Cost-Effective Strategies for Reducing CO_2 Emissions from Santa Barbara's Residential Sector:

Implementation of The 2030 Challenge

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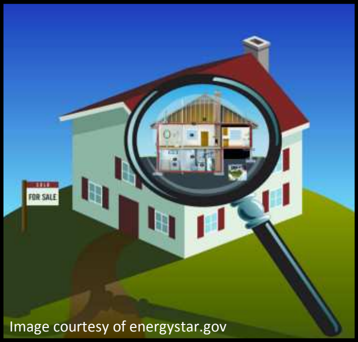

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DONALD BREN SCHOOL OF
ENVIRONMENTAL SCIENCE AND MANAGEMENT
University of California, Santa Barbara

As authors of this Group Project report, we are proud to archive it on the Bren School's web site such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Donald Bren School of Environmental Science & Management.

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The mission of the Donald Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principal of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a four quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

Dean Ernst von Weizsäcker, Advisor Date

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Abstract

In 2007, the city of Santa Barbara adopted The 2030 Challenge, an initiative calling for CO_2 emission reductions through building energy efficiency targets, including a 50% reduction in the kBtu/sf/year energy use of existing buildings compared to a regional baseline. This study identified and evaluated retrofit options that allow single-family homes in Santa Barbara to reduce consumption of electricity and natural gas. The regional baseline energy consumption was established using building energy modeling software, state and federal efficiency regulations and consumption data. Nine model homes representing Santa Barbara's housing stock were then retrofitted with 50 energy-efficient options addressing lighting, appliances, heating and cooling, hot water, and the building envelope. From these 50 options, we established combinations of technologies that reduce overall energy consumption to 50% below the regional average. The combinations were assessed for cost efficiency, revealing that Santa Barbara homes can meet the necessary reductions at costs ranging from $15,000 to $47,000 depending on age and size of the home. Through selective implementation of the most cost-efficient options, CO_2 emission reductions can be achieved for as little as $12.33 per tonne. Policies to achieve the necessary reductions were also identified and evaluated for effectiveness in Santa Barbara.

Executive Summary

INTRODUCTION & SIGNIFICANCE

Building construction and maintenance is the single greatest consumer of energy on the planet[1], and experts predict that building energy consumption will rise by 37% in the next twenty years under 'business as usual' scenarios[2]. Buildings account for almost 50% of United States energy consumption, and about 35% of US CO_2 emissions[3].

BACKGROUND

NATIONAL

In 2005, to address growing energy demand and emissions from the building sector, architect Ed Mazria introduced ***The 2030 Challenge***, a national initiative that asks the building community to adopt the following targets:

1. All new buildings and major renovations shall be designed to meet a fossil fuel, greenhouse gas-emitting, energy consumption performance standard of 50% of the regional average for that building type, while increasing reductions to reach carbon neutral (no net CO_2 emissions) by 2030.
2. At a minimum, an equal amount of existing building area shall be renovated annually to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 50% of the regional (or country) average for that building type[4].

Image courtesy of energystar.gov

The fossil fuel reduction standard for all new buildings shall be increased as follows:

Now: 50%
2010: 60%
2015: 70%
2020: 80%
2025: 90%
2030: 100% (Carbon Neutral)

LOCAL

In 2007, a group of local architects, engineers and non-profits formed the ***Architecture 2030 Coalition*** with goals to implement The 2030 Challenge in Santa Barbara. The Coalition is addressing Target 1 through policies that require new construction to exceed the requirements of California's Building Energy Code, Title 24.

BREN

This ***Group Project*** addresses Target 2 of The 2030 Challenge for Santa Barbara's residential sector, with the goal of identifying cost-effective technologies which can be installed into existing homes to achieve a 50% energy use reduction compared to a regional baseline.

GROUP PROJECT GOALS

1. **Identify technologies that achieve a 50% energy use reduction below a regional average baseline.**
2. **Calculate least cost options for reducing CO_2 emissions from existing residences in SB.**
3. **Provide alternative policy options to address The 2030 Challenge.**

METHODOLOGY

BASELINE

To establish a regional energy use baseline for residential homes, we addressed energy consumption associated with three main sources in the home:

1. Building envelope (windows, attic and wall insulation) & HVAC and DHW systems (Heating, Ventilation and Air Conditioning and Domestic Hot Water)
2. Lighting
3. Major Appliances

Consumption of kilowatt hours of electricity and therms of natural gas were normalized into one consumption unit: kBtu[*] per square foot per year (kBtu/sf/yr).

MODEL HOMES

The regional baseline was calculated using energy consumption associated with nine homes representing the existing housing stock in Santa Barbara. The nine 'model' homes range in size from 1,000 sf to 3,000 sf and were built between 1900 and 2007.

EQUATION PART 1: ENERGYPRO

EnergyPro is a software program that calculates energy use in buildings associated with HVAC, DHW, and building envelope characteristics. Using EnergyPro, we calculated the baseline energy use associated with the nine model homes as they currently exist. On average, homes in our region consume about 44 kBtu/sf/yr for HVAC & DHW.

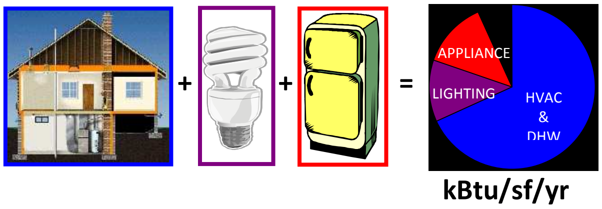
EQUATION PART 2: LIGHTING

A US Department of Energy survey conducted in 2002 revealed that, on average, homes across the nation consume 4.8 kBtu/sf/yr for lighting alone. This figure assumes that electricity use from lighting the home increases with the size of the home. This figure also assumes that home lighting is comprised of 80% incandescent light bulbs and 20% compact fluorescent light bulbs (CFLs), based on data specific to California.

EQUATION PART 3: MAJOR APPLIANCES

Energy consumption associated with major appliances was determined using minimum efficiency standards established by the US and California. Our baseline included a refrigerator, dishwasher, clothes washer, clothes dryer, electric stove-top, electric oven, microwave, television, DVD player, and six power supplies (phone, laptop charger, etc.). This part of the equation resulted in 13,221.89 kBtu/yr, regardless of the size or age of the home.

OVERALL EQUATION



RETROFITTING THE MODEL HOMES

After establishing the baseline energy consumption of homes in Santa Barbara, we calculated energy savings associated with retrofitting specific features within the nine model homes.

- In EnergyPro, we calculated energy use reductions associated with
  - increased attic insulation;
  - increased wall insulation;
  - more efficient windows;
  - exterior window shading;
  - more efficient HVAC systems;
  - more efficient DHW systems.
- For lighting, we calculated energy use reductions associated with changing all incandescent light bulbs to CFLs.
- For Major Appliances, we calculated energy use reductions associated with swapping all the minimally efficient appliances with the most efficient models available.

Retrofitting each single feature resulted in a specific energy use reduction; however no single feature achieved the 50% reduction goal.

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[*] kBtu = 1,000 British thermal units, a term used to describe the energy content of a fuel source.

METHODOLOGY

TECHNOLOGY COMBINATIONS

To reach the goal of 50% energy use reductions in existing buildings, we created combinations of technologies that provided cumulative reductions.

COMBO A – SOLAR THERMAL

- Efficient furnace & AC unit (94% AFUE & 13 SEER)
- Solar thermal hot water system with 50 gal storage tank
- Efficient windows with non-metal frame, double pane, low-E gas fill (U 0.32, SHGC 0.24)
- Increased attic insulation (R-40) & Radiant Barrier
- Increased wall insulation (R-19)
- All lighting to CFLs
- All new appliances

COMBO B – MUNCHKIN

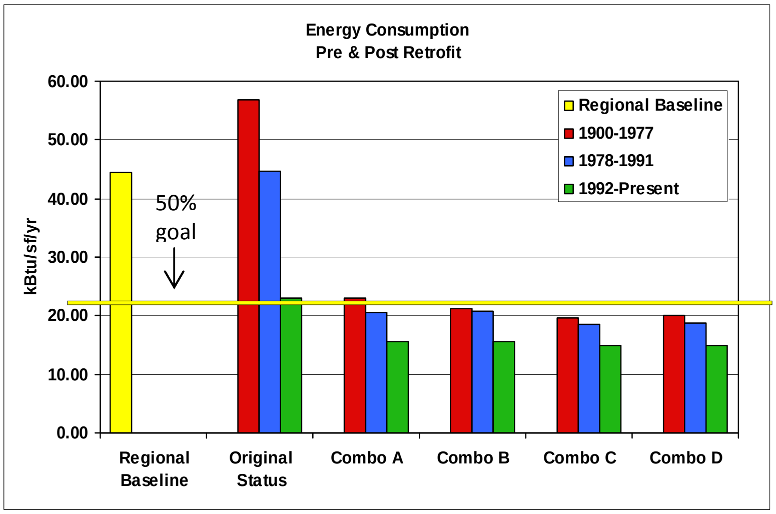
- Combined DHW/HVAC system with efficient Munchkin boiler & storage tank for hot water and radiant floor heating
- Efficient windows with non-metal frame, double pane, low-E gas fill (U 0.32, SHGC 0.24)
- Increased attic insulation (R-40) & radiant barrier
- Increased wall insulation (R-19)
- All lighting to CFLs
- All new appliances

COMBO C – GEOTHERMAL

- 3-ton geothermal heat pump & duct maintenance
- Tankless water heater (EF 0.84)
- Efficient windows with non-metal frame, double pane, low-E gas fill (U 0.32, SHGC 0.24)
- Increased attic insulation (R-40)
- Increased wall insulation (R-19)
- All lighting to CFLs
- All new appliances

COMBO D – LOW COST

- Efficient furnace & AC unit (94% AFUE & 13 SEER) & duct maintenance
- Tankless water heater (EF 0.84)
- Efficient windows with non-metal frame, double pane, low-E gas fill (U 0.32, SHGC 0.24)
- Increased attic insulation (R-40)
- Increased wall insulation (R-19)
- All lighting to CFLs
- All new appliances



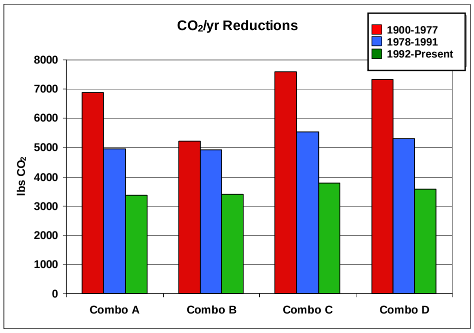
Almost all Combos resulted in reductions below the 50% goal for each set of homes.

RESULTS

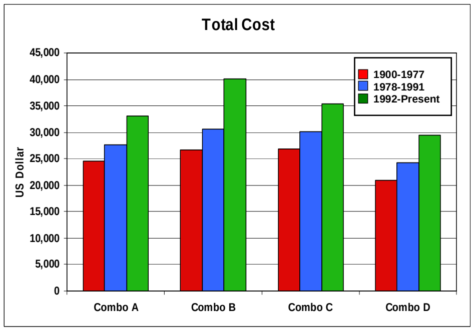
The combinations were assessed in terms of energy savings, CO_2 savings and overall cost. The following charts reveal the results from the nine model homes, which were divided into three data sets:

1. Older homes, built before Title 24 was established in 1978
2. Homes built between 1978 and 1991, when Title 24 received major requirement upgrades
3. Newer homes built between 1992 and present, after Title 24 was upgraded.

Because the three sets of homes were constructed under different building code requirements, the retrofits showed substantially different results in terms of energy use reductions, CO_2 reductions, and overall cost.



Combo C provides the biggest CO_2 reductions due to the geothermal heat pump, which drastically reduces natural gas consumption.



Combo D proves to be the least expensive.

RESULTS

We assessed cost efficiency of the single technologies and combinations in terms of payback, or the amount of time it takes to recoup the initial investment based on monthly utility bill savings. The following chart reveals payback times assuming an increasing cost of energy based on historical pricing trends[5].

Most Cost-Effective Technologies (Payback)

Technology	Time
Duct maintenance	6 months
All lighting to CFLs	7 months
Increased attic insulation (R-40)	21 months
Increased wall insulation (R-19)	4 years
Tankless water heater (EF 0.84)	4 years
Efficient furnace & AC unit (94% AFUE & 13 SEER) & duct maint.	6 years
Solar thermal hot water system	9 years
Efficient windows (U 0.32, SHGC 0.24)	10 years
New dishwasher	14 years
New clothes washer	15 years
Combined DHW/HVAC system with radiant floor heating	15 years
Combo A	23 years
Combo B	27. years
Combo C	24 years
Combo D	**21 years**

To determine the cost effectiveness of retrofits in terms of achieving carbon neutrality, we calculated the cost per pound of CO_2 reduced.

Most Cost-Effective Technologies (CO_2 Reduction)

Technology	Cost
All lighting to CFLs	1 cent/lb
Tankless water heater (EF 0.84)	9 cents/lb
Duct maintenance	11 cents/lb
New dishwasher	12 cents/lb
Increased attic insulation (R-40)	12 cents/lb
New clothes washer	12 cents/lb
Increased wall insulation (R-19)	22 cents/lb
Combined DHW/HVAC system with radiant floor heating	23 cents/lb
Solar thermal hot water system	26 cents/lb
Efficient furnace & AC Unit (94% AFUE & 13 SEER) & duct maint.	26 cents/lb
Combo A	35 cents/lb
Combo B	46 cents/lb
Combo C	32 cents/lb
Combo D	**27 cents/lb**

POLICY DISCUSSION

Implementing wide-scale retrofits of the existing residences in Santa Barbara to obtain substantial energy consumption and CO_2 reductions will require political and financial support, from both the local government and individual homeowners.

Because Santa Barbara is almost completely developed, addressing retrofits to existing buildings at the rate of new construction, as recommended by Architecture 2030, will not lead to substantial reductions. Following these guidelines will result in around 40 retrofitted homes per year, or less than 5% of the existing housing stock by 2030.

Alternatively, to adequately address the existing home stock, we suggest the use of a **time-of-sale ordinance** that requires specific retrofits each time a home changes ownership. Considering the number of home transactions that take place each year, this policy results in retrofits to over 80% of the existing homes in Santa Barbara by 2030.

To take some of the cost burden away from home buyers or sellers, the City of Santa Barbara could subsidize costs with a revenue-generating tax on energy prices. With a 5% non-compounding tax on projected increasing energy prices, the City could generate substantial revenue with which to support retrofitting. The City could also establish a financing mechanism whereby the retrofit costs could be rolled into the life of the mortgage loan, making the upfront expenditures appear less cost-prohibitive.

The time-of-sale ordinance could require retrofits that are prescriptive (same retrofits for every home regardless of age or size) or performance-based (retrofits specific to the home depending on existing features).

References:
1. Seattle Office of Housing, 2002
2. Architecture 2030, 2005
3. Architecture 2030, 2008
4. Seattle Office of Housing, 2002
5. UCSB Economic Futures Study, 2007

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Figures & Tables

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1. Significance

1.1 Energy Use and Emissions Related to the Building Sector

With only 5% of the world's population, the United States currently emits 25% of the world's total greenhouse gas emissions (Baer et al., 2000). Fifty percent of the emissions of the United States are linked to the building sector (City of Seattle Office of Housing [CSOH], 2002). Additionally, energy consumption by buildings is predicted to rise by 37% in the next twenty years under 'business as usual' scenarios (Architecture 2030, 2005).

1.2 Climate Change and the Building Sector

Anthropogenic emissions of greenhouse gases (GHGs) are causing a general warming of the Earth's climate regime (Intergovernmental Panel on Climate Change [IPCC], 2007a). This shift in climate will likely have substantial and overall negative impacts on human health, including an increase in malnutrition; increased death, disease and injury due to natural hazards such as fire, hurricanes, and drought (IPCC, 2007b). In addition to human health impacts, climate change will likely result in substantial landscape changes, including desertification, changes in crop productivity, and changes in freshwater regimes. Coastal areas will be uniquely affected due to storm flooding and general sea level rise.

