Building Community While Building Responsibly: A Sustainable Housing Complex for Central Los Angeles

by

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A special “thanks” to my thesis supervisor, John Fernandez, Yi Jiang for her instruction in CFD, and the many MIT professors and teaching assistants who have provided the foundation for this work.
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When the city of Los Angeles grew rapidly and relentlessly in the early to mid 20th century, many downtown homes were razed to make room for highways, office and civic buildings. Consequently, the downtown area lost its residential character and the area's more affluent residents fled to more desirable suburbs like Pasadena and West LA, leaving the central area to decay into a stereotypical inner-city slum. Today's mostly low-income minority residents live in crowded apartment units, give their public schools failing marks, and wallow through a sea of concrete and asphalt.

Shortage of open spaces, educational facilities, and housing units is a problem common to most growing big cities such as Los Angeles. Furthermore, these shortage crises often overshadow another equally important crisis: the environmental decay of the city. Buildings and cars pollute the environment, creating numerous health hazards for human life. Unfortunately, cities often sacrifice sustainable technologies for conventional designs that can be constructed quickly and inexpensively.

Rather than implementing a quick fix, dilapidated inner-city areas like Los Angeles's would better benefit from sustainable and affordable housing units and public outreach centers that build community and improve quality of life. In response to these needs, the proposed Sustainable Housing Project will place 40 affordable housing units, an educational outreach center, and a park on a Central Los Angeles site. The design will give careful attention to environmental responsibility and improving quality of life by following a set of sustainability priorities.
SITE BACKGROUND

Location

Located about one mile north of Downtown Los Angeles, the triangular-shaped site selected measures roughly 65,000 square feet and slopes to the southeast. The site is bounded to the north by Bellevue Avenue, south by US Highway 101, east by Beaudry Ave and Sunset Blvd, and to the west by Victor Street. The highest elevation, 388 feet above sea level, is located at the corner of Bellevue and Victor, while the lowest point is 25 feet downhill near the intersection of Beaudry Ave and US 101.

Nearby land uses include high density residential (apartment buildings) directly across and further uphill along Bellevue Ave and small shops along Sunset Boulevard. There is also a motel, nightclub, and clinic at the corner of Sunset and Bellevue, as well as a shopping center anchored by a drug store at the corner of Sunset and Beaudry. Two public educational institutions—the Downtown Business Magnet School and the partially completed Belmont Learning Center—are south of the site along Beaudry Ave. Downtown Los Angeles's skyline is visible from most parts of the site, with the exception of those areas immediately adjacent the highway embankment.

Centrally located, the site is accessible by public transportation: a bus line that runs along Sunset Boulevard places Hollywood, Chinatown, Olvera Street, and Downtown Los Angeles within minutes.

Aerial and topographical views of the site.
(Source: http://www.topozone.com, USGS 5' contour map, with 1' lines interpolated)
Climate

Taking advantage of moderate year-round temperatures and constant wind directions to implement a natural ventilation system can greatly reduce heating and cooling loads, and Los Angeles has the ideal climate for such to happen. Winter temperatures average 60 °F, and winds from December to January blow mostly from the northeast. However, the remainder of the year is a comfortable 65 – 75 °F with breezes coming out of the west.

While Los Angeles is usually sunny, or at worst hazy in the morning until clearing in the early afternoon, it does receive about 12 inches of rain each year, with most of rain falling between November and April. However, El Niño events (which some speculate are occurring more frequently as a result of global warming) can bring heavy rains, overwhelming storm drainage systems and causing flash floods and excess soil saturation (which increases the danger of landslides).

Wind Data, 1930-1996

<table>
<thead>
<tr>
<th>Direction</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual</th>
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</thead>
<tbody>
<tr>
<td>Speed</td>
<td>NE</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>Peak Gusts</td>
<td>49</td>
<td>40</td>
<td>47</td>
<td>40</td>
<td>39</td>
<td>32</td>
<td>21</td>
<td>24</td>
<td>27</td>
<td>48</td>
<td>42</td>
<td>44</td>
<td>49</td>
</tr>
</tbody>
</table>


Temperature, Average Highs

<table>
<thead>
<tr>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>58.3</td>
<td>60.1</td>
<td>60.7</td>
<td>63.3</td>
<td>66.1</td>
<td>69.9</td>
<td>74.3</td>
<td>75.1</td>
<td>73.7</td>
<td>69.7</td>
<td>63</td>
<td>58.3</td>
</tr>
</tbody>
</table>

DESIGN GOALS

The Central Los Angeles Sustainable Housing Project (CLASHP) is designed to bring together families and educational outreach services to a long-underserved area. By providing 40 units of affordable housing and classroom, computing, and meeting space, the CLASHP can begin to bring life back into a once-thriving area of Los Angeles.

