU/ft^2/year identify the breakpoints for the top and bottom performing quartiles in the distribution, respectively. In the top quartile, 39% of the buildings are less than 25 years old while in the bottom quartile an approximately equal number, 35%, are less than 25 years old. These counterintuitive data demonstrate that building age does not provide a useful metric to assess building energy performance. What metric might be more helpful?

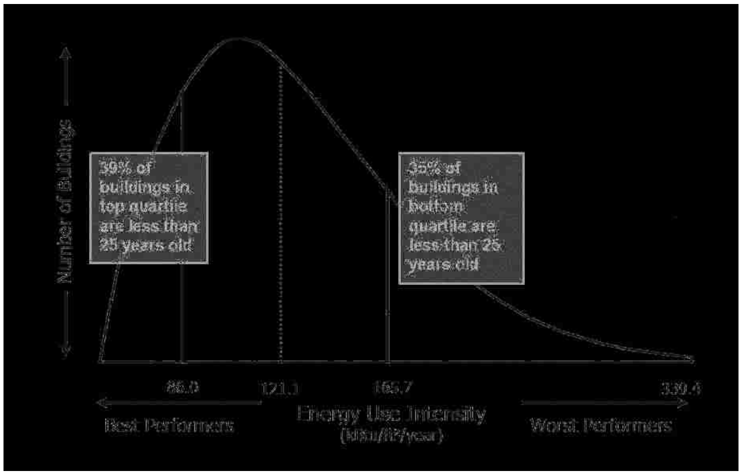

Figure 14. The distribution of the number of buildings as a function of energy use intensity for 4000 office buildings in the CBECS survey. Ref: Jean Lupinacci, "Green Buildings-Regulatory and Legislative, Initiatives", March 20, 2008

There are two types of rating scales in general use for evaluating building energy performance: statistical and technical. The fundamental performance metric is the EUI obtained by dividing the annual total of source energy consumed from all fuels used in the building by the total floor area inside its building envelope. Then simple corrections must be applied to "normalize" this raw performance metric to account for differences in climate, building size, number of occupants, operating schedule, and plug loads, e.g. the number of PCs in use inside the building. Statistical methods use a frequency distribution of the EUIs for the population of buildings sampled as shown in Figure 14 and rate a building according to its percentile location in the distribution. The commercial Energy Star rating, based on the Commercial Buildings Energy Consumption Survey (CBECS) database, is the leading method for this type of rating in the US. The simplicity of such statistical methods is attractive, but they offer no means by which to evaluate designs not yet built.

Technical rating methods are somewhat more complex. The EUI is mapped onto a scale nominally from 0 to 100 points. To define this linear mapping, we must first define the correspondence of two reference EUIs with points on the scale. While the reference points for this mapping are somewhat arbitrary, a good choice will make the scale more useful to designers, builders, owners, investors, and financiers.

In response to climate change and resource depletion, energy efficiency advocates have campaigned to increase building efficiency. For example, in 2006 Architecture 2030 established the 2030 Challenge to motivate designers to aim for net zero energy use in all new buildings in 2030. With the prominence of the net zero energy building (NZEB), it makes sense that it would be one of the reference points on the technical rating scale. What other reference point is logical and meaningful for use as the second datum?

All *current* technical ratings methods require whole building simulations, which demand detailed knowledge of the building geometry, materials, and active systems. Typically these methods define a standard building derived algorithmically from the building parameters of the building to be rated (with standard features such as insulation dependent upon climate zone, identical floor and fenestration areas, etc). This standard building is simulated and its calculated EUI used to define the second point on the rating scale that we use to compare the proposed building’s calculated EUI.

Alternatively the second point could be defined as the average EUI taken from the distribution of EUIs of a statistical sample of representative buildings. While this approach mixes concepts from the statistical approach with the technical approach, it enables comparisons to both the net zero building and the typical building in the inventory. Comparison of the technical and statistical scales is summarized in Figure 15.

The most significant difference between the technical and statistical rating scale is that a statistical scale is limited to the performance of buildings within the existing population. The technical rating provides differentiation on the scale for high performance buildings that are under-represented in the population sample used to derive the statistical scale[34].

Additional information regarding the history and the emerging trends of building energy labeling are presented in Appendix A.

2.3.3 Environmental labeling of building materials and products

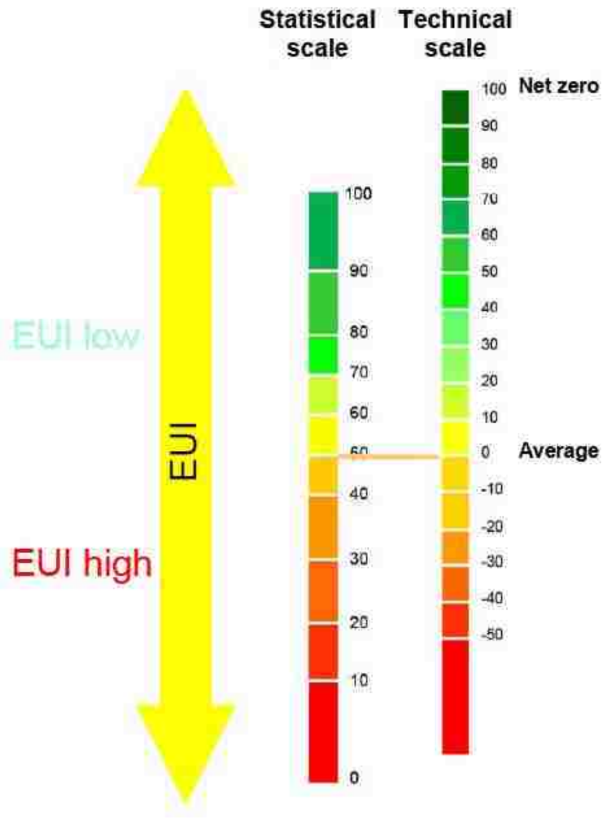

Figure 15. Example of graphical comparison of the statistical and technical scales. The statistical scale is defined by percentiles from the distribution of EUIs. The technical scale in this example assigns net zero energy buildings a score of 100 and an average EUI a score of zero.

While the labeling of building energy efficiency is intended to facilitate the well-informed sale and lease of buildings, the energy labeling of materials can help the architects, engineers, and builders as they design and construct buildings. There will be no high-performance buildings without high-performance materials and high-performance electro-mechanical systems to install in buildings. Consequently the testing and certification of materials and products is a key step in the process. Attention to both embodied energy and operational performance will be necessary. The US Environmental Protection Agency (EPA) has a successful voluntary program for testing, certifying and labeling equipment, appliances, lighting, insulation and windows for use in buildings. For example a similar voluntary program in the EU is now supplying 98% of European customers with refrigerators rated “A” on the EU scale of A-G—a testament to the market power of informed customers[35].

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[34] ASHRAE Building Energy Labeling Ad Hoc Committee, *Building Energy Quotient: Promoting the Value of Energy Efficiency In the Real Estate Market*, June 2009, p6.

[35] David Roberts, More Tidbits from the Energy Efficiency Global Forum, Grist, http://www.grist.org/article/2009-04-30-more-tidbits-efficiency/, 30 Apr 2009.

2.3.4 Energy audit programs

The OECD reports that five Member States have implemented energy audit programs that provide owners of buildings with technical assistance for upgrading the energy efficiency of buildings. For example the Energy Performance Advice Program in the Netherlands conducts audits and gives energy efficiency recommendations using government supplied software and financial support[36]. In New Jersey the Local Government Energy Audit Program provides local jurisdictions with cost-subsidized energy audits for municipal and local government facilities to identify cost-justified energy efficiency measures[37]. The information obtained from the energy audit drives refurbishment of the surveyed buildings.

2.3.5 Other intervention innovations

2.3.5.1 Green leases

Unlike the other interventions discussed in this chapter, "green" leases are the invention of private enterprise. Additional information is available from the Building Owners and Managers Association (BOMA) in their *Green Lease Guide*[38].

In the leasing business there are two sorts of commonly used leases: gross and net. A gross lease covers everything: space rental, utilities, insurance, taxes, and utilities. Although there are rent escalation clauses that cover potential inflationary increases in space rental, the owner is generally exposed to cost increases and volatility in the other areas—especially energy costs. Consequently most of today's contracts are net leases that effectively transfer all risks for building operating costs to the tenants.

Under a net lease tenants generally pay a prorated share of the building's cost of operation based on their fraction of the floor space in the building. Uncontrolled energy consumption follows from two problems: (1) the building owner has no incentive to

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[36] Op cit, OECD, p37.

[37] Local Government Energy Audit | NJ OCE Web Site, http://www.njcleanenergy.com/commercial-industrial/programs/local-government-energy-audit/local-government-energy-audit , Oct 10, 2009.

[38] New BOMA Green Lease Guide Offers Solutions for Writing Sustainability into Lease Agreements http://www.boma.org/news/pressroom/Pages/press062208-3.aspx, Oct 10, 2009.

upgrade building efficiency since the costs for electricity and gas are passed through to tenants and (2) any conservation measures adopted by a particular tenant are shared by all so there is no incentive for the tenant to conserve. Thus neither owner nor tenant has any motivation to conserve.

The solution to this dilemma is to adopt a modified “green” gross lease. The responsibility of the building operation and its costs are returned to the building owner. As opportunities present themselves, the owner will make appropriate capital upgrades to the building to increase its energy efficiency, and pass along to the tenants the amortized cost of the enhancement. The amortized cost must not exceed the amount saved in utility costs, so the tenant is guaranteed a savings. The building owner benefits since he capitalizes the upgrade expense via increased building value. To account for after-hours use or to prevent excess energy consumption by any maverick tenant, the lease provides for the sub-metering of each tenant’s energy use[39].

2.3.5.2 Energy Performance Contracting

Energy Performance Contracting (EPC) is an innovative financing technique that uses cost savings from reduced energy consumption to repay the cost of installing energy conservation measures. It shares this strategy with green leasing. Normally offered by Energy Service Companies (ESCOs), this approach allows building users to achieve energy savings without up front capital expenses. The costs of the energy improvements are borne by the performance contractor and paid back out of the energy savings. Other advantages of this approach include the ability to use a single contractor to do necessary energy audits, to perform the refurbishment, and to guarantee the energy savings from a selected series of conservation measures.

Like the green lease, this initiative comes from the private sector in response to market opportunities. However, 20 years ago EPC was stimulated by enabling legislation

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[39] Tony's Building Energy Performance Blog: "Green" Leases Growing http://blog.bepinfo.com/2009/02/green-leases-growing.html, July 25, 2009.

that encouraged jurisdictions to contract with ESCOs to achieve these energy savings[40]. Subsequently ESCOs operated without funding support from such policies.

While this seems like a great opportunity for organizations that lack capital funds or credit capacity to cover the costs for improvements, it extends the financial "leveraging" of firms through the use of "off-balance-sheet funding."[41] After the recent experience with highly leveraged firms on Wall Street, this approach may be less popular. Failures of business clients can have catastrophic ripple effects among ESCOs.

2.3.5.3 Recognition

Jurisdictions have seized the opportunity to implement low-cost or no-cost programs based on energy conservation awareness facilitated by information. As summarized in Table 2, these programs are local challenges or competitions to increase energy efficiency and rely upon the visibility of the "event," information, and the human urge to compete. Not only do such events increase efficiency, but the elevated awareness in the community will multiply energy savings among the non-competitors.

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[40] Energy Performance Contracting, http://www.cogeneration.net/EnergyPerformanceContracting.htm, Oct 11, 2009.

[41] Greg Zimmerman, Making ESCOs Pay, May 2009, http://www.facilitiesnet.com/energyefficiency/article/Making-ESCOs-Pay--10826.

Table 2. Illustrative sample of innovative programs sponsored by state and local jurisdictions. Extracted from EPA's list of jurisdictions leveraging Energy Star tools[42].

State/Municipality	Policy	Summary
City of Albuquerque, NM	Green Path Program	This program encourages and facilitates voluntary design and construction of energy-efficient buildings that meet measurable criteria, which includes earning Designed to Earn the ENERGY STAR through EPA's Target Finder.
City of Chicago, IL	Chicago Green Office Challenge	Participants in the Chicago Green Office Challenge will use EPA's Portfolio Manager to track energy and water use and compile results at the end of the contest period.
City of Louisville, KY	Louisville Kilowatt Crackdown	Participants in the Louisville Kilowatt Crackdown will track and work to improve their building's energy use in EPA's Portfolio Manager. The competition is open to owners and managers of all commercial buildings in the city.
City of Portland, OR	BOMA Energy Showdown	Participants in the BOMA Portland Office Energy Showdown will track and work to improve their building's energy use in EPA's Portfolio Manager. The competition is open to owners and managers of commercial offices.
City of San Francisco, CA	Earth Hour 24x7 Energy Challenge	Participants in the San Francisco Earth Hour 24x7 Energy Challenge will track and work to improve their building's energy use in EPA's Portfolio Manager. The competition is open to owners and managers of office buildings, hotels, retail stores, hospitals, medical office buildings, supermarkets, and schools.
City of Seattle and King County, WA	BOMA Kilowatt Crackdown	Participants in the BOMA Seattle/King County Kilowatt Crackdown will track and work to improve their building's energy use in EPA's Portfolio Manager. The competition is open to owners and managers of commercial offices.
New England EPA Region 1	EPA Region 1 Community Energy Challenge	This campaign challenges communities across New England to assess energy use, improve energy efficiency, and promote energy efficiency and renewable energy to local companies. Communities that take part in the New England Community Energy Challenge are provided with assistance, including Web-based training on EPA's Portfolio Manager.
State of WI	WI Lt. Governor ENERGY STAR School Challenge	This program challenges 100 new WI school districts to join as ENERGY STAR partners and reduce energy use by 10 percent or more across their building portfolios. Participating school districts agree to measure and track energy performance using EPA's Portfolio Manager and set goals and plan improvements based on ENERGY STAR Guidelines for Energy Management.

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[42] Op cit, EPA.

2.3.5.4 Metering disclosure

Washington, D.C. has adopted legislation that will disclose energy consumption data for all non-residential facilities, stipulating that data will be made available to the public through Portfolio Manager with the program starting in January 2010 and full implementation by 2013[43]. This recognition will reward efficient building owners and embarrass those with energy "hogs."

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[43] Leslie Cook, NASEO EPA ENERGY STAR Update, EPA, September 2008, p10, http://www.naseo.org/events/annual/2008/presentations/Cook.pdf

3 The opportunity

The preceding chapters have established that 1) energy consumption has grown exponentially as it has driven economic growth, 2) energy consumption has created environmental hazards, 3) economic and environmental saving opportunities exist and have not been fully exploited, and 4) commercial buildings have not improved their energy performance significantly in the last 30 years in contrast with other building sectors. Furthermore there are a plethora of policy measures which could facilitate realizing these savings if effectively implemented.

While in the past these interventions have been implemented haphazardly at the local, state, and national levels, in the midst of the current economic downturn, the US Congress appears ready to act. In an attempt to seize this energy opportunity, the House of Representatives narrowly passed the Waxman-Markey Bill in a vote of 219 to 212 on June 26, 2009, and the bill moved to the Senate for debate and revision. As it left the House, the significant features of the bill:[44]

- Require electric utilities to meet 20% of their electricity demand through renewable energy sources and energy efficiency by 2020
- Invest in new clean energy technologies and energy efficiency, including energy efficiency and renewable energy ($90 billion in new investments by 2025), carbon capture and sequestration ($60 billion), electric and other advanced technology vehicles ($20 billion), and basic scientific research and development ($20 billion)
- Mandate new energy-saving code and labeling standards for buildings, appliances, and industry
- Reduce carbon emissions from major US sources by 17% by 2020 and over 80% by 2050 compared to 2005 levels. Complementary measures in the legislation, such as investments in preventing tropical deforestation, will achieve significant additional reductions in carbon emissions

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[44] A useful summary of Waxman-Markey - Climate Progress, http://climateprogress.org/2009/06/02/a-useful-summary-of-the-house-clean-energy-and-climate-bill/, Sept 8, 2009.

- Protect consumers from energy price increases. According to estimates from the Environmental Protection Agency, the reductions in carbon pollution required by the legislation will cost American families less than a postage stamp per day

This legislation is not selective—it supports the majority of the measures discussed in Chapter 2. While it is understandable that using all of the firepower in your arsenal may be the right answer in time of war, in policy matters there areoften vested interests that resist change. To limit resistance and increase the possibility of advancing policy for energy efficiency, more selectivity may be essential. Consequently this thesis seeks to identify the policy of choice to focus the current political discussion and to explore the consequences for architecture.

The present moment offers a rare opportunity to make an economic and environmental selection. Our nation and the world demand our best analysis followed by action. In response this thesis posits that building energy labeling is the policy of choice and offers a path to improved energy performance especially for commercial buildings.

3.1 The question

Can building energy labeling provide a path to improved energy performance for commercial buildings?

To answer the question this thesis will establish that:

- Current building energy labeling systems are chaotic
- Better building energy labeling schemes exist
- Building energy labeling leads to more stringent building energy codes
- Building energy labeling produces value for owners and tenants
- Building energy labeling produces value for governments
- Building energy labeling leads toward net zero energy buildings
- Building design and construction practice must evolve

This thesis will restrict its argument to qualitative feasibility and will avoid quantitative assessments. Furthermore, there will be no attempt to formally prove that building energy labeling is the optimum policy intervention or even that it is effective. Such proofs are well beyond the scope of this thesis and well-funded and well-staffed research efforts. In their Chapter 6 of the Fourth Assessment Report entitled “Residential and commercial buildings,” the authors for the Intergovernmental Panel for Climate Change reported[45] that “While occupant behaviour, culture and consumer choice and use of technologies are also major determinants of energy use in buildings and play a fundamental role in determining CO_2 emissions…, the potential reduction through non-technological options is rarely assessed and the potential leverage of policies over these is poorly understood.” Yet the reader will see that a compelling case for building energy labeling is made in Chapter 6.

3.2 The research methodology

This thesis will employ extensive research of the literature like that demonstrated in the first two chapters, hands-on case studies with the building energy labeling tools in use today, and synthesis of the information and experience. Results from the literature research will be reported in Chapter 4, Current energy labeling standards, and in Chapter 6, Synthesis. Chapter 5 presents the case studies.

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[45] Levine, M., D. Ürge-Vorsatz, K. Blok, L. Geng, D. Harvey, S. Lang, G. Levermore, A. Mongameli Mehlwana, S. Mirasgedis, A. Novikova, J. Rilling, H. Yoshino,: Residential and commercial buildings. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007, p389.

4 Current energy labeling standards

This chapter summarizes the energy metrics, ratings, or labels currently used to characterize building energy performance. The emerging ASHRAE labeling scheme is covered briefly in Section 4.3 since it is likely to be well received due to ASHRAE’s established energy efficiency leadership. All aim to provide the buyer or tenant a “grade” and information to factor into their decision making process. Although these metrics show significant variations, they share common principles and methods. Each has its own niche and mission within the spectrum of building sectors. The Energy Star program run by the EPA concentrates on primarily the commercial building sector whereas the Home Efficiency Rating System (HERS) focuses upon residences only. A rating for an Energy Star home closely follows the HERS process and is covered in Section 4.2. HERS is sponsored by the National Association of State Energy Officials (NASEO). Each of these three building labeling systems exclusively rate *energy* performance and may be based upon measurements or simulations of designs.

Other familiar labeling standards, LEED and Green Globe, are inclusive and rate the more expansive *sustainability* performance of buildings—energy and more. Consequently a high rating is not necessarily intended to imply that the building offers high energy performance. When LEED ratings on the horizontal axis are compared with Energy Star ratings for the same buildings on the vertical axis, it is difficult to see any consistency whatsoever (see Figure 16).

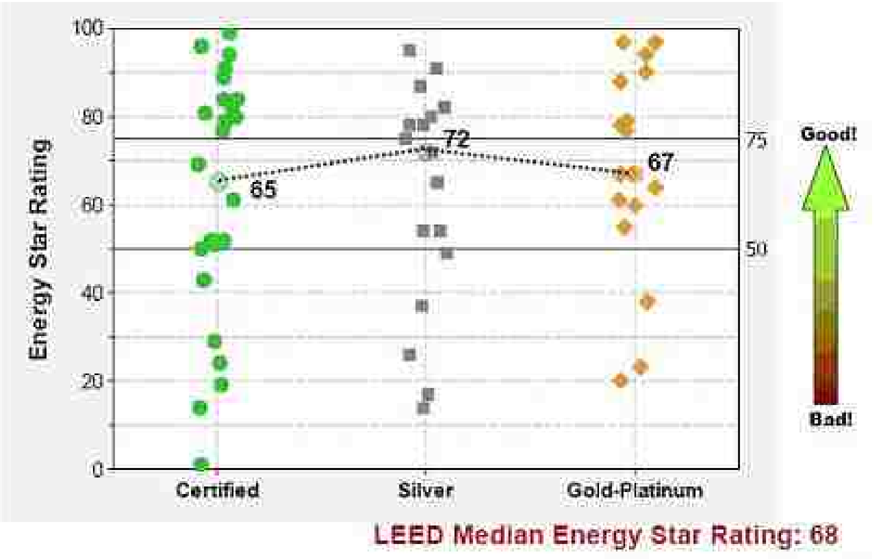

Figure 16. Energy Star Rating vs. LEED Level. Ref: Jean Lupinacci, “Green Buildings-Regulatory and Legislative, Initiatives”, March 20, 2008.

To shed light on this confusing situation, the following sections describe how these current labels are derived and what information they provide to owners, buyers and tenants. One sees that some labeling schemes apply to operational buildings, some to design, and some to both. Additional detailed information on the history of labeling and emerging standards is included in Appendix A.

4.1 Energy Star for commercial buildings

Figure 17. Sample Building Plaque. Dimensions: width 10 inches, height 12 inches, Color: cyan.

The EPA originally launched the Energy Star system in 1992 to apply energy labels to computers and computer equipment. Over time the scope of the rating system has expanded to cover such diverse energy-consuming devices as refrigerators, washing machines, light bulbs, and *buildings*. Energy Star was first extended to commercial buildings in 1995. As vendors improve their products, the EPA continually raises the standard for the qualifying performance; so consequently, a product may qualify in one year but then fail the next. Thus Energy Star plaques carry a date to inform consumers when the product was last certified as shown in Figure 17.

For buildings the Energy Star rating relies upon a statistical rating method. The rating system estimates how much energy the building would use if it were the best performing, the worst performing, and every level in between, based on its size, location with its associated weather, number of occupants, number of PCs, etc. The system then compares the actual energy consumed to the estimate to determine where the building to be rated ranks relative to its peers and assigns a score in the range 1-100. For example a score of 80 indicates that the building is better than 80% of its peers. Buildings in the top quartile earn the Energy Star label. Rated buildings may be of the following commercial types:

- Bank/Financial Institutions
- Courthouses
- Hospitals (acute care and children’s)
- Hotels

- K-12 Schools
- Medical Offices
- Municipal Wastewater Treatment Plants
- Offices
- Residence Halls/Dormitories
- Retail Stores
- Supermarkets
- Warehouses (refrigerated and non-refrigerated)

All of the calculations are based on source energy that includes inefficiencies in energy generation, conversion, and distribution. The use of source energy is the most equitable way to compare building energy performance, and also correlates best with environmental impact and energy cost.

To estimate how much energy a building would use at each level of performance, the EPA conducts statistical analysis on the data gathered by the Energy Information Administration (EIA) within the Department of Energy (DOE) during its quadrennial Commercial Building Energy Consumption Survey (CBECS). For each type of building for which EPA offers a rating, EPA goes through a rigorous process that involves[46]:

- Ensuring that the quality and quantity of the data will support a rating
- Creating a statistical model that correlates the energy data to the operational characteristics for each building to identify the key drivers of energy use
- Testing the model with real buildings

To be eligible for the Energy Star label a commercial building must meet certain size and operational requirements[47]. Since the building systems could potentially be operated in an energy saving mode incompatible with human comfort, a Professional

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[46] How the Rating System Works : ENERGY STAR, http://www.energystar.gov/index.cfm?c=evaluate_performance.pt_neprs_learn, Aug 10, 2009.

[47] Ibid, p4.

Engineer must certify that the buildings meet environmental standards for temperature, humidity, ventilation, and lighting as specified in the following documents[48]:

- American National Standards Institute (ANSI)/American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55: Thermal Environmental Conditions for Human Occupancy.
- ANSI/ASHRAE Standard 62.1, Ventilation for Acceptable Indoor Air Quality.
- Lighting Handbook: Reference & Application, 9th Edition. Illuminating Engineering Society of North America (IESNA).

The process that establishes an Energy Star rating for a building may be facilitated through use of two software tools: Target Finder and Portfolio Manager. Used during design to define an energy consumption goal, Target Finder interpolates energy consumption data from the CBECS baseline data and adjusts the nominal building energy consumption for building size, number of occupants, hours of operation, location, weather, etc. Used for operations to compare with similar buildings in the national building inventory, Portfolio Manager can automate the acquisition of data from the energy supply companies. These tools will be discussed in Section 4.1.2.

A criticism of the Energy Star label follows from the fact that a building need only be in the top quartile of the existing inventory to achieve the rating. Unfortunately there are few net-zero energy buildings in that inventory so the rating merely assesses best-in-class, not the best-in-concept. Thus the high end of the point scale is strictly relative—not absolute—and provides no means to discern how the building compares with net-zero energy.

4.1.1 CBECS

The Commercial Buildings Energy Consumption Survey (CBECS) is conducted quadrennially by the EIA to provide basic statistical information about energy consumption and expenditures in US commercial buildings and information about energy-related characteristics of these buildings. Not only does CBECS provide the data

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[48] *2009 Professional Engineer's Guide to the ENERGY STAR ® Label for Commercial Buildings*, US Environmental Protection Agency Office of Air and Radiation, 2009,pp 8,10,14.

that forms the basis for the Energy Star labeling system, but emerging labeling standards also use these data to establish average site-use EUIs for sector categories in the building inventory. All CBECS data measures energy consumption at the on-site meter—not energy at the production or generation site.

The survey is based upon a sample of commercial buildings selected according to the sample design requirements[49]. A “building,” as opposed to an “establishment,” is the basic unit of analysis for the CBECS because the building is the energy-consuming unit. For shopping malls, however, “establishments” were considered as separate entities like buildings. The 2003 CBECS was the eighth survey conducted since 1979 and is the last survey to be fully processed. Analysis of the data from the 2007 survey is still incomplete as of this writing.

The CBECS is conducted in two data-collection stages: a Building Characteristics Survey and an Energy Suppliers Survey[50]. The Building Characteristics Survey collects information about selected commercial buildings through voluntary interviews with the buildings’ owners, managers, or tenants. During the Building Characteristics Survey, respondents are asked questions about the building size, how the building is used, types of energy-using equipment and conservation measures that are present in the building, the types of energy sources used, and the amount and cost of energy used in the building.

Upon completion of the Building Characteristics Survey, the Energy Suppliers Survey is initiated only if the respondents to the Building Characteristics Survey can not provide the energy consumption and expenditures information, or the provided information appears flawed. This Suppliers Survey obtains data about the building’s actual consumption of and expenditures for site-use energy from records maintained by energy suppliers. These billing data are collected in a mail survey conducted under EIA’s mandatory data collection authority.

To be eligible for the survey, a building had to be: (1) larger than 1,000 ft^2; (2) a structure totally enclosed by walls that extend from the foundation to the roof and must

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[49] 2003 CBECS Sample Design, http://www.eia.doe.gov/emeu/cbecs/2003sample.html, Aug 10, 2009.

[50] Ibid.

be intended for human access; and (3) used primarily for some commercial purpose. It would be considered a commercial building if more than 50 percent of its floor area is devoted to activities that are not residential, industrial, or agricultural. The 2003 CBECS estimated that there were 4,859,000 buildings in this target population.

Due to the number of variables that characterize the sampled commercial buildings, the data may be presented in numerous ways. Table 3 shows the gross energy intensity for all fuels as a function of building, size, principal building activity, age of the building, region of the country, climate zone, and the number of establishments in the building. Note that CBECS data calculate the gross EUI without adjustments for efficiency losses at generation and during transmission. These data would be corrected for these effects when applied in Energy Star ratings.

Table 3. Consumption and Gross Energy Intensity for Sum of Major Fuels for All Buildings, 2003 CBECS. Ref: Table C3A, http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html, Aug 28, 2009.

	All Buildings			Sum of Major Fuel Consumption		
	Number of Buildings (thousand)	Floorspace (million square feet)	Floorspace per Building (thousand square feet)	Total (trillion Btu)	per Building (million Btu)	per Square Foot (thousand Btu)
All Buildings	4,859	71,658	14.7	6,523	1,342	91.0
Building Floorspace (Square Feet)						
1,001 to 5,000	2,586	6,922	2.7	685	265	99.0
5,001 to 10,000	948	7,033	7.4	563	594	80.0
10,001 to 25,000	810	12,659	15.6	899	1,110	71.0
25,001 to 50,000	261	9,382	36.0	742	2,843	79.0
50,001 to 100,000	147	10,291	70.2	913	6,230	88.7
100,001 to 200,000	74	10,217	138.6	1,064	14,436	104.2
200,001 to 500,000	26	7,494	287.6	751	28,831	100.2
Over 500,000	8	7,660	937.6	906	110,855	118.2
Principal Building Activity						
Education	386	9,874	25.6	820	2,125	83.1
Food Sales	226	1,255	5.6	251	1,110	199.7
Food Service	297	1,654	5.6	427	1,436	258.3
Health Care	129	3,163	24.6	594	4,612	187.7
Inpatient	8	1,905	241.4	475	60,152	249.2
Outpatient	121	1,258	10.4	119	985	94.6
Lodging	142	5,096	35.8	510	3,578	100.0
Mercantile	657	11,192	17.0	1,021	1,556	91.3
Retail (Other Than Mall)	443	4,317	9.7	319	720	73.9
Enclosed and Strip Malls	213	6,875	32.2	702	3,292	102.2
Office	824	12,208	14.8	1,134	1,376	92.9
Public Assembly	277	3,939	14.2	370	1,338	93.9
Public Order and Safety	71	1,090	15.5	126	1,791	115.8
Religious Worship	370	3,754	10.1	163	440	43.5
Service	622	4,050	6.5	312	501	77.0
Warehouse and Storage	597	10,078	16.9	456	764	45.2
Other	79	1,738	21.9	286	3,600	164.4
Vacant	182	2,567	14.1	54	294	20.9
Year Constructed						
Before 1920	333	3,784	11.4	303	912	80.2
1920 to 1945	536	6,985	13.0	631	1,177	90.4
1946 to 1959	573	7,262	12.7	588	1,026	80.9
1960 to 1969	600	8,641	14.4	791	1,317	91.5
1970 to 1979	784	12,275	15.6	1,191	1,518	97.0
1980 to 1989	768	12,468	16.2	1,247	1,622	100.0
1990 to 1999	917	13,981	15.2	1,262	1,376	90.2
2000 to 2003	347	6,262	18.1	511	1,473	81.6
Census Region and Division						
Northeast	761	13,995	18.4	1,396	1,834	99.8
New England	252	3,452	13.7	345	1,368	99.8
Middle Atlantic	509	10,543	20.7	1,052	2,064	99.7
Midwest	1,305	18,103	13.9	1,799	1,379	99.4
East North Central	728	12,424	17.1	1,343	1,846	108.1

West North Central	577	5,680	9.8	456	790	80.2
South	1,873	26,739	14.3	2,265	1,209	84.7
South Atlantic	926	13,999	15.1	1,241	1,340	88.7
East South Central	360	3,719	10.3	340	944	91.4
West South Central	587	9,022	15.4	684	1,164	75.8
West	920	12,820	13.9	1,063	1,156	82.9
Mountain	316	4,207	13.3	446	1,411	106.1
Pacific	603	8,613	14.3	617	1,022	71.6
Climate Zone: 30-Year Average						
Under 2,000 CDD and --						
More than 7,000 HDD	882	11,529	13.1	1,086	1,231	94.2
5,500-7,000 HDD	1,229	18,808	15.3	1,929	1,570	102.6
4,000-5,499 HDD	701	12,503	17.8	1,243	1,773	99.4
Fewer than 4,000 HDD	1,336	17,630	13.2	1,386	1,038	78.6
2,000 CDD or More and --						
Fewer than 4,000 HDD	711	11,189	15.7	879	1,236	78.6
Number of Establishments						
One	3,754	45,144	12.0	4,167	1,110	92.3
2 to 5	762	12,565	16.5	1,161	1,525	92.4
6 to 10	117	3,358	28.6	378	3,222	112.6
11 to 20	47	3,369	71.8	307	6,540	91.1
More than 20	22	5,060	227.3	473	21,234	93.4
Currently Unoccupied	157	2,161	13.8	37	237	17.2
Energy Sources (more than one may apply)						
Electricity	4,617	70,181	15.2	6,522	1,413	92.9
Natural Gas	2,538	48,473	19.1	5,042	1,987	104.0
Fuel Oil	465	16,265	35.0	1,867	4,012	114.8
District Heat	67	5,576	83.1	1,029	15,337	184.6
Energy End Uses (more than one may apply)						
Buildings with Space Heating	4,182	66,446	15.9	6,370	1,523	95.9
Buildings with Cooling	3,825	63,560	16.6	6,149	1,608	96.7
Buildings with Water Heating	3,659	62,827	17.2	6,158	1,683	98.0

See "Guide to the Tables" or "Glossary" for further explanations of the terms used in this table. Both can be accessed from the CBECS web site http://www.eia.doe.gov/emeu/cbecs.
Q=Data withheld because the Relative Standard Error (RSE) was greater than 50 percent, or fewer than 20 buildings were sampled.
N=No responding cases in sample.

Notes: ● Statistics for the "Energy End Uses" category represent total consumption in buildings that have the end use, not consumption specifically for that particular end use. ● HVAC = Heating, Ventilation, and Air Conditioning. ● Due to rounding, data may not sum to totals.
Source: Energy Information Administration, Office of Energy Markets and End Use, Forms EIA-871A, C, and E of the 2003 Commercial Buildings Energy Consumption Survey.

4.1.2 Target Finder/Portfolio Manager

Target Finder is an interactive online tool provided by the EPA that may be used during the design process to establish energy consumption goals and assess design performance. If desired, the project can apply for the “Designed to Earn the ENERGY STAR” certification from the EPA and use the associated logo on project documentation during the life of the project. In the preliminary-design phase Target Finder calculates the total energy consumption allowed for the specified design parameters. Then during the schematic-design phase, the estimates of energy consumption for the building can be compared to the Energy Star limits to establish an Energy Star rating and apply for the “Designed to Earn the ENERGY STAR” certification.

The EUI generated by Target Finder[51] reflects the distribution of commercial buildings derived from 2003 CBECS. The required data inputs are the primary drivers of energy use. The zip code is used to determine the climate conditions that the building would experience in a normal year based on a 30-year climate average. The total annual EUI for the target is based on the energy mix (ratio of energy from electricity or gas to the total energy for the building) established for the zip code, and this default is displayed. While users may enter their own mix, electricity must be selected as one of the choices. Site and source energy calculations are provided for both EUI and total annual energy. The EPA rating is then calculated from source energy use.

Portfolio Manager is an interactive online energy management tool provided by the EPA that helps you track and assess energy and water consumption within individual buildings as well as across your entire building portfolio if applicable. You may enter energy consumption and cost data into your Portfolio Manager account to benchmark building energy performance against other buildings in the US, assess energy management goals over time, and identify strategic opportunities for savings and recognition opportunities through the EnergyStar label. Some energy service providers offer the option to automatically download building energy and water consumption via Portfolio Manager.

Managers can efficiently track and manage any building resources through the use of Portfolio Manager. The tool allows you to streamline your portfolio’s energy and

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[51] Target Finder : Energy Star, http://www.energystar.gov/index.cfm?c=new_bldg_design.bus_target_finder, Aug 28, 2009.

water data, and track key consumption, performance, and cost information portfolio-wide. The tool enables you to[52]:

- Track multiple energy and water meters for each facility
- Customize meter names and key information
- Benchmark your facilities relative to their past performance
- View percent improvement in weather-normalized source energy
- Monitor energy and water costs
- Share your building data with others inside or outside of your organization
- Enter operating characteristics, tailored to each space-use category within your building.

For commercial building types supported by CBECS, you can rate their energy performance on the Energy Star scale of 1–100 relative to similar buildings nationwide. Note that your building is not compared to the other buildings entered into Portfolio Manager to determine your rating. Instead, statistically representative models are used to compare your building against similar buildings from the CBECS survey discussed in Section 4.1.1. Your building's peer group of comparison is those buildings in the CBECS survey that have similar building and operating characteristics.

4.2 NASEO and RESNET

Both the EPA and the National Association of State Energy Officials (NASEO) have vested interests in the energy ratings systems. Due to their different roles in the federal and states governments, their actions are neither synchronized nor coherent, yet their intent is to promote energy conservation through their building labeling initiatives. NASEO established the Energy Rated Homes of America (ERHA) in 1981, and the ERHA created its Home Energy Rating System (HERS) for the residential sector. The EPA has embraced HERS for its home labeling since 1992.

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[52] Portfolio Manager Overview, http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager, Aug 29, 2009.

In April 1995, the NASEO and ERHA founded the Residential Energy Services Network (RESNET®) to develop a national market for home energy rating systems and energy mortgages. RESNET's activities are guided by a mortgage industry advisory council composed of the leading national mortgage executives. Two type of energy mortgages enabled home owners or buyers to use monthly energy savings to finance energy upgrades of an existing home or to increase their buying power and capitalize the energy savings in the appraisal of a new home.

While the NASEO establishes the technical basis for the HERS[53], RESNET actually implements the system and appears a well established bureaucracy with essentially monopoly power. RESNET's mission is to ensure the success of the residential building energy performance certification industry, to set the standards of quality, and to increase the opportunity for ownership of high performance homes. In collaboration with the US mortgage industry, RESNET has established standards[54] that enable the mortgage loan industry to capitalize building energy performance and that the federal government uses for verification of building energy performance for such programs as federal tax incentives, the EPA's Energy Star Home program and the DOE's Building America Program[55].

4.2.1 HERS

RESNET Ratings provides a relative energy use index called the HERS® Index as shown in Figure 18. Using a scale where buildings with lower scales use lower energy, the HERS Index of 100 represents the energy use of the "American Reference Design home" and an index of zero indicates that the building uses no net purchased energy. Note that this scale is the inverse of the Energy Star scale in that smaller scores use less energy. A certified home rater assesses energy consumption and home geometry and

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[53] *National Home Energy Rating Technical Guidelines,* National Association of State Energy Officials (NASEO), September 19, 1999.

[54] *2006 Mortgage Industry National Home Energy Rating Systems Standards,* Residential Energy Services Network, amended July 22, 2009.

[55] RESNET: Residential Energy Services Network | Setting the Standard for Quality http://www.natresnet.org/, Aug 29, 2009.

construction to establish the rating and also to produce a set of recommendations for cost-effective improvements that can be achieved in the rated home.

While the commercial Energy Star rating depends upon the building type and comparisons with buildings in the CBECS database, the HERS system uses the concept of the "Reference Design home." This crucial Reference Design home is abstracted from the basic building parameters of the building to be rated whether proposed or completed—floor area, wall height, window area, door area, number of stories, climate zone, etc. Thus simulation is involved with *every* HERS rating, so software validation is essential. The simulation process features[56]:

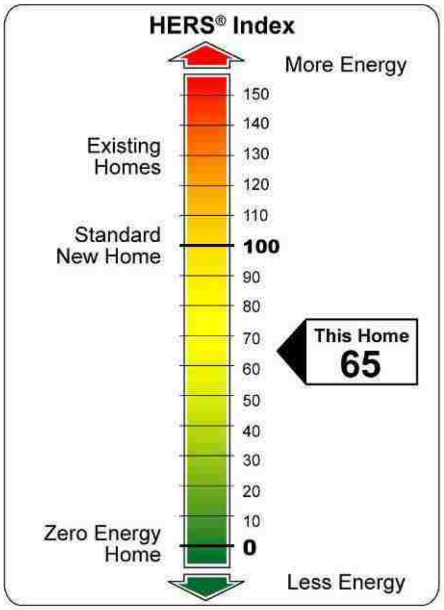

Figure 18. Sample HERS certificate. It shows the American (Standard) Reference Design home at 100 and a building with a net energy consumption of zero at 0.

