WINTER **2006**

a Living Laboratory concept proposal by the Civil and Environmental Engineering Department with

EHDD | ARCHITECTURE

STANFORD UNIVERSITY

greendorm

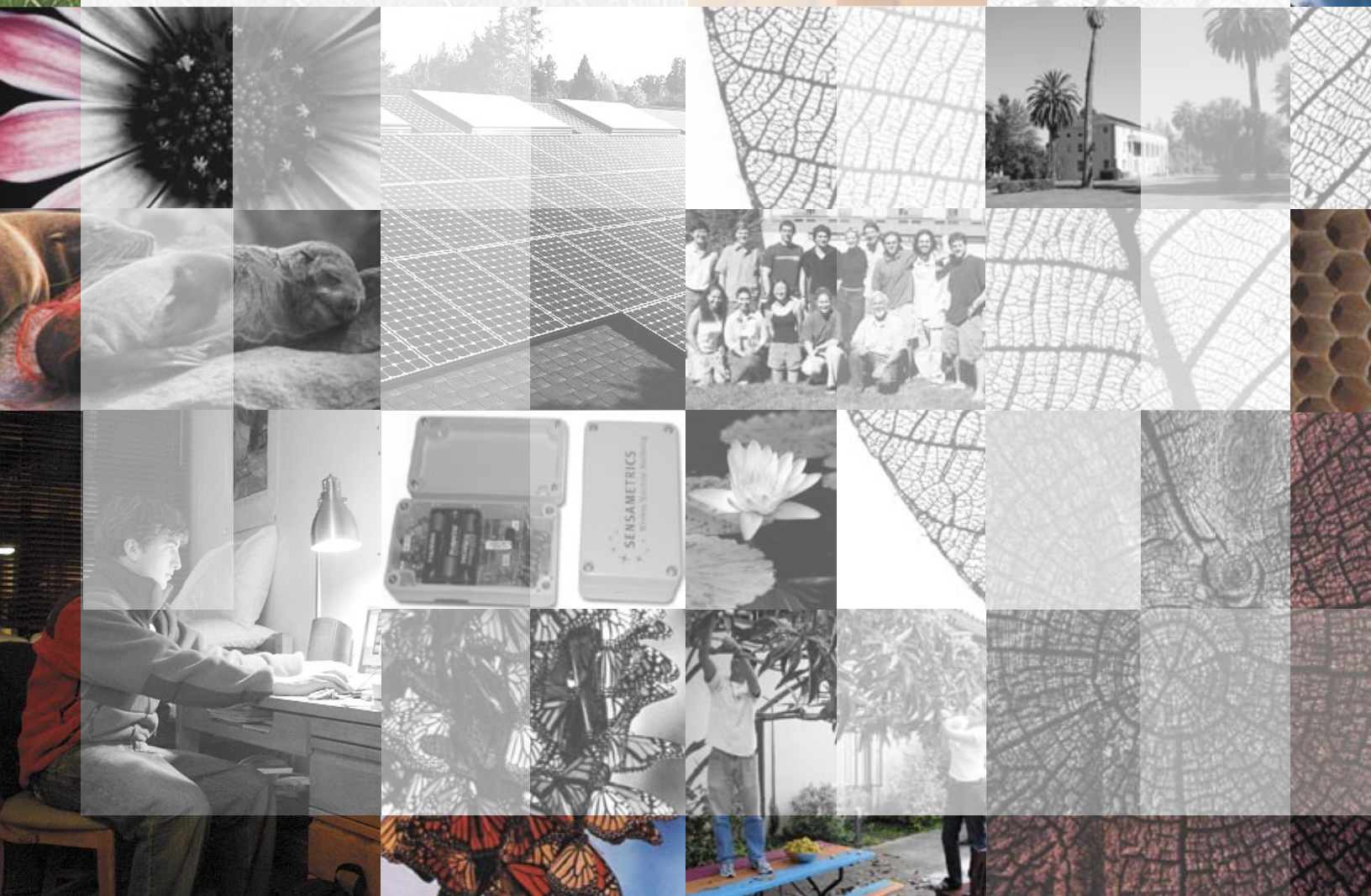

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FIGURE 1.0 - VIEW THROUGH INFORMATION CENTER TOWARDS MAIN ENTRY, WITH GREEN ROOF DECK ABOVE, STUDENT LOUNGE ON THE LEFT, AND BUILDING SYSTEMS LABORATORY TO THE RIGHT

Engineering for a sustainable future begins with examining how we live. . .

