Passive House – a Positive Net Energy Home

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1 Introduction

- 2000 Watt Society
- IEA World Energy Outlook
- Carbon Neutrality
The 2000 Watt Society, Novatlantis, ETH Zuerich (www.novatlantis.ch)

World-wide average annual energy consumption per capita:
17,500 kWh per year

= continuous consumption

This corresponds to limiting CO₂ emissions to 1 ton per capita possible by 2050
(500 watts of fossil fuel)

(www.novatlantis.ch: vision)

(www.novatlantis.ch: 2000 Watt Society)

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IEA World Energy Outlook 2006:

World Primary Energy Demand by Fuel in the Reference Scenario

(Slide with permission from Keynote Presentation Passive House Conference 2007: Dr. Wolfgang Feist)
Alternative Fuel Sources to reduce CO2 Emissions:

1. Nuclear
2. Renewables
3. Biofuels
4. Efficient Technologies

CO2 emissions estimated to increase by 56%. 32% in increase still remain unaccounted for!

(Slide with permission from Keynote Presentation Passive House Conference 2007:
Dr. Wolfgang Feist)
Stabilizing CO₂ Emissions until 2030 through:

1. Passive House technology applied for all new construction

2. Renewables II: Technological advancements in Renewable Technologies

(Slide with permission from Keynote Presentation Passive House Conference 2007:
Dr. Wolfgang Feist)
2 Basic Design Principles

• Why Passive House?
• Economic Feasibility as Core Concept
• Envelope & Thermal Comfort Principles
Why Passive House?

Optimize the House…  … to the Heating System
Minimize Losses First-
Maximize Gains

(Krapmeier and Drossler 2001)
Climate Neutrality achieved:

116% CO₂-Substitution by Wind Generator
Global cost curve for greenhouse gas abatement measures beyond "business as usual"; greenhouse gases measured in GtCO₂e\(^1\)

- Carbon capture and storage (CCS), new coal
- Medium-cost forestation
- Cofiring biomass
- Wind; low penetration
- Industrial feedstock substitution
- CCS, enhanced oil recovery, new coal
- Low-cost forestation
- Livestock
- Nuclear
- Industrial non-CCS
- Standby losses
- Sugarcane biofuel
- Fuel efficiency in vehicles
- Water heating
- Air-conditioning
- Lighting systems
- Fuel efficiency in commercial vehicles
- Building insulation

Cost of abatement, £ per tCO₂e\(^2\)

- Industrial non-CCS
- Standby losses
- Sugarcane biofuel
- Fuel efficiency in vehicles
- Water heating
- Air-conditioning
- Lighting systems
- Fuel efficiency in commercial vehicles

Abatement beyond "business as usual," GtCO₂e\(^1\) per year in 2030

Marginal cost\(^5\), £ per tCO₂e\(^2\)

Further potential\(^3\)

550 ppm\(^4\) 450 ppm\(^4\) 400 ppm\(^4\)

- 550 ppm\(^4\)
- 450 ppm\(^4\)
- 400 ppm\(^4\)

~25 ~40 ~50

1 GtCO₂e = gigaton of carbon dioxide equivalent; "business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.
2 tCO₂e = ton of carbon dioxide equivalent.
3 Measures costing more than £40 a ton were not the focus of this study.
4 Atmospheric concentration of all greenhouse gases recalculated into CO₂ equivalents; ppm = parts per million.
5 Marginal cost of avoiding emissions of 1 ton of CO₂ equivalents in each abatement demand scenario.

Image Source: McKinsey Quarterly Report
Economic Feasibility as Core Concept:

Passive House Concept Developed in the early 1990s by Dr. Wolfgang Feist and Professor Bo Adamson as optimization of early superinsulation work

First Passive House Prototype built in 1990 in Kranichstein, Germany

70-80% reduction in overall energy consumption, 90-95% reduction of heating and cooling energy

Passivhaus Institut (PHI) founded in 1996
The Small Homes Council
University of Illinois, Urbana-Champaign:
Wayne Schick’s Team develops the Lo-Cal House in 1974-76

Walls:
Double stud Walls, R-30

Roof:
R-40

The Illinois Lo-Cal House

The increasing scarcity of fuel makes it imperative to include more energy-conserving features in our housing. 

This publication describes the design, construction, and performance of a better which uses about one half the energy needed to heat a house of the same size which was built to meet 1974 minimum standards. G. S., Department of Housing and Urban Development standards for houses located in areas having a heating season of between 2400 and 3000 degree-days. 

