



American
Institute of Architects,
California Council

ZERO NET ENERGY PRIMER



The Cottle House
San Jose, CA
One Sky Homes
2012

American
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California Council

ZERO
NET
ENERGY
PRIMER

by Ann V Edminster

Design by Debra Turner
Illustrations by Steven Lee

American Institute of Architects,
California Council

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TABLE OF CONENTS

Introduction	7
Definitions and the Energy Code	8
Photovoltaics and Batteries	10
Design Principles	11
Walls and Roof Assemblies	13
Air Leakage Control	15
Fenestration	17
Heating and Cooling	18
Water Heating	20
Electric Loads	22
Top 10 Resources	22
Keys to Success	23



In 2016, the Net Zero Energy Coalition documented 3,137 zero-energy homes in California – 38% of all units in the US and Canada combined.

Net Zero Energy Modern House
Cupertino, CA
Klopf Architecture
Matarozzi Pelsinger Builders
2011
Mariko Reed photo



Zero-energy homes span all architectural styles, sizes, and price points.

The Cottages at Cypress

Fort Bragg, CA

K. Boodjeh Architects

Danco Builders

2014

Brandi Easter photo



Zero net energy homes produce renewable energy onsite and are tied to the electric power grid.

ZETA Townhome
Oakland, CA
ZETA Communities
dsa architects
2009

INTRODUCTION

CALIFORNIA LEADING NORTH AMERICA IN ZNE

In 2006, the State of California targeted 2020 as the date by which all new homes would be required to achieve zero net energy (ZNE). Although that goal will not be fully realized in 2020, Title 24-2019, Part 6, will require the highest level of energy efficiency to date: all new single-family and low-rise multifamily homes submitted for plan check after December 31, 2019, will need to include a Title 24 report showing zero net *electricity use*,¹ and it is very likely that Title 24-2022 will require a ZNE standard for both *electricity and gas*. The State also plans to adopt ZNE standards for non-residential buildings by 2030.

Quite a few cities in California (and elsewhere) already have adopted ZNE or solar energy requirements,² and other states are actively considering adopting ZNE. In the meantime, the private sector has taken the lead.

In its *2016 Residential Zero Energy Buildings Study*, the *Net Zero Energy Coalition* documented more than 8,000 residential units in the US and Canada, with the highest number (3,137) in California. Significantly, more than 90% of these homes are in developer-initiated, multi-unit projects, demonstrating that these pioneering developers believe that ZNE makes solid business sense – and not just at the high end of the market. The inventory includes thousands of units of ZNE workforce housing and production homes, in a wide range of US climates. The takeaway is that ZNE is highly affordable *when you know how to do it*.

This *Primer* was developed to familiarize California architects with the forthcoming residential energy standards, and what those standards mean in practical terms.

Note: The Title 24-2019 energy standards are likely to undergo further changes before they go into effect. Be sure to thoroughly familiarize yourself with them when they are issued.

HOW WILL ZNE CHANGE YOUR DESIGN PROCESS?

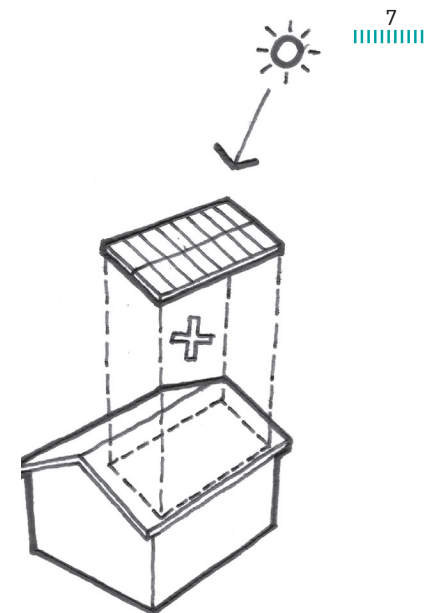
California's long-time leadership in energy efficiency means that architects who practice here already have gained a lot of practical knowledge that applies directly to achieving ZNE. In simplest terms, ZNE is nothing more than a very efficient building with photovoltaics (PVs) on top. You'll be able to meet the new code by focusing on a few key aspects of design and documentation; each of these topics is discussed in this *Primer*:

- An excellent thermal enclosure
- Highly efficient mechanical systems
- Solar energy systems

**In simplest terms,
ZNE is nothing
more than a very
efficient building
with photovoltaics
(PV) on top.**



Sol Lux Alpha Apartments
San Francisco, CA
RG Architecture
Off the Grid Design
2018



Title 24-2019 will require photovoltaics on new homes.

¹ Using California's time-dependent valuation, and excluding plug loads that are not regulated by Title 24, Part 6.

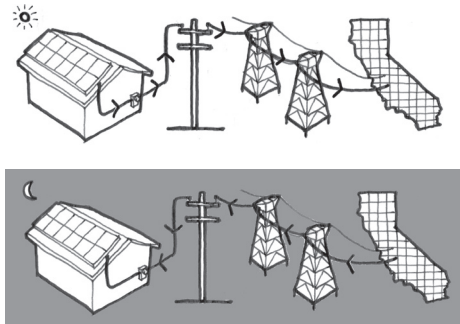
² Local ordinances exceeding the [California] 2016 energy efficiency standards.

DEFINITIONS & THE ENERGY CODE

LET'S START WITH DEFINITIONS

Zero net energy, in slightly more technical terms, means that a building has enough onsite renewable energy capacity (typically, a PV array on the roof) to meet its own annual energy needs. The building is tied to the electric power grid, so that at times when the PV array is producing more than the building is using, it feeds into the grid, and when the building needs more than the PVs are producing (e.g., at night), it draws from the grid. At the end of the year, the balance of in- and out-flows is (approximately) zero.

California's ZNE requirements, however, aren't based on conventional units of energy. The State applies hour-by-hour multipliers to energy usage based on the costs of delivering energy at different times. During demand peaks, energy is more expensive to generate because older, less efficient power plants need to be fired up. And so, from the State's perspective, not all units of energy have equal value; instead, they have a 'time-dependent valuation' (TDV), and TDV is the basis for calculating 'energy usage' for purposes of Title 24 compliance.³



Top: Excess energy production feeds into the grid.