- Software required to automatically generate the Reference Design home using only the input from the proposed building (i.e. software users have no control over the configuration and modeling of the Reference Design home)
- Configuration and modeling parameters for the Reference Design home carefully and completely specified as a modeling "rule set"
- Software accreditation achieved by passing a battery of software verification tests developed by US National Laboratories and RESNET[57]
- Proposed building and the Reference Design home modeled using accredited building simulation software tools and the results ratioed (proposed building divided by the reference design times 100)

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[56] RESNET - What is RESNET http://www.natresnet.org/about/resnet.htm, Aug 29, 2009.

[57] *Procedures for Verification of International Energy Conservation Code Performance Path Calculation Tools,* RESNET Publication No. 07-003, Residential Energy Services Network, September 2007, p2.

RESNET administrates standards in three areas[58]:

- Software accreditation. RESNET maintains the list of certified software that has passed a battery of software verification tests developed by US National Laboratories and RESNET[59]
- Rater certification. RESNET defines the knowledge base and skill sets that a rater must demonstrate through passing an online RESNET national rater test
- A quality assurance program. Each facility that trains certified raters must employ a certified Quality Assurance Designee that annually and independently verifies internal consistency of a minimum 10% of all building input files and independently field verify the accuracy of a minimum of 1% of each certified rater's homes

A criticism of the HERS Index follows from the fact that the Reference Design home bears little resemblance to real buildings and provides no calibration for the building performance with respective to standard building codes. On the other hand the yardstick has the benefit that it does not change as the building inventory evolves thus yielding consistent results over time until the Reference Design home is redefined.

4.2.2 Energy Star for homes

Leveraging the HERS program, the EPA launched its Energy Star Qualified Homes program in 1992, an initiative in the housing market to encourage voluntary adoption of efficient technologies and practices. Energy Star qualification signifies high-quality, efficient, and cost-effective new homes that provide a life-cycle cost advantage relative to unqualified homes.

Homes that earn the Energy Star must meet guidelines for energy efficiency set by the EPA and measured by the HERS Index. Energy Star qualified homes are at least 15 percent more energy efficient than homes built to the 2004 International Residential

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[58] Ibid.

[59] RESNET - National Registry of Accredited Tax Credit Compliance Software Tools http://www.resnet.us/programs/taxcredit_software/directory.aspx, Aug 29, 2009.

Code (IRC), and include additional energy-savings features that typically make them 20-30% more efficient than homes built to local residential construction codes[60].

To earn the Energy Star a home must[61]:

- Achieve a score of 85 or less on the HERS index if located in a "hot" climate region, comprised of 2004 IECC climate zones 1, 2 and 3, or
- Achieve a score of 80 or less on the HERS index if located in a "mixed" and "cold" climate region, comprised of 2004 IECC climate zones 4 through 8, or
- Install prescriptive measures outlined in a much-simplified but all-encompassing National Builder Option Package (BOP) which features:
    - 2004 IECC insulation levels
    - Energy Star qualified HVAC equipment and Energy Star qualified windows
    - A single simplified duct leakage specification (i.e., ≤ 4 cfm of duct leakage to the outside per 100 ft^2 of conditioned floor area at 25 Pa pressurization of the distribution system)
    - A simpler and more easily-determinable set of climate-zone-specific infiltration specifications based on ACH50 (i.e., air changes per hour at 50 Pa pressure difference between house and ambient)
    - A requirement to include one category of Energy Star qualified products

Each home is also required to pass the Thermal Bypass Checklist (TBC). The TBC is a comprehensive visual inspection of building details where thermal bypass, or the movement of heat around insulation or through some other material penetrating the insulation. While each home must pass the TBC, precedence must be given to state, local and regional codes if any as well as product manufacturers' warranty.

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[60] Certification Guidelines http://www.energystarhomes.com/homebuilders/certification.htm, Aug 29, 2009.

[61] *Overview of Evolving ENERGY STAR Qualified Homes Program & Methodology for Estimating Savings,* http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/2011_Technical_Background.pdf, Aug 30, 2009.

4.3 ASHRAE's Building Energy Quotient

ASHRAE has a long history of involvement in commercial building energy efficiency, beginning with the initial development of Standard 90 in 1975. Since that time ASHRAE has continued to develop Standard 90 and later Standard 90.1 as well as to provide other technical guidance for its members and the public. While ASHRAE Standard 90.1 provides the requirements for minimum levels of energy efficiency suitable for adoption into codes for commercial buildings, what has been missing is a rating program that evaluates individual buildings relative to their potential energy performance. Although some benchmarks already exist, such as the Energy Star and HERS systems, ASHRAE plans to launch its own comprehensive building energy labeling program in 2010 to incentivize achieving that potential performance[62].

The current ASHRAE Strategic Plan places a strong emphasis on sustainability, and energy efficiency is a key component of sustainability. ASHRAE's sustainability roadmap outlines its strategies for a global environment[63] and the Vision 2020 report sets a path toward achievement of net zero energy buildings[64]. Each of these documents has identified the need for leadership in energy efficiency, which could be satisfied by ASHRAE establishing a building energy labeling program.

Within the US, ASHRAE is viewed as a respected leader with a strong technical track record and credentials in the area of building energy efficiency. Within the global community, ASHRAE has many partners who are leaders in their own right in this field. By establishing a building energy labeling program, and by collaborating with its domestic and international partners, ASHRAE can facilitate moving the worldwide marketplace to a point where building energy efficiency is truly a valued commodity and where energy efficiency is an essential requirement for real estate transactions.

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[62] Op cit, ASHRAE Building Energy Labeling Ad Hoc Committee, p 4.

[63] ASHRAE Sustainability Roadmap Ad Hoc Committee, *ASHRAE's Sustainability Roadmap: The approach to defining a leadership position in sustainability*, January 22, 2006.

[64] ASHRAE 2020 Ad Hoc Committee, *ASHRAE Vision 2020: Producing Net Zero Energy Buildings*, January 2008.

With institutionalized and certified comparisons of building energy use, claims of building energy performance will enjoy credibility in the marketplace and through competition stimulate improved energy efficiency in commercial buildings. Therefore ASHRAE began work on its Building Energy Quotient (bEQ™) labeling system in 2008 that led to a prototype study in 2009 and the announcement of a trial system in June 2009. ASHRAE in collaboration with other organizations such as the EPA, the Chartered Institution of Building Services Engineers (CIBSE) in the UK, etc., is uniquely qualified and positioned to develop the technical basis for a building energy labeling standard.

While this new building energy labeling scheme is unknown to the general public at the time of this writing, ASHRAE's stature will demand credibility and acceptance of its proposal. Consequently the basic scheme for this significant rating system is introduced below, and extensive information is available in Appendix A.

4.3.1 ASHRAE Rating scale

The ASHRAE system, a technical rating method, compares a building's energy performance to technical potential reference points where net zero energy performance is zero on the scale and the building type population median is set at 100 as shown in Figure 19. The ASHRAE bEQ is the same basic scale that is used in the European Union for commercial buildings and is analogous to the scale used in North America for HERS. Thus the bEQ scale appears similar to the HERS scale shown in Figure 18 except that it is inverted—the net zero energy is at the top and the typical building with score 100 is toward the middle or bottom of the scale.

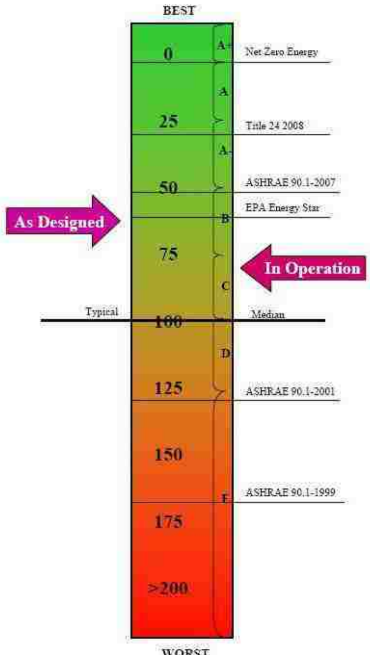

Figure 19. The ASHRAE bEQ scale. In this example the designed performance, 47, is not realized in building operation, which scores 72. Also shown are the scores associated with "baseline" buildings built to various codes.

To achieve a net zero energy building, on-site renewable power generation will be required. If this system generates more power than the building consumes, then it is possible that the score becomes a negative number indicating the building is a net producer of power. On the other end of the scale, the relative EUI or score is unbounded for buildings with very bad energy performance, and the initial version of the program, any score of 125 or greater is assigned the rating of “poor.” Note that the scale can include other benchmarking reference points such as building energy codes as shown in Figure 19.

4.3.2 ASHRAE Asset and operational ratings

The ASHRAE Advanced Building Energy Labeling (ABEL) asset rating is intended to be a measure of the energy efficiency quality of the as-designed, fixed physical components of a building. Like the Energy Star rating, it is intended to allow comparison among similar buildings, within a size range and of the same occupancy type within a climate zone. The asset rating is designed to have a particular relevance for real estate transactions in that it expresses an integral measure of the building’s inherent energy efficiency. The ABEL asset rating will be designated “As Designed” on the label.

An operational rating identifies how much energy an existing building is actually using relative to the set of benchmark metrics, typically taken from the CBECS database. Energy consumption data may be broken down by fuel type and area for conditioned space in a building, and may compare site consumption to source energy as an indicator of GHG emissions or carbon footprint. Furthermore operational ratings may compare efficiencies of energy using systems within buildings (heating, cooling, fans, lighting, etc) to gauge operational performance. Operational ratings require at least 12 months of utility-metered data provided directly by the customer or through the customer’s energy service provider and Portfolio Manager. The ABEL asset rating will be designated “In Operation” on the label.

4.4 Green labels with energy points

Both the Energy Star and HERS labeling systems are exclusively focused on building energy efficiency. However, the US Green Builders Council’s (USGBC) Leadership in Energy and Efficiency Design (LEED) and the Green Building Institute’s (GBI) Green Globe programs, while labeling schemes, have a broader perspective and consider more sustainable components, e.g. daylighting, indoor air quality, water conservation, public transportation, etc, in their scoring algorithms. Nevertheless the rating for the energy performance is rigorous and based upon a technical scale, ASHRAE 90.1.

4.4.1 LEED

While the LEED program offers ratings for many types of building projects (LEED for New Construction, LEED for Existing Buildings, LEED for Commercial Interiors, LEED for Retail, LEED for Schools and LEED for Core & Shell rating systems), for the purpose of illustrating LEED methodology, the scope of this work considers only commercial projects for new construction (LEED-NC). The LEED-NC program awards points to categories as listed in Table 4. The points awarded are governed by assessment procedures, but are always constrained to be less than or equal to the maximum as listed in Table 4. Thus a total of 69 points is the highest score possible for the sum of all categories, and the right-hand column lists the percentage contribution that the category contributes to this maximum score.

Table 4. Categories for LEED 2.2. Note that the category for "regional bonus credits" is first implemented in LEED 2009, which is introduced later.

Version	LEED 2.2	
Category	Points	%
Energy and atmosphere	17	25%
Optimize energy performance	*10*	*14%*
Onsite renewable energy	*3*	
Enhanced commissioning	*1*	
Enhanced refrigerant managem	*1*	
Measurement and verification	*1*	
Purchase green power	*1*	
Indoor environmental quality	15	22%
Sustainable sites	14	20%
Materials and resources	13	19%
Water efficiency	5	7%
Innovation and design process	5	7%
Regional bonus credits	0	0%
Totals	69	100%

Energy efficiency is equivalent to the subcategory "Optimize energy performance" listed under the category "Energy and atmosphere" and this subcategory is also referred to as "EA Credit 1". As can be seen from Table 4, the impact of all the subcategories of "Energy and atmosphere" is limited to 25% of the scoring with efficiency contributing only 14% of the total for the entire project. Given this weighting, it is easy to understand why the Energy Star scores shown in Figure 16 fail to exhibit any correlation with LEED scores.

However, once at the subcategory level the point allocation for energy efficiency proceeds in a rational way. Like the HERS Index, the building to be rated is compared with a virtual baseline building. The rating process requires that the proposed building demonstrate a percentage reduction in its energy performance rating compared to the baseline building performance rating per ASHRAE/IESNA Standard 90.1-2004. The performance results from a whole building simulation using the Building Performance Rating Method in Appendix G of the ASHRAE standard as discussed later in Section A.2.2.2. This ASHRAE simulation methodology forms the basis for other energy labeling schemes as well as qualifying buildings and renovations for special tax treatment in the US. Table 5 shows the points awarded for various energy saving percentages. Note that each additional LEED point requires a further 3.5% reduction in the EUI for the proposed building. Furthermore note that scoring at least 2 points is mandatory—if the building energy performance is not at least 14% better than the baseline building standard, then it fails to qualify for any LEED rating.

Table 5. Distribution of LEED 2.2 points for efficiency. Points are allocated on the basis of the percentage reduction of the EUI for the proposed building with respect to the baseline building.

New Buildings	Points	
10.5%	1	Mandatory
14.0%	2	Points
17.5%	3	
21.0%	4	
24.5%	5	
28.0%	6	
31.5%	7	
35.0%	8	
38.5%	9	
42.0%	10	

Plug loads in the proposed building must be included among the building's loads as well as included into the comparative baseline building. The USGBC states "For the purpose of this analysis, process energy is considered to include, but is not limited to, office and general miscellaneous equipment, computers, elevators and escalators, kitchen cooking and refrigeration, laundry washing and drying, lighting exempt from the lighting power allowance (e.g. lighting integral to medical equipment) and other (e.g. waterfall pumps)... For EA Credit 1, process loads shall be identical for both the baseline building performance rating and for the proposed building performance rating."[65]

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[65] New Construction-EA Credit 1: Optimize Energy Performance, http://www.usgbc.org/ShowFile.aspx?DocumentID=2303, Sept 15, 2009.

The entire LEED rating scheme is based upon the design performance as simulated with software verified by ASHRAE’s certification process (see Section A.2.2.2). No post-occupancy verification is required for the project although an extra LEED point is awarded for such measurements.

For a small office building two prescriptive LEED options are available in lieu of the whole building energy simulation described above. However, the points awarded are limited to 1 or 4 points, depending on the option selected.

Finally the LEED points achieved by the proposed building determine whether the building label is simply “certified,” certified silver, certified gold, certified platinum, or not certified at all. The mapping of points into labels obscures the assessment further, and the energy efficiency metric is effectively invisible.

4.4.2 Green Globes

The Green Globes building assessment system, a product of the Green Building Institute (GBI), has many similarities with the LEED process. Parallels could be expected since the legacy for Green Globes systems extends through Canada to the Building Research Environmental Assessment Method (BREEAM) system from the UK, which in turn extends to the LEED system back from the US[66]. As the tool evolved, it became less complex. Paperwork is initiated online and verified onsite by an expert, and the expense of certification is greatly reduced.

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[66] Timothy M. Smith, Miriam Fischlein, Sangwon Suh, Pat Huelman, “Green Building Rating Systems: A Comparison of the LEED and Green Globes Systems in the US,” University of Minnesota, September 2006, p2.

Table 6. The Green Globes Design Points System for Canada.

Percentage Score	Points Score	Areas and Sub-Areas of Assessment
5%	**50**	**A - Project Management**
	20	A.1 - Integrated design process
	10	A.2 - Environmental purchasing (including energy efficient products)
	15	A.3 - Commissioning
	5	A.4 - Emergency response plan
11.5%	**115**	**B - Site**
	30	B.1 - Development area (site selection, development density, site remediation)
	30	B.2 - Ecological impacts (native planting and vegetation, heat islands, night sky)
	20	B.3 - Watershed features (site grading, stormwater management, pervious cover, rainwater capture)
	35	B.4 - Site ecology enhancement
38%	**380**	**C- Energy**
	100	C.1 - Energy performance
	114	C.2 - Reduced energy demand (space optimization, microclimatic response to site, day-lighting, envelope design, metering)
	66	C.3 - Integration of energy efficient systems
	20	C.4 - Renewable energy sources (on-site renewable energy technologies)
	80	C.5 - Energy-efficient transportation (public transportation, cycling facilities)
8.5%	**85**	**D - Water**
	30	D.1 - Water performance
	45	D.2 - Water conserving features (sub-metering, devices, cooling towers, landscaping and irrigation strategies)
	10	D.3 - On-site treatment of water (greywater system, on-site wastewater treatment)
10%	**100**	**E - Resources**
	40	E.1 - Low impact systems and materials (selection of building materials based on the low environmental impact)
	15	E.2 - Minimal consumption of resources (reused, recycled, local, low-maintenance materials, certified wood)
	15	E.3 - Reuse of existing buildings
	15	E.4 - Building durability, adaptability and disassembly
	5	E.6 - Reduction, reuse and recycling of demolition waste
	10	E.7 - Recycling and composting facilities
7%	**70**	**F - Emissions, Effluents & Other Impacts**
	15	F.1 - Air emissions (low emission burners)
	20	F.2 - Ozone depletion
	10	F.3 - Avoiding sewer and waterway contamination
	25	F.4 - Pollution minimization (storage tanks, PCBs, radon, asbestos, pest management, hazardous materials)
20%	**200**	**G - Indoor Environment**
	55	G.1 - Ventilation system (intakes, ventilation rates, delivery, CO_2 monitoring, controls, parking areas, ease of maintenance)
	45	G.2 - Control of indoor pollutants (mould, AHU, humidification, Legionella cooling towers/ hot water, building materials, local exhaust)
	50	G.3 - Lighting (visual access, heights & depths of perimeter spaces, daylight factor, ballasts, glare, task lighting, controls)
	20	G.4 - Thermal comfort (thermal conditions meet ASHRAE 55)
	20	G.5 - Acoustic comfort (zoning, transmission, vibration control, acoustic privacy, reverberation, mechanical noise)
100%	**1000**	**TOTAL POINTS AVAILABLE**

The essence of the Green Globe system can be captured in a single page as shown in Table 6 for the Canadian system[67]. This scoring system actually provides a map of the design features that must be addressed for every project—there is not a different scoring

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[67] Green Globes™ Design for New Buildings and Retrofits: Rating System and Program Summary, ECD Energy & Environment Canada Ltd, December, 2004, www.greenglobes.com, p4.

system for schools, retail, etc. as in the LEED program. The Green Globes system is applicable to all types of buildings of any size including small and large office buildings, multifamily housing structures, schools, universities and libraries. As in LEED, there are categories and subcategories for scoring, each with its associated potential points and weight. A study of Table 4 and Table 6 reveals that the LEED categories are well aligned with those of Green Globes.

The focus for energy efficiency falls on section C. Subcategories C.1, C.2, and C.3 (energy performance, reduced energy demand, and integration of energy efficient systems) in Green Globes must be combined to compare with the subcategory “Optimize energy performance” in LEED. When combined the Green Globe subcategories yield 280 points or a 28% weight for efficiency versus 14% for LEED. This differentiation is a proper move toward placing efficiency in the prominent place it deserves.

In the US the Green Globes system is somewhat modified. While the categories remain the same, the subcategories vary, and the weightings for energy, water, and emissions change modestly by 1-2% as shown in Table 7. Like the Canadian system, the energy assessment area has the heaviest weight and is focused on reducing energy consumption, increasing use of renewables, and decreasing carbon emissions. The Green Globes system uses benchmark criteria for energy performance to estimate the energy consumption of a building. Unlike the LEED system, which compares the building design to the performance of a hypothetical structure designed to ASHRAE 90.1 standards, Green Globes compares against survey data accessed by the EPA's Energy Star tools and specifically selects those better performing buildings in the Energy Star database. Thus the energy efficiency is measured on a statistical scale. The GBI website did not reveal how it translated Energy Star ratings to Green Globe points. In addition to the energy performance, the Green Globes system directly addresses microclimatic design considerations, space optimization and the use of energy efficient technologies[68].

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[68] Green Globes FAQ The GBI : Commercial Green Building Certification http://www.thegbi.org/commercial/about-green-globes/faq.asp, Sept 16, 2009.

Table 7. Point systems for Green Globes by category for Canada[69] and the US[70].

Country	Canada		US	
Category	Points	%	Points	%
Project management	50	5%	50	5%
Site	115	12%	115	12%
Energy	380	38%	360	36%
Water	85	9%	100	10%
Resources	100	10%	100	10%
Emissions, effluents and other impacts	70	7%	75	8%
Indoor environment	200	20%	200	20%
Total	1000		1000	

As with LEED, the energy efficiency rating blurs when combined with other scoring that controls two-thirds of the final numeric tally. The GBI also abstracts its rating by mapping its score onto One, Two, Three, or Four Green Globes analogous to the LEED mapping onto Certified, Silver, Gold or Platinum.

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[69] Op cit, Green Globes, p4.

[70] Green Globes New Construction Module, http://www.thegbi.org/assets/PDFs/GG_Test_Drive.pdf, Sept 16, 2009.

5 Case studies

As discussions of rating systems in the previous chapter have indicated, building energy labeling is premised on the comparison of energy use intensity (EUI) for the building to be rated with either other buildings or the simulated performance of a virtual standard building. In fact all the rating schemes can be abstracted as the simple diagram shows in Figure 20. In this flow the scheme-dependent scoring algorithm is the last step—the step that simply processes two pieces of EUI data. This chapter takes these first steps in the rating process and develops this EUI information from case studies.

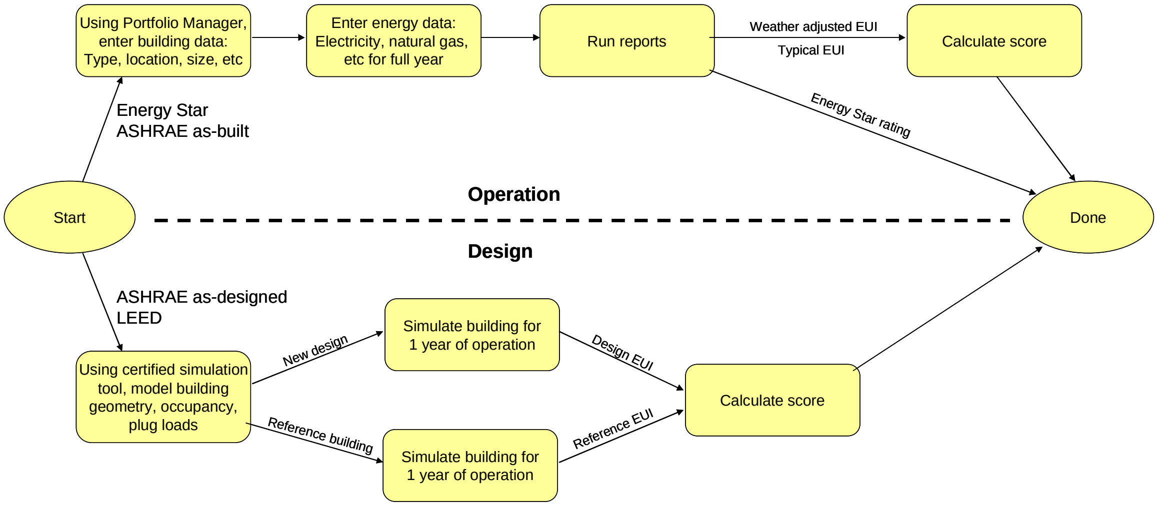

Figure 20. Diagrammatic summary of building energy labeling processes. The process separates into two sections: one for as-designed buildings (below) and one for as-operated buildings (above). Data from a full year of simulated or actual operation are required.

The case studies for this thesis, which consisted of 5 schools and a cluster of portables within the Albuquerque Public Schools (APS) portfolio, were performed in consultation with APS staff members in the Facilities Design and Construction as well as Maintenance and Operations departments. Ron Rioux, Head of the Energy Conservation Program, suggested the study of three schools that he was monitoring closely as part of his energy conservation program. Although initially we targeted three mid-schools, preliminary analysis revealed that they were excessively large and diverse and analysis would not fit into the timeframe available. Karen Alarid, the Director for Facilities Design and Construction, recommended three elementary schools whose design and construction spanned the last 70 years. They were selected to sample design and construction techniques from different periods since operations had noticed that some of the older buildings outperform the newer ones. This non-intuitive effect offered an interesting opportunity to investigate not only the influence of design upon energy efficiency, but also the influence of operations.

5.1 As-designed analysis

The details of the simulations necessary for the as-designed assessments appear in Appendix B. There the reader will find a full discussion of EnergyPlus and its companion tools. It is worth noting here that the flowchart in Figure 20 indicates that two simulations will be required for the as-designed rating: one to estimate the EUI for the building to be rated and another for the EUI of the standard reference building. However, performing two simulations does not double the effort. The standard reference building was automatically extracted from the model of the building to be rated and equipped with an HVAC system dependent upon the building size, the number of stories, and the energy efficiency code selected for comparison. I chose to benchmark against the ASHRAE 90.1-2004 standard since it is the current New Mexico commercial building energy code.

In addition to the building energy labeling process summarized in Figure 20, a passive building assessment process was developed during research for this thesis. Since it is intended for preliminary assessment early in the design process and does not lead to building labeling, it is presented in Appendix C.

5.1.1 Hubert Humphrey Elementary

The first building I modeled is the Hubert Humphrey Elementary School located at 9801 Academy Hills Dr NE in Albuquerque (see Figure 21). It was built in 1978 during a period when educators and conservationists felt it desirable to eliminate windows from schools. They thought that the low utilization of fenestration will mitigate energy consumption. Subsequently a detached kindergarten structure was added in 2006 to meet burgeoning requirements for classroom space. Even so, an additional 16 classrooms are provided in 12 portable buildings. I have not modeled these portables or the new kindergarten addition.

The basic floor plan is shown in Figure 23. Without the desire for windows, the building is massed around the media center with only 8 classrooms at the periphery. The noisy functions (band room, gym, kitchen and cafeteria) are placed along north side of the building. The administrative offices and teacher's lounge are distributed along the south side adjacent to the main entrance.

Figure 21. Photo of the main entrance to the Hubert Humphrey Elementary School.

My modeling divides the space into 23 thermal zones evident in the model shown in Figure 22. The shade structure colored purple in the figure is an object for casting shadows in EnergyPlus and is not modeled as a thermal object. Comparisons of the floor plan with the EnergyPlus model reveal that the recesses for entries along the west and east sides are ignored as one of the presumed negligible approximations used to simplify modeling. The modeled area is approximately 40,000 ft^2.

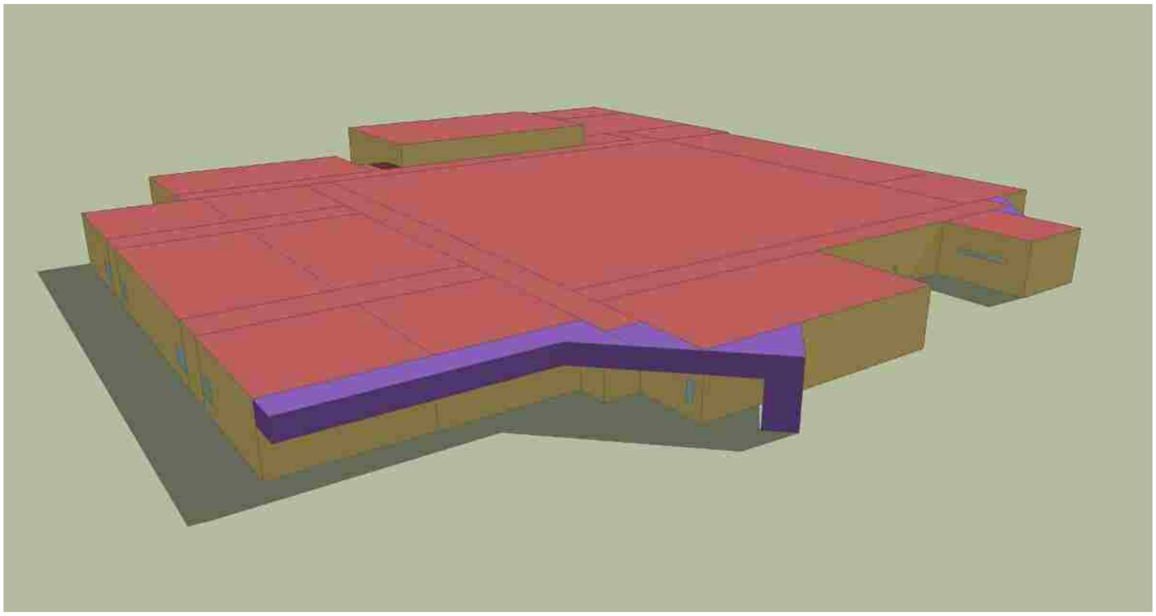

Figure 22. EnergyPlus model for the Hubert Humphrey Elementary. The main entry is under the prominent shade structure (purple). The division into 23 thermal zones is indicated by the lines on the roof. The shadows indicate a morning in mid-summer.

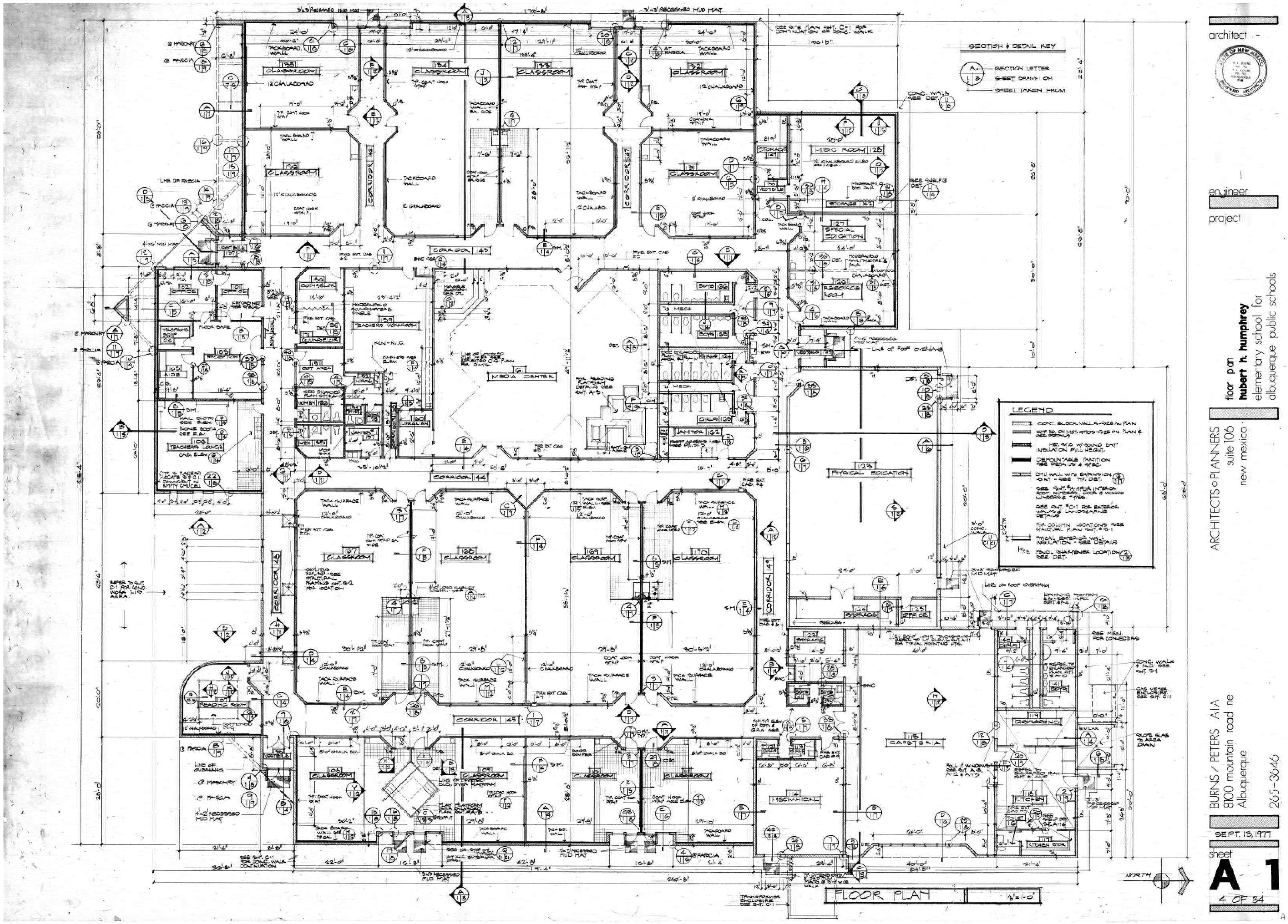

Figure 23. Floor plan for Hubert Humphrey Elementary. The north arrow (lower right) points to the right in this image.

Table 8 lists the materials and construction assemblies for use at Hubert Humphrey Elementary. The exterior walls are built with insulated construction except along the front corridor at the south end of the building and all the walls of the gym, kitchen, cafeteria and bathroom in the northeast corner of the building. These exceptions simply have exposed uninsulated concrete blocks.

Table 8. Details of the materials and construction for Hubert Humphrey Elementary. In the absence of further documentation, I assumed the roof insulation to be styrene like the wall insulation.

material	conductivity (W/m/K)	thickness (m)	R (m^2.K/W)	R (Ft^2.F.h/BTU)
ROOF				
built-up roof with gravel			0.0423	0.24
4" rigid insulation			2.8178	16.00
steel decking			0.0001	0.00
				16.24
BLOCK WALL				
8" CMU	0.5707	0.2033	0.3562	2.02
INSULATED WALL				
8" CMU	0.5707	0.2033	0.3562	2.02
2" styrene insulation			1.4089	8.00
1/2" gyp board	0.1602	0.0127	0.0793	0.45
				10.47

After detailing the model of Hubert Humphrey Elementary, running the simulation was straightforward, and I obtained the results summarized in Table 9. The table presents the energy consumed by end use for each energy source—electricity and natural gas in this case. I convert the site energy consumption to source using the conversion factors defined for primary schools used for DOE benchmarks (3.318 for electricity and 1.092 for natural gas). Both fuel types are combined to give the total source energy by end use and finally the source energy use intensity by end use. The last column expresses the percentage of source energy consumed by each end use for the simulation. After combining heating, cooling, and fans, the HVAC and ventilation use 40% of the energy, plug loads 36%, and lighting 24%. The overall building EUI is 213 kBTU/ft^2/yr.

Table 9. EnergyPlus simulation results for Hubert Humphrey Elementary.

	Site Electricity [kBTU]	Site Natural Gas [kBTU]	Source Electricity [kBTU]	Source Natural Gas [kBTU]	Percent Electricity	Percent Natural Gas	Total Source Energy [kBTU]	Source Energy Intensity [kBTU/ft2]	Percent Source Energy Intensity
Heating	0	140809	0	153764	0%	100%	153764	4	2%
Cooling	180233	0	598013	0	7%	0%	598013	15	7%
Interior Lighting	633742	0	2102756	0	25%	0%	2102756	52	24%
Exterior Lighting	0	0	0	0	0%	0%	0	0	0%
Interior Equipment	922662	0	3061393	0	36%	0%	3061393	76	36%
Exterior Equipment	0	0	0	0	0%	0%	0	0	0%
Fans	816001	0	2707493	0	32%	0%	2707493	67	31%
Pumps	0	0	0	0	0%	0%	0	0	0%
Heat Rejection	0	0	0	0	0%	0%	0	0	0%
Humidification	0	0	0	0	0%	0%	0	0	0%
Heat Recovery	0	0	0	0	0%	0%	0	0	0%
Water Systems	0	0	0	0	0%	0%	0	0	0%
Refrigeration	0	0	0	0	0%	0%	0	0	0%
Generators	0	0	0	0	0%	0%	0	0	0%
Total End Uses	2552639	140809	8469655	153764	100%	100%	8623418	213	100%

To complete the simulations required for building energy labeling of Hubert Humphrey Elementary, I also ran the simulations for the standard reference building. Figure 24 shows the SketchUp view of the reference standard building with an insert to magnify the southwest corner of the building, which illustrates the strip windows associated with the standard (see Appendix B). The shading structures were removed

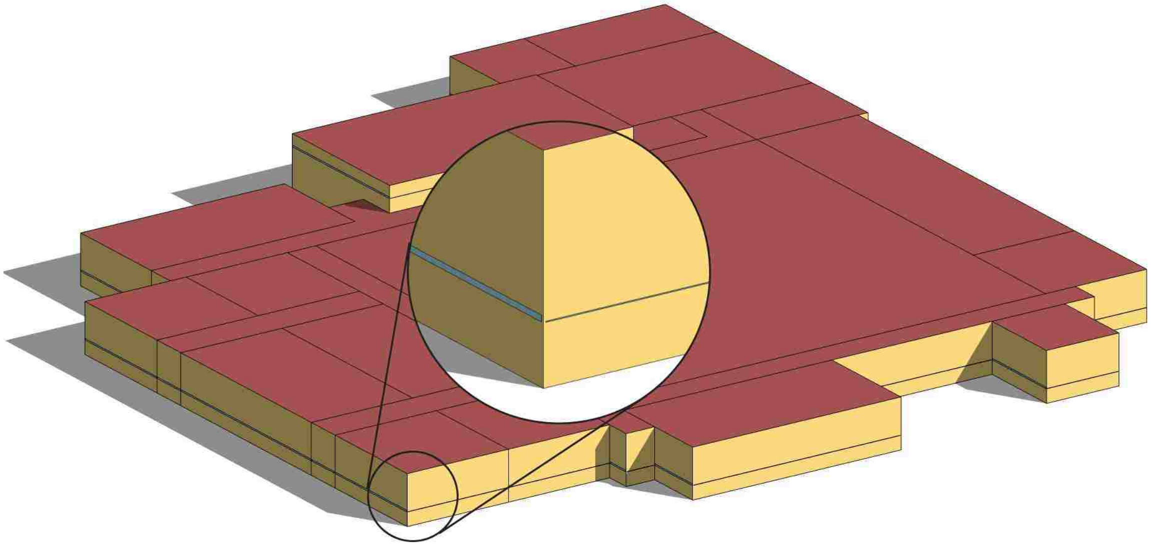

Figure 24. Standard reference building for Hubert Humphrey Elementary. Note that the shading is removed, and the fenestration redistributed as narrow strips around the periphery.

manually. Simulations were run for the four required orientations and the resulting building EUIs averaged to obtain an end result of 216 kBTU/ft^2/yr.

5.1.2 Tierra Antigua Elementary

Tierra Antigua is one of two “identical” schools built by the APS system both of which first opened for classes in August 2009 (see Figure 25). Targeted to become Certified LEED Silver, these schools are taking the steps necessary to improve the design of the energy performance as well as address the other LEED categories. Thus it is reasonable to expect this building to perform better than a school built 30 years ago.

Figure 25. Photo of the Tierra Antigua Elementary School located at 8121 Rainbow Blvd NW in Albuquerque's far northwest. The image shows only the two-story wing of the building—the portion modeled in this case study.

With a floor plan of 83,300 ft^2, the building is approximately twice the size of the Hubert Humphrey Elementary. Furthermore, it is equipped with a high-performance HVAC system. The facility has its own in-house chiller and boiler and uses 4-pipe technology. It is well positioned to deliver an excellent conditioned environment to its building occupants. The question is can it do it with energy efficiency?

As with Hubert Humphrey, I first modeled the building without an HVAC system and then duplicated the identical HVAC system as generated for the reference building. To simplify my assessment I modeled only the two-story classroom wing that includes approximately 37,300 ft^2.

The basic floor plan is shown in Figure 26. It features a double-loaded corridor with seven classrooms on each side. Midway along the wing the classroom pattern on each floor pauses to include a mechanical room on the north and a teacher’s lounge on the south. While this break in the pattern is recessed along both the north and south sides, my model shown in Figure 27 simplifies the building geometry with a simple flat face. At the west end I insert a buffer space that simply allows the adjacent classrooms and corridor to join with interior space as it does in reality.

