# A New Net Zero Definition: Thinking outside the Box

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## ABSTRACT

Zero net energy (ZNE) definitions focus on metered fuel and electricity use. This is due in part to simplify the calculation, but also due to a lack of understanding and accepted methodology for calculating other energy-related impacts. This paper compiles the best approaches to assess a meaningful measure of true net zero energy, which includes, along with fuel and electricity used on-site, transportation energy related to the building location, material usage and its embodied energy, and water consumption and its embedded energy.

If ZNE goals are to reduce absolute energy consumption, then this broader scope will assure ZNE implementation doesn't inadvertently shift building energy usage onto other sectors.

To assess the impact of building location on energy use there needs to be a method for calculating transportation energy use related to occupants, employees and visitors. Methods for reviewing residential transportation energy use, i.e., location efficiency, exist at the census tract level. Commercial building related travel requires different calculations factoring: business type, labor and customer distribution, taxes and competition.

Buildings use materials that require energy due to extraction and processing. The reuse of existing materials or structures can prevent the creation of new materials. Energy simulations can predict the materials' impact on operational energy, while life cycle analysis can appraise the materials' embodied energy.

Buildings use water for potable and process functions. Water requires pumping, filtration, treatment and disposal. The paper will review methods to determine water consumption and its embedded energy, which is likely regionally dependent.

This paper will assess gaps in data needed to conduct this type of complete analysis for commercial or residential projects and make recommendations for filling these absences in data.

## Introduction

The goal of zero net energy buildings has moved rapidly from a broad philosophical aspiration to a set of real and implementable policies. California, for example, has set a goal of net zero by 2020 for new residential construction and net zero by 2030 for new commercial construction. In 2012, the state adopted new energy code proposals that are broadly consistent with the goal. The 2012 standards represent the largest triennial-cycle improvement in the code in the state's history. Although the residential standards fall somewhat short of a track leading to net zero by 2020, the commercial standards suggest that the 2030 net zero goal may be met ahead of schedule.

As a part of this process, the state (California) is beginning to address the issues of **avoiding the error of suboptimization**—in which savings in the performance of the *utility energy using portion of a building*'s *impact* compromises the *ability to save energy in other energy end uses* also associated with the building.

The issue of avoiding suboptimization was raised in Goldstein 2010, and the state is beginning a process of developing specific recommendations on how to calculate net zero energy use that respond to those concerns.

This paper begins by reviewing the issues, explaining what steps California has taken to address them in principle, and then discusses how one might move to metrics that address full system[1] optimization that could be implemented immediately (within a year). It then describes evaluations of these metrics to show how much of a difference they would make using some prototypical development patterns intended to represent realistic choices that builders could make.

## Avoiding Suboptimization

Energy use by utilities in a typical American home is about 108 MBTU (31.6 MWh) per year of source energy (Jonathan Rose Companies 2011), and costs the typical household $2500 a year. Reducing on-site energy, again with a source metric, to net zero evidently reduces both usage and operating costs to zero[2].

But the typical analysis of the cost-optimal path to achieve net zero requires that roughly 30% of current energy use be supplied by on-site solar electricity. This expectation requires collector areas that make high rise developments infeasible, especially for commercial buildings, and in general limits the density of development, especially when one considers the issues of shading.

But density is a prime determinant of transportation energy use. For an average household, personal transportation consumes 80-90 MBTU/yr (23-26 MWh/yr) and costs about $10,000/yr. If reaching net zero utility energy on a given site increases transportation energy use by even a tenth[3] as much (proportionally) as the incremental renewable energy not generated, then society is behind on a cost basis. The EPA funded study by Jonathan Rose Companies 2011 found that conventional home construction and conventional car ownership had lower overall energy use compared to a low-energy home and hybrid car when the energy efficient home was in a typical suburban development and the average home was transit oriented.

Suboptimization is also possible if low energy use comes at the expense of greater water use or greater embodied energy in construction. For example, if a complete teardown and reconstruction allows utility energy to meet the net zero concept, but deep retrofit and reuse still allows 80% savings, which option is better? A recent study by the National Trust (Frey 2012) found that it can take 10 to 80 years (depending on type of construction and climate) for a new building that is 30% more efficient to overcome the negative climate change impacts related to construction compared to a renovated existing building.

Many regions in the southwest are arid, which makes evaporative cooling effective in offsetting vapor-compression based air conditioning to reduce electricity consumption and peak demand. These same regions also have water scarcity issues and contain water utility districts

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[1] Since this paper is about energy policy, we define “full system” to include the four energy-related parameters described herein. One could also optimize more broadly for other environmental needs, such as considering the value of water as higher than just its energy content, or for reducing nonrenewable use of wood, reducing supply chain water and air emissions impacts, etc.