Under a moderate warming scenario, mean California temperatures are likely to increase by 5.5 degrees to 8 degrees Fahrenheit by the end of the century, although levels of precipitation are not predicted to change dramatically (California Climate Change Center [CCCC], 2006). Despite a relative constancy of precipitation, the increased temperatures will mean that more of the moisture will fall as rain instead of snow, changing the water regime of a state that has already allocated most of its water resources. What has been a natural storage of water in the Sierra Nevada Mountains in the form of snow, will increasingly wash into the Pacific as unusable runoff. Other potential impacts to California include decreasing air quality, increased chance of wildfire, and varied impacts on valuable crops including fruit and nut trees, and wine grapes (CCCC, 2006).

Local impacts from climate change in Santa Barbara are distinct possibilities as well. The city's beaches and ocean-front property will be under pressure from increased erosion and sea level rise. Marine and wildlife could be threatened from the increase in competition from non-native pest and pathogen invasions. The agricultural economy may find itself facing unexpected challenges from temperature changes.

1.3 Energy Independence and the Building Sector

In addition to the risks posed by climate change, our region and nation face the threat of fuel scarcity. As oil production slows and fossil fuels become more difficult to find, 'peak oil' may become a reality. This technically refers to the point at which the rate of oil extraction from the earth has reached its maximum possible level (Community Environmental Council [CEC SB], 2007). After this point, the cost of energy will steadily increase unless alternative energy sources are readily available. Many experts agree that peak oil has already occurred (CEC SB, 2007), and with oil prices closing at over $100.00 per barrel and gas prices at over $3.50 per gallon in Santa Barbara, we are quickly being forced to reconcile with that reality.

As a first step towards energy independence, and to immediately lessen the burden of rising energy prices energy, we must address energy conservation. Given the fact that buildings are extreme energy users, reducing energy demand in buildings will play a large role in achieving energy independence.

2. Background

2.1 California Building Energy Policy

In 1978 California mandated increases in the energy efficiency of its built environment. The state established Title 24, part 6: Energy Efficiency Standards for Residential and Nonresidential Buildings. The first iteration of the policy placed requirements on building features including insulation, heating, ventilation and air conditioning (HVAC) systems, domestic hot water (DHW) systems, and window efficiencies (California Energy Commission [CEC], 1978). In 1992 the code was updated with increased requirements for wall insulation (up to R-11 minimum[1]), and attic insulation (up to R-19 minimum) (CEC, 1992). In 2005 the standards were updated again, and wall insulation requirements were increased to R-13 minimum. Raised floor and duct insulation requirements were also increased (CEC, 2005a). In 2008, Title 24 will be updated again, and is expected to maintain its position as the most stringent set of building energy efficiency standards in the nation.

In the US, municipalities have often led the way on innovative climate policy, and this has been particularly true in California (Kousky and Schneider, 2003). An example is the City of Santa Monica, which passed legislation in 2005 requiring a 10% improvement in building efficiency gains above and beyond Title 24 standards. These municipal efforts are generally driven by perceived cost savings and other associated benefits. In Santa Monica's case as well as other recent legislation, energy conservation has taken on new meaning; it not only addresses sustainable growth and development, but also global climate change.

2.2 The 2030 Challenge

In an effort to decrease buildings' contributions to climate change on a national level, Ed Mazria and the American Institute of Architects developed The 2030 Challenge. The Challenge addresses the need for buildings, particularly those in the US, to reduce consumption of non-renewable resources and thereby reduce emissions of greenhouse gases to slow or reverse the effects of global warming. Specifically, The 2030 Challenge presents two targets:

> *Target 1* calls for all US buildings to reach carbon neutral status by the year 2030. Stepwise goals involve immediate energy use reductions to 50% based on a national or regional baseline or average for that building type, followed by a 10% reduction every five years, eventually reaching carbon neutrality in the year 2030.
>
> *Target 2* requires that for each new building constructed to these standards, one existing building of the same size should be improved to the 50% reduction goal.

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[1] R-value refers to the insulation's ability to resist flow of heat through the material. Higher R-value indicates better (thicker, more resistant) insulation.

2.3 Architecture 2030 Coalition

To promote The 2030 Challenge, Ed Mazria and his team began urging citizens, businesses, and governments to adopt the 2010 Imperative. This measure aimed to educate people about the need for greenhouse gas reductions and how to reduce emissions. One of the key participants in the Architecture 2010 Imperative, and also the first mayor to accept The 2030 Challenge, was Mayor Chavez of Albuquerque. Mayor Chavez played a large role in getting The 2030 Challenge publicized in local governments throughout the nation.

Formal acceptance of the Challenge in Santa Barbara began with Resolution No. 50, a resolution proposed by Mayor Chavez to get local governments to address global climate change via implementation of The 2030 Challenge. In June of 2006, the US Conference of Mayors unanimously adopted The 2030 Challenge. Among the signatories of the resolution was Mayor Marty Blum, Mayor of Santa Barbara. In response to Resolution No. 50, in 2007, Santa Barbara City Council adopted The 2030 Challenge with a unanimous vote on January 31, 2007. Additionally, a group of local architects, engineers and non-profits formed the Architecture 2030 Coalition with goals to implement The 2030 Challenge in Santa Barbara. The Coalition is addressing Target 1 (see above) through policies and educational outreach. They recently created legislation that requires new construction and large building additions to exceed the requirements of California's Building Energy Code, Title 24, by 20%. The Santa Barbara City Council and the California Energy Commission approved the ordinance on February 5, 2008. This new 'Above Title 24' building code is similar to but more stringent than that of Santa Monica.

Environmental activism and citizen participation also helped influence the Santa Barbara City Council to adopt The 2030 Challenge. Grassroots involvement in environmental issues has been historically important in Santa Barbara, and has influenced other important pieces of legislation. For example, after a 1969 oil spill occurred off the coast of Santa Barbara, local citizens rallied to achieve formalized protection of the California coast. The result of this public activism was the inception of the Coastal Zone Management Act (1972), which is a currently relevant piece of legislation protecting large tracks of coastal land in the United States. The Architecture 2030 Coalition is proof that environmental responsibility and activism is still current and very influential in Santa Barbara.

3. Introduction

3.1 Bren Group Project

The Architecture 2030 Coalition approached the Bren School regarding involvement in the Group Project thesis program. Groups of three to five students work together on a group project that aims to solve a real-life problem for a specific client. Working for the Architecture 2030 Coalition, this Group Project was initially charged with creating an implementation plan for the City of Santa Barbara to reach the goals of the 2030 Challenge by addressing Targets 1 and 2. However, three factors unique to Santa Barbara led us to limit our scope to address Target 2 for the residential sector: 1) the Coalition was already addressing new construction via the 'Above Title-24' ordinance; 2) Santa Barbara is practically at complete build-out in terms of land available for construction; and 3) single family residences comprise 54% of the total building stock (City of Santa Barbara, 2004).

3.2 Objectives and Goals

Retrofits of existing buildings to meet a 50% energy use reduction compared to a regional baseline will achieve large overall reductions in energy consumption and CO_2 emissions from Santa Barbara's building sector. Achieving these reductions in a cost-effective manner is ideal, and policies that promote cost-effective implementation are available for use in Santa Barbara.

This research aims to address three specific goals relating to existing homes in Santa Barbara:

1. Identify technologies that achieve a 50% energy use reduction below a regional average baseline.
2. Calculate least cost options for reducing CO_2 emissions from existing residences in Santa Barbara.
3. Provide alternative policy options to address The 2030 Challenge.

4. Methodology

4.1 Baseline

In accordance with the first goal of The 2030 Challenge, the aim of this study was to calculate how retrofits to Santa Barbara homes could make them 50% more efficient than other existing homes, when compared to a baseline energy consumption value. Architecture 2030 stipulates that implementing organizations can choose to use either national or a regional energy consumption values to establish an energy use baseline in terms of kBtu per square foot per year (kBtu/sf/yr)[2], depending on local conditions (Architecture 2030, 2008).

Policy and climatic circumstances specific to Santa Barbara favor the use of a regional baseline to ensure that a city-wide implementation of The 2030 Challenge results in substantial energy use and CO_2 reductions. California has the lowest per capita energy use of any state, and energy consumption in the state is about half of the national average (CEC, 2003). California's low per capita energy use can be attributed in part to the fact that its buildings' energy consumption has been regulated for many decades. In 1978, California established strict building energy standards known as Title 24. Compared to energy consumption in buildings at the national level, Title 24 has saved around 40,000 GWh of energy per year since its inception (CEC SB, 2007).

Due to these standards, Santa Barbara homes should not be compared to a national energy consumption baseline, because many local houses are already much more efficient than the average American home. In addition to existing regulatory circumstances, Santa Barbara has a mild climate, with only 2121 heating degree days per year, compared to a national average of 6037 per year (National Climatic Data Center [NCDC], 2002). The heating degree day statistic specifies the annually-aggregated degrees per day that the temperature is lower than 65 degrees Fahrenheit, and is therefore correlated with the amount of time that people use their heating systems (NCDC, 2002). Because of the climate, homes in the area consume around a third less energy for heating on an annual basis than average homes in the United States.

The factors of regulation and mild climate result in an average energy consumption in a Santa Barbara home being well below the national average of 44.7 kBtu/sf/yr (Architecture 2030, 2008). Thus, to achieve real gains in the area, a regional baseline is appropriate. A regional comparison was also desired by the group project client, the Architecture 2030 Coalition.

To determine the regional baseline value for this study, we chose to model the energy use of nine homes representative of the Santa Barbara single-family housing stock. The baseline value consisted of three contributors to energy use within the home: the building envelope (including HVAC and DHW), lighting, and appliances. The Appendix contains information regarding the model homes and Santa Barbara's existing homes in terms of year built and size.

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[2] kBtu = 1000 British thermal units. A British thermal unit indicates the heat value of fuel.

4.1.a Building Envelope, HVAC & DHW

For the first part of the baseline modeling process, we received detailed housing energy use information from local engineers. The information was in the form of EnergyPro files. EnergyPro is a commercially available software used by mechanical engineers and contractors to measure a building's compliance with Title 24 regulatory requirements. The software measures building energy use in terms of kBtu/sf/yr, which allows for normalization between both electricity (in kilowatt hours [kWh]) and natural gas (in therms) consumption by translating each into a kBtu value.

EnergyPro allows the user to include external conditions such as climate zone[3]. This allows for more exact measurements of the amount of energy consumed by several systems in the home while considering interactions with the local environment. EnergyPro also allows the user to construct a home by creating a "building tree". To construct the building tree, the user specifies types of floor slab, wall and roof insulation, windows, HVAC and DHW systems for each home.

The EnergyPro files provided data that expressed the yearly amount of energy that each house would consume given their specific characteristics in terms of kBtu/sf/year. We took each home's specific annual energy consumption and averaged those values across all nine homes to obtain the first part of our equation: a regional kBtu/sf/year energy consumption for existing single family homes in Santa Barbara, excluding lighting and appliances. The following describes the status of the original building envelope features, HVAC and DHW systems in the nine model homes:

4.1.a.1 Attic Insulation

Title-24 requires a specific R-value insulation for residential attics. As Title-24 has been upgraded over the last two decades, the attic insulation requirements have steadily increased. Our oldest homes, those built before Title-24 was established in 1978, originally had attic insulation of R-13. Homes built after 1978 had attic insulation of R-19. In all cases, we assumed the insulation to be comprised of fiberglass batting.

4.1.a.2 Wall Insulation

Our nine model homes varied in terms of their existing wall insulation. The four homes constructed before 1978 did not have wall insulation, although the wood framing provided an R-value of 2.8. The three homes built between 1978 and 1991 had R-11 and R-9 insulation, and the two newest homes had R-13 insulation, as required by the most recent version of Title 24. We determined the energy use in kBtu/sf/yr for each model home with the existing wall insulation.

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[3] Santa Barbara is in climate zone 6 (CEC, 2006).

4.1.a.3 Windows

Windows have many defining features including the U-value[4], solar heat gain coefficient (SHGC)[5], glazing (number of panes), special pane-related films or gases, and frame type. Most of our older model homes were originally equipped with fairly inefficient windows that had a U-value of 0.99 and SHGC-value of 0.74, a single pane with no special films, and a non-metal frame. Home 7 had improved double paned windows with metal frames, with U-values of 0.79 and SHGC-values of 0.7. Home 8 was equipped with double-paned, non-metal framed windows with U-values of 0.58 and SHGC-values of 0.62. Home nine had non-metal framed, double-paned windows with a low-emissivity (Low-E)[6] gas between the panes, with U-value of 0.4 and SHGC value of 0.35.

4.1.a.4 Exterior Window Shading

EnergyPro does not require the inclusion of exterior window shading in the building tree. If window shading is not specified, the program assumes minimal shading associated with a bugscreen.

4.1.a.5 HVAC

All of the homes built before 1992 had gas-fired heaters with Annual Fuel Utilization Efficiency (AFUE) [7] ratings below the current Title 24 minimum of 80%. The AFUE of the systems in these seven homes ranged from 65-75%, while the two new homes had ratings of 80% and 84%. As Santa Barbara has an exceptionally mild climate, air conditioning did not play a role in the files we were given, although we did experiment with high efficiency combined systems in our retrofitting scenarios.

4.1.a.6 DHW

Our model homes varied in terms of original DHW systems. The homes built before 1992 were all equipped with 50-gallon tank heaters with efficiency factors (EF) [8] of 0.525. The homes built after 1992 were equipped with electric tankless water heaters with 0.84 EF. None of the homes' DHW piping was insulated.

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[4] U-value is a measure of insulation and indicates how well the window assembly prevents heat from escaping. Lower U-value yields better insulation (Efficient Windows Collaborative [EWC], 08).

[5] SHGC indicates the window's ability to block incoming solar radiation from becoming a source of interior heat. Lower SHGC yields better radiation blockage (EWC, 08).

[6] Low-E coatings are designed to allow for low, moderate or high solar heat gain through the use of a microscopic metal oxide layer applied to the glazing surface. Low-E coatings affect the window's U-value by suppressing thermal heat flow from a warmer glazing panel to a cooler glazing panel and subsequently into the building (EWC, 08).

[7] AFUE indicates the percent of energy directly transferred from fuel to heat. AFUE doesn't include heat lost through the duct system or piping, which can be as high as 35% (CTG Energetics, Inc., 2005).

[8] EF describes the efficiency of the energy flow of the unit, or its ability to transfer electric or natural gas energy into water as heat.

4.1.b Lighting

The second part of the baseline equation addressed lighting. Baseline lighting electricity usage in the nine model homes was evaluated using a kBtu/sf/yr metric based around an overall national average figure of 4.801 kBtu/sf/yr. This figure is adapted from the results of a detailed Lighting Market Characterization study by Navigant Consulting for the US Department of Energy, and is based upon an energy consumption assessment of 161 US homes (CEC, 2008). The use of this kBtu/sf/yr calculation rests on the assumption that lighting electricity usage in residential homes increases in direct correlation with the size of the home.

This metric was used to determine the overall lighting electricity use in each of the nine model homes, and then parsed into total number of incandescent bulbs versus non-incandescent bulbs using research regarding bulb-type saturation from the California Lighting Technology Center. Saturation data shows that 80% of lighting in existing California homes uses incandescent bulbs, while 20% use some form of fluorescent or halogen bulb (RLW Analytics, 2005). The average wattage for a residential incandescent bulb is 62W, while the average installed CFL is 18W (RLW Analytics, 2005). Since the vast majority of non-incandescent residential installed bulbs are some type of fluorescent bulb, this wattage was used to represent all non-incandescent bulbs (US EPA, 2007). Finally, through a detailed study of lighting use patterns in the home, the California Energy Commission has determined a daily usage time of 2.3 hours for the average residential bulb (Heschong Mahone Group, 1999). Using this information the total number of incandescent bulbs was calculated for each home, and from this, we calculated the lighting baseline.