The model includes shading structures for all the south facing windows. Each shade meets the window 16” below the top of the window frame to enable light to enter the classroom and bounce off an internal light shelf. The internal light shelf and the vertical shades to the sides of the windows are omitted in this model.

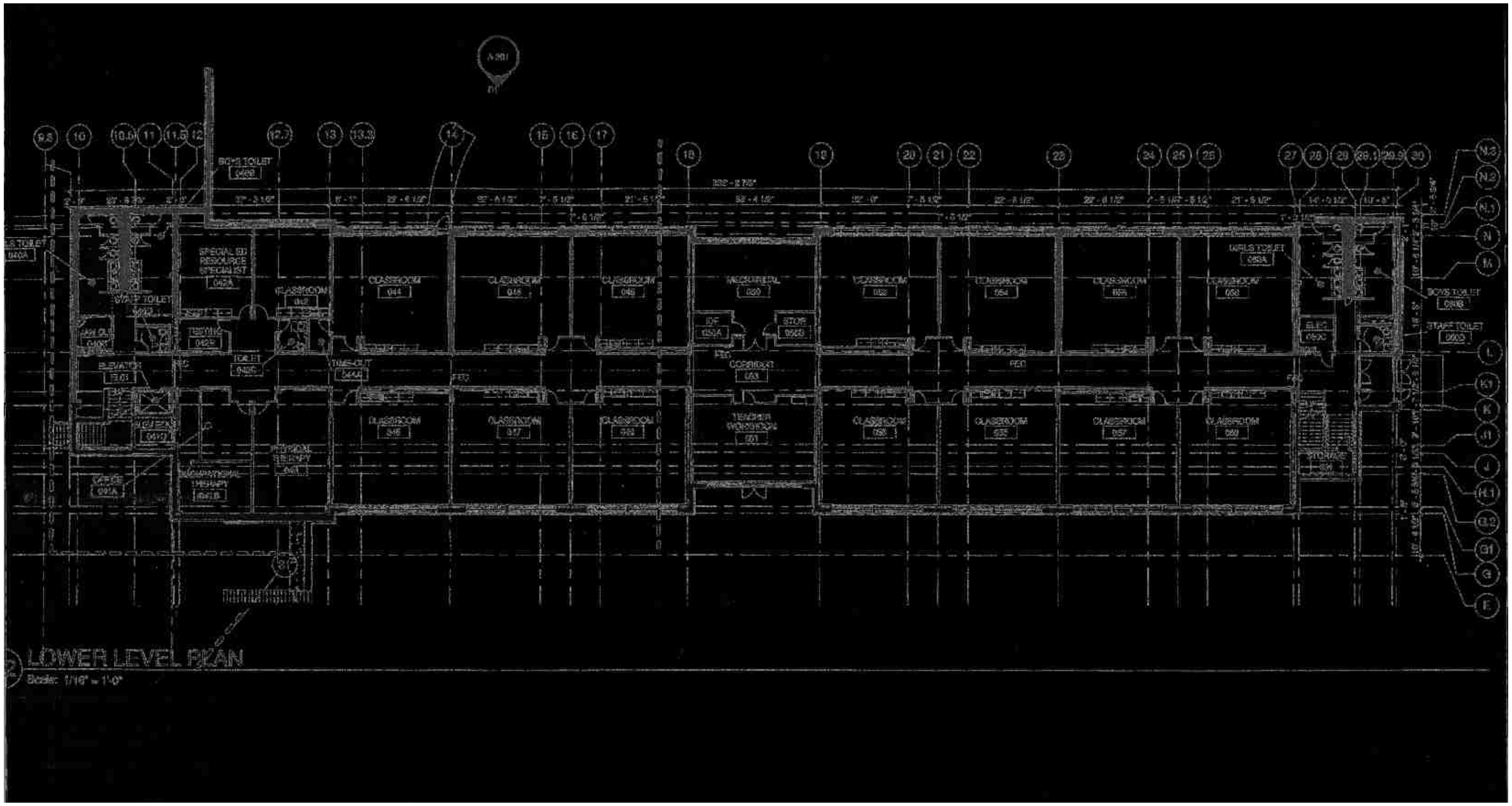

Figure 26. Floor plan for the lower level of the east-west wing of Tierra Antigua Elementary.

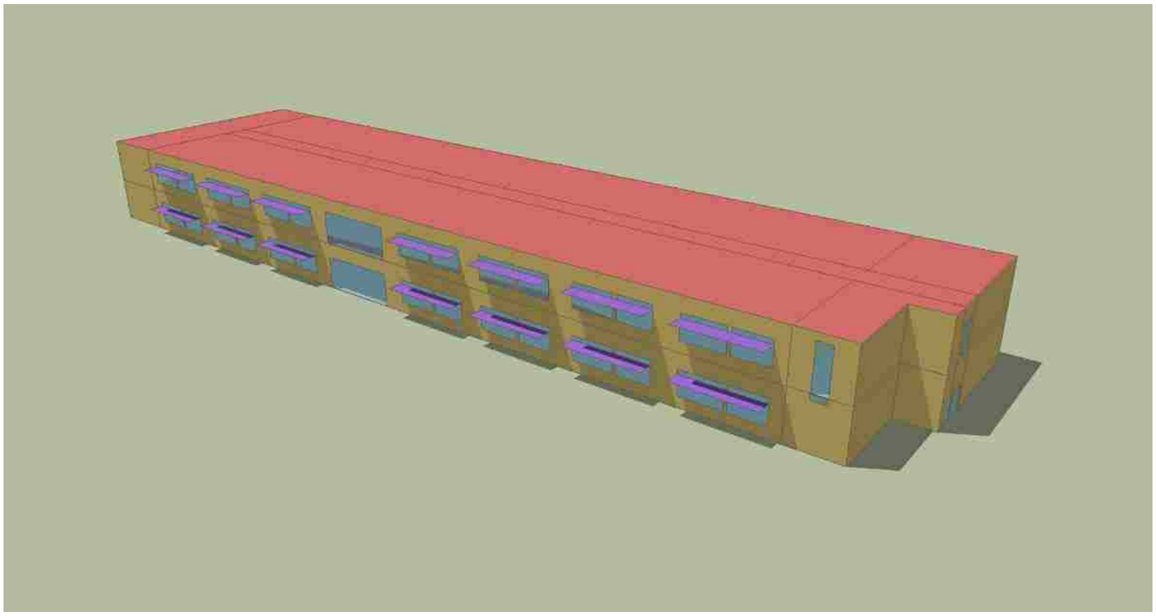

Figure 27. EnergyPlus model of the geometry for the two-story wing of Tierra Antigua. Lines along the walls and on the roof suggest the boundaries of the thermal zones. The zones at the west end are included simply to simulate the presence of the unmodeled portion of the school. The shadows are calculated for a mid-summer afternoon.

The materials and construction were easy to ascertain from the construction documents and specifications. These data are summarized in Table 10. To address the framing factor, the R-factors for the wall were calculated for 6” of steel and for 6” of air within the framing layer. Since the metal studs for the walls were sandwiched between layers of insulation not penetrated by the studs, weighting by wall area indicated that the steel studs could be ignored. Note that EnergyPlus models the air gap internal to the wall.

Table 10. Details of the materials and construction for Tierra Antigua Elementary. The wall sections in the constructions documents are very detailed and the building specifications are available so the building envelope is not uncertain.

material	conductivity (W/m/K)	thickness (m)	R (m^2.K/W)	R (Ft^2.F.h/BTU)
EXTERIOR WALL				
7/8" stucco 3-coat system	0.6918	0.022225	0.3626	2.06
1/2" exterior gyp sheathing	0.1602	0.0127	0.0793	0.45
fiberglass batt wall insulation R-19			3.3461	19.00
6" 18 GA metal studs			0.0126	0.07
fiberglass batt wall insulation R-15			2.6417	15.00
5/8" type X gyp board	0.1602	0.015875	0.3626	2.06
				38.64
7/8" stucco 3-coat system	0.6918	0.022225	0.3626	2.06
1/2" exterior gyp sheathing	0.1602	0.0127	0.0793	0.45
fiberglass batt wall insulation R-19			3.3461	19.00
6" air		0.1524		1.20
fiberglass batt wall insulation R-15			2.6417	15.00
5/8" type X gyp board	0.1602	0.015875	0.3626	2.06
				39.77
ROOF				
Thermoplastic membrane roofing	0.16	0.0095	0.0594	0.34
Polyisocyanurate roofing insulation R-38			6.6922	38.00
steel decking			0.0001	0.00
				38.34

The simulations of the as-designed building and its standard baseline followed the pattern established for Hubert Humphrey Elementary. The results are summarized in Table 11. With heating, cooling, and fans, the HVAC and ventilation use 35% of the energy, plug loads 33%, and lighting 32%. The overall building EUI is 164 kBTU/ft^2/yr, down 24% from Hubert Humphrey. The EUI for the standard reference building is 237 kBTU/ft^2/yr, up significantly from Hubert Humphrey. The increase is expected as the window area is large in comparison and in the reference building is not treated for the additional cooling load due to solar gain.

Table 11. EnergyPlus simulation results for Tierra Antigua Elementary

	Site Electricity [kBTU]	Site Natural Gas [kBTU]	Source Electricity [kBTU]	Source Natural Gas [kBTU]	Percent Electricity	Percent Natural Gas	Total Source Energy [kBTU]	Source Energy Intensity [kBTU/ft2]	Percent Source Energy Intensity
Heating	0	27823	0	30383	0%	100%	30383	1	0%
Cooling	141046	0	467991	0	7%	0%	467991	12	7%
Interior Lighting	631772	0	2096220	0	32%	0%	2096220	52	32%
Exterior Lighting	0	0	0	0	0%	0%	0	0	0%
Interior Equipment	671518	0	2228096	0	34%	0%	2228096	55	33%
Exterior Equipment	0	0	0	0	0%	0%	0	0	0%
Fans	551987	0	1831494	0	28%	0%	1831494	45	28%
Pumps	0	0	0	0	0%	0%	0	0	0%
Heat Rejection	0	0	0	0	0%	0%	0	0	0%
Humidification	0	0	0	0	0%	0%	0	0	0%
Heat Recovery	0	0	0	0	0%	0%	0	0	0%
Water Systems	0	0	0	0	0%	0%	0	0	0%
Refrigeration	0	0	0	0	0%	0%	0	0	0%
Generators	0	0	0	0	0%	0%	0	0	0%
Total End Uses	1996323	27823	6623801	30383	100%	100%	6654183	164	100%

5.2 *As-operated analysis*

5.2.1 Three Mid-Schools

In contrast to rating building designs for energy performance, the assessment of the operational performance for existing buildings requires no simulation and, therefore is somewhat simpler. More facilities should consider this practice since it is facilitated by the EnergyStar's Portfolio Manager discussed earlier in Chapter 4. At a minimum one needs 12 months of fuel consumption data from the electric and gas utilities and the floor area of the facilities. In the case of schools, it would also be helpful to know the number of PCs in use and the number of walk-in refrigerators and freezers for each facility.

Portfolio Manager assists you with the data entry process. After logging into your web account, you may create a new facility, enter data, or generate reports and graphs. Also, data summaries can be downloaded, which include comparisons with schools nationally as well as year-to-year comparisons for each managed facility. Portfolio Manager automatically calculates an EnergyStar rating, the raw *source* EUI, the weather corrected source EUI (that enables year-to-year comparisons without comparing weather conditions), and various other statistics.

The three mid-schools that Ron Rioux recommended were constructed over a period of 70 years. In the order of decreasing age we evaluated Jefferson Mid-School Jimmy Carter Mid-School, and James Monroe Mid-School. Using the web interface, I entered the 24-month fuel consumption data that Ron provided for each mid-school[71]. The data from Portfolio Manager's two-period comparison report is shown in Table 12. The weather corrected EUI may be used as input to other rating algorithms and will be discussed in Section 6.1.2. Using regional factors for translating site energy use to source energy use, Portfolio Manager estimates the source energy required for generation, transmission, and distribution of energy for each site.

The Portfolio Manager bases its EnergyStar rating on the CBECS data, the energy consumption corrected for weather, and the category of the building—schools in our case. The Portfolio Manager assumes that building use (occupancy, plug loads, lighting) conforms to the average for buildings of like category. In particular, the rating as shown in Table 12 places Jefferson, the oldest building, in the 83rd percentile—well ahead of the others. At this level Jefferson is eligible for EnergyStar certification since it is in the top 25%.

David Robertson, who oversees the performance of all HVAC systems in the APS suite of 140+ schools, speculates that the older buildings have more manual systems controlled individually in classrooms, and this alters consumption due to the responsible behavior of the teacher. As the steward for the space, the teacher takes personal responsibility to ensure that energy is conserved by switching systems on and off as the room occupancy changes. Robertson adds that automated systems are assumed to take care of themselves, whereas in reality their alarms go unseen. The APS facilities have no wide-area network capability, so the alarm condition persists until someone at the school logs a trouble call.

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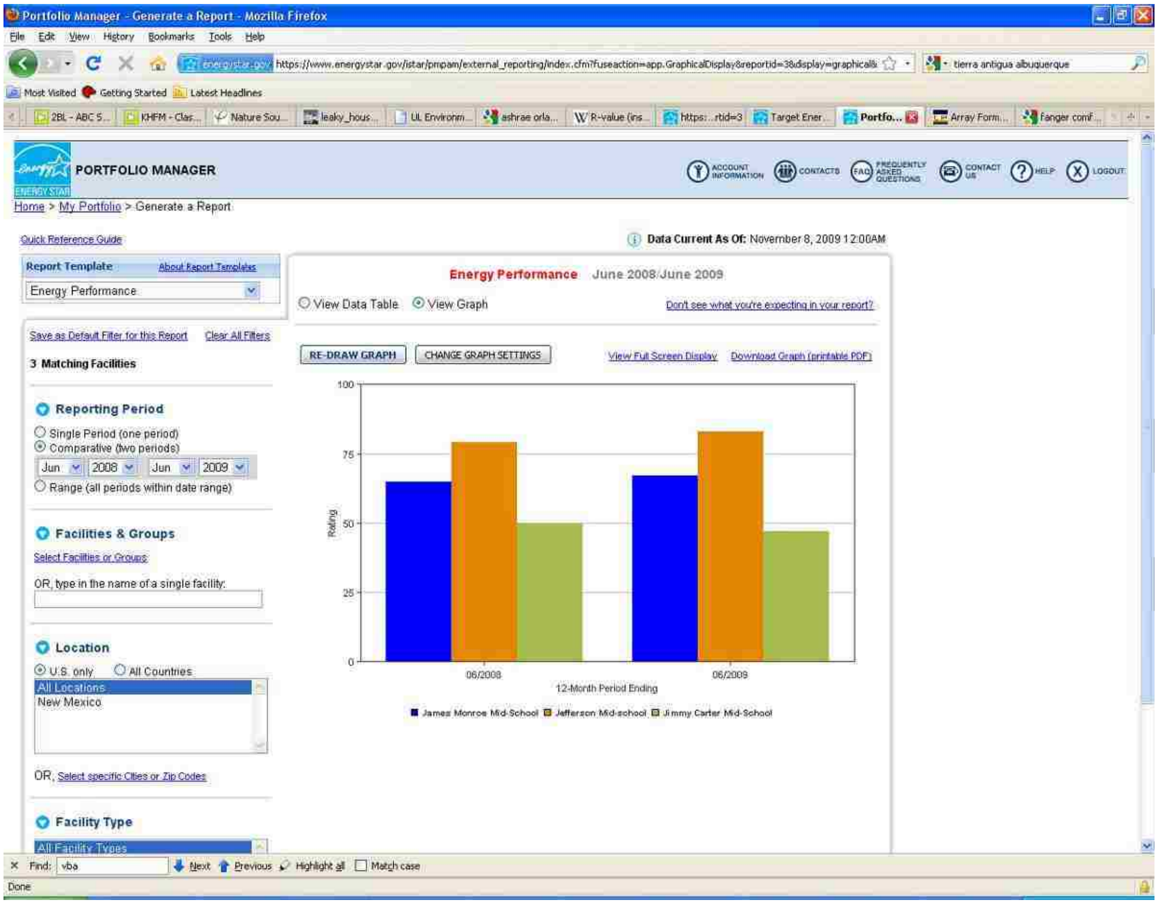
[71] Ron Rioux, APS, electricity and gas consumption data, private communication.

Table 12. Data pulled from Portfolio manager for the three APS mid-schools.

Facility Name/Year	**James Monroe Mid-School 2007**	**James Monroe Mid-School 2008**	**Jefferson Mid-school 2007**	**Jefferson Mid-school 2008**	**Jimmy Carter Mid-School 2007**	**Jimmy Carter Mid-School 2008**
EnergyStar Rating	65	67	79	83	50	47
Period Ending Date	06/30/2008	06/30/2009	06/30/2008	06/30/2009	06/30/2008	06/30/2009
Total Floor Space (Ft^2)	172,695	171,806	121,580	121,580	143,031	151,917
Site Energy Use (kBtu)	11,900,689	10,957,394	7,838,361	7,069,284	11,060,618	11,158,720
Source Energy Use (kBtu)	20,189,227	19,413,150	12,819,001	11,897,360	19,831,671	20,494,562
Site EUI ($kBtu/Ft^2$)	68.9	63.8	64.5	58.1	77.3	73.5
Source EUI ($kBtu/Ft^2$)	116.9	113.0	105.4	97.9	138.7	134.9
Weather Normalized Site EUI ($kBtu/Ft^2$)	70.9	69.3	66.6	63.8	80.0	80.4
Weather Normalized Source EUI ($kBtu/Ft^2$.)	119.7	119.8	107.6	103.8	142.2	142.2
Electric Use (kWh)	987,920	1,014,960	589,520	574,640	1,054,640	1,126,240
Natural Gas Use (therms)	85,299	74,944	58,269	51,086	74,622	73,160
Change from Baseline: Adjusted Energy Use (kBtu)	0	-388,908	0	-743,979	0	586,476
National Average Site EUI ($kBtu/Ft^2$.)	79.9	75.4	86.8	83.1	77.6	71.6
National Average Source EUI ($kBtu/Ft^2$)	135.6	133.7	142.0	139.9	139.2	131.6
% Difference from National Average Source EUI (%)	-13.8	-15.5	-25.8	-30.0	-0.4	2.5

In addition Portfolio Manager offers an on-line graphic analysis capability for users that are not comfortable with manipulating graphics with spreadsheet software. Figure 28 shows a screen image of the year-to-year comparisons of the three mid-schools



Data Current As Of: November 8, 2009 12:00AM

Report Template: Energy Performance

Energy Performance June 2008/June 2009

○ View Data Table ● View Graph

3 Matching Facilities

Reporting Period

○ Single Period (one period)

● Comparative (two periods)

Jun 2008 Jun 2009

○ Range (all periods within date range)

Facilities & Groups

OR, type in the name of a single facility:

Location

● U.S. only ○ All Countries

All Locations

New Mexico

Facility Type

All Facility Types

Figure 28. Screen image for use of Portfolio Manager.

whose data was summarized in the table above. The data displayed are the EnergyStar ratings for the facilities for two reporting periods.

5.2.2 Single meter limitation

In the school environment, portable classrooms come and go as the population of children in neighborhoods fluctuates and can account for up to 25% of the school's footage. Invariably this adds to the frustration of the energy modeler since the schools generally have a single meter for electricity and a single meter for gas. Thus the fuel consumed by any building or combination of buildings must be estimated using corrections to utility-company data for portables based on historical consumption patterns. These same corrections are required in the Rio Rancho Public School system[72].

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[72] Martin Montano, Rio Rancho Public Schools, private conversation.

For good energy assessments, there is a desperate need of sub-metering within facilities. Not only are there uncertainties in our energy consumption modeling, but also in the experimental data. Where possible, we should minimize these uncertainties.

Fortunately a cluster of 21 portable classrooms is separately metered for both electricity and natural gas at the Cleveland Mid-School. Data derived from this site can be used to estimate corrections for the variable portable space at the schools.

5.2.3 Hubert Humphrey Elementary and portables

In addition to operational data for the 3 mid-schools, I obtained data for Hubert Humphrey Elementary to enable both the as-designed and the as-operated building energy labeling. Since the school has 13,000 ft^2 of portables in use, information on portable performance is helpful in refining the estimate for the EUI of the permanent portion of the school. The operational assessment process for the portables and Hubert Humphrey Elementary is identical to that for the mid-schools so the results are simply presented here in Table 13. Note that the excellent Energy Star ratings for the portables are erroneous since the portables do not really constitute a school—there is no gym, no office, no library, no ancillary functions nominally associated with a primary school. However, the source EUI for the portables is correct and is useful in making adjustments to the EUI for Hubert Humphrey.

Assuming that the 13,000 ft^2 for portables at Hubert Humphrey used the 71 kBTU/ft^2/yr for the year ending in June 2008 like the portables at Cleveland, then one can calculate that the modeled portion of the school plus the unmodeled kindergarten wing used 146 kBTU/ft^2/yr. I will assume that the kindergarten and main building spaces have similar EUIs, and since the main building (40,000 ft^2) is 5 times larger than the kindergarten, any difference has only a small (20%) effect.

Table 13. Pulled from Portfolio manager for the suite of portables at Cleveland Mid-School and for Hubert Humphrey Elemartary.

Facility Name	**Cleveland Middle School portables**	**Cleveland Middle School portables**	**Hubert Humphrey Elementary**
Rating	99	95	66
Period Ending Date	06/30/2009	06/30/2008	06/30/2008
Total Floor Space (ft^2)	18816	18816	61414
Site Energy Use (kBtu)	660651	880791	4543346
Source Energy Use (kBtu)	970069	1304299	7864464
Site EUI ($kBtu/ft^2$)	35	47	74
Source EUI ($kBtu/ft^2$)	52	69	128
Weather Normalized Site EUI ($kBtu/ft^2$)	39	49	76
Weather Normalized Source EUI ($kBtu/ft^2$)	56	71	130
Electric Use (kWh)	35580	48840	397200
Natural Gas Use (therms)	5393	7142	31881
Change from Baseline: Adjusted Energy Use (kBtu)	-318603	0	7993068
National Average Site EUI ($kBtu/ft^2$)	88	89	86
National Average Source EUI ($kBtu/ft^2$)	130	132	149
% Difference from National Average Source EUI (%)	-60	-47	-14

6 Synthesis

This chapter interprets and integrates the information and data presented in Chapters 2 and 4, and takes into account data from the case studies in Chapter 5. The discussion is divided into two major sections: one for insights into building energy labeling schemes and the other for consequences to architects, engineers, and builders.

6.1 Building energy labeling schemes

My discussion of building energy labeling begins with a systematic comparison of the current ratings schemes and then turns to the system that I believe would be the “ideal” chaos-ending scheme. Then I make observations about the synergistic relationship between building energy labeling and building energy codes, comissioning issues, and the value to society.

6.1.1 Comparisons of building energy labeling options

Chapter 4 described the current building energy labeling systems, and Figure 29 graphically summarizes that discussion. My building energy saving (BES) proposal is included to the right. Shades of green indicate the desirable efficient scores and red the poor scores for energy “hogs.” Moving from left to right, the horizontal orange line traces the scores for the average or typical buildings through scores of 50, 100, 100, and 0 for the various scales. Similarly the green line tracks the net zero energy building (NZEB) scores through the scales bouncing from 100 to 0 to 0 (but located at the top of the scale rather than the bottom) and finally to 100. For all but the Energy Star scale, the scores are linear functions of the EUI of the rated building.

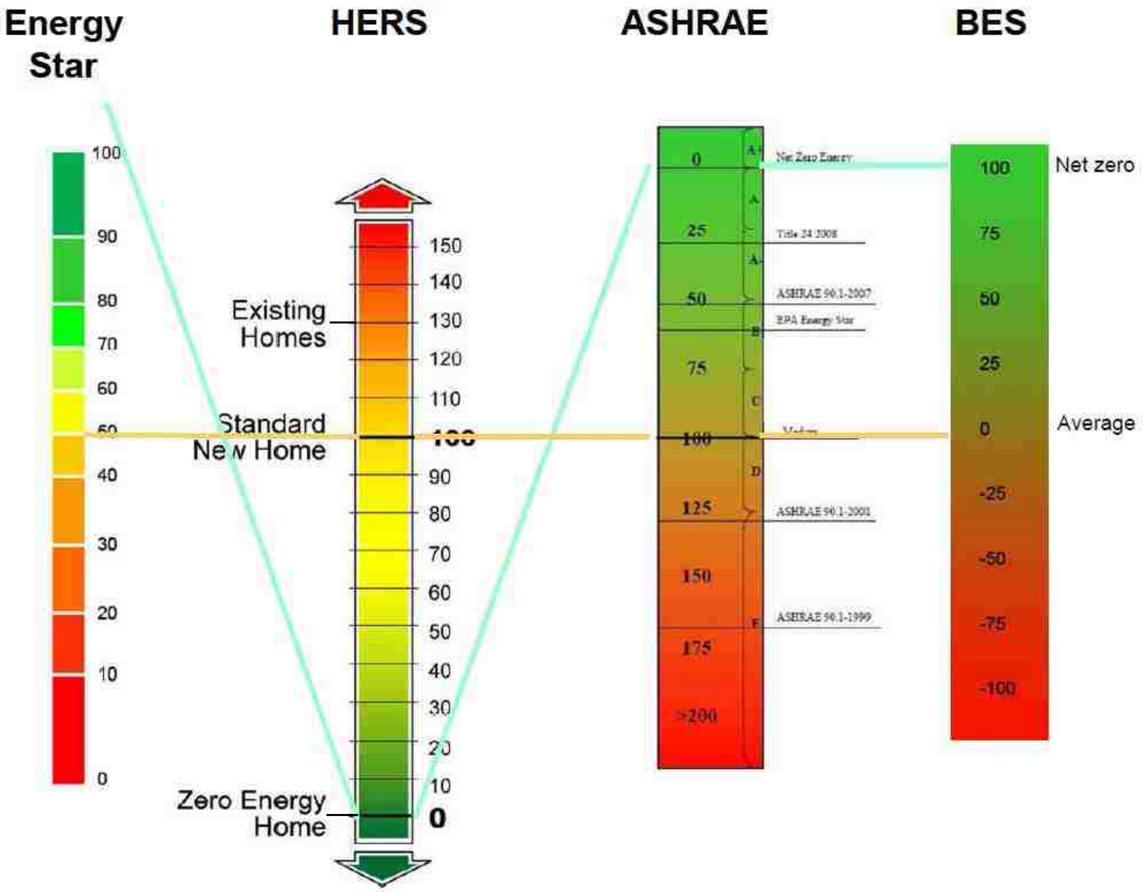

Figure 29. Summary of the building energy labeling schemes. This thesis proposes the scale shown on the right, the building energy savings (BES) scale.

With the aid of Figure 29 one can see the essential features common to all scoring schemes. Although each scheme exhibited its own unique feature set as summarized in Table 14, the characteristics that differentiate the approaches are limited in number and appear to be concepts worthy of additional explanation. After discussion, I will use them as building blocks to configure what I would recommend as the ideal rating system.

While I include six columns in my table to facilitate the discussion below, note that statistical and technical are mutually exclusive—each scheme uses one or the other. Similarly normalization-to-simulation and normalization-to-median are also mutually exclusive. Hence there are really only four independent choices to make.

Table 14. Features of the current and emerging building energy labeling systems. This thesis recommends labeling schemes later in this section, and they are included at the bottom of this table.

Building energy labeling scheme	**Statistical scale**	**Technical scale**	**Energy efficient buildings at top of scale**	**Scale tied to net zero energy buildings**	**Scale normalized to simulation results of standard reference building**	**Scale normalized to statistical median**
Energy Star	Yes	No	Yes	No	No	Yes
Designed to earn the Energy Star	Yes	No	Yes	No	No	Yes
HERS	No	Yes	No	Yes	Yes	No
LEED-NC (energy portion)	No	Yes	N/A	No	Yes	No
Green Globes (energy portion)	Yes	No	N/A	No	No	Yes
ASHRAE bEQ as designed	No	Yes	Yes	Yes	No	Yes
ASHRAE bEQ as operated	No	Yes	Yes	Yes	No	Yes
BES as designed	No	Yes	Yes	Yes	Yes	No
BES as operated	No	Yes	Yes	Yes	No	Yes

Statistical scale. The statistical scale requires considerable data gathering and processing before scoring can begin. Whether used for establishing a scale or not, the data are essential for understanding the building inventory, its energy consumption, and trends. The median, a single metric extracted from the distribution, tracks the central tendency of building efficiency and provides an excellent trending parameter. Once the data are obtained, the scoring against the building inventory to determine a percentile ranking is straightforward, but gives no insights into how well a building is doing in advancing toward the NZEB goal.

Technical scale. The technical scale pegs the NZEB to the top-performing end of the scale. The scale is then normalized with either the performance of the standard-reference-building or the performance of the median extracted from the data.

Energy efficient buildings at top of scale. All these rating systems present their scores on a vertical scale, like a thermometer. Some have the best buildings at the top and others at the bottom. In our culture we would prefer to be at the top and not at the bottom if we are the best. While we associate the NZEB with a EUI equal to zero, an overachieving building can actually be a net source of energy into the grid, and therefore scores negative values on the EUI scale. The notion of putting negatives numbers at the top of a vertical scale could be difficult for some.

Scale tied to net zero energy buildings. Most technical scales fix one end of the scale to NZEB. This choice acknowledges the significance of the goal of designing and building only NZEBs by year 2030—the 2030 Challenge.

Scale normalized to simulation results of standard reference building. The use of the standard reference building is widespread. It takes into account the solar variations at different latitudes, climate variations for different locations, and geometric features of the design. But the algorithm for deriving the reference building from the design is fraught with debate and periodic changes. For example, the window fenestration area of the reference currently matches the design building, but is distributed around the four sides of the building equally as a window strip. However, ASHRAE 90.1- 2010 is considering fenestration for the reference building that mimics the orientation features of the proposed design, and therefore it will be more difficult to achieve energy savings against the more rational derived design for the reference building. In the end one must decide whether the thresholds for recognition of excellent performance change as a function of time while holding the standard reference building constant, or whether the thresholds remain fixed and the standard reference building changes.

Scale normalized to statistical median. The median is a convenient metric easily extracted from data. If one has some preconceived notion regarding the fraction of buildings that should be recognized, then using the median as a proxy for the distribution is an excellent approach. It will adjust itself over time as new data sets are gathered and processed and thus this approach obviates the question of whether the thresholds or standard reference model changes.

6.1.2 Recommendation for building energy labeling options

My recommendation for the “ideal” building energy labeling scheme, the building energy savings (BES) scale, is shown in Table 14 and Figure 29 along with the existing systems. Like the ASHRAE scheme, it offers two ratings: one for new designs and one of existing buildings. My basis for selection is as follows:

Technical scale. It is fundamental that the goal which architects, engineers, and builders are working toward, NZEBs in year 2030, should be present on the scale used to measure building energy performance. Its presence is a constant reminder that designers should close the gap between typical buildings and the goal.

Energy efficient buildings at top of scale. Except for the percentile rating of the commercial Energy Star label, the other ratings schemes basically compare a building's EUI with zero and another EUI calculated from a reference buildings or the median EUI from a reference distribution. The concept is profoundly simple and meaningful. However, it is unfortunate that as buildings get better, their EUI moves toward zero, and the public seldom thinks of zero as a good thing. Zero on an exam is horrid. Zero on the thermometer means you might shiver and be uncomfortable. Zero in your bank account means trouble. But zero debt is a good thing. So this notion of reversing the scale suggests we adopt a metric that measures what we strive to achieve with conservation—energy savings.

By measuring energy savings, we also solve the awkward problem of buildings better than the NZEB—those buildings that actually produce positive net energy averaged over the year. In the ASHRAE scheme these building get a negative score for energy *use* since they actually *produce* net energy. That the best would have negative scores is strictly counterintuitive to our cultural experience. But from the energy savings perspective, they are simply saving more by both using less and producing more. This transparency will require no thinking from the public and we have no need to explain why negative numbers are good.

In the absence of conservation, the energy savings score goes negative. This is ideal since it resonates with a negative balance in your bank account, and the discomfort found when encountering negative temperatures outside. All these symptoms are bad!

The BES scale enables the best buildings to be visually portrayed at the top. For energy consumption, the less we use, the better we are doing. We are scaling performance for the public and the concept of 100 representing excellence is something we all learned in elementary school. It communicates well. Put the 100 on top. Buildings that are net energy sources desire extra credit—their scores can be over 100.

The BES rating scale is no more complicated than the definition of the *building energy savings*:

$$BES_{unnormalized} = EUI_{standard} - EUI_{my\_building}$$

Of course buildings types with high energy utilization have a bigger opportunity for savings. To make the comparisons among building types more meaningful it is appropriate to normalize the savings. It follows that the normalized building energy savings metric is:

$$BES_{normalized} = \frac{EUI_{standard} - EUI_{my\_building}}{EUI_{standard}}$$

$$= 1 - \frac{EUI_{my\_building}}{EUI_{standard}}$$

Taking the building energy savings metric to a percentage simply means multiplying by 100. Thus for the as designed score we get

$$BES_{asset} = 100 - \frac{EUI_{as\text{-}designed}}{EUI_{standard}} \text{ X } 100$$

and for the operational case

$$BES_{operational} = 100 - \frac{EUI_{measured}}{EUI_{median}} \text{ X } 100$$

Although the BES numeric scale shown in Figure 29 loses its direct connection to the EUI metric with meaningful physical units, it has all the desirable numeric features that make it transparent to the public. Negative scores imply bad buildings. A zero indicates an average building—something we would like to avoid. At 100 we have the target for energy efficiency—the NZEB. Scores above 100 are those fantastic buildings actually generating more energy than they consume.

Scale tied to net zero energy buildings. Of course we want the ultimate goal in plain sight at one end of the scale, so I have the net zero energy building at 100.

Scale normalized to median or to simulation. For me this choice is the most difficult since there are valid arguments for either normalization-to-simulation or normalization-to- median. For the “as operated” rating, it is straightforward, and I chose to normalize with the statistical median since this allows comparison with the building stock at one end of the scale and the end goal, the NZEB, at the other. Furthermore the rating then uses experimental data throughout.

Now for designs it is arguable that comparisons to the standard reference building might make sense—they are both calculations. Assumptions and approximations would apply to both and might have a tendency to cancel in the normalization process. So this argument favors normalizing to the simulation.

Building data can be distorted due to the variations in use patterns that do not conform to the assumptions about the standard work week. For example, if the building houses an architecture firm, it is likely that the lights will be on and people working well beyond the normal office hours. If this use pattern is not taken into account, then the building would be penalized in its assessment since the extra energy required for the extra hours of lighting and air conditioning would cause the building to be rated lower. These penalties would distort the building data and bias the median towards lower performance. Thus this argument also favors normalizing to the simulation, where the office hours strictly apply to both simulation of the proposed building and its baseline reference.

However, it is critical to remove these usage-dependent variations from the collected data since we want to use this data for the “as operated” rating in any case. Appendix A discusses the efforts of COMNET to develop the methodology to improve the quality of the data used for these metrics. COMNET will be developing the National Energy Protocol Specification (NEPS) to standardize the treatment of unregulated variables like the actual schedule for operations. Once defined and implemented, the objection to normalization-to-median vanishes, and comparison of the proposed building to the existing building inventory and to the NZEB goal is not only feasible but it is equivalent. However, the systematic benefit from comparing simulation to simulation for design problems tips the scale toward normalization-to-simulation for the "as designed" rating. Thus my asset rating relies on only building simulations.

Sanity check. To validate these arguments and my choice of the BES as "ideal," I offer the following hypothetical but instructive examples. Table 15 rates 6 buildings: an exceptional building producing more power than it consumes (we have no such buildings today), an net zero energy building (none today), a world class building today, an average building, one just slightly below average, and an energy "hog" sucking up far more energy than the average building of this type.

Table 15. EUIs for hypothetical rating example.

Facility description	Weather Normalized Source EUI (kBtu/Sq. Ft.)	National Average Source EUI (kBtu/Sq. Ft.)	Energy Star Rating	ASHRAE bEQ Rating	BES Rating
Net power producer	-20.0	139.9	100	-14	114
NZEB	0.0	133.7	100	0	100
Great building today	30.0	130.0	99	23	77
Average	133.7	133.7	50	100	0
Slightly below Average	142.2	131.6	47	108	-8
Energy hog	250.0	149.0	30	168	-68

The Energy Star ratings do not differentiate between the net power producer, the NZEB, and today's great building. This insensitivity is the greatest flaw in the Energy Star scheme. The other Energy Star scores seem rational.

The ASHRAE scores have a sign error. The best buildings should not have negative scores. The worst buildings should not have large positive scores.

The BES with its 100-point offset from zero allows buildings better than average but less than the NZEB, the standard of performance for 2030, to enjoy the dignity of a positive score between 0 and 100. The hogs get negative scores and the superstars exceed

100. The BES scale coincides with our life experiences where grades are assigned, and the other scales fail.

Case study benchmarks. Using operational data from the Albuquerque schools and simulation results for the two elementary schools analyzed in Chapter 5, we can compare the ratings for the Energy Star, ASHRAE bEQ, and proposed BES scores. These results are tabulated in Table 16 and Table 17 for the as-designed and as-operated ratings, respectively.

Table 16. Comparisons of the design rating for two schools using ASHRAE bEQ and the proposed BES (accented in yellow). All data are taken from simulations of the schools. The reference standard is ASHRAE 90.1-2004.

Facility Name	Proposed building As Designed EUI (kBtu/Sq. Ft.)	Reference building EUI (kBtu/Sq. Ft.)	ASHRAE bEQ Rating	BES Rating
Hubert Humphrey Elementary	213.0	216.0	99	1
Tierra Antigua Elementary	164.0	237.0	69	31

Table 17. Comparisons of the operational rating for four schools using Energy Star, ASHRAE bEQ, and the proposed BES (accented in yellow). All data are derived from meter readings at the schools.

Facility Name	Weather Normalized Source EUI (kBtu/Sq. Ft.)	National Average Source EUI (kBtu/Sq. Ft.)	Energy Star Rating	ASHRAE bEQ Rating	BES Rating
Jefferson Mid-school	103.8	139.9	83	74	26
James Monroe Mid-School	119.8	133.7	67	90	10
Jimmy Carter Mid-School	142.2	131.6	47	108	-8
Hubert Humphrey Elementary	146.0	149.0	51	98	2

First, I call attention to the striking difference between the calculated EUI (Table 16) and the actual EUI (Table 17) for Hubert Humphrey Elementary. The simulations governed by ASHRAE 90.1 Appendix G must conform to certain methods and standards as discussed in Appendix A of this thesis. This procedure specifies that modeled space shall be subjected to defined heat loads for the purpose of comparisons against the standard baseline building. It is recognized that the EUIs obtained may not agree with the actual operation of the building, but this is not the goal. Rather the goal is to use the same conditions for the building to be rated and the reference baseline to facilitate meaningful comparisons. Indeed the ASHRAE standard schedule for lighting the school is based upon 14-hour days whereas in reality the 10-hours days are the routine for APS. While it would be interesting to explore the parameter space associated with the modeling in search of an accurate model, ASHRAE 90.1 Appendix G defines schedules and thermal loads and they are used to establish this consistent basis for comparison.

Now looking at the as-designed scoring in Table 16, the BES scale tells us that the design of Tierra Antigua completed this year has traveled roughly one third (31 percent) of the way from the ASHRAE 90.1-2004 standard toward the goal of net-zero energy consumption. The ASHRAE bEQ score of 69 “feels” not so different from the 31 since the score lies near the point where the two scales cross. Tierra Antigua is well ahead of Hubert Humphrey built in 1978, which is doing well to be match the 90.1-2004 energy code with a score of “1” 31 years after construction. The ASHRAE scale scores Hubert Humphrey at 99, giving the impression of a more satisfactory performance than a score of 1. Thus the BES scale delivers the right message to the non-expert.