Bottom: The grid supplies energy when solar production doesn't meet the home's demand.¹

There are several other definitions in use in the US, the most widely used of which is the US Department of Energy (DOE) "**Common Definition of ZNE.**" Other **definitions** have been proposed by the National Renewable Energy Laboratory (NREL).

The procedure for complying with California ZNE requirements will be unchanged from the current procedure for complying with Title 24: you will submit your design along with the Title 24 report, showing compliance with the code, and you're done. There is no requirement to document for the occupants' actual energy use once they are living in the home ("operational ZNE").

WHAT WILL CHANGE?

A number of the Title 24 prescriptive requirements and mandatory measures are expected to change with the 2019 code – all of them found by the State to be cost-effective.⁴ The anticipated changes from the 2016 code are summarized in the table on the following page and elaborated on later in this *Primer*. As in the past, if you use the performance approach (energy modeling) to comply with code, you may be able to incorporate different performance measures in place of some of the prescriptive requirements. However, because of the increased stringency of the prescriptive requirements, it's likely that the trade-offs will be less effective in improving the modeled performance.

California's 2019 code will not require that the home operate at ZNE, only that it be designed to meet the standard.



The Cottle House
San Jose, CA
One Sky Homes
2012

³ Time Dependent Valuation of Energy for Developing Building Efficiency Standards: 2019 Time Dependent Valuation (TDV) Data Sources and Inputs

⁴ Presentation - Proposed 2019 Building Energy Efficiency Standards ZNE Strategy

Proposed Changes from 2016 to 2019 Standards

(prescriptive and tradeable except HVAC, as noted below)⁵

Attics



Two options:

- ❑ Vented, high-performance attic with increased insulation requirements, or
- ❑ Directly conditioned attic

Walls



U-factor reduced from 0.051 to 0.048 (e.g., R-21 cavity insulation plus R-7 exterior continuous insulation) in single-family new construction in all CA Climate Zones (CZ) except CZ 6 and 7, where it remains at 0.065; and all homes must meet QII (Quality Insulation Installation)

Windows & Solid Doors



Windows:

- ❑ Maximum U-factor 0.30 in all climate zones
- ❑ No solar heat gain coefficient (SHGC)⁶ requirement in CZ 1, 3, 5 and 16
- ❑ Maximum SHGC 0.23 in CZ 2, 4, and 6-15

Solid Doors:

- ❑ Maximum U-factor requirement of 0.20, and NFRC-rated

DHW



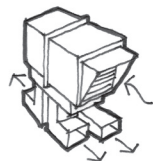
If using a tank water heater, then drain water heat recovery and either HERS verified compact hot water design or HERS verified pipe insulation; added provisions for electric resistance and heat pump water heaters.

PVs



Required in all climate zones (with certain exceptions, e.g., inadequate solar access) – sized to meet the electric load only, not gas; may NOT be used to trade off efficiency measures

HVAC & Whole House Fans



Mandatory changes, not tradeable:

- ❑ Gas furnace air handling systems – fan efficacy maximum 0.45 W/cfm systems.
- ❑ Air filter increased to minimum MERV 13
- ❑ Range hoods to be HERS verified as Home Ventilation Institute (HVI) certified

Whole House Fans:

- ❑ Products must be certified through Modernized Appliance Efficiency Database System ([MAEDBS](#))



Spring Lake Apartments
Woodland, CA
Kuchman Architects
Mutual Housing
2015
Frank Domin photo

If you use a performance-based approach to compliance, you may have quite a few other options.

⁵ Because the 2019 code is still being formulated, some of these requirements may change somewhat from what is shown here.

⁶ The lower a window's SHGC, the less solar heat it transmits.

PHOTOVOLTAICS AND BATTERIES

The most notable and obvious change from the 2016 code is the added **requirement to include PV in your design**; it will no longer be available for trade-off with efficiency measures. Regardless of whether the house is all-electric or dual-fuel (using electricity and natural gas or propane), only the electric load will be factored into the required size of the PV array; and for all-electric homes, the required PV system size will be based on the electric use of a similar, code-compliant, dual-fuel house.

The new code compliance software will provide two different "Energy Design Ratings" (EDRs) – one for the efficiency measures alone and another for the renewable energy system. Each one, independently, will need to meet a minimum (climate zone-specific) threshold to achieve compliance.

WHAT IF MY PROJECT DOESN'T SEE THE SUN?

There will be exceptions to the PV requirements in situations where it's simply not feasible to meet them; for example:

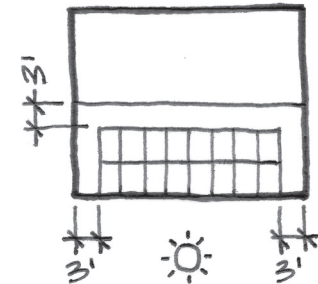
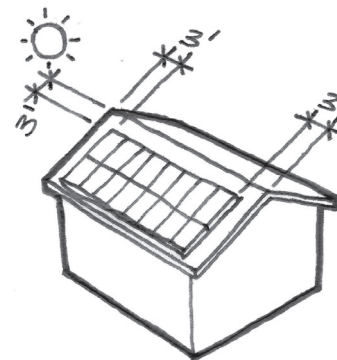
- ☐ The PV requirement may be waived entirely if the structure is shaded by other structures or offsite landscape features
- ☐ Three-story or taller homes may require a smaller PV array
- ☐ Projects that include battery storage may require a smaller PV array

DO I NEED TO INCLUDE BATTERY STORAGE?

Battery storage systems will not be required in the 2019 code; however, the State may require them in future versions of the code, and they may be a helpful feature to consider including in new homes, to allow surplus energy generated by onsite PV systems to be stored for onsite use during periods when the home's demand exceeds the PV production at that time. Energy storage systems will likely earn credit towards Title 24 compliance.



