Sustainable Building Design and Technology

John Carmody
Center for Sustainable Building Research
University of Minnesota
www.csbr.umn.edu
UNIVERSITY OF MINNESOTA

Center for Sustainable Building Research

Welcome to the Center for Sustainable Building Research (CSBR). There is a substantial and growing amount of building research activity in the following areas: sustainable design, energy-efficient buildings, windows & glazing research, improved building delivery process, building science & engineering, and human factors in transportation.

AREAS OF RESEARCH
- Sustainable Design
- Windows & Glazings
- Building Evaluation
- Affordable Housing
- Renewable Energy
- Human Factors
- Building Physics
- Building Foundations
CSBR Activities

Sustainable Design
- Buildings, Benchmarks & Beyond (B3) Project: The State of Minnesota Sustainable Building Guidelines (MSBG)
- Minnesota Sustainable Design Guide (MSDG)
- Minnesota Building Materials Database
- Greening CALA and the University

Windows and Glazing
- Efficient Windows Collaborative web site and selection tool
- “Window Systems for High Performance Buildings”
- Commercial Windows web site and selection tool
**CSBR Activities**

**Affordable Housing**
- HUD Communities Outreach Partnership Center
  (Includes Department of Architecture, Metropolitan Design Center, and Cold Climate Housing Program)
- Demonstration Homes in the Frogtown Neighborhood
- Green Affordable Housing Guide
- Green Communities Program

**Building Evaluation**
- Post Occupancy Evaluations of buildings for MNSCU, University of Minnesota, Departments of Natural Resources and Transportation
- Post Occupancy Evaluations of sustainable pilot projects for Hennepin, Ramsey, Dakota, and Carver Counties
- Post Occupancy Evaluation of Rapson Hall
- Evaluation of Green Community Pilot Projects
Solar/Hydrogen Fuel Cell Demonstration Project

Louise F. Goldberg and John Carmody
Center for Sustainable Building Research

• Three 24-panel, photovoltaic arrays on the roof of Rapson Hall.
• Two of the arrays, are connected directly to the power via grid-tie inverters.
• The third array is connected to a hydrogen generator based on a proton exchange membrane stack.
• The hydrogen produced is stored in an exterior 400 gallon tank that can be adapted to service an automotive fueling station.
• The hydrogen is routed to a proton exchange membrane fuel cell with a rated capacity of 1200 W. The fuel cell DC output is connected to the grid via a charge controller and grid-tie inverter operating in single-phase, 120 VAC mode.
Solar/Hydrogen Fuel Cell Demonstration Project

Sponsors
- Xcel Energy
- Minnesota Office of Environmental Assistance
- Initiative for Renewable Energy and the Environment (IREE)
Origins in the 1970s
One Definition of Sustainability

“Sustainable development involves... meeting the needs of the present without compromising the ability of future generations to meet their own needs.”

Brundtland Report, United Nations, 1987
Impact of Buildings on People and the Natural Environment

- Buildings use one-sixth to one-half of the world's wood, minerals, water, and energy. Buildings generate 40% of the waste going to landfills.
- Blame for much of the environmental damage occurring today, from destruction of forests and rivers to air and water pollution and climate destabilization, must be placed on modern buildings.
- Many buildings do harm on the inside as well making us both less healthy and less productive than we are capable of being: 30% of the commercial buildings constructed since the 1960’s are unhealthy.

From the U.S. Environmental Protection Agency (EPA), National Resource Defense Council (NRDC), and World Watch Institute
Environmental Impact of Commercial and Residential Buildings in the United States

- 65.2% of total U.S. electricity consumption\(^1\)
- > 36% of total U.S. primary energy use\(^2\)
- 30% of total U.S. greenhouse gas emissions\(^3\)
- 136 million tons of construction and demolition waste in the U.S. (approx. 2.8 lbs/person/day)\(^4\)
- 12% of potable water in the U.S.\(^5\)
- 40% (3 billion tons annually) of raw materials use globally\(^6\)
Benefits of Sustainable Design

- Reduced operating expenditures for energy, water and waste.
- Improved human health and productivity leading to reduced employee expenditures.
- Reduced municipal infrastructure costs.
- Conservation of natural resources and valued ecosystems.
- Reduced impact on global warming, as well as soil, air, and water degradation.
Sustainable Design Advances in the United States

