FORENSIC REPORT

AFFORDABILITY. CONSTRUCTABILITY. SUSTAINABILITY.

UC House
Habitat for Humanity
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**Closing Conversation**

**Image Sources**
Each topic will be examined in terms of its design intention and effective outcome. The principles of affordability, constructability, and sustainability serve as measurements of success for each topic. The goal is to learn from the UC Habitat House, and provide a resource for the future of Habitat green building. Alternative strategies and precedents will also be discussed.
University of Cincinnati School of Architecture and Interior Design students competed to design a new Habitat for Humanity model that promotes innovative design and strategies for accessibility and sustainability in affordable single family housing. The design proposals focus on the following criteria:

- Livability
- Accessibility
- Sustainability
- Affordability
- Feasability
- Sociability
- Beauty

The site is located at 3253 Wolseley Lane in Avondale, situated between two other Habitat houses planned for people with disabilities. The new model was intended to set a precedent for other Habitat affiliates around the nation.

The winning design boards are shown to the right, and incorporate the following:

- Concrete ramp
- Modified cabinets
- Larger bathroom
- Vaulted ceilings
- Additional shade
- Additional insulation
On the north bank of the Ohio River, Cincinnati sits in a steep-sided valley. The region’s climate produces a wide range of temperatures from winter to summer. Winters are moderately cold with frequent periods of extensive cloudiness, and summers are warm and humid. The following climatic data and analysis is from: Climate Consultant software http://www2.aud.ucla.edu/energy-design-tools/ Energy Plus weather data http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm

USDOE Climate Zone: 4
January Average Temperature: 31°F
July Average Temperature: 77°F
Annual Average Temperature: 54°F
Heating Degree Days: 5248
Cooling Degree Days: 996

Latitude: 39°
June 21 Sun Angle: 74.5°
December 21 Sun Angle: 27.5°
Average Annual Precipitation: 40.14 in. (23.9 in. of snow)
The psychrometric chart below illustrates a calculated set of design guidelines specific to Cincinnati's climate. The top 5 recommended design priorities are highlighted.

As shown above, Cincinnati's prevailing wind direction is calculated by averaging the 12 monthly wind directions. An 132 average wind direction means that wind is primarily coming from the southeast in Cincinnati (at an average wind speed of 5.6 mph). Prevailing wind direction is an important consideration for effective NATURAL VENTILATION.
The building envelope separates the interior and exterior environment - serving as a barrier to outdoor weather conditions including water, temperature, and wind. The components of the building envelope - including insulation, siding, and roofing - and their fabrications and connections determine the performance of the barrier.

The wide range of temperatures in Cincinnati’s climate from winter to summer make the effectiveness of the envelope essential for interior comfort. The weather barrier will act to keep summers cool and winters warm, and also provide moisture control particularly from snow in cold months.

INSULATION as Thermal Barrier

INSULATION is a material that fills the gaps between structural members to reduce the rate of heat transfer (and acoustic transmittance) between the exterior and interior environment. The most common insulation type, used traditionally in Habitat homes, is batt fiberglass insulation, made of long, resilient glass fibers bonded with an acrylic. Batts come as pre-cut panels in a variety of lengths and widths to fit within standard wall framing.

SIDING as Wind and Water Barrier

SIDING is the outermost layer of the exterior wall - in direct contact with wind and water in the exterior environment. Vinyl siding is typically used on Habitat homes, and its material properties act to repel water away from the building. Vinyl siding is layered in an overlapping pattern to block water penetration into the building envelope. Vinyl is nailed to each stud to prevent wind from wafting behind the siding. A layer of Tyvek wrap is laid underneath siding to function as a backup, or secondary water barrier.

ROOFING as Temperature, Wind, and Water Barrier

ROOF surface material is in direct contact with exterior weather conditions including solar heat, wind, and water (rain, ice, and snow). Habitat typically uses asphalt shingles in layered rows that effectively shed water off the roof. If not installed carefully, however, shingles may flap in the wind and risk water penetration into the structure below. The roof is directly exposed to the sun’s heat, and will absorb or reflect that heat, radiating its temperature into the houses’ interior.
Insulation improves the energy efficiency of a home by providing substantial resistance to heat flow. In effect, it minimizes the need for heating and cooling by keeping heat in during the winter and maintaining cooler interior temperatures during summer. Insulation also acts as a sound barrier, increasing the privacy and comfort of a home.

To improve the insulation of a traditional Habitat house, expanding spray foam insulation was considered, but not used due to its higher cost. As an alternative, 2x6 studs were used (instead of the usual 2x4 studs) to increase the width of the wall to 5 ½", and the spacing of studs to 24” on center. The 2x6 studs offered more space for batt fiberglass insulation (R-13 minimum) within the wall. The increased stud spacing was also intended to save lumber material and cost.

In both summer and winter, heat transfer through the roof dominates at 25-35% - so roof insulation is most important. The exterior roof surface is most affected by the sun's heat, causing a great temperature difference between interior and exterior that encourages heat transfer. In the UC house, the roof has more significant insulation than the walls: R-38, 12” minimum. However, window heat transfer is equally high in summer, whereas walls become more important in winter.
**Heating Degree Days**

Heating Degree Days are a calculated per city as the number of days in which the outside temperature is cold enough to require interior heating. Cincinnati’s Heating Degree Days are calculated from the following source: [http://www.climate-zone.com/climate/united-states/ohio/greater-cincinnati-airport/](http://www.climate-zone.com/climate/united-states/ohio/greater-cincinnati-airport/)

\[ \text{HDD} = 5248 \]

The scientists at the University of Illinois determined that if you live in an area that experiences 5,750 or more degree days per year, then it begins to make economic sense to switch to 2x6 exterior walls.


**R-value**

Insulation materials are rated according to their **resistance to heat flow**. Resistance to heat flow is measured by the insulator’s R-value. The higher the R-value, the greater the insulating effect.

\[ \text{R-value} = \frac{m^2}{K/W} \]

- \(m^2\) refers to 1 meter squared of material’s thickness
- \(K\) refers to 1 degree of temperature (Kelvin or Celsius) difference across the material
- \(W\) refers to amount of heat flow across the material in watts

**U-value**

Insulation may also be measured in terms of U-value, the **transfer of heat though a material**. Since U-value is the transfer of heat through a material and R-value is the resistance of heat through a material, U-value is the reciprocal of R-value: \(U = \frac{1}{R}\).
INSULATION Analyzed

Objective Measures:
- Heating Degree Days
- R-value of insulation
- insulation material thickness
- amount of material: lumber, insulation

Subjective Measures:
- Difficulty of installation
- Cost/benefit of heating/cooling energy saved

Measures were evaluated through conversations with the Habitat construction manager, site supervisor, and project architect. The below internet sources are used as references, and are actively linked to the report:

Insulation Benefits:

Insulation Thickness:

Insulation Types:
http://www.sustainablebuild.co.uk/InsulationMaterials.html

Spray-Foam Insulation
http://www.envirofoaminsulation.com/why.html

CONCLUSION:

Overall, the thermal performance of 5 1/2” wall insulation does not justify its cost implications and construction complications. However, an increase to R-18 in the walls with 2x4 studs would meet the Cincinnati’s climate zone recommendations. An increase in R-value at the attic and cathedral ceiling should be seriously considered since most of the heat transfer (25-35%) occurs at the ceiling in both summer and winter. R-49 in the attic and R-38 at the cathedral ceiling are recommended. The U-value of windows will be especially important during summer months when 25-35% heat transfer through windows is equivalent to ceiling heat transfer.
COMPARATIVE ANALYSIS: 5 1/2” vs. 3 5/8” Batt Fiberglass Insulation

### AFFORDABILITY

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>→ 24” oc spacing: less studs purchased</td>
<td>→ 2x6 studs require wider top/bottom plates: additional expense</td>
</tr>
<tr>
<td>→ reduction in heat flow: save heating/cooling energy costs</td>
<td>→ standard doors/windows don’t fit 2x6 stud width: extra wood expense, need block or drywall piece to fit gap</td>
</tr>
<tr>
<td></td>
<td>→ 5 1/2” insulation: more expensive</td>
</tr>
</tbody>
</table>