Church Hill Townhomes
Fortuna, CA
K. Boodjeh Architects
Danco Builders
2013
Brandi Easter photo



Only the electric load will be factored into the required size of the PV array.

DESIGN PRINCIPLES

EARLY DESIGN CONSIDERATIONS

Some of the factors that make it easiest to achieve ZNE – and to keep it affordable for your client – can also be easy to overlook, and need to be factored into the early stages of design. Not all of them are necessarily captured effectively in the energy modeling, but they will affect how well the home operates with people living there, so they do matter! At right is a checklist of things to keep in mind as you begin your design.

Early Design Checklist

- ☐ Plan for efficient framing – walls @ 24" o.c., openings aligned with framing, etc.
- ☐ Provide enough space for all the HVAC equipment and ducts (with required insulation) in conditioned space.
- ☐ Work with an HVAC system designer who really understands high performance (few do, so pick yours carefully).
- ☐ Run an energy model very early in design to get a sense of how much PV you're going to need – that will be important as you design the roof form.
- ☐ Avoid complexity in your roof design; simplicity carries multiple benefits:
 - + easier to detail so as to reduce risk of water intrusion
 - + easier to air-seal and insulate
 - + less costly to build
 - + more space for PVs
- ☐ Reduce overall complexity. Changes of plane and complicated intersections add cost; compromise thermal performance; are harder to build while maintaining continuity of water, air, and thermal barriers, and therefore increase risk of defects.
- ☐ Build in flexibility to accommodate changes over the building's life span, such as fuel switching (gas to electricity), addition of electric vehicle charging, etc.

RESOURCES

- Pacific Gas and Electric Company Zero Net Energy Production Builder Demonstration: Habitat for Humanity of San Joaquin County
- PVWatts® Calculator, National Renewable Energy Laboratory (NREL) – allows a quick, early calculation of energy generating potential
- *Residential Envelope and Solar Ready* – Energy Code Ace resource on California 'solar-ready roof' requirements
- Berkeley Deep Green Building Initiative solar roof recommendations (more comprehensive than building code requirements) – see Appendix A, Section 3 (pg. 17 in PDF)

Some of the factors that make it easiest to achieve ZNE can also be easy to overlook, and need to be factored into the early stages of design.

CLIMATE-SPECIFIC & PASSIVE DESIGN STRATEGIES

California's energy code recognizes 16 climate zones, which fall into five general types: north and mid-coast, southern coast, inland valley, mountain, and desert. However, these differences have relatively minor implications for designing ZNE homes; heating and cooling loads may dictate slightly different space conditioning specifications or a somewhat different set of passive design strategies.

Because different people mean different thing by 'passive' design, some definitions and guidance are provided at right.

Passive design as a generic term refers to ways of achieving a comfortable, healthy indoor environment that aren't mechanized and will function even in a power outage. A robust, well-sealed thermal enclosure is a cornerstone of passive design, as are shading strategies that respond to solar geometry.

Passive solar design, 1970s-style, was popularized in a context of drafty, poorly-insulated enclosures. It emphasized thermal mass and large expanses of south-facing glazing. A moderate amount of thermal mass can sometimes be helpful but should be used with great caution – it works better in some climates than others, and can be overdone. Too much south-facing glass can be a HUGE liability in a ZNE home, as it can cause catastrophic overheating, particularly in spring and fall when sun angles are low and bypass overhangs.

Passive House is a design system (including proprietary software) based on very stringent efficiency requirements for the building enclosure. There are two variants in use in the US, one affiliated with Passiv Haus International (PHI, headquartered in Germany) and the other an adaptation developed by Passive House Institute US (PHIUS, headquartered in Illinois) to align with North American climates. Both systems have devoted California ZNE practitioners.



D'Souza De La Torre Residence
Belmont, CA
Arkin Tilt Architects
2005
Edward Caldwell photo

RESOURCES

- "California Supreme Court Rules Against SOM" – [cautionary tale about overheating in mild climates](#)
- International Passive House Association
- Passive House Institute US
- *Passive Solar Architecture: Heating, Cooling, Ventilation, Daylighting and More Using Natural Flows*, David Bainbridge & Ken Haggard, 2011

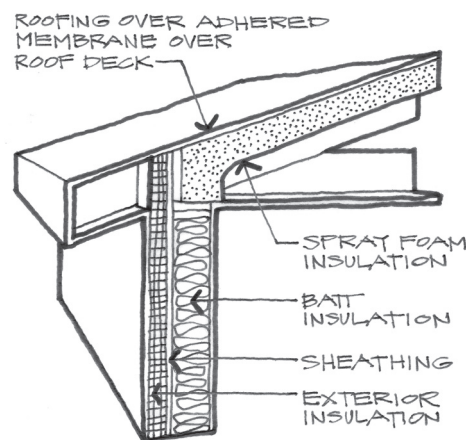
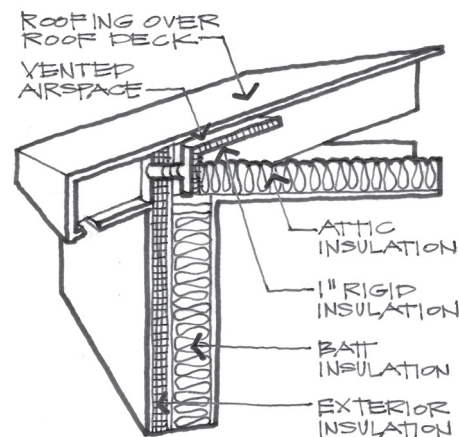
WALL & ROOF ASSEMBLIES

A high-quality enclosure is the bedrock of efficient construction, thus well-designed, well-detailed, and well-constructed wall and roof assemblies are critical to achieving ZNE. Key elements in high-performance assembly design include the framing, cavity insulation, exterior insulation, barriers, and air leakage control. Each of these elements is discussed below, and extensive relevant resources are listed on page 16.

FRAMING

Framing acts as a “thermal bridge” between interior and exterior surfaces; incorporating “advanced framing” or “optimum value engineering” features will reduce thermal bridging, thereby improving thermal performance while also saving the builder money on lumber. Although only a few specific advanced framing measures (e.g., 24” o.c. framing instead of 16”) can be modeled in Title 24 software, all of them will reduce your project’s framing factor, improving operating energy performance. Several advanced framing references are listed in the RESOURCES section on page 16.