[2] Zero net source energy does not exactly equal zero net cost, depending on how on-site generation is treated in the ratemaking process, how time of use rates mirror the effect of calculating source energy, and many other factors. But this assumption is good to first approximation, in that it is not evident what the sign of the correction term would be.

[3] Remaining utility energy after 70% efficiency savings is about $750 a year, compared to $10,000 for transportation

which may be pumping fresh water supplies over vast distances. If achieving net zero is done on the back of water use, then the result is largely a shell game where the boundary is redrawn beyond the property's lot line and considered at a community level. ***The simple way to avoid suboptimization is to expand the definition of the metric to be optimized so that it embraces all of the relevant variables.***

What this demands is an index of total energy impact of a home or a commercial building that embraces the energy consequences of all four attributes: operations, transportation, water and materials.

This process can be done in the immediate future for the larger parameters, particularly if we are willing to live with some uncertainty for a time. The next section demonstrates current levels of preparedness for such a move, what steps must be taken, and how they could be taken.

## Implementing Total Net Energy Metrics

There are four well-developed parameters that we suggest need to be evaluated. Additional parameters should be included as they are judged to be of policy interest and as the methodology in calculating them matures. This section reviews that status of methodologies for doing so.

### Utility Energy

There are now well-developed methods in the North America[4] for evaluating utility energy use based on building design and independent of knowledge not available when the building permit is issued on how the building will be used and operated.

California's energy code provides methodologies for both residential and commercial buildings that project average energy consumption—that is, energy consumption assuming standardized operating conditions--and these methods are used in code compliance by 98% of homes and 70-80% of commercial buildings that include envelope compliance (Gabel 2012). Parallel methods to estimate energy use globally (but with emphasis on North American conditions) are available from Residential Energy Services Network (RESNET) and Commercial Energy Services Network (COMNET) (RESNET 2012 and COMNET 2011). These standards were developed through an informal consensus process and will be submitted to a formal American National Standards Institute (ANSI) consensus process in 2012.

These evaluation methods, known as asset ratings, have been shown to predict measured energy use well for a cohort of buildings (Hassel, Blasnik & Hannas 2009). The correlation with measured use for individual buildings is expectedly weaker as variations in usage and operation make it impossible for a test standard to predict individual results (Goldstein 2010).

### Source Energy

California evaluates energy use in terms of "Time Dependent Valuation" (TDV) which is a system that weights individual units of gas or electric consumption by the relative cost of each fuel at each hour of the year and in each of California's 16 climate zones. It can be considered a form of source energy, but since the metric is cost it weights peak usage a lot more heavily than

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[4] Other countries have also developed methods, but comparative review of them is beyond the scope of this paper.

off-peak. Use of this method or of source energy eliminates one cause of suboptimization by making the substitution of a fuel with high impact for one with low impact raise the energy use rating, and typical results are similar to those derived using source energy.

For simplification and broader reach, the energy estimates in this paper use a constant electricity fuel mix of 0.69 lbs of CO2 per kWh (0.31 kg of CO2 per kWh) and assume a 3.34:1 source to site energy ratio per DOE recommendations. Sartori & Hestnes 2007 found that operational energy over an assumed fifty year life cycle is markedly larger than embodied energy for materials and maintenance. As such a more detailed study would vary the operational electricity fuel mix. For natural gas usage we assume the Pacific Gas and Electric Company (PG&E) reported average of 0.134 lbs of CO2 per kBTU (0.207 kg of CO2 per kWh) which allows for distribution and use. We used DOE's source to site of 1.047:1 when conversions were needed.

## Site Boundaries

The California Public Utilities Commission (CPUC) has not yet settled on a definition of the boundaries over which energy use has to net to zero, although it is tending to broader definitions, which would permit ZNE "equivalencies". This would allow a site with poor solar or wind access to use resources from nearby sites to meet ZNE goals, while the most restrictive ZNE definitions limit the renewable energy sources to the building footprint and any other location on the property's site including parking structures. There is still disagreement over the extent that remote sources, such as those producing Renewable Energy Credits, are appropriate for inclusion in the definition of Zero Net Energy. The National Renewable Energy Laboratory (NREL) has proposed a categorization of net-zero energy building definitions based on similar criteria (Pless & Torcellini 2010).

The nuances in definitions are not trivial in that they impact development patterns and need to factor where the distributed generation needed to meet ZNE goals is most beneficial and cost effective to the society in which it is located. That is are hundreds of grid-connected, roof-mounted photovoltaic (PV) panels any better than one larger community-scale PV installation connected to the same utility substation? Is the answer to this universal or regionally dependent?

## Transportation Energy

Distinct methodologies apply to residential buildings compared to commercial. These are discussed next.

