Passive House in California

BayREN December Forum
San Rafael, CA, December 10, 2015

Graham Irwin
Principal, Essential Habitat Architecture
www.essentialhabitat.com
What is Passive House?

• Rigorous, Voluntary Energy Efficiency Standard
• Formalized by European Scientists ~1990
• Based on Super-Insulated, Passive Solar & “Low-Energy” Buildings
• 30,000+ Worldwide: Residential, Commercial, Institutional Buildings

The Passive House Standard is a rigorous building performance standard. Consultants, projects or building components that have obtained the right to carry the logo have committed themselves to design excellence and the Passive House energy performance criteria.

World’s 1st Passive House
Kranichstein Passive House
Darmstadt, Germany (1990)

1st Passive House in US
Smith House

1st Passive House in CA
Tahan Residence
Berkeley, California (2007)

1st Certified Passive House in CA
1st Certified PH Retrofit in US
O’Neill Residence
Sonoma, California (2010)
Passive House in Marin County

The Blue, House (PH Retrofit)
Community Land Trust of West Marin (CLAM)
Point Reyes Station (2009)

James Residence (Staged Retrofit)
Larkspur, CA (2010)

Blue, (Affordable Rental Housing)
Community Land Trust of West Marin (CLAM)
Point Reyes Station (2010)

Green Gulch Farm Zen Center (6 Unit Dormitory)
Muir Beach (2011) 1st Certified Multi-Unit PH in US
Passive House in California Code

• Marin County Building Code (2013)
  – Passive House recognized in Marin County Green Building Requirements

• San Francisco Planning Code (2014)
  – Priority processing for Passive House projects
1st Multi-Family PH in California

Sol-Lux Alpha, 4 Net-Zero Condominiums, San Francisco, CA (Under Construction)
How Does Passive House Work?

- Minimize Losses
- Maximize Gains

1. Super-Insulation
2. Air-Tightness
3. Heat Recovery Ventilation
4. Controlled Solar Gains
5. Efficient Equipment, Appliances & Lighting

Image Source: Passivhaus Institut (PHI)
Centralized Ventilation for “Heat Recycling” & Superior IAQ

- Centralized Ventilation
- Air Extracted from “Wet” Rooms
- Air Supplied to Living & Sleeping Rooms
- Balanced & Continuous
- Use Windows in Nice Weather

Passive House HRVs Recover 8-15x Their Electrical Use (PHI)
Passive House Ventilation (0.3 ACH) Exceeds ASHRAE 62.2 Levels

Image Source: www.greenbuildingstore.co.uk/mvhr.php
What About Cooling?

Source: Passive Houses in Mediterranean Climates, PHI
What About Cooling?

Peak Loads: Seville, Spain, Standard Construction

Source: Passive Houses in Mediterranean Climates, PHI
What About Cooling?

Peak Loads: Seville, Spain, Passive House

Source: Passive Houses in Mediterranean Climates, PHI
Proof in Practice
A Passive House in a Heat Wave

Midori Haus, Santa Cruz, CA - Summer Comfort without Air Conditioning

www.midorihaus.com
Proof in Practice
A Passive House in a Heat Wave

Comfortable Inside During Heat Wave
example at 14-May-2014 14:35

Sensor data from WELserver

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Midori Haus, Santa Cruz, CA - Summer Comfort without Air Conditioning

www.midorihaus.com
The “Classic” Passive House Standard

1. Maximum Air Leakage: 0.6 ACH<sub>50</sub>

2. Max. Heating or Cooling Demand
   - 15 kWh/m<sup>2</sup>/yr (4.75 kBtu/ft<sup>2</sup>/yr)
   - OR Max. Heating Load
   - 10 W/m<sup>2</sup> (3.17 Btu/hr./ft<sup>2</sup>)