To calculate the total number of bulbs used in each home we used the following equation:

Figure 1: Number of Bulbs per Home Equation

$$\boxed{n_t = \frac{e}{\left(\left(w_i * p_i * t * 365\right) + \left(w_f * p_f * t * 365\right)\right) * 1000}}$$

The total number of incandescent bulbs used in a home was found by:

Figure 2: Number of Incandescent Bulbs per Home Equation

$$\boxed{n_i = n_t * p_i}$$

Where the variables represent:

n_t = total number of bulbs
i = incandescent bulbs
f = compact fluorescent bulbs
p = proportion of bulbs
w = wattage

t = number of hours used per day
a = area of home
e = lighting energy used

By calculating n_i and applying the previously mentioned assumptions regarding average wattage and usage times, we calculated a lighting baseline in terms of kWh/sf/year and converted that value to kBtu/sf/yr.

4.1.c Appliances

To set the baseline for energy use from appliances, we chose to model all major appliances that are regulated by the State of California or the US government. Currently, both levels of government regulate appliances by setting minimum efficiency standards that each appliance must meet in order to be sold either in California or in the US.

The market for appliances is large, and thousands of brands and models are available for consumers (US Department of Energy [US DOE], 1998). This presents a challenge in determining which of the thousands of combinations of appliances may exist in an average home. However, regulated appliances are given specific efficiency standards each year, allowing for a relatively precise estimate of average yearly energy consumption of any regulated appliance by looking at the minimum efficiency standards. The model includes the following ten appliance categories, which currently have either California and/or Federal standards: refrigerators, dishwashers, clothes washers, clothes dryers, ovens, stove tops, microwave ovens, televisions, DVD players, and power supplies. We modeled only one appliance from each of the aforementioned appliance categories with all appliances except power supplies. The average California home has six power supplies, so for this appliance category we assumed that each home had two small, two medium, and two large wattage power supplies (Wenzel et al., 1997).

The second step in modeling appliances involved measuring the baseline efficiency of each of the aforementioned options. To do this, we used the minimum efficiency standards outlined by the Federal government or by the government of California for each appliance. Both California and Federal appliance standards are constantly subject to change, and over time they have expanded in terms of number and types of appliances regulated and the stringency of efficiency standards (CEC, 2007).

We used the California standards as a baseline for refrigerators, dishwashers, clothes washers, clothes dryers, televisions, DVD players, and power supplies, because these standards are either as strict as or stricter than the Federal standards (CEC, 2007). We used the Federal standards for all cooking products, including ranges, stove tops, and microwave ovens, because cooking products are not separately regulated by California (CEC, 2007).

We chose to use the most current appliance standards, which for all appliances except cooking products meant using the 2007 California Appliance Efficiency Regulations. Standards for cooking products were last updated by the Federal government in 1998, and we therefore set our baseline for cooking products by using those standards (US DOE, 1998).

Appliance standards for the Federal and California government are set in terms of minimum efficiency factors (MEF). For each appliance, we converted the MEF into consumption values of kBtu/yr. Within each conversion, we made assumptions about the usage of each appliance based on data from the Lawrence Berkeley National Laboratories (Wenzel et al., 1997). Below is a table that describes the standards as they are written by the government along with assumptions and sizes used to arrive at our consumption values:

Table 1. MEF to Consumption Conversions

Appliance	Subtype/Assumption	Size	Standard (MEF)	Consumption (kBtu/yr)
Refrigerator-freezer	Automatic defrost with in-door ice service	20.7 cf	10.20AV + 356.0	1935.00
Clothes Washer	- Standard, top-loading - Assumption: 392 cycles/yr	2.6 cf	1.04	3343.90
Clothes Dryer	- Standard, electric - Assumption: 416 cycles/yr	7 lb	3.01	3301.05
Dishwasher	- Standard - Assumption: 229 cycles/yr	N/A	0.46	1697.60
Microwave Oven	N/A	N/A	0.557	794.53
Electric Cooktop	Coil Elements	N/A	0.742	1002.54
Electric Oven	Non self-cleaning	N/A	0.107	910.47
Television	Assumption: continuously plugged	N/A	3W	119.48
DVD Player	Assumption: continuously plugged	N/A	3W	89.61
Power Supplies	Assumption: 0.5 W	0 to 1 W	0.49* Output	1.83
	Assumption: 25 W Output	≥1 and ≤49 W	0.09* Ln(Output) +.49	5.67
	Assumption: 75 W Output	>49 W	0.84	6.27

4.1.d Whole Home Energy Use Baseline

After defining separate methodologies associated with the building envelope and major systems, home lighting, and appliances, we were able to create a picture of the whole-home energy use in terms of kBtu/sf/yr. The overall equation is:

Figure 3. Overall Baseline Energy Consumption Equation

(Building Envelope, HVAC & DHW) + Lighting + Appliances = 'Whole-Home' Energy Use

We calculated the regional baseline energy consumption value, based on our nine model homes, to be 44.36 kBtu/sf/yr.

4.2 Retrofits to Achieve Reductions

After establishing the baseline energy consumption value, we retrofitted features across the whole home in attempts to achieve the 50% energy use reduction goal. On average, we strived to reach 22.18 kBtu/sf/yr post retrofit.

4.2.a EnergyPro

Once the building tree components, or specific features of the home, are constructed in EnergyPro, they can be modified separately. For example, the wall material and wall insulation type can be changed or replaced. Similarly, the windows, attic insulation, HVAC and DHW systems can be altered according to desired specifications and available technologies.

After calculating energy consumption (in kBtu/sf/yr) resultant from the nine model homes' current conditions in EnergyPro, we retrofitted the nine building trees with specific components or technologies, and recalculated an adjusted annual energy consumption. We altered single technologies first, and then retrofitted the homes with several combinations of technologies to reveal interactions between them. For example, we not only replaced the existing windows with higher efficiency models, we also replaced windows, DHW, HVAC and insulation simultaneously, to reveal energy consumption data associated with these combinations of technologies.

The following describes the specific features, or technologies, that were modified through EnergyPro as part of our analysis. As a general rule, homes were retrofitted with altered technologies only when the upgrade exceeded the existing conditions. If the home had more efficient windows or insulation than that chosen for retrofits, we did not alter the existing conditions.

4.2.a.1 Attic Insulation

We replaced the original attic insulation with five different options: R-19, R-30, R-40, R-30 w/radiant barrier, and R-40 w/radiant barrier. R-19 was only used in retrofits of homes 1-4 that originally had R-13 insulation.

4.2.a.2 Wall Insulation

We replaced the existing insulation with four different variations of improvements. For the four oldest homes, and the mid-aged home with R-9, we increased the existing insulation to R-13. We also examined the impacts of retrofitting all nine homes with R-19 insulation. For these retrofits, we assumed the use of a spray-in cellulose material. We also modeled the use of Icynene, which has an R-15 value. Icynene is a spray foam that is different from spray cellulose because it expands to fill all empty spaces in the insulation cavity. Lastly, we modeled the use of structurally insulated panels, or SIPS. SIPS consist of plywood panels with rigid foam insulation between them. SIPS are typically used in new construction as opposed to retrofit situations, and have an R-value of 26.

4.2.a.3 Windows

We retrofitted our model homes with new technologies only when the upgrade exceeded the existing conditions. If the home had more efficient windows than those chosen for retrofits, we did not alter the existing conditions. In cases where retrofits were applied, we modified the existing conditions with four specific window options:

- A double paned, non-metal framed, clear technology with U-0.6 and SHGC-0.65.
- A double paned, non-metal framed window with Low-E gas between panes, with U-0.4 and SHGC-0.35.
- A double paned, metal framed, with Low-E gas, and U-0.65 and SHGC-0.4.
- A triple paned with metal frame, and U-0.32 and SHGC-0.24.

4.2.a.4 Exterior Window Shading

We retrofitted our model homes with exterior window shading in two forms: louvered sunscreens and low angled sunscreens. These features are not typically used in residential settings currently; however they may become more popular in the future, particularly in areas with a high number of cooling days. Also, regardless of their current lack of use in residential settings, they provided an indication of the effect that similar shading devices like awnings would have on energy use in the home.

4.2.a.5 HVAC

Furnaces with AFUE ratings of 90-94% are increasingly available. We chose to examine the impacts of a furnace with 90% AFUE, as well as a combined furnace/air conditioning unit of 94% AFUE and a Seasonal Energy Efficiency Ratio (SEER)[9] of 13.0, the minimum required by Title 24. Before 1979, a typical SEER range was 4.5-8.0, illustrating the improvements in efficiencies that have been made in AC units in the past 30 years.

Highly efficient geothermal heat pumps were modeled in all homes (with a SEER of 19.0). Although not currently used in many residences, they may be in the near future, as it is a newer technology that holds great promise for both heating and cooling. Ground source (geothermal) and water source pumps work the same way, through a simple principle of heat exchange. Indeed, geothermal pumps may have higher levels of efficiency because of the temperature

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[9] SEER is defined as the total cooling output (in Btu) provided by the unit during its normal annual usage period divided by its total energy input (in watt-hours) during the same period (Environmental and Energy Study Institute, 2007).

gradient between the building's air and the heating/cooling supply air source/sink. Specifically, during the heating season (winter), the ground is warmer than the air. Conversely, during the cooling season (summer), the ground remains cooler than the air. These systems are rated according to heating season performance factor (HSPF) and cooling efficiency is indicated by the SEER rating.

We also chose to examine the option of retrofitting all homes with a combined HVAC/DHW system that uses an efficient ‘Munchkin’ boiler paired with radiant floor heating – an option that derives both its space heating and domestic hot water from the same heat source. Radiant floor systems consist of heated water, typically from a boiler, pumped through tubes in the floors of a building. These are known as "zoning tubes" -- meaning the temperature can be controlled for each room. The ‘Munchkin’ system also uses a ‘Superstor’ storage tank, and is much more efficient than separate HVAC and DHW systems.

Lastly, maintenance and replacement (if necessary) of ducts is essential. We modeled energy efficiency improvements associated with a one-time professional service of a home’s duct system and increased duct insulation.

4.2.a.6 DHW

We chose to upgrade the existing DHW systems with several more efficient options. These included two tankless water heaters, one with 0.66 EF and one with 0.84 EFF. The two newest homes were not retrofitted with these options as they already had similar or better systems installed. We also retrofitted all homes with a solar thermal system that uses an electric 50-gallon tank for hot water storage. The EF of this system is 1.0, as solar energy is used to heat water for domestic uses. The fourth retrofit option is the combined HVAC/DHW Munchkin boiler and radiant floor system described above.

4.2.b Lighting

Using the lighting model equation presented in the baseline lighting narrative above, we calculated the potential electricity savings potential in each home that would result from a complete replacement of incandescent bulbs with more efficient compact fluorescent bulbs. As stated above, the typical California home contains 20% CFLs and 80% incandescent bulbs. We simply changed the equation so that all homes contained 100% CFLs and calculated the energy savings. The results varied across the nine homes, as the energy consumption associated with lighting changes in correlation with home size.

The specific equation used to calculate energy savings was:

Figure 4. Energy Savings from Lighting Retrofit Equation

$$\text{Energy saved} = \left[\frac{\left[\frac{\left(n_i * (w_i - w_f) * t * 365\right)}{1000} \right]}{a} \right] * 3.416$$

Where: n_t = total number of bulbs
i = incandescent bulbs
f = compact fluorescent bulbs
w = wattage
a = area of home

4.2.c Appliances

In modeling appliances, as with lighting and building features, we calculated the energy gains that Santa Barbara homes can achieve from retrofitting with more energy efficient options. After establishing the baseline consumption for appliances, we looked to the Federal Energy Star Program to model more efficient appliances. Appliances can become Energy Star qualified and receive an Energy Star label by having an MEF that is 10-15% more water and/or energy efficient than the federal standard (Energy Star, 2008a).

We replaced each appliance that was compliant with current standards with an appliance of the highest Energy Star rating (most efficient option available). This was done for all appliances except clothes dryers, which are not regulated by Energy Star in terms of efficiency. To model energy conservation associated with clothes dryers, we cut down the assumed usage from 416 cycles per year to 208 cycles per year, assuming that homeowners can air dry their clothing half of the time to reduce energy consumption.

Below is a table that describes MEFs for our baseline and retrofit appliance options:

Table 2. Comparison of Appliance MEFs

Appliance	MEF (Fed or CA)	Energy Star
Refrigerator-freezer	10.20AV + 356.0	30% more efficient
Clothes Washer	1.04	2
Clothes Dryer	3.01	50% usage time
Dishwasher	0.46	0.65
Microwave Oven	0.557	15% more efficient
Electric Cooktop	0.742	15% more efficient
Electric Oven	0.107	15% more efficient
Television	3W	1W

DVD Player	3W	1W
Power Supplies (0.5W)	0.49*Output	60% more efficient
Power Supplies (25W)	0.09* Ln(Output) + 0.49	60% more efficient
Power Supplies (75W)	0.84	60% more efficient

For all homes we modeled the replacement of each appliance separately, calculating the difference of energy usage between the baseline appliance and the most efficient Energy Star appliance. We also explored the option of replacing all appliances at once.

4.2.d Whole-Home Retrofit Combinations

The final step in reaching the goals of The 2030 Challenge as it applies to existing homes was to determine ways to reduce overall home energy consumption to 50% of the regional baseline. Once we established a baseline that included the majority of the home energy use, we were able to apply retrofits across all three parts of the equation represented in Figure 4.

Because none of the single technologies provided energy use reductions of 50%, we needed to combine technologies. Specifically, we chose to address all the major parts of the home including wall and attic insulation, windows, HVAC, DHW, lighting, and appliances. We created four combinations of retrofit technologies that achieved the 50% energy use reduction goal set by The 2030 Challenge. The combinations are named after their most distinguishing feature.

Table 3. Retrofit Combinations

Combination A: Solar Thermal
Efficient Furnace & AC Unit (94% AFUE & 13 SEER)
Solar Thermal hot water system with 50 gal storage tank
Non-metal framed, double paned, Low-E gas fill windows (U 0.32 & SHGC 0.24)
High Attic Insulation (R-40) & Radiant Barrier
High Wall Insulation (R-19)
All Lighting to CFLs
All New Appliances
Combination B: Munchkin
Combined Munchkin DHW/HVAC system
Non-metal framed, double paned, Low-E gas fill windows (U 0.32 & SHGC 0.24)
High Attic Insulation (R-40) & Radiant Barrier
High Wall Insulation (R-19)
All Lighting to CFLs
All New Appliances
Combination C: Geothermal
3-ton Geothermal Heat Pump & Duct Maintenance
Tankless water heater (EF 0.84)
Non-metal framed, double paned, Low-E gas fill windows (U 0.32 & SHGC 0.24)
High Attic Insulation (R-40)
High Wall Insulation (R-19)
All Lighting to CFLs
All New Appliances

Combination C: Low Cost
Efficient Furnace & AC Unit (94% AFUE & 13 SEER) & Duct Maintenance
Tankless water heater (EF 0.84)
Non-metal framed, double paned, Low-E gas fill windows (U 0.32 & SHGC 0.24)
High Attic Insulation (R-40)
High Wall Insulation (R-19)
All Lighting to CFLs
All New Appliances

4.3 Cost Analysis

The above combinations demonstrate four ways in which Santa Barbara homeowners can retrofit their houses to be 50% more energy efficient than the regional average baseline. However, a significant component of public acceptance in accomplishing this goal will be to demonstrate cost efficiency. It is important to note that the cost analysis results consider retrofits of only the seven oldest homes in our data set. Because they already perform very close to the 50% reduction goal, a full-scale retrofit would not be practical or cost-effective for the two newest homes. This fact may not be true for all newly built Santa Barbara homes, however, as the two homes we modeled were very efficient, performing 12.5% and 14% more efficient than Title 24 Standards.

4.3.a Payback

The first cost analysis we completed was a simple payback analysis, a common method for looking at energy efficiency investments. We calculated the time it would take to recoup the initial investment of each technology based on the amount of energy (and thus money) that would be saved on monthly utility bills.