Program

The CLASHP consists of three distinct public elements: an educational outreach center (EOC), a park, and a residential building. The combined square footage of the residential building and EOC is about 70,000 square feet. Due to size constraints, a parking garage will be necessary to provide enough parking for the complex’s residents, employees, and visitors.

The residential building will consist of approximately 10 one-bedroom, 20 two-bedroom, and 10 3-bedroom units, with a substantial amount of common outdoor space. A total of 60 parking spaces will be necessary for the residents. The EOC will have a public meeting hall and a library/study center in visible and accessible locations; classrooms, individual tutoring rooms, offices, the computer lab, and support spaces will also be included in the EOC, though need not be as visible. The EOC and residential building will be separated by public open space.
Sustainability Goals and Challenges

As a sustainable project, the CLASHP addresses the following goals:

1. Design for natural ventilation to assist in providing thermal comfort.
2. Achieve passive heating and cooling by maximizing and minimizing solar heat gains in the winter and summer, respectively.
3. Incorporate water and plants at various scales (from site to unit planning) to clean and cool air.
4. Control water runoff to alleviate load on drainage systems.

Goals 3 and 4 above can supplement each other and should not be difficult to achieve. Water runoff can be detained in a pool or basin; this water can then help cool ambient air and possibly be treated to help irrigate plants. More challenging though is designing for natural ventilation and passive thermal control: winds prevail out of the west, which is the same direction of the sun at its most intense (afternoon) hours.

Solution Method

In order to achieve the aforementioned sustainability goals, a schedule consisting of design and testing phases was established. The first design period, which produced a general massing of programmatic elements, was subsequently tested using computational fluid dynamic software to determine the ability to naturally ventilate. The second design period focused on mitigating solar heat gains through various screening devices; an energy analysis tested the performance of the building envelope. The last design phase incorporated the preceding design and testing phases to arrive at a final overall design.
DESIGN PHASE I: Massing

Initial placement of elements was achieved through an examination of the surrounding land uses and the need to position the Educational Outreach Center in the most visible and easily accessible portion of the site. The resulting scheme thus layered the elements on the site from the most public to most private. The EOC was placed along Beaudry Avenue—an axis of existing public educational institutions—and was followed by public open space. The public open space, shielded from Beaudry Avenue traffic by the EOC and highway traffic by planting, is exposed to Bellevue Avenue and acts to soften the transition from fully public (EOC) to private (residential units). The residential building is then placed farthest from Beaudry and Sunset and closest to the residential zones further down Bellevue Avenue.
With the EOC and public open space in place, the massing exercises then concentrated on determining a general distribution and orientation of residential units that would aid in natural ventilation and the reduction of solar heat gains. However, the challenge of achieving these two sustainability goals through massing resulted in rather unconventional and undesired building forms. Stepped, low-rise, or multi-core building schemes required a larger footprint and began to encroach upon the public open space. Therefore, the scheme selected for testing exhibited a smaller footprint, 7-story single-core building with separation between three smaller towers. The core is open to the southwest and southeast while the building as whole faces southwest, which allows for some ventilation without entirely exposing the building to western solar radiation. A southwest orientation also creates a northeast "back" which can be more solid to prevent the colder winter winds from circulating through the core.
DESIGN PHASE I: Massing

Overhead view of massing model.
Scale: 1" = 32'-0"
A three-dimensional computer model of the proposed scheme was created for testing with Phoenics, a computational fluid dynamics (CFD) software. The computer model consisted of simple boxes and did not take into account openings other than the open core. Therefore, the CFD study did not take into account airflow through the buildings but rather around them. The CFD study helped determine whether a pressure differential existed on opposite sides of the buildings, which is necessary for airflow. Individual residential units would then be designed to allow for proper air circulation through the unit.