3. Max. Primary Energy Demand*
   - 120 kWh/m<sup>2</sup>/yr (38.1 kBtu/ft<sup>2</sup>/yr)

*Before PV ← Efficiency vs. “Net” Zero Energy

Measured

Modeled

Shell Performance
- Comfort,
- Good IAQ,
- Durability,
- Open Building

Source Energy
Passive House Planning Package (PHPP) for Predictable Performance

- Climate Zone
- Building Form & Orientation
- Building Assembly R Values
- Thermal Mass
- Heat Losses to Ground
- Thermal Bridges
- Air Tightness
- Window U Values, SHGC & Installation
- Shading
- Solar Heat Gains
- Internal Heat Gains
- Internal Heat Recovery
- Heating & Cooling Loads
- Summer Conditions
- Mechanical & Natural Ventilation
- DHW & Solar Thermal
- District Heating
- Plug Loads, Appliances, Lighting
- Source Energy
- CO₂ Emissions
- Occupancy Patterns & Schedules
Passive House Planning Package (PHPP) and Cost-Optimization

Heating & Cooling Demand

- Roof Insulation
- Clerestory Wall Insulation
- Wall Cavity Insulation
- Wall Exterior Insulation
- Floor Insulation
- Exterior Doors U-Value
- Orientation
- Roof Overhang
- Roof Absorptivity
- Air Tightness (ACH50)
- Heat Recovery Efficiency
- Thermal Mass
- Front Windows
- Left Windows
- Back Windows
- Right Windows
- Glazed Doors
- Solid Door Glazing
- Glazing U-Value
- Glazing SHGC
- Roof Exterior Insulation
Perspective: Our California Projects

Av. Min. Temperature (deg. F)
01/1/2014 - 1/31/2014

Generated 2/1/2014 at WRCC using provisional data.
NOAA Regional Climate Centers
Questions About Wider Adoption

2. How Does Passive House Compare with 2013 Title 24 (CA Energy Code)?
3. What is Generally Required in Other California Climates?
4. What are the Most Effective Improvements?
Study: CA Code ➔ Passive House
2013 California Code vs. Passive House


Study: CA Code → Passive House

T24 “Prototype” One Story House

Figure A-1: One Story Prototype Front View

Figure A-2: One Story Prototype Back View

Study: CA Code → Passive House

T24 “Prototype” One Story House

- Conditioned Floor Area: 2100 ft²
- Ceiling Height: 9 ft
- Conditioned Volume: 18,900 ft³
- Slab Area: 2100 ft²
- Slab Perimeter: 162 ft
- Ceiling Area: 2100 ft²
- Glazing: 5% “Conditioned Floor Area” (CFA) in Each Direction (108 ft²)
- 12” Overhangs

Study: CA Code → Passive House
**Title 24 vs. PH Energy Modeling**

- **Proposed Design**
  - Equal Wall Areas & Glazing (5% CFA)
  - Rotated to True North
  - Floor Area & Volume = Prop. Design
  - Prescriptive Measures
  - Standard Assumptions
  - No Overhangs

- **Standard Design**
  - 1 of 16 Cities
  - No Landscape Shading
  - Bug Screens Year ‘Round

- **Modeled Compliance**
  - Proposed H/C/DHW <= Std Design?

- **Performance**
  - Localized Climate Data
  - Landscape Shading
  - H/C/Src. Energy <= PH Standard?

**State-Approved Energy Modeling Software**
Performance vs. Compliance

2012 GMC Yukon Denali 1500 (15 MPG)

2012 Honda Civic HF (33 MPG)

2012 Yukon Denali 1500 Hybrid (21 MPG)

2012 Honda Civic Hybrid (44 MPG)

40% (6 MPG) Improvement

33% (11 MPG) Improvement

Reference: www.fueleconomy.gov, US DOE

Performance is an absolute standard, compliance is always relative.
# Compliance Approach
Comparing the Building to Itself, Not to a Standard

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<th>Low Rise</th>
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<th>‘L’ Shape</th>
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<td>Total Heat Flow</td>
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<td>x1.4</td>
<td>x1.5</td>
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</table>
Compliance is “Sticky” to Baseline Regardless of Reference Point