• Several states and cities have adopted green building requirements
• New York has green building tax credits and requires renewable energy systems on state buildings
• Many federal agencies have green building requirements including architect selection criteria based on sustainable design experience
• The US Green Building Council has grown and LEED has continued to evolve into a consensus national set of guidelines
Sustainable Design Guidelines and Tools

US Green Building Council
www.usgbc.org

Minnesota Sustainable Design Guide
www.msdg.umn.edu

Minnesota Sustainable Building Guidelines
www.csbr.umn.edu/B3
Applicable Minnesota Legislation
Sustainable Building Guidelines

The guidelines must

– Exceed existing energy code by at least 30 percent
– Achieve lowest possible lifetime costs for new buildings
– Encourage continual energy conservation improvements in new buildings

MSBG Team:
LHB Inc., CSBR, The Weidt Group
Applicable Minnesota Legislation
Sustainable Building Guidelines

The guidelines must

• Define air quality
• Create and maintain a healthy environment
• Facilitate productivity improvements
• Specify ways to reduce material costs
• Consider the long-term operating costs of the building including the use of renewable and distributed energy sources
Organization of Minnesota Sustainable Building Guidelines

The guidelines are organized into the following categories

– Performance Management
– Site and Water
– Energy and Atmosphere
– Indoor Environmental Quality
– Materials and Waste

MSBG Team:
LHB Inc., CSBR,
The Weidt Group
Minnesota Sustainable Building Guidelines

Performance Management Strategies

P.1 Guideline Management
P.2 Planning for Conservation (3)
P.3 Integrated Design and Construction Process
P.4 Design and Construction Commissioning (2)
P.5 Ongoing Operations Commissioning
P.6 Lowest Life Cycle Cost
P.7 Process Documentation

MSBG Team:
LHB Inc., CSBR,
The Weidt Group
A Sustainable Process of Building Delivery

Project A

Project B

CSBR Center for Sustainable Building Research
Site and Water Strategies

S.1 Avoid Critical Sites (1)
S.2 Erosion and Sedimentation Control (P)
S.3 Stormwater Management (2)
S.4 Reduce Site Disturbance (2)
S.5 Restorative Design
S.6 Reduce Site Water Use for Plants (1-2)
S.7 Reduce Site Lighting Pollution (1)
S.8 Appropriate Location and Density (0-1)
S.9 Brownfield Redevelopment (0-1)
S.10 Efficient Transportation Alternatives (0-4)
S.11 Use Gray Water to Reduce Wastewater
S.12 Use Biological Waste Treatment System (0-1)
S.13 Reduce Building Water Use (2)
S.14 Outcome Documentation
E.1 Reduce Energy Use by At Least 30% (4-10)
E.2 Efficient Equipment and Appliances
E.3 Evaluate Renewable and Distributed Energy Generation (0-4)
E.4 Atmospheric Protection (1)
E.5 Outcome Documentation
Minnesota Sustainable
Building Guidelines

Indoor Environmental Quality Strategies

I.1 Restrict Environmental Tobacco Smoke (P)
I.2 IAQ and Ventilation Framework
I.3 Specify Low-Emitting Materials (4)
I.4 Ventilation Based on Anticipated Pollutants (1)
I.5 Ventilation Based on CO2 Limits
I.6 Moisture Control (1)
I.7 Thermal Comfort (1)
I.8 Daylight (1)
I.9 Quality Lighting
I.10 View Space and Window Access (1)
I.11 Whole Body Vibration
I.12 Effective Acoustics
I.13 Personal Control of IEQ Conditions (0-2)
I.14 Encourage Healthful Physical Activity
I.15 Outcome Documentation

MSBG Team:
LHB Inc., CSBR,
The Weidt Group

Center for Sustainable Building Research
M.1 Evaluation of Design for Minimum Resource Use (0-5)
M.2 Evaluation of Material Properties for Improved Performance (0-6)
M.3 Waste Reduction and Management (1-2)
M.4 Outcome Documentation

MSBG Team:
LHB Inc., CSBR,
The Weidt Group
### LEED-NC Version 2.2 Registered Project Checklist