### CONSTRUCTABILITY

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>→ 24” oc spacing: less studs to assemble</td>
<td>→ heavier studs for volunteers to handle</td>
</tr>
<tr>
<td></td>
<td>→ construction complications @ doors and windows</td>
</tr>
<tr>
<td></td>
<td>→ 5 1/2” insulation: more difficult to install than 3 5/8” insulation</td>
</tr>
</tbody>
</table>

### SUSTAINABILITY

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>→ 24” oc spacing: uses less lumber</td>
<td>→ uses more insulation material: contains wide range of chemical fire retardants, adhesives, and other additives; high embodied energy during manufacture</td>
</tr>
<tr>
<td>→ heating/cooling energy saved: reduces greenhouse gas emissions and non-renewable resources</td>
<td>→ working with fiberglass insulation may irritate upper respiratory and skin</td>
</tr>
</tbody>
</table>

Data from Map/Graph (*Image [11], page 11*) and UC House Construction Documents:

<table>
<thead>
<tr>
<th>Climate Zone Recommended R-values</th>
<th>UC House R-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attic</td>
<td>49</td>
</tr>
<tr>
<td>Cathedral Ceiling</td>
<td>38</td>
</tr>
<tr>
<td>Walls</td>
<td>18</td>
</tr>
<tr>
<td>Floors</td>
<td>25</td>
</tr>
<tr>
<td>Crawl Space</td>
<td>19</td>
</tr>
<tr>
<td>Slab Edge</td>
<td>8</td>
</tr>
</tbody>
</table>
DISCUSSION:
Alternative Strategies

Habitat could consider “panelization” of walls off-site for a more efficient process. The walls can be cut and laid out off site, and nailed together and erected by volunteers on-site. This will reduce scrap and encourage recycling from one house to the next. For instance, the scrap from a window cut out on one house can be used as the header on the next house. A staging area would be necessary for this process. Unbuilt Habitat-owned lots could be used as a staging area for prefabrication.

ALTERNATIVE INSULATION MATERIALS

Expanding Spray-Foam Insulation

**PROS**
At a higher cost this water-blown insulation can be sprayed in between standard 2x4’s to cut down energy costs. The liquid expands and fills the space to create a continuous air-tight seal regardless of complex framing and penetrations. In contrast, batt insulation is dependent on a detailed install that takes more time.

The closed cell structure of spray-foam stops convection currents which eliminates condensation, moisture, and mold. The rigid insulation structure also adds structural strength, significantly increasing shear strength. Spray foam acts as a more effective sound barrier than batt.

**CONS**
Batt insulation offers a known, consistent R-value, whereas blown insulation thickness can vary with non-uniform R-values. Spray-foam insulation typically requires a professional installation because specialized machinery is used - adding cost to the build.

2 lb. Closed Cell Spray Foam has the highest R-Value as compared to all other types of available insulation products.
Methods Used

2x6 Stud Walls @ 24” oc

Volunteer Install:
Batt Fiberglass Insulation

Alternative Methods

Professional Install:
Spray-Foam Insulation
Vinyl siding acts as the **water-repellent** panel sheathing at the outermost layer of the building envelope. The vinyl panels are layered horizontally and **overlapped 1” at each joint** to increase the effectiveness of the water barrier. Vinyl is a **durable** material that does not rust or corrode with exposure to water, and is **easy to install**.

As an alternative, **cement-fiberglass** is considered a more attractive and sustainable material. However, the **complications of construction** and added **cost** of the material discouraged its use. Therefore, a compromise was reached to break up the monotony of vinyl with accent strips. The accent strips are intended to differentiate and define the facade’s appearance.

### ENVIRONMENTAL CONCEPT:

**Siding**

**Water Shedding**

Vinyl siding repels or sheds water and has weep holes to allow water runoff, preventing moisture from entering the exterior wall structure. A **secondary Tyvek water barrier** acts as backup to keep water out of the wall.

If **moisture** seeps past these barriers to the insulation and wood studs, mold and deterioration will occur and compromise **structural integrity**.
Amount of Water Repelled
Both vinyl and fiber-cement material have remarkable water-repellent properties. Their performance is largely dependent on correct installation, particularly at points of transition. Vinyl siding involves the use of many transition pieces including: starter strips, J- and Z-flashing. Fiber-cement board involves expensive Axec trim. The parts are made to fit into one another, but more transitions add construction complications and create more possibility for gaps that let water in.

Expected Product Life Span
The product life of siding is dependent on its durability to the weather and resistance to bugs, rot, and fire.

Cement-fiber board is expected to last twice as long as vinyl.
ANALYSIS:
Objective vs. Subjective

SIDING Analyzed

Objective Measures:
- amount of water repelled
- expected product life
- price per square foot of material
- price of installation

Subjective Measures:
- difficulty of installation
- aesthetics of siding material
- cost/benefit of appearance and product life span

Measures were evaluated through conversations with the Habitat construction manager, site supervisor, and project architect. The below internet sources are used as references, and are actively linked to the report:

Siding Types:
http://www.greenhousing.umn.edu/comp_cladding.html

Vinyl Installation:
http://www.doityourself.com/stry/h2installvinylsiding

Fiber-Cement Board Installation:

Siding Costs:
http://www.tammlumber.com/cgi-bin/cart/items.pl?category=Hardboard_Products

CONCLUSION:

Overall, using vinyl accent strips for aesthetic value was a good compromise to using fiber-cement board. However, the price of vinyl transition parts adds up so the final price of vinyl material should be reassessed with the price of fiber-cement board. Perhaps, a white vinyl strip could achieve the same effect, and require no constructability or affordability compromises.

The current construction methods of cutting and placing fiber-cement panels seem unrealistic for volunteer labor. To make the construction process more volunteer-friendly, site supervisors could pre-mark nail spacing and make simple spacer strips to be used as placement guides.
**COMPARATIVE ANALYSIS: Vinyl vs. Fiber-Cement Board**

### AFFORDABILITY

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VINYL:</strong></td>
<td></td>
</tr>
</tbody>
</table>
| → affordable material, easy maintenance | → trims are more expensive: starting at about $45 for 25’ (45/52” x 9/16”)
| → durable: resists scrapes, rips, etc. | |
| → many available manufacturers | |
| **FIBER-CEMENT BOARD:** | | 
| → trims are less expensive, starting at about $25 for 18’ (3/4” x 3 1/2”)| → expensive: costs about $2-3/sf vs. $3-4/sf vinyl siding
| → lasts 50 years; twice as long as vinyl | → heavy: more cost spent on transport
| | → painting adds cost and maintenance |

### CONSTRUCTABILITY

| | |
| **VINYL:** | | 
| → siding has top flange with spaced nailing slots and J-shaped interlocking bottom flange for easy install | → vinyl expands/contracts so must leave 1/16” between nail head and panel
| | → cannot nail directly through vinyl; nail through provided slots |
| **FIBER-CEMENT BOARD:** | | 
| → can nail directly through panels | → cut panels are fragile & produce dust
| | → slower cutting process that requires specialty circular saw
| | → slower install with non-interlocking parts; need spacer stick for alignment
| | → must manually space nails at 16” oc |

### SUSTAINABILITY

| | |
| **VINYL:** | | 
| → recycles virtually all waste back into process; 99% of manufactured vinyl ends up in finished product | → releases carcinogen dioxin during manufacturing process and during fire
| | → releases acid smoke during fire
| | → susceptible to bugs and rot |
| **FIBER-CEMENT BOARD:** | | 
| → recyclable and more durable than vinyl | → dust contains silica that can cause lung damage
| → lasts twice as long because resistant to bugs, rot, and fire | → heavy: more energy used in transport |
DISCUSSION:
Alternative Strategies

**ALTERNATIVE SIDING MATERIALS**

*Wood Siding* is typically made of Western Red Cedar, Redwood, Cypress, Northern White Cedar, and Eastern White Pine species. Possible siding types include bevel lap siding, shiplap, board-and-batten, and shingles.