**Personal Transportation Energy (for homes).** Transportation energy from homes is considered to be the amount of energy used by residents of a dwelling to travel. The modes of transport include motorized vehicles, mass transit, cycling and walking. Transportation energy can be measured with good accuracy using the results displayed on abogo.org. This site developed by the Center for Neighborhood Technology (CNT) accesses statistical fits that predict average car ownership and usage based on regressions that correlate these rates to such variables as compactness and transit access. The methodology is similar to that of Holtzclaw 2002, which found that the average car ownership rate—the biggest determinant of energy use—can be predicted for a neighborhood with an $R^2$ of 80-90%. Since this method is available for use today, there is no limitation on consideration of transportation energy in residential projects. Perhaps the statistical work underlying the website could be refined, but the results appear to be consistent with the equations in Holtzclaw 2002. Note that the amount of travel due to commuting from home to work and return accounts for only 15.6 percent of person trips and 27.8 percent of vehicle miles of travel (DOT 2009).

**Business transportation energy (for commercial buildings).** The transportation energy use associated with commercial buildings consists of the energy used for employee commuting, customer visits, and business-to-business travel. These include travel by all modes, including automobiles (both single occupancy vehicles and high occupancy vehicles), mass transit, cycling, and walking. There are methodologies for computing these figures for an individual building. The CNT has developed a beta version of a site[5] which estimates Transportation Energy Intensity (TEI) based on data from the Census Transportation Planning Package (CTPP) 2000 and associated census tract. The building's TEI is predicted for each mode of travel for all the employees and visitors. This requires knowledge of the site address, building occupancy type, building size, number of employees, their median income, annual operating days and number of visitors and the region from which visitors travel. The site includes default values for these parameters, which is probably the most repeatable measure of impacts over the life of a commercial building as its tenants change. Further analysis is needed to confirm or refine these predictions. For this paper's analysis the visitors' contribution was set to zero and employees were evaluated on a per employee per day basis. The buildings tested for TEI in CNT's web-based tool were not all a common size. This allowed comparisons between similar buildings.

## Double-Counting Savings

The methodology used for deriving personal transportation energy involves measuring odometer readings of private cars. Thus to the extent that privately owned cars are used for commuting to a commercial building, or shopping at one, or traveling to anther business during the working day using a personal car that the staff member used for commuting will double-count travel that was already recorded using the residential methodology.

At present it is hard to see how such double-counting can be avoided without painstaking individual calculations. Fortunately, there does not appear to be any serious side effect of tolerating the double count. First, there are not any current or foreseeable policies that would ask for a calculation of travel demand summed over all buildings. Without such a sum, the double-count would not lead to errors. Second, the purpose of using transportation energy in measuring the approach to ZNE is to encourage smarter locations, and overestimating travel slightly will offer stronger encouragement for transportation energy savings. This error is tolerable because as noted above the economic value of these savings is higher than for the other forms of energy use. Third, since most current buildings in North America have low location efficiency, the double-counting problem will decline over time.

## Embodied Energy of Building Materials

To create a building requires energy needed to produce construction materials. Building materials typically use energy to extract natural resources, process, manufacture, transport and install them. Additionally some materials will require recurring energy inputs for maintenance or

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[5] http://tei.cnt.org

replacement and most also entail demolition and disposal energy. The cumulative energy inputs are termed Embodied Energy.

Embodied energy is a subset of the data available from a full life cycle assessment (LCA). LCA studies evaluate more environmental impacts than simply energy inputs and estimate toxicity, eutrophication, acidification, ozone depletion, greenhouse gas emissions, particulate emissions, and smog contributions. LCA data including embodied energy vary regionally depending on materials, transportation practices and electricity sources. This makes sharing datasets across countries or even states problematic.

The Athena Sustainable Materials Institute in Canada has created life cycle inventory (LCI) databases of materials for North America per the International Organization for Standardization (ISO) standards 14040 and 14044 for LCA calculation methodology. These are accessible in their Impact Estimator software. The Impact Estimator contains data for individual materials and requires some proficiency to use, but the Athena Institute also has a simplified version of spreadsheets, EcoCalculator, which take the same data and compile them into typical construction assemblies such as concrete slabs, curtainwall or windows, interior walls, roof assemblies and more based on regional construction practices which factor in seismic reinforcements. This spreadsheet approach is better suited for early estimates of construction impacts and will be used for this paper's analysis. The EcoCalculator requires knowledge of surface area or volume of material assemblies used in the building.

When we use this methodology to evaluate prototypical buildings, we find that the embodied energy is significant and important as buildings get more efficient and policies direct operational energy toward net zero. Also unknowns like structural lifetime start to matter a lot. The life of a house can exceed a 100 years, but the energy intensive products in it like drywall or windows do not last as long as this. Quantis 2012 created tables of building materials and expected service life, which was used in Frey 2012.  For example they assumed lifetimes of 63 years for gypsum board in commercial and residential buildings, and 42 years for windows in commercial buildings, and 44 years for windows in residential buildings. For the analyses in this paper we assumed a 50 year building service life similar to EHA 2008.