<table>
<thead>
<tr>
<th>Prereq 1</th>
<th>Storage &amp; Collection of Recyclables</th>
<th>Required</th>
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<td>Credit 1.1</td>
<td>Building Reuse, Maintain 75% of Existing Walls, Floors &amp; Roof</td>
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<td>Credit 1.2</td>
<td>Building Reuse, Maintain 100% of Existing Walls, Floors &amp; Roof</td>
<td>1</td>
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<tr>
<td>Credit 1.3</td>
<td>Building Reuse, Maintain 50% of Interior Non-Structural Elements</td>
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</tr>
<tr>
<td>Credit 2.1</td>
<td>Construction Waste Management, Divert 50% from Disposal</td>
<td>1</td>
</tr>
<tr>
<td>Credit 2.2</td>
<td>Construction Waste Management, Divert 75% from Disposal</td>
<td>1</td>
</tr>
<tr>
<td>Credit 3.1</td>
<td>Materials Reuse, 5%</td>
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<tr>
<td>Credit 3.2</td>
<td>Materials Reuse, 10%</td>
<td>1</td>
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<tr>
<td>Credit 4.1</td>
<td>Recycled Content, 10% (post-consumer + ½ pre-consumer)</td>
<td>1</td>
</tr>
<tr>
<td>Credit 4.2</td>
<td>Recycled Content, 20% (post-consumer + ½ pre-consumer)</td>
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<tr>
<td>Credit 5.1</td>
<td>Regional Materials, 10% Extracted, Processed &amp; Manufactured Regionally</td>
<td>1</td>
</tr>
<tr>
<td>Credit 5.2</td>
<td>Regional Materials, 20% Extracted, Processed &amp; Manufactured Regionally</td>
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</tr>
<tr>
<td>Credit 6</td>
<td>Rapidly Renewable Materials</td>
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<tr>
<td>Credit 7</td>
<td>Certified Wood</td>
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</table>
Building Material Use

Reduction & Reuse

Material Volume Required

Volume / SF of Building

Life Cycle Assessment from Building Material Use

GWP
Air Pollution
Water Pollution
Primary Energy
Solid Waste
Resource Use

Building Material Properties

Salvaged
PC Recycled Content
PI Recycled Content
Local
Rapidly Renewable
FSC Wood

MSBG Team:
LHB Inc., CSBR,
The Weidt Group

Center for Sustainable Building Research
Case Study: Iowa Association of Municipal Utilities

- Restore agricultural field to natural prairie
- Reduce storm-water runoff from site to pre-existing conditions - composting
- Process wastes utilizing sanitary wetland technology
Case Study: Iowa Association of Municipal Utilities
Case Study: Iowa Association of Municipal Utilities
Energy Simulations utilizing DOE2.1E were performed to investigate various strategies and estimate the final performance. Long term building environmental and energy monitoring will be performed to further evaluate and improve the building’s operation.

Case Study: Iowa Association of Municipal Utilities Energy Performance

Energy Simulations utilizing DOE2.1E were performed to investigate various strategies and estimate the final performance. Long term building environmental and energy monitoring will be performed to further evaluate and improve the building’s operation.
Case Study: Cambria Office Building—Pennsylvania, USA
Case Study: Cambria Office Building—Pennsylvania, USA
Case Study: Cambria Office Building—Pennsylvania, USA
Challenges

• Meeting Multiple Criteria
  – Affordable to own and operate, healthy, durable, energy efficient, low environmental impact
  – Livable communities, aesthetics, economic stability, transportation, quality of life . . .

• Measuring Real Performance Outcomes
• Seeing Whole System Interconnections
• Finding Reliable Information and Developing a Knowledge Base
The Affordable Housing Initiative
A HUD Community Outreach Partnership Center

The University of Minnesota,
  • Department of Architecture
  • Center for Sustainable Building Research
  • Design Center for the American Urban Landscape
  • Cold Climate Housing Center

The Greater Frogtown, CDC

The Wilder Foundation
Goals of Community Outreach Partnership Center

Affordability Goals:
• Construction cost of $85,000 to $100,000 (40-60% of the area median income)

Sustainability Goals:
• minimize resource use and lower impacts on site, energy, water, and materials
• meet or exceed Energy Star performance
• meet American Lung association Health House performance

Social Cultural Goals:
• Respond to diverse social, cultural, and user needs.
• Foster neighborhood involvement an acceptance through community participation
• Integrate Universal Design guidelines to provide accessibility

Educational Goals:
• Educate architecture students
• Educate design professionals and builders.
New Technology:
Promoting Sustainable, Healthy, Durable & Energy Efficient Housing

MINNESOTA GREEN AFFORDABLE HOUSING GUIDE

The MINNESOTA GREEN AFFORDABLE HOUSING GUIDE is a web-based resource to assist designers, contractors, and housing agencies integrate sustainability, health, durability, and energy efficiency into cold climate housing. It includes design strategies, decision making tools, comparative analyses, best practices, and resources.