Wood is a **renewable resource** and supports diverse ecological habitats. The manufacturing process is **energy-efficient** with little waste produced. The sustainability of the material is dependent on forestry practices.

*Aluminum Siding* offers a variety of enameled colors, and a color **protective coating** which **improves durability** and offers greater color selection. Aluminum is **low maintenance**, **resistant to corrosion or deterioration**, lightweight, and requires minimal repainting. The use of aluminum siding declined when vinyl was introduced because aluminum was prone to denting. Its protective coating reduces denting, but introduced PVC’s to the product and may affect its recyclability. Additionally, a large amount of energy is used during the manufacturing process.

<table>
<thead>
<tr>
<th>Cladding Alternatives</th>
<th>cost/sf (materials &amp; labor)</th>
<th>expected product life (years)</th>
<th>life cycle thinking</th>
<th>practice</th>
</tr>
</thead>
<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>
</tr>
<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>
</tr>
<tr>
<td>aluminum</td>
<td>$2.60</td>
<td>20-50</td>
<td>good</td>
<td>standard</td>
</tr>
<tr>
<td>vinyl</td>
<td>$1.71</td>
<td>25</td>
<td>typical</td>
<td>standard</td>
</tr>
<tr>
<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>
<td>standard</td>
</tr>
</tbody>
</table>

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.
Methods Used

UC House Front Elevation
[22]

Alternative Methods

4” Exterior Vinyl Siding over 1/2” OSB Sheathing

Cedar Wood Siding
[23]

Aluminum Siding
[24]
Asphalt shingles are made up of a flexible fiberglass core coated with embedded crushed rock. The shingles are nailed in rows so that the upper rows of shingles overlap to prevent leakage and guide water to the roof’s edge. Shingles are weather resistant, but over time may become susceptible to leaks and algae over time.

As an alternative to asphalt, a metal roof was considered. Metal is a recyclable material that costs about 30% more initially, but requires less maintenance, lasts longer, and adds value to the house. However, asphalt shingles are donated and shipped free to Habitat lots. The difficulty of metal roof construction was also a concern for volunteer labor.

Protection From the Elements

Roofing material provides the outermost protection against precipitation and wind forces. The sun’s radiation hits the roof’s surface and is absorbed into the interior and reflected or emitted back into the atmosphere. The climate determines how much of the sun’s radiation should be absorbed into the building below.
Reflectance of Roof Materials
Solar reflectance of roof material is measured as the percentage of the sun's total radiation reflected from the roof. The difference between the temperature of the roof and air temperature also serves as a measure of roof reflectance. The chart below shows reflectance values for various roof materials.

Expected Product Life
The product life of a roof material is dependent on its durability to weather conditions, particularly precipitation and wind. The average product life of roofing materials is shown in the graph below.

Thermal Resistance
R-values measure resistance to heat flow, and therefore help determine the effectiveness of a roof against thermal gain. The higher the R-value, the more thermal gain to the building's interior.

- Asphalt Shingles: R-44
- Metal Panels: negligible
ANALYSIS:

Objective vs. Subjective

ROOF Analyzed

Objective Measures:
- reflectance of roof material
- expected product life
- thermal resistance
- price of material

Subjective Measures:
- difficulty of installation
- aesthetics of roofing material
- cost/benefit of material’s initial cost vs. life span

Measures were evaluated through conversations with the Habitat construction manager, site supervisor, and project architect. The below internet sources are used as references, and are actively linked to the report:

Shingle vs. Metal Roofs:
- http://www.coloradoenergy.org/procorner/stuff/r-values.htm

Metal Roof Installation and Products:

CONCLUSION:

Overall, the lifespan of metal panels outweighs the initial 30% higher cost. Metal roofs are long lasting and recyclable, making them a more sustainable option than asphalt shingles. However, metal’s benefits of solar reflectivity may not be favorable in Cincinnati’s climate where Heating Degree Days (5248) are much greater than Cooling Degree Days (996).

The constructability of asphalt shingles is much more volunteer-friendly, but volunteers could install an interlocking metal roof with careful instruction and supervision. If a metal roof was donated, it would be worth the difficulty of installation.
# COMPARATIVE ANALYSIS: Asphalt Shingles vs. Metal Panels

## Affordability

<table>
<thead>
<tr>
<th><strong>Pros</strong></th>
<th><strong>Cons</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Asphalt Shingles:</strong></td>
<td></td>
</tr>
<tr>
<td>➔ affordable material donated to Habitat</td>
<td>➔ product lifespan: 15-30 years</td>
</tr>
<tr>
<td>➔ no-cost volunteer installation</td>
<td></td>
</tr>
<tr>
<td><strong>Metal Panels:</strong></td>
<td></td>
</tr>
<tr>
<td>➔ product lifespan: 30-50 years</td>
<td>➔ costs 30% more than asphalt shingles</td>
</tr>
<tr>
<td>➔ adds value to house</td>
<td>➔ professional installation cost</td>
</tr>
<tr>
<td>➔ saves on cooling, maintenance, and replacement costs</td>
<td></td>
</tr>
<tr>
<td>➔ fireproof material saves insurance costs</td>
<td></td>
</tr>
</tbody>
</table>

## Constructability

<table>
<thead>
<tr>
<th><strong>Pros</strong></th>
<th><strong>Cons</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Asphalt Shingles:</strong></td>
<td></td>
</tr>
<tr>
<td>➔ simple, quick installation with 12”x36” three-tab shingles</td>
<td>➔ shingles heat up on the roof and may be</td>
</tr>
<tr>
<td>➔ easy to cut and nail</td>
<td>difficult to handle</td>
</tr>
<tr>
<td><strong>Metal Panels:</strong></td>
<td></td>
</tr>
<tr>
<td>➔ weighs 1/7 less than asphalt shingles; easy to handle and less stress</td>
<td>➔ more difficult to cut and manipulate</td>
</tr>
<tr>
<td>➔ interlocking system: lips on four sides that clip and lock into</td>
<td>➔ pieces: need aviation snips and hemming</td>
</tr>
<tr>
<td>➔ minimum roof slope of 3:12</td>
<td>➔ tool</td>
</tr>
<tr>
<td>➔ requires screws and cordless drill on roof</td>
<td></td>
</tr>
</tbody>
</table>

## Sustainability

<table>
<thead>
<tr>
<th><strong>Pros</strong></th>
<th><strong>Cons</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Asphalt Shingles:</strong></td>
<td></td>
</tr>
<tr>
<td>➔ higher R-value for winter heat gain</td>
<td>➔ not typically recycled</td>
</tr>
<tr>
<td>➔ shorter lifespan: susceptible to leakage and algae over time</td>
<td></td>
</tr>
<tr>
<td><strong>Metal Panels:</strong></td>
<td></td>
</tr>
<tr>
<td>➔ reflects solar radiation: reduce summer cooling costs</td>
<td>➔ metal reflectivity does not allow winter</td>
</tr>
<tr>
<td>➔ fully recyclable</td>
<td>➔ heat gain</td>
</tr>
<tr>
<td>➔ manufacturing uses significant energy</td>
<td></td>
</tr>
</tbody>
</table>
DISCUSSION:
Alternative Strategies

Overall roof’s performance is much more complex than just the outer layer of roofing material. The diagram below shows the layers that make up a roof system. Proper felt underlayment, drainage strategies, insulation, venting, and truss construction are critical components of a high-performance roof.

ALTERNATIVE ROOFING MATERIALS

White Vinyl Roof Membrane is a good option for a flat roof. It is more difficult to install than shingles, but offers great reflectivity. As shown on the “Reflectance of Roof Materials” chart (image [26], page 23), the white membrane has a reflectance of 70-80%. The flatness of the roof hides the appearance of white vinyl from a person’s view at ground level.

Light-colored Shingles offer up to 35% reflectivity compared to 5% reflectivity of black shingles. However, they may streak with visible algae and collect dirt over time, losing some their initial reflectivity. Light tan or gray shingles may a good compromise.
Methods Used

Alternative Methods

Light Gray Asphalt Shingles

Metal Panel Roofing
Space Planning for DAYLIGHTING and NATURAL VENTILATION

DAYLIGHTING can substantially reduce the energy need for electric lighting, but can also increase heating and cooling loads. By carefully placing and sizing windows according to solar orientation, a balanced daylighting strategy can save energy costs. Daylighting has also been shown to benefit inhabitant’s health and productivity.