Quantis 2012 determined that replacement rates for its Rehabilitation & Retrofit (RR) cases differed from the New Construction (NC) ones. For a 50-year service life the replacement embodied energies were 1.1 to 2.3 times the original materials' energy and emissions. For this paper's analysis the replacement material energy was conservatively fixed at 1.0 times the initial value for respective NC case in commercial and residential. This would assume that even though the RR case may have half the initial embodied energy of the comparable NC version, they would both have the same replacement materials over the 50 yr study period. More research should be done to validate replacement materials assessment. Additionally Sartori & Hestnes 2007 found that operating energy over 50 years exceeded materials' energy inputs even when low energy buildings increased mass by adding materials in order to reduce operational consumption.

## Embedded Energy in Water

Energy embedded in water refers to the amount of energy that is used to collect, convey, treat, and distribute a unit of water to end users, and the amount of energy that is used to collect and transport used water for treatment prior to safe discharge of the effluent in accordance with regulatory rules (GEI/Navigant 2010).

California agencies and utilities have been studying the water-energy nexus for the past decade with the goal of better understanding the linkages between these two scarce resources. Besides the filtration and treatment, many regions in CA are not gravity fed and require pumping water across vast distances and over mountain ranges to provide fresh water. Then utility water districts treat their waste water in facilities which require more energy inputs prior to disposal (when not in an overflow emergency event).

The California Energy Commission (CEC) and CPUC have funded studies that assessed the embedded energy in water delivery and treatment for various water districts in the state. These range from low energy regions where there is little filtration and the municipal systems are largely gravity fed to high energy input systems that utilize desalinization or large pumping energy. The embedded energy varies from below 1000 kWh per 1 million gallons to twelve times that. The CPUC study (GEI/Navigant 2010), also found large seasonal variations.

In this paper we will use two annual averages for a given site as recommended by Gary Klein of Affiliated International Management. For indoor water use which is presumed to be treated downstream in a waste water treatment plant we will use the full embedded energy from the CPUC studies. For outdoor water use such as irrigation and pool makeup water, we assume that none of the water runs off the site thereby avoiding any downstream water treatment. We are assuming that all water supplied and used is potable. Strategies such as rainwater harvesting could reduce potable water use, but are not commonplace. For statewide California indoor water use we are using 5.0 kWh/1000 gallons (1.3 kWh/1000 L) and for exterior uses we are using 2.5 kWh/1000 gallons (0.66 kWh/1000 L) (Klein 2012).

## Estimating Water Use

Unlike predicting energy use for a proposed building using energy model simulations, there are fewer tools for estimating water use. Projections could be based on statistical data for indoor water use based on occupants and fixture flow rates. This is typically done for Leadership in Energy and Environmental Design (LEED) water efficiency credits but ignores water use for non-EPACT fixtures and appliances such as dishwashers, clothes washers, ice makers, humidifiers, swimming pools and any and all heating, ventilating and air conditioning (HVAC) and process water uses. The former uses are rated under the National Appliance Energy Conservation Act for water use, but the latter uses if present in a building can be more than half of the potable water consumption.

**Indoor.** The daily residential indoor per capita water use ranges from 45-85 gallons (170-332 L) depending on the age of the fixtures and their compliance with current EPAct 1992 or newer water efficiency requirements. This includes the US EPA estimated average American home leaks 10,000 gal per year (38,000 L per yr). Water efficient homes can reduce consumption from the higher end of this range by 50% and eliminate leaks. This yields a range of 45,000-85,000 gal per year (170,000-332,000 L) of indoor use per average California home. For the baseline indoor water use in this paper we will assume 60 gallons per capita per day (gpcd) (227 L per capita per day).

For over a decade LEED indoor water use credits in commercial buildings focus on toilet room and pantry fixtures and those which go beyond the federal levels. As such, estimating building water consumption due to bathroom use is fairly routine in commercial buildings.

**HVAC.** California and much of the Southwest are prime conditions for evaporative cooling—both indirect and direct. The summers are generally not humid, which provides hot dry air to absorb moisture. Evaporating water at room temperatures near seal level requires about 1050 BTU per pound of water (2453 kJ/kg). This heat is taken from the air stream which lowers the air temperature accordingly. The efficacy of evaporative cooling will vary based on the wetting media, the ambient wetbulb and indoor conditions desired. Typical evaporative cooler efficiencies and operating conditions result in 1.4-3.0 gal per hr per ton of cooling or 30 gal per day. In CA this could yield 2000-4000 gal per yr (8,000-15,000 L/yr) for evaporative cooling in homes. Our allowance for evaporative cooling when included is 3500 gal per yr (13,000 L/yr) and will reduce the vapor compression-based cooling by 2000 kWh/yr. This compares to about 18 kWh/yr of embodied energy in the water: a good tradeoff from an energy-centric perspective.