The Guide »
Overview »
For Policy- & Decision-makers »
For Developers »
For Builders & Architects »
For Homeowners »

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The guide is organized into five scales: Neighborhood, Yard, House, Assemblies, and Components. Each scale has Design Strategies, Analysis & Recommendations, and Resources. The Design Strategies are a list of actions to be taken and are organized by environmental topic: site, water, energy, health, materials and waste. The Decision Tools are a series of comparative analyses based on cost, energy and environmental performance. Resources include web sites, publications, a glossary, and case studies.
### Cladding Alternatives

<table>
<thead>
<tr>
<th>alternatives</th>
<th>cost/sf (materials &amp; labor)</th>
<th>expected product life (years)</th>
<th>life cycle thinking</th>
<th>practice</th>
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<tbody>
<tr>
<td>stucco</td>
<td>$3.41</td>
<td>50+ (depending on maintenance)</td>
<td>good</td>
<td>standard</td>
</tr>
<tr>
<td>brick</td>
<td>$8.23</td>
<td>100+</td>
<td>good</td>
<td>standard</td>
</tr>
<tr>
<td>wood</td>
<td>$3.58</td>
<td>25-75 (depending on maintenance)</td>
<td>good</td>
<td>standard</td>
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<tr>
<td>fiber-cement</td>
<td>$2.15</td>
<td>50</td>
<td>better</td>
<td>May require some training (cutting &amp; sealant joints)</td>
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<td>aluminum</td>
<td>$2.60</td>
<td>20-50</td>
<td>good</td>
<td>standard</td>
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<td>vinyl</td>
<td>$1.71</td>
<td>25</td>
<td>typical</td>
<td>standard</td>
</tr>
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<td>hardboard</td>
<td>$1.91</td>
<td>10-25</td>
<td>typical</td>
<td>standard</td>
</tr>
<tr>
<td>wood-resin/plastic composite</td>
<td>n/a</td>
<td>20-30</td>
<td>good</td>
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The cost and energy model is a Minnesota code base zone 2, 1-story 864 sf house, with wood siding, window area as noted, double low-E argon glazing, equally distributed on all for orientations, 80 AFUE furnace, and 10 EER air conditioning. Cost information is based on Means Cost Works 2004. Energy modeling was conducted on Visual DOE 3.1.
### TABLE 4: LIFE CYCLE COST CALCULATION
#### ENERGY STAR APPLIANCE COMPARISON

Center for Sustainable Building Research  
University of Minnesota

<table>
<thead>
<tr>
<th>APPLIANCES</th>
<th>ENERGY Electricity (kWh)</th>
<th>Nat. Gas (therms)</th>
<th>TOTAL ENERGY COST</th>
<th>TOTAL ENERGY SAVINGS</th>
<th>ADDITIONAL COST (dollars)</th>
<th>SIMPLE PAYBACK (years)</th>
<th>LCC SAVINGS (NPV dollars)</th>
<th>BREAKEVEN AMOUNT (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>3200</td>
<td>30</td>
<td>$ 295</td>
<td>$</td>
<td>$</td>
<td>15 years</td>
<td>$ 672</td>
<td>$ 1,047</td>
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<tr>
<td>Energy Star</td>
<td>2115</td>
<td>19</td>
<td>$ 194</td>
<td>$ 101</td>
<td>$ 375</td>
<td>3.7</td>
<td>$</td>
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</table>

<table>
<thead>
<tr>
<th>APPLIANCES</th>
<th>SAVINGS PER MONTH UTILITIES</th>
<th>COST PER MONTH (7% mortgage)</th>
<th>NET GAIN</th>
</tr>
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<tr>
<td>Standard</td>
<td>$ 8.41</td>
<td>$ 2.93</td>
<td>$ 5.48</td>
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<tr>
<td>Energy Star</td>
<td>$</td>
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### ASSUMPTIONS

- 15 years
- 0.05 discount rate
- $ 1.18 therm for gas
- $ 0.08 kWh for elec.
# Table 1: Life Cycle Cost Calculation Comparison of Four Houses