NATURAL VENTILATION can minimize the energy needed to cool a building during warmer months. To achieve natural ventilation, the placement of operable windows, air inlets, and air outlets must be considered according to prevailing wind direction. The openings must relate to one another to encourage cross ventilation through the interior space. The comfort of the interior environment is improved with the circulation of fresh air.

Selecting Efficient MECHANICAL HEATING

MECHANICAL HEATING equipment type and placement has a significant impact on energy usage, particularly in Cincinnati where conventional heating is the top design priority (according to the Climate Consultant Analysis (image [7], page 7)). ENERGY STAR qualified heating equipment offers lower utility bills, fewer maintenance problems, and a quieter home. Centralizing duct work minimizes duct runs to supply and return registers in interior spaces, and saves energy. Adequate space must be left in the walls and floors to incorporate ducts and pipes. The proper sizing of equipment is necessary so that the system does not overcompensate and waste energy.

Selecting Low-Emitting INTERIOR FINISHES

INTERIOR FINISHES can emit air contaminants that are odorous, irritating, and/or harmful to the installers and occupants. These contaminants pollute indoor air quality (IAQ), and can affect the health and comfort of inhabitants. Therefore, interior paints and coatings, carpeting and its adhesives, and wood or agrifiber products should be evaluated for contaminants before install.
UC House: Site Plan and Floor 01 Plan

SITE FORCES

East: AM SUN
South: All-day SUN
West: PM SUN
Southeast: Prevailing WIND
The best strategy for good daylighting is to place windows so that natural light enters the each room from more than one direction. The **multi-directionality** produces less glare with a more even **distribution** of light that illuminates dark surfaces and corners. **Window placement** should be considered with which spaces will benefit from daylight most.

Other daylighting strategies include skylights, clerestory windows, and roof monitors or cupolas. **Skylights** may cause overheating, and receive uneven distribution of light throughout the day. Sunlight peaks at midday and falls off significantly in the morning and afternoon. **Clerestory windows** are vertical glazing located high on the exterior wall. **Sloped ceilings** can enhance the effect of clerestory windows by reflecting light into nearby rooms. Southern overhangs are essential to block heat gain from clerestory windows. A **roof monitor or cupola** is a small section of roof raised above an adjacent roof that has its own shading and glazing. Light is reflected off the walls and ceilings and transmitted to the interior as transmitted light.

**ENVIRONMENTAL CONCEPT:**

Daylight is the **natural light** of day. A daylit space provides daylight as the primary source of daytime illumination to accommodate the inhabitants’ visual needs. Effective daylighting achieves a visually and thermally comfortable space. Using daylight for **interior illumination** maximizes **electric lighting energy savings**.

Rooms that require good quality daylight year-round should be placed along the north and south walls. Each room’s **orientation** makes a difference in the quality of light it receives.

The depths of rooms should remain short adjacent to the daylight source. A window will produce useful illumination to a depth of 1.5 times the height of the window.

**Rule of Thumb:** the higher the window, the deeper the daylight penetration.

To distribute natural light deep within a home, **interior glazing** allows light to be shared from one space to another. Examples of interior glazing include transom windows above doors, vision glass, and translucent panels.
Measuring Daylight Effectiveness

Building Solar Orientation
Solar orientation determines the quality of daylight on each side of a building through the course of a day.

MORNING [AM]:
Eastern windows - bright, direct light; low, sharp sun angles

ALL DAY:
Northern windows - diffused, indirect light
Southern windows - bright, direct light (shading desired)

EVENING [PM]:
Western windows - bright, direct light; low, sharp sun angles

Recommended from LEED for Homes Rating System:

The glazing area on the north- and south-facing walls of the building is at least 50% greater than the sum of the glazing area on the east- and west-facing walls.

The east-west axis of the building is within 15 degrees of due east-west.

At least 90% of the glazing on the south-facing wall is completely shaded at noon on June 21 and unshaded at noon on December 21.

Window Height and Room Depth
The depth of useful illumination into a room can be measured in terms of window height.

USEFUL ILLUMINATION DEPTH = 1.5 (WINDOW HEIGHT)

Daylight Factor
Daylight factor is the percentage of interior illuminance at a horizontal point in the building to exterior illuminance (under an overcast sky) on a horizontal surface.

\[
\text{DAYLIGHT FACTOR} = \frac{\text{INSIDE ILLUMINANCE}}{\text{OUTSIDE ILLUMINANCE}} \times 100
\]

The higher the daylight factor, the more natural light available in the room.

<table>
<thead>
<tr>
<th>[Average DF]</th>
<th>[Appearance]</th>
<th>[Energy implications]</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2%</td>
<td>Room looks gloomy</td>
<td>Electric lighting needed most of the day</td>
</tr>
<tr>
<td>2% to 5%</td>
<td>Predominantly daylit appearance, but supplementary artificial lighting is needed</td>
<td>Good balance between lighting and thermal aspects</td>
</tr>
<tr>
<td>&gt; 5%</td>
<td>Room appears strongly daylit</td>
<td>Daytime electric lighting rarely needed, but potential problems due to overheating in summer and heat losses in winter</td>
</tr>
</tbody>
</table>
ANALYSIS:

Objective vs. Subjective

DAYLIGHTING Analyzed

Objective Measures:
- house's solar orientation analysis:
  - glazing area of north/south vs. east/west windows
  - east-west axis of building
  - percentage shaded southern glazing
- useful illumination depth with respect to window height
- calculated daylight factor

Subjective Measures:
- daylight appropriate for different interior program
- desired balance between lighting gains vs. thermal gains

Measures were evaluated through conversations with the Habitat construction manager, site supervisor, and project architect. LEED For Homes Rating System is referenced as standard for daylighting practice. The below internet sources are used as references, and are actively linked to the report:

Daylighting in Buildings:
http://www.archlighting.com/industry-news.asp?articleID=670541&sectionID=1306

Calculating Daylight:
http://www.learn.londonmet.ac.uk/packages/clear/visual/daylight/analysis/hand/daylight_factor.html

Daylighting and Energy Savings:

Framing for Windows:
http://en.wikipedia.org/wiki/Framing_(construction)

CONCLUSION:

Overall, the high performance UC house windows, doubled-glazed windows with low-E coating and a max U-value of .36 (recommended is .4 or less), are effective in preventing heat loss. The existing number of windows is appropriate for daylighting needs, but their placement and height should be evaluated. Testing each room for “useful illumination depth” would be worthwhile to ensure the best return on window investment.

The 3’-2” southern overhang is overcompensating for shade, and blocking 66% of desired winter (Dec 21) sun. A 2’-0” overhang would sufficiently shade during summer and allow daylight in during winter, while effectively blocking precipitation and wind. Transom windows, placed above existing windows, could also be considered for security reasons, and to bring light deeper into the space.
### COMPARATIVE ANALYSIS: Additional Daylighting Windows

#### AFFORDABILITY

<table>
<thead>
<tr>
<th><strong>PROS</strong></th>
<th><strong>CONS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>→ saves up to 75% on electric lighting bills</td>
<td>→ windows add extra cost to the house including window itself, header, sill plate, jamb, and cripple studs</td>
</tr>
<tr>
<td>→ adds value to house: exterior aesthetic, quality of interior space</td>
<td>→ windows could be a wasted cost if the homeowner keeps the blinds shut</td>
</tr>
</tbody>
</table>

#### CONSTRUCTABILITY

<table>
<thead>
<tr>
<th><strong>PROS</strong></th>
<th><strong>CONS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>→ interrupts regular stud pattern for rough opening: requires cutting and nail- ing of additional pieces including jamb, header, sill, jack and cripple studs</td>
</tr>
<tr>
<td></td>
<td>→ windows lack structural integrity (load from above rests on the header)</td>
</tr>
</tbody>
</table>