I assert that examination of the operational scores under the three ratings systems shown in Table 17 also reveals rather different impacts on the reader. The score for Jefferson under the Energy Star is high and might indicate that the energy conservation job is moving along rather nicely. A boost of only 17 percentile points moves this building to the very top of the heap, but really says nothing quantitative about the additional energy savings required. In contrast the BES score shows the conservation journey only one quarter of the way from average at zero to the goal at 100—a serious challenge. So a big opportunity still exists for Jefferson.

Jimmy Carter Mid-School performs below the national average, and its numeric scores show the largest contrasts among the three schemes. The Energy Star score is just below the 50th percentile while the BES score shows it below zero—a bad score. The bEQ score of 108 indicates it’s a really long way from zero, the target, yet the “tone” of the score feels good and in no way alarming.

Taking the three schools as a set, the as-operated BES scores and the goal at 100 clearly indicate that these three are not vastly different in their energy performance, that all have low scores, and that all offer savings potential. The Energy Star scores diminish the apparent need for energy conservation enhancements. Of course the bEQ scores are telling the same story as the BES, but they require us to think of zero or negative scores as the target.

After the incredible effort to simulate the thermal performance of a building or to collect its operational data and process it to allow meaningful comparisons, it is crucial that the last step—the calculation of the single number that represents the building to the public, the naïve owner, and the uninformed tenant—produce the highest fidelity information possible regarding the buildings energy performance. In Chapter 3 I ruled out the possibility of a proof, but these case studies with real buildings and real EUIs effectively illustrate that the scales do matter. Of the three scales analyzed, the BES scale best leverages our cultural experiences with grading scales, accurately communicates building energy performance, and deserves serious consideration for the national building energy labeling standard.

The agreement between the as-designed and as-operated scales for Hubert Humphrey Elementary is spectacular but not significant. Had I chosen a baseline of ASHRAE 90.1-1999 or 90.1-2007, then the as-designed score would have been higher or lower, respectively. The design of the building envelope was well ahead of the code requirements of its day, and thus it just happens to barely meet today’s code for new construction—the standard I chose to compare against. It does suggest that today’s code requirements may not be very difficult to meet and underscores the fact that moving beyond code with building energy labeling can come none too soon. The next section continues to explore the relationship between building energy codes and building energy labeling.

6.1.3 Relationship of building energy labeling and energy codes

After our investigation of present and emerging labeling schemes, the dissimilar yet complimentary nature of building energy codes and labeling begins to take shape. Perhaps one of the greatest differences between building energy codes and labels is their mandatory versus voluntary nature. Thanks to their roots in public safety, building codes are mandatory. Fire protection demands that specific types of buildings are constructed with specific types of materials with minimum fire-resistance characteristics. Analogously, energy conservation requires minimum standards for insulation. However, energy labeling encourages designers and builders to move beyond the minimum requirements of a code and toward high-performance buildings. Thus metrics for energy labeling performance are defined on a continuous scale and can move well beyond the pass-fail thresholds required to satisfy code requirements and receive a building permit. This voluntary rating is often a wise business decision that rewards building owners with savings over the life cycle of the building. Proponents of mandatory labeling argue that such money-smart and environmentally-correct choices should be automatic—that is mandatory.

Might building energy codes be a special case of building energy labeling? It is arguable that a building energy code is a particular case of a building energy labeling system where there are only two values—a binary system, 0 and 1, pass/fail. Under such a system, no one would bother to actually affix labels to buildings since only the buildings that pass actually get built and such qualified buildings would all display identical certifications—not so useful. Let’s dig a little deeper.

Despite the federal law that requires states to adopt building energy efficiency codes (see Section 2.1.1.1), not all have done so. Perhaps they passed the requirement for legislation down the jurisdictional hierarchy. Whatever the approach, their apparent lethargy indicates that some states and jurisdictions have little to no serious interest in energy conservation.

The status of the energy codes among the various states is summarized[73] in Figure 30. The upper portion shows the residential codes among the states, and the key indicates that codes range from IECC 2009 equivalent or better down to no statewide code. Similarly, the lower portion shows the commercial codes among the states, and the key indicates that codes range from ASHRAE 90.1-2007/IECC 2009 equivalent or better down to no statewide code. When there is no statewide code, counties and municipalities may independently adopt an energy code.

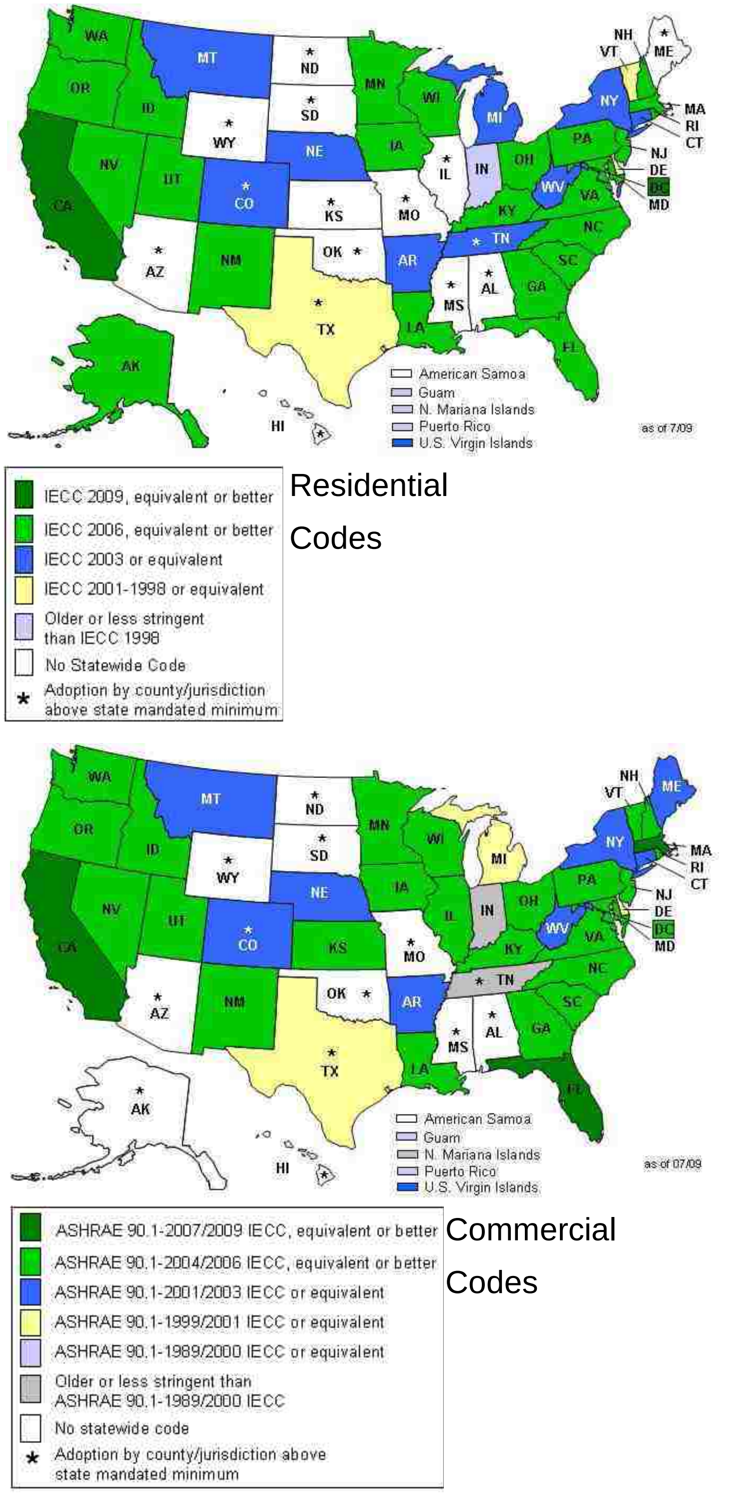

Figure 30. Status of building energy codes. The lower portion shows the status of states with commercial energy codes while the upper portion shows the status of states with residential energy codes.

If these energy codes were sufficiently stringent, then the discussion of building energy labeling would be superfluous. However, the reality is that these codes are woefully inadequate for the challenge we face. Ed Mazria of Architecture 2030 makes this point very nicely when he compares the 2030 Challenge to the various US

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[73] DOE: Building Energy Codes - Status of State Energy Codes http://www.energycodes.gov/implement/state_codes/index.stm, Aug 25, 2009.

codes[74] that are currently in use in Table 18. He deftly compares the initial 50% energy savings targeted for year 2010 in the 2030 Challenge to a percentage margin below the various codes (and standards). Two things are apparent from his code equivalents: (1) the goal for energy consumption in 2010 is 10-30% lower than the efficiency standard defined by our current energy codes, and (2) energy codes define a specific EUI threshold on a continuous scale for each building. If the building uses less energy, it passes. Otherwise it fails. It is totally discontinuous—pass/fail.

Table 18. 2030 Challenge Interim Code Equivalents. Source: Architecture 2030.

CODE / STANDARD	COMMERCIAL	RESIDENTIAL
ASHRAE 90.1-2004	30% below	
ASHRAE 90.1-2007	25% below	
ASHRAE 189 (in progress)	0	
IECC 2006	30% below	30% below
California Title 24 2005		15% - 20% below[13]
California Title 24 2008	10% below[14]	
Oregon Energy Code[15]	25% below	30% below
Washington Energy Code	25% below	25% - 30% below[16]
RESNET HERS Index		65 or less
LEED NC 2.2 / Homes	New - EA Credit #1: 6 pts Renovation - EA Credit #1: 8pts	HERS Index: 65
LEED 2009 (in progress)	New - EA Credit #1: 7 pts Renovation - EA Credit #1: 9pts	
GBI Standard (in progress)[17]	PATH A. 8.1.1.1: 150pts	
EECC Option[18] (prescriptive path)		EC - 154
NBI Option[19] (prescriptive path)	New - Core Performance w/ enhanced measures	

Also notice how nicely the scaling of a code creates a continuous building efficiency rating metric. Suddenly codes seem to offer a very handy and continuous scale rather like the energy efficiency labeling we are studying with buildings ranking a certain percentage above or below the threshold for the building code. Could it be that building energy labels and building energy codes are not so different?

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[74] Edward Mazria, Kristina Kershner, “Meeting the 2030 Challenge Through Building Codes,” Architecture 2030, June 20, 2008, p4.

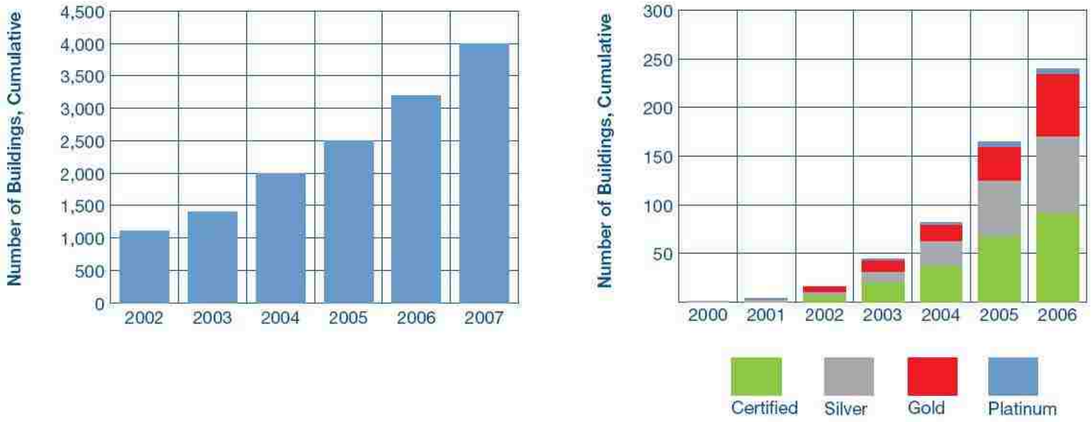

Figure 31. The number of rated commercial buildings in the Energy Star (left) and LEED (right) programs.

Energy labeling and energy codes may enjoy other synergies. From the numbers of Energy Star and LEED rated buildings, it is clear that the design and construction of high-performance buildings is in its infancy. First look at the trends in the current labeling programs for commercial buildings. While the numbers shown in Figure 31 represent a tiny fraction of the 4,860,000 buildings in the commercial inventory, both of these new programs show exponential growth[75]. The numbers reflect increasing participation of both government and private sectors presumably due to increased awareness of the savings opportunity for energy and emissions and to increased brand recognition of the labels.

Such exponential growth is typical early in the lifecycle of a new product. If we treat building energy efficiency as a product, then its market penetration might look like the schematic diagram shown in Figure 32. In its early days growth is slow. Gradually its performance and value are understood in the market, architects and builders adopt the necessary techniques for design and construction, and the growth begins to accelerate. In this phase of the lifecycle, voluntary building energy labeling is especially useful as an incentive to early adopters. They want recognition, differentiation, and savings, so moving beyond the building code makes sense for them. In addition social marketing offers the potential to accelerate the move of buyers and tenants towards high performance buildings.

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[75] Op cit, Office of Energy Efficiency and Renewable Energy, *Energy*, p25.

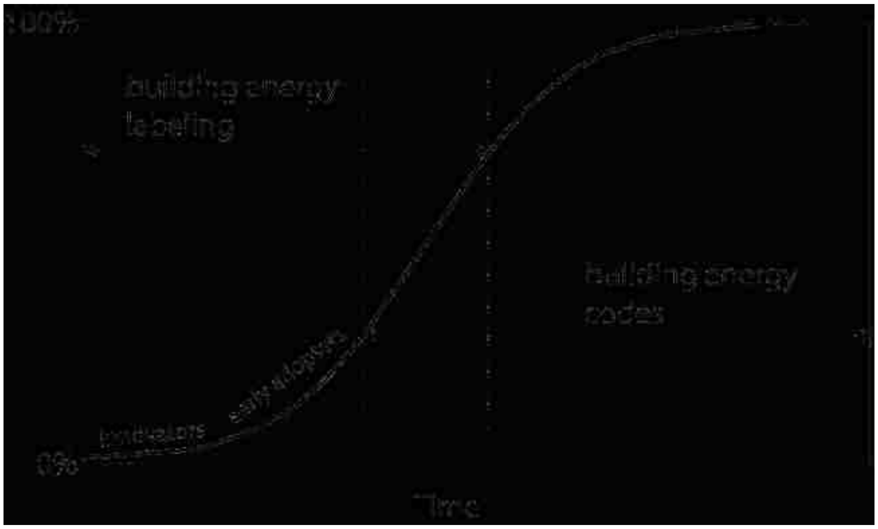

Figure 32. Model for the market penetration of high-performance buildings. Early in the life cycle of high performance buildings, the growth will be exponential. During this phase early adopters seek to exploit the strengths of these buildings and to use them for competitive advantage.

As the market penetration becomes significant, it is appropriate to introduce mandatory energy labeling for both new and existing buildings since the technical and experience basis for the high-performance buildings has been established. However expect to see significant political resistance to mandatory labeling from realtors and owners who would prefer that the public remain uninformed. Voluntary labeling in the early adopter phase probably serves realtors' and owners' purposes by enhancing the values of high performance buildings while the numbers of such properties are low and also by maintaining prices in the business-as-usual market. In contrast mandatory labeling reveals the whole truth—it reveals the fact that the building inventory is filled with energy "hogs." In an informed competitive market, energy hogs will be harder to sell, and their prices may suffer as market preferences transition to energy efficient buildings. Yet there will be a market for "hogs" driven by entrepreneurs who recognize an opportunity to refurbish such buildings and give them a second "efficient" life.

Further into the life-cycle of high-performance buildings, the market will accommodate more stringent standards for building codes. These code changes are incremental changes that bring steady EUI improvements. At this point in the life-cycle the technologies are maturing, the production capacity has grown, and the workforce is trained and experienced.

This life-cycle for high-performance buildings implies a life cycle for the BES scale. The evolution of the BES scale can be represented diagrammatically as shown in

Figure 33. The latest CBECS data or the latest standard baseline building will define a reference EUI for the scale. The average of the 2003 CBECS data for the building type or the ASHRAE 90.1-2004 Appendix G simulation defines the current reference. The range of EUIs covered by the 0-100 portion of the BES scale will run from the time-dependent reference point to zero, the goal established by the NZEB. The BES scale is represented by the red-turning-to-green bar in each EUI profile shown in Figure 33 for various years. As the BES scheme draws in adopters willing to go beyond the code requirements, new CBECS data will reflect improved efficiency and the ASHRAE 90.1 Appendix G requirements will become more stringent. The reference point will move towards smaller EUI values—from right to left as indicated by the arrows.

The diagram clearly indicates the role of the BES scale—1) it occupies the energy efficiency performance regime beyond the average or beyond code requirements and connects to the NZEB goal and 2) for a rated building it scores the percentage of the gap closed between the goal for net zero energy and the current building stock or current building code. As the EUIs for the building stock and building codes grow smaller, this energy intensity range will decrease until the point it vanishes. As that range approaches zero, the BES labeling will no longer serve any useful purpose and building energy codes

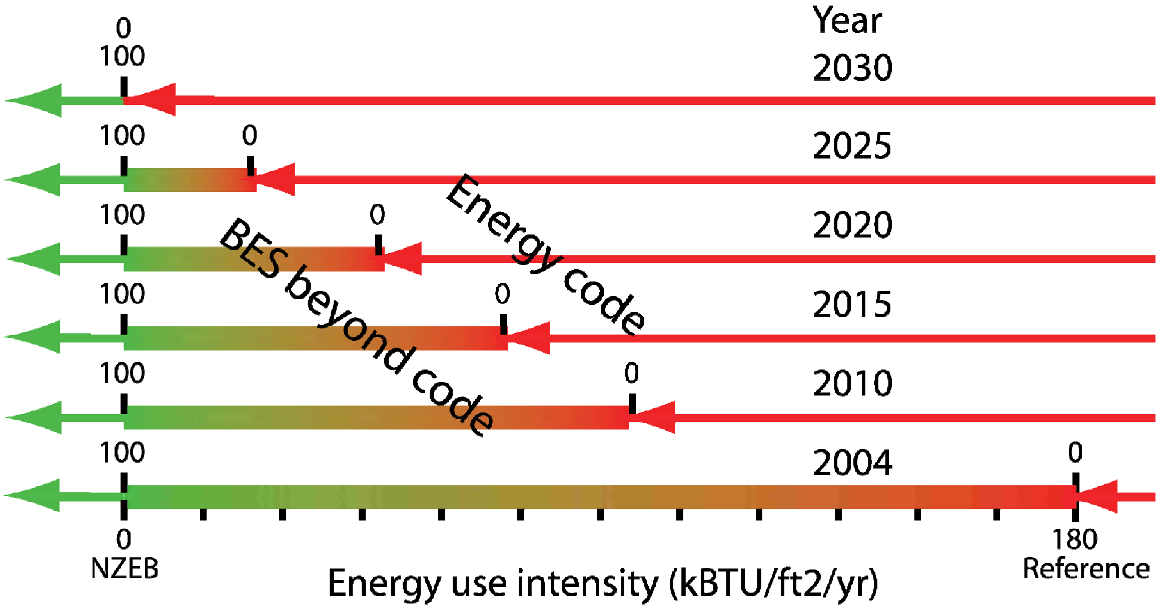

Figure 33. Example of the evolution of the BES scale for food sales. The reference EUI for the building type gets lower year after year as the BES scale pulls more adopters toward the NZEB goal. The red-turning-to-green portion of the EUI axis is the BES scale between scores of 0 and 100. The EUI range for the BES scale deceases until the point it vanishes—year 2030 in this example.

will suffice.

The processes illustrated in Figure 32 and Figure 33 demonstrate the synergistic relationship of buildings energy labeling and building energy codes. As building energy labeling brings more early adopters into the market, codes will tighten. Finally as the market penetration saturates, most buildings will have energy efficiency labels, and thus the opportunity for differentiation is lost. It may be appropriate to abandon energy efficiency labeling at this point, and let the building energy codes assume command and ensure the construction of high-performance buildings. Consequently the market transformation from today’s poor energy performers to tomorrow’s NZEBs is facilitated through the use of BES labeling followed by stringent building energy codes. They go hand-in-hand. They follow in sequence.

Before leaving codes, let me issue a note of caution. Prescriptive codes do not account for basic passive design strategies such as orientation and mass and active strategies such as high quality HVAC systems. It may be that future codes governing NZEB design must be performance based.

6.1.4 Commissioning, field inspections, and compliance

Great energy efficient designs mean nothing if they are not implemented in the field. Thus to close the gap between building energy efficiency “as designed” and “in operation,” design teams will need to define and execute commissioning plans just as governmental jurisdictions will need to define and implement energy inspections and enforcement actions to ensure compliance. Due to the complexity of energy efficient systems, validation may be a lengthy process. While we all would prefer that inspections were unnecessary, we only need consider our own behaviors while driving to realize that compliance without inspection is unrealistic.

Energy inspections are essential both during construction and operation. While construction is in progress, inspectors can see the materials that comprise the building envelope, verify their compliance with design, and see the thermal bridges that will compromise energy efficiency. Once the building is complete, inspectors should validate that the energy systems of the building are appropriately commissioned and verified to be operating correctly. The commissioning step is also critical to ensure that the potential of the design is realized, and if not, that it is understood what part of the design/construction process failed. Subsequently, the building should be inspected periodically to ensure continued performance as designed. Alternatively excessive building energy consumption could automatically trigger an inspection. Building systems require periodic maintenance, and it is insufficient only to trust that it is completed. Therefore it is critical that an adequate supply of trained energy inspectors is available within the jurisdiction.

The challenge of training and maintaining a staff of building energy inspectors will require significant effort. Perhaps it will be possible to economize the effort by combining fire inspections with energy inspectors[76] especially in developing countries where inspection personnel are stretched thin. Not only might the inspector be the same individual, but one field trip to the facility should be sufficient for both inspections. This of course requires more training and a broader basis of knowledge than for either the energy or fire inspector separately. For quality purposes it will be important to have a third party perform confirmatory inspections to independently spot check that inspectors are completing their assessments satisfactorily.

This program for the certification of energy commissioning and inspection is the subject of wide concern. The World Business Council for Sustainable Development[77] recommends comprehensive measures for quality assurance as does the Northeast Energy Efficiency Partnerships' (NEEP) Model Progressive Building Energy Code Policy[78].

6.1.5 Value to society

As established in the introduction, the globe is facing climate change and energy resource depletion. While these effects were brandished by alarmists to motivate action, a more pragmatic approach is simply to get busy mitigating the problem and to omit the panic.

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[76] World Business Council for Sustainable Development, "Energy Efficiency in Buildings, Transforming the Market," World Business Council, April 2009, p8.

[77] Ibid, p55.

[78] Op cit, Northeast Energy Efficiency Partnerships, p27-30.

As we have seen, the most powerful action available to us in the near term is conservation. While actually saving on costs, by 2020 society can reduce its CO_2 emissions by 23%[79], while also taking a significant step toward net zero-energy buildings. Although the potential for these savings has been available for the past three decades, little progress has been made in this direction due to various market failures and barriers. At this juncture with the economy in a deep recession, society is renewing its efforts to abate its CO_2 emissions, to conserve its energy, and to enhance its research efforts. Thus tools like energy BES efficiency labeling and stricter codes are in demand.

6.1.5.1 Visibility of building energy labeling

USGBC continues to popularize the concept of building labeling. Although the LEED label addresses a broad spectrum of sustainability issues, one of which is energy conservation, the tool is generating public awareness and political actions from governments. In New Mexico the state government is committed to LEED Silver designs for new construction of buildings larger than15,000 square feet. Both Albuquerque Public schools and the City of Albuquerque are also committed to LEED Silver certification. Even the existing government building inventory is now the target of refurbishment programs. The public directly benefits from energy efficiency labeling through better government buildings that reduce utility expenses and through lessons learned that might be applied in businesses and private homes.

Since labeling is influencing the manner in which people are purchasing appliances these days, our goal is to facilitate owners, purchasers, and renters in transferring this conservation behavior to buildings. When we see labels appearing in public buildings that we visit, then we will consider them normal and in time desirable. Certainly the image of “green” and the response of “green washing” is something that corporations have quickly mastered. In Section 4.4.1 we learned that the LEED label can be misleading and in the worst case manipulating, but the LEED tool is intended to be a tool for good. It can only be a matter of time before the negative aspects of this early venture into building labeling are corrected.

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[79] Hannah Granade, Jon Creyts, Anton Derkach, Philip Farese, Scott Nyquist, Ken Ostrowski, *Unlocking Energy Efficiency in the U.S. Economy,* McKinsey & Company, July 2009, piv.

6.1.5.2 Enhanced property and rental values for energy efficient buildings

Having reviewed building energy labeling programs as currently implemented (and their histories and futures in Appendix A), how do we assess that building labeling is effective? At least two ways seem apparent: increased voluntary adoption and enhanced marketplace values. Certainly the trend in the number of rated buildings shown in Figure 31 indicates success for building labeling, but it begs the larger question—Are the resources expended earning “good” returns? Two scenarios come to mind and they clarify the notion of “good.”

First, while developers may share a desire to promote sustainability with the environmentalist, the developer is also keen to know that there is a market for any sustainable building that he may construct. Similarly owners are keen to know that if they invest in “green” buildings or “green” upgrades for their building stock, then their investment will generate a reasonable return on their investment through increases in rental rates and/or sales prices. If there is no premium for the green building, then why go to the trouble and expense of creating a premium product? Until now the anecdotal evidence was encouraging, but none of this has been quantified in the marketplace.

Secondly, governments seeking to motivate changes in behavior have similar economic concerns as regards policy choices and implementations. While most governments are interested in promoting energy conservation, what policy investment will produce good returns as measured in BTUs saved or tons of CO_2 not emitted? What is the cost to produce the effect? Many policies make sense and will move society in the right direction, but it is important to quantify the process to see how much change results given the amount of the investment. It is all about effectiveness *and* cost-effectiveness.

Generally quantitative measures of efficacy evaluate the incremental change in an observed metric per unit of cost to implement some program or policy assumed responsible for the observed change. For example, since we are interested in the impact of building energy labeling, we might want to know the market value increase of our commercial building for each dollar we spend improving its energy efficiency to qualify for an Energy Star label. It is apparent that such metrics at best can only be approximated since the marketplace is complex and closely linked to the psychology of the globe's inhabitants.

To assess the value of energy labeling for buildings, researchers have analyzed in recently published work the financial performance of "green" office buildings in the US. Using the records from the EPA and the USGBC, all certified office buildings in the US were identified for study. These 1,360 energy-efficient office buildings were labeled by either the Energy Star program (1,045) or LEED (286) or both (29)[80].

To examine the financial performance of these buildings it was necessary to have either the monthly rental rates or the sales prices for financial transactions. Using an extensive database for commercial buildings maintained by the CoStar Group, the researchers determined that of the 1,360 buildings, rents were available for 694, and 199 were sold between 2004 and 2007. This period was selected for sales transactions since prices were relatively stable during the period.

For comparisons with the non-green building stock, all office buildings within a ¼ mile (1,300 ft) radius of a green building were selected for comparative studies. In effect this defined 893 circular clusters of buildings with an area of 0.2 square miles and a green building at its center. On average the number of buildings in a cluster was about 12 with a high of 41 and low of 2. There were a total of 8,182 commercial buildings in the sample for green buildings and corresponding control building for the assessment of rental space, and 1,816 buildings for the assessment of building sales.

The systematic process and quantitative conclusions of the study are surely a first for the financial efficacy of building energy labeling, and so the brief conclusions are reproduced below[81].

> The results clearly indicate the importance of a green label in affecting the market rents and values of commercial space. The results suggest that an otherwise equal commercial building with an environmental certification will rent for about three percent more per square foot; the difference in effective rent is estimated to be about six

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[80] Piet Eichholtz, Nils Kok, John Quigley, *Doing Well By Doing Good? An Analysis of the Financial Performance of Green Office Buildings in the USA*, Published by RICS, March 2009, p17.

[81] Ibid, p28.

> percent per square foot. The increment to the selling price may be as much as 16 percent.
>
> These are large effects. For example, the average effective rent for the 7,488 control buildings in the sample of rental office buildings is $23.51 per square foot. At the average size of these buildings, the estimated annual rent increment for a green building is approximately $329,000. At prevailing capitalization rates of six percent, the incremental value of a green building is estimated to be about $5.5 million more than the value of a comparable unrated building nearby. The average selling price for the 1,617 control buildings in the sample of buildings sold in the 2004-2007 period is $34.73 million. *Ceteris paribus*, the incremental value of a green building is estimated to be about $5.7 million more than the value of a comparable unrated building nearby.
>
> Our results also show that the type of label matters. We find consistent and statistically significant effects in the marketplace for the Energy Star labeled buildings. We find no significant market effects associated with the LEED label. Energy Star concentrates on energy use, while the LEED label is much broader in scope. Our results suggest that tenants and investors are willing to pay more for an *energy-efficient building*, but not for a building advertised as “sustainable” in a broader sense [emphasis added].
>
> The premium in rents and values associated with an energy label varies considerably across buildings. It is positively related to the intensity of the climate surrounding the rated building: a label appears to add more value when heating and cooling expenses are likely to be a larger part of total occupancy cost. We disentangle the energy savings required to obtain a label from the unobserved effects of the label itself, which could serve as a measure of reputation and marketing gains obtained from occupying a green building. The energy savings are important. A 10 percent decrease in energy consumption leads to an increase in effective rent of about 20 basis points and an increase in value of about two percent, over and above the rent and value premium for a labeled building. Rough comparisons of the monetary value of the link between energy savings and asset values also suggests that the intangible effects of the label itself are important in determining value in the marketplace.

This is good news for developers, investors, owners, tenants, governments, environmental enthusiasts, and residents of the Earth. While the USGBC may be disappointed with the performance of LEED-rated buildings, it is crucial to the viability of building energy labeling that the markets reward the life-cycle savings available in properly designed buildings. This reward will drive market penetration.

The Energy Star program has demonstrated that this label is valued. It reflects building quality with directly reduced operating costs and commands an incremental premium over normal buildings in the inventory. Consequently investors, owners, and renters have learned the lessons that investments in efficient energy systems during construction return dividends during the life of the building. Refurbishments of existing buildings are also good investments and demonstrate breakeven operation in up to ten years. This claim does not rely on extremely high future energy costs or expenses due to cap and trade evaluations of carbon emissions. Such events would only serve to reduce the breakeven time.

Building owners would benefit from a comprehensive policy to label all buildings types—types beyond those now covered by CBECS. These labels should require periodic recertification to eliminate any possibly of degradation of equipment or the failure to maintain a high-performance operation, which could jeopardize the credibility of the labeling program. To further enhance quality and credibility, the program should require some measure of third-party verification of the labeling procedures, and strict certification of the credentials of software tools and energy assessors.

6.1.5.3 Efficacy of building energy efficiency labeling

The previous section establishes that building energy labeling does increase the value of buildings. While this is essential, to what degree does it actually reduce energy consumption and emissions? Is it cost effective? How does this policy compare with the myriad of other policies discussed earlier? This section will address these questions.

While numerous studies answer one or two of these questions, only one study answers them all. This recent comprehensive review of the literature assessed all the published studies of policy efficacy for emissions and energy reductions worldwide[82]. First the authors selected 20 policies they deemed to be the most significant, and grouped them into four categories: control and regulatory instruments, economic and market-based instruments, fiscal instruments and incentives, and information and voluntary

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[82] Diana Urge-Vorsatz1, Sonja Koeppel1, and Sebastian Mirasgedis, “Appraisal of Policy Instruments for Reducing Buildings’ CO_2 Emissions,” *Building Research & Information*, 35(4), 2007, pp458–477.

action. These categories were the same as those in Chapter 2 except that economic instruments were further subdivided into market-based instruments, policies without incentives other than simple profit motive, and financial instruments with incentives. These categories and instruments are listed in Table 19, which also provides page number references to the majority of policy instruments that have already been discussed.

Table 19. Policy instruments chosen for assessment[83]. The right column references the page where a policy is discussed in this thesis. If not discussed, a brief notional description of the policy is provided.

Control and regulatory instruments	**Description**
Appliance standards	Example: Energy star for home appliances
Building codes	Page 18
Mandatory labeling and certification programs	Page 31
Procurement regulations	Typically a requirement for government agencies to buy energy efficient equipment
Energy efficiency obligations and quotas	Example: In UK government agency is charged with reducing residential electrical consumption. Unused in the US.
Mandatory demand-side management programs	Page 24
Economic and market-based instruments	
Energy performance contracting	Page 36
Cooperative procurement	Example: Joint venture in the private sector to design and manufacture a high-volume product that is energy efficient
Energy efficiency certificate schemes	After producers, suppliers or distributors effect a consumption reduction, they receive a white certificate to document the savings. Can be sold to others failing to achieve mandated reductions.
Kyoto protocol flexible mechanisms	Schemes that enable emission reductions in foreign projects to count as reductions mandated for parties to the Kyoto protocols.
Fiscal instruments and incentives	
Taxation (on CO2 or household fuels)	Page 30
Tax exemptions/reductions	Page 28
Public benefit charges	A form of energy tax reinvested in energy efficiency.
Capital subsidies, grants, subsidized loans	Page 30
Support, information and voluntary action	
Voluntary certification and labeling	Page 31
Voluntary and negotiated agreements	Voluntary emission reductions achieved with the threat of regulation.
Public leadership programs	Example: Governor of NM requires new state buildings be LEED certified.
Awareness raising, education, information campaigns	Education programs that supplement other programs.
Mandatory audit and energy management requirement	Page 35
Detailed billing and disclosure programs	Page 39

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[83] Ibid, p460.

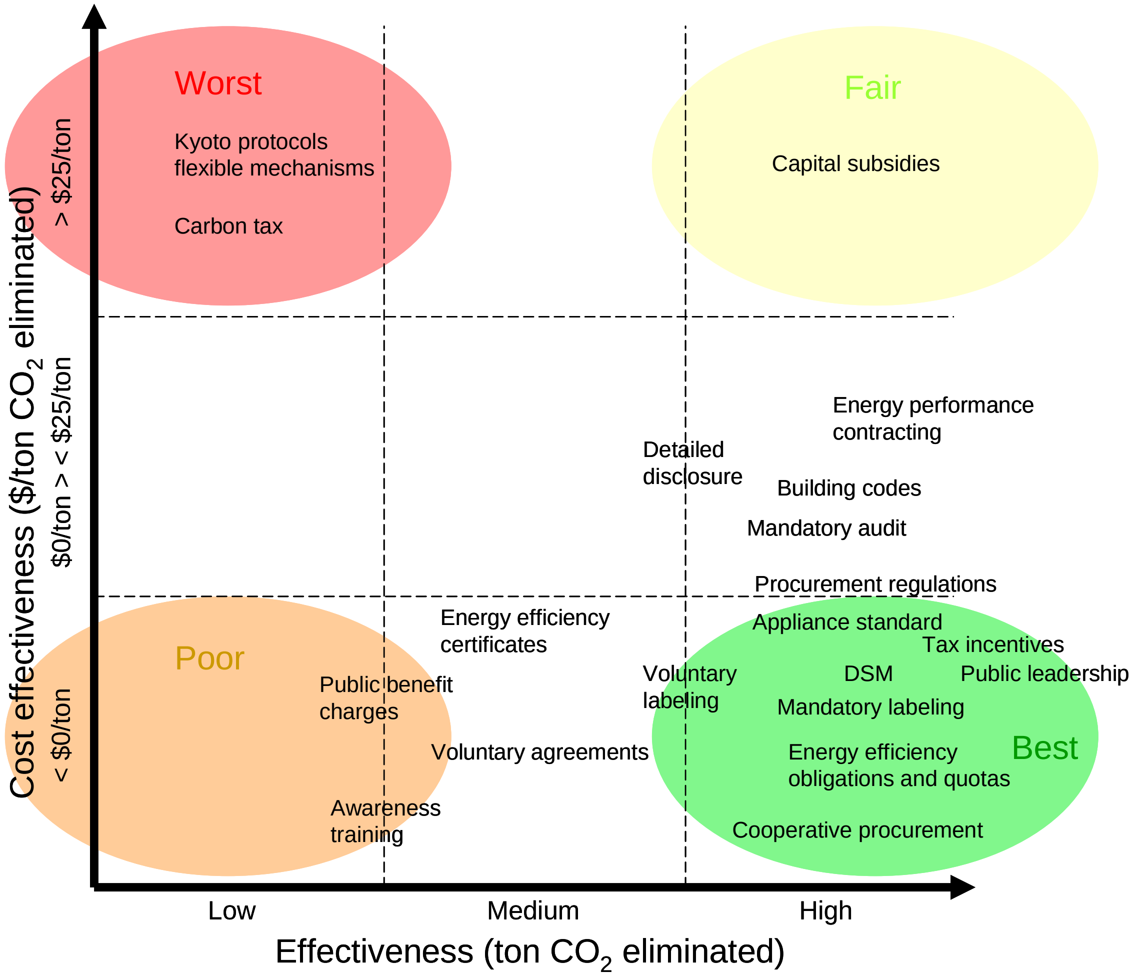

Figure 34. Summary of the efficacy of the 20 most common policy instruments used globally. The cost-effectiveness is measured in $/ton equivalent CO_2.

Based on the referenced reports, the authors then rank each policy in its effectiveness and cost effectiveness for CO_2 reductions. The effectiveness reflects the tons of CO_2 eliminated and the cost effectiveness estimates the cost/ton eliminated. They lump the effectiveness metric into three bins: low, medium, and high; and the cost effectiveness metric into three cost intervals: less than $0/ton, between $0-25/ton, and greater than $25/ton. Since the authors were primarily focused on CO_2 reductions, they converted energy consumption data to emissions data[84]. Thus three analogous bins for cost effectiveness of energy conservation can reasonably be inferred. I summarize their

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[84] Ibid, p462.

results in Figure 34. Positions within each of the 9 zones are arbitrary and policies on zone boundaries represent intermediate assessments.

In such a diagram the best policies are located in the lower right-hand corner (the green zone) where policies are effective and costs are negative, i.e. a savings. There we find four familiar polices: mandatory energy efficiency labeling, appliance standards, tax incentives, and DSM. Of course public leadership is used in combination with other policies that are applied to government-owned buildings. Energy efficiency quotas and cooperative procurements are unfamiliar in the US, but apparently enjoy success in Europe and Japan[85]. Naturally I am delighted to see mandatory energy labeling in the corner for the best policies, and voluntary energy labeling is nearby on the edge with a medium-to-high effectiveness rating.

The upper right-hand corner (the yellow zone) has only one policy instrument: capital subsidies. I rate this corner as fair—effectiveness of reductions is high, but they cost more than $25/ton. In the region between the yellow and green zones where costs lie between 0 and $25/ton and where effectiveness is high, we find the building energy codes and mandatory energy audits along with several policies not common in the US.

In the upper left-hand corner (the red zone) where costs are high and effectiveness low, we find only two policies: the carbon tax and the "Kyoto protocol flexible mechanisms." Curiously the cap-and-trade policy usually associated with the Kyoto protocol was noticeably absent from the referenced study.

The authors concluded[86]:

> This study did not identify any single policy instrument as the most effective or most cost-effective. Rather, it demonstrated that many of the policy tools can be effective when applied under the right economic, political and social conditions, and when certain criteria are respected during their design, implementation and enforcement. However, in the sample, appliance standards, building codes, tax exemptions or reductions as well as labelling, DSM programmes and energy efficiency obligations were revealed as being especially effective and cost-effective. …

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[85] Ibid, pp464-465.

[86] Ibid, p474.

> This study revealed significant research gaps in the evaluation of policies for GHG mitigation in buildings, especially in developing countries. Therefore, further comparative studies as well as evaluations of (new) policy instruments for mitigation options in buildings are needed in order to identify more solidly the most effective and most cost-effective instruments. It is also recommended that a few typical, often used, well matching combinations of instruments should be evaluated in several countries in order to capture better the synergistic effects and in order to be able to understand effective packages of policy tools.

Thus the study validates the proposition that building energy labeling like the BES scheme is an appropriate, effective, and cost-effective tool for transforming the market. The next section addresses how architects, engineers, and builders will need to adapt to meet the challenge.