Raised-heel trusses are another particularly valuable efficiency measure; while they require a bit more lumber, they allow the full depth of insulation to be installed all the way to the edge of the roof.



Title 24-2019 offers two roof/attic prescriptive options, vented (top) and unvented (bottom).



Plaza Point
Arcata, CA
K. Boodjeh Architects
2012
Brandi Easter photo

A high-quality enclosure is the bedrock of efficient construction .

CAVITY INSULATION

Several variables affect the ultimate thermal performance of insulation – not just R-values. The types and location of the insulation you use and the quality of installation also are extremely important in terms of energy efficiency, occupant comfort, and health.

Quality insulation installation (QII) is a prescriptive measure in the draft 2019 code, and should be utilized in all ZNE projects. Insulation, especially batt insulation, has commonly been poorly installed, with many defects including air gaps and compression around wires, pipes, and electrical boxes. Meeting the QII requirement entails field verification by a HERS rater. Achieving a high-quality installation that will pass a rigorous HERS verification requires that you write explicit installation specifications and review them with the general contractor and the insulation sub.

In general, blown rather than batt insulation is easier to install and will yield the best results. It is difficult, though not impossible, for installers to meet QII standards (and pass inspections) when using batts. Blown insulation types include:

- ☐ Fiberglass
- ☐ Cellulose
- ☐ Wool
- ☐ Spray foam (low- and high-density)

EXTERIOR INSULATION

In the past you may have avoided exterior insulation by trading off the prescriptive requirement for exterior insulation for another efficiency measure. Under the 2019 code, due to the overall increases in efficiency requirements, that trade-off will become more difficult in most CA climate zones (1-5 and 8-16), where the 2019 code includes a decrease in the prescriptive value for wall assembly U-factor, from 0.051 to 0.048. This translates to an increase in both cavity insulation (from R-19 to R-21) and continuous, rigid board, exterior insulation (from R-5 to R-7).

Options for exterior insulation include:

- ☐ Expanded polystyrene (EPS)
- ☐ Extruded polystyrene (XPS)
- ☐ Polyisocyanurate (“polyiso”)
- ☐ Cork
- ☐ Mineral wool

Each insulation type has a unique set of characteristics (e.g., installation method, vapor permeability, aged R-value, global warming potential, and others). Before specifying your assemblies, research the pros and cons of the available options. Whatever product you select, incorporate the appropriate wall assembly details in your drawings – in particular, transition points such as window header and sill details and wall-to-roof transitions – to maintain continuity of moisture, air, and thermal barriers. See RESOURCES on page 16.

BARRIERS

With buildings getting more and more airtight and well-insulated, there also is more concern about making sure that air, vapor, and moisture barriers are correctly specified, appropriately placed within the building assembly, well-detailed, and properly installed.

These topics are well beyond the scope of this document to address in depth, but several excellent resources to help you address these issues successfully are listed on page 16.

Changing QII from a credit to a prescriptive requirement means that it will be included in the baseline (“standard” home) energy model, so omitting QII from the “proposed” home will reduce the modeled performance.

Quality insulation installation (QII) should be utilized in all ZNE projects.

AIR LEAKAGE CONTROL

AIR LEAKAGE CONTROL

Controlling air leakage is a critical aspect of building a ZNE home and is required in Title 24-2016, Residential Appendix 3. Air sealing is an uncommon skill and not yet well-established as a trade in California (or in many other parts of the US). As a result, this is among the most challenging aspects of building ZNE homes – and thus requires considerable attention by architects as well as builders.

Uncontrolled air leakage can compromise comfort, substantially reduce thermal performance, and increase risks of condensation, dry rot, and mold growth – and associated liability. Wall and ceiling assemblies do not need to ‘breathe’ – they need to be tight, while also designed to permit drying. Building Science Corporation has conducted extensive research on this topic (and many others) for the US Department of Energy, much of which is available free of charge at www.buildingscience.com.

To aid in achieving successful air sealing, include the following information in the contract documents:

- Specification for airtightness with other enclosure specifications;

(PG&E recommends an air leakage rate of 1.5 to 2.0 ACH₅₀ for its ZNE demonstrations, although lower rates are possible with good detailing and careful construction)

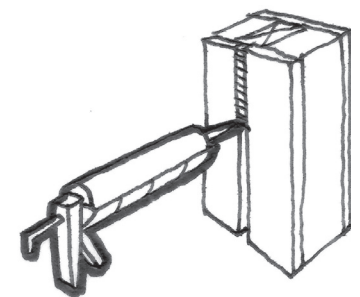
- Section drawing showing a continuous air barrier around the entire building section – the icon at right links to an example drawing created by Coldham & Hartman Architects
- Architectural details showing the correct means of air-sealing specific areas – also shown in drawing linked at right
- Accountability for outcomes

Because of the current level of experience with the practice in California, successful air sealing also requires both communication about the intent of air sealing with the contractor and subcontractors and vigilance during construction. Consider including the following requirements for the general contractor in your specifications:

- Assign specific responsibility for air sealing to one individual (air sealing manager, or ASM) who reports to the site superintendent or project manager – this is typically the insulation subcontractor
- Ensure that the ASM receives specific training in effective air sealing techniques and in blower door testing

- Brief all affected workers/ subs (e.g., framing, windows, plumbing, electrical, drywall) on the importance of air sealing to the ZNE goal, and inform them that they are answerable to the ASM for their specific contributions to the overall air sealing strategy
- Demonstration by the ASM of specific techniques the subs will use
- Frequent inspections by the ASM as trade work involving air sealing proceeds
- A preliminary blower door test conducted by the ASM as soon as the house is fully closed in, i.e., after all exterior windows and doors are installed; after rough plumbing, electrical, and all other penetrations in the pressure boundary are complete; and preferably before any materials cover the exterior sheathing and/or shear walls and before any insulation or drywall is installed
- Use of appropriate diagnostic techniques (e.g., smoke testing) to identify leak sources
- Correction of air sealing defects
- Additional blower door testing by the ASM during and post-correction activities until the targeted airtightness is achieved

In a ZNE home, it is important to include a mechanical ventilation system to supply fresh, filtered air at an appropriate rate for the size of the home. Mechanical ventilation avoids air quality problems and greatly reduces the energy penalty of uncontrolled air leakage – even factoring in the fan energy. Most California ZNE homes are now using heat-recovery or energy-recovery ventilators (HRVs or ERVs).