Center for Sustainable Building Research  
University of Minnesota

## Scenario A
Current energy and solar panel costs

<table>
<thead>
<tr>
<th>SCENARIO</th>
<th>ENERGY USE (kWh)</th>
<th>Natural Gas (therms)</th>
<th>ELECTRICITY COST</th>
<th>ELECTRICITY SAVINGS</th>
<th>ADDED COST</th>
<th>SIMPLE PAYBACK (years)</th>
<th>LCC SAVINGS (NPV dollars)</th>
<th>BREAKEVEN AMOUNT (dollars)</th>
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<tbody>
<tr>
<td>1. AVERAGE HOUSE</td>
<td>9000</td>
<td>800</td>
<td>$1,673</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2. EFFICIENT HOUSE</td>
<td>6000</td>
<td>400</td>
<td>$958</td>
<td>$715</td>
<td>$5,000</td>
<td>7.0</td>
<td>$5,991</td>
<td>$10,991</td>
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<tr>
<td>3. VERY EFFICIENT</td>
<td>3000</td>
<td>200</td>
<td>$479</td>
<td>$1,194</td>
<td>$20,000</td>
<td>16.8</td>
<td>$1,645</td>
<td>$18,355</td>
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<tr>
<td>4. VERY EFF + SOLAR</td>
<td>0</td>
<td>200</td>
<td>$236</td>
<td>$1,437</td>
<td>$41,287</td>
<td>28.7</td>
<td>$19,197</td>
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<tr>
<th>SCENARIO</th>
<th>SAVINGS PER MONTH UTILITIES</th>
<th>COST PER MONTH (7% mortgage)</th>
<th>NET GAIN</th>
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<tr>
<td>1. AVERAGE HOUSE</td>
<td></td>
<td></td>
<td>$21</td>
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<tr>
<td>2. EFFICIENT HOUSE</td>
<td>$60</td>
<td>$39</td>
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<tr>
<td>3. VERY EFFICIENT</td>
<td>$100</td>
<td>$156</td>
<td>$(57)</td>
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<tr>
<td>4. VERY EFF + SOLAR</td>
<td>$120</td>
<td>$322</td>
<td>$(202)</td>
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</table>

**Assumptions**
- 30 years  
- 5% discount rate  
- $1.18/therm  
- $0.08/kWh

**Cost of Photovoltaic Panels**
- Panel cost: $1,632  
- Annual output: 230 kWh  
- Annual use: 3000 kWh  
- Panels required: 13

- System cost: $21,287
**TABLE 2: LIFE CYCLE COST CALCULATION COMPARISON OF FOUR HOUSES**

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**SCENARIO B**
Higher energy costs and lower solar panel costs

**ASSUMPTIONS**
- 30 years
- 0.05 discount rate
- Panel cost $816
- Annual output 230 kWh
- Annual use 3000 kWh
- Panels require 13

<table>
<thead>
<tr>
<th></th>
<th>ENERGY USE</th>
<th>ENERGY COST</th>
<th>ENERGY SAVINGS</th>
<th>ADDITIONAL COST</th>
<th>SIMPLE PAYBACK</th>
<th>LCC SAVINGS (NPV dollars)</th>
<th>BREAKEVEN AMOUNT (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ENERGY USE</strong></td>
<td>Electricity (kWh)</td>
<td>Natural Gas (therms)</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
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<tr>
<td>1. AVERAGE HOUSE</td>
<td>9000</td>
<td>800</td>
<td>2,680</td>
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<td>2. EFFICIENT HOUSE</td>
<td>6000</td>
<td>400</td>
<td>1,520</td>
<td>1,160</td>
<td>5,000</td>
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<tr>
<td>3. VERY EFFICIENT</td>
<td>3000</td>
<td>200</td>
<td>760</td>
<td>1,920</td>
<td>20,000</td>
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<td>4. VERY EFF + SOLAR</td>
<td>0</td>
<td>200</td>
<td>400</td>
<td>2,280</td>
<td>30,643</td>
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<thead>
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<th>SAVINGS PER MONTH UTILITIES</th>
<th>COST PER MONTH (7% mortgage)</th>
<th>NET GAIN</th>
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<tbody>
<tr>
<td>1. AVERAGE HOUSE</td>
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<td></td>
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</tr>
<tr>
<td>2. EFFICIENT HOUSE</td>
<td>$97</td>
<td>$39</td>
<td>$58</td>
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<td>3. VERY EFFICIENT</td>
<td>$160</td>
<td>$156</td>
<td>$4</td>
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<tr>
<td>4. VERY EFF + SOLAR</td>
<td>$190</td>
<td>$239</td>
<td>$(49)</td>
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Panel cost $816
Annual output 230 kWh
Annual use 3000 kWh
Panels require 13
System cost $10,643