Test results of its low energy requirements for heating, which have been called the “Illinois Lo-Cal House,” if the Lo-Cal House is compared to the typical house at 1974, the savings are even more dramatic. 

A comparison with a house built to the 1980 HUD standards is also included. It should not be noted however, that the level of insulation recommended in the new minimum standards is the improvement recommended in the Fo 1980 publication in 1979, which was considered extreme at the time.

The major features which account for the exceptional reduction in energy usage are:
- Superior insulation
- Solar orientation

Design and Construction Features:
- Insulation
- Heavy wall insulation
- Insulated wall insulation
- Insulated roof and space insulation
- Triple-glazed windows
- Complete vapor barrier (framing)
- Tighter construction to minimize air leakage

Siting:
- Major ends of house oriented seaward
- Roof overhang designed for solar control
- No influence on the east and west walls
- Major glass area on the south wall

General Features:
- Can be built with standard, readily available building materials
- No new technology or labor skills required
- Design conforms to current practice
- Design adapts to various sit situations

Benefits:
- Low-cost heating system
- Low-energy cost for heating
- Low-cost cooling system
- Low energy cost for cooling
- Permanent reduction of fuel in use
- Improved acoustic performance

Construction Details:
This design is considered appropriate for most areas of the United States having a heating season of 2000 degree-days or more.
Harold Orr builds the Saskatchewan Conservation House
In Saskatoon, Canada in 1977

First superinsulated house that showed that airtight construction is feasible. It is equipped with a ventilation system with an air-to-air heat exchanger.

Peak heat load at -10 degrees Fahrenheit is 3000 watts (10,640 Btu per hour)

Walls: 12” thick, R-44

Roof: R-60
Amory and Hunter Lovins finish the Rocky Mountain Institute in Snowmass, Colorado in 1984

“Tunneling through the cost barrier”
Amory Lovins
Eliminating the Heating System for Market Viability:

Cost asymptote occurs when standard heating system is eliminated
Envelop and Thermal Comfort Principles

1. **Continuous Insulation** - creating steady indoor temperatures that won’t drop below 50 degrees without heating source

2. **Thermal Bridge Free Construction** - minimizes condensation/building deterioration

3. **Compact Building Shape** - excellent surface-to-volume ratio (< 1)

4. **Airtightness** - minimizes moisture diffusion into wall assembly

5. **Balanced Ventilation with Heat Recovery with minimal Space Conditioning System** - exceptional efficiency, indoor air-quality and comfort

6. **Optimal Solar Orientation and Shading** — maximizing solar gains for winter, minimizing gains for the summer case

7. **Energy Efficient Appliances and Lighting** - highly efficient use of household electricity

8. **User Friendliness** - user manuals are recommended to be given homeowners
Major comfort criteria

conventional house
Low surface temp = discomfort

(Slide with permission from Manfred Brausem)
Passive House

min 64°F surface temp = comfort

Slide with permission from Manfred Brausem
Windows & Doors

Passive house window requirements for cold climates (triple-pane, argon filled, low-e on the right)
• $U_{\text{glass}} = 0.54$ SHGC, triple glazing
• $U_{\text{frame}} = 0.64 \text{ W/(m}^2\text{K)}$, superior insulation
• $U_{\text{window}} = 0.77 \text{ W/(m}^2\text{K)}$, R7.4 whole window

www.optiwin.net/mueller-en?set_language=en

www.enersign.de
• Passive house window frames, door frames and doors for cold climates need to be insulated

• Multiple lock systems for operable windows and doors to ensure air-tightness and even wear

• Excellent, multiple seals at sill
# Wall Construction Components

<table>
<thead>
<tr>
<th>Wall Type</th>
<th>Insulation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural insulated panel (SIP)</td>
<td>foam</td>
</tr>
<tr>
<td>Insulated Concrete Form (ICF)</td>
<td>foam</td>
</tr>
<tr>
<td>Double stud wall</td>
<td>cellulose, fiberglass, foam,</td>
</tr>
<tr>
<td>Wooden I-Joist</td>
<td>cotton, wool, etc</td>
</tr>
<tr>
<td>Straw Bale</td>
<td>Straw</td>
</tr>
</tbody>
</table>

No ‘best’ method, just must meet the thermal resistance requirements of the building in the specific climate
Insulation Materials

- Expanded Polystyrene in various densities for wall and under-slab insulation

- Cellulose damp-spray insulation (40 times lower embodied energy than fiberglass)