Air sealing drawing by Coldham & Hartman Architects

RESOURCES

(Note: some of these are free, others available for purchase)

HIGH-PERFORMANCE ASSEMBLIES (GENERAL)

- *Guide for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climate Zones in North America*, FP Innovations and RDH Building Engineering Ltd., Graham Finch, et al.
- *Illustrated Guide - R22+ Effective Walls in Residential Construction in B.C.*, BC Housing
- *Field Test of Hygrothermal Performance of Highly Insulated Wall Assemblies*, M. Fox, et al.
- *Hygrothermal Analysis of California Attics*, Building Science Corporation, Joseph Lstiburek and Christopher Schumacher
- Building Science Corporation case studies – in the search window, select “Designs That Work” as the document type, and the appropriate US climate zone⁷ (or “Any”)
- *Building Science Corporation assembly guidance documents*, e.g., “ETW: Walls - 2x6 Advanced Frame Wall Construction High R-Value” – in the search window, select “Enclosures That Work” as the document type and select “Any” as the climate zone
- *Residential High Performance Walls*, California Energy Codes & Standards

- Building America Solution Center, U.S. Department of Energy – Energy Efficiency & Renewable Energy – *Ceilings Guide* and many other relevant guides
- *Construction Guide, Next Generation High Performance Walls, Climate Zones 3-5 Part 1: 2x6 Walls*. Home Innovation Research Labs, V. Kochkin and J. Wiehagen
- Several listed at Workforce Instructions for Standards and Efficiency (WISE), e.g., *Illustrated Guide: R22+ Effective Walls in Wood-Frame Construction in British Columbia*, Homeowner Protection Office, BC Housing

FRAMING

- *Advanced Framing Construction Guide*, APA – The Engineered Wood Association

INSULATION

- The BuildingGreen Guide to Insulation – each insulation type analyzed, including thermal performance (R-value), response to aging, performance in extreme temperatures, off-gassing, global warming potential, health impacts, and other key factors
- *Builder’s Guide to Continuous Insulation*, Dow, Building Science Corporation
- *Measure Guideline: Incorporating Thick Layers of Exterior Rigid Insulation on Walls*, US Department of Energy, Building Science Corporation
- *Residential Insulated Sheathing – Design Guide*, Roxul, Building Science Consulting, John Straube

AIR SEALING

- “Fact Sheet: Envelope Air Sealing 2013 California Energy Efficiency Building Standards,” California Energy Commission
- Coldham & Hartman Architects continuous air barrier drawing
- Hammer and Hand Best Practices Manual
- *Forty Years of Air Barriers*, Building Science Corporation
- *Passive House Design*, Gonzalo Roberto
- *Details for Passive Houses*, Österreichisches Institut für Baubiologie und -ökologie

INSULATION SPECIFICATIONS AND SCOPES OF WORK

- State of California Quality Insulation Installation specifications
- HERS fact sheet
- *Ace Installation Residential*, Energy Code Ace
- Energy Code Ace Quality Insulation Installation resources – a sample plan set including air sealing details, a QII note block to be added to architectural plans, and a contractor’s QII checklist
- *Revisions to Quality Management Products: Four Scopes of Work for High Performance Homes* – NREL, National Association of Home Builders Research Center – covers excavation, foundations, framing, and HVAC



Valley Glen Apartments
Dixon, CA
Pacific West Communities
2014
Glen McDowell photo

⁷ See <https://energy.gov/eere/buildings/climate-zones> for definitions of US climate zones, which are distinct from California climate zones.

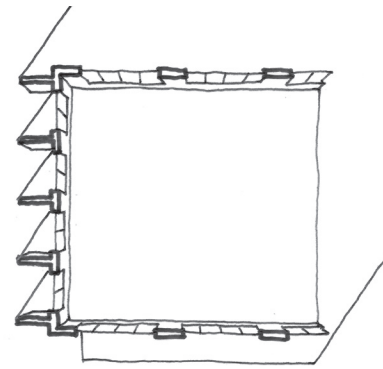
FENESTRATION

Windows are important to many aspects of occupant satisfaction and comfort, as well as having a potentially profound effect on energy performance. Key design measures to consider in ZNE homes include:

- Holding glass area in check. The most efficient window is considerably less efficient than the most inefficient wall, *and* the more glass you have, the more challenging protection from overheating becomes. (Tip: avoid floor-to-ceiling glass; your clients' kneecaps and feet won't enjoy the view at floor level, it's a thermal liability, and the lower the glass is on the wall, the harder it is to shade)

- Incorporate shading and glare protection. While especially critical in cooling-dominated climates, shading is important in *all* ZNE homes – if the SHGC is too high or shading is inadequate, they can overheat quite easily compared with homes built to earlier standards.
- Use skylights judiciously. They typically result in both unwanted heat gain during daylight hours and heat loss at night.

As shown on page 8, while the draft 2019 code calls for a maximum SHGC of 0.23 in climate zones with higher cooling loads (CZ 2, 4, and 6-15), there is no SHGC requirement in CZ 1,3, 5 and 16. However, many CA ZNE demonstration projects have adopted a specification of U 0.27 or less and SHGC 0.20 or less to further improve comfort and enclosure efficiency, and reduce overheating risks.



Top: Overhangs provide shading on south facades when the sun is high in the sky.

Bottom: Vertical fins provide shading on east and west facades when the sun is low in the sky.