CFD

The computer model was tested under a 2.5 meter per second test wind prevailing from the west, and Phoenics provided predictable results: wind speeds around buildings, including through the separations, were accelerated as high as 3.7 m/s. On the other hand, the areas of low pressure behind the building exhibited decreased wind speeds as low as 0.006 m/s.
The Phoenics test case, while not the actual final massing model, did provide a general sense of how the winds affected the building for the given test conditions. In reality, wind is not constant in its westerly direction and may actually shift to a northwest or southwest direction. The test case was important in determining a magnitude of the winds, which when high can make an open space feel uncomfortable. CFD thus indicated that separation between buildings, while successful and imperative for natural ventilation, could also create wind tunnels that need to be addressed for safety and comfort. While the massing model was adjusted to solve geometric problems, the final model does not deviate greatly from the test configuration and thus accomplishes natural ventilation.
DESIGN PHASE II:
Solar Heat Gain Reduction

With a satisfactory ventilation scheme, the focus of design then shifted to alleviating the impact of solar heat gains. Data about sun's movement was useful in devising screen geometries that would reduce solar heat gains in the summer while allowing them in the winter.

Screens proposed for the southwest elevation (facing US 101) were designed to reduce mid-day to early afternoon solar radiation, during which sun's azimuth is mostly south to southwest. Two screening devices—recessed windows and aluminum slats over glass walls—were engineered to achieve the desired goals. Slats were dimensioned and spaced to block all direct light at 60° and higher (10am-2pm at summer solstice) while blocking minimal light at 30° (10am-2pm at winter solstice). A successful vertical screen needs slats with cross sections of about 1½"x12", angled 30° from the horizontal, and repeated every 15"o.c. Recessed windows were similarly studied, and the ideal depth dimension for a 4'-0" high window was 2'-4". The ideal use for the extra-deep sill is a planter, since plants could help clean and reduce air temperature. If this dimension were still too deep, then a combination recessed window/canopy system could be implemented.

Top: Geometrical study of aluminum slats.
Bottom: Application of slat geometry to recessed windows.
Since the slat screens and recessed windows perform similarly, there is a freedom to use either or both systems in any elevation. However, not all rooms in an apartment need (or should have) full-glazed walls; it is not practical to have a glass wall over a kitchen or bathroom. Furthermore, glass walls are *not* the most energy-conscious material as they have a high thermal conductivity (for a building material). The elevations should therefore utilize both systems, using recessed windows for more private rooms or where a glass wall is not practical, while using the slats over glass walls in living rooms, dining rooms, and perhaps one wall of a master bedroom.

A preliminary building envelope was designed using both recessed windows and aluminum slats. The US 101 elevation exhibited a combination of slats and recessed windows; the Beaudry Avenue elevation consisted of stats and solid walls; the northeast (Bellevue Avenue) elevation was a combination of wall and glass (without screening devices, as that face of the building receives little direct sunlight); and the Victor Street elevation, which faces northwest, was given recessed windows. For testing purposes, it was assumed that either screen allows 75% of summer and 25% of winter light to pass.
In order to assess the performance and thermal comfort of the residential units, an energy analysis was conducted for a south-facing two-bedroom unit during the month of June, the month during which most thermal discomfort in Los Angeles might occur. The unit selected had a total of about 300 ft² glazed and 1,000 ft² of stone-faced exterior wall. A list of typical apartment electronics and appliances and the time of day during which they are used (Appendix 1) was compiled to determine equipment loads. These loads were then added to solar heat gain loads and energy flows due to conduction/convection/radiation to arrive at a total energy load that was used to calculate the change in indoor temperature throughout the day.