What is less standardized is estimating water use in cooling towers and other HVAC equipment. EPA estimates a typical office building uses 26% of its water usage for heating and cooling, while The Alliance for Water Efficiency estimates cooling towers can account for 15% to 50% of an office building's water use when present. Commercial buildings with cooling towers serving condenser water systems may consume 2.4 gpm per ton-hour (0.043 L/s per kWh). Cooling towers are typically sized for a peak cooling occurrence at a high humidity design day when evaporative cooling is less efficient due to the existing saturated air. Weather does not remain at peak, cooling loads fluctuate and buildings may shut down or may have a reduced operating schedule. All these factors make cooling tower operation and subsequent water use not constant. Makeup water lines to cooling towers are rarely metered separately and typical blowdown cycles are automated rather than done when actually needed. These items lead to high water use without actually being able to directly quantify it. Conductivity controllers permit towers to monitor water quality and have higher cycles of concentration, which reduces blowdown and subsequent makeup water needs. Load profiles can help estimate part load water usage, but cooling tower operators can shift loads off of a chiller for example and onto the tower, such as water side economizers. Better tools are needed for HVAC water usage predictions and simulations.

For this paper cooling tower water use was estimated at 4 cycles of concentration, operating 260 days per yr, with a 300 ton (1055kW) tower sized for a 7°F (3.9°C) approach with 0.002% drift.

Winters in California's population centers are milder than most other portions of the country. As such when saturated cold air is heated to indoor temperatures, in CA the resulting conditions are not as dry as cold climates. This reduces humidifier usage. For the purpose of this paper we are not including any humidifier water use in commercial or residential estimates.

**Outdoor.** The amount of water used for exterior purposes such as irrigation, ornamental fountains, pools, spas, sidewalk washing and vehicle washing is difficult to predict based on site location and lot size alone. Landscaping plans can help determine plantings, their watering needs and the type of irrigation system designed.

**Irrigation.** Document searches for turf grass watering in California and the Southwest reveal that water use varies based on types of grasses planted, seasonal growing and dormant periods, ambient conditions when watering occurs, type of irrigation system and available precipitation. Rules of thumb recommend turf grass is watered one inch of water per week. Based on growing periods for the SW and CA rain patterns we are estimating 20-30 gal/sf/yr (7-10.6 L/m2/yr) of turf grass. This could be refined by further research. Some cities have ordinances such as

Prescott, AZ which allows up to 33.6 gal/sf/yr (11.8 L/m2/yr) for a maximum of 1000 sf (93 m2) of high water use plants. The LEED water efficiency credit for irrigation looks at the peak month in which watering occurs and provides credits based on reductions from this baseline, but unlike their indoor fixture calculation, irrigation is not estimated for annual consumption. For the purposes of this paper we will allocate 25 gal/sf/yr (8.8 L/m2/yr) for turf grass.

**Pools**. Predicting pool water consumption requires a number of variables: surface area, hours and months of operation, splashing/activity, ambient wetbulb, wind velocity, precipitation and pool cover use. Typical residential pool sizes range from 450-550 sf (42-51 m2) in surface area (Lee & Heaney 2008). The CEC estimates that pools can consume the same water per unit area as irrigated lawns, but that pools are not typically used year round; therefore pool water use per annum is typically smaller than lawn usage. For this paper we are assuming 16,000 gal/yr (60,000 L/yr) when pools are present.

**Process and other uses.** For residential and commercial purposes we are not allocating any process water consumption. EPA and Federal Energy Management Program estimate 9% of building water use is miscellaneous along with 15 gallons of water per person per day (gpd) (56Lpd) for all uses. This permits some rough approximation for total water usage and some granularity for end use projections.

## Results

We next use the methodologies discussed above to quantify the energy and emissions impacts of several prototypical examples of residential and commercial developments. We begin by summarizing the results for energy and greenhouse gas emissions in Figures 1 to 4.

These figures illustrate that at least three of the four factors we have discussed are significant contributors to total energy impacts in all cases, and that their relative impacts are different between the different prototypes. These additional parameters matter, in that their magnitude is large compared to direct utility energy impacts and in that they do not vary in proportion to each other, but rather change their relative impacts across prototypes.

### Analyze Multiple Commercial and Residential Properties

Residential studies:

1. Review impact of a typical subdivision with a new home.
2. Review impact of the same home in a transit oriented development.
3. Review impact of a swimming pool.
4. Review impact of lawn size.
5. Review impact of evaporative cooling.
6. Review impact of major renovation rather than new construction.