RESOURCES

- [Efficient Windows Collaborative](#)
- [Passive Solar Architecture: Heating, Cooling, Ventilation, Daylighting and More Using Natural Flows](#), David Bainbridge & Ken Haggard, 2011

Many CA ZNE demonstration projects have adopted a specification of U 0.27 or less and SHGC 0.20 or less to further improve comfort and enclosure efficiency, and reduce overheating risks.

HEATING AND COOLING

Designing a highly efficient enclosure yields big benefits: it creates a more comfortable home for your clients while reducing the size, complexity, and thus the cost of the heating and cooling systems. However, realizing those benefits requires that you work with an HVAC design professional who really understands high performance, will calculate heating and cooling loads that accurately reflect the high-performance enclosure, and then will select, size, and locate the system components accordingly. Assumptions and 'rules of thumb' commonly used by HVAC contractors don't apply to a home with a superior enclosure. If loads and sizing aren't calculated using accurate information, they will not be correct.

Variables that affect the overall efficiency of heating and cooling systems include fuel selection, air handler and distribution system locations, proper sizing, equipment efficiency, distribution system design, installation quality, and commissioning.

California Energy Commission (CEC) research shows that good design and installation of heating and cooling systems can increase system performance by 80% and that this is the most cost-effective opportunity for improvement in residential buildings.⁸

Achieving high-performance heating and cooling solutions is complicated by infinite possible combinations of system variables, with each variable affecting others. For example, larger ducts require less fan energy to push air through them, but have more heat loss due to their larger surface area. And larger supply grilles are quieter because they reduce air velocity – but air velocity that is too low cannot mix air in the room, resulting in uncomfortable temperature stratification. To successfully address all these variables, it is imperative to select an HVAC contractor who commissions all installations and whose testing results will align with the "ZNE Quality Heating and Cooling Specification Guidelines"

ZNE QUALITY HEATING AND COOLING SPECIFICATION GUIDELINES⁹

■ Air conditioner sizing	2,000+ sq.ft. per ton (even in warmer climates – valley, inland empire, and desert)
■ Heating system sizing	Less than or equal to 12 Btu/sq.ft. (even in cold climates)
■ Duct leakage	zero (too small to measure)
■ Duct conductive losses	R-6.0 insulation, ducts in conditioned space, and as short as possible
■ Fan energy	less than 0.2 watts per CFM
■ Cooling air flow	550+ CFM per ton
■ Subcooling	low end of manufacturer's acceptable range
■ Superheat	less than 8°F

above. These specifications are achievable with experienced high-performance trades people.

LOCATION

Locating the air handling equipment and ducts within conditioned space is critical to minimize air handler and distribution system losses.

Good design and installation of heating and cooling systems can increase system performance by 80%.

⁸ *Efficiency Characteristics and Opportunities for New California Homes (ECO)*, March 2011, CEC Project 500-2012-062, J. Proctor, R. Chitwood, B. Wilcox.

⁹ Developed by Rick Chitwood, Chitwood Energy Management.

PROPER SIZING

Design of the HVAC system is closely related to the building form and to the quality of the thermal enclosure. The ratio of surface area to volume is an important variable in the architect's control – a smaller ratio (a simpler form) reduces unwanted heat loss and gain. An excellent thermal enclosure (low air leakage rate, QII, etc.) also substantially reduces heating and cooling loads. As a result, much lower-capacity heating and cooling equipment can – and should – be used. However, too often, HVAC systems are sized using 'rules of thumb' that are completely inappropriate for efficient ZNE enclosures.

As a result, oversizing equipment is very common, and it is problematic because oversized systems compromise comfort – for example, an oversized furnace will provide a short blast of heat (typically creating higher-than-desired temperatures in some parts of the home) and then shut off until the thermostat drops again; and then this will repeat, so the occupants are alternately too warm and too cool. Furthermore, oversized, rapidly cycling equipment fails prematurely because it is designed to run continuously, not in short cycles.

ZNE homes in California require much smaller equipment than is typical in standard construction. The industry standard for sizing in California is 500 to 800 square feet of conditioned floor area per ton of cooling capacity. Several

examples of ZNE homes are shown below, with sizing ranging from 1,600 to 3,400 square feet per ton. These examples demonstrate that equipment capacities 3 to 5 times lower than are typically specified will meet the heating and cooling needs of highly-efficient, ZNE homes.

In modestly-sized ZNE homes in many California climates, the heating and cooling loads may be low enough that the only equipment option that has a small enough capacity is a single, ducted, mini-split electric heat pump (which provides both heating and cooling).

EQUIPMENT EFFICIENCY

Title 24 minimum required equipment efficiencies in most cases will be completely adequate for ZNE homes – if the system is properly designed and installed.

DISTRIBUTION SYSTEM DESIGN

As with water heating systems, a compact layout will contribute to efficient performance. Keep ducts as short as possible – in your well-insulated ZNE enclosures, there is no need to run ducts to exterior walls. Sizing system components using the applicable Air Conditioning Contractors of America (ACCA) manuals, in compliance with CALGreen requirements (Title 24, Part 11), is also very important. Passing the new HVAC

mandatory tests (listed on page 8) will be very hard if duct systems are not designed and installed correctly.

INSTALLATION QUALITY/ COMMISSIONING

Installation shortcomings can greatly reduce system performance, so include specifications requiring commissioning of all elements of the heating and cooling systems – e.g., duct blaster, blower door, and room-by-room air flow testing.

Most residential building features and performance are verified visually, e.g., inspecting a header size or noting the insulation R-value stamped on fiberglass batts. Heating and cooling performance can only be verified with performance measurements. The performance goals are not the same as the HERS verification, which simply checks for code-minimum performance. More appropriate performance goals for ZNE homes are shown in the "ZNE Quality Heating and Cooling Specification Guidelines" table on page 18.

Be very selective about who you work with, and require that the HVAC system designer submit load calculations, equipment sizing based on load calculations, and all specifications, for your approval.