6.2 Impacts on Architecture

Energy efficiency impacts architects, engineers, and builders, designs and buildings, and building inhabitants. Sustainable buildings offer an environment that people prefer. The daylighting and natural ventilation have reportedly increased the productivity and satisfaction of workers in buildings[87] while simultaneously reducing energy consumption. While these effects are still debated, there seems to be an opportunity for enhanced and unexpected benefits from these energy efficiency measures.

In addition clients are increasingly sensitive to the high operational costs of buildings. Ron Rioux of the Albuquerque Public Schools stated his perspective succinctly: “I want a life-cycle cost estimate for the building.” Historically architects, builders and clients have focused upon the first costs of construction and less frequently considered the options available for optimizing life-cycle costs. To shift the emphasis and to push the performance of buildings, architects, engineers, and builders are obliged to change.

This section introduces the principal changes that will impact the design and construction business. As team leaders and team members architects will work with others on the design teams in new ways to optimize design through an integrated design

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[87] Judith H. Heerwagen, “Green Buildings, Organizational Success, and Occupant Productivity,” *Building Research and Information,* Vol. 28 (5), 2000, pp353-367.

process that “frontloads” the design cycle with an iterative multidisciplinary evolution of a solution. Architects, engineers, and builders must be fluent with the materials that enable the construction of energy efficient buildings and the energy infrastructure—both as they exist today and as they evolve to achieve higher performance in the future. And finally architects become educators that inform clients of the economics of energy efficiency and become advocates for policies that promote energy efficiency.

6.2.1 Integrated design process

For high performance buildings architects will need to work as team members to conceive of a design and to process it through multiple iterations that steadily improve the design. While this concept may not seem revolutionary, it demands a higher intensity effort early while concepts are malleable and changes are cheap. This integrated design process (IDP) is the subject of considerable recent interest to researchers, governments, and firms[88]. The American Institute of Architecture (AIA) is promoting the identical concept under the name Integrated Project Delivery (IPD).

IDP is necessarily a multidisciplinary effort involving the architect and all the consultants and is often mediated by the owner or the owner’s representative. For example, suppose in a brainstorming design charette the architect suggests that the addition of light shelves on the south side could reduce the need for artificial light by 40% and reduce the solar gain. The mechanical engineer notes that the reduced heat load will reduce the cooling requirements in the building such that the cooling units could be downsized. Similarly the electrical engineer observes that the reduction in power will result in a smaller transformer. Both of these changes enable the architect to reduce the floor space allocated to mechanical and electrical equipment.

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[88] Integrated Project Delivery: A Guide, American Institute of Architecture, 2007, p 3.

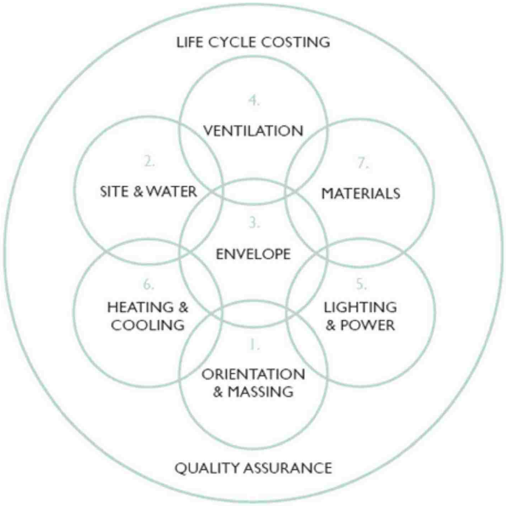

Figure 35. Model of the technology areas for the integrated design process for buildings. Ref: Bunting Coady - Integrated Design Process - Energy Efficient Development http://www.buntingcoady.com/integrated-design.html, Sept 21, 2009.

This simplified example illustrates the complex coupling that exists in building design. Figure 35 and Figure 36 make an effort to capture this complexity diagrammatically but fall short. In reality each technology and each driver interacts with all of the other technologies and other drivers as well as the building—not just its neighbors as shown in this sketch. In an unoptimized conventional process the design from the architect with owner approval would over-allocate space in mechanical rooms and in overhead "voids." Likewise the mechanical engineers would oversize HVAC equipment to provide a performance margin for unforeseen loads. The sequential process would continue through the various technical consultants with each padding estimates for the requirements of the others so as to eliminate the chance for any adverse interactions.

IDP seeks interaction—especially early in the project. The fundamental principle of IDP responds to the complexity of the building project by using a front-loaded process. This is accomplished by bringing together the multiple perspectives of Figure 35 at the outset to collaboratively define goals and make the initial decisions that guide the course for the duration of the project. This multi-disciplinary approach shares a common toolset based on building information modeling (BIM).

Figure 36. Model of the drivers for the integrated design process for buildings. Ref: Whole Building Design | Whole Building Design Guide http://www.wbdg.org/wbdg_approach.php, Sept 21, 2009.

With early collaboration, IDP begins to evolve as an ecological process where multiple forces, as shown in Figure 36, simultaneously influence development. "[I]t has been proven that, by doing so, the process is more effective and the solutions are more efficient. The integrated design process was developed in conjunction with the green architecture movement, and many practitioners insist that an effective green building cannot be created without it."[89]

In professional practice, IDP does not end with construction. Operators, occupants, tenants, owners, and facilities managers need training to understand how every interrelated optimization behaves. Tenant and operator manuals document this understanding and improve the likelihood of a successfully integrated and efficient building. But the proof is the commissioning that verifies a healthy and functioning building and is the mechanism that confirms the design intent is met.[90]

IDP collaborations give rise to new legal considerations. Since project participants share in the success or failure of the overall venture, IDP arrangements are more likely to be classified as joint ventures than the independent contractor arrangements typically encountered under traditional models. A unique risk feature of joint ventures is the joint liability of all joint parties. Therefore, if all major IDP participants are considered joint venturers, they may be liable to third parties for the failings of their joint venture partners. For example, the construction team might well bear the risk of design error and the design team could be at risk for construction errors. Should a building fail to achieve its designed energy efficiency or labeling score, which party is at fault when the calculations can be verified to be correct and the building passed all of it inspections? This risk can be managed through careful planning (e.g., appropriate insurance products and structuring the legal relationships between the parties) and contract drafting[91].

6.2.2 Performance strategies for today

The mitigations and strategies for energy efficiency that architects, engineers, and builders will need to employ are scattered throughout this thesis as various labeling programs were introduced and discussed. Clearly the same technologies apply to both

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[89] Lisa Hiserodt, "The Integrated Design Process Is Demystified," *Boston Woman's Business*, V9, I8, May 2008.

[90] Marian Keeler, Bill Burke, *Fundamentals of Integrated Design for Sustainable Building*, John Wiley & Sons, May 2009, p5.

[91] Op cit, AIA, p18.

new construction and refurbishments—the implementations differ. We are reminded that it is best to build it right the first time and that some technologies may be impossible to retrofit into existing buildings. Nevertheless life-cycle savings argue in favor of remediating poor design and construction—even in the face of significant costs.

So in this section I will discuss the performance strategies that architects and engineers should implement to achieve a high-performance building with every new design and in the existing building inventory as well. I will analyze these strategies from two very different viewpoints and establish that they reach a consensus.

The first perspective is offered by McKinsey & Company—a international management consulting firm with expertise and research capabilities available to the world's leading businesses, governments, and institutions. As expected for a global think-tank, the McKinsey viewpoint is "top-down" and analyzes the potential for saving on a national level. In this study the focus is on opportunities for cost savings in "stationary" applications only—no transportation but exclusively buildings, all buildings old and new, commercial and residential.

In their report, *Unlocking Energy Efficiency in the U.S. Economy,*[92] McKinsey considers the usual market segments: residential, commercial, and industrial. The analysis modeled the deployment of 675 energy-savings measures and their life-cycle costs through 2020. Those that produced a net present value (NPV) savings were further analyzed by grouping similar or related energy efficiency measures together. NPV is a well-defined term from economics that values all cash flows both present and future and factors in the time-value of money. Savings are measured as the difference between the NPV for the scenario with the energy-saving measure minus the NPV for the status quo.

Figure 37 shows the groupings of measures that save money. The width of each column measures the amount of *energy* saved and the height measures the cost saved per unit of energy. Therefore the area of each column represents the cost savings—the expense saved for that bundle of energy-efficiency measures. Columns are also color coded per the key at the top of the graph for residential, commercial, or industrial.

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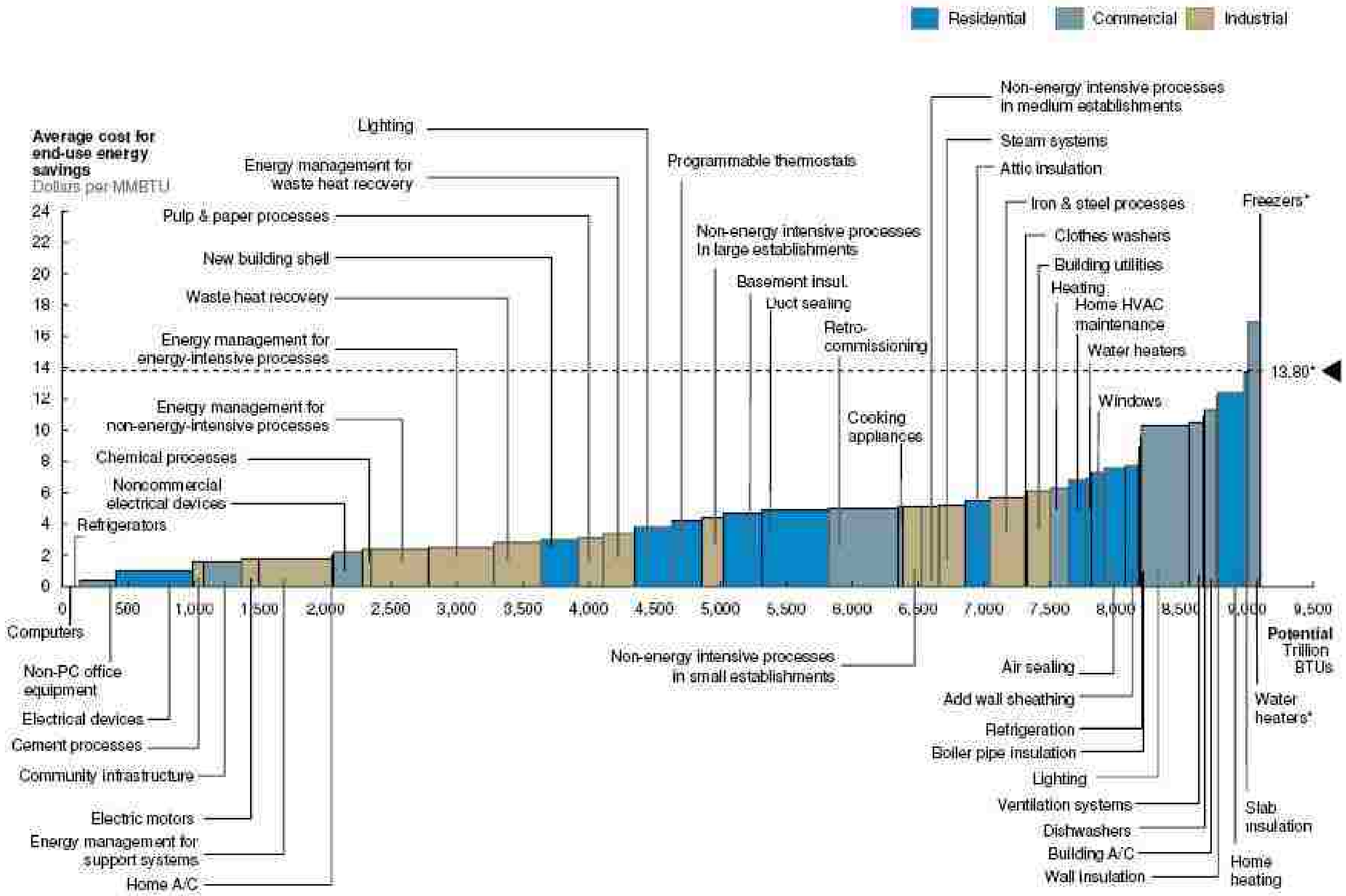
[92] Op cit, Hannah Granade, p15.



* Average price of avoided energy consumption at the industrial price; $35.60/MMBTU represents the highest regional electricity price used; new build cost based on AEO 2008 future construction costs

Source: EIA AEO 2008, McKinsey analysis

Figure 37. US energy efficiency supply curve in 2020 from McKinsey. The width of each column represents the amount of efficiency potential (in trillion BTUs) found in that group of measures, as modeled in reference 92. The height of each column corresponds to the average annualized avoided cost (savings potential in dollars per million BTUs) of that group of measures.

All the measures in Figure 37 actually save money between now and 2020 when compared to the costs incurred by taking no efficiency measures. Those efficiency measures that analysis found to actually increase costs are not shown. The fact that these cost-effective energy-savings measures have not been widely implemented says interesting things about the barriers and market failures in place today. The BES initiative seeks to inform and motivate owners to consider this remediation. Other polices will also play roles as we seek to exploit such potential.

The second viewpoint is advanced by the Keystone Home Builders Association (HBA) for Bucks and Montgomery Counties in suburban Philadelphia as they focus more narrowly on the construction of high-performance new homes. I argue that this view represents a pragmatic "bottom-up" view represented by community businesses responding to environmental sustainability issues and customer demands. These builders have hands-on experience with the different construction techniques.

Their *Keystone Green Building Initiative: User's Guide* covers recommendations and scoring for sustainability features that the HBA seeks to encourage. The guide is comprehensive and addresses the gamut of techniques from energy efficiency to indoor air quality to water conservation. For the purposes of my thesis, I list in the left-hand column of Table 20 only their energy efficiency measures. A few strategies (daylighting, fenestration, renewable energy generation) offer architects an opportunity for aesthetic expression, but the majority simply forms the technical foundation, the bedrock, for constructing energy efficient buildings. Normally unseen, building energy labeling offers the design team the opportunity to make these important features "visible" to the public.

Table 20. Energy efficiency measures for Keystone left[93] and McKinsey top. “X” marks overlaps.

McKinsey efficiency measure→ **Keystone efficiency measure**	electrical devices	lighting	programmable thermostats	basement insulation	duct sealing	attic insulation	home HVAC maintenance	water heaters	windows	air sealing	wall sheathing	home heating	slab insulation
Increase effective R-value by reducing thermal bypass				X		X					X		X
Incorporate air sealing package to improve envelope										X			
Energy Star rated windows									X				
HVAC Duct system tightness ≤ 6.0 CFM per 100 ft^2 of floor area when pressurized to 25 Pa					X								
HVAC Duct system tightness (use mastic or foil tape)					X								
HVAC Ductwork not installed in exterior envelope surfaces					X								
Install return ducts, jump ducts and/or transfer grilles in every room having a door except baths, kitchens, closets, pantry, laundry room					X								
HVAC duct air quality and performance					X								
Install Energy Star labeled programmable thermostats			X										
Install Geothermal (GHP)												X	
Energy Star rated heating and cooling equipment												X	
Environmentally friendly refrigerants													
Water Heating								X					
Install Tankless Hot Water Heater(s)								X					
Insulate all exposed hot water lines								X					
Install manifold plumbing system								X					
Install On-demand hot water recirculation pump system								X					
Daylighting		X											
Install Energy Star Advanced Lighting Package (ALP)		X											
Install Energy Star appliances	X												
Renewable Energy													
Renewable Electricity Generation													
Alternative Technologies													

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[93] *Keystone Green Building Initiative: User’s Guide*, Home Builders Association of Bucks/Montgomery Counties, May 22, 2008, p32-41.

Continuing the discussion of measures that architects, engineers, and builders can take to increase building energy efficiency, it is worthwhile to note that “bottom-up” and “top-down” views are in excellent agreement. Since the Keystone HBA assesses only residential construction, I list along the top of Table 20 all the residential measures shown in Figure 37 working from right to left. Where Keystone measures (rows) intersect McKinsey measures (columns), I place an “X” in the table to accentuate the connection. Generally one or more Keystone measures will link to the one McKinsey measure, which is consistent with the Keystone list being somewhat longer. Since the Keystone measures refer to the “thermal bypass checklist” (TBC), this insulation measure from the Keystone list actually links to several insulation measures considered separately in the McKinsey list.

Inspection of Table 20 reveals that some Keystone measures have no corresponding McKinsey measures and vice versa. The four unmatched measures on the Keystone list are environmentally friendly refrigerants, renewable energy, renewable electricity generation, and alternative technologies. The first measure appears aimed more toward the prevention of damage to the environment, and is considered out of place for the efficiency-measures list. Both the second and third measures pertain to alternate energy sources—not conservation, so they too are out of place. Finally “alternative technologies” is a wildcard and unspecified. The McKinsey measures were grouped into bundles of similar measures and no wildcards were considered. In summary, substantive measures in the Keystone list all have corresponding measures in the McKinsey list.

Only one measure in the McKinsey list finds no corresponding member in the Keystone measures—home HVAC maintenance. This can easily be understood since the Keystone measures are limited to new construction, and maintenance belongs to post-occupancy operations appropriate for the McKinsey study of new and existing buildings.

So we find the same issues and their corresponding solutions facing architects, engineers, and builders whether they are working with new buildings or refurbishing existing stock—and whether residential or commercial. While the physical laws governing heat transfer do not distinguish between the applications, the details of the solutions exhibit very application-specific dependencies. Thus architects, engineers, and builders are assured a challenge as they solve these energy problems common to buildings in general and negotiate a path through conflicting requirements, codes, and ever increasing demands for efficiency.

6.2.3 Performance strategies for tomorrow

The previous section presented the energy efficiency measures that architects, engineers, and builders must address fluently to design and construct high-performance buildings using the technologies that exist today. Since most energy labeling schemes like the BES system want to lock the top end of the scale to a net zero energy building (NZEB), design professionals must be asking: What strategies and technologies are required to get there? Understanding the answer to this question will provide insight into the tool set necessary to advance with the times.

In its feasibility study for NZEBs published in 2007, the NREL considered how the existing commercial inventory might respond to remediation efforts by 2025. The study is interesting not only in understanding how far one can push efficiency measures, but also what technologies will be necessary to implement the measures.

While not reaching the lofty goal of net zero energy for the entire existing commercial inventory, 62% of buildings could reach net zero. Calculated according to floor area, rather than by number of buildings, 47% of commercial building floor area could achieve NZEB status. The corresponding reduction in energy consumption from 90 kBTU/ft^2/yr (CBECS 2003 data for existing buildings) to 12 kBTU/ft^2/yr on average (the Max Tech scenario with PV) is impressive, an 86% savings (see Figure 38). Note that achieving the NZEB goal on a given building project depends largely on four characteristics: (1) number of stories; (2) plug and process loads; (3) principal building activity (PBA); and (4) location[94]. Single-story buildings are the most likely to achieve net zero energy consumption. According to 2003 CBECS, 40% of the nation’s commercial buildings are single story and, of these, 85% could reach the NZEB goal by 2025. Here building geometry assumes a critical role since the relatively larger roof area

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[94] B. Griffith, N. Long, P. Torcellini, R. Judkoff, D. Crawley, J. Ryan, *Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector*, Technical Report NREL/TP-550-41957, December 2007, p xii.

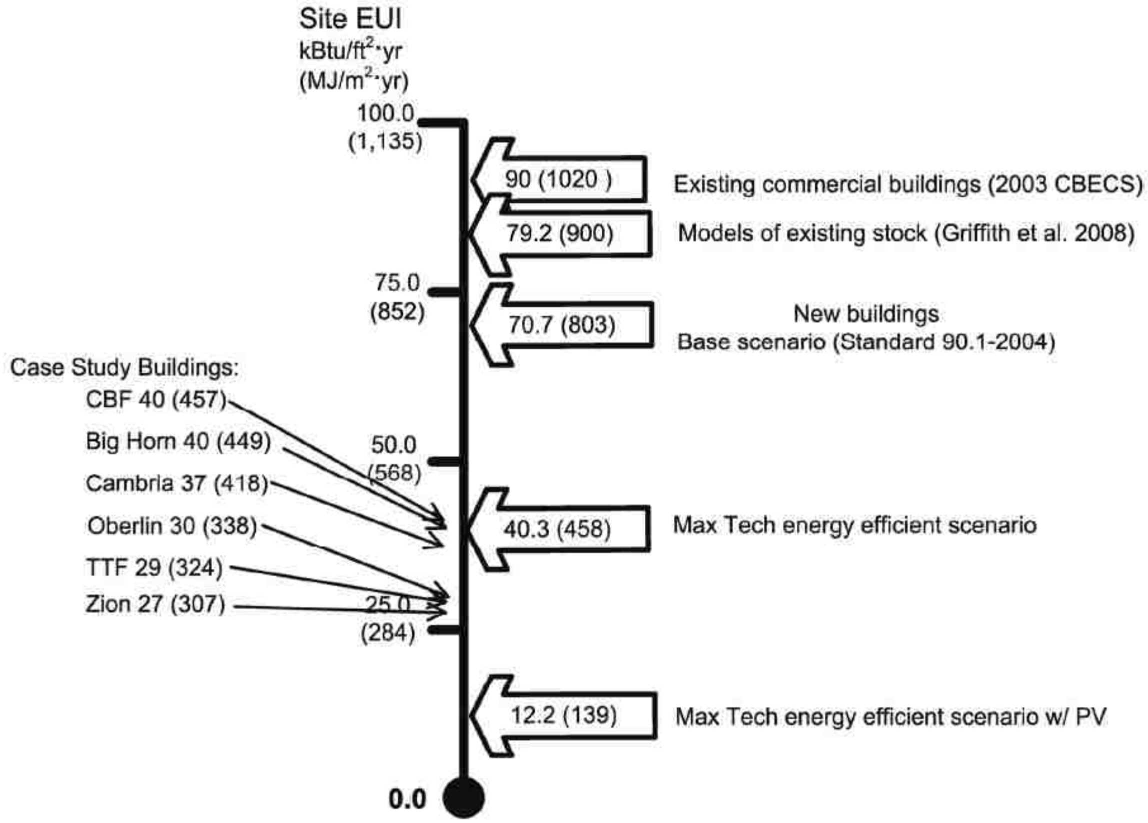

Figure 38. Average results for EUI for current stock, minimum standard, and Max Tech.

compared with building volume is favorable for the installation of photovoltaic (PV) systems necessary to achieve NZEB performance. Buildings with lower plug and process loads (for appliances, office equipment, computers, and other electrical and gas equipment) are also better able to achieve net zero energy.

The technology changes for the buildings themselves require no “break through” discoveries, but are simply the result of continual improvements. To illustrate the anticipated performance changes, I include in Table 21 lists of parameters used in the simulations for building shells, windows, and lighting/daylighting. The fact that six case studies (see Figure 38) already perform at the Max Tech level today suggests that the goal is not a stretch beyond reach.

Table 21. Net zero energy building parameters for opaque envelope, fenestration, and light power density (LPD)[95].

Opaque Envelope Maximum Assembly U-Factors by Climate Zone: Mass Walls above Grade

Climate Zones	Baseline Btu/h/ft^2/°F (W/m^2/°K)	Standard 189P Btu/h/ft^2/°F (W/m^2/°K)
1A, 1B	0.580 (3.29)	0.151 (0.86)
2A, 2B	0.580 (3.29)	0.123 (0.70)
3A, 3B, 3C	0.151 (0.86)	0.104 (0.59)
4A, 4B, 4C	0.151 (0.86)	0.090 (0.51)
5A, 5B, 5C	0.123 (0.70)	0.080 (0.45)
6A, 6B	0.104 (0.59)	0.071 (0.40)
7	0.090 (0.51)	0.060 (0.34)
8	0.080 (0.45)	0.060 (0.34)

Fenestration Maximum Assembly U-Factors by Climate Zone: Fixed Vertical Glazing 0% to 10% of Wall

Climate Zones	Baseline Btu/h/ft^2/°F (W/m^2/°K)	Standard 189P Metal Frame Btu/h/ft^2/°F (W/m^2/°K)
1A, 1B	1.22 (6.93)	1.20 (6.81)
2A, 2B	1.22 (6.93)	0.75 (4.26)
3A, 3B	0.57 (3.24)	0.55 (3.12)
3C	1.22 (6.93)	0.55 (3.12)
4A, 4B, 4C	0.57 (3.24)	0.45 (2.56)
5A, 5B, 5C	0.57 (3.24)	0.45 (2.56)
6A, 6B	0.57 (3.24)	0.45 (2.56)
7	0.57 (3.24)	0.35 (1.99)
8	0.46 (2.61)	0.35 (1.99)

LPDs by PBA for Various Scenarios: IP Units

Principle business activity	Existing (W/ft2)	Baseline (W/ft2)	Draft Standard 189P (–15%) (W/ft2)	Max Tech 20% LPD (–20%) (W/ft2)	Max Tech (–50%) (W/ft2)
Vacant	2.1	1.02	0.87	0.82	0.51
Office/professional	1.8	1.02	0.87	0.82	0.51
Laboratory	1.7	1.39	1.18	1.11	0.70
Nonrefrigerated warehouse	1.4	0.84	0.71	0.67	0.42
Food sales	1.9	1.49	1.27	1.19	0.74
Public order/safety	1.3	1.02	0.87	0.82	0.51
Healthcare (outpatient)	1.7	1.02	0.87	0.82	0.51
Refrigerated warehouse	1.4	0.84	0.71	0.67	0.42
Religious worship	1.4	1.30	1.11	1.04	0.65
Public assembly	1.4	1.21	1.03	0.97	0.60
Education	1.8	1.21	1.03	0.97	0.60
Food service	1.6	1.39	1.18	1.11	0.70
Healthcare (inpatient)	1.7	1.21	1.03	0.97	0.60
Skilled nursing	1.3	1.02	0.87	0.82	0.51
Lodging	1.3	1.02	0.87	0.82	0.51
Strip shopping	1.9	1.49	1.27	1.19	0.74
Service (excluding food)	1.7	1.39	1.18	1.11	0.70
Other	1.7	1.02	0.87	0.82	0.51

Note the "Max Tech" scenario intends no connotation that some technology limit has been reached. Rather it denotes that in the NREL study it is the most aggressive technology alternative. Standard 189P refers to ASHRAE's proposed sustainability

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[95] Ibid, p15-24.

standard. The allowable infiltration rates for 189P and Max Tech scenarios are one half and one quarter the baseline rates[96].

While the results of the NREL study deserve consideration, our attention is focused on the measures architects, engineers, and builders will need to implement NZEBs. How are these techniques different from those in use today? In the next 15 years buildings will be dramatically reshaped by combining the results of research and product development in a variety of fields—energy-efficient building shells; HVAC equipment; lighting; daylighting; windows; passive and active solar; PV power systems; fuel cells; advanced sensors and controls; and combined heating, cooling, and power. Such technologies combined with IDP will produce NZEBs.

Passive assessment. As discussed in Section 6.2.1, IDP will result in the iterative analysis of the design—especially in the early in the life of the project. The architects on the multi-disciplinary team should ensure that the passive performance of the design is excellent. If the passive building does not perform well without assistance from active systems, then the design simply can not be energy efficient. At a minimum the "un-conditioned" building should maintain safe conditions for human occupancy even though the environment inside might be uncomfortable. The closer the passive building approaches levels considered comfortable in the absence of HVAC systems, the better will be the energy performance of the powered building.

When speaking of the passive building, I mean that the environmental controls include no active systems. The building should include the loads from human occupancy and plug loads since such thermal loads are inseparable from the function and design of the building. Indeed such features in a mass dominated building may obviate the need for any heating systems in some climates. Thus to adopt some unrealistic thermal load profile for design or design assessment is to introduce a significant distortion in the design problem actually confronting the IDP team.

The passive rating scheme developed with this thesis and documented in Appendix B appears to be a useful tool in such an assessment. Although it requires that

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[96] Ibid, p23.

architects develop sufficient skills to run thermal energy simulations, it obviates the need to deal with the complexities of HVAC systems. The model of the building envelope need only be primitive for thermal calculations and thus may be rapidly modified to accommodate the inevitable changes that result from the investigations of the design team.

My experience with EnergyPlus suggests that it is a viable tool for this passive thermal performance assessment and one the engineers on the design team would also appreciate. While the program has the flexibility to tackle a spectrum of difficult problems, once the architect becomes familiar with a prototype template, modifications and variations should not prove too difficult. Although I did not investigate other simulation options, commercial packages come with helpful visual interfaces that could lower the barrier for acquisition of this new skill, but license fees can be substantial.

Returning to product developments, perhaps the largest technology stretch assumed in the NREL study of NZEBs was the wide use of dynamic fenestration, glass with opacities controlled electronically, and PV systems. The NREL authors did not speculate about the impact of advanced efficient lighting such as light emitting diodes or semiconductor light panels. Since changes in the electrical power infrastructure are tangential to the feasibility of the NZEBs, these topics were also ignored. These materials and infrastructure elements, which impact the designs and construction of energy efficient buildings in the next 20 years, are briefly discussed here for completeness.

Dynamic fenestration. In the pursuit of dynamic fenestration to support the implementation of NZEBs, researchers at the Lawrence Berkeley National Laboratory (LBNL) developed a prototype window[97] in 2006 as shown in Figure 39. To reach U factors significantly below 0.3 BTU/h/ft^2/F, the prototype abandoned the conventional low-e, gas filled double glazed system. To achieve an affordable window, one that could be built with existing industry manufacturing capacity, the researchers selected a three-layer window system with commercially available low-e technology and krypton gas fill, and avoided vacuum glazing and aerogels. A rigid center plastic layer was added as a

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[97] Zero Energy Window Prototype: High Performance Window of the Future, LBNL, http://windows.lbl.gov/adv_Sys/hi_R_insert/ZeroEnergyWindowDOE-FactSheet.pdf, Oct 17, 2009.

low-cost convection barrier, and a wood/fiberglass combination frame was used. Finally, the dynamic solar control (and second low-e layer) was provided using Sage Glass® electrochromic glazing as the outboard film. It consists of multiple metal oxide coatings on glass. This prototype is already a zero energy window in many U.S. climates and demonstrates the feasibility of reaching the ultimate goal of being a zero energy window in all US climates.

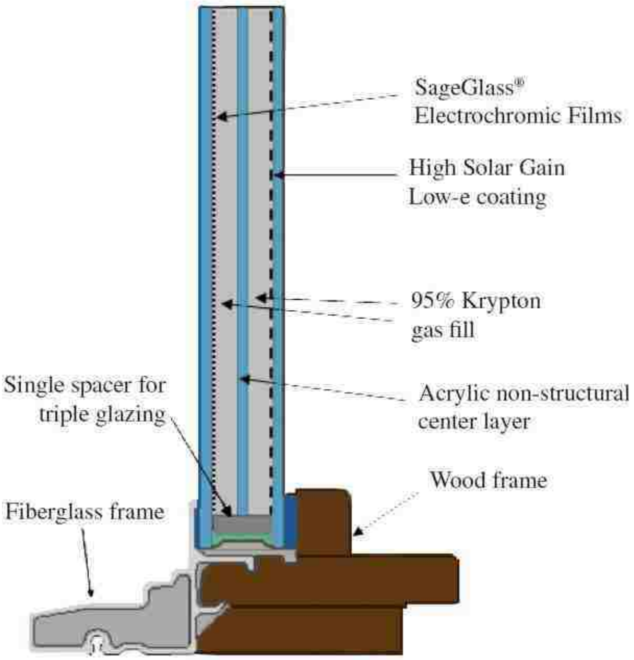


Figure 39. LBNL prototype of dynamic fenestration.

As modeled in the NREL study, the dynamic glass assumed properties only slightly better than those achieved in the LBNL prototype as comparisons show in Table 22. Consequently, such dynamic fenestration appears very credible.

Table 22. Measured properties of the LBNL prototype window.

Property	Center-of-Glass	Whole Window	NZEB assumption
U-factor (Btu/h-ft2-F)	0.12 (R 8.3)	0.18 (R 5.6)	
SHGC	> 0.05 and < 0.36	> 0.04 and < 0.34	> 0.058 and < 0.40
Visible Transmittance	> 0.03 and < 0.56	> 0.01 and < 0.49	> 0.02 and < 0.65

Photovoltaic systems. Currently available multi-crystalline PV products already reach 20% efficiency (see Figure 40), so the Max Tech scenario for the NREL study assumed low-cost, amorphous PV products with 20% efficiency for 2025. The data shown represent the best performance for optimized laboratory tests, so the efficiency of production panels would be expected to lag behind. Nevertheless, the slope of the efficiency development curve in Figure 40 suggests this goal is feasible.

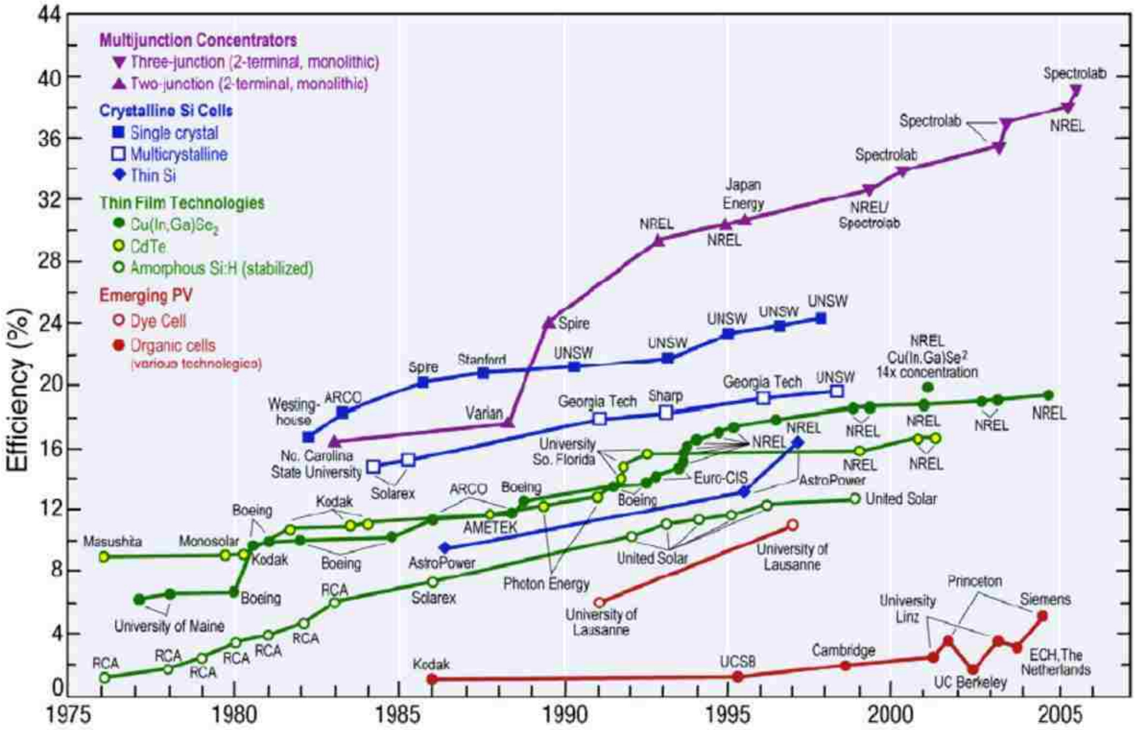
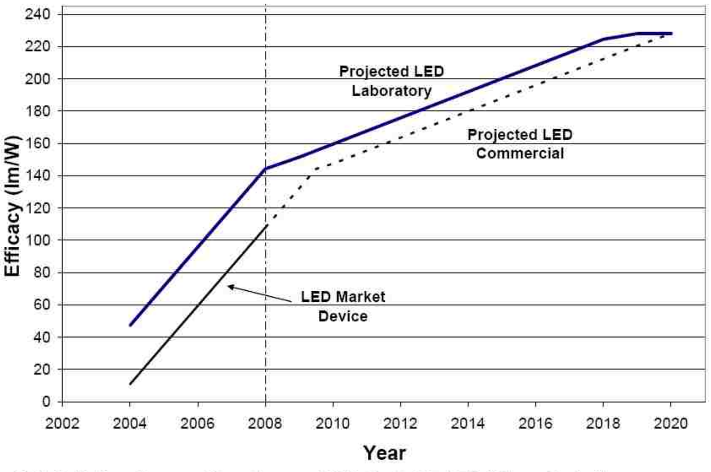


Figure 40. The history for the efficiency of photovoltaic developments by technology. Source: http://www.rpi.edu/dept/phys/Courses/PHYS1010/Persans.pdf, Mar 2008.

The PV system for the Max Tech scenario in the NREL study was sized to cover 50% of the roof and included an inverter with an efficiency of 95%. There was no electrical storage, and any excess power was returned to the grid.

Advanced lighting. During the next 15 years energy efficient lighting will make significant advances. Even today light emitting diode (LED) products are appearing on store shelves. The DOE forecasts that the light efficacy (lumens/W) will markedly improve[98] in that time as



SSL Multi-Year Program Plan - January, 2008. Cool white LED Efficacy Projection

Figure 41. LED efficacy trends. For comparison the efficacy of compact fluorescent lamps (CFL) and T8 tubes is shown.

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[98] James R. Brodrick, DOE SSL Research & Development Program Update, DOE, January 30, 2008. p4.

shown in Figure 41. The impact of dropping power requirements a factor of two is huge, especially for commercial buildings. However, this potential efficiency gain was not included in the NREL study.

Smart grids. Although not mentioned in the NZEB study, architects are going to need to know how to use smart grids. Grid operators must know what power is being supplied by the NZEBs moment by moment since it is subject to intermittent change. If a bank of clouds rolls into the region, there will be a significant drop in power production from these buildings, and some other source will need to be added to the grid or some loads dropped. The algorithms for these contingencies will be well defined in advance and building operators will have agreements with utilities as regards what loads they can shed on short notice, intermediate notice, and by other arrangement.

TDV adaption. Just as buildings adapt to fluctuations in the renewable energy supplies, the buildings may choose to adapt to time-dependent price variations in the energy supplied from the utility. While the adaption can be as simple as the load shedding described in the paragraph above, it can be far more complex perhaps with the introduction of thermal storage systems for both heating and cooling capacity that only operate when the power is cheap.

Sub-metering. In the absence of information there will be no way to troubleshoot unexpected energy performance in buildings. Consequently architects will want to design more diagnostics into buildings, and the easiest diagnostics quantify electricity consumption. We need to know where the power goes. Are building occupants installing 1500-W heaters under every desk in the office because the HVAC system is maladjusted? This sub-metering is intended to enable the building operations manager to see the power consumption for different end uses. In multi-tenant building the sub-meters could also be used to equitably allocate the costs to the parties using the power. Metering with timely energy consumption information is also essential to enable consumers to develop more responsible energy-use behaviors.

Power factor. Architects should be aware that as electrical innovations enter the market, they may not all be equivalent for an optimized power generation, power distribution, and end-user application. It is important to the overall efficiency of the power system that electrical devices have high power factors. Failure here results in the operation of what is really excess generation capacity similar to that required to meet peak capacity. Technically it differs since the generators must be operating, but power is flowing back and forth between the generators and the “reactive” (not simple resistive) loads.

This effect limits efficiency in two ways: extra currents in the transmission system incur line losses and extra hardware is required. Line losses directly impact efficiency. Therefore the hardware must be designed for higher peak currents than would otherwise be necessary and peak power generation capacity must also be higher. To meet these requirements the power companies must increase their capital investments over what would otherwise be required. Therefore paying attention to the power factor can reduce the number of power plants in operation and save the waste associated with their attendant inefficiencies.

An example will clarify the significance of the power factor. The use of compact fluorescent lamps (CFL) is encouraged since they are far more energy efficient than incandescent bulbs. True, but they typically have poor power factors due to the cost of a high-performance miniaturized “ballast” or high voltage power supply to drive the lamp. For applications where T8 and T5 tubes are used, the fixtures are larger so the ballasts can be larger, more sophisticated, and reused again after bulb replacement. In CFLs the space for the power supply is limited and it will be thrown away when the lamp is dead. Therefore the power supplies tend to be cheap, disposable, and less efficient than the ideal.

