ARCH 4150: Whole Building Analysis

RESIDENTIAL HALL

FOURTH STREET

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The information gathered from our midterm analyses informed some of our decisions going into our final analyses:

- Exterior Wall R-values: optimal at $R = 45$
- Roof R-values: optimal between $R = 60-80$
- Overhangs less than 2’ long
- High window placement while still providing views
- Triple pane windows have minimal benefits from double pane
RESIDENCE HALL BUILDING TRENDS

Res Halls across the country are starting to use:

- renewable energy systems
- compact fluorescent lamps
- solar panels
- efficient water systems
- recycling waste facilities
- bicycle storage

Increasing trend of construction ‘green’ campus residential buildings.

BUNDLE ANALYSIS

-Bundling combines multiple strategies into one building
-Clients can see different sets of strategies and related costs to pick the best applications for their needs

OUR ANALYSIS:
-**Bundle 1** focuses on advanced mechanical systems and envelope strategies
-**Bundle 2** takes a daylight-mechanical-water approach to achieve greater energy use reduction
-**Bundle 3** combines these strategies for even greater reduction

### BUNDLE BREAKDOWN-4th STREET RESIDENCE

<table>
<thead>
<tr>
<th>Renewable/Reduction Strategies</th>
<th>BUNDLE 1</th>
<th>BUNDLE 2</th>
<th>BUNDLE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Envelope Used Throughout</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall R Value</td>
<td>R41.8</td>
<td>R41.8</td>
<td>R41.8</td>
</tr>
<tr>
<td>Roof R Value</td>
<td>R68.9</td>
<td>R68.9</td>
<td>R68.9</td>
</tr>
<tr>
<td>Window U Value</td>
<td>U.343</td>
<td>U.343</td>
<td>U.343</td>
</tr>
</tbody>
</table>

| **Daylighting**               |          |          |          |
| Green Roof                    | X        | X        | X        |
| Solar PV                       | X        | X        | X        |
| Lightshelves                   | X        | X        | X        |
| Window Placement- high and low | X        | X        | X        |
| Overhangs                      |          |          | X        |
| Visible Light Transmittance   | X        |          | X        |

| **Advanced Mechanical Systems** |          |          |          |
| Radiant Floor Heating          | X        | X        | X        |
| Radiant Floor Cooling          | X        | X        | X        |
| Ground Source Heat Pump        | X        |          | X        |

| **Advanced Envelope Systems**  |          |          |          |
| Trombe Wall                    | X        |          | X        |
| Living Wall                    | X        |          | X        |

| **Water**                      |          |          |          |
| Low Flow Fixtures              | X        | X        | X        |
| Rainwater reuse                | X        | X        | X        |
| Greywater Reuse                | X        | X        | X        |
| Blackwater Reuse               | X        | X        | X        |

| **Wastewater Treatment**       |          |          |          |
| Living Machine                 | X        |          | X        |
Model Properties Used:
- Building Type = Dormitory
- Exterior Walls = 4” face brick, 2” insulation and 4” light weight concrete block (U = .0971)
- Interior Walls = Lightweight plasterboard partition (U = .2807)
- Ground Floor Slabs = Un-insulated solid ground floor (U= .1243)
- Roof = Flat roof (insulated to 1995 UK Regulation U = .0401)
- Upper Floors = 2” Light weight concrete floor deck (U = .5278)
- Doors = Metal Door (U = .652)
- Exterior Windows = Low E Double Glazing (6mm+6mm) (2002 UK Reg) (U = .3435)
LIGHTING
LIGHTSHELVES, OVERHANGS, AND WINDOW PLACEMENT

BUNDLE 1

-18” overhangs

BUNDLE 2

-18” light shelf 7’ above floor
-2 sets of 2’ tall windows at 3’ and 7’ above the floor

BUNDLE 3

-18” overhangs and light-shelves
-windows as in bundle 2

-Radiance images show the best light distribution when using a combination of lightshelves and overhangs in Bundle 3
LIGHTING
VISIBLE LIGHT TRANSMITTANCE (VLT)

**BUNDLE 1**

- 70% VLT
  - Shading devices had minimal impact on the lighting conditions and the room was too bright.