- **a research facility for innovative building systems, design and construction processes, and emerging technologies...**
- **a community-minded student residence offering hands-on learning opportunities...**
- **a demonstration of high-perfomance, sustainable building systems and technologies ...**
- **and the most desirable - and resource-efficient - student residence at Stanford.**

Executive Summary

Overview

The Feasibility Study for the Stanford Green Dorm was commissioned to determine the scope and budget for an innovative, sustainable dorm and research building proposed for the Stanford campus. This project is unique in many ways: this is a housing project spearheaded by the School of Engineering; this is an engineering lab within a 47-unit student dorm; but most of all, this is a Living Laboratory for ongoing research and education on sustainable engineering and student living.

The impacts of the groundbreaking vision outlined in this report would be felt near and far in the worlds of engineering, architecture, and student housing. These impacts would extend over time as students and faculty continually monitor and modify the building, improving on its environmental performance while expanding building knowledge. The School of Engineering's commitment to sustainability could find no better ambassador than the Green Dorm project.

During the Feasibility Study, the project goals coalesced into four primary categories:

1] A Living Laboratory for Research
2] Measurable Environmental Performance
3] The Most Desirable Housing on Campus
4) Economic Sustainability

This report details these goals for the project and documents the investigations to determine the appropriate program, site, building configuration and estimated cost for execution of this pioneering vision.

Project Background

The initiative began with a brainstorming session on November 20, 2003 organized by the Department of Civil and Environmental Engineering (CEE) in which faculty, students and invited professionals developed the initial vision for an "evolving", "influential", "flexible", and "desirable" living and learning facility (*see figure 1.1)*. The proposal advanced through the work of Engineering students and faculty (*see figure 1.2-1.4*), peer review by outside professionals, and the efforts of several univeristy entities including Student Housing and Land and Buildings. A design team led by EHDD Architecture was selected in August 2005 to spearhead this Feasibility Study.

Report Findings

This Report concludes that desirable student housing and world-class building research can be realized in a shared facility that operates at the highest standards of environmental performance.

Site, Program, and Building

The preferred site comfortably accommodates the 21,150 square foot program in a three-story building. A building systems laboratory shares an enlarged ground floor with residential common spaces while the majority of dorm rooms occupy the upper two floors in a mix of singles and two-room doubles. Building features include: a west-facing entry porch; a second floor roof deck supporting solar panels, green roof test beds, and student social space; and an "information center" where vistors and residents can learn about building systems and access real-time performance monitoring.

A Living Laboratory for Research

School of Engineering faculty will mine project-based data to further their own research agendas, while testing and developing emerging technologies. General topics will include: design and construction process, sensing and monitoring, water, materials, structure, building energy, and vehicle energy. The project will

FIGURE 1.1 - INITIAL BRAINSTORMING TEAM, NOVEMBER 2003

FIGURE 1.2 - CEE 136 (FALL 2004) DEVELOPED PRELIMINARY ARCHITECTURAL VISIONS

FIGURE 1.3 - CEE 299 (WINTER 2004) DEVELOPED INITIAL TECHNOLOGY AND PROGRAM REPORTS

FIGURE 1.4 - CEE 136 (WINTER 2006) IS CURRENTLY TAKING THE FEASIBILITY STUDY ONE STEP FURTHER INTO SCHEMATIC DESIGN

provide formal and informal educational opportunites, as is has already (*see Appendix)*. Demonstration is a critical goal and will be built into the project through multiple channels.