#### SUSTAINABILITY

<table>
<thead>
<tr>
<th><strong>PROS</strong></th>
<th><strong>CONS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>→ better interior environment: natural quality lighting, views to exterior</td>
<td>→ significant heat energy flows in and out of a building through windows</td>
</tr>
<tr>
<td>→ saves lighting energy during the day</td>
<td>→ extra material for windows and its surrounding wood framing: energy consumed in manufacturing and transport</td>
</tr>
<tr>
<td>→ daylight has been shown to increase inhabitant productivity</td>
<td></td>
</tr>
</tbody>
</table>

**Objective Statistics: UC House**

*(LEED for Homes Rating System used as standard - shown in bold below)*

**North + South Glazing Area [at least 50% greater than] East + West Glazing**

- N+S Glazing = 12374 sq ft
- E+W Glazing = 12219 sq ft
- \[\frac{(N+S)-(E+W)}{(E+W)} \times 100 = 1.3\%\text{ greater}\]

**June 21: 90% southern glazing = shaded**

- Dec 21: 90% southern glazing = unshaded

**Existing 3’-2” Overhang**

- June 21: 100% shaded
- Dec 21: 44% unshaded

**Proposed 1’-6” Overhang**

- June 21: 100% shaded
- Dec 21: 88% unshaded
DISCUSSION:
Alternative Strategies

HIGH PERFORMANCE WINDOW TERMS AND OPTIONS
http://www.recycleworks.org/greenbuilding/windows.html

U-factor - rate of heat loss through window
- lower U-factor keeps heat inside when it’s cold outside
  **Recommended: 0.40 or less**

Visible Transmittance (VT) - % of light that comes through window
- higher VT, more daylight into house

Air Leakage (AL) - rate of air leakage through cracks in window assembly
  **Recommended: 0.30 or less**

Double Pane - 2 panes of glass separated by air gap (aka. double-glazed or insulated windows)
- slows heat transfer between indoors and out
- reduce sound transmission for a quieter home

Low-E Coating - transparent coating on inside of panes that reflects a room’s heat back inside
- reduces need for winter heating

Solar-Control Coating - transparent coating on inside of panes that limits the sun’s heat energy entering through the glass
- reduces need for summer air conditioning

ALTERNATIVE WINDOW FRAME

Wood - energy efficient, but requires regular painting to prevent moisture damage
Vinyl - less expensive than wood, no maintenance
Fiberglass - no maintenance, energy efficient, costs more than vinyl
Aluminum - inexpensive, less energy efficient because conducts heat (must purchase frames with ‘thermal break’ to prevent heat transfer through metal)

USEFUL ILLUMINATION TEST:

The diagram to the left shows Bedroom 1 of the UC House evaluated in terms of WINDOW HEIGHT and ROOM DEPTH to determine the spread of useful illumination.

Depth of Useful Illumination = 1.5 (Window Height)
Methods Used

Alternative Methods

Exterior Window Placement

Effective Interior Illuminance

Low-E Window System [33]

Transom Windows and Skylights [34]
Natural ventilation is the intentional harnessing of air into and out of an enclosed space, a practical strategy in small residential buildings. The natural ventilation system relies on the size and placement of openings in a building. The air moves as a circuit through a building, supplied and exhausted through openings to the exterior.

Interior openings between rooms such as transom windows can encourage airflow throughout the building. Vertical stair elements can be used as stacked exhaust, enabled by the buoyancy effect that causes hot air to rise and exhaust through the top of a building. The prevailing wind direction, southeast in Cincinnati, should be considered to make the best use of wind forces.

Most natural ventilation strategies are only effective when the outdoor temperature is comfortable, in the warmer months. So natural ventilation strategies are supplemented by mechanical systems that control temperature and humidity, acting to heat, cool, humidify, and dehumidify. When possible, natural ventilation is desirable for indoor air quality and comfort.

**ENVIRONMENTAL CONCEPT:**

Natural ventilation is a passive strategy that uses wind and temperature difference to cool and ventilate interior spaces. The natural circulation of air should be considered in terms of a site's prevailing wind direction and the buoyancy effect that causes hot to rise in a space.

**Buoyancy Effect:** When air heats up it becomes less dense and rises above denser cold air. Therefore, fresh air should enter lower in a building and rise to exhaust higher in the building. Therefore, lower windows should be placed toward the prevailing southeast wind direction to capture incoming wind forces.
Building Orientation and Shape
A building should be oriented with openings facing the prevailing wind direction. This orientation effectively receives and harnesses incoming wind to maximize the cooling effect of natural ventilation.

Window Type and Operation
Ventilating windows must be operable by users. The direction of wind flow should be considered to determine which way the window should open. For example, if wind flow prevails parallel along a north wall, then the window would have side hinges (rather than top or bottom hinges) to scoop and direct wind to the interior building.

Obstructions between windward inlets and leeward exhausts should be avoided. Windows should be oriented across the room and offset from each other to maximize the mixing of air flow in the interior.

Room-by-Room Air Velocity and Flow

Residential Unit, Suitable Ranges for Natural Ventilation:

Air Flow Rate: .03-.04 m^3/s
Room Air Velocity: 1 m/s

Air speed within the unit rather than the amount of air-changes per hour determines the adequacy of natural ventilation. The human body reacts more to air-flow rather than the quality of air.
ANALYSIS:
Objective vs. Subjective

NATURAL VENTILATION Analyzed

Objective Measures:
- building orientation and shape
- window type and operation
- room-by-room velocity and air flow

Subjective Measures:
- natural ventilation appropriate for different interior program
- predicted homeowner's use of ventilated windows
- energy efficiency of additional windows vs. heat loss

Measures were evaluated through conversations with the Habitat construction manager, site supervisor, and project architect. The below internet sources are used as references, and are actively linked to the report:

Natural Ventilation in Buildings:

CONCLUSION:

Overall, natural ventilation can easily be incorporated when carefully considered in the preliminary arrangement of the floor plan. The homeowner should be informed about how to practice effective natural ventilation, and about its financial payback, comfort and health benefits. For security reasons, a homeowner may be uncomfortable opening windows. In this case, investing in an efficient mechanical cooling systems is more worthwhile. The success of natural ventilation is entirely dependent on the homeowner’s willingness to use the system.
**Cross Ventilation: UC House**

The open space at the eastern front of the house is effectively planned with windows across the room and offset from one another to mix interior air flow.

Potential Improvements:

- **Screened doors** could be added so that existing openings become useable for natural ventilation. However, they can be easily damaged by wind and need replacement.
- **Extend back hallway** to the west edge of the house to eliminate the dead air zone, and encourage continuous air flow.
- **Stacked ventilation at stair zone** in a 2-story house can function as vertical air exhaust.

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**AFFORDABILITY**

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>→ saves hundreds of dollars on annual cooling bills</td>
<td>→ operable windows could be wasted cost if homeowner doesn’t open them</td>
</tr>
<tr>
<td></td>
<td>→ may be significant added cost when combined with traditional A/C system</td>
</tr>
</tbody>
</table>

**CONSTRUCTABILITY**

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>→ the addition of operable windows in the place of fixed ones does not complicate the construction process</td>
<td></td>
</tr>
</tbody>
</table>

**SUSTAINABILITY**

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>→ occupant control over interior environment comfort level</td>
<td>→ open windows may allow conditioned air to escape and unfiltered air enter</td>
</tr>
<tr>
<td>→ naturally cool and ventilate interiors in spring/fall moderate temperatures</td>
<td>→ increased threat of air/water leakage</td>
</tr>
<tr>
<td>→ save cooling energy and reduce carbon footprint</td>
<td>→ less comfort during summer/winter temperature extremes</td>
</tr>
<tr>
<td></td>
<td>→ security for inhabitants may be a concern with operable windows</td>
</tr>
</tbody>
</table>
DISCUSSION: Alternative Strategies

FLOOR PLANNING

Prevailing wind direction in Cincinnati is from the southeast on average. So the Cincinnati floor plan should open up at the southeast corner to maximize use of incoming wind.

Continuous openness along the longer dimension of the plan would greatly increase the effectiveness of cross ventilation within the interior - the air flow would intersect and mix comfortably in the interior.