The first step of computing payback involved finding cost estimates of each individual technology. Some of the costs of technologies, such as appliances and lighting, were based on current market values (as of January 2008) found at local hardware stores. The majority of cost estimates, for DHW systems, insulation, windows, etc. were solicited from local architects and engineers. Prices that were not available from these sources were found by sampling current online prices from various sources.

The second step involved computing what each individual technology would cost for retrofit within each of the seven oldest model homes. This process was unvarying for appliances, where each home was assumed to have one of each of the ten appliance categories, but made a significant difference for technologies that were dependent on home size, such as insulation, lighting and radiant flooring. We then calculated the difference in energy usage between newly installed technologies and the technologies that were initially installed in the home. We translated this value of energy savings into monetary savings by calculating how much money each home would save on their monthly utility bills through a retrofit with the new technologies.

The translation between energy savings and monthly utility savings involved an assumption of energy prices, and for this we used two different sets of values. First, we speculated a price increase based on historical energy price trends (UCSB Economic Forecast Project [UEFP], 2007). Second, we place a non-compounding 5% tax on the aforementioned rising energy price projection. We then calculated how much time it would take for each technology to pay for itself in savings based on the two aforementioned energy scenarios.

4.3.b Cost per Tonne CO_2

In addition to paybacks, we also calculated the costs associated with carbon savings of each technology in terms of cost per pound and tonne of CO_2 reduced. For this analysis we divided the total cost of each single technology and combination by the total amount of CO_2 reduced over 22 years (out to 2030), for each of the nine model homes. We then averaged the values for each retrofit option across the seven oldest homes to achieve an average cost/lb and cost/tonne figure. Again, we excluded the two newest homes because they already perform very close to the 50% reduction goal, and a full-scale retrofit would not be practical or cost-effective. This methodology allowed us to determine the most cost-effective technologies for reaching the 50% carbon reduction goal within the timeframe of The 2030 Challenge.

To determine the amount of CO_2 reductions that resulted from retrofitting our model homes, we considered the carbon intensity (CO_2 emissions/unit energy) associated with generation, transmission and in-home consumption of both natural gas and electricity in Santa Barbara. According to the California Energy Commission, there are 11.7 lbs of CO_2 emissions associated with one therm of residential natural gas (CEC, 2005b).

The carbon intensity associated with one kWh of electricity (0.827 lbs per kWh) is a result of the specific fuel mix of Southern California Edison in 2007. Table 4 shows the average lb CO_2 emissions per MWh associated with specific electricity fuel sources—coal and natural gas—for California, as reported in the EPA's egrid database. These carbon intensities were used to determine the average lb CO_2 emissions per MWh of electricity sold by Southern California Edison. All fuel types classified as renewable, as well as nuclear and large hydroelectric, were determined to have zero or negligible associated CO_2 emissions (CEC, 2000).

Electricity sold by Southern California Edison has an average transmission and distribution loss of 6.5%, meaning that 6.5% less power is delivered to an end user than that transmitted from the generation source (CEC, 2000). For this reason, the CO_2 emissions associated with a MWh were multiplied by 1.065 to calculate to true emissions associated with a MWh of electricity used in the home. Additionally, all MWh quantities were converted to kBtu for analysis.

Table 4. SCE Electricity Mix Carbon Intensity

	Southern California Edison 2007 Power Mix	CO_2 Emission Coefficients for California (lb/MWh)	Total CO_2 impacts (lb/MWh)
Biomass & Waste	2%	0	0
Geothermal	9%	0	0
Small hydro	1%	0	0
Solar	1%	0	0
Wind	3%	0	0
Coal	7%	2179	153
Large Hydroelectric	6%	0	0
Natural Gas	51%	1224	624
Nuclear	20%	0	0
Other	<1%	0	0
		Total CO2 (lb/MWh)	777
		Total CO2 (lb/MWh) w/transmission and distribution loss	827.243

4.4 Policy Options to Implement Reductions

After analyzing the technical and financial aspects of reaching The 2030 Challenge goals, we assessed different policy options to determine the best political strategy for implementation in Santa Barbara.

First, we assessed the technical and political feasibility of The 2030 Challenge as specified by Ed Mazria and Architecture 2030. California census data provided new home construction data and allowed us to calculate the time that it would take to retrofit all existing single family homes in accordance with the amount of new single family residences that are built.

Second, we examined another relevant policy option that already exists in Santa Barbara, a local energy ordinance called The Architecture 2030 Energy Ordinance. This requires upgrades and modifications to current building codes and standards that will increase energy efficiency within the building sector of Santa Barbara (City of Santa Barbara, 2008). Just as with our analysis of The 2030 Challenge, we examined this ordinance as it pertains to the existing housing stock and housing characteristics of Santa Barbara.

Next, we examined a third policy option that does not currently exist in Santa Barbara known as a time-of-sale-ordinance, which would require energy efficient retrofits any time a building is bought or sold. Although it does not currently exist in Santa Barbara, this legislation has been successful in the cities of Berkeley and Oakland in California, and is being considered in several other cities as well (City of Oakland, 2006).

Finally, we looked into political means by which Santa Barbara could subsidize or finance retrofit costs for homeowners. For this analysis, we considered potential revenue that would be generated through the energy tax discussed in the second energy price scenario in Cost Analysis above.

5. Results

We followed a three-step process to arrive at four final combinations of retrofit technologies, all of which brought our homes below 50% of the regional energy use average. The first step was to replace the elements of a home with each of the single retrofit options, one at a time, while documenting the increase or decrease in energy use in each home resulting from that particular retrofit. Replacements of attic and wall insulation were not performed in homes that had insulation of higher R-value than the retrofit technology, so as not to skew our results. EnergyPro software calculations provided informative outputs regarding the impacts on energy use from retrofits to window, shading, DHW, HVAC, and insulation options in each of our model homes. Energy use reductions resulting from lighting and appliance replacements were calculated independent of the EnergyPro model.

Given the results of this initial step we moved on to combine top-performing single technologies together, forming a total of eleven different combination options. Our third and final step involved choosing four optimal technology combinations that each achieved the 50% reduction goal. The top four combinations all greatly improved the energy efficiency of homes (even new models) and reduced CO_2 emissions, but the costs varied significantly between the options. Tables presented in Sections 5.1 and 5.2 below indicate the percent change in energy use and CO_2 emissions compared to each home's original starting point.

5.1 Energy Consumption Reductions

Energy consumption reductions were achieved through most retrofits modeled in this study. The smallest reductions resulted from replacing single appliances, followed by changing out all incandescent lights for CFLS, and retrofits to windows and exterior shading. More efficient HVAC and DHW systems, as well as wall insulation and some attic insulations provided slightly higher energy reductions, while the combined technologies achieve the highest reductions.

5.1.a Building Envelope

Energy consumption decreases for heating resulting from attic insulation were related to the R-value of insulation installed. In general, as the R-value increased, so did the energy efficiency of the home. However, beyond R-30, the marginal improvements were negligible. This includes the use of R-40 insulation, as well as radiant barriers. Wall insulation also improved energy efficiency with increasing R-value, with R-19 maximizing performance in existing homes. Newly constructed homes performed best with the use of R-26 structural insulated panels (SIPS).

In general, double-paned, non-metal-framed, low-E windows proved to be the most efficient (more so than triple-paned windows) in most homes. Exterior window shading, both louvered and low-angled sunscreens, showed varying results across the model homes. Four homes experienced efficiency gains, although small, while five homes experienced decreased efficiency. This last result is most likely due to the fact that shading increased heating needs, and did not save much energy due to the lack of air conditioning units in Santa Barbara. The actual percent change in energy use associated with each single retrofit technology is shown in Table 5.

Table 5. Percent Decrease in Energy Use Associated With Building Envelope Retrofits.[*]

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
Attic Insulation R-13	1.18	2.15	2.08	1.00	**	**	**	**	**
Attic Insulation R-19	3.21	5.97	5.53	2.83	0.24	0.22	**	**	**
Attic Insulation R-30	6.03	8.96	8.31	5.89	3.66	4.19	5.61	3.86	3.87
Attic Insulation R-40	5.63	10.42	9.53	5.10	5.08	6.00	8.04	5.72	5.41
Attic Insulation R-30 + Radiant Barrier	6.03	10.68	9.67	5.89	5.00	6.68	8.19	5.94	5.41
Attic Insulation R-40 + Radiant Barrier	6.70	11.82	10.67	6.60	6.26	8.08	10.09	7.73	6.73
Wall Insulation R-13	28.39	30.62	25.61	37.14	1.14	1.26	7.28	**	**
Wall Insulation R-19	31.38	33.85	28.39	41.38	4.92	5.42	11.50	6.94	9.74
SIP Wall R-26	35.14	37.99	36.31	46.58	9.69	10.65	16.58	14.88	21.04
Icynene Wall R-15	31.94	34.44	28.89	42.09	5.63	6.19	12.26	8.15	11.45
Double Non Metal Clear Window	4.41	9.70	5.44	10.38	6.73	19.65	8.16	**	**
Double Non Metal Low-E Window	8.10	12.49	5.69	21.46	4.57	41.37	27.17	11.44	-1.16
Double Metal Low-E Window	5.05	5.41	2.08	14.57	0.00	30.00	17.77	-5.58	-10.90
Triple Metal Clear Window	9.04	11.59	5.17	23.97	3.07	42.00	12.89	11.02	-5.26
Exterior Low Angle Sunscreen	0.90	-13.10	-9.28	4.69	-17.49	5.32	2.71	-27.40	-25.68
Exterior Louvered Sunscreen	1.26	-7.29	-6.03	6.11	-12.09	13.11	10.09	-10.37	-13.38

[*] Negative (-) values represent an increase in energy use.

[**] Retrofits of attic and wall insulation and windows were not performed in homes that had insulation of higher R-value or more efficient windows than the retrofit technology.

5.1.b HVAC

The options available for HVAC in existing homes encapsulate a wide range of possibilities, some of which are more cost-effective than others. For the most part, we found that increasing the AFUE rating corresponded with increasing energy efficiency within the whole HVAC system. A combined heating and air conditioning unit with 94% AFUE rating and 13 SEER resulted in exceptional improvements in all of our homes. Although air conditioning is not required in most areas of Santa Barbara, this particular option offers that capability and proved to be extremely effective in general.

Our most efficient option within the HVAC sector was a 3-ton geothermal heat pump – a unit that can cool or heat, depending upon the desired result, using convection and the temperature of the earth near the house to adjust indoor temperatures. Unfortunately, the current high cost of this technology has made it impractical for implementation in the residential sector. Furnaces with a 90% AFUE rating were an improvement over many of our HVAC technologies as well, given the fact that many homes began with furnaces with efficiency ratings of 80% AFUE or below. The actual percent change in energy use associated with each single retrofit technology is shown in Table 6.

Table 6. Percent Decrease in Energy Use Associated With HVAC Retrofits

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
90% AFUE	11.29	7.61	7.28	14.61	4.25	8.69	9.45	1.86	4.02
Ducts Ins R8	1.58	2.52	2.28	2.30	1.34	2.66	12.07	1.50	1.31
90% AFUE + Duct Ins R8	12.49	9.78	9.22	16.45	5.40	10.94	15.06	3.36	5.18
Radiant floor with forced air cooling + Duct Ins R8	15.84	14.93	14.08	20.81	8.27	14.74	17.27	6.51	8.97
94% AFUE & 13 SEER + R8	14.58	12.33	11.17	20.08	6.58	14.98	18.82	6.72	6.73
94% AFUE & 13 SEER + R12	15.02	13.15	11.89	20.75	7.01	15.80	19.41	7.30	7.19
3-ton Geothermal Heat Pump	21.97	20.41	17.28	33.25	9.29	26.71	27.04	2.79	11.21

5.1.c DHW

The most efficient option for DHW was a combined DHW and HVAC system (the Munchkin boiler). This innovative technology illustrated the potential in combining technologies within a home. Although radiant flooring is required for its implementation (a high upfront cost), the combination of DHW with space heating proved to be an exceptionally efficient technology. The actual percent change in energy use associated with each single retrofit technology is shown in Table 7.

Table 7. Percent Decrease in Energy Use Associated With DHW Retrofits*

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
Tankless (EF 0.66) + all pipes ins	10.47	6.26	8.14	2.67	11.54	4.86	6.05	-20.82	-27.07
Tankless (EF0 0.84) + all pipes ins	26.12	19.01	23.19	10.01	32.93	15.58	19.76	1.86	2.24
Solar Thermal & 50-gal tank (EF 1.0) + all pipes ins	19.19	15.83	18.67	8.91	26.47	13.38	17.11	-1.50	-3.02
Munchkin Superstor & Radiant Floor	42.48	35.37	38.28	33.57	38.64	29.23	49.83	5.29	7.66

* Negative (-) values represent an increase in energy use.

5.1.d Appliances

Replacing all appliances with more efficient options resulted in the highest decreases in energy consumption within a home. However, the replacement of certain appliances had noticeably larger gains than others. Across all nine homes, replacing clothes washers made the largest impact in terms of decreased energy consumption. We retrofitted homes with the most efficient Energy Star-rated, top-loading clothes washers, which uses about 50% of the energy of the version meeting minimum California standards. Recent technological updates to top-loading clothes washers allow for these appliances to use much less hot water, a fact which drastically reduces energy consumption when compared to standard models (Energy Star, 2008b)

The refrigerator also showed noticeable relative improvements. As with clothes washers, recent advances have allowed for energy efficiency in refrigerators to increase greatly (Energy Star, 2008c). Standard Energy Star guidelines require that appliances be at least 10-15% above federally mandated efficiency standards, however we modeled Energy Star labeled refrigerators that are 30% more efficient than standard models.

Dishwashers were also important appliances to replace. They, like clothes washers, have the capability of using large amounts of hot water. Additionally, they often have drying cycles that are potentially high sources of energy consumption. The Energy Star compliant dishwashers that we modeled contain mechanisms to cut down on the amount of water used during the wash and rinse cycles, and also to reduce the amount of energy used in the drying cycle (Energy Star, 2008d).

Overall, it is important to note that none of the retrofitted appliances increased energy consumption. The starting point in our model was federal and state mandated efficiency levels, and we replaced each appliance with models that are currently on the market and heavily promoted by Energy Star. This illustrates that efficiency standards should be increased for all mandated appliances, because the technology and equipment already exists for consumers, and increasing standards would reduce energy consumption in all appliance categories.

Table 8. Percent Decrease in Energy Use Associated With Appliances Retrofits

	Home 1	**Home 2**	**Home 3**	**Home 4**	**Home 5**	**Home 6**	**Home 7**	**Home 8**	**Home 9**
Refrigerator	0.66	0.68	0.81	0.39	1.04	0.57	0.68	0.88	1.08
Clothes Washer	1.51	1.55	1.85	0.89	2.36	1.30	1.55	2.00	2.46
Microwave	0.14	0.14	0.17	0.08	0.21	0.12	0.14	0.18	0.22
Oven	0.33	0.34	0.40	0.19	0.51	0.28	0.34	0.43	0.53
Television	0.10	0.10	0.13	0.06	0.16	0.09	0.10	0.14	0.17
DVD Player	0.07	0.07	0.08	0.04	0.11	0.06	0.07	0.09	0.11
Six Power Supplies	0.07	0.07	0.08	0.04	0.10	0.06	0.07	0.09	0.11
Dishwasher	0.57	0.58	0.69	0.33	0.88	0.49	0.58	0.75	0.92
All Appliances	3.44	3.53	4.22	2.03	5.37	2.96	3.52	4.56	5.61

5.1.e Lighting

Lighting improvements resulted in the same kBtu/sf/yr reductions in each home, because the number of bulbs was calculated using the square footage of the home. However, the percentage reduction associated with changing out bulbs varies across homes (Table 9) because each home uses a different amount of energy overall, thus the reductions from lighting represent a different percentage reduction in each home. In general, this figure is a function of both the size of the home and the amount of energy the home uses per square foot. As Table 9 shows, in newer, larger homes, lighting changes represent a larger percentage reduction than in older, smaller homes.