When issuing specifications, architects should always be alert for the chance to optimize the overall system. For this case, attention to the power factor for all electrical devices is essential.

Labeling of materials. With more information, design decisions are possible where today we simply build with conservative margins. Material labels could reveal the embodied energy content in all the components that we could design into our buildings. At the discretion of the owner with the recommendation of the architect, the buildings could be designed to minimize this energy content. Furthermore the labels can ensure that the design of the building avoids volatile organic compounds that have been linked to "sick" buildings and unhealthy building occupants.

The more information we have, the better decisions we can make. While the complexity of building design and operation increases, we have the opportunity to optimize whereas before we were ignorant. The number of ways we can optimize the building simply continues to increase—energy consumption with a push from BES ratings, water consumption, lighting, smart power utilization, indoor air quality, cost, functional utility, emissions, etc, and aesthetics.

Aesthetics. Unlike the previous technologies, this characteristic is technology agnostic. In the extreme, aesthetics may critically depend on technology or completely ignore it. It really does not matter. Aesthetics are essential to architecture. Although aesthetics depend upon the eye of the beholder, there are many trained eyes that tend to perceive similar visions. Without labeling, energy efficiency may be invisible—even to the trained eyes. As architects concerned with aesthetics and sustainability, we seek to increase the visibility of energy efficiency with the BES ratings and through training even to expand aesthetics to include a glimpse of the energy efficiency label—at least figuratively if not literally.

In summary the skills for the technologies expected in net zero energy buildings are rational extensions of those used today. With continuing education the transition will be straightforward for architects, engineers, and builders.

6.2.4 Architect's role as student

The previous sections make the point that there is much to learn to adapt to the changes necessary to meet the challenges of energy efficiency in buildings. Firms and sole proprietors will need to allocate time and resources to continuing education. While this is not a new feature for the profession, it may have a quantitative aspect that suggests the rigor of engineering that feels unfamiliar and possibly uncomfortable. If so, be sure to engage design team members with these skills whether they are architects or consulting engineers. Today's BES labeling will be tomorrow's building energy code so change and its associated education requirement is inevitable.

Mid-sized and large firms may find it appropriate to establish a formal research capability whether it is simply part of one person's responsibilities or possibly a small team. Their research would be strictly secondary—they would follow developments in the literature and successes enjoyed by other firms. In turn they would pass along the lessons learned to other members of the firm thus facilitating the learning process. In addition to new information, these lessons could include instructions on the use of new tools. For example BIM will be essential to successful multi-disciplinary teams and the use of BIM tools will require a significant investment in education.

The outlook for NZEBs in 2030 points toward performance assessments for buildings rather than the simpler prescriptive procedures. Whole building design will push the profession toward broader understanding of interrelated systems and whole building simulations. Design team members will not be able to exclusively focus on their special competency.

6.2.5 Architect's role as educator

Buildings are high-cost items, and routinely owners are seeking opportunities to cut cost without compromising quality in design or construction. Architects should resist any owner pressure to decrease the first costs by eliminating systems that will jeopardize the building energy efficiency. It is critical that the architect explain the impact of life-cycle costs with *today's* energy prices. The payback period only gets shorter in the future as resources are depleted and the externalities (indirect societal costs) are included in the price of fossil fuels. Architects must know the economic ramifications of operation for their buildings and advocate that owners seek to certify and label these buildings as part of the design, construction, commissioning, and operation process. Architects must know the asset value of building energy efficiency and be able to connect that value to building energy labeling with BES.

In some circumstances, architects may need to engage in a bit of social marketing. Architects know that sustainable design is essential today on planet Earth. Failure to change the way we design and build risks the future of mankind through climate change and resource depletion. Since not every client will subscribe to this ideology, a touch of social marketing in the pursuit of sustainability may be appropriate with such clients.

There is no need to convert their attitudes and beliefs about the environment, but rather stress how the end goal of increased conservation is totally compatible with the end goal of reducing life-cycle costs in buildings. Owners are interested in economic arguments that impact the bottom line favorably.

Furthermore, architects should play a role in educating owners about the asset value of image. Building energy labeling offers an owner the possibility to differentiate his building from others in the market. If the building includes rental space, then labeling offers information on building performance to prospective tenants that is otherwise difficult to ascertain. The public image of an efficient building may also resonate with owner's clientele as the public becomes more aware of the impact buildings have upon resource depletion and climate change.

6.2.6 Architect's role as advocate

Architects need to stay knowledgeable of the economic environment in which they do business. For example the electrical power industry is a key partner for the viability of all of our buildings. Even in a world full of NZEBs, the utilities will be supplying backup power for most buildings and architects should ensure that this symbiotic relationship between buildings and power is sustained through policies that enable utilities to derive profits in a highly regulated business where continuous growth is not an option.

Architects are major stakeholders in the renewable energy business. For sustainable buildings we seek to install significant renewable energy in most of our buildings, and not all of it will be consumed within the building at every moment. We need the electrical grid to absorb this power and distribute it to other users. Since this intermittent source of power is tricky for the grid to predict and handle, we need smart grids that enable control of sources and sinks in end-user applications.

These key energy-related issues demand that architects remain informed of such problems and opportunities and take active roles in advocating sensible policy changes. At its worst, it is self serving—sustaining our design and construction business, and at its best, it serves the public and creates jobs.

7 Conclusions

This thesis has examined our energy predicament and policy options to identify opportunities to directly improve energy efficiency in buildings, especially commercial buildings, and thereby indirectly to extend the lifetime of limited natural resources, to reduce the threat of climate change, and to actually save money thereby stimulating the economy and creating jobs. Conservation of energy appears the best opportunity especially in the near-term.

Analysis of the end-use of energy reveals that our building sector consumes approximately half the energy used in the US for its construction and operation. Since over the past three decades the commercial inventory has failed to keep pace with the energy efficiency improvements realized in the residential and industrial sectors, I see commercial buildings as a strategic target of opportunity for enhanced efficiency.

Governments, nonprofits, and various building organizations have all promoted energy efficiency programs and policies and many have enjoyed success. Yet there remains a persistent failure to transform the commercial building sector due to market barriers and malfunctions that demands renewed attention from those who can see the possibilities for economic savings and concurrent environmental savings. Thus our dilemma requires political action, but what policies would be most effective in promoting energy efficiency in commercial buildings?

After significant reading, the topic of building energy labeling emerged as the appropriate policy to ensure movement toward the goal of designing and constructing net zero energy buildings. It seemed well focused and manageable at the outset of my investigation six months ago. However, its tentacles reached into crevices I had not imagined, and the volume of research exceeded what I expected. While the thesis covers the gamut of these related topics, I now summarize the insights gained through this work that can guide architects, engineers, builders, and others who seek to design and construct high-performance energy conserving commercial buildings. My recommendations for immediate action include:

Recommendation 1: Implement a nationwide building energy label that emphasizes building energy savings (BES) beyond code requirements and clearly measures progress toward the goal of net zero energy consumption for buildings. The BES labeling defined in this thesis does precisely that and leads the way toward more stringent building energy codes. While it is desirable that the program be mandatory, initially political forces may limit it to a voluntary program. Either would be an improvement from the current information vacuum as regards buildings. Once owners, tenants, realtors, architects, and builders learn that building energy performance needs to be documented, market forces will provide the incentives to design and construct high-performance sustainable buildings and to label them as special—they are differentiated as energy efficient buildings. The benefit is threefold: through reduced consumption we extend the life of our limited natural resources; through reduced consumption we reduce our emission of greenhouse gases and thus reduce the threat of climate change; and through reduced consumption we save enough money to pay for refurbishment of existing buildings and energy efficiency enhancements built into new designs.

Recommendation 2: Train architects, engineers, and contractors to participate in the integrated design process. The optimum efficiency gains will not be fully realized unless a multidisciplinary team jointly works on the design challenge. There can be no vision of an integrated solution without the diversity of expertise early in the design process. Such teams should measure the efficacy of their designs with the proposed BES rating during design and post occupancy.

Recommendation 3: Train architects to evaluate preliminary design concepts for passive energy efficiency. Using conceptual models without excessive details, thermal energy simulation tools such as EnergyPlus can estimate comfort levels throughout a building with no HVAC system early in the design process. Such passive energy assessment is well suited to the iterations of the integrated design process and leads to higher BES ratings. The same simulation model can be extended during the design cycle as further elaboration becomes appropriate.

Recommendation 4: Design sub-metering into buildings. Modern buildings are complex products, and diagnostic capability is essential. At a minimum, lighting, branch circuits for plug loads, and major HVAC components should be separately monitored with a data acquisition system. Data can then be compared with estimates from simulations performed during design and the calculations for the BES rating.

Recommendation 5: Fund continued research and development contributing to enhanced building energy efficiency. We seek commodity pricing for high-performance fenestration for buildings and photovoltaic systems. Smart grid research and infrastructure will be required to accommodate higher percentages of distributed renewable electric power. Such research is essential for the progress that BES labeling seeks to quantify, the progress of reaching the goal for net zero energy buildings.

Recommendation 6: Become an advocate. Change in the business-as-usual patterns may not materialize rapidly enough to avert undesirable environmental consequences. In recent decades market forces have failed to produce the potential savings available through building refurbishment. Therefore it is appropriate and essential to advocate policies that accelerate market transition. The adoption of a national BES labeling system that offers a clear assessment of progress toward the NZEB goal and stimulates more stringent building energy code is such an appropriate policy. Furthermore it is appropriate to share technical insights and convictions with clients, peers, and the congressional delegation.

This research has significantly advanced my understanding of the design and construction process and its recommendations can improve the outcomes for the planet and future generations. Yet I am but one voice among many. We must all continue to seek the most effective path forward, discuss our perceptions with colleagues, and then act. I have sought and discussed. It is time to act.

A Appendix—History of labeling and emerging standards

A.1 History of energy labeling

Following the first “energy crisis” in 1973, governments and industries developed a new sensitivity to the opportunities for energy conservation. Thus the history of energy labeling initiatives and legislation extends over 36 years. During that period we have seen the leadership that started in the US shift to other parts of the globe and then return.

My discussion of history of building labeling will first cover developments of voluntary programs in the US followed by mandatory programs in the European Union (EU). While the work on conservation in Japan, Brazil, and other countries is significant, I will limit my remarks to the US and the EU.

A.1.1 US

Initially the conservation measures in the US centered upon building code development. As experts in the environmental controls industry, the American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) were the first to establish standards leading toward increased efficiency. The original ASHRAE Standard 90 was first published in 1975 and later revisions published in 1980, 1989, and 1999 using the ANSI and ASHRAE periodic maintenance procedures. Since 1999, the standard is on continuous maintenance enabling the standard to be updated several times each year through the publication of approved addenda. Updates were published in 2001 and 2004.

Through the Energy Policy Act of 1992 the DOE established ASHRAE Standard 90.1 as the commercial building reference standard for state building energy codes. The ASHRAE standard provides minimum energy-efficiency requirements for the design and construction of new buildings, additions to buildings and their systems, and new systems and equipment in existing buildings. In addition it establishes criteria for determining compliance with these requirements. The scope of ASHRAE 90.1 applies to:

- The envelope of the building—the insulation of walls, roofs, floors, perimeters of slab foundations, and fenestration. Each must meet maximum values for thermal transmittance and the fenestration must also meet solar heat gain coefficient (SHGC) limits.

- The systems and equipment used in conjunction with buildings—heating, ventilation and air conditioning, service water heating, electric power distribution and metering provisions, electric motors and lighting.
- The interior must satisfy lighting power density limits.

Home energy ratings followed the building code initiatives and date back to 1981, when a group of mortgage industry leaders set up the National Shelter Industry Energy Advisory Council. The Council consisted of representatives of Fannie Mae, Freddie Mac, the Federal Home Loan Bank, American Society of Real Estate Appraisers and the leading Multi-Listing Services. The Council's goal was to establish a measurement system which factored the energy efficient features of a home into the mortgage loan. The result was the establishment of Energy Rated Homes of America (ERHA), a national non-profit organization[99].

Energy Mortgages also date back to the early 1980s when Fannie Mae, Freddie Mac, the US Department of Housing and Urban Affairs' Federal Housing Administration (FHA) and the Veteran's Administration (VA) all adopted energy mortgage programs. There are two types of energy mortgages: energy improvement mortgages that finance energy upgrades using monthly energy savings and energy efficient mortgages that use the energy savings from a new energy efficient home to increase the home buying power. However, these programs were not widely used for a variety of reasons: a lack of consumer and lender awareness, no uniform method of efficiency evaluation except in a few states with home energy rating systems and complicated program procedures.

In 1984 home energy ratings and energy mortgages emerged as a national policy issue. Both the Democratic and Republican National Conventions adopted party platforms with a national system of home energy ratings and energy mortgage programs. In 1990 President George Bush included market-driven initiatives, such as home energy ratings and energy mortgages, in his administration's national energy strategy.

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[99] RESNET - HERS Primer - History of Home Energy Ratings and Energy Mortgages http://www.natresnet.org/ratings/overview/resources/primer/HP02.htm, Aug 30, 2009.

In 1990 the NASEO asked the DOE to collaborate with the states, the mortgage, and the housing industries to operate home energy rating systems and to develop protocols encouraging nationwide uniformity in home energy ratings and energy mortgages. In response the DOE and the Department of Housing and Urban Development (HUD) formed a national collaborative on home energy ratings and energy mortgages in 1991.

The collaborative represented a broad spectrum of the housing market including state governments, fledgling home energy rating systems, realtors, builders, appraisers, consumer and environmental groups, and the secondary mortgage market. The following year, the collaborative issued its recommendations calling for a national uniform system of voluntary home energy ratings and energy mortgages. These were included in several pieces of legislation passed by Congress that year:

- The National Energy Policy Act of 1992 required the DOE to promulgate voluntary guidelines to encourage the adoption of home energy ratings in all states after consultation with the states.
- The Housing and Community Development Act of 1992 required HUD to test a pilot energy efficiency mortgage program in five states.
- The Veterans' Home Loan Program Amendment of 1992 required the VA to adopt a national energy efficiency mortgage program for its veteran home loan program.

As a result of this legislation, in 1993 the DOE contracted with the HERS Council to develop voluntary technical guidelines for home energy rating systems. A joint task force of the NASEO and HERS Council technical committees developed a consensus recommendation of a technical standard. This recommendation was the basis of DOE's proposed guidelines in its 1995 notice of rule making. Because of a dispute between competing utilities over using site energy versus source energy in the guidelines (fuel neutrality), DOE never adopted the proposed standard. However, using the recommendations of the joint RESNET/HERS Council, NASEO adopted technical guidelines in September 1999 that accommodated the fuel neutrality issue, and these guidelines continue to govern RESNET operations today.

In October of 1993 the Clinton-Gore Administration announced its Climate Change Action Plan in compliance to the Rio Accord that sought to reduce CO_2 emissions to their 1990 levels by 2000. The Climate Change Action plan included a provision for making home energy ratings and energy mortgages available nationally. In 1995 DOE selected seven ERHA state organizations (Alaska, Arkansas, California, Colorado, Mississippi, Vermont, and Virginia) to provide support for the national home energy rating effort.

In April 1995 the NASEO and ERHA founded RESNET to develop a national market for home energy rating systems and energy mortgages. RESNET’s activities are guided by a mortgage industry advisory council composed of the leading national mortgage executives.

In October 1998 the mortgage industry, RESNET, and the NASEO adopted the Mortgage Industry National Home Energy Rating System Accreditation Standard. After more than a decade of development, the infrastructure needed to make energy efficiency a standard feature in the nation’s housing market was finally in place. Across the US in partnership with their housing industries, states are forging the public/private partnerships required for successful home energy rating systems. RESNET is providing the technical, program and marketing assistance required for this effort.

As a result of the legislative initiatives in 1992, the EPA launched Energy Star, a voluntary labeling program, designed to identify and promote energy-efficient products. Computers and monitors were the first labeled products. Through 1995, EPA expanded the label to additional office equipment products and residential heating and cooling equipment. In 1996, EPA partnered with the DOE for particular product categories. Energy Star provides a trustworthy label on over 60 product categories (and thousands of models) for the home and office. These products deliver the same or better performance as comparable models while using less energy and saving money.

Through its partnerships with more than 15,000 private and public sector organizations, Energy Star delivers the technical information and tools that organizations and consumers need to choose energy-efficient solutions and best management practices. The Energy Star program has successfully delivered energy and cost reductions across the country to businesses, organizations, and consumers saving about $19 billion in 2008 alone[100]. Over the past decade, Energy Star has been a driving force behind the more widespread use of such technological innovations as efficient fluorescent lighting, power management systems for office equipment, and low standby energy use.

From its beginning in 1992 the EPA's Energy Star for Homes has been based upon the HERS system. Thus the Energy Star program is hostage to the business practices and quality standards of RESNET, which has sole administration, implementation, development and oversight of the HERS (and therefore the Energy Star program) as well as the implementation of the tax credit program. The EPA claims that it never intended to give RESNET this kind of monopoly power[101].

A.1.2 EU

While Denmark first introduced a mandatory energy labeling scheme for residential buildings in 1997, building energy labeling and certification in the European Union (EU) began in earnest with the implementation of the Energy Performance of Buildings Directive (EPBD) adopted by the European Parliament and Council in 2003 and has evolved rapidly in recent years. Unlike the voluntary programs in the US, this mandatory program was originally promulgated to be adopted and enforced by all EU Member States as of January 2006. The EPBD requires that an energy performance certificate be made available when buildings are constructed, sold or leased. The certificate is required to express the energy performance of the building, defined as "the amount of energy actually consumed or estimated to meet the different needs associated with a standardized use of the building."[102]

The amount of energy consumed as shown on the energy certificate must be reflected in one or more numeric performance indicators, which assess the building's thermal envelope, technical and installation characteristics, solar orientation and other

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[100] History : Energy Star http://www.energystar.gov/index.cfm?c=about.ab_history, Aug 30, 2009.

[101] The Highjacking of the Energy Bill by Mortgage Companies - DivineCaroline http://www.divinecaroline.com/22354/80529-highjacking-energy-bill-mortgage-companies/print, Aug 30, 2009.

[102] ASHRAE Building Energy Labeling Ad Hoc Committee, ASHRAE Building Energy Labeling Program: Promoting the Value of Energy Efficiency In the Real Estate Market, June 2009, p5.

climatic features, on-site energy generation, and other factors such as indoor climate that influence the energy demand. Labels must reflect benchmarking data for EUI and/or CO_2 emissions per unit floor area, and some national labels may also include additional environmental parameters (e.g., water consumption). The certificate is also required to include cost-effective recommendations for improving the building's energy performance (e.g., estimated energy savings, CO_2 emissions, investment costs and payback period). The validity of the certificate is limited to 10 years.

All EU Member States are developing building energy labels and/or certificates in response to EPBD, with many of the technical details coordinated to make different Member State activities as consistent as possible. The European Committee for Standardization (CEN) has developed over 30 standards to satisfy the requirements of the EPBD, including EN 15217 (Energy performance of buildings—Methods for expressing energy performance and for energy certification of buildings). In January 2006, the Buildings Platform was created as an information service for helping the implementation of the EPBD[103] across Member States. In many EU countries the energy performance ranges on a scale from "A" to "G"—from buildings of highest energy performance to lowest—presented in a format consistent with the European appliance energy labeling scheme that has high consumer recognition.

An example of an energy certificate is shown in Figure 42. The labeling indicator may be based on the 1) calculated energy demand (asset rating) or 2) measured energy consumption (operational rating). It should also be possible to have a certificate include both ratings, with the asset rating (as built) being mandatory for building completion, sale or rental, and the operational rating (as used) mandatory for public display. The asset rating has been adapted by most EU Member States and has been the focus for the development of Europe's CEN standards.

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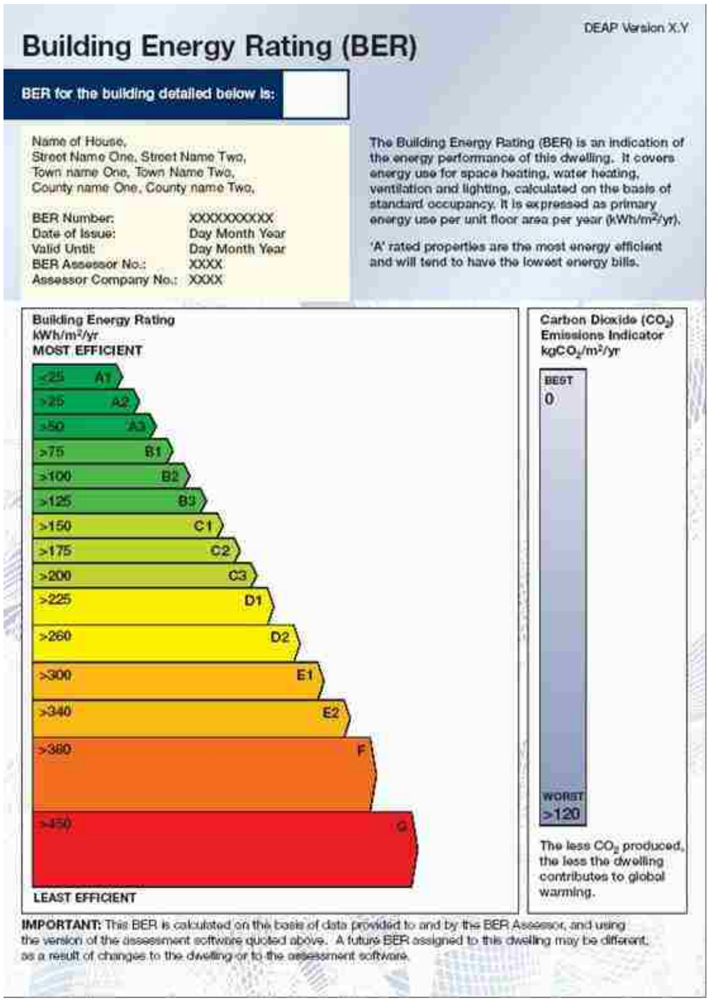
[103] R. Lamberts, S. Goulart, J. Carlo, F. Westphal, "Regulation for energy efficiency labelling of commercial buildings in Brazil," 2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century, September 2007, p604.

In February 2009 Eduardo Maldonado summarized the status of the EU effort on performance ratings for buildings as follows[104]:

- Every new building receives a certificate as a precondition to obtain a license (a few Member States will start this requirement later in 2009 or in 2010)
- Every existing building sold or rented must already have a certificate (required in the majority of Member States)
- Most public buildings must display a certificate by 2010 (a delay was necessary due to lack of sufficient qualified experts to issue the certificates to unusually complex buildings)
- Thousands of new jobs for qualified experts have been created in the EU providing cost-effective advice to building owners
- Several million certificates are expected to be issued every year when all the Member States have their systems fully operational



DEAP Version X.Y

Building Energy Rating (BER)

BER for the building detailed below is:

Name of House,
Street Name One, Street Name Two,
Town name One, Town Name Two,
County name One, County name Two,

BER Number:	XXXXXXXXXX
Date of Issue:	Day Month Year
Valid Until:	Day Month Year
BER Assessor No.:	XXXX
Assessor Company No.:	XXXX

The Building Energy Rating (BER) is an indication of the energy performance of this dwelling. It covers energy use for space heating, water heating, ventilation and lighting, calculated on the basis of standard occupancy. It is expressed as primary energy use per unit floor area per year (kWh/m²/yr).

'A' rated properties are the most energy efficient and will tend to have the lowest energy bills.

The less CO_2 produced, the less the dwelling contributes to global warming.

IMPORTANT: This BER is calculated on the basis of data provided to and by the BER Assessor, and using the version of the assessment software quoted above. A future BER assigned to this dwelling may be different, as a result of changes to the dwelling or to the assessment software.

Figure 42. The Irish Building Energy Rating (BER) certificate. Ref: http://www.activethermal.ie/ber.php, Sept 3, 2009.

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[104] Eduardo Maldonado, The European Union Energy Performance of Buildings Directive (EPBD), RESNET Building Performance Conference New Orleans, Feb. 16, 2009.

A.2 Emerging energy labeling standards

In response to the evidence that in the US our building inventory is the source of half the national CO_2 production and a sink of half the national energy consumption, buildings have increasingly been identified as an opportunity for conservation measures that will produce significant energy savings and emissions reductions. Since its inception in 2002, Architecture 2030 has advocated design changes for new buildings and retrofits for the existing inventory to address this opportunity. As discussed in Chapter 2, studies have repeatedly concluded that not only is there an opportunity to reduce emissions and energy consumption through retrofits, but in so doing the actual life-cycle costs for a building can be decreased.

Thus it comes as no surprise that during a period of economic malaise and recovery that the federal government might seize the opportunity to initiate legislation that promotes this cost-effective conservation. While HR 2454 (otherwise identified by the names of its authors as the Waxman-Markey Bill) seeks to address a broad swath of energy-related issues, it specifically includes legislation addressing building codes and building labeling as interventions targeted to breakthrough the market failures enumerated in Chapter 2.

The Waxman-Markey legislative initiative offers only modest innovation, but is a precedent since it gathers a large number of interventions in a single package. As regards buildings, it proposes as federal law some of the guidelines under active consideration among the states in the Northeast Energy Efficiency Partnerships (NEEP). Seeking to foster energy conservation, the ultimate goal of these guidelines is to support state adoption and implementation of policies that will lead the majority of new building construction by 2030 to be comprised of net zero energy buildings (NZEB)[105]. These guidelines apply in three categories:

- Code adoption
- Code compliance
- Measuring and reporting energy performance

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[105] Northeast Energy Efficiency Partnerships, *Model Progressive Building Energy Codes Policy for Northeast States,* March 2009, p 4.

The NEEP initiative includes building energy labeling as one component of a three-pronged strategy as shown in Figure 43. Code adoption provides the requirements for building energy efficiency and code compliance ensures enforcement through inspections with qualified inspectors. Finally the third prong, building energy labeling, provides the efficiency information that buyers require to make an informed decision at the time of sale. This information may describe a building either “as designed” or “as built” depending upon the history of the building, and provides additional information to lenders for brokering a mortgage. Since NEEP building energy labeling requires benchmarking for commercial buildings, operators must have the data for the energy consumption for their facility and, therefore, can observe deviations from the expected or established building performance and can identify opportunities for building enhancement to reduce energy consumption.

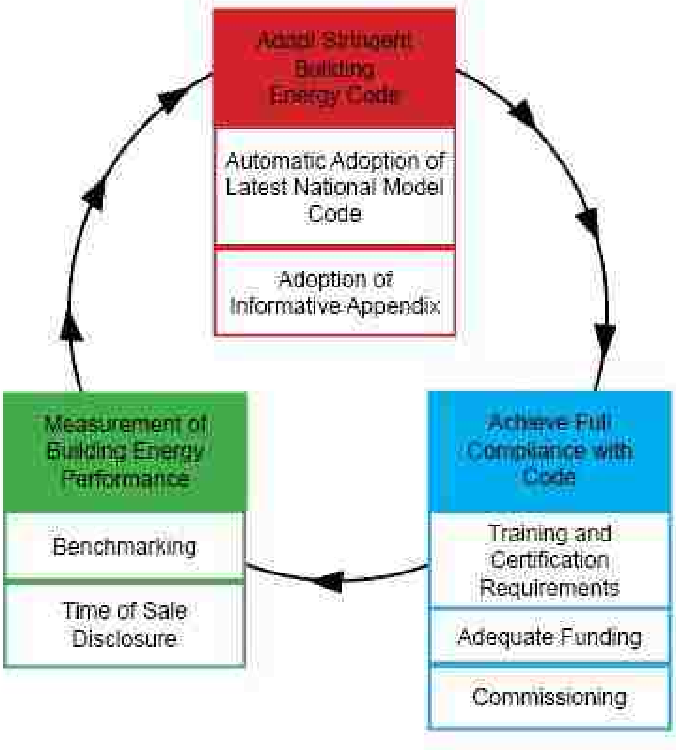

Figure 43. Maximizing energy performance as proposed by the Northeast Energy Efficiency Partnerships.

This section reviews the current initiatives that aim to change energy policy as it relates to building design and operation. It includes the proposals in the Waxman-Markey Bill, the requirements for labeling in California beginning in January 2010, ASHRAE's building labeling prototype, and the proposed changes for Energy Star 2011 and LEED 2009.

A.2.1 HR 2454 (Waxman-Markey Bill)

The Waxman-Markey Bill has five separate titles (legislative jargon for major sections)—Clean Energy, Energy Efficiency, Reducing Global Warming Pollution (also known as cap and trade), Transitioning to a Clean Energy Economy, and Agriculture and Forestry Related Offsets. The bill narrowly passed in the House of Representatives on June 26, 2009 by a vote of 219 to 212 and moved to the Senate for debate and revision. As it left the House, the significant features of the bill:[106]

- Require electric utilities to meet 20% of their electricity demand through renewable energy sources and energy efficiency by 2020
- Invest in new clean energy technologies and energy efficiency, including energy efficiency and renewable energy ($90 billion in new investments by 2025), carbon capture and sequestration ($60 billion), electric and other advanced technology vehicles ($20 billion), and basic scientific research and development ($20 billion)
- Mandate new energy-saving code and labeling standards for buildings, appliances, and industry
- Reduce carbon emissions from major US sources by 17% by 2020 and over 80% by 2050 compared to 2005 levels. Complementary measures in the legislation, such as investments in preventing tropical deforestation, will achieve significant additional reductions in carbon emissions

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[106] A useful summary of Waxman-Markey - Climate Progress, http://climateprogress.org/2009/06/02/a-useful-summary-of-the-house-clean-energy-and-climate-bill/, Sept 8, 2009.

- Protect consumers from energy price increases. According to estimates from the Environmental Protection Agency, the reductions in carbon pollution required by the legislation will cost American families less than a postage stamp per day

The Waxman-Markey Bill requires that the Administrator of the EPA establish several new regulatory programs including the building energy labeling program as sketched by the process in Section 204 of the bill. In reality the bill is process oriented—it says little about the particulars of the labeling program, but identifies milestones for establishing and operating the program. It notes that existing programs like the EPA Energy Star and HERS programs ought to be considered as useful precedents.

The development of the efficiency program must first extend the list of building types to cover ninety percent of all commercial buildings types and compile the associated building performance data in the CBECS database within five years. Likewise protocols and any required databases for the residential market must be developed and compiled such that residential assessments may proceed within five years. Such feasibility studies and demonstration projects as necessary will be conducted.

The building energy label must display both the designed and achieved performance for all building types both residential and commercial as long as protocols and measures are "available, practicable, and cost effective." Demonstration projects will test the prototype system with an array of building types including:

- buildings from diverse geographical and climate regions
- buildings in both urban and rural areas
- single-family residential buildings
- multi-housing residential buildings with more than 50 units, including at least one project that provides affordable housing to individuals of diverse incomes
- single-occupant commercial buildings larger than 30,000 square feet
- multi-tenanted commercial buildings larger than 50,000 square feet
- buildings from both the public and private sectors

Passage of the bill will require that the EPA and DOE implement the energy labeling scheme within their facilities, launch a business and consumer education program focused on energy efficiency, and work with the states to implement the energy labeling scheme as defined in the bill both at the state and local levels. Building energy label assessment may be required at the time of a:

- building audit conducted with support from federal or state funds
- building energy-efficiency retrofit conducted in response to such an audit
- final inspection of major renovations or additions made to a building in accordance with a building permit issued by a local government jurisdiction
- sale that is recorded for title and tax purposes
- new lien recorded on the property for more than a set percentage of the assessed value of the property, if that lien reflects public financial assistance for energy-related improvements to the building
- change in ownership or operation of the building for purposes of utility billing

Opposition to the bill is fierce. Opponents argue that it will impose an effective tax on energy costs that will double the cost of energy and kill the economy. Their logic also argues against government intervention and regulation in what they view as an adequately controlled economy. While it is premature to plan on any outcome from the Waxman-Markey Bill, one can see the mounting influence of the EU initiatives requiring energy conservation legislation in Member States, and from the US the desire to respond.

A.2.2 ASHRAE’s Building Energy Quotient

The ASHRAE building labeling scheme was introduced in Chapter 4. Since it is emerging at the time of this writing, it benefits from the lessons learned from other labeling efforts. Consequently in this appendix it is appropriate to cover some of these details not immediately germane to my thesis proposal. However, I omit the introductory details here and refer the reader to Chapter 4.

A.2.2.1 ASHRAE Asset and operational ratings

The ASHRAE Advanced Building Energy Labeling (ABEL) asset rating is intended to be a measure of the energy efficiency quality of the as-designed, fixed physical components of a building. Like the Energy Star rating, it is intended to allow comparison among similar buildings, within a size range and of the same occupancy type within a climate zone. The asset rating is designed to have a particular relevance for real estate transactions in that it expresses an integral measure of the building’s inherent energy efficiency. The desired attributes of the asset rating are listed in Table 23. The ABEL asset rating will be designated “As Designed” on the ABEL Label.

Table 23. Desired characteristics for the asset (as designed) rating[107].

- The scale should be readily understandable by the real estate marketplace and the public and have general cultural consistency (for example an ascending letter scale wouldn't be good: A as worst and G as best would be culturally inconsistent).
- The top end of the scale should be consistent with the Net Zero Energy building movement, and the Architecture 2030 Challenge.
- The scale should have some consistency with other building labels around the world.
- The top end of the scale should be immediately recognizable as connoting excellence. There should be no ambiguity about what is a good score, and what is a better score.
- Because the asset (as designed) rating methodology is somewhat similar to a LEED EA Credit 1 submission, there should be some milestone within the rating that would indicate likely compliance with current energy code. This milestone would be recognizable by consumers. An asset rating higher than a certain level on the scale would be better than code, and lower on the scale would be worse than code.
- The scale should be compatible with state and local requirements being implemented for building energy disclosure to improve the marketability of the label.
- The scale should have a consistent logical relationship with the operational (in operation) rating scale, so that different levels of achievement for the two scales by the same building could have a consistent meaning for users of the scale.
- The scale should be based upon source energy, rather than site energy, to provide a stronger relationship to energy consumption related green-house gas (GHG) emissions.

Creating a method of comparing energy efficiency for buildings is the primary intent of this rating. To ensure the validity of this comparison, the asset rating methodology proposes to normalize for the major sources of variable energy consumption in buildings—sources that are natural consequences of different building applications and different design intent. These source factors, unregulated variables, include[108]:

- Schedule of operation
- Schedule of occupancy
- Occupant density
- Occupant installed plug loads

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[107] ASHRAE Building Energy Labeling Ad Hoc Committee, *Building Energy Quotient: Promoting the Value of Energy Efficiency In the Real Estate Market*, June 2009, p8.

[108] Ibid, p9.

- Specific climate data related to a location
- Outdoor air ventilation rates

The asset (as designed) rating achieves this normalization by utilizing standard occupancy and operational schedules, and standard equipment and occupant densities that have been developed for each occupancy type. These parameters will be developed as part of the National Energy Protocol Specification (NEPS) by the Commercial Energy Services Network (COMNET) project sponsored by the New Buildings Institute (NBI)[109].

Not only would the NEPS establish methods and parameters to standardize the unregulated variables, but essentially they would work to define a set of rules for performing a building energy simulation to evaluate the fixed variables of a building design. This protocol would include[110]:

- Standards for accuracy and capability for acceptable energy analysis programs
- Standard modeling assumptions for the above non-regulated variables
- Standard modeling assumptions for operational procedures for conventional building systems
- Standards for modeling advanced energy conservation measures and commissioning
- Standards for energy analysis reporting that facilitates verification and comparison with other projects

However, the standards of the COMNET project are not expected to be delivered until after the initiation of ABEL, so an interim source for standardized non-regulated occupancy, operational variables, and model building procedures must be utilized.

Should the Waxman-Markey Bill succeed and become law, the process aimed at establishing an advanced energy labeling system should embrace both of the NEPS sets of standards discussed above. Standardizing corrections for the unregulated variables

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[109] Commercial Energy Services Network (COMNET), http://www.imt.org/comnet.html, Aug 8, 2009.

[110] Op cit, ASHRAE Building Energy Labeling Ad Hoc Committee, p10.

associated with the CBECS data would improve its utility, and standardizing the building energy simulations would facilitate comparisons to operational measurements.

The asset (as designed) rating would be one hundred times the ratio of the as-designed source EUI for the building as calculated in a building energy simulation using the NEPS procedures and a "standard" source EUI for that building type of the same size range and in the same climate. Without this standard in place at the moment, ASHRAE recommends that for building types covered under the Energy Star program; this value can be defined using the EPA Target Finder program, entering 50% as the percentile target, and using occupancy inputs consistent with the standard schedules. Success of the Waxman-Markey Bill and subsequent data compilation will increase the coverage of the building types supported for this procedure. A building whose EUI was equal to the standard would have an asset (as designed) rating score of 100. A net zero energy building would have a score of 0. For mixed use buildings, the "standard" EUI for a particular building would be developed by weighting the EUI's of the different occupancy types according to the floor area of that particular occupancy. The equation below summarizes this discussion.

$$bEQ_{asset} = \frac{EUI_{as\text{-}designed}}{EUI_{standard}} \text{ X } 100$$

An operational rating identifies how much energy an existing building is actually using relative to the set of benchmark metrics, typically taken from the CBECS database. Energy consumption data may be broken down by fuel type and area for conditioned space in a building, and may compare site consumption to source energy as an indicator of GHG emissions or carbon footprint. Furthermore operational ratings may compare efficiencies of energy using systems within buildings (heating, cooling, fans, lighting, etc) to gauge operational performance. Operational ratings require at least 12 months of utility-metered data provided directly by the customer or through the customer's energy service provider and Portfolio Manager. Table 24 presents the features of the operational rating.

The operational rating will be designated as “In Operation” on the ABEL Label. Like the asset (as designed) rating, the operational (in operation) rating is fundamentally a ratio and may be expressed with the equation below. In contrast to the asset rating, it uses only measured data and no simulations. The measured EUI is calculated from the metered fuel types consumed by the building and converted to equivalent source energy. The median EUI is extracted from Target Finder as described above for the asset (as designed) rating.

$$bEQ_{operational} \quad = \quad \frac{EUI_{measured}}{EUI_{median}} \text{ X } 100$$

Table 24. Features of the operational (in operation) rating[111].

- Provides an existing building with a comparative energy performance rating based on like type buildings in similar regions with similar characteristics. This will allow building owners to “measure” improved building performance over time, while investing in operation and equipment improvements.
- Includes energy consumption by major energy using system categories, if measured data is available, thus providing a building system comparison (e.g. envelope, lighting, heating, cooling, ventilation, and service hot water) with those systems in comparable building types.
- Includes peak demand and fraction of energy provided from renewable sources
- Encourages the undertaking of a building survey (site visit) used to identify measures to improve energy performance. The building survey will inform and educate building owners and operators of discretionary operational choices which will improve both occupant comfort and reduce energy usage and will verify that performance measurement protocols have been properly applied and operating data is valid.
- Identifies opportunities for optimizing building energy systems and reducing energy consumption and peak demand for building owners and operators.
- Utilizes the same scale for a direct comparison with the asset rating scale.
- Provides a value for both site and source energy used for common building energy using systems.
- Leads building owners to invest in energy audits which may provide an inventory of energy using equipment or initiate energy end uses to be measured.

While ASHRAE recommends using the median EUI for the building type and occupancy parameters as given by EPA’s Target Finder for both the asset and operational ratings in these early days of the prototype system, in the future it intends to calculate the standard EUI for the asset rating from the baseline building design as defined in Standard 90.1 Appendix G. With this approach the most difficult part of developing the asset (as designed) rating methodology is coordinating the standard EUIs for the different building

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[111] Ibid, p11.

occupancy types, size ranges and climate zones with the values for the non-regulated variables and schedules. The schedules and occupancy densities for each building type as developed in the NEPS process should be configured such that the baseline building with "average" values for the construction variables regulated by energy codes, when simulated using the NEPS non-regulated variables, would yield an EUI approximately equal to the "median" EUI from Target Finder. Thus, a building of "average" construction when simulated with the standard NEPS schedules and occupancy variables, would give an EUI approximately equal to the "median" EUI used to calculate the operational rating. This relationship is extremely important because it would enable the comparison of the *completely analytical* asset rating with the *completely experimental* operational ratings. Then, if a building were to achieve a very good asset (as designed) rating, yet have a mediocre operational (in operation) rating, one could conclude that the building operations, either density variances or duration of daily use fluctuations or possibly operational difficulties were the reason for its operational (in operation) rating performance.