ADDITIONAL NATURAL VENTILATION STRATEGIES

Low Opening to Introduce Fresh Air: Basement windows introduce air at the lowest point in the building and provide for the most complete circuit of air.

Enhance Interior Circulation: Ceiling fans can provide up to 9°F effective temperature drop in the interior at 1/10 the electrical energy used by mechanical air-conditioning systems.

High Opening to Exhaust Stale Air: Clerestory is a high wall with a band of narrow windows along the very top of a building. It often rises above adjoining roofs or is placed just under the roof line.

Vented Skylight can dually function as a solar chimney that brings significant daylight into the interior.

Ventilated Attic: Whole Building Attic Fans greatly reduce heat transfer from the exterior to conditioned rooms below. Ventilated attics are about 30°F cooler than unventilated attics. However, the UC house already employs a ridge vent for attic ventilation.

Whole-Building Attic Fan
Methods Used

- Ceiling Fan
- White Vinyl, Double-Glazed, Double-Hung Windows

Alternative Methods

- Ceiling Fan in Exposed Ceiling
- Attic Fan
- Vented Skylight
- Operable Transom Windows
Heat loads in a building are usually dominated by heat gain/loss through the exterior envelope. However, mechanical heating is also needed to create a comfortable interior environment for the inhabitants. In Cincinnati, the basement houses the major mechanical equipment and larger distribution lines. During the preliminary design process, a high efficiency heating system should be selected that doesn't waste energy, and is compact, clean, quiet, and reliable.

Gas furnaces, the most common heating system, are used in Habitat homes with 90% energy efficiency. Rinnai tankless water heaters are being considered for water heating because they provide clean, fresh water at a constant temperature at up to 40% energy savings. They can be installed on virtually any wall inside or outside of a home, but should be placed close to their point of use for maximum performance.

Mechanical heating systems are required during the cold Cincinnati winter to keep homes comfortable. Water heating accounts for about 15% of percent of national residential energy consumption- the second-largest energy user in homes. Tankless water heaters offer flexibility in installation so the heater to be located closer to fixtures and appliances. This saves water consumption, and its on-demand service saves energy.

If not carefully selected, a heater may emit harmful gases, polluting the air and house interior. The lifespan of a heater impacts how much and how often the disposed material ends up in a landfill.

**INTENTION:** Install Efficient Mechanical Heating System

**Method:** Select Most Effective Heating System

**ENVIRONMENTAL CONCEPT:**

Mechanical heating systems are required during the cold Cincinnati winter to keep homes comfortable. Water heating accounts for about 15% of percent of national residential energy consumption- the second-largest energy user in homes. Tankless water heaters offer flexibility in installation so the heater to be located closer to fixtures and appliances. This saves water consumption, and its on-demand service saves energy.

If not carefully selected, a heater may emit harmful gases, polluting the air and house interior. The lifespan of a heater impacts how much and how often the disposed material ends up in a landfill.
**System Location and Size**

**Gas Furnace:** (existing)
- **Location:** basement, upflow furnace heats air with gas flame and circulates throughout interior by a fan and system of duct work
  - other location possibilities are a downflow furnace on slab and a horizontal furnace in the attic
- **Size:** 24” width, 30” depth, 84” height (including adjacent primary duct work)
  - a working space 3’ square is required on the side adjacent to the burner

**Tankless Water Heater:** (proposed)
- **Location:** any wall inside or outside the house, compact design allows for flexible placement of unit but it should be close to the point of use for maximum performance and space savings
  - Interior Location: vent directly to outside with one penetration for intake and exhaust to maximize safety and space usage
  - Exterior Location: requires no venting, may be recessed into enclosure and painted to match exterior appearance
  - Multiple Units: can be used individually, in pairs, or in groups to supply all hot water needs; a cable links the units together
- **Size:** 14” width, 23-26” height, 8-10” depth

**Annual Fuel Utilization Efficiency (AFUE), Energy Factor (EF)**

**MINIMUM ENERGYSTAR STANDARD**

**Gas Furnace:**
- **AFUE =** 85-90%
  (15% more efficient than standard models)
- existing Gas Furnace has 90% efficiency

**Tankless Water Heater:**
- **EF =** 0.82
  (up to 40% energy savings)

**Initial Cost, Maintenance, Life Expectancy**

**Gas Furnace:**
- **Initial Cost:** ranges between $500 - $1,500
- **Maintenance:**
  - Change filters every 1 to 3 months
  - Annual Service Contract
- **Life Expectancy:** typically 20-25 years

**Tankless Water Heater:** (Rinnai model)
- **Initial Cost:** ranges between $900 - $1400, depending on the model
- **Maintenance:**
  - In-line screen filter should be checked periodically for debris
  - Flush the unit periodically to keep free of scale and lime
- **Life Expectancy:** up to 20 years
ANALYSIS:

Objective vs. Subjective

MECHANICAL HEATING Analyzed

Objective Measures:
- system location and size
- AFUE and EF
- initial cost, maintenance, life expectancy

Subjective Measures:
- preferred system maintenance by homeowner
- preferred control over temperature
- system noise

Measures were evaluated through conversations with the Habitat construction manager, site supervisor, and project architect. The Architect's Studio Companion is used as a book reference. Additionally, the below internet sources are used as references, and are actively linked to the report:

Heating Systems:
http://www.sustainablebuild.co.uk/HeatingDesign.html
http://www.constructionresources.com/products/services/heating.asp
http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12530

Gas Furnace:

Tankless Water Heater:
http://www.rinnai.us/
http://www.freemoneyfinance.com/2006/08/are_tankless_wa.html

Radiant Heating:

CONCLUSION:

Overall, the gas furnace used in the UC house holds the ENERGYSTAR standard and functions with high efficiency. If affordable, the Rinnai water heater is a great heating option in terms of constructability and sustainability. A radiant heating system should also be considered a viable option that could simply install between floor joists with high 98-100% efficiency to effectively serve Cincinnati's colder months.

Low-income families often receive state funding for heating/cooling costs- so money invested in an efficient furnace could work against the homeowner financially. Therefore, money invested in an ENERGYSTAR Plus heater may be best spent elsewhere to better serve the homeowner.
## COMPARATIVE ANALYSIS: Gas Furnace vs. Tankless Water Heater

### AFFORDABILITY

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
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</thead>
<tbody>
<tr>
<td><strong>GAS FURNACE:</strong></td>
<td><strong>TANKLESS WATER HEATER:</strong></td>
</tr>
<tr>
<td>→ lower available initial cost: $500-1500</td>
<td>→ on-demand service with standby mode</td>
</tr>
<tr>
<td>→ longer life expectancy of 20-25 years-replacements needed less often</td>
<td>pending the next call for hot water - saves up to 40% on energy bills</td>
</tr>
<tr>
<td>→ higher initial cost: $900-1400</td>
<td>→ estimated savings of $100/year on energy bills</td>
</tr>
<tr>
<td>→ possible 30% tax credit (only if homeowner applies for the credit)</td>
<td>→ shorter life expectancy of 20 years</td>
</tr>
<tr>
<td>→ requires professional installation cost</td>
<td>→ professional installation cost</td>
</tr>
<tr>
<td>→ requires dedicated, sealed vent system, which could easily add $500 to $1,000 to the installation cost</td>
<td>→ requires dedicated sealed vent system</td>
</tr>
</tbody>
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### CONSTRUCTABILITY

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<tr>
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</thead>
<tbody>
<tr>
<td><strong>GAS FURNACE:</strong></td>
<td><strong>TANKLESS WATER HEATER:</strong></td>
</tr>
<tr>
<td>→ more widespread installation - placed in basement so ducts must run up to distribute heat throughout house</td>
<td>→ simple wall-mount installation with minimum space requirements</td>
</tr>
<tr>
<td>→ more energy consumed with the continuous production of heat</td>
<td>→ requires professional install of special dedicated sealed vent system</td>
</tr>
<tr>
<td>→ more heat loss during longer runs to fixtures/appliances</td>
<td>→ flexibility in locating mechanical system will likely make installation easier</td>
</tr>
</tbody>
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### SUSTAINABILITY

<table>
<thead>
<tr>
<th>PROS</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>GAS FURNACE:</strong></td>
<td><strong>TANKLESS WATER HEATER:</strong></td>
</tr>
<tr>
<td>→ ENERGY STAR units have 90% AFUE</td>
<td>→ ENERGY STAR units have .82 EF</td>
</tr>
<tr>
<td>→ seasonal energy efficiency ratio (SEER) = 13 or better</td>
<td>→ reduce energy consumption up to 40% by heating water on demand and avoiding standby loss</td>
</tr>
<tr>
<td>→ heater located closer to fixtures/appliances so “wait time” for hot water is reduced - saving water consumption</td>
<td>→ produces very low NOx and CO2 emissions - cleaner air, healthier home</td>
</tr>
<tr>
<td>→ primary recyclable components - copper heat exchanger &amp; steel burners</td>
<td>→ more heat loss during longer runs to fixtures/appliances</td>
</tr>
</tbody>
</table>
DISCUSSION:
Alternative Strategies

ALTERNATIVE MECHANICAL HEATING SYSTEMS

**DC Blowers** provide the benefit of **continuous air flow** at a constant speed. The direct current air opening produces uni-directional flow of electric charge.