To find the overall thermal conductivity of the stone and glazed walls, the conductive properties of each material were added to convection and radiation to arrive at an overall wall U-value. Indoor and outdoor radiation was assumed at 1 BTU/hr ft² °F; indoor convection at 1 and outdoor convection 3 BTU/hr ft² °F. The stone veneer’s conductivity was assumed to be 0.5 (that of concrete); the conductivity of glass, insulation, and gypsum board are 0.5, 0.03 and 0.2. (Source: “Heat Transfer,” Table 1. Leon R. Glicksman, 1991, 1997)

The U-value of a stone-faced wall section with 2” stone veneer, 10” insulation, and 1” of gypsum board was 0.034 BTU/ hr ft² °F, while that of a 1/4” glass pane was 1.27 BTU/hr ft² °F. With these U-values, the rate of energy transfer between the interior and exterior of the unit, q, was calculated using the equation $q_{wall} = UA (T_{out} - T_{in})$. 
With winter outdoor temperature values ($T_{out}$) of 60°F and indoor values ($T_{in}$) at 75°F for, the rate of energy $q_{net}$ revealed a heat loss from the unit to the outdoors of 5.6 W/ft² (19.1 BTU/hr) through glass and 0.15 W/ft² (0.51 BTU/hr) through stone-faced walls. Summer outdoor temperature values ($T_{out}$) of 80°F and indoor values ($T_{in}$) at 70°F yielded a heat gain of 3.7 W/ft² (12.7 BTU/hr) through glass and 0.10 W/ft² (0.34 BTU/hr) through stone-faced walls.

Added to the conductivity of the walls was the solar heat gain through the windows. Solar heat gain data for 34° N was found through [http://www.susdesign.com/windowheatgain](http://www.susdesign.com/windowheatgain), a JavaScript solar heat gain calculator. This online calculator takes into account solar heat gain coefficient for the window (0.79 for this case), window type (single-glazed aluminum frame) and ground reflectance (green grass, or 0.25), and then returns data for each month in the form of average watt-hours/m² per day. The data was then converted to Watts and multiplied by the screen coverage factor to arrive at a total solar heat gain. This data, along with calculations for thermal conductivity, are presented in Appendices 2 and 3.

The average rate of heat transfer for the month of June accounts for equipment loads, solar heat gains, and wall conductivity. The morning and evening energy usage peaks reflect the greater use of electronics and appliances; the drop in the load in the middle of the day represents reduced activity in the apartment unit.

### Solar Heat Gains

**2 Bedroom Test Unit**

**Q Solar Gains Through Windows, 34°N**
(Data Source: [http://www.susdesign.com/windowheatgain](http://www.susdesign.com/windowheatgain))

<table>
<thead>
<tr>
<th>Month</th>
<th>WEST WINDOWS Jan - Dec W-hr/m², Daily Watts/ft²</th>
<th>SOUTH WINDOWS Hours/Day Watts/ft²</th>
<th>Screen Coverage of 75% (Summer Approx.) and 25% (Winter Approx.) Watts/ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>Daylight Hours/Day Hourly Average (W/m²) Watts/ft²</td>
<td>2007 15 134 12</td>
<td>893 15 60 6</td>
</tr>
</tbody>
</table>

Modified SHG - West South

Daily SHG Average [(W+S)/2] in W/ft² 2.25

SHG, total for 300 ft² of glazing, in Watts 674

Energy Transfer due to Convection, Conduction, Radiation, through windows in W/ft² * 3.7

Total, for 300 ft² of glazing, in Watts 1110

Energy Transfer due to Convection, Conduction, Radiation, through walls in W/ft² * 0.10

Total, for 1,000 ft² of walls, in Watts 100

TOTAL HEAT TRANSFER, in Watts 1884

See Appendix 3 for other months
TESTING PHASE II: Energy Analysis

Total Heat Transfer (June):

<table>
<thead>
<tr>
<th>Time</th>
<th>Equipment</th>
<th>Cond/SHG</th>
<th>Total (q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8am-Noon</td>
<td>1947 W</td>
<td>2000 W</td>
<td>~4000 W</td>
</tr>
<tr>
<td>Noon-4pm</td>
<td>573 W</td>
<td>2000 W</td>
<td>~2500 W</td>
</tr>
<tr>
<td>4pm-8pm</td>
<td>2425 W</td>
<td>2000 W</td>
<td>~4500 W</td>
</tr>
</tbody>
</table>

Indoor vs. Outdoor Temperature

Load totals were next used to determine the change in temperature within the test unit. Treating the air and slab as single system in equilibrium simplified the task of tracking temperature changes throughout the day. \( \Delta T \) was found through the heat transfer equation 

\[
Q = \Sigma mc \Delta T
\]

where \( Q \) is the total energy in watts (Joules/second) and \( mc \) is the product of a material's mass and specific heat capacity. The initial apartment temperature (8am) was assumed the same as ambient temperature, or 68°F (20°C), and according to the calculations described above, the temperature in the unit had risen to 73.2°F by noon, 76.4°F by 4pm, and 82.2°F by 8pm. These calculations are detailed in Appendix 4.