Zero Carbon Building
Through effective design of the building envelope, selection of water and lighting fixtures, and smart use by residents, energy consumption should be 20% below the current best-performing row house on campus. Heat delivery and on-site energy production will engage a combination of traditional (ex. radiant heating) and experimental (ex. shower water heat recovery) systems to provide thermal comfort and power efficiently. A Zero Carbon building - one that produces enough energy to offset its greenhouse gas impacts - is achievable through an integration of simple, cost-effective energy saving strategies and innovative energy generation technologies.

Closing the Water Cycle
A combination of water-conserving fixtures, water catchment and experimental wastewater treatment systems will result in a building with the potential to eliminate water inputs and outputs. As techniques and monitored results improve over time, bolder sources and uses of recycled water will be incorporated, pending approval by local jurisdictions.

Material Resources
A high-performance steel structure will ensure that the building will not end up in a landfill when the next big earthquake strikes. Low-cement concrete will complement other low-embodied energy, salvaged, or renewable materials in improving the project's impact on climate and ecosystems. Research in sensing, materials, and structural systems will be integrated into the design to provide a testing ground for ongoing research within the structural engineering department.

The Most Desirable Housing on Campus
All of these research components and sustainable strategies will contribute towards making this row house the most attractive residence on campus. Residential education will be taken to a new level with students engaged in learning about the local and global impacts of their lifestyles on a daily basis. The architectural design of the dorm will be guided by respect for the residential quality of neighboring row-houses. The highest levels of indoor environmental quality and thermal comfort will foster health and happiness amongst residents.

Economic Sustainability
The building package that incorporates all of the project goals -- dubbed the "Living Laboratory" -- commands a first cost premium over a standard design. It is important to note, however, that this cost does not accurately reflect the cost to build green housing at Stanford. In fact, the project team has concluded that cost-neutral sustainable housing is achievable with significantly higher environmental performance and occupant comfort than conventional housing. This "Baseline Green" model is embedded within the design for the Living Laboratory green dorm, serving as the armature upon which technologies and systems are laid which support performance, research, and educationsl goals. Life cycle cost analysis provides long-term payback justification for energy-saving and energy-generating technologies.

Report Structure

Chapter Three outlines the program requirements and site characteristics and describes the conceptual building and site design. The next three chapters explain the primary *project goals*, the design *options* considered and proposed to meet those goals, and the *analyses* used to guide decision-making. Chapter Seven addresses the goal of Economic Sustainability and provides estimated project cost data. Finally, a series of appendices provide back-up data and examples of project-based research.