**Radiant Heating** uses hot water and/or steam pipes called electronic resistance coils that are installed within the floor, walls, or ceiling. Every radiant system is custom designed to fit all rooms regardless of size and shape. No floor buildup or additional construction is required - the heating element can be installed in between floor joists. This heating system is comfortable, clean, quiet, and maintenance free. It has a warranty of about 25 years. The heating **efficiency is 98-100%** at any building elevation, evenly heating every area of the room.

**Ground Source Heat Pump (GSHP)** uses the natural solar heat stored within the ground. A high-quality loop and heat pump system collects heat, converts it to energy and stores it. It is expensive to install and is naturally limited to heating a maximum of 70% of a building’s needs.
Methods Used

Existing Basement: Gas Furnace and Duct work

Alternative Methods

Rinnai Tankless Water Heater

Radiant Heating

Ground Source Heat Pump
Low-emitting materials, adhesives and sealants, and paints and coatings should be selected to reduce the quantity of indoor air contaminants. These contaminants can be odorous, irritating, and/or harmful to both the installers and the residents. Product manufacturers will provide information about the amount of off-gasing. Major concerns for indoor air quality in homes include mold, radon, carbon monoxide, toxic chemicals, and volatile organic compounds (VOC’s).

Establishing a standard for interior finishes will help avoid pollutants that create an unhealthy interior environment. The following sustainable materials will be compared against the conventional material:

- No- and low-VOC paint vs. Conventional paint
- Natural/Recycled carpet vs. Conventional carpet
- Bamboo flooring vs. Hardwood flooring

Most Americans spend a minimum of 90% of their lives indoors, and studies by the Environmental Protection Agency have found that pollutant concentrations inside a building can be 2-5 times higher than outside.

Establishing a minimum for indoor air quality (IAQ) performance enhances the air quality of buildings, and contributes to the well-being of the occupants. Effective ventilation, both natural and mechanical, is an important factor in controlling filtration and humidity to create an acceptable IAQ.

Several serious respiratory illnesses have been linked to pollutants found in the air inside buildings. In less drastic circumstances, poor IAQ can have adverse effects on the quality of life or the productivity of residents.
VOC Levels
VOC’s are volatile organic compounds that pollute the interior environment. They are measured in units of grams per Liter (g/L). The LEED for New Construction & Major Renovations establishes the following VOC content limits:

- Flat Paint: 50 g/L
- Non-Flat Paint: 150
- Floor Coatings: 100
- Waterproofing Sealers: 250
- Stains: 250
- Indoor Carpet Adhesives: 50 g/L
- Wood Flooring Adhesives: 100
- Drywall & Panel Adhesives: 50

Recycled Content
A manufactured product is likely made up of various components. The amount of recycled content incorporated in the finished product can be measured as a percentage of the overall product. The LEED for New Construction & Major Renovations establishes the following standard:

> “Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the pre-consumer content constitutes at least 10% (based on cost) of the total value of the materials in the project” (51).

RECYCLED CONTENT VALUE = MATERIAL COST [POST-CONSUMER + 1/2 (PRE-CONSUMER)]
(amount of post-consumer and pre-consumer are measured by weight)

Post-consumer material - waste material generated by end-users of a product
Pre-consumer material - waste material generated during the manufacturing process

Renewability of Resource
A renewable resource is inexhaustible or replaceable by new growth. The use of sustainable materials helps sustain the environment and ensure that the product can be produced in the future. The renewability of an interior finish is measured by the amount of time it takes a resource to grow to maturity.

EX/ Oak takes 120 years to grow to maturity.
Renewability = 120 years
ANALYSIS:

Objective vs. Subjective

INTERIOR FINISHES Analyzed

Objective Measures:
- VOC levels
- % recycled content
- renewability of resource
- cost per square foot

Subjective Measures:
- preferred appearance - color, texture, etc.
- sensitivity to unhealthy IAQ
- desired comfort level - durability, softness
- desired thermal and acoustical properties

Measures were evaluated through conversations with the Habitat construction manager, site supervisor, and project architect. LEED for New Construction & Major Renovations are referenced as standard IAQ guides. Additionally, the below internet sources are used as references, and are actively linked to the report:

**IAQ and Building Materials**

Paints:
http://paints.sustainablesources.com/

Carpet:

Bamboo Flooring:

Countertops:

CONCLUSION:

Overall, the lifespan, healthy IAQ, and maintenance benefits of no- or low-VOC paint outweigh the initial higher cost.

With free volunteer installation, the end cost of recycled carpet tiles is comparable to conventional carpeting while also offering natural stain resistance and better IAQ.

Although bamboo flooring is renewable, its overall sustainability is questionable in terms of transportation energy consumption and potential toxic finishes. Since the differences in affordability and constructability are negligible, a bamboo floor could be considered for aesthetic reasons.
## COMPARATIVE ANALYSIS: Low-Emitting Interior Finishes

### AFFORDABILITY

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NO-TO LOW-VOC PAINT:</strong>&lt;br&gt;→ requires repainting 1 time/20 years vs. 4-5 times/20 years for conventional paint&lt;br&gt;→ lasts longer: more durable and cleans easily with soap and water</td>
<td>→ less manufacturing availability&lt;br&gt;→ more expensive initial cost: same as a manufacturer’s premium paint line - around $30/gallon</td>
</tr>
<tr>
<td><strong>NATURAL/RECYCLED CARPET:</strong>&lt;br&gt;→ recycled carpet squares: about $1/sf with volunteer installation&lt;br&gt;→ longer product life: natural stain resistance</td>
<td>→ higher initial cost: $3-3.50/sf vs. $1.50-3/sf conventional carpet</td>
</tr>
<tr>
<td><strong>BAMBOO FLOORING:</strong>&lt;br&gt;→ less expensive than hardwood flooring: starts at $3.50/sf</td>
<td>→ transport cost: shipped internationally</td>
</tr>
</tbody>
</table>

### CONSTRUCTABILITY

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
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</thead>
<tbody>
<tr>
<td>no construction complications with NO-TO LOW-VOC PAINT/BAMBOO FLOORING (compare to: conventional paint/hardwood)</td>
<td></td>
</tr>
<tr>
<td><strong>NATURAL/RECYCLED CARPET:</strong>&lt;br&gt;→ recycled carpet squares: easy to install and replace: volunteer-friendly install</td>
<td></td>
</tr>
</tbody>
</table>

### SUSTAINABILITY

<table>
<thead>
<tr>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NO- TO LOW-VOC PAINT:</strong>&lt;br&gt;→ better IAQ: low VOC’s and offgassing&lt;br&gt;→ less health problems including allergy and chemical sensitivities&lt;br&gt;→ no odorous “new paint smell” (from release of harmful contaminants)</td>
<td></td>
</tr>
<tr>
<td><strong>NATURAL/RECYCLED CARPET:</strong>&lt;br&gt;→ natural fibers: eliminate use of polluting petroleum-based fibers (nylon, olefin)&lt;br&gt;→ better IAQ: low VOC’s and offgassing&lt;br&gt;→ natural jute backing: alternative to synthetic rubber backing&lt;br&gt;→ natural stain resistance eliminates need for spray-on stain resistant chemicals</td>
<td></td>
</tr>
<tr>
<td><strong>BAMBOO FLOORING:</strong>&lt;br&gt;→ renewable grass, unharmed in harvest: renewability: 3.5 - 7 years</td>
<td>→ energy consumed in transport from international exporters</td>
</tr>
</tbody>
</table>
DISCUSSION:

Alternative Strategies

ALTERNATIVE COUNTERTOP FINISHES

Laminate countertops (used in the UC house) are an affordable option made with sheets of resin-saturated paper pressed together, with the topmost layer being decorative. This plastic laminate is petrochemical based with high embodied energy (and often ends up in a landfill. Low-VOC adhesives should be specified.