Conclusions

The screening devices played an important role in keeping indoor temperatures close to outdoor ambient temperature. Although the overall energy analysis of a test unit shows that temperatures reach uncomfortable levels by late afternoon, a cooling system could provide the necessary relief. An ideal cooling system would be a radiant slab, where chilled water is circulated through concrete slabs. Water can be circulated as temperatures indoor rise above a certain tolerable limit (75°F), and the system could be part of a geothermal cooling scheme that would greatly reduce energy consumption.

Equally important in any passive design is to educate the users, or residents in the case of the apartments, about what they can and should do as their share of responsibility. Night cooling will be necessary to bring morning temperatures down and keep daytime temperatures to a minimum. And in general, the residential units should be kept well ventilated whenever summertime ambient outdoor temperature is lower than indoor temperature.
DESIGN PHASE III:
Final Design

In summary, the final design of the Central Los Angeles Sustainable Project incorporates the conclusions of the two design and testing phases as follows:

1. The residential building consists of three separated blocks. Separation aides air circulation through the buildings by creating localized pressure differentials. CFD testing confirms the separation’s satisfactory performance.

2. Screening devices in the form of aluminum slats and deep windows help shade undesirable summer solar radiation. Energy analyses showed only slightly intolerable levels of internal heat gains, which could be rectified by a radiant slab cooling system.

The sustainability goals of runoff control and planting were achieved through site planning which took advantage of the site’s slope. A detention basin is included near the base of the site, close to the study hall of the Educational Outreach Center. There are generous plants planned to create a buffer between the complex and the major highway. Street trees are standard around the site, as are trees in the park between the EOC and residential building. This site planning scheme of water and plants should help cool air while creating a more inviting and comfortable space for the entire community to use.

With a sustainability framework in place, the final design process followed a more traditional design exercise in detailing the layout of individual units. A short exercise in computer modeling yielded visualizations of the interior of a three bedroom unit. Those renderings, along with plans, elevations, and photos of a physical model are presented in the following pages.
DESIGN PHASE III:
Final Design
DESIGN PHASE III:
Final Design
DESIGN PHASE III:
Final Design

U.S. 101 ELEVATION
(Parking Structure Section)
DESIGN PHASE III:
Final Design
DESIGN PHASE III:
Final Design

Ground Level
(APT Parking, EOC 1)
DESIGN PHASE III:
Final Design

Main Level
(APT 1, EOC 2)
DESIGN PHASE III:
Final Design

Residence Floor Plans

Floors 3-5
DESIGN PHASE III:
Final Design

3-Bedroom Floor Plan (Detail) and computer model looking in from balcony
Close up of 3-bedroom units
### Appendix 1

#### Equipment Loads

<table>
<thead>
<tr>
<th>Equipment</th>
<th>8a-12p</th>
<th>12p-4p</th>
<th>4p-8p</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Lighting - Room Lights, 4x75 W</td>
<td>150</td>
<td>0</td>
<td>600</td>
<td>300</td>
</tr>
<tr>
<td>Electrical Lighting - Other Lamps, 2x75 W</td>
<td>75</td>
<td>0</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Full-Size Refrigerator</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Microwave Oven (Compact)</td>
<td>113</td>
<td>0</td>
<td>113</td>
<td>900</td>
</tr>
<tr>
<td>Coffee Maker</td>
<td>113</td>
<td>0</td>
<td>0</td>
<td>900</td>
</tr>
<tr>
<td>Toaster</td>
<td>313</td>
<td>0</td>
<td>0</td>
<td>1250</td>
</tr>
<tr>
<td>Iron</td>
<td>275</td>
<td>0</td>
<td>0</td>
<td>1100</td>
</tr>
<tr>
<td>Hair Dryer</td>
<td>156</td>
<td>0</td>
<td>0</td>
<td>1250</td>
</tr>
<tr>
<td>Blender</td>
<td>50</td>
<td>0</td>
<td>50</td>
<td>400</td>
</tr>
<tr>
<td>TV-25&quot;</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td>TV-19&quot;</td>
<td>0</td>
<td>0</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>VCR</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>Computer</td>
<td>125</td>
<td>0</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Computer Monitor</td>
<td>45</td>
<td>0</td>
<td>360</td>
<td>90</td>
</tr>
<tr>
<td>Laser Printer</td>
<td>10</td>
<td>0</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>People</td>
<td>73</td>
<td>73</td>
<td>292</td>
<td>73</td>
</tr>
<tr>
<td><strong>Total Watts, all Equipment</strong></td>
<td><strong>1947</strong></td>
<td><strong>573</strong></td>
<td><strong>2425</strong></td>
<td></td>
</tr>
</tbody>
</table>
Appendix 2
Thermal Conductivity Calculations