Table 9. Percent Decrease in Energy Use Associated With Lighting Retrofits

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
100% CFL Replacement	4.64	6.44	6.49	5.45	8.26	6.10	7.50	13.86	13.90

5.1.f Combined Technologies

Of the four combinations we chose, combination C performed the best in terms of energy use reduction, mostly due to inclusion of a geothermal heat pump which drastically reduces overall energy demand (Table 10). Combination D, Low Cost, performed almost as well as combination C, and better than combinations A and B.

Table 10. Percent Decrease in Energy Use Associated With Combination Retrofits

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
COMBO A Solar Thermal	64.55	58.72	60.64	76.17	44.19	67.99	57.42	27.97	17.25
COMBO B Munchkin	68.95	70.07	63.31	76.70	46.20	68.72	53.89	26.97	18.17
COMBO C Geothermal	73.16	72.16	67.14	79.58	53.41	72.03	65.68	29.54	28.54
COMBO D Low Cost	72.13	71.71	66.69	78.11	52.78	70.70	64.07	29.18	26.84

5.2 CO_2 Emission Reductions

Many of the CO_2 reduction results were closely correlated with energy efficiency improvement results described above. However, decreases in electricity consumption had a greater impact on CO_2 emissions than did corresponding decreases in natural gas, due to the differing carbon intensities of these two sources. These results are illustrated in a graph comparing kBtu reductions with CO_2 reductions (see Figure 9). Thus, switching from incandescent to CFL bulbs (powered with electricity) will have a greater impact on reducing CO_2 emissions than will improvements in gas-fired furnace efficiencies. Clearly, the overall reductions will be greatest if both retrofits are undertaken.

5.2.a Building Envelope

Attic and wall insulation again proved effective in most homes as the R-value increased, with R-40 and radiant barriers in the attics providing very small marginal gains above R-30. R-19 wall insulation helped to decrease CO_2 emissions significantly in most homes, and the benefits of R-26 SIPS in new construction are clearly illustrated in the chart below. In general, we found double-paned, non-metal framed, low-E windows to be the most efficient (more so than triple-paned windows) in most homes. Exterior window shading, both louvered and low-angled suncreens, showed varying results across the model homes. Four homes experienced efficiency gains, although small, while five homes experienced decreased efficiency from increased heating demand. The actual percent change in energy use associated with each single retrofit technology is shown in Table 11.

Table 11. Percent Decrease in CO2 Emissions Associated With Building Envelope Retrofits*

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
Attic Insulation R-13	0.48	1.12	0.90	0.64	**	**	**	**	**
Attic Insulation R-19	1.40	3.13	2.64	1.77	0.00	0.22	**	**	**
Attic Insulation R-30	2.68	4.69	4.01	3.45	1.46	4.19	-1.49	1.34	1.38
Attic Insulation R-40	2.51	5.38	4.62	3.09	2.17	6.00	-0.43	2.05	1.93
Attic Insulation R-30 + Radiant Barrier	2.99	5.53	4.64	3.46	2.05	6.68	-0.39	2.07	1.94
Attic Insulation R-40 + Radiant Barrier	2.99	6.08	5.13	3.86	2.63	8.08	0.49	2.65	2.36
Wall Insulation R-13	15.49	17.91	15.68	26.18	0.56	1.26	0.74	**	**
Wall Insulation R-19	17.19	19.79	15.68	29.05	2.24	5.42	3.35	2.87	3.55
SIP Wall R-26	19.19	22.22	17.67	32.61	4.50	10.65	6.45	6.23	7.87
Icynene Wall R-15	17.48	20.21	16.03	29.56	2.67	6.19	3.84	3.38	4.21
Double Non Metal Clear Window	2.21	5.43	1.64	7.16	2.88	7.73	0.13	**	**
Double Non Metal Low-E Window	2.94	4.52	1.64	10.06	1.09	6.86	1.77	0.28	-0.87
Double Metal Low-E Window	1.23	0.75	-0.37	5.11	-1.00	3.27	-3.79	-7.01	-4.54
Triple Metal Clear Window	3.08	3.49	1.14	10.51	0.42	5.88	-10.97	-1.07	-2.65
Exterior Low Angle Sunscreen	-2.15	-12.3	-7.30	0.00	-9.68	-5.40	-18.46	-19.39	-10.52
Exterior Louvered Sunscreen	-1.47	-8.33	-5.37	-3.48	-7.06	-9.16	-12.21	-10.70	-5.74

* Negative (-) values represent an increase in CO_2 emissions.

** Retrofits of attic and wall insulation were not performed in homes that had insulation of higher R-value than the retrofit technology.

5.2.b HVAC

Although among the most expensive of our options, the geothermal heat pump and 94% AFUE furnace, along with radiant floor heating and cooling, showed the greatest improvements for nearly every home when calculating percentage change in CO_2 emissions from the home's original baseline.

Table 12. Percent Decrease in CO_2 Emissions Associated With HVAC Retrofits

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
90% AFUE	6.62	4.95	4.31	11.86	2.16	6.62	2.49	0.93	1.56
Ducts Ins R8	0.87	1.50	1.19	1.58	0.57	1.34	4.79	0.55	0.54
90% AFUE + Duct Ins R8	7.35	6.15	5.27	13.05	2.59	7.67	4.79	1.36	1.97
Radiant floor with forced air cooling + Duct Ins R8	9.41	8.88	7.75	15.90	3.72	10.18	6.03	2.57	3.14
94% AFUE & 13 SEER + R8	8.16	7.35	6.25	14.75	3.04	9.10	5.85	2.15	2.53
94% AFUE & 13 SEER + R12	8.45	7.78	6.62	15.19	3.32	9.58	6.05	2.40	2.80
3-ton Geothermal Heat Pump	17.18	19.36	16.61	31.28	8.00	19.06	11.89	1.90	8.59

5.2.c DHW

The greatest CO_2 emission reductions resulted from the system that heats water for both domestic uses (showering, etc.) and space heating . This system includes a Munchkin boiler to heat the water and a Superstor tank to hold the water prior to use. The second most efficient technology was a tankless water heater with an EF of 0.84. A tankless water heater with an EF of 0.66 did not perform nearly as well in any of the model homes.

Table 13. Percent Decrease in CO_2 Emissions Associated With DHW Retrofits[*]

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
Tankless (EF 0.66) + all pipes ins	5.81	3.76	4.53	2.08	5.40	6.14	0.00	-9.20	-10.15
Tankless (EF0 0.84) + all pipes ins	14.73	11.59	13.03	7.69	15.52	16.51	9.38	0.82	0.78
Solar Thermal & 50-gal tank (EF 1.0) + all pipes ins	10.81	9.71	10.43	6.84	12.41	11.81	7.57	-0.58	-1.17
Munchkin Superstor & Radiant Floor	24.21	21.69	21.54	26.14	18.15	23.24	19.62	2.26	2.75

[*] Negative (-) values represent an increase in CO_2 emissions.

5.2.d Appliances

The percent decrease in CO_2 emissions associated with appliance retrofits is a reflection of the aforementioned percent increases in energy efficiency. Because we only modeled electric appliances, and not a combination of electric and gas appliances, the relative changes in CO_2 emissions due to retrofitting appliances are in direct proportion to these relative decreases in energy use. Therefore, just as with changes in energy use, we calculated the biggest reductions in CO_2 emissions from retrofitting all appliances together. For single technologies, again, we found that clothes washers, refrigerators, and dishwashers had the greatest decreases in CO_2 emissions relative to the other appliances.

Table 14. Percent Decrease in CO_2 Emissions Associated With Appliance Retrofits

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
Refrigerator	1.60	1.18	1.35	0.77	1.60	1.12	1.34	1.38	1.54
Clothes Washer	3.65	2.68	3.06	1.76	3.65	2.56	3.05	3.15	3.52
Microwave	0.33	0.24	0.28	0.16	0.33	0.23	0.28	0.28	0.32
Oven	0.79	0.58	0.67	0.38	0.79	0.55	0.66	0.68	0.76
Television	0.25	0.18	0.21	0.12	0.25	0.17	0.21	0.21	0.24
DVD Player	0.17	0.12	0.14	0.08	0.16	0.12	0.14	0.14	0.16
Six Power Supplies	0.16	0.12	0.14	0.08	0.16	0.11	0.14	0.14	0.16
Dishwasher	1.37	1.01	1.15	0.66	1.37	0.96	1.15	1.18	1.32
All Appliances	8.33	6.11	6.98	4.02	8.32	5.82	6.96	7.18	8.02

5.2.e Lighting

The percentage reductions of CO_2 emissions associated with lighting retrofits varies with both the size and the original energy use of the home. In a larger, newer home, the lighting retrofit represents a much larger percentage reduction in associated CO_2 emissions than it does in a smaller, older home. There are greater CO_2 emissions reductions associated with a single kBtu of energy use reduction from lighting retrofits than from an HVAC retrofit because reducing lighting energy use entails reducing electricity use, rather than natural gas, and electricity has a greater CO_2 footprint per unit than residential natural gas.

Table 15. Percent Decrease in CO_2 Emissions Associated With Lighting Retrofits

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
100% CFL Replacement	7.76	11.13	10.73	10.76	12.77	11.99	14.80	21.79	19.85

5.2.f Combined Technologies

Of the four combinations, combination B performed the best in terms of CO_2 emission reductions. Combination B includes the combined DHW and HVAC system with a Munchkin boiler, Superstor tank and radiant flooring. Combination D, Low Cost, performed almost as well as this, and was still better than combinations A and B.

Table 16. Percent Decrease in CO_2 Emissions Associated With Combination Retrofits

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
COMBO A Solar Thermal	34.13	34.64	32.81	49.54	20.00	35.90	21.38	6.87	6.31
COMBO B Munchkin	36.63	21.69	21.54	26.14	20.87	36.47	19.06	6.67	6.65
COMBO C Geothermal	39.79	42.25	38.22	53.63	26.44	39.92	28.12	9.22	12.79
COMBO D Low Cost	38.45	40.75	36.24	51.19	24.09	37.69	25.58	7.69	9.90

5.3 Cost per tonne CO_2 Reductions Through 2030

While the cost for a specific retrofit technology is, in general, calculated as a one-time initial expenditure, the CO_2 reduction benefits associated with that technology continue to accrue annually. The cost-per-tonne-of-CO_2-reduced metric represents the overall cost of the retrofit technology, divided by the total amount of CO_2 reductions associated with that technology through the year 2030. We calculated the cost per tonne of CO_2 emissions reductions metric for two reasons. First, it enabled us to identify which individual technologies offered the cheapest opportunity for achieving reductions—the so-called 'low-hanging fruit'. Second, it offers a metric against which we might compare the cost-effectiveness of other strategies and policies, such as a carbon cap-and-trade system or a carbon tax.

5.3.a Building Envelope

Attic insulation options varied in terms of cost efficiency among the nine model homes. The most cost-effective attic insulation options for the oldest homes (those built before Title 24 came into effect in 1978) were R-30 and R-40. For the middle age homes (built between 1979 and 1990), R-40 attic insulation performed the best, and for newest homes, none of the retrofit options was particularly cost effective due to the fact that new homes are initially constructed with thick attic insulation. In the oldest homes, R-13 and R-19 wall insulation proved to be almost equally cost-effective. For newer homes (built after 1992), SIP walls were more cost-effective than retrofits with increased wall insulation. The newer homes already contain wall insulation close to R-13 (R-9 or R-11) and a retrofit with only slightly better technologies proved to be impractical. SIP walls, however, are typically installed during construction and are not suitable for retrofits. In a new construction situation, the cost per tonne CO_2 reduced for SIP walls would be substantially lower.

Due to limited window and exterior shading pricing information, cost-efficiencies for these technologies are not complete. Our analysis did show that double, non-metal clear windows are somewhat more cost-effective than their low-E counterparts.

Table 17. Cost per Tonne CO_2 Reduced Associated With Building Envelope Retrofits

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
Attic Insulation R-13	$666	$409	$489	$693	*	*	*	*	*
Attic Insulation R-19	$320	$206	$235	$352	$0	$6,455	*	*	*
Attic Insulation R-30	$242	$199	$224	$261	$731	$437	$0	$1,358	$1,202
Attic Insulation R-40	$275	$184	$206	$310	$522	$320	$0	$946	$914
Attic Insulation R-30 + Radiant Barrier	$264	$205	$235	$316	$634	$347	$0	$1,070	$1,042
Attic Insulation R-40 + Radiant Barrier	$277	$196	$224	$298	$520	$298	$3,236	$878	$900
Wall Insulation R-13	$93	$115	$127	$76	$4,684	$3,087	$4,092	*	*
Wall Insulation R-19	$94	$117	$142	$77	$1,291	$731	$1,002	$1,718	$1,269
SIP Wall R-26	$120	$148	$180	$98	$842	$485	$680	$1,036	$747
Icynene Wall R-15	$229	$284	$345	$188	$2,467	$1,462	$1,986	$3,320	$2,427
Double Non Metal Clear Window	$752	$830	$1,502	$648	$1,017	$986	*	*	*
Double Non Metal Low-E Window	$797	$1,444	$2,173	$667	$3,889	$1,611	$5,055	--	--
Double Metal Low-E Window	--	--	--	--	--	--	--	--	--
Triple Metal Clear Window	--	--	--	--	--	--	--	--	--
Exterior Low Angle Sunscreen	--	--	--	--	--	--	--	--	--
Exterior Louvered Sunscreen	--	--	--	--	--	--	--	--	--

*Retrofits of attic and wall insulation were not performed in homes that had insulation of higher R-value than the retrofit technology.

5.3.b HVAC

Insulating HVAC ducts with R-8 insulation proves to be the most cost-effective way to reduce CO_2 emissions. This is an option with inexpensive upfront costs and can be quite effective in its immediate impacts on heating and cooling efficiency in the home. In what should prove to be an encouraging sign for highly efficient HVAC options, our more expensive furnace of 94% AFUE and the geothermal heat pump both proved more effective than a 90% AFUE furnace. This is because their reductions in CO_2 emissions are so large that they outweigh their larger upfront costs. Radiant floor distribution systems are still a bit too expensive to compete in this metric.

Table 18. Cost per Tonne CO_2 Reduced Associated With HVAC Retrofits

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
90% AFUE	$689	$675	$888	$185	$2,110	$482	$1,534	$4,219	$2,813
Ducts Ins R8	$394	$167	$241	$104	$601	$179	$60	$539	$612
90% AFUE + Duct Ins R8	$682	$598	$799	$185	$1,933	$458	$875	$3,174	$2,453
Radiant floor with forced air cooling + Duct Ins R8	$568	$835	$929	$446	$2,302	$782	$1,627	$5,579	$4,176
94% AFUE & 13 SEER + R8	$531	$433	$581	$142	$1,422	$333	$619	$1,741	$1,651
94% AFUE & 13 SEER + R12	$513	$408	$549	$138	$1,302	$316	$599	$1,554	$1,492
3-ton Geothermal Heat Pump	$644	$419	$559	$171	$1,380	$406	$778	$5,022	$1,240

5.3.c DWH

Due to the minimal upfront costs associated with tankless water heaters, the more efficient tankless technology proved to be the most cost-effective in reducing CO_2 emissions across all nine model homes.

Table 19. Cost per Tonne CO_2 Reduced Associated With DHW Retrofits

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
Tankless (EF 0.66) + all pipes ins	$426	$482	$458	$572	$458	$282	*	*	*
Tankless (EF0 0.84) + all pipes ins	$207	$193	$196	$191	$196	$129	$271	$3,219	$3,755
Solar Thermal & 50-gal tank (EF 1.0) + all pipes ins	$651	$531	$566	$496	$566	$417	$777	*	*
Munchkin Superstor & Radiant Floor	$395	$485	$498	$349	$704	$470	$680	$7,941	$6,245

*DHW retrofits were not performed in homes that had systems that were more efficient than the retrofit technology.