- High-density spray-in fiberglass insulation

- Mineral Wool (Rock Wool)

- Vacuum Insulation
Wall Construction Methods

Rastra (insulated Concrete form made from recycled material) and Straw Bale Wall

Structural insulated panels: Agriboard panels (Straw boards instead of EPS)

Various Passive House applicable Wall Type Sections

Regular insulated concrete forms
3 US Projects

- Built Examples
- Townhouses
- Apartment Buildings
Detailing & Construction:

2nd FLOOR PLAN

1st FLOOR PLAN

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Lastabtragung:

Bei Balloon- und Platform Framing Details kommt es zu exzentrischer Lastverteilung in den TJ²-Stielen. Die folgende Darstellung zeigt wie die Lastverteilung auf der Schwellen infolge exzentrischer Lastverteilung angenommen ist.

Die Gesamtlast verteilt sich über die modifizte Querschnittfläche des TJ²-Stiels mit 70% auf der Innenseite und 30% auf der Außenseite. Diese Lastverteilung ist für alle TJ²-Stiels bis zur Tragkraft von 406 mm anzunehmen.

exzentrische Last

\[
\text{vorrh. } \sigma_{DL} = \frac{1.4 \times P_{\text{exzentr.}}}{A_{\text{mod}}} \leq zul. \sigma_{DL}
\]

Hinweise:
- Vorh. Auflagerpressungen der Schwellen (N/mm²)
- Exzentrische Last (N)
- Modifizte Querschnittfläche des TJ²-Stiels (mm²) – Summe der Gurtquerschnitte und des im Verhältnis der E-Modul abgeminderten Stegquerschnitts – siehe Technische Anleitung
Fairview 2: Prefabricated Panels
Smith House - 2003
3 Passive Houses in Illinois
Fairview 1+2 and Smith House in Urbana, built in 2005-07 and 2003
Tahan Residence, Berkeley - 2008
Isabella Lake Passive Home in Minnesota:
Mike LeBeau, Conservation Technologies
Towards the Passive House in Duluth, MN:
Skyline House Wagner-Zaun Architects, Mike LeBeau. Conservation Technologies
Solar Decathlon 2007

University of Darmstadt
BioHaus School, Bemidji MN – 2006
Martha’s Vineyard
Planned Multifamily Projects in the US

- 70 Unit Multifamily Development in Boston, Massachusetts
- 36 Unit Townhouses and Multifamily Residences, Urbana, Illinois
- 30 Unit Multifamily Development in Yellow Springs, Ohio
- 250 Unit Multifamily/mixed Development in Boulder, Colorado
Kerr Avenue, Urbana IL: Passive Townhouses 2006
Kerr Avenue, Urbana IL: Passive Townhouses 2006
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Kerr Avenue, Urbana IL: Passive Townhouses 2006
PHPP Multifamily Calculation:

1. Overall Volume can be used to certify building/meet PH standard

2. End house or worst case scenario apartment has to be modeled separately to calculate heat/cooling load

3. Passive Townhouse only needs about 4kW PV array to become a net positive energy and carbon negative home! Cost for PH components: $18,000  PV after Rebate: $20,000

4. 10% additional cost for PH, approx. 10% for PV
4 European built Examples

- Townhouses
- Apartment Buildings
Nuremberg, Germany: Passive Townhouses 2007
Cologne, Germany: Passive Townhouses 2007
Nuremberg, Germany: Passive Apartments 2006
Community Center built to Passive House standards in Vorarlberg, Austria.
Retrofitted to Passive House standards: the Drexel & Weiss factory.
European Passive House Examples:

 Passive House Gym
 Heidelberg, Germany

 Passive House School
 Waldshut, Germany

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European Passive House Examples:

Passive House Office Building
Ulm, Germany

Single Family Passive House,
Austria
Energie Agentur Oberoesterreich,
75 m tall office tower,
Linz Austria
Summary

• Outlook
• Measured Energy Performance Comparison
• Certification
Passive House Requirements:

<table>
<thead>
<tr>
<th>Requirements: Units</th>
<th>SI Units</th>
<th>IP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Heating Energy Demand (per net floor area)</td>
<td>≤15 kWh/(m²a)</td>
<td>≤4750 Btu/ft²</td>
</tr>
<tr>
<td>Annual Cooling Energy Demand (per net floor area)</td>
<td>≤15 kWh/(m²a)</td>
<td>≤4750 Btu/ft²</td>
</tr>
<tr>
<td>Annual Total Primary Energy Demand</td>
<td>≤120 kWh/m²</td>
<td>≤11.1 kWh/ft²</td>
</tr>
<tr>
<td>Air Leakage @ 50 Pa</td>
<td>n₅₀≤0.6 ACH</td>
<td>n₅₀≤0.1 CFM</td>
</tr>
</tbody>
</table>
# Passive House recommendations

**Recommendations:**

<table>
<thead>
<tr>
<th></th>
<th><strong>SI Units</strong></th>
<th><strong>IP</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat Load:</strong></td>
<td>≤10 W/m²</td>
<td>≤ 1 W/ft²</td>
</tr>
<tr>
<td><strong>Cooling Load:</strong></td>
<td>≤ 8 W/m²</td>
<td>≤ 0.8 W/ft²</td>
</tr>
<tr>
<td><strong>Envelope Insulation:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA</td>
<td>U≤0.26 W/m²K</td>
<td>R≥22 hr-ft²- F/Btu</td>
</tr>
<tr>
<td>Europe</td>
<td>U≤0.15 W/m²K</td>
<td>R≥38 hr-ft²- F/Btu</td>
</tr>
<tr>
<td>IL</td>
<td>U≤0.1 W/m²K</td>
<td>R≥56 hr-ft²- F/Btu</td>
</tr>
<tr>
<td><strong>Thermal Bridge Free Construction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear Thermal Transmittance</td>
<td>Ψ≤0.01 W/mK</td>
<td>Ψ≤0.006 Btu/hr-ft- F</td>
</tr>
<tr>
<td><strong>High Performance Windows</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall Thermal Transmittance</td>
<td>U≤0.8 W/m²K</td>
<td>U≤0.14 Btu/hr-ft²- F</td>
</tr>
<tr>
<td>Solar Heat Gain Coefficient</td>
<td>g-value≥50%</td>
<td>SHGC≥50%</td>
</tr>
<tr>
<td><strong>Heat Recovery Ventilation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Efficiency</td>
<td>η≥75%</td>
<td>η≥75%</td>
</tr>
<tr>
<td>Electric Consumption of motor</td>
<td>≤0.4 Wh/m³</td>
<td>≤0.68 Wm/ft³</td>
</tr>
</tbody>
</table>
Outlook:

Passive House construction has grown exponentially in Germany and Austria and continues with that trend.

10,000 passive house units had been constructed by the end of 2007 and are inhabited.
Study done by the Florida Solar Energy Center in conjunction with the Lawrence Berkeley National Laboratory, Author: Danny Parker
Quality Approved Passive House

The planning of this building meets the criteria for Passive Houses set up by the Passive House Institute.

With appropriate execution it will conform to the following standards:

- The building features excellent heat insulation all around and first grade component joint details in regard to building physics. Estival sun protection has been considered. Heat requirement is limited to

  15 kWh per m² living area and year

- The building shell features excellent air tightness proven according to ISO 9972 which guarantees to be free of draught as well as little energy consumption. Air change rate of the building shell at 50 pascal pressure differential is limited to

  0,6 ach, in reference to the building’s volume

- The building features a controlled ventilation system with high class filters, highly efficient heat recovery and low electric power consumption. Thus, excellent air quality together with low energy consumption are achieved.

- The demand in primary energy for heating, warm water, ventilation and household electricity totals with standard use less than

  120 kWh per m² living area and year

This certificate is to be used together with the certification documents only. From these the precise data of the building can be obtained.

Passive Houses offer high comfort in summer as well as in winter conditions and can be heated with little effort, e.g. by heating of supply air. The building shell of a Passive House is evenly warm on the inside, inside surface temperatures are hardly different from room air temperatures. By means of the high grade air tightness drought appearance is impossible in normal use. The ventilation system steadily provides good air quality. Heating costs in a Passive House are very low. Due to little energy consumption Passive Houses offer a high rate security against future rise in energy prices and energy scarceness. Moreover the environment is ideally protected as energy resources are spent very economically and only small amounts of carbon dioxide (CO₂) and other concentrations are emitted.
YOU ARE INVITED TO THE

3rd ANNUAL NORTH AMERICAN PASSIVE HOUSE CONFERENCE

“WHOLE > SUM:PARTS”

November 7-9, 2008
Hosted at the Duluth Entertainment Convention Center, Duluth, Minnesota

www.passivehouse.us