Stone-faced wall

\[ U_{\text{stone}} = \frac{1}{\left[ \frac{1}{(h_{\text{rad}} + h_{\text{conv}})_{\text{out}}} + \frac{L}{k_{\text{stone}}} + \frac{L}{k_{\text{insulation}}} + \frac{L}{k_{\text{gypsum}}} + \frac{1}{(h_{\text{rad}} + h_{\text{conv}})_{\text{in}}} \right]} \]

where \( h_{\text{rad},\text{out}} = h_{\text{rad},\text{in}} = 1 \)
\( h_{\text{conv},\text{out}} = 3 \) and \( h_{\text{conv},\text{in}} = 1 \)

\( L = \) thickness in feet, \( L_{\text{stone}} = 2''; L_{\text{insulation}} = 10''; L_{\text{gypsum}} = 1'' \)
\( k = \) conductivity, \( k_{\text{stone}} = 0.5; k_{\text{insulation}} = 0.03; k_{\text{gypsum}} = 0.2 \)

\[ U_{\text{stone}} = \frac{1}{\left[ \frac{1}{(1+3)} + \frac{(2/12)}{0.5} + \frac{(10/12)}{0.03} + \frac{(1/12)}{0.2} + 1/(1+1) \right]} \]
\[ = \frac{1}{[0.25 + 0.33 + 27.78 + 0.42 + 0.5]} \]
\[ = \frac{1}{29.28} \]
\[ = 0.034 \text{ BTU/hr ft}^2 \text{ °F} \]

\[ q_{\text{stone wall, winter}} = (T_{\text{out}} - T_{\text{n}})(\text{Area of Wall})(U_{\text{wall}}) \]
\[ = (60 \text{ °F} - 75 \text{ °F})(\text{Area of Wall})(0.034 \text{ BTU/hr ft}^2 \text{ °F}) \]
\[ = -0.51 \text{ BTU/hr ft}^2 \quad (1 \text{ watt} = 3.4 \text{ BTU/hr}) \]
\[ = -0.15 \text{ watts/ft}^2 \]

\[ q_{\text{stone wall, summer}} = (T_{\text{out}} - T_{\text{n}})(\text{Area of Wall})(U_{\text{wall}}) \]
\[ = (80 \text{ °F} - 70 \text{ °F})(\text{Area of Wall})(0.034 \text{ BTU/hr ft}^2 \text{ °F}) \]
\[ = 0.34 \text{ BTU/hr ft}^2 \quad (1 \text{ watt} = 3.4 \text{ BTU/hr}) \]
\[ = 0.10 \text{ watts/ft}^2 \]

For all stone walls: (1,000 ft²) (-0.15 watts/ft²) = -150 watts in the winter
(1,000 ft²) (0.10 watts/ft²) = 100 watts in the summer
Appendix 2 (Continued)

Glazed wall or window

\[ U_{\text{window}} = \frac{1}{\left[ \frac{1}{h_{\text{rad}} + h_{\text{conv}}^{\text{out}}} + L/k_{\text{window}} + \frac{1}{h_{\text{rad}} + h_{\text{conv}}^{\text{in}}} \right]} \]

where \( h_{\text{rad}} = h_{\text{rad}}^{\text{in}} = 1 \)