5.3.d Appliances

Clothes washers and dishwashers have the lowest CO_2 cost per tonne values. Retrofitting clothes washers, dishwashers, and refrigerators results in the greatest reductions of CO_2 relative to the other appliances. However, refrigerators, and especially the highly efficient refrigerators that we modeled, are quite expensive. Thus, although retrofitting refrigerators can substantially reduce CO_2 emissions, they cost more than other options when considering cost per tonne of CO_2 reduced. Conversely, efficient clothes washers and dishwashers are relatively inexpensive appliances. This makes clothes washers and dishwashers more attractive and worthwhile as investments in terms of CO_2 reductions, because they can reduce the largest amount of CO_2 at a lower price than any of the other appliances.

Table 20. Cost per Tonne CO_2 Reduced Associated With Appliance Retrofits

	All Homes
Refrigerator	$703
Clothes Washer	$265
Microwave	$897
Oven	$935
Television	$2,309
DVD Player	$691
Six Power Supplies	$1,684
Dishwasher	$258
All Appliances	$534

5.3.e Lighting

The cost per tonne of CO_2 reductions achieved by replacing all incandescent bulbs with CFL bulbs is the same among all homes, due to the way that lighting use was calculated, on a per-square-foot basis. As seen in Table 21, lighting represents the cheapest per tonne option for reducing CO_2 emissions when compared to all other modeled retrofits.

Table 21. Cost per Tonne CO_2 Reduced Associated With Lighting Retrofits

	All Homes
100% CFL Replacement	$12

5.3.f Combined Technologies

As expected, combination D proved to be the least expensive option available in cost per tonne of CO_2 reduction. Because it was intentionally constructed as the 'Low Cost' option, this fits our expectations. For the most part, combination B proved to be the most expensive as the Munchkin Boiler is a very expensive unit. Surprisingly, despite the high upfront costs of a geothermal heat pump, the technology is so efficient that it helps to make combination C relatively competitive (and cheaper in many cases than A or B) on a cost per tonne basis.

Table 22. Cost per Tonne CO_2 Reduced Associated With Combination Retrofits

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
COMBO A Solar Thermal	$606	$628	$619	$360	$1,222	$731	$1,276	$5,530	$4,802
COMBO B Munchkin	$516	$1,103	$999	$822	$1,240	$801	$1,632	$6,924	$5,494
COMBO C Geothermal	$593	$562	$593	$356	$1,030	$705	$1,050	$4,360	$2,568
COMBO D Low Cost	$438	$462	$470	$310	$852	$622	$935	$4,475	$2,666

5.4 Policies for Implementation

The following table outlines the current characteristics of new and existing single-family residences in Santa Barbara (RAND, 2001). By dividing the amount of existing square footage by the amount of new square footage that is built each year, our calculations show that it would take over 450 years to bring Santa Barbara's current housing stock up to compliance with The 2030 Challenge if this rule were followed.

Table 23. Santa Barbara Construction Statistics

Single Family Homes	
New Homes Built per Year	41
Average New Home Size (sf)	1,618
Average Annual Building Area (sf)	66,909
Number of Existing Homes	19,971
Average Existing Home Size (sf)	1,508
Average Square Footage of Existing Homes	30,118,764
Time Until Upgrades Complete	450
Year Completed	2,458

Over 700 transactions of single-family houses occur in Santa Barbara every year (see Table 24). If houses were required to incur retrofits any time that they were bought or sold, Santa Barbara could meet compliance with The 2030 Challenge by 2035 (RAND, 2001).

Table 24. Santa Barbara Real Estate Transaction Statistics

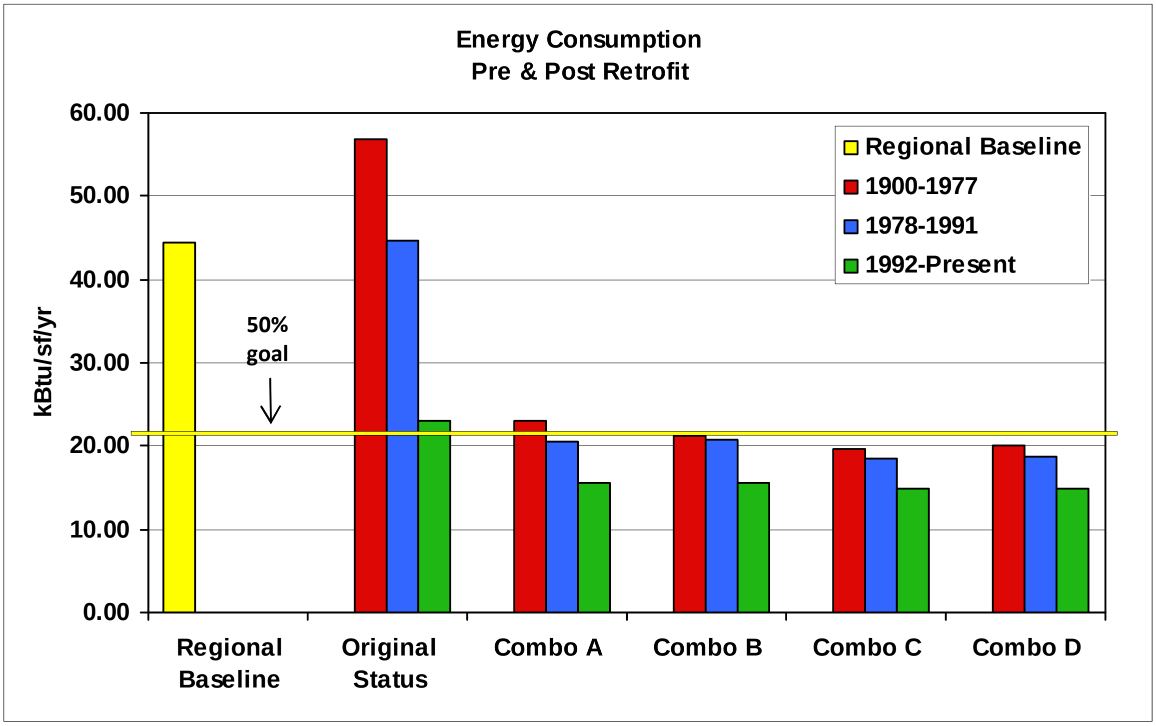
Single Family Homes	
Number of Existing Structures	19,971
Number of Transactions per year	716
Time Until Upgrades Complete	27
Year to be achieved	2035

6. Discussion

6.1 Reaching the 50% Reduction Goal

The results of this study demonstrate that existing single-family, detached homes in Santa Barbara can achieve The 2030 Challenge target for existing homes by retrofitting with any one of the four combinations of technologies. Specifically, achieving a 50% reduction from a regional baseline in terms of kBtu/sf/yr energy use is possible in each of our model homes after applying any of the combinations. The only exception is combination A, which did not fully reduce homes in the 1900-1977 age bracket to 50% below the regional baseline.

Figure 5. Energy Consumption Pre- and Post-Retrofit Compared to Regional Baseline



6.2 Cost-Effectiveness

Achieving the 50% consumption reduction goal through retrofits with commercially available technologies as described in this study could be relatively expensive for homeowners. The initial cost of retrofitting the model homes with the combined technologies ranged from \$15,000 to \$47,000, as indicated in Table 25. Even the least expensive combination would cost homeowners around \$15,000 in the most favorable circumstances. This fact makes retrofits seem undesirable, but in the long term homeowners will realize benefits associated with such investments, because retrofits will reduce the costs of monthly utility bills. If the price of electricity continues to increase, as it has historically, then homeowners will have even greater incentives to retrofit their homes and reduce their energy consumption.

Table 25. Cost of Implementing Retrofit Combos ($)

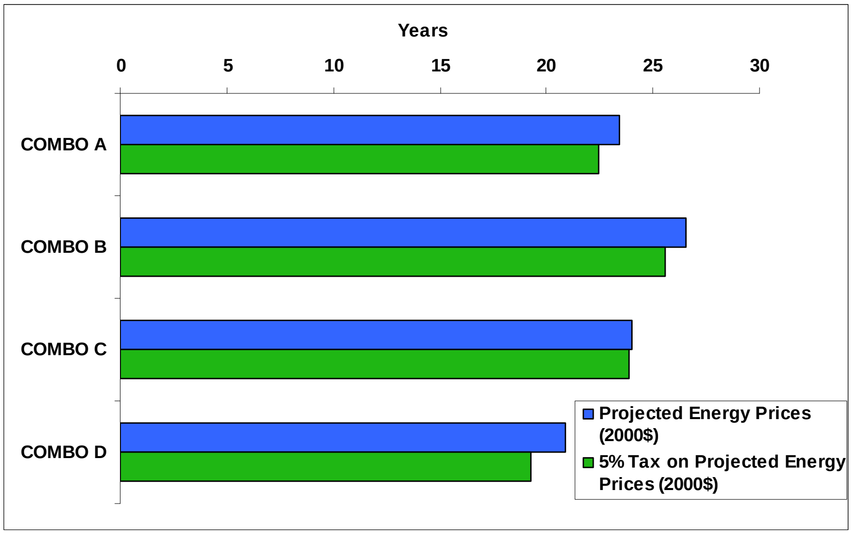
	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7	Home 8	Home 9
Combo A	18,150	26,015	21,252	32,466	21,468	32,925	28,611	38,638	27,606
Combo B	16,565	28,620	22,507	39,096	22,723	36,640	32,641	46,943	33,281
Combo C	20,677	28,425	23,699	34,763	23,916	35,304	30,981	40,889	29,930
Combo D	14,777	22,525	17,799	28,863	18,016	29,404	25,081	34,989	24,030

While future savings on energy bills play a part in incentivizing energy efficient retrofits, they do not diminish the fact that few homeowners can afford to spend tens of thousands of dollars in upfront costs. If Santa Barbara were to make The 2030 Challenge a requirement for homeowners, it might also consider a mechanism for helping to finance the cost of the retrofits. If the City of Santa Barbara were to implement a non-compounding 5% tax on both electricity and natural gas they would generate substantial revenue by 2030. Such a tax would have several benefits: first, the revenues could be put into a fund with which the city could subsidize energy efficient retrofits; second, increasing the price of energy would make energy efficient retrofits more attractive by decreasing payback time; and third, increasing the price of energy may further reduce residential energy demand. The upfront costs could also be incorporated into the mortgage loan to spread the costs over time.

6.2.a Payback

Payback is a metric often used by corporations and individuals to calculate the amount of time it would take to recoup, through energy cost savings, the initial investment for an energy efficient technology (Decanio, 1994). Despite its limitations—most notably that it does not provide for the time value of money—this metric offers a useful way for consumers to determine the value of an investment. Additionally, it provides a method of valuation and comparison between technologies.

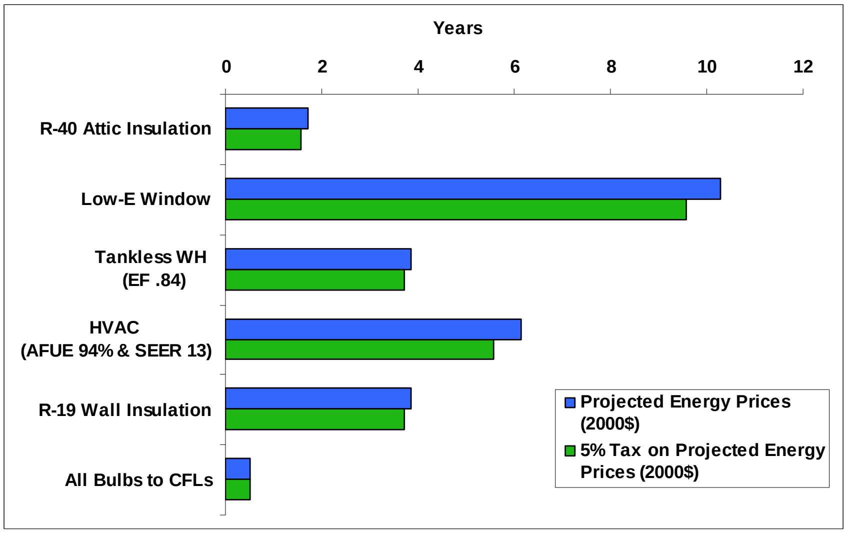
Figure 6. Payback Periods Associated with Retrofit Combos



The costs of implementing any one of the combinations that achieve the desired 50% reductions is substantial. The lowest overall cost for implementing the combinations was $14,777 for combination D in the oldest set of homes. Considered in a vacuum, this cost may seem prohibitive. However, when the energy savings are factored into the equation, combination D has a 21 year payback period, meaning that, given projected, inflation-adjusted energy prices, a homeowner would recoup his or her initial expense after 21 years (see Fig. 7).

The payback metric is particularly compelling when considering the payback period for some of the least expensive, best-performing technologies. Tankless water heaters, R-19 wall insulation, R-40 attic insulation, and lighting, when averaged across the 7 older homes, have payback periods of 4 years, 4 years, 2 years, and less than one year, respectively. From a payback perspective, these technologies all represent good financial investments for the homeowner, regardless of the environmental benefits.

Figure 7. Payback Periods Associated with Single Retrofit Technologies



6.2.b Performance-Based Retrofits

The total price of retrofitting older homes in Santa Barbara with the combinations presented in this study ranges from around $15,000- $47,000, with payback periods ranging from 17 to 30 years, depending on the combination and the size of the home. The process of retrofitting a home with a specific combination of features, regardless of the existing features, is considered ‘prescriptive’. This method is used primarily for wide-scale cost-benefit analyses as opposed to individual retrofit applications. In many cases, home-specific, ‘performance-based’ retrofits may be more cost-effective and successful for homes in Santa Barbara.

Performance-based retrofits are implemented via an assessment of the home, typically concentrating on the major features addressed in this report (HVAC, DHW, building envelope, lighting, appliances, etc.). After assessing the existing home features for energy efficiency, specific retrofits can be performed based on their respective cost effectiveness, or individual payback estimates.

Specifically, if a home built in the 1960s underwent a partial upgrade in the late 1990s, it may have hypothetically received efficient windows and a fairly efficient HVAC system, while making no changes to the wall insulation or DHW system. Retrofitting this home with combination D, which includes a new HVAC system and windows, as well as wall insulation and a new DHW system, may not be the most cost-effective option. Alternatively, retrofitting this home with a tankless water heater and installing blow-in cellulose wall insulation could provide substantial returns in terms of energy savings while remaining much more feasible in terms of the upfront investment.

The performance approach often proves to be more cost-efficient, while the prescriptive approach, as presented in this analysis, may prove to be cost-prohibitive. The prescriptive approach is often more appealing in a wide-scale implementation, or for use in a city-wide ordinance, for example. However, wherever possible, performance-based retrofits should be considered as a primary option and the best-case scenario.

6.3 Limitations

The approach taken in this study was designed to provide a robust yet replicable method for evaluating energy efficiency gains achieved from retrofitting technologies in the home. However, there are inherent limitations to the modeling method, as well as constraints imposed by the assumptions made.

6.3.a Sensitivity to Inherent Home Features

The EnergyPro software calculates energy consumption of buildings stemming from the HVAC and DHW systems, and considers interactions associated with the building envelope. Additionally, EnergyPro considers features such as the orientation of the building on the site, whether or not the building is constructed on a slab or a crawl space and the associated insulation, occupancy schedules, ceiling height, and more. Although the software program allows the user to make changes to these features, we did not alter them for our analysis.

In our study, we made changes to HVAC, DHW, and building envelope features including attic and wall insulation, windows, and shading. We chose to keep the other features constant for each home due to the limitations on time and scope. We realize, however, that these features alter the energy performance of the home. Specifically, orientation of the building relates to differing levels of solar insolation and directly impacts the heating and cooling loads. Similarly, building foundation and related insulation will affect HVAC performance. Occupancy and use scheduling also impact energy consumption. We chose to keep this parameter on a setting that specifies little use during the day (when occupants are at work or school) and increased activity in the evenings.

The unchanged parameters varied across the homes, complicating the results, but also driving home the point that prescriptive measures that apply to all homes regardless of age, size, and implicit features may not provide the most effective results. Alternatively, a home-specific energy performance analysis and subsequent performance-based retrofit will, in most cases, provide the greatest gains in terms of energy use and emission reductions.