**BUNDLE 2**

- 30% VLT
  - Light shelves made the light distribution more even, but also blocked some of the light coming in.

**BUNDLE 3**

- 50% VLT
  - A balance for VLT was hard to reach, but our final bundle used a combination of overhangs and light shelves to achieve a better VLT.
WATER
USE OF LOW FLOW FIXTURES

FIXTURE BREAKDOWN:
Water Closets = 120
Urinals = 40
Water Basins = 160
Kitchen Sinks = 4

BUNDLE 1
-50% conventional fixtures
50% low-flow

BUNDLE 2
-0% conventional
100% low-flow

BUNDLE 3
-0% conventional
100% low-flow
WATER REUSE

**BUNDLE 1**
- Proposed building water consumption: 3620490.1 US gals/yr
- 20.8 US gals/ft² yr
- 1072.4 US gals/person yr
- 47% Reduction

-Catchment area 5,382 sf.
-10% of site impervious pavement and building footprint
-47% REDUCTION

**BUNDLE 2**
- Proposed building water consumption: 1525017.1 US gals/yr
- 8.7 US gals/ft² yr
- 451.7 US gals/person yr
- 79% Reduction

-Catchment area 50,821 sf.
-100% of site impervious pavement and building footprint
-79% REDUCTION

**BUNDLE 3**
- Proposed building water consumption: 1384430.0 US gals/yr
- 7.9 US gals/ft² yr
- 410.1 US gals/person yr
- 82% Reduction

-Catchment area 50,821 sf.
-100% of site impervious pavement and building footprint
-82% REDUCTION
ADVANCED ENVELOPE STRATEGIES

LIVING WALL

BUNDLE 1
- 1,500 sf. of E and W walls
- 3,500 sf. of S wall
- ENERGY SAVINGS: 10,989 kBTU

BUNDLE 2
- [strategy not used for bundle 2]

BUNDLE 3
- 3,000 sf. of E and W walls
- 5,000 sf. of S wall
- ENERGY SAVINGS: 13,896 kBTU

TROMBE WALL

BUNDLE 1
- 1,000 sf.
- ENERGY SAVINGS: 10,989 kBTU

BUNDLE 2
- [strategy not used for bundle 2]

BUNDLE 3
- 2,000 sf.
- ENERGY SAVINGS: 13,889 kBTU

GREEN ROOF

BUNDLE 1
- 25% of roof area
- ENERGY SAVINGS: 14,041 kBTU

BUNDLE 2
- 50% of roof area
- ENERGY SAVINGS: 21,064 kBTU

BUNDLE 3
- 100% of roof area
- ENERGY SAVINGS: 35,636 kBTU
RENEWABLES

PV PANELS

**BUNDLE 1**

- 5% of building energy supplied by roof PV
- square footage requirements: 18,525 sf

**BUNDLE 2**

- 10% of building energy supplied by roof PV
- square footage requirements: 34,680 sf

**BUNDLE 3**

- 30% of building energy supplied by roof PV
- square footage requirements: 39,336 sf

SOLAR THERMAL DOMESTIC HOT WATER SYSTEM

**BUNDLE 1**

- 10% of system energy supplied by solar
- square footage requirements: 1,330 sf

**BUNDLE 2**

[strategy not used for bundle 2]

**BUNDLE 3**

- 30% of system energy supplied by solar
- square footage requirements: 3,990 sf
## HEATING AND COOLING

### RADIANT FLOOR HEATING

<table>
<thead>
<tr>
<th>Bundle 1</th>
<th>Bundle 2</th>
<th>Bundle 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>-[strategy not used for Bundle 1]</td>
<td>-184,121 sf</td>
<td>-184,121 sf</td>
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<tr>
<td>-ENERGY SAVINGS:</td>
<td>-ENERGY SAVINGS:</td>
<td>-ENERGY SAVINGS:</td>
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<tr>
<td>82,898 kBu</td>
<td>73,089 kBu</td>
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</table>