**Figure 1: Residential Annual Energy Inputs in kBTU**

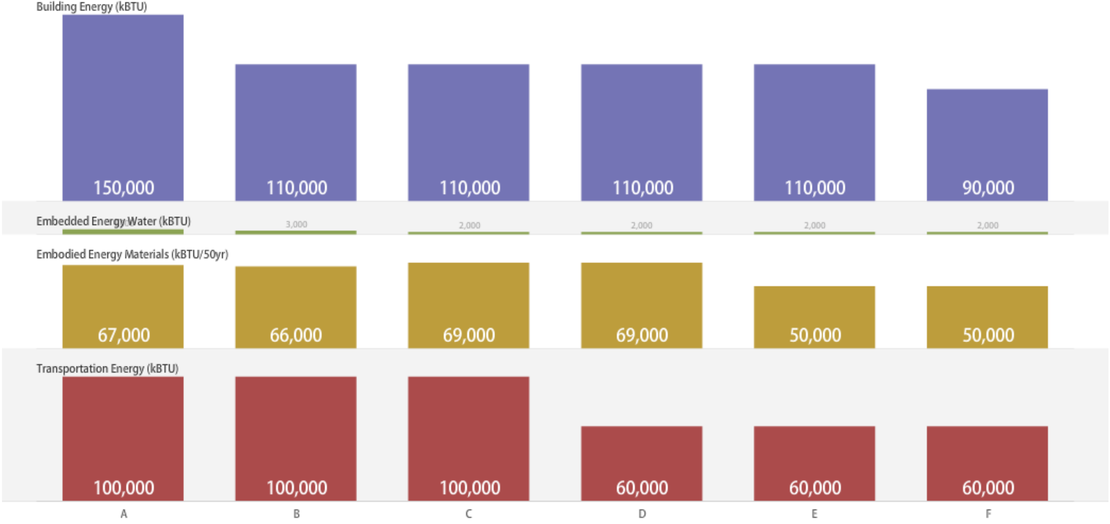
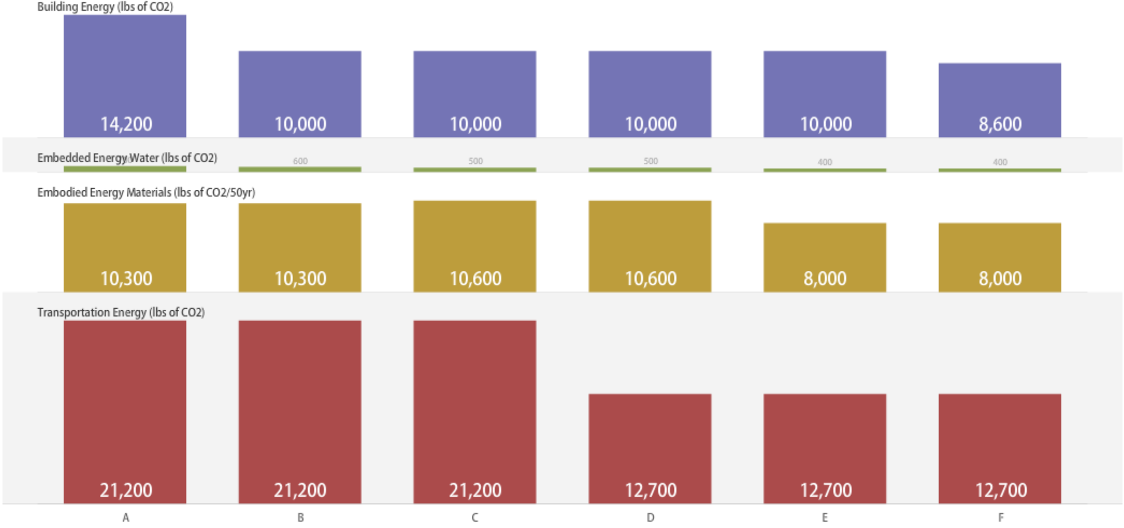


**Figure 2: Residential Annual Emissions in Pounds of CO2**



Residential examples tested:

A. New 2-Story 2700 sf Single Family Home over Crawl Space in Suburban Development with Pool with 0.2 acres of lawn.
B. New 2-Story 2700 sf Single Family Home over Crawl Space in Suburban Development with 0.2 acres of lawn.
C. New 1-Story 2100 sf Slab on Grade Single Family Home in Suburban Development with 0.1 acres of lawn.
D. New 1-Story 2100 sf Slab on Grade Single Family Home in Transit-Oriented Development with 0.1 acres of lawn.
E. Renovated Single Family Home in Transit-Oriented Development with 1/16th acre of lawn.
F. Renovated Single Family Home in Transit-Oriented Development with Evaporative Cooling and 1/16th acre of lawn.

Assumptions:
California has an average 2.85 persons per household.
All of the above were studied in the same climate zone.

Home models:

CEC has prototype buildings in its energy code[6]. We used Prototype C[7] and D[8] as templates for the above studies. These building plans specify geometry but not the properties which are described in the energy code.

Commercial studies:

1. A low rise office building in a suburban park with landscaping.
2. Same office building but in a transit-oriented location.
3. New office building with same floor area but high-rise in urban infill site.
4. Same high-rise office building with the same floor area but with reused structure and urban infill site.