- \( h_{\text{conv}}^{\text{out}} = 3 \) and \( h_{\text{conv}}^{\text{in}} = 1 \)
- \( L \) = thickness in feet, \( L_{\text{glass}} = 0.25'' \)
- \( k \) = conductivity, \( k_{\text{glass}} = 0.5 \)

\[ U_{\text{stone wall}} = \frac{1}{\left[ \frac{1}{1+1} + \frac{0.25/12}{0.5} + 1/(1+1) \right]} \]
\[ = \frac{1}{[0.25 + 0.042 + 0.5]} \]
\[ = \frac{1}{0.79} \]
\[ = 1.27 \text{ BTU/hr ft}^2 ^{\circ \text{F}} \]

\[ Q_{\text{window, winter}} = (T_{\text{out}} - T_{\text{in}}) (\text{Area of Window}) (U_{\text{window}}) \]
\[ = (60 ^{\circ \text{F}} - 75 ^{\circ \text{F}}) (\text{Area of Window}) (1.27 \text{ BTU/hr ft}^2 ^{\circ \text{F}}) \]
\[ = -19.1 \text{ BTU/hr ft}^2 \quad \text{(1 watt = 3.4 BTU/hr)} \]
\[ = -5.6 \text{ watts/ft}^2 \]

\[ Q_{\text{window, summer}} = (T_{\text{out}} - T_{\text{in}}) (\text{Area of Window}) (U_{\text{window}}) \]
\[ = (80 ^{\circ \text{F}} - 70 ^{\circ \text{F}}) (\text{Area of Window}) (1.27 \text{ BTU/hr ft}^2 ^{\circ \text{F}}) \]
\[ = 12.7 \text{ BTU/hr ft}^2 \quad \text{(1 watt = 3.4 BTU/hr)} \]
\[ = 3.7 \text{ watts/ft}^2 \]

For all glazing:

\begin{align*}
(300 \text{ ft}^2) (-5.6 \text{ watts/ft}^2) &= -1680 \text{ watts in the winter} \\
(300 \text{ ft}^2) (3.7 \text{ watts/ft}^2) &= 1110 \text{ watts in the summer}
\end{align*}
APPENDIX 3: Solar Heat Gains

Q Solar Gains Through Windows, 34°N
(Data Source: http://www.susdesign.com/windowheatgain/)

<table>
<thead>
<tr>
<th>WEST WINDOWS</th>
<th>Jan-Dec W-hr/m², Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylight Hours/Day</td>
<td>1098 1510 1869 2014 2011 2007 2476 2344 1945 1489 1164 981</td>
</tr>
<tr>
<td>Hourly Average (W/m²)</td>
<td>122 137 170 155 134 134 165 180 177 135 129 109</td>
</tr>
<tr>
<td>Watts/ft²</td>
<td>11 13 16 14 12 12 15 17 16 13 12 10</td>
</tr>
</tbody>
</table>

SOUTH WINDOWS

| Hours/Day | 2940 2894 2313 1453 999 893 1231 1682 2437 2831 3094 2981 |
| Hourly Average | 9 11 11 13 15 15 15 13 11 11 9 9 |
| Watts/ft² | 327 263 210 112 67 60 82 129 222 257 344 331 |

Screen Coverage of 75% (Summer Approx.) and 25% (Winter Approx.)

| Modified SHG - West | Jan Feb Mar Apr May June July Aug Sept Oct Nov Dec |
| South | 8.50 9.57 3.95 3.60 3.11 3.11 3.84 4.19 4.11 3.15 9.01 7.60 |
| Daily SHG Average [(W+S)/2] in W/ft² | 22.77 18.34 4.89 2.60 1.55 1.38 1.91 3.01 5.15 5.98 23.96 23.09 |
| SHG, total for 300 ft² of glazing, in Watts | 15.64 13.95 4.42 3.10 2.33 2.25 2.87 3.60 4.63 4.56 16.49 15.34 |

Energy Transfer due to Convection, Conduction, Radiation, through windows in W/ft² *

| Energy Transfer, through windows in W/ft² | -5.6 -5.6 0 0 3.7 3.7 3.7 3.7 3.7 0 -5.6 |
| Total, for 300 ft² of glazing, in Watts | -1680 -1680 0 0 1110 1110 1110 1110 1110 0 -1680 |