Compliance vs. Construction Cost

- Reference Energy Use
- Typical Efficiency vs. Cost Curve
- Constant Cost (Steeper = Cheaper)
- “Expensive” Improvement

% of Reference Energy Use vs. Construction Cost
Orientation & Shading Matter

Cliff Dwelling, Mesa Verde, CO (Wikipedia)  Priene, Ancient Greece (Solarpedia)

...without purpose they wrought all things in confusion. They had neither knowledge of houses built of bricks and turned to face the sun nor yet of work in wood; but dwelt beneath the ground like swarming ants, in sunless caves - Aeschylus, PROMETHEUS BOUND
Air Sealing Matters for Health

A Washington State University Extension Energy Program (WSU-EEP) study found that up to 40% of the air in the test homes originated in the crawl space.

Source: Terry Nordbye, The Practical House
Air Sealing Matters for Comfort

9 mph Wind = -30% R Value (Dupont, 2007)
Air Sealing Matters for Durability

- Air movement accounts for 98%+ of water vapor movement in building cavities
- Canadian Study (One Heating Season, Indoors @ 70°F, 40% RH)
  - Diffusion: 4’x8’ sheet of drywall = 1/3 quart of water
  - Infiltration: 1 in² hole = 30 quarts of water
  - 90:1 ratio!!

In Quickly (Air Leakage) - Out Slowly (Diffusion) = Accumulation
Air Sealing Matters for Durability

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“Walls don’t need to breathe, but they do need to sweat!!!”
Air Sealing Matters for Performance

- 30-50% of Space Conditioning Energy (DOE)
- 9 MPH Wind = -30% R-Value (DuPont, 2007)
- Average US House: 3 ft² of Holes
- Typical 2500 ft² Home: ½ Mile of Cracks

Investigation of the Impact of Commercial BuildingEnvelope Airtightness on HVAC Energy Use (NISTIR 7238) - NIST, US D.O.C.

Passive House: 60-70% Savings, BEFORE PV
Air Sealing Matters for Predictable Performance

- ACH$_{\text{NAT}}$ Very Unpredictable
- “Infiltration: Just ACH$_{50}$ Divided by 20?”
  - Alan Meier, Home Energy Magazine, January/February 1994
- “Translating blower door measurements into an average infiltration rate has bedeviled the retrofitter and researcher alike.”

- $N = C \times H \times S \times L$
  - C = climate factor
  - H = height factor
  - S = wind shielding factor
  - L = leakiness factor

Figure 1: Climate correction factor, “C,” for calculating average infiltration rates in North America. Note that the climate correction factor depends on both average temperatures and windiness. It also includes possible air infiltration during the cooling season. For these reasons, locations in greatly dissimilar climates, such as Texas and Vermont, can have equal factors. Select the value nearest to the house's location and insert it in Equation 2. This map is based on data from 250 weather stations.

Source: PHI
Air Sealing Matters for Predictable Performance

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- \( \text{C} \) = climate factor
- \( \text{H} \) = height factor
- \( \text{S} \) = wind shielding factor
- \( \text{L} \) = leakiness factor

Source: PHI
Insulate Slabs!

United States Average Annual Temperature (Fahrenheit)

CA Ground Temp. – Fine in Summer, Winter’s a Bummer!
The Windows Matter
For Performance

Energy Star
Double Pane
U = 0.3 (R3)

VS.