Fibercement offers a natural stone look and a substrate-free countertop as thin as .75 inches. It is lighter and cheaper than concrete, but stains with acidic liquids and has limited, muted color options.

Concrete cast-in-place and precast countertops can incorporate recycled materials, but the cement portion of concrete is not sustainable (consider alternative fly-ash). It requires a sealer for water and stain resistance, but this sealer may be damaged by heat. Concrete is a custom product that compares in cost to high-end granite countertops.

Metal countertops are non-porous with good stain resistance, but may be scratched or dented (matte or distressed finish is recommended). Stainless steel makes the most durable countertop. Prices generally start at $100/sf, and regular polishing and waxing maintenance is necessary. Metal requires large amounts of energy for mining and refining, but it is recycled as a valuable commodity.

R-VALUE FOR TYPICAL BUILDING MATERIALS

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<tr>
<th>THERMAL RESISTANCE</th>
<th>h R°F / Btu</th>
<th>R / inch</th>
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<tbody>
<tr>
<td>Concrete</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Stone</td>
<td>0.05 - 0.10</td>
<td></td>
</tr>
<tr>
<td>Brick</td>
<td>0.10 - 0.35</td>
<td></td>
</tr>
<tr>
<td>Hardwood</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td>Softwood / plywood</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>Particle board</td>
<td>0.65 - 1.85</td>
<td></td>
</tr>
<tr>
<td>Insulating board</td>
<td>2.30 - 2.80</td>
<td></td>
</tr>
<tr>
<td>Sidings</td>
<td>0.80 - 1.00</td>
<td></td>
</tr>
<tr>
<td>Asphalt shingles</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>Wood shingles</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>Built-up roofing</td>
<td>0.70 - 0.90</td>
<td></td>
</tr>
<tr>
<td>Rock wool</td>
<td>3.20 - 3.70</td>
<td></td>
</tr>
<tr>
<td>Mineral wool or fiber batt</td>
<td>2.90</td>
<td></td>
</tr>
<tr>
<td>Cellulose</td>
<td>3.20 - 3.70</td>
<td></td>
</tr>
<tr>
<td>Lightweight aggregate concrete</td>
<td>1.00 - 2.00</td>
<td></td>
</tr>
<tr>
<td>Cement board</td>
<td>1.50 - 2.30</td>
<td></td>
</tr>
<tr>
<td>Stucco / plaster</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Gypsum / plaster board</td>
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<tr>
<td>Fiberglass</td>
<td>3.16</td>
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<tr>
<td>Fiberboard</td>
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<tr>
<td>Polystyrene extruded</td>
<td>6.00 - 6.40</td>
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<tr>
<td>Polystyrene expanded</td>
<td>3.85 - 4.35</td>
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<tr>
<td>Polyurethane foam</td>
<td>5.80 - 7.70</td>
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<tr>
<td>Building paper / felt</td>
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<tr>
<td>Cork</td>
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<tr>
<td>Ceramic tile</td>
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<tr>
<td>Vinyl / linoleum / rubber tile</td>
<td>0.64</td>
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<tr>
<td>Synthetic carpet (weel loop)</td>
<td>3.50 - 5.90</td>
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<tr>
<td>Synthetic carpet (clash)</td>
<td>2.40 - 4.50</td>
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<tr>
<td>Wool carpet</td>
<td>4.50</td>
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<tr>
<td>Fiber / burl / sail cushion</td>
<td>3.88</td>
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<tr>
<td>Flat rubber cushion</td>
<td>2.72</td>
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<tr>
<td>Roped rubber cushion</td>
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<tr>
<td>Prime urethane cushion</td>
<td>4.44</td>
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<tr>
<td>Bonded urethane cushion</td>
<td>3.96</td>
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**Facts at a Glance**

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<thead>
<tr>
<th>Material</th>
<th>Maintenance Requirements</th>
<th>Stain Resistance</th>
<th>Scratch Resistance</th>
<th>Heat Resistance</th>
<th>Manufacturing &amp; Resources</th>
<th>Lifecycle</th>
<th>Cost</th>
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<td>4</td>
<td>2</td>
<td>3</td>
<td>$$$$</td>
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<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>$$$$</td>
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<tr>
<td>Metal</td>
<td>3</td>
<td>2-4</td>
<td>2</td>
<td>2-4</td>
<td>2</td>
<td>4</td>
<td>$$$$</td>
</tr>
</tbody>
</table>

* Based on greenest available options

Key: 4= Excellent/ 3= Good/ 2= Fair/ 1= Poor
Cost (installed, per SF): $= $10-40/ $=$ $40-80/ $$=$ $80-150
Methods Used

- Laminate countertop, Sheet Vinyl Flooring

Alternative Methods

- Low-VOC Paint
- Recycled Carpet Tiles
- Bamboo Flooring
Habitat for Humanity's new SUSTAINABLE initiative is consistently challenged by their fundamentals of AFFORDABILITY and CONSTRUCTABILITY. Volunteer labor is free and essential for the affordability of Habitat homes. However, this unskilled labor is an obstacle for the installation of many new green technologies including spray-foam insulation, fiber-cement board, and metal-panel roofing. Material donations keep building material expenses low, but also discourage the use of alternative, sustainable materials. For instance, asphalt shingles are donated and shipped free to Habitat sites. Therefore a metal-panel roof would be a significant extra cost and may require professional installation. Furthermore, Habitat needs additional funding to absorb the initial cost of building materials, but does not receive payback acquired from a product’s sustainable performance. Instead, the homeowner benefits financially from less maintenance, fewer replacement costs, and lower energy bills.

An open floor plan configuration with careful placement of windows and openings will harness the environment’s free resources, sun and wind, for interior energy efficiency. However, privacy and security concerns may discourage the homeowner from opening their blinds and operating windows to enjoy daylight and natural ventilation. Perhaps, top-down blinds could be used so that the homeowner feels secure and comfortable using their windows. To encourage a sustainable lifestyle, Habitat could provide a simple homeowner handbook that explains basic green concepts and highlights their financial benefits.

Sustainable design is site specific, dependent on the location of existing trees and neighboring houses, and the orientation to prevailing wind direction and southern sun exposure. Therefore a regional prototype should be adaptable to a site’s microclimate in order to receive maximum return for investment. For example, a fully shaded site with southeast wind exposure would benefit from openings designed for natural ventilation. On this site, an investment in light-colored roof material and additional daylighting windows would be inappropriate, providing minimal payback.

One of the most accessible sustainable strategies for Habitat for Humanity is a more efficient build process. A staging area could be set up off-site where Habitat leaders cut and lay out wall panels. At this location, the scrap would be sorted and organized by material to be used on future houses. The prefabricated panelized walls would be nailed together and erected into place on-site. Unbuilt Habitat lots could be used as temporary staging areas, particularly those in close proximity to the build site.

Habitat for Humanity can further community awareness of sustainable building practices by challenging volunteers to learn hands-on green building skills. This on-site experience increases knowledge of green technologies, and potentially inspires them to practice and apply it in their own homes. Furthermore, providing a sustainable house will empower homeowners to operate their homes responsibly and effectively with respect to their surrounding environment.
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All unannotated images are original photographs and/or diagrams.