Energy Transfer due to Convection, Conduction, Radiation, through walls in W/ft² *

| Energy Transfer, through walls in W/ft² | -0.15 -0.15 0.00 0.00 0.10 0.10 0.10 0.10 0.10 0.00 -0.15 |
| Total, for 1,000 ft² of walls, in Watts | -150 -150 0 0 100 100 100 100 100 0 -150 |

TOTAL HEAT TRANSFER, in Watts

| TOTAL HEAT TRANSFER, in Watts | 2861 2356 1325 929 1909 1884 2071 2289 2598 2579 4947 2773 |

* For March, April, November, \( T_{in} = T_{out} \)
Appendix 4

Total Heat Transfer (June):

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Equipment W</th>
<th>Cond/SHG W</th>
<th>Total (q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8am-Noon</td>
<td>1947 W</td>
<td>2000 W</td>
<td>~4000 W</td>
</tr>
<tr>
<td>Noon-4pm</td>
<td>573 W</td>
<td>2000 W</td>
<td>~2500 W</td>
</tr>
<tr>
<td>4pm-8pm</td>
<td>2425 W</td>
<td>2000 W</td>
<td>~4500 W</td>
</tr>
</tbody>
</table>

Change in Temperature over Time

\[ q = \sum mc \Delta T \]

mass, \( m = \rho V \)

density, \( \rho \)  
- \( \rho_{\text{concrete}} = 2,400 \text{ kg/m}^3 \); \( \rho_{\text{air}} = 1.21 \text{ kg/m}^3 \)
specific heat, \( c_{\text{concrete}} = 880 \text{ J/kg} \degree \text{C} \); \( c_{\text{air}} = 700 \text{ J/kg} \degree \text{C} \)

Volume of air in test unit: 10,000 ft\(^3\) or 283 m\(^3\)
Volume of 4" concrete slab: \((1,000 \text{ ft}^2)(4/12") = 333 \text{ ft}^3\) or 9.42 m\(^3\)

From 8am-Noon:

\[ \Delta T = \frac{q}{[(1.21 \text{ kg/m}^3)(283 \text{ m}^3)(700 \text{ J/kg} \degree \text{C}) + (2,400 \text{ kg/m}^3)(9.42 \text{ m}^3)(880 \text{ J/kg} \degree \text{C})]} \]
\[ = \frac{(4,000 \text{ W})}{[239,701 \text{ J/} \degree \text{C} + (19,895,040 \text{ J/} \degree \text{C})]} \]
\[ = (4,000 \text{ J/s}) / [20,134,741 \text{ J/} \degree \text{C}] \]
\[ = 0.00019866 \degree \text{C/s} \quad (1 \text{ hr} = 3600 \text{ s}) \]
\[ = 0.72 \degree \text{C/hr} \]

From Noon-4pm:

\[ \Delta T = \frac{q}{[(1.21 \text{ kg/m}^3)(283 \text{ m}^3)(700 \text{ J/kg} \degree \text{C}) + (2,400 \text{ kg/m}^3)(9.42 \text{ m}^3)(880 \text{ J/kg} \degree \text{C})]} \]
\[ = (2,500 \text{ W}) / [(239,701 \text{ J/} \degree \text{C} + (19,895,040 \text{ J/} \degree \text{C})]} \]
\[ = (2,500 \text{ J/s}) / [20,134,741 \text{ J/} \degree \text{C}] \]
\[ = 0.0001242 \degree \text{C/s} \]
\[ = 0.45 \degree \text{C/hr} \]

From 4pm-8pm:

\[ \Delta T = \frac{q}{[(1.21 \text{ kg/m}^3)(283 \text{ m}^3)(700 \text{ J/kg} \degree \text{C}) + (2,400 \text{ kg/m}^3)(9.42 \text{ m}^3)(880 \text{ J/kg} \degree \text{C})]} \]
\[ = (4,500 \text{ W}) / [(239,701 \text{ J/} \degree \text{C} + (19,895,040 \text{ J/} \degree \text{C})]} \]
\[ = (4,500 \text{ J/s}) / [20,134,741 \text{ J/} \degree \text{C}] \]
\[ = 0.0001235 \degree \text{C/s} \quad (1 \text{ hr} = 3600 \text{ s}) \]
\[ = 0.80 \degree \text{C/hr} \]