It is important to consider the limitations associated with the lighting methodology as well. Formal cost estimates for lighting were based upon observations at a variety of retail outlets in the Santa Barbara area. Prices for standard 60W incandescent and 18W CFL bulbs were researched in 5 retail outlets, arriving at an average price of $0.59 for a 60W incandescent and $3.92 for an 18W CFL. These prices were confirmed through online research, and through recent academic literature (CEC, 2008).

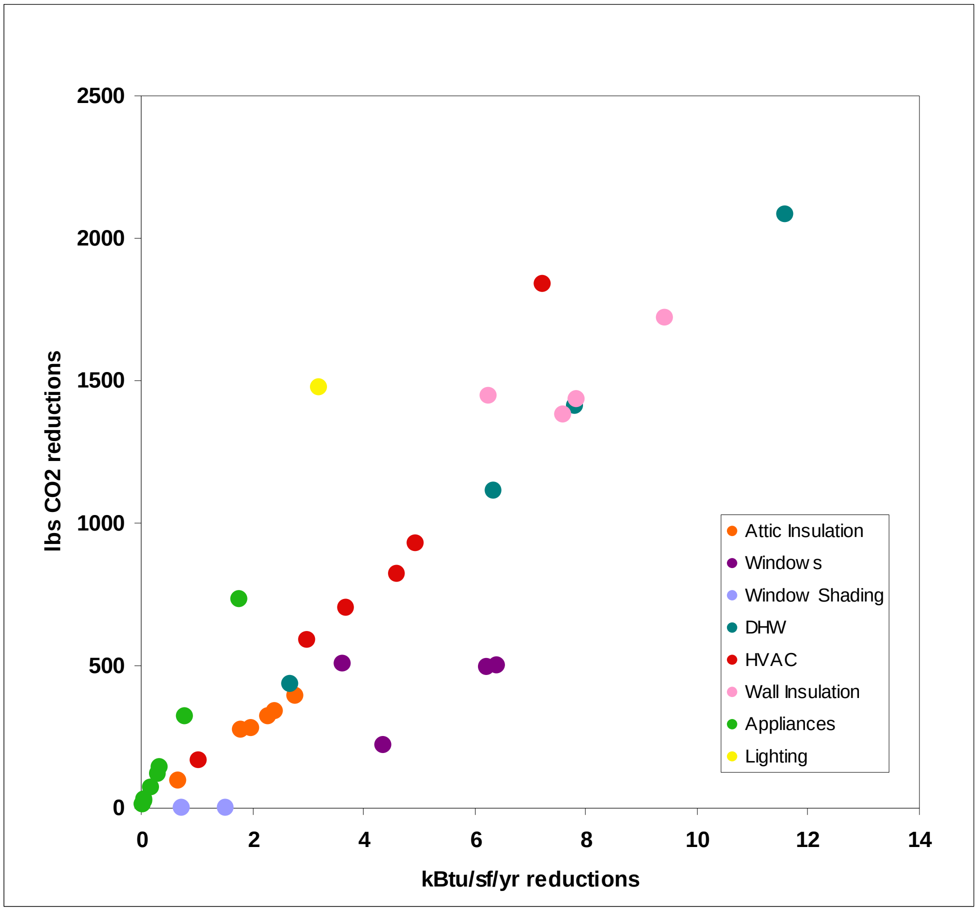
This methodology was arrived at with the aim of providing a reasonably accurate yet flexible calculation that could be applied to a range of home sizes given limited data regarding number of occupants, and behavior. Assumptions inherent in this methodology necessarily limit the precision of the calculated energy savings. In truth, there is a complex correlation between home size and lighting electricity usage due in part to the fact that the actual daily usage of individual bulbs is influenced by the number of occupants in the home, and the home occupancy is not directly correlated with home size.

6.3.b Limits of a Metric

Different technologies have varying impacts on energy and CO_2 reductions, depending upon their relative reliance upon electricity or natural gas. Switching out lighting results in substantial gains in CO_2 reductions, partially due to the fact that lighting is run entirely on electricity, a more carbon intensive source than natural gas. Appliances display this characteristic as well, also due to their reliance purely upon electricity. Because windows and insulation resulted in a decreased natural gas use, their CO_2 reductions tended to be a bit lower or in line with the trend. One surprising result in the HVAC category was the 3-ton geothermal heat pump. Although this option is still focused on natural gas savings, and even uses a significant amount of electricity, it is such an efficient technology that the CO_2 savings are still among the highest in our model. The Munchkin combined DHW/HVAC system resulted in the most savings in terms of both CO_2 and kBtu/sf/yr.

The figure below portrays our results as averaged across all nine homes.

Figure 8. kBtu/sf/yr Reductions vs. CO2 Reductions



As stated in Methodology, EnergyPro helps to translate electricity and natural gas consumption into therms and kWh, both of which can be converted to kBtu. However, this fails to take into account the different carbon intensities of natural gas and various sources of electricity. Despite discrepancies in CO_2 intensities associated with electricity and natural gas, The 2030 Challenge poses consumption reduction targets for all buildings in terms of kBtu/sf/yr. Although efficiency is a good starting point for achieving CO_2 emission reductions, use of renewable or carbon-free energy sources provides a much better solution. For example, if a house in Santa Barbara were to perform efficiency retrofits and also attain all of its electricity through onsite generation by solar panels on its roof, it might have the same kBtu/sf/year reduction results as a house powered entirely from the grid, while resulting in clear differences in CO_2 emissions.

The kBtu/sf/yr metric also fails to adequately account for the size of homes. Our results include one example of the limitations of using this metric when attempting to address greenhouse gas emissions. The newest homes in this study, built in 2007, have starting points of energy use nearly half that of our oldest homes, when measured in kBtu/sf/year. This is due in large part to the much more stringent requirements of Title 24 as they apply to new construction.

However, these results fail to draw attention to the significant increase in average home size corresponding with age. Our nine sample homes illustrate this point well. The newer homes are nearly twice the size of older ones. Extrapolating this further, a 10,000 square foot home (increasingly prevalent in wealthy communities) built in 2007 may appear to be twice as efficient as a 1,000 square foot home built in 1920 on a per-square-foot basis. But even if this is the case, it will still be emitting five times the amount of CO_2 as the smaller, less efficient home, because it is ten times as big. We advise Architecture 2030 to take this into consideration for further study and discussion in their future recommendations. When considering energy use in the residential sector, it is important to address the size of the home and to promote construction of "the not so big house" (Susanka & Obolensky, 2001).

6.3.c. Model Homes

Another limitation to this research is the way in which we chose model homes. As mentioned previously, we selected our model homes based on files given to us by local mechanical engineers. Within our selection process, we solicited files of homes that were built within specific age brackets (corresponding to Title 24 upgrades), and within certain size classes.

While housing stock data shows that the model homes we selected give a fair representation of the Santa Barbara housing stock in terms of size and age, they do not necessarily represent the current housing stock in terms of baseline energy consumption. We modeled our homes in EnergyPro by addressing features of each home's building envelope, HVAC, and DHW systems as a baseline for assumed energy consumption. We used this method because we were unable to find accurate data that described internal features of Santa Barbara homes, and thus we used a sample of homes to represent the baseline conditions of all homes in the city.

In order to fully investigate the feasibility of implementing The 2030 Challenge in the entire existing housing stock of Santa Barbara, a survey should be completed to assess the current internal contents of existing homes.

6.3.d. Appliance Baselines

Similar to limitations with the model homes approach, this study was limited in its ability to accurately address baseline energy consumption for appliances. The variation in appliance types, sizes, and ages makes it difficult to assume the energy consumption that occurs as a result of appliance use in Santa Barbara homes. Thus, we assumed baseline energy consumption from appliances based on mandated minimum efficiency standards set by the state or federal government.

A follow-up study for this report could include a survey of the types, sizes, and ages of appliances within Santa Barbara homes to calculate a more accurate baseline.

6.3.e. Lighting Methodology

The lighting methodology aims to provide a reasonably accurate yet flexible calculation that could be applied to a range of home sizes given limited data regarding number of occupants, and behavior. Assumptions inherent in this methodology limit the precision of the calculated energy savings. In truth, there is a complex correlation between home size and lighting electricity consumption due in part to the fact that the actual daily use of individual bulbs is influenced by the number of occupants in the home, and the home occupancy is not directly correlated with home size.

6.4 Achieving Greater Efficiency through New Technologies and Behaviors

This study was intentionally constrained to considering only commercially available, technology retrofits for reducing energy use in the home. These constraints allowed us to develop accurate predictions for resultant energy efficiency gains, and associated costs.

These constraints necessarily excluded a number of technologies that, while not presently commercially viable, hold great promise for the future. Additionally, they excluded consideration of behavioral changes as a way of reducing energy consumption; such behavioral changes could represent a more economically efficient approach to reducing energy consumption, but are also difficult to affect through policy instruments.

6.4.a. Lighting

Some of the most promising technologies for decreasing energy use in buildings are solid-state lighting systems including light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDs). These semiconductor-based light sources are extremely efficient, with a typical efficacy of 45 lumens output per watt of power input (lm/W), compared to normal incandescent efficacy of 14 lm/W (DOE 2006). While LEDs currently lag behind fluorescent bulbs, which average 83 lm/W, rapid advances in semiconductor technology indicate that LEDs may far surpass the efficacy of fluorescent bulbs (Bergh et al. 2001, OIDA 2002) perhaps even within a few years. LED bulbs also have extremely long lifetimes, predicted to last 50,000 hours.

At the same time, the cost of LED technology is currently prohibitive to broad adoption for general residential lighting. LED bulbs are more than 100 times as expensive as incandescent bulbs, when normalized for light output (DOE, 2006). This discrepancy is significantly reduced, although not eliminated, when lifecycle costs, including bulb replacement, are factored in. However, costs are predicted to drop as efficacy increases. This is a trend posited by Roland Haitz , formerly of Agilent Technologies, who has accurately predicted that the light generated by an LED will increase by 20 watts every ten years, while the cost per lumen will decrease by a factor of 10 (Steele, 2007).

LEDs have penetrated a number of commercial markets, most visibly in traffic signals, automobile indicators, and power indicators on appliances, where monochromatic light is acceptable and longevity a priority. As prices decrease and efficacy increases over the coming decade, LED lighting will likely represent a substantial opportunity for residential energy efficiency in Santa Barbara. This should be considered when crafting plans and goals for energy efficiency.

6.4.b. HVAC

The choices an individual makes in the design and use of their HVAC systems will depend upon their preferences for "thermal comfort". Some people have greater tolerances for temperature variation, while others prefer to maintain certain temperatures which require greater energy intensity (high use of air conditioning, for example).

Perhaps the most efficient approach to indoor air temperature is, in Amory Lovins' words, "cooling the people, not the building." (Lovins, 2007). Different areas of the US have varying attitudes towards HVAC. In some locations, an individual might be more accustomed to turning on an air conditioner when they feel too hot, instead of opening a window, or designing one's house to contain natural ventilation. Thorough understanding of tendencies and tolerances are crucial to developing effective policies for the building sector.

An integrated approach to HVAC can attempt to achieve the ultimate goals of indoor thermal comfort and air quality by controlling the "micro-climates" of buildings. New technologies and trends in modern building design approach the traditional issues of HVAC with innovations to achieve this end goal without the vast amounts of energy previously required to heat, cool, and then re-heat air throughout the building. The US Department of Energy estimates that HVAC accounts for 40% to 60% of US residential buildings' energy use (DOE, 2007). There are ways to decrease this. Heat from a building can be put to use for multiple purposes, for example, heating other spaces before it is released outside. What follows is a brief discussion of a few of these options.

In a heat recovery ventilation system, heat that is being forced out of a building can be used to warm incoming air as it leaves, thus decreasing the amount of energy needed to heat the rest of the building's air. Additionally, to achieve high degrees of energy efficiency within most HVAC systems, "smart metering" can help residents manage their energy use by showing them the energy that is being used by their systems at any given point in time. Onsite, in-home meters give residents more control and knowledge about the energy their HVAC systems use, addressing the fact that it's hard to conserve what you can't measure.

Moving air within a building or exchanging it between the indoors and outdoors can be an energy-intensive process if not well designed. The Department of Energy advises in its initial checklist for ventilation to deliver only the air needed, use variable-air-volume systems (VAV)[10], and in most cases, to increase the duct size of the distribution system. Implementing this last suggestion can result in a reduction of the necessary velocity required to move air through the ducts, and thus increased energy savings from a lower requirement of fan output. Low-pressure-drop duct design can reduce energy usage by 30-65% by reducing the pressure differential with which the air handling system must operate, allowing air to flow more easily between the ducts and the building's interior. The easiest and most effective way to assure efficiency in all parts of an HVAC system is to provide regular maintenance. Duct sealing, equipment replacement, and other upkeep measures can vastly improve efficiencies at comparatively low cost. Other technological improvements can further improve efficiencies of ventilation systems. Proper fan sizing is essential, and variance-frequency-drives (VFD)[11] for their motors offer a straightforward approach to gaining efficiency.

A displacement ventilation system is a natural option for residents in the temperate climate of Santa Barbara. This system requires little to no duct installation, and uses the natural properties of warm air to ventilate a building. Instead of a diluted air mixture inside of a building, the air displacement system keeps the warm and cool air in separate layers. Air is supplied at the floor level, where temperatures are slightly lower than room temperature. This cooler air then pushes the less dense, warmer air out of the room -- displacing it and creating a zone of cooler, fresher air in the living area. The warmer air rises, and can be exhausted through the top of the buildings, or used in a heat recovery ventilation system, as described above. This also helps protect against the spread of disease within a building by not circulating "used" air.

Heat pumps are a newer technology that hold great promise for increased use in residential buildings as both a heating and a cooling system. These pumps use the outdoor air or ground as heat sources or sinks depending upon the needs of the house. Typically, water or anti-freeze liquid is circulated through pipes and either exports or imports heat into the building. Because an air-source heat pump moves heat instead of converting it from electrical energy, it can deliver one to three times the heat energy to a home than the electrical energy it consumes (DOE, 2007).

Options besides traditional AC systems are available for cooling as well. Desiccant dehumidification may not be as necessary in a climate such as Santa Barbara's, but it is an interesting development for other areas. Much of an individual's perception of thermal comfort can come from levels of relative humidity – dry air feels cooler than moist air. A desiccant dehumidification system will dry the air before it enters the air-conditioned space,

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[10] In contrast to constant air volume distribution, VAV can be more efficient because of the ways in which it allows control over the amount of air delivered to various locations within a building, instead of a centralized approach.

[11] VFD controllers adjust the speed of the fan's motor by converting its normal power to variable frequency power, improving engine efficiency by controlling the speed with which the AC power is input to the motor.

thus reducing the amount of energy needed to cool the air. The National Renewable Energy Laboratory has even qualified humidity levels in AC systems as a possible health issue (NREL, 2007).

Perhaps more appropriate for Santa Barbara is an evaporative cooling option. Well suited to warmer and dryer climates, these systems work much like a humidifier, typically making use of the simple process of evaporation of liquid contained in a vented box. This cooled air around the liquid is then blown throughout the house by a fan. Passive cooling, however, may be the ultimate design for energy savings. With this technology, areas of a building that are heated through the sun drive convective air flow throughout the building. Ventilative, radiative, and ground/water loop coupling all qualify as passive. It may even be possible for Santa Barbara to follow the example of the Natural Energy Laboratory of Hawaii (LEED platinum building) which uses deep seawater for space cooling (Lovins, 2007).

Superefficient refrigerative cooling technologies are currently being developed as possibilities for the future. Thermoelectrics and thermoacoustics are cutting edge innovations that use temperature gradients created through electricity and sound in extremely efficient ways to cool buildings. They may show some promise for a technological breakthrough that could help bring down costs and increase the ease with which great degrees of energy efficiency are achieved in the realm of HVAC.