**Figure 3: Commercial Annual Energy Inputs in kBTU**

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[6] Section 4.2.2.1 of the 2008 Residential Alternative Calculation Method (ACM) Approval Manual
[7] Prototype C is a 2,100 ft², one-story, single-family detached home
[8] Prototype D is a 2,700 ft², two-story detached home

**Figure 4: Commercial Annual Emissions in Pounds of CO2**

Commercial examples tested:

A. A low rise 3-story 150,000 sf office building in a suburban park, with air-cooled rooftop HVAC equipment and multizone VAV distribution. Site contains approximately 1-acre of sprinkler-irrigated turf grass.
B. Same office building but transit-oriented location and with approximately ½-acre of sprinkler-irrigated turf grass.
C. New 6-story office building with same 150,000 sf floor area, with water-cooled HVAC equipment and multizone VAV distribution in urban infill site. Site does not contain irrigated landscaping. HVAC system includes a 300-ton cooling tower with 4 cycles of concentration.
D. Similar high-rise office building with the same floor area and same water-cooled HVAC equipment and multizone VAV distribution in urban infill location but with reused structure and new glazing.

Assumptions:
Each office had 250 gross sf per person and operated 260 days per year.
All of the above were studied in the same climate zone.

Note: the commercial building water usage varied from 800,000 gal/yr to 2.0 M gal/yr, but resulted in embedded energy of only 19-23 MBTU/yr with only 1.5-2.5 tons of CO2/yr.

## Conclusions

We demonstrated that a full quantification of the energy impacts of homes or commercial buildings can be performed to sufficient accuracy to be used with current tools and methods. We estimated the impacts on overall energy use from the four parameters identified as potential suboptimization problems in the policy formulation that will drive buildings towards zero net energy use over the next decade or two, and found that the data validate our hypothesis *that the consequences of suboptimization can be significant*.

Both for transportation and for embodied energy, the inclusion of these new factors changes the total energy use significantly, and such inclusion allows policy makers and building developers to make "greener" decisions than a sole focus on utility energy allows. The analytic process that we used to produce these results is sufficiently robust and repeatable. It can be used to evaluate policy progress toward net zero energy beginning right away, while recognizing that several elements of the methodology could benefit from refinement.

In particular, further analytic development should focus on transportation impacts from commercial buildings. As shown in the case studies, these effects are both large and subject to uncertainty both with respect to data and to methodology. The methodology is also relatively weak for water. But since the water impacts on energy are not so large—in the case of urban[9] office buildings they are negligible--the underdevelopment of water methodology does not prevent its inclusion in this approach today. Further refinement and review of the water-energy nexus is still warranted to fully quantify energy impacts on water use. This paper only reviewed emissions and energy inputs to water, ignoring potential consequences in terms of financial cost.

Embodied energy of initial and replacement materials indicates the energy inputs of the construction materials can be 20-30 yrs of home energy use while the emissions due to the materials can be even higher on the order of 40-50 yrs of operational energy use; this is perhaps due to the fuel mix assumed in the LCI. New construction commercial buildings can have embodied energy equivalent to 10 to 20 yrs of operational energy, this figure is already high because of California's low carbon fuel mix, which will only increase in the future. This increase is assured not only because buildings will become more efficient, but also but also because the carbon intensity of electricity will decrease in the coming decades to meet the state's 33% renewable portfolio standard.

Renovation over new construction can greatly decrease the embodied energy while potentially approaching the energy efficiency of a new construction home or office building. The assumed building life greatly influences the benefits of one over the other, but clearly other characteristics such as location are as important.

The current calculations do not consider demolition energy. Methodologies that can address demolition must encompass policy as well as analytic issues. For example, does the energy needed to demolish a derelict building get counted when a new building is constructed on the same site? What if the choice is to build a new building in place of the old one versus choosing an entirely new site? What if the site is to be rezoned to a higher density than the previous structure could accommodate?

Transportation energy is almost equal to the operational energy of a low energy commercial building. The significance of transportation is that developers often have the opportunity to make choices that increase density or focus development around transit availability, and the choice of density may represent a tradeoff with the availability of solar on-site. It is also significant in the context of new urban development plans in California that are developed in accordance with the Sustainable Communities and Climate Protection Act of 2008 ("SB375").

These new plans, which often include large expansions of transit access, empower developers to make choices of building at higher density in neighborhoods with greater connectivity, and will encourage infill and, potentially, upgrading and reusing existing buildings

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[9] An urban office building will not use significant water for landscaping.

rather than demolition in one place and construction somewhere else. These factors—density at the Traffic Analysis Zone level (such a zone is intermediate in area between a ZIP code and a Census Tract), transit service levels, and to a lesser extent pedestrian/cyclist accessibility and proximity to services, are the primary determinants of transportation energy use (Holtzclaw 2002). Knowing quantitatively the tradeoff between utility energy and transportation energy will allow better decisions to be made.