### RADIANT FLOOR COOLING

<table>
<thead>
<tr>
<th>Bundle 1</th>
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<tr>
<td>-[strategy not used for Bundle 1]</td>
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<tr>
<td>-ENERGY SAVINGS:</td>
<td>-ENERGY SAVINGS:</td>
<td>-ENERGY SAVINGS:</td>
</tr>
<tr>
<td>165,796 kBu</td>
<td>146,840 kBu</td>
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</table>

### GROUND SOURCE HEAT PUMP

<table>
<thead>
<tr>
<th>Bundle 1</th>
<th>Bundle 2</th>
<th>Bundle 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20% of load</td>
<td>-50% of load</td>
<td>-70% of load</td>
</tr>
<tr>
<td>-ENERGY SAVINGS:</td>
<td>-ENERGY SAVINGS:</td>
<td>-ENERGY SAVINGS:</td>
</tr>
<tr>
<td>307,481 kBu</td>
<td>632,935 kBu</td>
<td>874,145 kBu</td>
</tr>
</tbody>
</table>

### CHILLED BEAM

<table>
<thead>
<tr>
<th>Bundle 1</th>
<th>Bundle 2</th>
<th>Bundle 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>-[strategy not used for Bundle 1]</td>
<td>-184,121 sf</td>
<td>-184,121 sf</td>
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<tr>
<td>-COOLING ENERGY SAVINGS:</td>
<td>-COOLING ENERGY SAVINGS:</td>
<td>-COOLING ENERGY SAVINGS:</td>
</tr>
<tr>
<td>165,796 kBu</td>
<td>146,919 kBu</td>
<td>146,919 kBu</td>
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</tbody>
</table>
OVERALL BUILDING ENERGY REDUCTIONS

Baseline		Building 1		Building 2		Building 3

KBtu

- Total Ann. Equip. Load (KBtu)
  - Baseline: 1,338,895
  - Building 1: 764,024
  - Building 2: 764,024
  - Building 3: 764,024

- Total Solar Thermal Output (kBTu)
  - Baseline: -
  - Building 1: (347,760.000)
  - Building 2: -
  - Building 3: -1,090,320

- PV production (kBTu)
  - Baseline: -
  - Building 1: (3,137,105.413)
  - Building 2: (5,872,075)
  - Building 3: -6,654,684

- Total Ann. Lighting Load (kBTu)
  - Baseline: 3,482,092
  - Building 1: 1,692,992
  - Building 2: 2,605,322
  - Building 3: 2,605,322

- HVAC Fans and Pumps (KBtu)
  - Baseline: 153,430
  - Building 1: 619,387
  - Building 2: 557,279
  - Building 3: 544,608

- Total Ann. Cooling Load (kBTu)
  - Baseline: 472,933
  - Building 1: 1,386,646
  - Building 2: 953,406
  - Building 3: 611,670

- Total Ann. Heating Load (kBTu)
  - Baseline: 12,136,217
  - Building 1: 3,043,648
  - Building 2: 1,989,554
  - Building 3: 1,753,186

Building Energy Use

KBtu

- 0
- 5,000,000
- 10,000,000
- 15,000,000
- 20,000,000
## COST COMPARISON

### WATER SYSTEM COSTS

<table>
<thead>
<tr>
<th>Capital Costs</th>
<th>Base Case</th>
<th>Design Case 1</th>
<th>Design Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixtures</td>
<td>$158,260.00</td>
<td>$279,825.00</td>
<td>$441,285.00</td>
</tr>
<tr>
<td>Plumbing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical Systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landscape</td>
<td>$1,695,900.00</td>
<td>$2,027,500.00</td>
<td>$2,701,900.00</td>
</tr>
<tr>
<td>Water Hookup</td>
<td>$2,000.00</td>
<td>$2,000.00</td>
<td>$2,000.00</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>$1,856,160.00</strong></td>
<td><strong>$2,309,325.00</strong></td>
<td><strong>$3,145,185.00</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operating Costs</th>
<th>Base Case</th>
<th>Design Case 1</th>
<th>Design Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixtures Demand</td>
<td>$15,553.75</td>
<td>$5,970.76</td>
<td>$1,348.29</td>
</tr>
<tr>
<td>Mechanical Systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landscape</td>
<td>$66,180.00</td>
<td>$51,954.00</td>
<td>$44,860.00</td>
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<tr>
<td>Sewage</td>
<td>$2,402.40</td>
<td>$2,300.03</td>
<td>$1,868.28</td>
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<tr>
<td>Runoff</td>
<td>$11,171.81</td>
<td>$9,546.89</td>
<td>$7,880.77</td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landscape - Irrigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>$95,307.96</strong></td>
<td><strong>$69,771.68</strong></td>
<td><strong>$55,957.34</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost Escalation Factors</th>
<th>Base Case</th>
<th>Design Case 1</th>
<th>Design Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount Rate</td>
<td>5.00%</td>
<td>5.00%</td>
<td>5.00%</td>
</tr>
<tr>
<td>Water Rate</td>
<td>7.00%</td>
<td>7.00%</td>
<td>7.00%</td>
</tr>
<tr>
<td>Electricity</td>
<td>12.00%</td>
<td>12.00%</td>
<td>12.00%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Payback (yrs)</th>
<th>Base Case</th>
<th>Design Case 1</th>
<th>Design Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>14</td>
</tr>
</tbody>
</table>