6.4.c Plug Loads

Our methodology for appliances did not specifically address the issue of plug loads. This refers to the energy drain caused by a device that is plugged into an outlet, and thus constantly receiving some degree of power. Plug load describes any electrical device ranging from large appliances to cell phone chargers (Ecos Consulting, 2008). Over the past few decades outlets have become much more heavily used in households, and thus represent a larger portion of electricity demand than ever before. A 2007 study by Ecos Consulting predicts that 19% of residential electricity consumption will be from miscellaneous household electronics by 2020 (Calwell, 2007).

The standard formula for estimating the amount of energy used in a home due to plug loads is: (Wattage * Hours Used Per Day)/1000 = Daily kWh consumption (EERE, 2005). Thus, excessive plug loading is a product of both inefficient electronics (with high wattages) and behavioral factors relating to appliance selection and use.

In our study, we addressed efficiency of electronics for several categories of appliances, including televisions, DVD players, and power supplies. However, because we only addressed regulated appliances, we did not address consumption due to many other electronic devices. Information from the Lawrence Berkeley National Laboratories suggests that we did not model about 7% of each home’s energy consumption by excluding miscellaneous appliances (Wenzel et al., 1997).

Furthermore, we did not address behavioral components that affect the frequency with which people use their electronic devices. Because the amount of time electronics are used has a large impact on the amount of energy that they consume, it is important that behavior be addressed. The City of Santa Barbara should work on public awareness campaigns to attempt to get people, especially children, weaned off of spending too much time indoors, playing with electrically-charged devices. Unplugging appliances or switching off power strips when not in use can help reduce their "phantom load" as well, an unnecessary use of electricity that occurs even when many appliances are powered off.

6.5 Policies for Reaching Goals

Architecture 2030 suggests the following method for determining the number of existing buildings to be upgraded: "At a minimum, an equal amount of existing building area (relative to new building area) shall be renovated annually to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 50% of the regional (or country) average for that building type" (Architecture 2030, 2008). Therefore, under the terms of The 2030 Challenge, the amount of retrofitting that occurs for existing buildings is limited by the amount of new building construction. This scenario is not realistic for Santa Barbara, given the extremely limited amount of new construction that occurs within the city each year. Following The 2030 Challenge guidelines, it would take 450 years to bring all homes in Santa Barbara to the 50% goal (see Table 23).

Another relevant policy option that recently passed in Santa Barbara is a local energy ordinance called The Architecture 2030 Energy Ordinance. This ordinance is a modification to the current building codes that will increase energy efficiency within the building sector of Santa Barbara (City of Santa Barbara, 2008). It was passed on February 5, 2008, and applies to residential buildings that fit within any of the following classifications:

1. Any new building or structure of any size,
2. Any addition to an existing building or structure where the addition is greater than 100 square feet of conditioned floor area,
3. All new mechanical heating or cooling systems,
4. All new heaters or circulation pumps for swimming pools, spas, and water features.

As with The 2030 Challenge, this energy ordinance focuses largely on new construction and is limited to addressing existing residential buildings.

Due to the amount of existing residential buildings in Santa Barbara and the limited amount of new construction that occurs each year, we suggest that Santa Barbara expand the current Architecture 2030 Energy Ordinance to go beyond the scope of The 2030 Challenge in setting mandates for existing residential buildings. One possibility for accomplishing this is creating time-of-sale legislation that requires energy efficient retrofits any time a building is bought or sold.

Time-of-sale (TOS) ordinances provide a systematic approach to addressing energy efficiency in the building sector by taking advantage of the sale ‘trigger’ and address homes and buildings that may otherwise escape a timely energy use inspection. Time-of-sale ordinances require building owners to assess energy use and perform upgrades to meet minimum efficiency standards set by the locality prior to sale. The benefits of a time-of-sale energy efficiency ordinance are obvious – a better understanding of current energy use trends and guaranteed improvements in efficiency coupled with reduced emissions. However, TOS is not without its costs. Management of a time-of-sale program will result in administration costs to the municipality, most of which can be offset by charging fees, and the implementing would be responsible for fees and the cost retrofits required to achieve compliance.

Most of the TOS ordinances discussed in this section require specific prescriptive measures, or mandatory retrofits, in order to achieve compliance. An alternative to achieving energy efficiency involves performance-based requirements that would require a building to reach a certain energy efficiency rating. Performance-based approaches typically allow the building owner to choose from a wider range of upgrades that each relate to quantifiable efficiency improvements.

Either approach to improving building efficiency has associated pros and cons. While prescriptive measures are easier to implement and enforce, they are somewhat limiting and, depending on the specific building systems, may not always result in the most cost-effective methods of performance improvements and emissions reductions. A performance-based approach allows for a more flexible and cost-effective approach to improving the building’s overall performance. By first assessing the building and providing a rating based on its current systems and efficiency levels, conservation pit-falls are revealed, providing a baseline from which to compare improvement measures based on their costs and performance gains. Performance-based approaches are typically more complex, requiring that energy auditors be trained and available for assessments. However, the potential for greater performance gains at lower costs presents incentives that could result in smoother implementation and a quicker buy-in by industry professionals. Performance-based requirements also allow for a more straight-forward tie-in to CO_2 emissions.

A time-of-sale ordinance would be ideal in Santa Barbara due to the high amount of real estate transactions that occur within single-family residences each year. In contrast to the time horizon required to upgrade existing buildings under the terms of The 2030 Challenge, a time-of-sale ordinance would theoretically result in complete retrofitting of Santa Barbara’s current single-family housing stock within 28 years.

We believe it is feasible for the City of Santa Barbara to mandate a policy requiring existing homes to incorporate any one of the four combinations proposed above that bring existing residences to 50% above the regional average baseline. However, due to cost issues associated with these combinations, it is imperative that the City of Santa Barbara subsidize costs for homeowners that are unable to secure the upfront costs associated with the retrofits. It may be feasible for some homeowners to secure upfront costs, however, as the average $15,000 price tag associated with combination D is less than 2% of a $1 million dollar home transaction.

To take some of the cost burden away from home buyers or sellers, the City of Santa Barbara could subsidize costs with a revenue-generating tax on energy prices. With a 5% non-compounding tax on projected increasing energy prices, the City could generate substantial revenue by 2030. This potential revenue does not take into account possible decreases in energy use due to rising prices. Homeowners would likely reduce consumption in response to increasing prices.

Additionally, the city could establish a funding mechanism whereby the initial cost of retrofits could be incorporated into the home buyer's overall mortgage loan. In this way, what seems like an exorbitant cost could be slowly paid back over the life of the mortgage loan, make the upfront expenditure appear much less cost-prohibitive.

6.6 Rationale for Government Intervention

Given the fact that some off-the-shelf technologies could provide substantial economic benefit to homeowners, one might expect that the best among them would be met with widespread adoption. The low adoption rate of CFL bulbs in California residential buildings (20%), however, shows that this transition is not coming quickly enough. A number of market barriers and failures exist which hamper the adoption of more economical technologies. Such hindrances have been widely acknowledged and discussed in the economic literature (Brown 2001, Howarth & Anderson 1993, Kousky & Schneider 2003), and include imperfect information, misplaced incentives (from landlord-tenant rent structures), lack of pricing for public goods, capital market barriers for debt-financed investments, and hidden costs.

Such market failures and barriers offer a rationale for governmental policies promoting energy efficiency and energy-efficient technologies (Brown, 2001). It is here that our proposals for subsidies of retrofits, financed through a small compounding energy tax, may help support homeowners.

6.7 Carbon Neutrality: Going Beyond Efficiency

Traditionally, people achieve energy savings within the building sector through two routes: efficiency and conservation. These two methods may function well in reducing energy consumption to very low levels, but cannot entirely eliminate a building's need for energy. Even if a building achieves maximum efficiency with regards to HVAC, the building envelope, lighting, and appliances, it still requires energy to function. In order to get Santa Barbara's residential sector to carbon neutrality, the energy that is still consumed within each residence will need to be carbon neutral.

With today's technology, residents in Santa Barbara have two realistic choices for consuming energy that is entirely carbon-neutral: producing it on-site with solar panels, or using carbon neutral energy from the grid. There may be other options in the future for local methane digesters or neighborhood wind turbines, but solar-powered photovoltaic panels are presently the most effective way for individuals to generate their own carbon-neutral energy. The only way to procure carbon-neutral energy from the grid in the future would be through the pursuit of exceptionally progressive methods taken up by SCE (unlikely to meet the aggressive objectives of Architecture 2030), or through a Community Choice Aggregator (CCA), in which the city takes control and responsibility for sourcing and procuring their own energy into the SCE grid infrastructure.

Sources such as nuclear and large hydropower projects typically count as carbon neutral (although they do not qualify as “renewable”), but contain many aspects that do not appeal to those with environmental concerns. Impacts on aquatic life, radioactive waste, and terrorism targets are just a few of the potential problems with these technologies. This is especially the case if these particular projects happen to occur close to the residential neighborhoods that make use of the energy for their electricity – posing a classic “not-in-my-backyard” (NIMBY) problem.

Older, retrofitted homes will have a particularly hard time reaching the goal of carbon neutrality. Most stoves and heating furnaces are gas-fired in these homes, and although natural gas is less carbon intensive than SCE’s current electricity mix, it nevertheless releases a significant amount of CO_2. Therefore these homes would have to replace all natural gas appliances – an exceptionally ambitious and unlikely scenario.

The last option through which residences may strive towards carbon neutrality would be through the purchase of carbon credits. As in any carbon market, transparency and a guarantee that purchases of these credits was indeed going into afforestation, soil improvements, or other sequestration techniques would have to be credible for this option to work in practice. It is beyond the scope of this paper to propose the specific carbon trading or credit-purchasing mechanisms through which this might be accomplished. One possibility is for the homeowner to offset their carbon use through the planting of trees in a neighborhood park or nearby location in which the growth and persistence of the projects can be maintained and monitored.

7. Conclusion

The research completed in this study addresses the technical, financial, and political feasibility of implementing Target 2 of The 2030 Challenge by demonstrating strategies for achieving 50% energy efficiency gains in Santa Barbara's existing single-family residences compared to a regional baseline. This research is useful in getting The City of Santa Barbara on track with implementing both targets of The 2030 Challenge, especially due to the large amount of single family residences that exist in Santa Barbara. However, if Santa Barbara wants to fully implement The 2030 Challenge, this research will need to be expanded to address all of the stepwise goals for the residential building sector, as well as the commercial and industrial building sectors.

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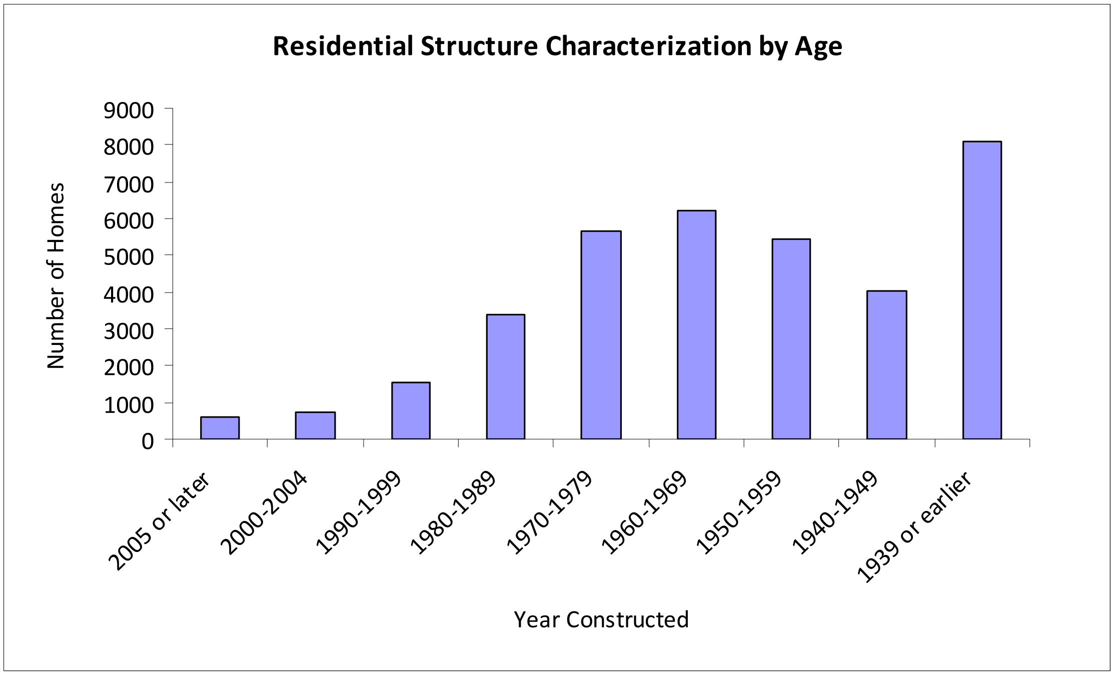
Appendix. Model Homes and Santa Barbara Existing Homes

Table 26: Model Home Characteristics

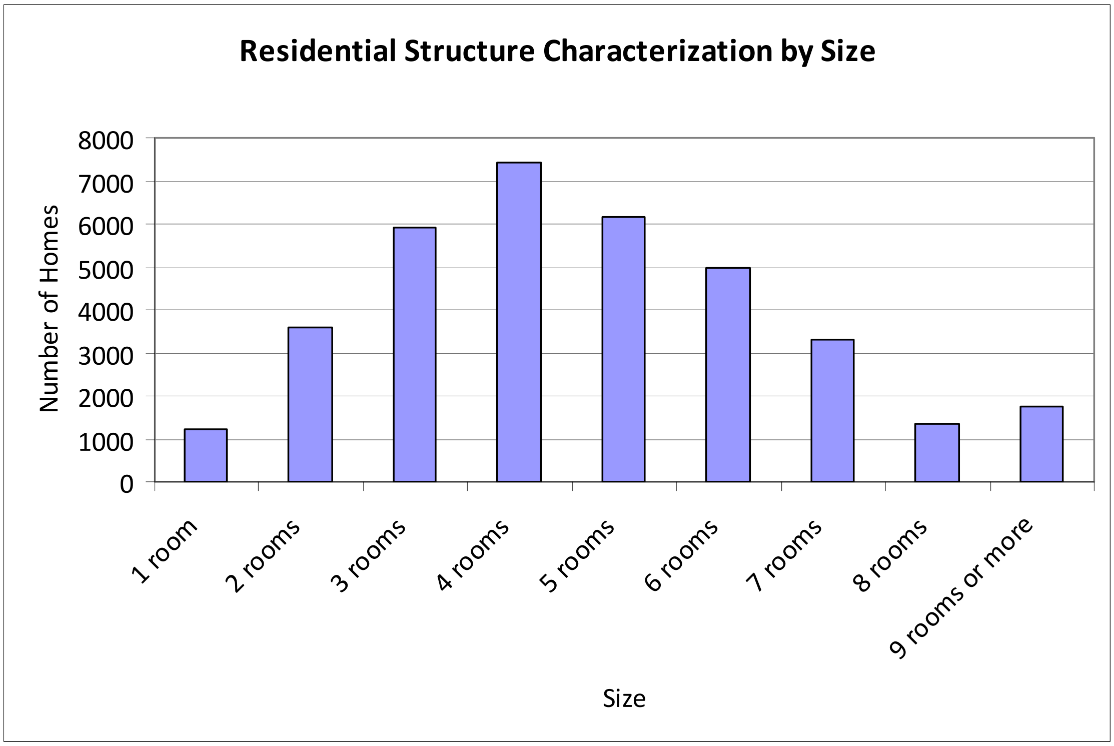
Home	Year Built	Square Feet
1	1900	877
2	1900	2,520
3	1967	1,445
4	1970	1,445
5	1978	1,445
6	1978	1,937
7	1985	2,000
8	2007	2,855
9	2007	2,329

Figure 1: Santa Barbara Housing Stock in terms of Year of Construction*



*US Census Bureau, 2000

Figure 2: Santa Barbara Housing Stock in terms of Size*



*US Census Bureau, 2000

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