Passive House
Triple Pane
U = 0.12 (R8)

Source: Zola Windows
The Windows Matter
For Performance

2X4 Wall
20% Glazing

7.4” Cavity
20% Glazing

2X6 Wall
20% Glazing

19.4” Cavity
20% Glazing

R10 (R8 Window)  R10 (R3 Window)  R14 (R8 Window)  R14 (19.4” Cavity)
The Windows Matter
For Performance

2X4 Wall
20% Glazing

7.4” Cavity
20% Glazing

2X6 Wall + R8
20% Glazing

Infinite Cavity
20% Glazing

R10 (R8 Window)  R10 (R3 Window)  R18 (R8 Window)  R17 (R3 Window)
# The Details Matter

## Thermal Bridges

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The Details Matter
Thermal Bridges

Images: Gavin Healy, Balance Point Home Performance
The Details Matter
Thermal Bridge Analysis of Intersections
The Details Matter
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Thermal Bridge Analysis of Intersections
The “Duck Curve” and the End of Net-Zero?

California Grid Load (March 31)

Energy: 13 GW x 3 hrs / 2 = 19,500,000 kWh / 10 kWh / 70% = 2,790,000 Tesla 10 kW Powerwalls
Power: 13 GW / 2 kW = 6,500,000 Tesla 10 kW Powerwalls
California: 12% Renewable in 2014, 33% by 2030, 50% Renewable by 2050
Unheated Building vs. τ (San Francisco, CA, July)

The Dao of Tau 🤍 of 🌲
The Dao of Tau 🤝

Unheated Building vs. τ (San Francisco, CA, December)

- **Tout**
- **Tout (avg.)**
- **Tint, τ=3 hrs**
- **Tint, τ=10 hrs**
- **Tint, τ=30 hrs**
- **Tint, τ=200 hrs**
Net Zero Energy
Just Add Solar & Call It Done?
Net Zero Energy
Just Add Solar & Call It Done?

Summer
Winter
Winter
Summer

Heating Demand
Solar
Net Zero Energy
Just Add Solar & Call It Done?

[Diagram showing heating demand and solar energy throughout the year with different months highlighted for Summer and Winter]
Net Zero Energy
Just Add Solar & Call It Done?
Net Zero Energy
Just Add Solar & Call It Done?

Summer

Winter

Heating Demand
Solar + IHG
Internal Heat Gain

Winter

Summer
Proof in Practice
Passive House “Flattened” Seasonal Energy Use

2869 kWh Elec. + 50 Therms (1,465 kWh) Nat. Gas = 4,334 kWh (before PV!)
Before Retrofit 21,928 kWh/yr, Similar CA Home 19,596 kWh/yr

www.midorihaus.com
Proof in Practice
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2869 kWh Elec. + 50 Therms (1,465 kWh) Nat. Gas = 4,334 kWh (before PV!)
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www.midorihaus.com
Where Does Our Energy Go?
Average PG&E Household (1584 ft²)

PG&E Household Electricity Use

- Electronics: 18%
- Refrigerator/Freezers: 20%
- Lighting: 9%
- Pool/Spa: 6%
- Cooking: 4%
- Laundry: 6%
- Heating: 3%
- Lighting: 9%
- Pool/Spa: 6%
- Miscellaneous: 24%

PG&E Household Natural Gas Use

- Hot Water: 41%
- Laundry: 4%
- Cooking: 4%
- Pool/Spa: 2%
- Miscellaneous: 0%
- Heating: 51%

Electricity: 6446 kWh/yr
Natural Gas: 399 Therms/yr

Reference: 2009 Residential Appliance Saturation Survey (RASS), California Energy Commission (CEC)
Where Does Our Energy Go?
Average PG&E Household (1584 ft²)

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PG&E Household Natural Gas Use
- Hot Water: 41%
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- Cooling: 6%
- Hot Water: 4%

Electricity: 6446 kWh/yr
Natural Gas: 11,683 kWh/yr

Reference: 2009 Residential Appliance Saturation Survey (RASS), California Energy Commission (CEC)
Where Does Our Energy Go?
Average PG&E Household (1584 ft²)

Site Energy: 18,263 kWh/yr
Electricity: 35%
Natural Gas: 65%

Reference: 2009 Residential Appliance Saturation Survey (RASS), California Energy Commission (CEC)
Thank You! Questions?

Graham Irwin
Principal, Essential Habitat Architecture
www.essentialhabitat.com