California has a low carbon electricity mix with policies enacted to reduce this even further in the coming decade. California also has some of the most stringent building energy codes of any state, which will keep operational energy use and subsequent emissions low. While the transportation energy use, as noted, is similar to operational energy in magnitude, its emissions are much greater owing to the fact that automotive transportation dominates and at present are largely fossil fuel-driven. Aggressive low carbon fuel standards, new federal Corporate Average Fuel Economy Standards, and adoption of electric vehicles could bring transportation emissions per unit of energy use to parity with building operational energy-related emissions. A more detailed study could estimate long term emissions impacts. Any policies interested in reducing greenhouse gas emissions should include building location.

We note therefore the importance of further development of models that predict travel demands of commercial buildings. In performing the analysis presented in this paper, we looked at the travel demands of a downtown office building located near one or more mass transit systems with those of an office in suburban environments, and in one particular case found lower impacts in the suburb. This was a consequence of the employees of that particular neighborhood all living nearby. The authors feel that this result is anomalous, in that it does not predict the consequences of additional offices being built there. Further research is necessary to see if this feeling is justified and if more refined methods are necessary.

Finally, we note that by expanding the scope of energy that should be considered in the context of a zero-net goal, we have changed the context of the goal. Thus, if we were to define a scale in which 100 is the system-wide impact of today's energy use, and “net zero' is recalibrated to zero out system-wide energy use, the score of a building with net zero utility energy would be about 40 to 50. This raises the question of what a reasonable policy goal for system-wide energy impact should be. Is 40 or 50 still the right goal? If not, should the goal be lower or higher, and what arguments support such a modification?

Further analysis beginning with the methods discussed in this paper could shed light on what a reasonable system-wide energy goal should be.

## References

[DOT] U.S. Department of Transportation, Federal Highway Administration. 2009. National Household Travel Survey. http://nhts.ornl.gov.

[EHA] Empty Homes Agency Ltd. 2008. “New Tricks with Old Bricks: How reusing old buildings can cut carbon emissions.” http://emptyhomes.com/what-you-can-do-2/resources/empty-homes-publications/.

Frey, P., et al. 2012. "The Greenest Building: Quantifying the Environmental Value of Building Reuse." The Preservation Green Lab of the National Trust for Historic Preservation http://www.preservationnation.org/information-center/sustainable-communities/sustainability/green-lab/lca/The_Greenest_Building_lowres.pdf.

Gabel, Michael (Gabel Associates, LLC). 2012. Personal communication. March 5.

GEI Consultants/Navigant Consulting. 2010. "Embedded Energy in Water Studies Study 2: Water Agency and Function Component Study and Embedded Energy-Water Load Profiles." http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/EM+and+V/Embedded+Energy+in+Water+Studies1_and_2.htm.

Goldstein, D. et al 2010. "Zeroing in on Net Zero Buildings: How Can We Get There? How Will We Know When We Have Arrived?" Paper presented at ACEEE Summer Study on Energy Efficiency in Buildings 2010 Conference, August 2010, Pacific Grove, Ca.

Hassel, S., M. Blasnik & B. Hannas. 2009. "Houston Home Energy Study." Raleigh, North Carolina: Advanced Energy. http://www.advancedenergy.org/buildings/knowledge_library/FINAL_Paper_Houston_Energy_Efficiency_Study.pdf.

Holtzclaw, J., et al. 2002. "Location efficiency: neighborhood and socio-economic characteristics determine auto ownership and use – studies in Chicago, Los Angeles, and San Francisco." *Transportation Planning and Technology* 25 (1): 1-27.

Jonathan Rose Companies. 2011. "Location Efficiency and Housing Type—Boiling it Down to BTUs." http://www.epa.gov/dced/pdf/location_efficiency_BTU.pdf.

Klein, Gary (Affiliated International Management). 2012. Personal communication. March 13.

Lee, J. G. & J. P. Heaney. 2008. "Measure 4: Swimming Pool Water Use Analysis by Observed Data and Long-term Continuous Simulation." http://ees-diglib.ad.ufl.edu/publications/10884264.pdf.

Pless, S. & Torcellini, P.A. 2010. "Net-Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options." NREL Report No. TP-550-44586 ; Golden, Co.: National Renewable Energy Laboratory.

Quantis. 2012. "Quantifying the Value of Building Reuse: A Life Cycle Assessment of Rehabilitation and New Construction." http://www.preservationnation.org/information-center/sustainable-communities/sustainability/green-lab/lca/Quantis_Tech_Report.pdf.

Sartori, I., & A.G. Hestnes. 2007. "Energy use in the life cycle of conventional and low-energy buildings: a review article." *Energy and Buildings* 39 (2007): 249–257.