A.2.2.2 ASHRAE Quality control

To ensure the quality of the simulations and the quality of the measurements, ASHRAE requires three types of certifications:

- Building energy modelers
- Building energy assessors
- Simulation software

Initially ASHRAE proposes that registered Professional Engineers (PE) will oversee both the work of the buildings energy modelers and assessors. However, this interim procedure will transition to a formal system that COMNET is currently researching[112]. To ensure the credibility of the system, COMNET will provide certification standards for raters of commercial buildings. RESNET, which has a comprehensive system for certifying trainers, raters, and field inspectors for the home energy rating program as described in Section 4.2.1, offers a tested starting point for

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[112] Op cit, Commercial Energy Services Network (COMNET).

developing COMNET certification protocols. However, COMNET certification will have to reflect many technical and institutional factors unique to the commercial sector. RESNET and the Institute for Market Transformation (IMT), under the supervision of NBI, are currently developing criteria and procedures for certification of individuals and institutions involved with COMNET training and implementation. A primary goal of this work will be to maximize compatibility with existing certification processes already in place among professional societies and governmental licensing agencies.

The ASHRAE certification program for simulation software was the first codified method of test for building energy software in the world[113] and has been operational since 2001. Building simulation programs must meet the requirements of ASHRAE 90.1, Informative Appendix G, Section G2.2 Simulation Program and achieve certification under ASHRAE Standard 140-2007 *Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs.* Furthermore, building energy simulations must be performed in accordance with the latest version of ASHRAE Standard 90.1, Informative Appendix G, Performance Rating Method. All accredited software is listed in Table 25.

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[113] R. Judkoff and J. Neymark, "Model Validation and Testing: The Methodological Foundation of ASHRAE Standard 140", NREL/CP-550-40360, July 2006, p1.

Table 25. ASHRAE Standard 140-2007 accredited software tools[114].

Product	**EnergyPlus version 3.1.0.027**	**DOE-2.1E-JJH version 130**	**EnergyGauge Summit version 3.20**
Company	U. S. Department of Energy EE-2J	The Weidt Group	Florida Solar Energy
Address 1	1000 Independence Avenue SW	5800 Baker Road	1679 Clearlake Road
Address 2	Washington, DC 20585-0121	Minnetonka, MN 55345	Cocoa, Florida 39922
Phone		(952) 938-1588	(321) 638-1410
Email	Drury.Crawley@ee.doe.gov	jasons@twgi.com	swami@fsec.ucf.edu
Website	http://www.energyplus.gov		http://www.energygauge.com
Contact	Drury Crawley	Jason Steinbock	Dr. Muthusamy Swami
Effective Date	8-May-09	5-Nov-07	5-Jun-09
Product	**EnerSim version 07.11.30**	**Autodesk Green Building Studio web service version 3.4**	**Hourly Analysis Program version 4.41.0.6**
Company	Southern Company Services	Green Building Studio, Inc	Carrier / United Technologies Corporation
Address 1	241 Ralph McGill Boulevard	444 Tenth Street Suite 300	P. O. Box 4808
Address 2	Atlanta, Georgia 30308	Santa Rosa, California 95401	Syracuse, New York 13221
Phone	(404) 506-3717	(707) 569-7373	(800) 253-1794
Email	ARBhiman@southernco.com	info@greenbuildingstudio.com	Software.systems@carrier.utc.com
Website		http://www.autodesk.com	
Contact	Mr. Ambavi Bhimani	John F. Kennedy	
Effective Date	6-Dec-07	16-Oct-08	10-Apr-09
Product	**Owens Corning Commercial Energy Calculator (OC-CEC) version 1.1**	**TRACE 700 version 6.1.2.0**	
Company	Green Building Studio, Inc	TRANE	
Address 1	444 Tenth Street Suite 300	3600 Pammel Creek Road	
Address 2	Santa Rosa, California 95401	LaCrosse, Wisconsin 54601	
Phone	(707) 569-7373	(608) 787-3926	
Email	info@greenbuildingstudio.com	CDSHelp@trane.com	
Website	www.owenscorning.com/comminsul/calculator.asp	www.tranecds.com	
Contact	John F. Kennedy		
Effective Date	14-Aug-07	9-Nov-07	

The ASHRAE standard method for testing is used for identifying and diagnosing predictive differences from whole building energy simulation software that may possibly

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[114] Tax Deduction Qualified Software, http://www.buildings.energy.gov/qualified_software.html, Aug 8, 2009.

be caused by algorithmic differences, modeling limitations, input differences, or coding errors. The current categories for tests include[115]:

- comparative tests that focus on building thermal envelope and fabric loads and mechanical equipment performance
- analytical verification tests that focus on mechanical equipment performance.

The tests summarized in Table 26 constitute the overall validation methodology. These cases test software over a broad range of parametric interactions and for a number of different output types, thus minimizing the chance for concealment of algorithmic differences by compensating errors. Different building energy simulation programs, representing different degrees of modeling complexity, can be tested. However, some of the tests may be incompatible with some building energy simulation programs.

Of course these tests are a subset of all the possible tests that could occur. A large amount of effort has gone into establishing a sequence of tests that exercise many of the thermal models relevant to simulating the energy performance of a building and its mechanical equipment. However, because building energy simulation software operates in an immense parameter space, it is impractical to test every combination of parameters over every possible range of function.

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[115] ASHRAE Standing Standard Project Committee 140, ASHRAE STANDARD 140: Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs, 2007, p1.

Table 26. Software verification tests for ASHRAE certification[116]**.**

- **Building Thermal Envelope and Fabric Load Base Case –** The base building plan is a low mass, rectangular single zone with no interior partitions.
- **Building Thermal Envelope and Fabric Load Basic Tests –** The basic tests analyze the ability of software to model building envelope loads in a low mass configuration with the following variations: window orientation, shading devices, setback thermostat, and night ventilation.
- **Building Thermal Envelope and Fabric Load In- Depth Tests –** In-depth Cases 195 through 320 analyze the ability of software to model building envelope loads for a non-deadband on/off thermostat control configuration with the following variations among the cases: no windows, opaque windows, exterior infrared emittance, interior infrared emittance, infiltration, internal gains, exterior shortwave absorptance, south solar gains, interior shortwave absorptance, window orientation, shading devices, and thermostat setpoints. In-depth Cases 395 through 440, 800, and 810 analyze the ability of software to model building envelope loads in a deadband thermostat control configuration with the following variations: no windows, opaque windows, infiltration, internal gains, exterior shortwave absorptance, south solar gains, interior shortwave absorptance, and thermal mass.
- **Space-Cooling Equipment Performance Analytical Verification Base Case –** The configuration of the basecase (Case E100) building is a near-adiabatic rectangular single zone with only user-specified internal gains to drive steady-state cooling load. Mechanical equipment specifications represent a simple unitary vapor-compression cooling system or, more precisely, a split-system, air-cooled condensing unit with an indoor evaporator coil.
- **Space-Cooling Equipment Performance Parameter Variation Analytical Verification Tests –** In these steady-state cases (cases E110 through E200), the following parameters are varied: sensible internal gains, latent internal gains, zone thermostat setpoint entering dry-bulb temperature (EDB), and outdoor dry bulb temperature (ODB).
- **Space-Cooling Equipment Performance Comparative Test Base Case –** The configuration of this base case (Case CE300) is a near-adiabatic rectangular single zone with user-specified internal gains and outside air to drive dynamic (hourly varying) loads. The cases apply realistic, hourly varying annual weather data for a hot and humid climate. The mechanical system is a vapor-compression cooling system similar to that described in Case E100, except that it is a larger system and includes an expanded performance data set covering a wider range of operating conditions.
- **Space-Cooling Equipment Performance Comparative Tests –** In these cases (cases CE310 through CE545), which apply the same weather data as Case CE300, the following parameters are varied: sensible internal gains, latent internal gains, infiltration rate, outside air fraction, thermostat setpoints, and economizer control settings.
- **Space-Heating Equipment Performance Analytical Verification Base Case –** The configuration of the basecase (Case HE100) building is a rectangular single zone near adiabatic on five faces with one heat exchange surface (the roof). Mechanical equipment specifications represent a simple unitary fuel-fired furnace with a circulating fan and a draft fan.
- **Space-Heating Equipment Performance Analytical Verification Tests –** In these cases (cases HE110 through HE170), the following parameters are varied: efficiency, weather (resulting in different load conditions from full load to part load to no load to time-varying load), circulating fan operation, and draft fan operation.
- **Space-Heating Equipment Performance Comparative Tests –** In these cases (cases HE210 through HE230), the following parameters are varied: weather (realistic temperature conditions are used), thermostat control strategy, and furnace size (undersized furnace).

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[116] Ibid, p5.

A.2.2.3 ASHRAE Rollout plan

Given the downturn in the economy and the potential to generate jobs with remediation projects, the threat of climate change and resource depletion, and the opportunity to offer a viable building energy labeling program, ASHRAE appears to be aggressively pushing its proposed labeling program forward. While it established its Building Energy Labeling Ad Hoc Committee during the previous administration and Congress, it surely senses the opportunity at hand for the timely implementation of this program. In June 2009 it published the results of a prototype effort to assess and label its technically advanced headquarters in Atlanta, and announced the schedule for its program as shown in Table 27.

Table 27. The recommendation of the ABEL Committee for the implementation schedule (dated June 9, 2009)[117].

June 2009	• Prototype operational (in operation) label revealed at annual summer meeting • Label and certificate graphics finalized • Preliminary list of additional technical needs identified and sent to relevant technical committees (Including data sources for building types) • Initiation of ASHRAE ABEL Committee to take over management of the program
August 2009	• Identify criteria for Qualified Energy Assessor • Preliminary website launched • Identify education and publication needs • Develop web-based submission tools and background database set-up • Establish quality control criteria • Publish checklists and other support documents
September 2009	• Publish operational (in operation) rating instruction manual • Launch operational (in operation) rating portion of the label
November 2009	• Begin marketing campaign • Work with other organizations to implement • Identify requirements for modeling software to produce label documentation
January 2010	• Launch certified energy modeler program (name for certification TBD) • Abel implementation report – June 9, 2009 final draft • Initiate ASHRAE Guideline on Technical Rating Process • Implement operational (in operation) rating renewal process
March 2010	• Launch asset (as designed) rating portion of the label • Publish asset (as designed) rating instruction manual
June 2010	• Finalize program

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[117] Op cit, ASHRAE Building Energy Labeling Ad Hoc Committee, p24.

A.2.3 Energy Star 2011

While the Energy Star Qualified Homes program does not apply to commercial buildings, developments in this sphere may be analogous to developments on the commercial side. Consequently the next version of Energy Star is interesting for it changes and enhancements. Currently in its second "version" since 1995, analysis and field observations during the decade resulted in experience which revealed several previously untapped opportunities for significant increases in energy and GHG emission savings from the program. In many respects, these mitigations are often good building science practices that are simply neglected. The key measures proposed for the 2011 Energy Star Qualified Homes program are as follows[118]:

- Quality control of installation/commissioning
- Hot water delivery efficiency
- More efficient lighting and appliances
- Improving the equivalence between the performance and prescriptive paths and improving adoption of market-transforming technologies and practices
- Addressing absolute house size and carbon footprint

The public comment period was open through July 10, 2009.

A.2.3.1 Quality control of installation/commissioning

At the beginning of this Section, A.2 Emerging energy labeling standards on page 142, we noted that states organized in NEEP were arguing for increased energy efficiency through building energy codes, building energy labeling, and code enforcement. Energy Star 2011 recommends increased emphasis on the latter.

Despite increases in the "claimed" performance indices for insulation and HVAC equipment, poor quality installation and commissioning often occurs resulting in a failure

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[118] Energy Star Program, Overview of Evolving ENERGY STAR Qualified Homes Program & Methodology for Estimating Savings, May 5, 2009, p3-5.

to achieve the full potential of energy savings. Common examples of poor installation and commissioning practices include[119]:

- Insulation with voids, gaps, compression and lack of alignment between the air barrier and thermal surfaces, producing convective and conductive bypasses that seriously compromise effective insulating value
- High framing factors that allow parallel-path thermal bypasses through un-insulated studs
- Air conditioning units with significant over-sizing, improper refrigerant charge, and incorrect air-flow across the coil that significantly degrades the achievable performance of the unit
- Furnaces, heat pumps, and air-conditioners coupled with duct systems that are leaky, inadequately insulated, and with high pressure drops

Even though quality control of installation and commissioning is often legislated in residential energy codes, field observations indicate that it is often not being enforced or adequately inspected perhaps due to code inspectors' lack of training, budgetary constraints, or indifference. Regardless of cause, the lack of proper installation and commissioning also jeopardizes the delivery of Energy Star qualified homes that meet expected performance levels.

To address concerns about proper installation and commissioning, the 2011 guidelines integrate additional checklists to the single thermal bypass inspection and require third-party verified quality control. The new checklists are:

- Framing quality checklist
- HVAC quality contractor checklist
- HVAC quality rater checklist
- Indoor air quality checklist
- Water-managed construction checklist

Enforcement will be carried out primarily by raters though, in some cases, builders and contractors may complete certain quality assurance activities with oversight

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[119] Ibid, p3.

from raters. EPA analysis indicates that significant potential energy savings are possible with implementation of these checklists.

A.2.3.2 Hot water delivery efficiency

A renewed focus is also being placed on the reduction of hot water heating loads, which in the prior two "versions" of the Energy Star guidelines have only been incrementally addressed with nominal improvements in the energy factor of Energy Star qualified water heaters. Research indicates that large increases in effective energy factors would result from the following measures[120]:

- Hot water conservation measures (e.g., low-flow showerheads, Energy Star qualified clothes washers, Energy Star qualified dishwashers)
- Efficient hot water distribution systems that use one of the following strategies:
    - Structured plumbing
    - Manifold layouts
    - Demand controlled pumping systems

Because of the cost-effectiveness of these measures, they become mandatory in the 2011 guidelines.

A.2.3.3 More efficient lighting and appliances

Leveraging Energy Star rating for lighting and appliances, the EPA will require the adoption of either the Advanced Lighting Package (ALP), which requires a minimum of 60% of all hardwired fixtures to be Energy Star qualified, or the use of 80% screw-in Energy Star qualified CFLs. Furthermore to address savings available from lighting and plug-loads and to promote integration with other Energy Star qualified products, the 2011 guidelines will require that all major consumer appliances (e.g., dishwasher, refrigerator, clothes washer), bathroom exhaust fans, and ceiling fans installed during construction of the home be Energy Star qualified. Both of these measures will be mandatory requirements in the 2011 guidelines.

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[120] Ibid, p4.

A.2.3.4 Improving the equivalence between the performance and prescriptive paths and improving adoption of market-transforming technologies and practices

To date the Energy Star Qualified Homes program required a fixed HERS index value. As presented in Section 4.2.2, an Energy Star qualified home must implement energy efficiency measures to achieve a HERS index of 80 in mixed/cold climate zones or 85 in hot climate zones. Unfortunately, while keeping the energy efficiency measures constant and simply changing one or more design features, the HERS index could be manipulated to vary significantly. Such design anomalies, which are largely not influenced by the Energy Star Qualified Homes program, include[121]:

- Fuel choice for space and water heating (e.g., gas, oil and electric)
- House size and dimensions
- Degree of attachment to other structures (i.e., single-family detached vs. multi-family)
- Geographic locations within the same climate zone, or across a nearby climate zone boundary
- Foundation construction (e.g., basement, crawl space, slab-on-grade)
- Number of bedrooms
- Number of stories

Given a constant set of energy efficiency features, individual design features can alter the HERS index up to several points each and in combination to more than 15 points. As a result, a home could be thrown into or out of program compliance without changing any energy efficiency measures promoted by the Energy Star Qualified Homes program. This unintended consequence interferes with the market transforming goal of the program—recognizing and rewarding builders that have changed their building practices relative to non-participants to create high-quality energy efficient homes, and thereby to create value in the marketplace for qualified homes. If a large two-story basement home in a cold climate can qualify with significantly fewer improvements than

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[121] Ibid, p4.

a smaller single-story slab-on-grade home next door, then the metrics fail to recognize homes that are meaningfully more efficient.

To advance toward a more equitable assessment methodology, the EPA has proposed a new Energy Star Reference Design home used for the performance path. The characteristics of this new Energy Star Reference Design home closely follow EPA's prescriptive qualification requirements. For the Energy Star Reference Design home, any given proposed home would be modeled using accredited rating software and these prescriptive requirements, and then compared to the EPA's reference home with modified modeling rule set. The resulting HERS Index would then be used as the base HERS Index for that home. This base HERS Index would be further modified by a size adjustment factor, if necessary, to arrive at the qualifying HERS Index for the proposed home[122].

Not only does this approach eliminate the problems associated with disparities in HERS scores caused by differences in the design features as listed above, but it enables the program to achieve true parity between the performance path and the prescriptive (Builder Option Package) bundle of available, cost-effective Energy Star qualified equipment and products. In addition it allows the Energy Star HERS index target to automatically adapt to changes in the:

- HERS reference home
- HERS algorithms
- Energy Star Qualified Homes prescriptive path

A.2.3.5 Addressing absolute house size and carbon footprint

One of the advantages of the revised definition for the performance path discussed above is to take away the "per-square-foot" performance bias for large homes. With earlier versions of the guidelines, a 5,500 sq. ft. home could qualify for Energy Star more easily than a similarly constructed 1,500 sq. ft. home, even though it might consume more energy and produce more greenhouse gas emissions by up to a factor three. After careful analysis EPA will adopt a policy to "reward appropriate smallness" and "penalize

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[122] RESNET, RESNET Summary and Positions On EPA's Proposed 2011 ENERGY STAR New Homes Guidelines (v3.0), June 19, 2009, p4.

wasteful largeness"[123]. To accomplish this, a decreased HERS index will be required for homes larger than the average size new homes currently being built with the same number of bedrooms.

The size of today's "average" home with a given quantity of bedrooms has a conditioned floor area (CFA) referred to as the baseline size. The CFA for the baseline size is shown in Table 28. For homes larger than the baseline size, the required HERS index value for Energy Star qualification is decreased by multiplying by the following size adjustment factor (SAF) taken from Figure 44.

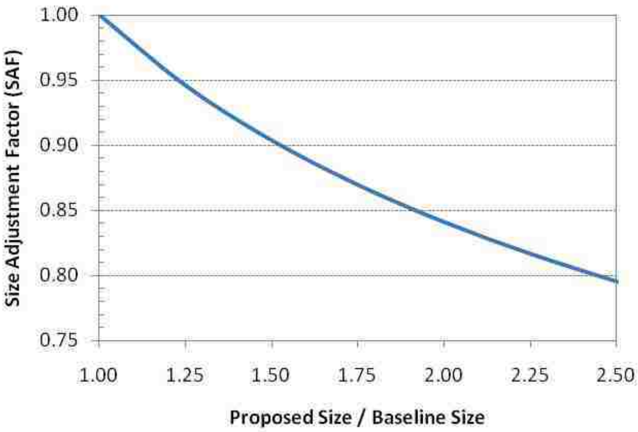

Figure 44. EPA's proposed Size Adjustment Factor (SAF) shown relative to the ratio of the proposed size divided by EPA's baseline size. Ref: RESNET Summary and Positions On EPA's Proposed 2011 ENERGY STAR New Homes Guidelines (v3.0), June 19, 2009, p7.

Table 28. Conditioned floor area of baseline size for given quantity of bedrooms[124].

Bedrooms in Home to be Built	1	2	3	4	5	6	7	8
CFA of the baseline size [ft^2]	1,000	1,600	2,200	2,800	3,400	4,000	4,600	5,200

There are two additional constraints regarding achievement of the resulting HERS index value for homes larger than the baseline size[125]:

- The HERS index of the Energy Star Reference Design home must include the use of all renewable energy generated on-site.
- The reduction in HERS index imposed by the application of the size adjustment factor can be met by the use of renewable energy generated on-site as well as by any combination of conservation measures.

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[123] Op cit, Energy Star Program, p5.

[124] Ibid, p5.

[125] Ibid, p6.

A.2.4 LEED 2009

The recent publication of “LEEDing from Behind: The Rise and fall of Green Building”[126] reviews the shortcomings of the LEED rating system and its failure to properly weight energy efficiency given the state of climate change and the weakened economy. “[I]n its own study last year of 121 new buildings certified through 2006, the Green Building Council found that more than half — 53 percent — did not qualify for the Energy Star label and 15 percent scored below 30 in that program, meaning they used more energy per square foot than at least 70 percent of comparable buildings in the existing national stock.”[127] However, the USGBC is only a few months away from launching LEED v3.0, also known as LEED 2009, and it is making changes aimed at increasing the weighting of energy efficiency. Table 29 compares the current LEED 2.2 with the new algorithm for LEED 2009. Inspection reveals that the “Energy and atmosphere” category has moved from an overall weight of 25% to 32%—a significant increase. However, the subcategory for efficiency (“Optimize energy performance”) has only nudged up a few percent. Consequently, the LEED rating will continue to effectively hide the significance of building energy efficiency from the public.

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[126] Pat Murphy, “LEEDing from Behind: The Rise and Fall of Green Building,” *New Solutions*, Community Solutions, May-June 2009.

[127] Mireya Navarro, “Some Buildings Not Living Up to Green Label,” *The New York Times*, August 31, 2009.

Table 29. Comparisons for LEED 2.2 and LEED 2009.

Version	LEED 2.2		LEED 2009	
Category	Points	%	Points	%
Energy and atmosphere	17	25%	35	32%
Optimize energy performance	*10*	*14%*	*19*	*17%*
Onsite renewable energy	*3*		*7*	
Enhanced commissioning	*1*		*2*	
Enhanced refrigerant management	*1*		*2*	
Measurement and verification	*1*		*3*	
Purchase green power	*1*		*2*	
Indoor environmental quality	15	22%	15	14%
Sustainable sites	14	20%	26	24%
Materials and resources	13	19%	14	13%
Water efficiency	5	7%	10	9%
Innovation and design process	5	7%	6	5%
Regional bonus credits	0	0%	4	4%
Totals	69	100%	110	100%

With 2 mandatory points in the efficiency category to qualify for certification (see Table 30), the threshold for all LEED ratings remains at 14% below the EUI calculated for the standard reference building as defined by ASHRAE/IESNA Standard 90.1-2007 Appendix G. However, since this standard is approximately 5% more efficient than the previous ASHRAE/IESNA Standard 90.1-2004, the qualifying threshold for LEED ratings has moved down 5% as well. While any energy conservation discernment is hidden in a quantitative sense, at least the threshold effect, pass/fail, may prevent some business-as-usual buildings from achieving LEED certification.

Table 30. Distribution of LEED 2009 points for efficiency. Points are allocated on the basis of the percentage reduction of the EUI for the proposed building with

New Buildings	Points	
12%	1	Mandatory
14%	2	Points
16%	3	
18%	4	
20%	5	
22%	6	
24%	7	
26%	8	
28%	9	
30%	10	
32%	11	
34%	12	
36%	13	
38%	14	
40%	15	
42%	16	
44%	17	
46%	18	
48%	19	

A.2.5 Building energy benchmarking

Building energy benchmarking is similar to building energy labeling—only the plaque on the wall of the building is missing. As its name suggests, "benchmarking" involves gathering energy performance data from operating buildings and comparing with the building inventory, typically CBECS. If coordinated with an energy service provider, the use of Portfolio Manager can enable an essentially continuous automated monitoring process, which can detect problematic trends in building operations for the building owner or manager.

Some states and cities are now taking benchmarking to a level just short of labeling. These jurisdictions are requiring that certain classes of building collect this data. Frequently these buildings are government owned, so they are not inflicting what should be perceived as good practice on the private sector. However in California, which is known for innovative standards in environmental legislation, nonresidential building owners were required to start collecting building energy consumption data on January 1, 2009 under California's Assembly Bill 1103 (AB 1103). State owned buildings were already subject to this requirement. As of January 1, 2010, the most recent 12 months of this data must be made available to parties in a commercial real estate transaction involving the sale, lease or financing of a *whole* building. According to the California Energy Commission (CEC)[128], the intent of the law is "commercial valuation of energy usage" during a financial transaction, just as floor area is valued.

The CEC has a work group in place to create the regulations regarding California's AB 1103. They will need to address issues such as an implementation schedules, how exactly the benchmarked data will be disclosed, and what to do about exceptional spaces, e.g. buildings vacant for months. Because many building types in California extend beyond the types supported by Portfolio Manager and consequently can not be rated through Portfolio Manager, the CEC is considering a statewide assessment that would offer a California-specific rating so that these building types can be compared to their peers within California[129]. The initiatives proposed in the Waxman-Markey

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[128] Naomi Millán, California AB 1103 Requires Energy Benchmarking Data Released During Sales, http://www.facilitiesnet.com/energyefficiency/article/California-AB-1103-Requires-Energy-Benchmarking-Data-Released-During-Sales--11020, Sept 19, 2009.

[129] Ibid.

legislation if passed and implemented would cover 90% of these exceptional types and obviate the need for this California effort.

California is not alone with its energy use disclosure legislation. Washington, D.C., also passed a benchmarking law for all non-residential facilities, extending the disclosure requirements stipulating that data will be made available to the public through Portfolio Manager with the program starting in January 2010 and full implementation by 2013. Table 31 summarizes these nationwide benchmarking efforts, which use EPA standards.

Table 31. Benchmarking policies leveraging Energy Star tools[130].

State/Municipality	Policy	Summary
Borough of West Chester, PA	Borough Ordinance	This Ordinance requires new commercial construction to be Designed to Earn the ENERGY STAR and benchmarked annually in EPA's Portfolio Manager.
City of Austin, TX	ECAD Ordinance for Owners of Commercial Buildings	Austin's Energy Conservation Audit and Disclosure Ordinance requires that eligible commercial facilities calculate their energy performance ratings not later than June 16, 2011, using a rating system approved by the director of the Austin Electric Utility. Facilities must disclose this information to a purchaser or prospective purchaser of the facility before the time of sale. The City has defined EPA's Portfolio Manager as the approved system for buildings with more than 5,000 square feet of space.
City of Denver, CO	Executive Order 123	Executive Order 123 requires new construction and major renovations of existing and future city-owned and operated buildings to be Designed to Earn the ENERGY STAR and benchmarked in EPA's Portfolio Manager.
District of Columbia	Green Building Act of 2006 Clean and Affordable Energy Act of 2008	The Green Building Act of 2006 requires District-owned commercial buildings to be "Designed to achieve 75 points on the EPA national energy performance rating system as determined by the ENERGY STAR Target Finder tool" and benchmarked annually in EPA's Portfolio Manager. The Clean and Affordable Energy Act of 2008 requires that, beginning in 2010, eligible privately-owned commercial buildings be benchmarked using Portfolio Manager on an annual basis. Statements of energy performance will be published on a publicly available online database.
State of CA	AB 1103, 2007	Assembly Bill 1103 requires, as of January 1, 2009, electric and gas utilities to maintain and make available to building owners the energy consumption data of all nonresidential

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[130] EPA, State and local governments leveraging Energy Star, June 3, 2009, p1, http://www.energystar.gov/ia/business/government/State_Local_Govts_Leveraging_ES.pdf

		buildings in a format compatible for uploading to EPA's Portfolio Manager. It also requires, as of January 1, 2010, that a nonresidential building owner or operator disclose Portfolio Manager benchmarking data and ratings to a prospective buyer, lessee, or lender as part of a whole-building transaction.
State of MI	EO 2005-4, 2005	Executive Order 2005-4 requires the Department of Management and Budget to establish an energy efficiency savings target for all state buildings managed by the Department or another department or agency within the Executive Branch of state government. It requires that all state buildings occupied by state employees be benchmarked using EPA's Portfolio Manager.
State of OH	EO 2007-02	Executive Order 2007-02 establishes that the State of Ohio will use EPA's Portfolio Manager as the benchmarking tool for state-owned facilities to establish building baselines and measure and track energy use and carbon emissions within the state.
State of WA	SB 5854 - 2009-10	SB 5854 - 2009-10 requires qualifying utilities to maintain records of energy data of all nonresidential customers and qualifying public agency buildings in a format compatible with EPA's Portfolio Manager. The State will use Portfolio Manager for state-owned facilities and make resulting energy performance metrics publically available. Beginning in 2010, eligible privately-owned commercial buildings are required to be benchmarked using Portfolio Manager and resulting metrics will be disclosed to a prospective buyer, lessee, or lender. For new construction, the WA Department of Community, Trade, and Economic Development must determine the appropriate methodology to measure achievement of state energy code targets using EPA's Target Finder or equivalent methodology.

B Appendix—Methodology for simulations

After the discussions in Chapter 4 and Appendix A of rating building energy labeling schemes, I anticipated that the case studies of APS schools could provide not only insights into the building energy labeling processes, but offer the opportunity to learn about energy analysis tools, their strengths and weaknesses, their appropriate use, and the level of effort required to use them. This appendix describes the approach for my modeling and the calculations of EUIs for designs.

B.1 EnergyPlus

I chose EnergyPlus as the software for all energy modeling for these case studies for three primary reasons: 1) it is the flagship tool for modeling today, 2) it is certified to meet ASHRAE 90.1 Appendix G performance requirements, and 3) it is public domain software. EnergyPlus is the direct descendant of two colossal efforts sponsored by the US government: DOE2 from the Department of Energy and its predecessors, and BLAST from the Department of Defense. Each had their own strengths and when merged, the code had more capability than any other energy-transport simulation package. Furthermore as the research community developed additional energy transport algorithms, those with general applications were ported into the EnergyPlus environment. At the time of the merger the original Fortran source code was basically abandoned and the code rewritten to enhance ease of maintenance and code enhancements.

As a public domain code it is available for free downloads to all and consequently available to all design firms regardless of size or financial backing. By developing this tool, the US government felt it would make an important contribution the development of energy efficient buildings. Part of the government's vision included private businesses that would use EnergyPlus as the core for their design tools and add graphic user interfaces to facilitate ease of use. While several commercial products have incorporated EnergyPlus, the market penetration has not been as great as the government had hoped.

Four utility programs come with the EnergyPlus package: EP-Launch, IDFEditor, xESOViewer, and OpenStudio. EP-Launch submits an input data file (IDF) to the EnergyPlus code and upon completion parses the main output file into a spectrum of special purpose files. Not all of these files are of interest each time the simulator runs. The IDFEditor is a tool helpful for the preparation and editing of the IDF file. It also formats the file to give it a human-readable form. xESOViewer is a quick-look graphing tool for very simple graphical output. Finally, OpenStudio is a plug-in code that operates in the Google SketchUp tool. With this plug-in, SketchUp users can quickly learn to create and edit models of the geometry required for EnergyPlus while preserving all the non-geometric content in an IDF. In combination I found the toolset surprisingly powerful and easy to use. The version of EnergyPlus that I am using is V 4.0.0 issued in October 2009.

The challenge is to learn the vocabulary of capabilities that EnergyPlus can perform if needed. I found example files included with the distribution to be a very powerful asset and made extensive use of them. For example, I consulted the multiple story building example to see how stories were “linked.” For natural ventilation, I checked that model. When I needed school schedules, I searched for an example and found one.

B.2 Modeling

The geometric form for the building to simulate is captured with the OpenStudio plug-in for SketchUp. Text based data entry is simply not an option—it’s far to complex and error prone. First scan the floor plan of the target building and create a JPEG file that is then imported into SketchUp. Then trace lines over walls needed to define thermal zones in the building. After the zones are all defined, extrude only one of these footprints into a volume. The exact dimensions of the footprint for the thermal model are not critical, although the overall floor area should be in fair agreement. Then edit the IDF produced by OpenStudio naming all walls, roofs, and floors with a pattern easily modified with a text editor. Next clone the geometric form of the first zone making as many copies as needed, and with a text editor modify the names of zones and surfaces to ensure uniqueness. Then return to SketchUp. At this point edit zone positions and the wall positions and extents to achieve the desired geometry. No additional naming of walls is required until a wall needs to be subdivided due to zone-adjacency requirements or to create a fundamentally different footprint for the zone.

It is then necessary to identify adjacent thermal zones in contact through common walls and identify the composition of each wall. This process is tedious and error prone. Fortunately EnergyPlus produces meaningful error messages in response to bad inputs, so debugging the IDF can precede systematically.

EnergyPlus needs to know the materials and thermal properties for each bounding surface surrounding a thermal zone. I found it helpful to use spreadsheets to gather this information and to identify each layer in the construction of a roof, wall, or window. Either you give EnergyPlus the R-value for the layer or you provide sufficient physical properties such that the code can calculate the R-value. The latter is preferred since this information also enables the material to transport *and* hold heat.

Locating the information for an older building can be challenging. In all cases I found floor plans for schools in the archives, but the plans frequently failed to provide sufficient information to ensure correct modeling of layers. For example in Figure 45, I demonstrate the dearth of information regarding the energy performance properties of the windows. This fragmentary detail is virtually all the information provided for these important building components. A search for the window specifications in the APS archives failed to locate any further data. With experience, a modeler will know the standard practice for various building components given the date of construction.

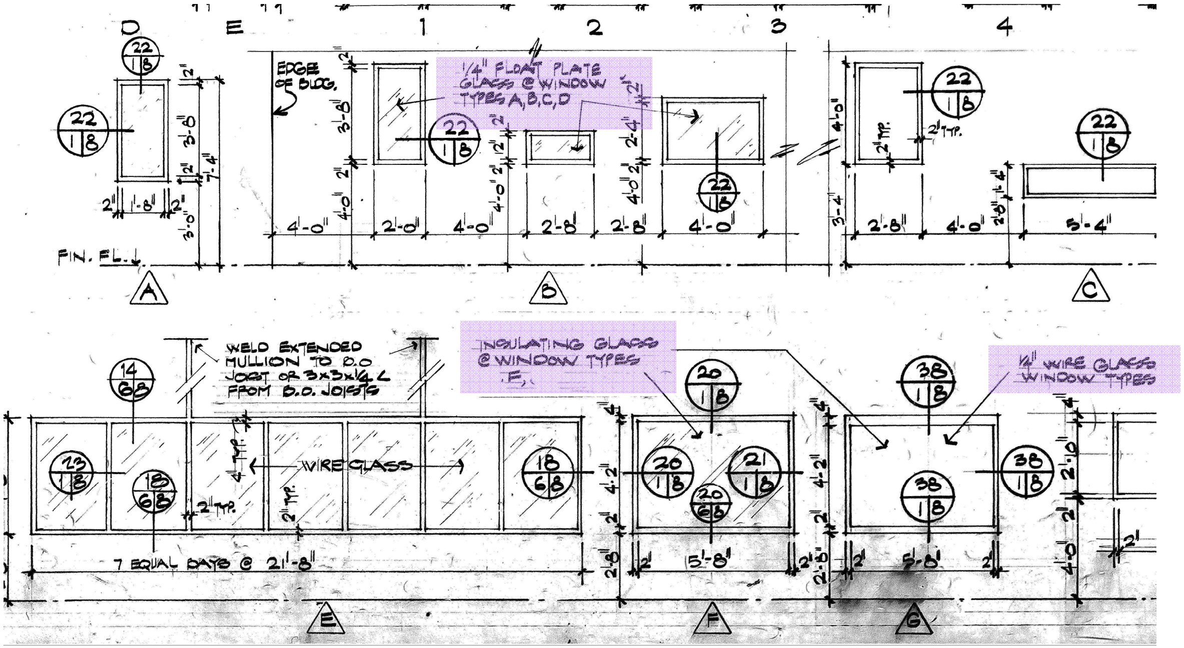

Figure 45. Sample window documentation for Hubert Humphrey Elementary. No additional window performance information for this 1978 building was found.

In situations such as these, educated guesses must also be made for the R-values of roof and wall layers.

As discussed in Chapter 4 and Appendix A, occupancy schedules, plug loads, and other unregulated variables introduce ambiguity for the modeler. To minimize arbitrary decisions, I adapted loads for my simulations from the internal loading for primary schools used for DOE benchmarks[131]. Although the benchmark used fixed loads for each zone, I converted these to internal loading densities and occupancy loading densities to generalize their flexibility for use in other geometries, e.g. the case studies presented here. These data are summarized in Table 32.

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[131] Net-Zero Energy Commercial Building Initiative: New Construction Benchmark Data Files http://www1.eere.energy.gov/buildings/commercial_initiative/new_construction.html, Oct 22, 2009.

Table 32. Internal loading densities used in the case studies.

Room classification	Internal load densities		
	People (no/m2)	Lights (W/m2)	Plug loads (W/m2)
Classrooms	0.25	15	15
Library	0.25	15	15
Offices	0.05	12	11
Lobby		15	4
Corridors	0.1	6	4
Bathrooms	0.01	10	4
Gym	0.3	15	5
Cafeteria	0.7	15	25
Kitchen	0.15	13	200
Mechanical	0.01	15	10

Each load is subject to a specified schedule to simulate actual building utilization. For example, students and employees will show up for classes on weekdays but not on weekends. The light and plug-load schedule would be correlated with student activities, but might include additional extracurricular activities on weekends and holidays. I used the schedules as defined by the DOE benchmark model for APS schools without modification.

The intent of the modeling is simply to assess the energy efficiency of the design. Professionals in the business indicate that agreement between the model prediction and the operational building ranges between 20-50%[132]. If agreement better than 20% is achieved, it should be considered simply a statistical phenomenon. Consequently selected details of the geometry may be approximated where in the judgment of the modeler the simplification are warranted. At this point with my very limited experience, I rely on the review of experts.

Unless the school being assessed is new, it is likely to have been renovated and expanded during its history. Bandelier Elementary, one of the three schools initially targeted for analysis, has experienced five different building phases. For the modeler this poses the additional complexity of establishing the materials and assemblies for walls,

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[132] Michael Witte, GARD Analytics Inc, private communication.

roofs, and fenestration. It essentially requires development of a separate model for each phase of construction.

B.3 Standard reference building

The flowchart in Figure 20 indicates that two simulations will be required for the as-designed rating: one to estimate the EUI for the building to be rated and another for the EUI of the standard reference building. The latter was extracted from the model of the building to be rated using the NREL's EnergyPlus Example File Generator,[133,134] an online tool still under beta testing. It preserves the geometry information from the IDF, redistributes the fenestration as a strip on windows along each face, and replaces the materials, constructions, and HVAC systems with ASHRAE 90.1 code compliant assemblies. The abstracted fenestration maintains the same window area on each side of the building, a feature proposed in for ASHRAE 90.1-2010. The materials may be selected to meet the requirement for either ASHRAE 90.1 1999, 2001, 2004, or 2007. I chose to benchmark against the ASHRAE 90.1-2004 standard since it is the current New Mexico commercial building energy code. For commercial buildings the HVAC system for the reference building depends upon the building size and the number of stories.

Identical thermal loads and schedules for building operations were extracted from the proposed building design and placed in the standard reference model. Consequently comparisons between the proposed building and the reference building are more meaningful than the comparison of calculated and actual EUIs for the building to be rated since no one can control its use.

Shading structures may be deleted from the reference building. Thus the proposed design gets credit for proper shading of windows. Similarly proper orientation counts as well. The reference building must be simulated in four orientations: the designed orientation, rotated 90°, rotated 180°, and rotated 270°. The resulting EUIs are then averaged to yield an EUI without optimization for orientation.

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[133] EnergyPlus Example File Generator, EPXMLPreproc2 (Windows 32 Version 0.1.2.30), http://apps1.eere.energy.gov/buildings/energyplus/cfm/inputs/index.cfm, Dec 2, 2009

[134] Nicholas Long, EnergyPlus: State-of-the-Art in Building Energy Simulation, National Renewable Energy Laboratory, September 11 , 2009.