**COST OF PHOTOVOLTAIC PANELS**

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### TABLE 3: AIR EMISSIONS
**COMPARISON OF FOUR HOUSES**

Center for Sustainable Building Research  
University of Minnesota

#### AIR EMISSIONS FROM ELECTRICITY GENERATION

<table>
<thead>
<tr>
<th></th>
<th>ELECTRICITY (kWh)</th>
<th>CO₂ lbs/yr</th>
<th>SO₂ lbs/yr</th>
<th>NOₓ lbs/yr</th>
<th>particulates lbs/yr</th>
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<tr>
<td>1. AVERAGE HOUSE</td>
<td>9000</td>
<td>12902.40</td>
<td>32.26</td>
<td>38.30</td>
<td>36.29</td>
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<td>2. EFFICIENT HOUSE</td>
<td>6000</td>
<td>8601.60</td>
<td>21.50</td>
<td>25.54</td>
<td>24.19</td>
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<td>3. VERY EFFICIENT</td>
<td>3000</td>
<td>4300.80</td>
<td>10.75</td>
<td>12.77</td>
<td>12.10</td>
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<td>4. VERY EFF + SOLAR</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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#### AIR EMISSIONS FROM NATURAL GAS COMBUSTION

<table>
<thead>
<tr>
<th></th>
<th>NATURAL GAS (therms)</th>
<th>CO₂ lbs/yr</th>
<th>SO₂ lbs/yr</th>
<th>NOₓ lbs/yr</th>
<th>N₂O lbs/yr</th>
<th>VOC lbs/yr</th>
<th>CO lbs/yr</th>
<th>PM10 lbs/yr</th>
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<tr>
<td>1. AVERAGE HOUSE</td>
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<td>9366.40</td>
<td>0.05</td>
<td>12.00</td>
<td>0.18</td>
<td>0.43</td>
<td>1.92</td>
<td>0.15</td>
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<td>2. EFFICIENT HOUSE</td>
<td>400</td>
<td>4683.20</td>
<td>1.43</td>
<td>1.70</td>
<td>0.09</td>
<td>0.22</td>
<td>0.96</td>
<td>0.07</td>
</tr>
<tr>
<td>3. VERY EFFICIENT</td>
<td>200</td>
<td>2341.60</td>
<td>0.72</td>
<td>0.85</td>
<td>0.04</td>
<td>0.11</td>
<td>0.48</td>
<td>0.04</td>
</tr>
<tr>
<td>4. VERY EFF + SOLAR</td>
<td>200</td>
<td>2341.60</td>
<td>0.72</td>
<td>0.85</td>
<td>0.04</td>
<td>0.11</td>
<td>0.48</td>
<td>0.04</td>
</tr>
</tbody>
</table>

#### Pollution per kWh from XCEL ENERGY

<table>
<thead>
<tr>
<th></th>
<th>CO₂</th>
<th>SO₂</th>
<th>NOₓ</th>
<th>NO₂</th>
<th>N₂O</th>
<th>VOC</th>
<th>CO</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>0.00064 tons</td>
<td>0.000016 tons</td>
<td>0.000019 tons</td>
<td>0.00022 tons</td>
<td>0.000539 lbs</td>
<td>0.0024 lbs</td>
<td>0.000186 lbs</td>
<td>0.00006 lbs</td>
</tr>
</tbody>
</table>

#### Pollution per therm of Natural Gas

<table>
<thead>
<tr>
<th></th>
<th>CO₂</th>
<th>SO₂</th>
<th>NOₓ</th>
<th>N₂O</th>
<th>VOC</th>
<th>CO</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>11.708 lbs</td>
<td>0.0006 lbs</td>
<td>0.015 lbs</td>
<td>0.00022 lbs</td>
<td>0.000539 lbs</td>
<td>0.0024 lbs</td>
<td>0.000186 lbs</td>
</tr>
</tbody>
</table>
Resources

Center for Sustainable Building Research
— www.csbr.umn.edu

US Green Building Council
— www.usgbc.org

GreenSpec and Building Green Suite
— www.buildinggreen.com

Minnesota Sustainable Building Guidelines
— www.csbr.umn.edu/B3

Minnesota Building Materials Database
— www.buildingmaterials.umn.edu

Minnesota Green Affordable Housing Guide
— www.greenhousing.umn.edu