*Note: A value of 0 pays back in the first year. A value of 501 never pays back.*

- Attention to water systems like low-flow fixtures can easily decrease the amount of water demanded and contribute to the quick payback (10-14 years) of more sustainable systems.

*NOTE: An error in the Calculator prevented us from obtaining water costs data for Design Case 3*
## COST COMPARISON

### OVERALL BUNDLE COSTS

<table>
<thead>
<tr>
<th>Building Energy Costs (Excluding RE system generation)</th>
<th>Baseline</th>
<th>Building 1</th>
<th>Building 2</th>
<th>Building 3 Zero+ Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Energy Costs</td>
<td>$264,226</td>
<td>$151,508</td>
<td>$142,830</td>
<td>$128,595</td>
</tr>
<tr>
<td>Heating Cost</td>
<td>$128,097</td>
<td>$32,670</td>
<td>$21,000</td>
<td>$18,505</td>
</tr>
<tr>
<td>Cooling Cost</td>
<td>$3,610</td>
<td>$9,379</td>
<td>$7,277</td>
<td>$4,669</td>
</tr>
<tr>
<td>Fans &amp; Pumps   Cost</td>
<td>$3,848</td>
<td>$13,641</td>
<td>$13,977</td>
<td>$13,659</td>
</tr>
<tr>
<td>DWH Aux Systems Cost</td>
<td>$7,758</td>
<td>$34,195</td>
<td>$34,195</td>
<td>$34,195</td>
</tr>
<tr>
<td>Lighting Cost</td>
<td>$87,333</td>
<td>$42,461</td>
<td>$47,220</td>
<td>$38,406</td>
</tr>
<tr>
<td>Equip. Cost</td>
<td>$33,580</td>
<td>$19,162</td>
<td>$19,162</td>
<td>$19,162</td>
</tr>
</tbody>
</table>

-When taken together, all of the above strategies can combine to create a 51% decrease in total energy costs. Not only is this a significant reduction in the financial burden for a building’s lifetime, but also represents a reduction in energy use and more sustainable contribution to the built environment than conventional projects.
- **Lightshelves** successfully increase daylight penetration and distribution within a room.

- Overly bright conditions near windows can be reduced by **overhangs**.

- **Low-flow fixtures** significantly reduce the demand for potable water.

- Up-front costs are greater for **water catchment and reuse systems**, (green roof, rain, grey, and black water catchment and reuse, and low-flow fixtures), but their lower operational costs makes them financially feasible.

- Water strategies also provide ecological benefits by decreasing water runoff, among other things.

- The energy decrease obtained from **radiant heating and cooling** is significant in bringing down the overall energy use of a building.

- Use of **PV panels** can offset energy use by providing a renewable source.
RECOMMENDATIONS FOR IMPLEMENTATION

- Low flow fixtures to reduce water consumption
- Radiant floor heating and cooling
- Lightshelves and overhangs in combination for best light distribution
- PV panels and/or Solar Thermal DHW to help with energy payback
- Water catchment and reuse systems
- Green roof to provide energy reduction
- Living Machine on site to treat wastewater for reuse