B.4 HVAC models

The complexity of the HVAC system can be completely modeled in EnergyPlus in agonizing detail, and appropriately so, since engineers use the code to design and size systems. As I examined the chiller and boiler water loops of the 4-pipe system that feed the five air handling units, 20 fans, 15 variable speed drives, and 73 terminal units distributed to the thermal zones at Tierra Antigua Elementary, I realized that creating an as-built model for this complex HVAC system might not provide the optimum use of my time for this thesis. In response I simply used the HVAC system automatically generated for the reference building.

For the schools modeled, the automatically generated HVAC systems featured a direct expansion (DX) cooling coil and a natural gas heater coil in a single air loop for each thermal zone. Depending upon the size of the zone, the coefficient of performance (COP) varies for the DX system between 3.8 and 4.5, and the heater coil has an efficiency of 80%. A fan and an outside air mixer complete the air-handling components for each zone's HVAC system. For control there is dual thermostat with setbacks and a controller in each zone. Reuse of these HVAC systems in the proposed design fixes yet one more potential “variable” that would obscure the fundamental performance of the building envelope and its passive design features that architects can control. Of course the building owners and tenants very much care that both passive *and* active systems are well designed and well operated.

In this analysis I did not attempt to introduce a mixed-mode operation utilizing both the HVAC system and natural ventilation.

During simulations of a full year, the modeled building is subjected to weather conditions that represent typical conditions for the site. Although this data does not present extreme conditions, in preliminary assessments weather extremes are introduced specifically for ensuring proper sizing of the HVAC systems.

C Appendix—Passive performance of buildings

As done for millennia in ancient civilizations, architects, engineers, and builders should use materials, orientation, and geometry to create passive buildings with effective energy performance. Essentially one can mitigate the outdoor climate thus producing a more comfortable indoor climate. Is this passive performance a prerequisite for an energy efficient building? Can we rate this performance? The answer to both questions is "yes."

Consider the following four buildings: 1) a cover only—a shed with "air" walls, 2) a sealed insulated box, 3) a sealed insulated box with a south facing Trombe wall, and 4) now add natural ventilation. Our set of buildings is shown in Figure 46. The Trombe wall is configured as ¼"-glass, 4"-air, black solar absorber, and 16"-concrete layers. Table 33 shows all the materials and the construction of surfaces for simulations.

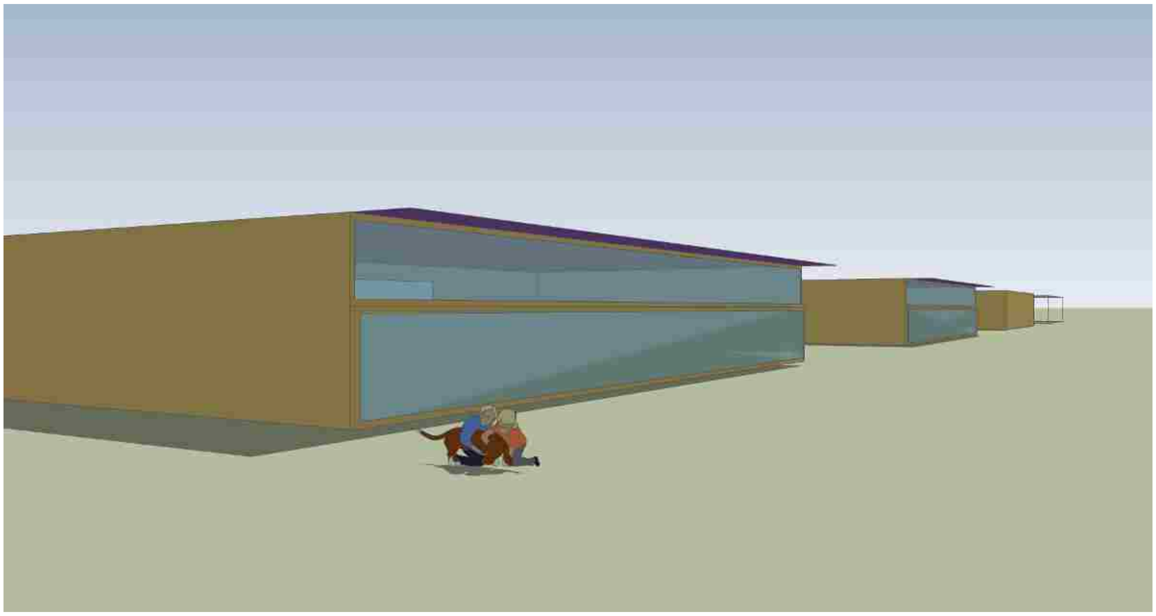

Figure 46. Four south facing buildings in the northern hemisphere. To the right in the distance is a simple insulated cover with walls made of air. These virtual walls trap air eliminating convection but conduct heat in and out. Moving to the left we find a sealed insulated box with an inoperable window on the north side. Next is the box with a low-rise Trombe wall facing south. The lower half (roughly speaking) is the unvented Trombe wall with double-pane glazing in the upper half. All windows are inoperable. Finally at the left is the box with Trombe wall plus it features operable windows to provide natural ventilation.

Table 33. Details of the materials and construction for the four passive buildings. EnergyPlus computes the performance of the air in the double-pane window.

material	conductivity (W/m/K)	thickness (m)	R (m^2.K/W)	R (Ft^2.F.h/BTU)
ROOF				
shingles	0.1141	0.0191	0.1674	0.95
sheathing	0.0635	0.0127	0.2000	1.14
3" dense insulation	0.0432	0.0762	1.7639	10.02
3" dense insulation	0.0432	0.0762	1.7639	10.02
2" insulation	0.0432	0.0509	1.1782	6.69
2" insulation	0.0432	0.0509	1.1782	6.69
1/2" gyp board	0.16	0.0127	0.0794	0.45
				33.86
EXTERIOR WALL				
stucco	0.6918	0.0254	0.0367	0.21
3" dense insulation	0.0432	0.0762	1.7639	10.02
3" dense insulation	0.0432	0.0762	1.7639	10.02
8" LW concrete block	0.5707	0.2033	0.3562	2.02
5/8" gyp board	0.1602	0.0159	0.0993	0.56
				22.83
SLAB FLOOR				
4" concrete - sand and gravel	1.729577	0.1014984	0.0587	0.33
TROMBE WALL				
3 mm low iron glass	0.9	0.003	0.0033	0.02
100 mm air				
Tabor solar absorber	392.61	0.0016	0.0000	0.00
8" HW concrete	1.729577	0.2033	0.1175	0.67
8" HW concrete	1.729577	0.2033	0.1175	0.67
DOUBLE PANE WINDOW				
1/8" clear glass	0.9	0.003	0.0033	0.02
air		0.013		
1/8" clear glass	0.9	0.003	0.0033	0.02

Data from the EnergyPlus simulation is shown in Figure 47. The buildings are sited in Albuquerque and use data for the weather from Albuquerque’s typical meteorological year, which includes weather data for every hour of the year (8760 hours). Looking at the temperature data in the upper half of the figure, the cover with its “air” walls track the outside temperature variations but seems to stay warmer without air exchange to the outside. The insulated box is warmer yet and smoothes out most of the diurnal variations. When the Trombe wall is functioning, the box gets warm and stays

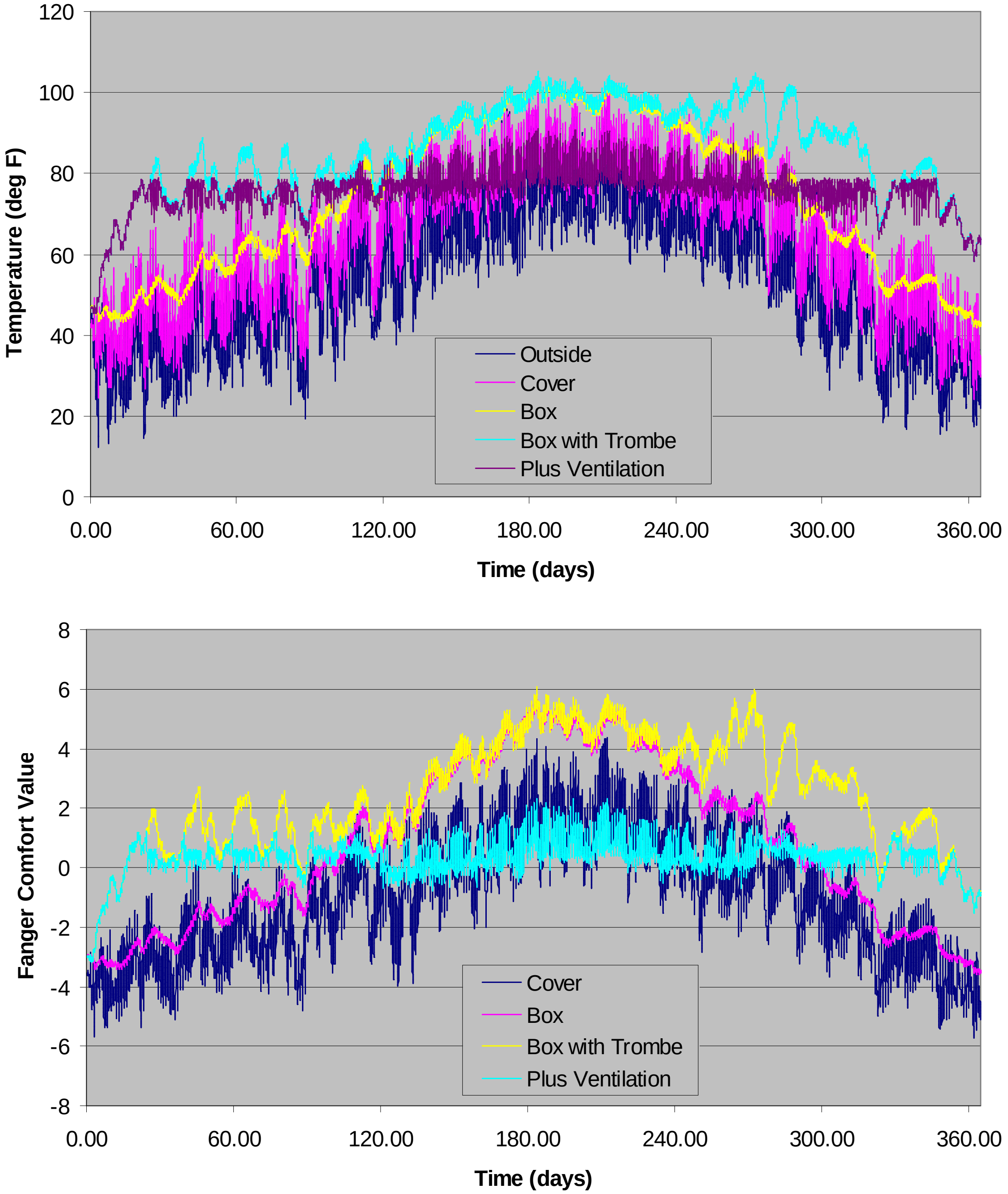

Figure 47. EnergyPlus simulation results for four passive buildings. The upper portion of the image shows the temperatures inside each building plus the outside temperature. The lower portion shows the Fanger Comfort Value inside each building. Note that the Trombe wall takes 20 days to warm up beyond the warmup days automatically allocated in EnergyPlus. This may be a problem with the convergence criteria, which I am unfamiliar with.

warm especially in the summer when the temperatures inside are routinely breaking 100°F from May to October. Finally the fourth building has operable windows and thus can exploit natural ventilation. The simulation opens the window when the internal temperature exceeds 76°F and assumes 10 air changes per hour (ACH). During the cold months this is very effective but less so in the summer when the outside air temperature is hot. However, the night flush cools the mass of the Trombe wall and helps moderate the temperature the following day.

Considerable research has been performed in understanding how and when humans feel comfortable in their environment. The environmental variables that influence the conditions of thermal comfort include:

- Air Temperature
- Mean Radiant Temperature
- Relative air velocity
- Water vapor pressure in ambient air

Fanger's Comfort model was the first one developed. First published in 1967[135], Fanger’s work set the stage for the other two models. EnergyPlus supports calculations of these comfort metrics. The scale of the comfort values is intended to reflect the thermal sensations as shown in Table 34. To explore the concept of the comfort value, I enabled EnergyPlus to calculate the Fanger comfort value for the four passive buildings and the results are displayed in Figure 47. The shapes of the curves look rather similar to the temperature data displayed above. Note that Fanger’s model takes clothing into account, and EnergyPlus enables clothing protection to be scheduled. I used the default from the DOE benchmark school.

Table 34. Nine point thermal sensation scale.

Sensation	**Value Description**
4	very hot
3	hot
2	warm
1	slightly warm
0	neutral
-1	slightly cool
-2	cool
-3	cold
-4	very cold

To further investigate the Fanger comfort value, I though it might be insightful to move my “cover” only building to a variety of locations that represent weather in the different climate zones of the US. But rather than display a Fanger comfort value for

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[135] P.O. Fanger, “Calculation of Thermal Comfort: Introduction of a Basic Comfort Equation”, *ASHRE Trans*., Vol.73, Pt 2. 1967.

8760 different hours, I summed all the negative values and also all the positive values. Then I added the *magnitudes* together and divided by 8760 to get the average Fanger displacement from the ideal zero. I expect that larger numbers to indicate less favorable climates and lower numbers those more favorable. If this result produces a sensible outcome, then I can believe such a metric actually evaluates comfortable climates.

The average of the (unsigned) Fanger comfort values for weather during an entire typical meteorological year is shown in Figure 48 for selected cities in different climate zones across the US. The Los Angeles climate achieves the minimum score. Climates to the left of LA in the chart are generally hotter or more humid and the climates to the right are cooler. In principle Las Vegas and Los Angeles are in the same climate zone but this metric says they are significantly different. My personal experience says Vegas is hotter and deserves the higher score. On balance I find it plausible that Los Angeles in climate zone 3B wins the weather competition. So my initial impression is that the average Fanger score does produce a sensible weather rating.

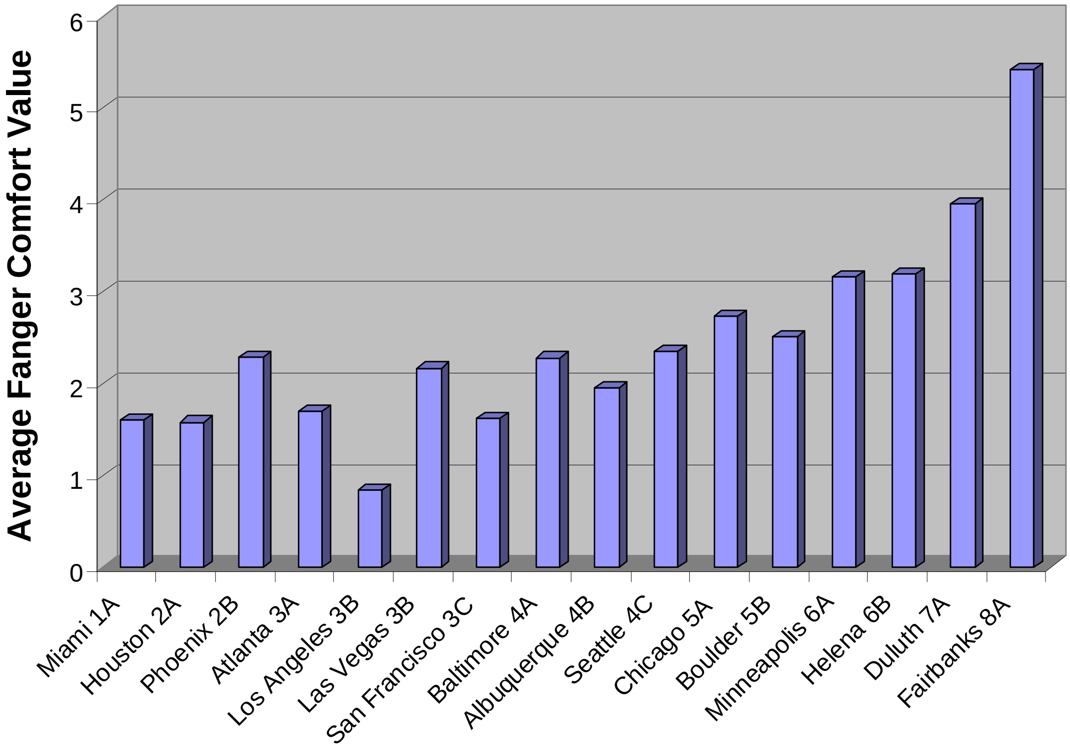

Figure 48. Average Fanger comfort values for selected cities in the different climate zones in the US.

Having justified or validated the average Fanger value as a comfort metric, we can apply it to buildings. After all, what is a building but an intervention to establish a microclimate inside the building that is more comfortable than the one outside? To test this metric with buildings we similarly apply the average Fanger comfort value algorithm to the four passive buildings in Albuquerque. These resulting metrics, shown in Figure 49, summarize nicely the temperature data presented in Figure 47.

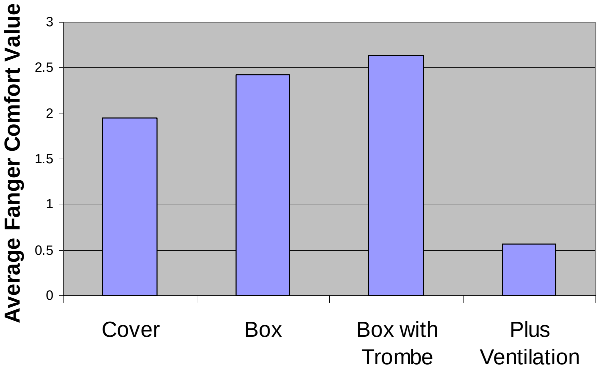

Figure 49. Average Fanger comfort value for the four passive buildings in Albuquerque.

In conclusion it seems apparent that when the average Fanger comfort value is low (< 0.5), the conditions appear favorable for no or little HVAC conditioning of the space to achieve human comfort. If the building can produce this mild microclimate indoors, then it is well on its way to becoming an energy efficient building. Having now established a simulation methodology that includes an assessment of the microclimates inside this simple passive building, we turn now to real buildings.

C.1 Hubert Humphrey Elementary

The model for the passive performance assessment is the same as that presented in Chapter 5 except the HVAC systems are entirely deleted. In its place I added natural ventilation to zones at the periphery that had windows. As with the passive building of the previous section, this ventilation provided 10 ACH.

The results of the simulations were very different from the four passive building due to the occupancy, lights, and plug loads. As the simulation for kitchen shows in Figure 50, the comfort value varies significantly over the course of a day (see upper left hand corner). This January morning starts cold, gets warm, and then cools off again in the night as a consequence of the human activity and the use of equipment in the space. In the upper right hand corner the figure shows a January week that features the five school days followed by a weekend. Finally at the bottom of the figure the data for the entire year is presented.

As modeled, the passive kitchen exposes its workers to very hot temperatures during the summer months. While it seems odd that the school kitchen is in use during the summer months, during the school year in May and September the kitchen would be unusable without ventilation and an HVAC system. In contrast the nearby gym only gets warm in the summer as shown in the data of Figure 52. The day, week and year are shown with the same layout as data for the kitchen. We see the same weekly patterns for comfort value variations, but the excursions for the gym are far cooler ranging from cold to warm. Perhaps this condition is desired in a gym where the kids are exercising but little kids may not like those cold mornings in January. Perhaps an HVAC system in the gym would be useful. Perhaps insulation over the block walls would be even better.

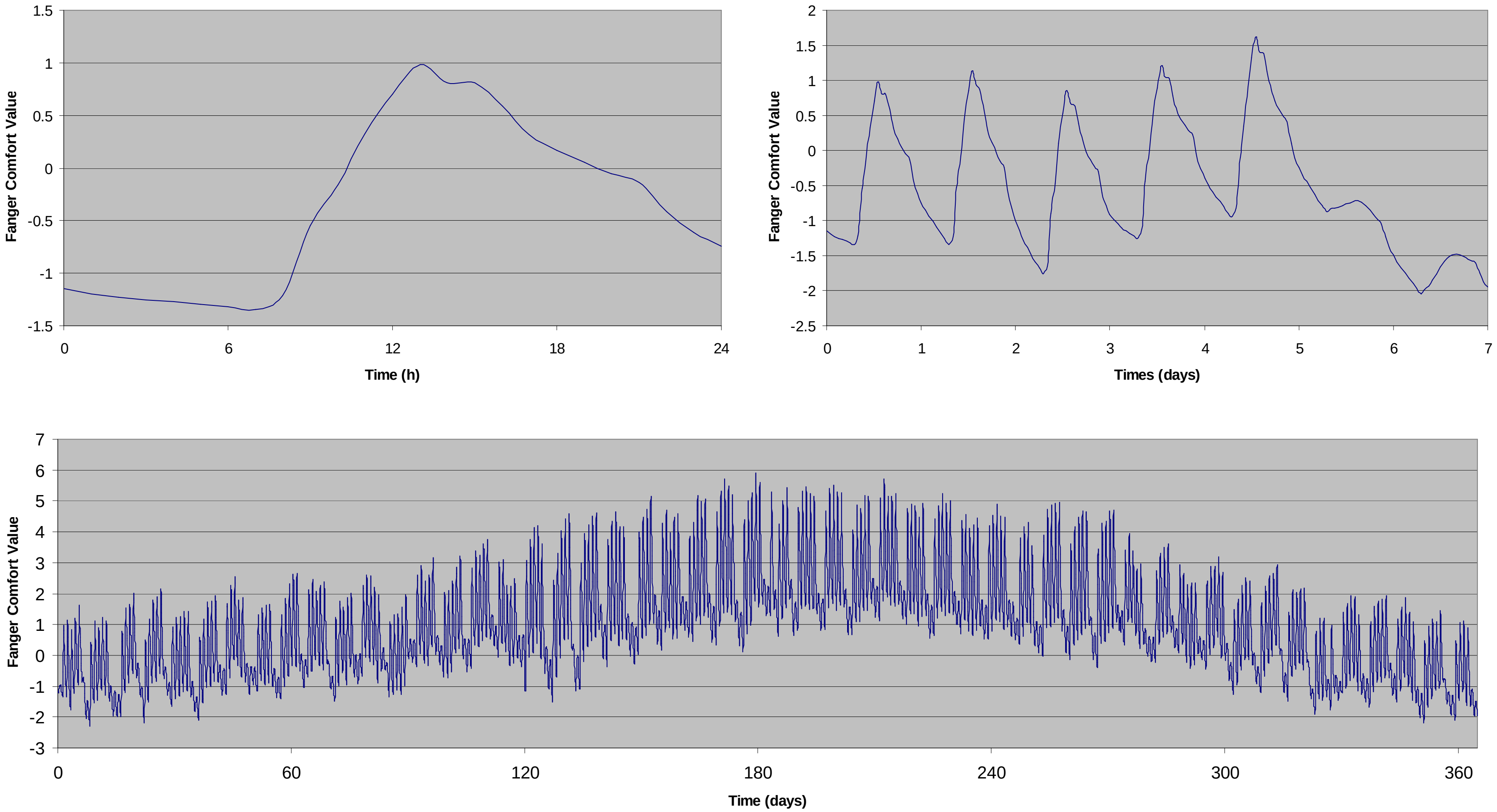

Figure 50. Calculated Fanger comfort values for the kitchen zone at Hubert Humphrey Elementary. Each plot starts on Jan 1 for the simulated year of operation. The upper left shows the first day, the upper right the first week, and the bottom the entire year. The five day work week is readily apparent as a source of heat loading. During the summer the kitchen is well past very hot (Fanger comfort value = 4). We see that the kitchen demands an HVAC system for routine operation. A similar plot for the gym reveals that unlike the kitchen, it is cold during much of the year.

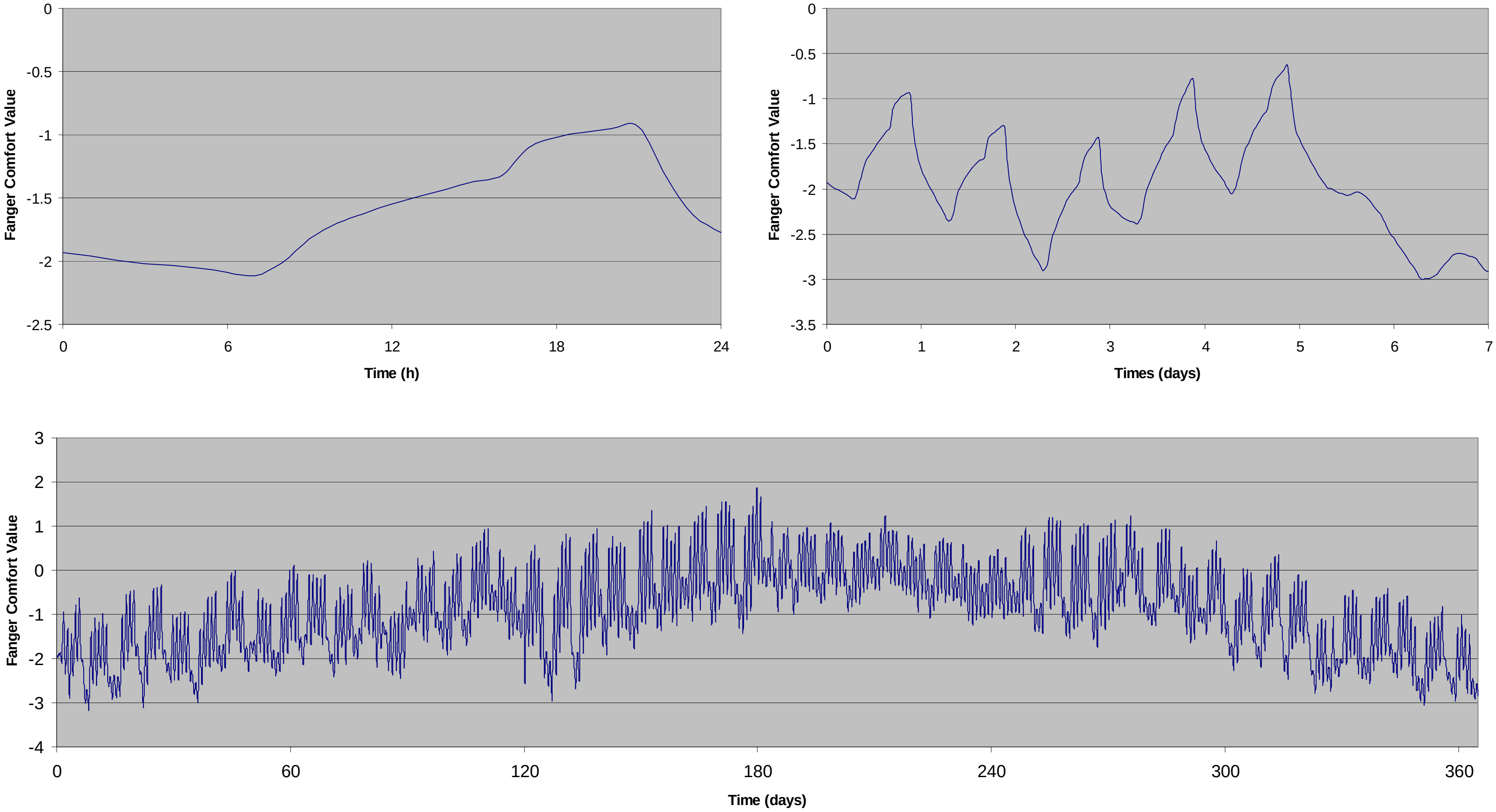

Figure 51. Calculated Fanger comfort values for the gym zone at Hubert Humphrey Elementary. Each plot starts on Jan 1 for the simulated year of operation. The upper left shows the first day, the upper right the first week, and the bottom the entire year. During the winter the gym is frequently cold, but with use warms up to the "cool" level late in the day. Although both the kitchen and the gym share the uninsulated concrete block walls, the heat loads produce dramatically different environments.

The hourly data reveals the fluctuations expected in a heavily used passive building. Clearly more ventilation and/or an HVAC system could target the comfort zone especially during the hours of operation. As the average Fanger comfort values in Figure 52 show, the kitchen and gym are extreme cases at Hubert Humphrey Elementary. While few of the other spaces achieve the metric associated with the LA climate, the passive features of the building have moved the indoor climate most of the way from Albuquerque to Los Angeles—not a bad starting point for the HVAC system to begin its work.

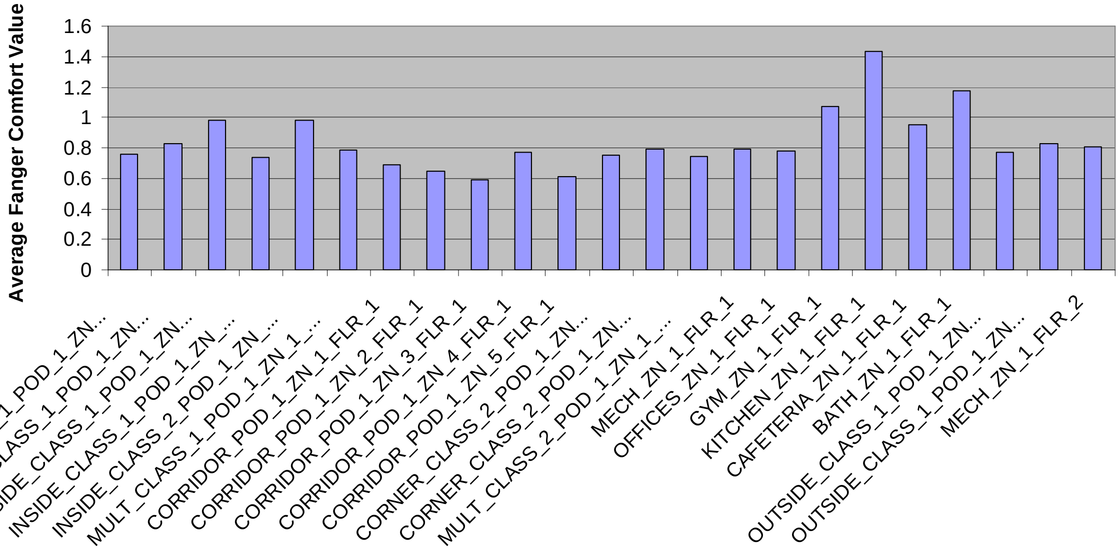

Figure 52. Annual average of the unsigned values of the Fanger comfort value for each of the zones in the model for Hubert Humphrey Elementary. The gym, kitchen, cafeteria, and bath occupy the uninsulated north side of the building, and these are among the least comfortable spaces in the school.

C.2 Tierra Antigua Elementary

The passive performance calculations for Tierra Antigua use the same model as the calculations in Chapter 5 except the HVAC systems are entirely deleted. In its place natural ventilation is added with 10 ACH when the indoor temperatures exceed 76°F.

For the purpose of comparisons the results are displayed with the same sequence of time frames as for the thermal zones at Hubert Humphrey—by the day, week, and year. Basically the comfort levels bounce from cool to warm each day, and except for ventilation to maintain indoor air quality there appears to be no need for an HVAC system to manage the heat loads given the “typical” weather modeled. I should point out that the “typical weather” is selected month by month from data accumulated over 30 years, and any months with extreme weather are excluded. So periods of weather can reasonably be expected to be harsher, and therefore the HVAC system is essential to provide comfort during these extremes.

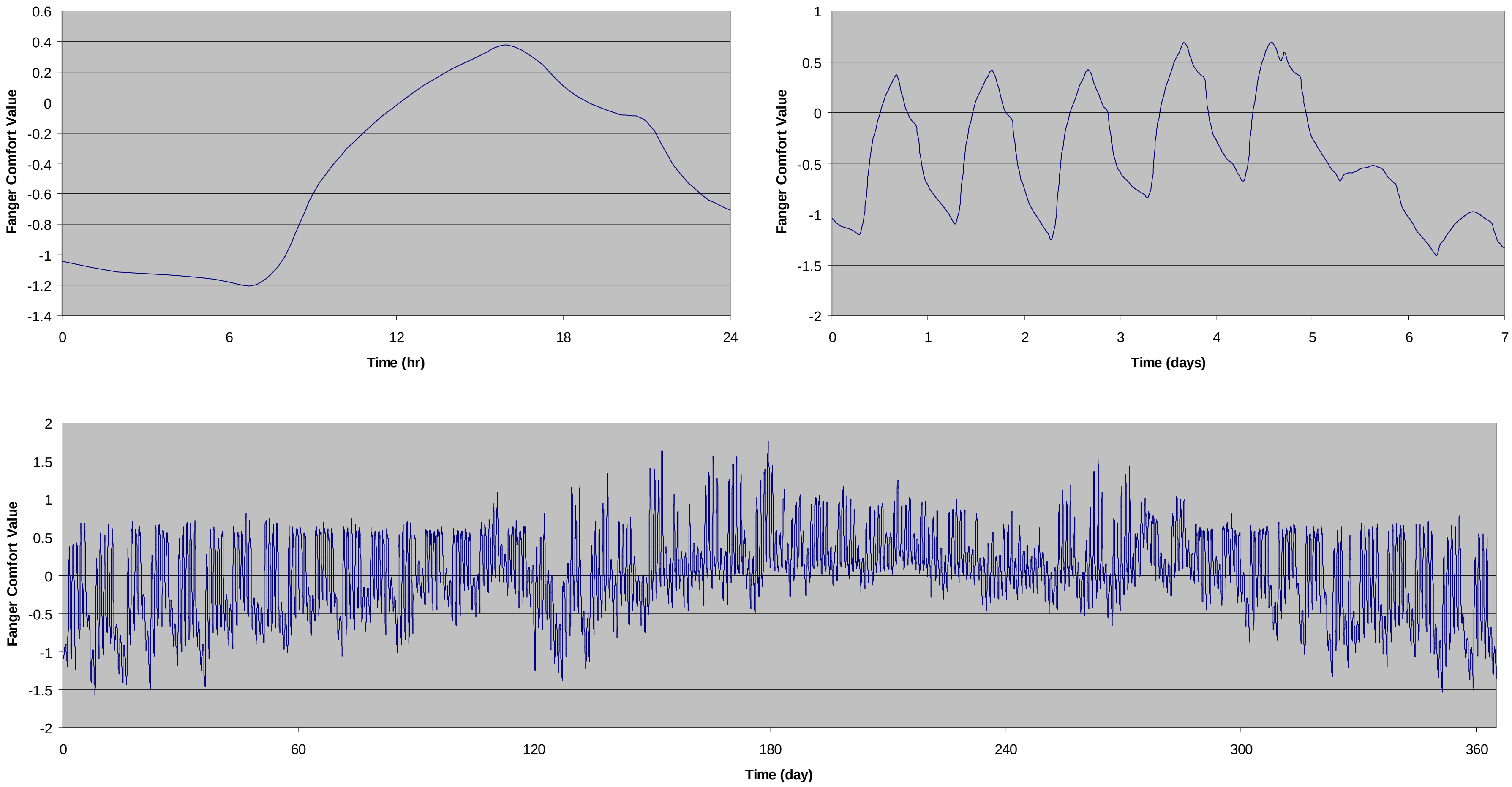

Figure 53. Calculated Fanger comfort values for a corner downstairs zone at Tierra Antigua Elementary. Each plot starts on Jan 1 for the simulated year of operation. The upper left shows the first day, the upper right the first week, and the bottom the entire year. The five day work week is readily apparent as a source of heat loading.

Figure 54 presents the indoor climate metric to characterize the thermal zones in the two-story wing of Tierra Antigua. The five zones on the lower floor (names ending in FLR_1) are systematically more comfortable than the zones on the upper level (names ending in FLR_2). While the difference is small, we would expect the space on the lower floor to be moderated by the overhead structure, and this result is obtained. The long "classrooms" that flank the north and south sides of the building show no significant difference from the south to north sides of the building—a tribute to the sunshades. Although my model of the sunshade is solid and does not include louvers, EnergyPlus does support louvers with a specified angle. The architect's specification required the vendor to supply shop drawings with their submittal, and this document should denote the relevant information for an improved model of the sun shade. Nevertheless, the performance of the passive building is quite good even without the controlled solar gain.

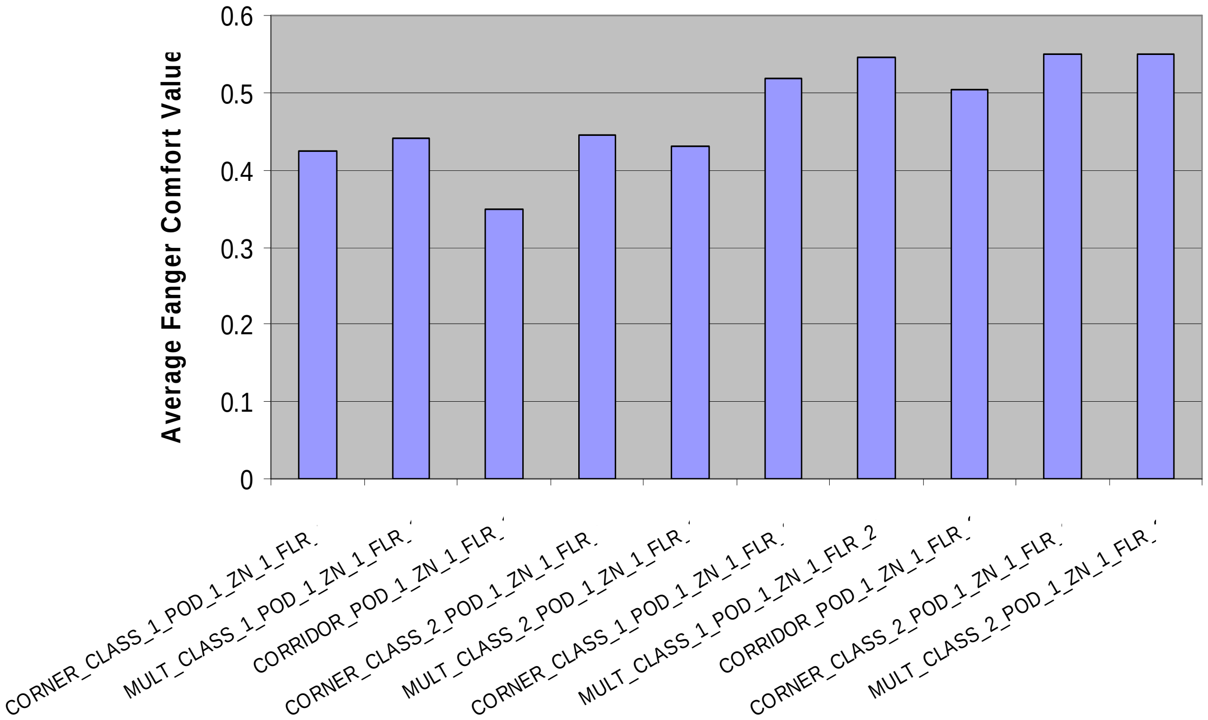

Figure 54. Annual average of the unsigned values of the Fanger comfort value for each of the zones in the model for Tierra Antiqua Elementary. These values are approximately half those for the classrooms in Hubert Humphrey.

The fact that there is little difference between the north and south sides is initially counterintuitive. Of course during the winter, the solar gains warm the south side as the sun gets low enough in the sky to shine under the shading. The Fanger comfort values reflect this and the south side is significantly more comfortable than the north during the cold months. But examination of the 8760 hourly Fanger values in the year reveal that the summer heat dominates the average. There the north and south rooms look similar thanks to the shading, and thus the average comes out about the same. This is a problem of trying to “summarize” 8760 data points with a single value.

The results with operational HVACs systems in Chapter 5 indicated the building would use essentially no heat for the winter season. However, it did require cooling during the summer months. The success of the passive performance demonstrated here suggested that natural ventilation be included in the model along with the HVAC system. Unfortunately this naïve approach resulted in the HVAC system fighting against the natural ventilation, and a more sophisticated strategy is necessary for mixed-mode ventilation. However, this analysis is beyond the scope of this thesis. The results of the passive performance study indicate that such a mixed-mode approach is warranted.