Builder	Location	CA Climate Zone	CDD	Home Size (Sq. Ft.)	Cooling Load (Btu/Hr)	Cooling Capacity Need (tons)	Standard Sizing (tons)	Square Feet per Ton
Habitat for Humanity of San Joaquin Valley ¹⁰	Stockton, CA	12	1,470	1,200	6,000	3/4	2	1,600
CHISPA	Greenfield, CA	4	257	1,167				
PG&E Redding Demo [builder?]	Redding, CA	11	1,132	2,550	9,000	3/4	3.5	3,400

¹⁰ "House 10" in *Final Report*, March 2017, Pacific Gas and Electric Company Zero Net Energy Production Builder Demonstration, Habitat for Humanity of San Joaquin County Dream Creek Subdivision, Stockton, CA.

WATER HEATING

To minimize the energy needed for water heating, think about the layout of hot water draws throughout the house, and the water heater location, in the very early stages of design, and locate them as compactly as possible. A compact system also may allow you to incorporate drain water heat recovery. An efficient water heater is also important, as are efficient appliances and fixtures.

LOCATION & DISTRIBUTION

Locate the water heater in conditioned space. To the extent possible, design hot water draws close to one another and to the water heater, to minimize heat loss through the pipes. When a compact system is not practicable, install an on-demand recirculation loop; an excellent guidance document is available from the EPA (listed on page 21 under RESOURCES).

DRAIN WATER HEAT RECOVERY

Drain water heat recovery (DWHR) may be a beneficial feature to incorporate – in the draft 2019 code, this is an option with a tank water heater and a credit with a tankless unit. DWHR systems transfer heat from outflowing hot water in drain lines (e.g., from shower stalls) to the incoming cold water line, as shown at right – the coil is the incoming cold water line.

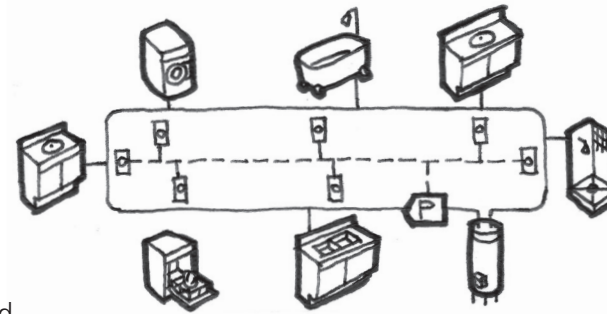
WATER HEATER EFFICIENCY

Title 24-2019 offers three prescriptive water heating options; those options, along with a comparison of their pros and cons, is shown in the table on page 21.

APPLIANCE AND FIXTURE PERFORMANCE

Showers, dishwashers, and clothes washers have significant impacts on household energy use (as well as water use). Particularly in relatively mild climates and in multifamily buildings, they may represent a very high fraction of overall energy consumption. Appliance selection is often heavily influenced by clients, particularly when aesthetics are a major concern. Nevertheless, you can provide your clients with some excellent guidance in choosing high-efficiency options. While Energy Star is a reasonable starting point, higher standards include Energy Star “Most Efficient,” CEE1.org ‘Tier 3’ listings, and models rated 90+ on Enervee.com.

Specify showerheads with the lowest practicable flow rate (gallons per minute, or gpm) that will provide acceptable performance. CALGreen requires that the combined flow rate of all showerheads controlled by a single valve may not exceed 2.0 gpm @ 80 psi; however, it’s important to note that flow rate isn’t a good predic-

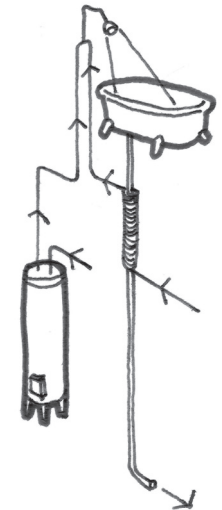


When a compact layout is not feasible, install an on-demand recirculating hot water loop.

tor of a satisfactory shower experience, and showerheads with lower flow rates can provide greater energy savings without compromising performance. Be sure to consult credible, current reviews (e.g., on BuildingGreen.com) to assist in specifying models. Another important variable in shower performance is the height of the showerhead relative to the height of the person showering; if too great a distance between the two, the water droplets will cool too much before hitting the person. A good solution to ensure a happy shower for everyone is to specify adjustable-height fixtures whenever possible.

SOLAR WATER HEATING

In multifamily buildings, solar water heating (a.k.a. solar thermal) systems are a prescriptive requirement under Title 24. In single-family homes, solar water heating earns performance credit. However, many ZNE practitioners believe that for single-family homes, ‘solar thermal is dead,’ because comparable results are achieved with an electric heat pump water heater in combination with a modest increase in the size of the PV array – while also being simpler and cheaper, and requiring less maintenance.¹¹



Drain water heat recovery diagram

¹¹ See articles on this topic by Martin Holladay at <http://www.greenbuildingadvisor.com/blogs/dept/musings/solar-thermal-dead> and <http://www.greenbuildingadvisor.com/blogs/dept/musings/solar-thermal-really-really-dead>.

Water Heater Pros and Cons¹²

Factor	Heat Pump (Gas or Electric)	Gas or Propane Tankless ("instantaneous")	Gas or Propane Storage Tank
Space	<ul style="list-style-type: none"> ■ Relatively large (6+ square feet of floor space) and relatively tall, and require air space around them. 	<ul style="list-style-type: none"> ■ Relatively small, wall-mounted 	<ul style="list-style-type: none"> ■ Relatively large (4-6 square feet of floor space).
Location	<ul style="list-style-type: none"> ■ Can be installed in a closet only if both supply and return air are ducted. 	<ul style="list-style-type: none"> ■ Condensing (higher efficiency) units can be located in conditioned space, closer to fixtures and with shorter delivery time. 	<ul style="list-style-type: none"> ■ Condensing (higher efficiency) units can be located in conditioned space, closer to fixtures and with shorter delivery time.
Hot Water Delivery	<ul style="list-style-type: none"> ■ Recovery rate (time to reheat a new tank) is relatively slow. 	<ul style="list-style-type: none"> ■ Can provide endless hot water at typical flow rates; may not be able to meet several simultaneous demands (which are relatively uncommon). ■ Most models are not "instantaneous" as they start out with cold water; delivery time also depends on distance to fixture. 	<ul style="list-style-type: none"> ■ Can provide hot water for typical flow rates and meet several simultaneous demands. ■ When water in the tank is below desired temperature, flow rate is limited.
Maintenance	<ul style="list-style-type: none"> ■ Manufacturers recommend yearly valve check. ■ Anodes and flush tank should be checked at least every 5 years. ■ Efficiency drops when the air filter is dirty. 	<ul style="list-style-type: none"> ■ Manufacturers recommend yearly service for cleaning filters and flushing heat exchangers. 	<ul style="list-style-type: none"> ■ Controls are simpler and less prone to malfunction than those of tankless models. ■ Manufacturers recommend yearly valve check. ■ Anodes and flush tank should be checked at least every 5 years.
Other	<ul style="list-style-type: none"> ■ Best choice for all-electric homes. ■ 1.5 to 2.5 times more efficient than tankless or traditional storage water heaters when well maintained. ■ Grid-connected models can be programmed to heat when electric rates are low, for later use. ■ Relatively new technology, shorter track record. 	<ul style="list-style-type: none"> ■ Good for intermittent uses such as vacation homes (water doesn't age and become smelly). 	

RESOURCES

- Energy Star Water Heaters – [select Energy Star "Most Efficient"](#)
- Consortium for Energy Efficiency – [the most efficient models are designated as Tier 3](#)
- Enervee.com
- *WaterSense New Home Specification Guide for Efficient Hot Water Delivery Systems*, US Environmental Protection Agency – [on-demand hot water recirculation system design guidance](#)
- [Drain Water Heat Recovery Characterization and Modeling](#), Natural Resources Canada
- [Drain-water heat recovery energy efficiency ratings](#), Natural Resources Canada
- "Drain Water Heat Recovery Systems are Energy Efficient and Economical," [EcoBuilding Pulse](#), Heidi Moore

¹² Table developed with extensive input from Gary Klein and Larry Weingarten, hot water experts extraordinaire.

ELECTRIC LOADS

LIGHTING

Title 24 has stringent regulations governing choice of lighting fixtures, lamps, and lighting controls. All residential lighting requirements are prescriptive. That means going above and beyond those requirements won't affect your energy model, but it can reduce operating energy use. Many homes have excess numbers of fixtures or ill-placed fixtures. "Better" lighting includes going 100% LED, focusing on lighting quality that addresses functional needs and reinforces the architectural design while reducing the fixture count, and avoiding recessed cans in insulated ceilings.

APPLIANCES AND ELECTRONICS

The 2019 code is expected to include credit for Energy Star appliances. For best operating energy performance, specify or recommend best-in-class (Energy Star Most Efficient, CEE1.org Tier 3, or Enervee.com 90+) for all appliances and electronics – refrigerators are at the top of the list!

MONITORING

Performance monitoring devices and dashboards are increasingly common, heightening occupant awareness of their energy-using behaviors.

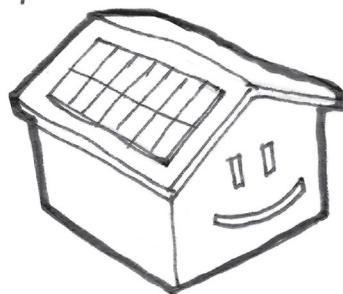
RESOURCES

- *Residential Lighting*, California Lighting Technology Center, UC Davis (this document may require some updates to reflect 2019 code)
- Consortium for Energy Efficiency – the most efficient models are designated as Tier 3
- *Liberty Lighting Guidelines for Zero Net Energy Communities*, California Lighting Technology Center, UC Davis
- *Enervee.com* – models are rated on a 100-point scale; choose ratings of 90+

TOP TEN RESOURCES

- California Energy Commission, 2019 Title 24, Part 6 draft code language
- Building Science Corporation
- Building America Solution Center
- Net Zero Energy Coalition case study database
- Energy Code Ace
- Green Building Advisor
- DOE Tour of Zero
- National Renewable Energy Laboratory
- Zero Energy Project
- *Energy Free: Homes for a Small Planet*





KEYS TO SUCCESS



START WITH THE END IN MIND

Set ZNE as a project goal from the very beginning, to calibrate your mindset (and your client's). Then you'll figure out how to do it and stay on budget!

Learn from the pioneers – research how other architects have tackled the ZNE challenge.



Pick a rock star team, and involve all of them from early in the design process – include a really great mechanical system designer, a really great energy modeler, and a really great general contractor! The ideal qualifications are:

- + **Commitment** to the ZNE goal
- + **Creativity** to go beyond business-as-usual
- + **Experience** with high-performance/ZNE projects
- + **Engagement** ("plays well with others")

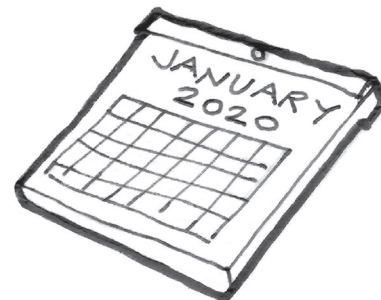
Focus on the enclosure – it's the key to success with ZNE. Dedicate time to developing a comprehensive set of air sealing and air-vapor-water barrier continuity details that you can use over and over again.

Control what happens in the field as much as you can – develop a rigorous set of quality management specifications to include in your CDs (every time); include field diagnostics (blower door testing, duct blaster testing, infrared imaging, etc.) and commissioning.

Make a checklist of the new things you will need to accommodate now (and should plan for in the future), and their space needs: shading, PVs, more PVs for electric vehicles, mechanical equipment in conditioned space, etc.



HAVE FUN!



RESOURCES

"Making Choices Instead of Paying Premiums,"

Northeast Sun,
Bruce Coldham –
excellent article on the
relationship between
goals and budget

**Net Zero Energy
Coalition/NESEA**
case study database

**Tour of Zero, US
Department of Energy**
project profiles

**California Association
of Building Energy
Consultants (CABEC)**
listing of Certified
Energy Analysts