FIGURE 1.5 - VIEW FROM GREEN ROOF DECK

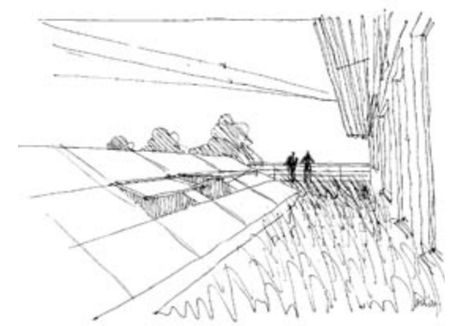


FIGURE 1.6 - VIEW FROM SOUTHEAST, TOWARDS DINING HALL

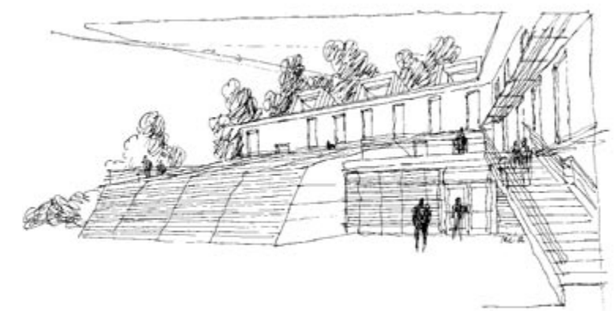
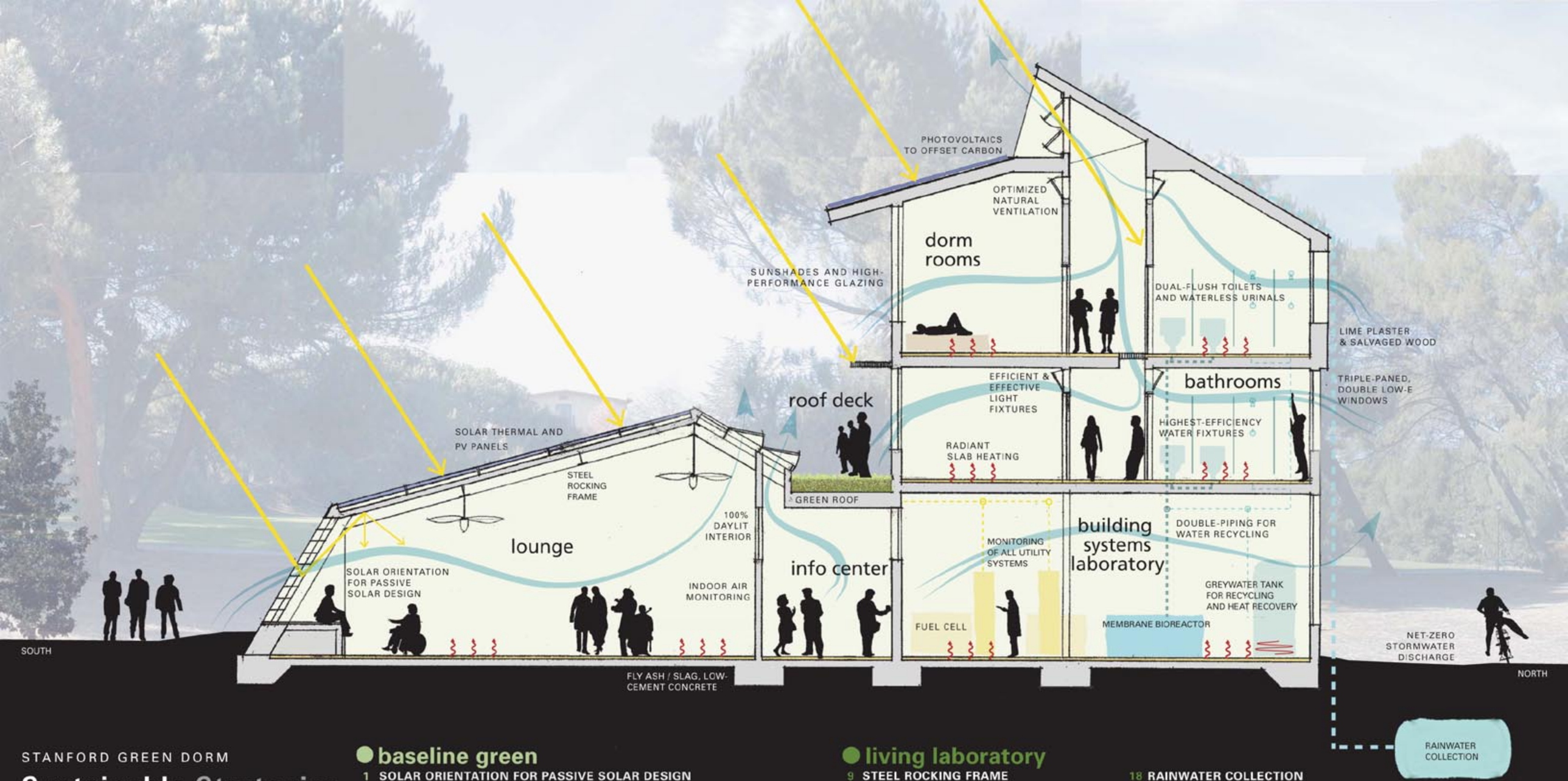


FIGURE 1.7 - VIEW FROM SOUTHWEST



STANFORD GREEN DORM

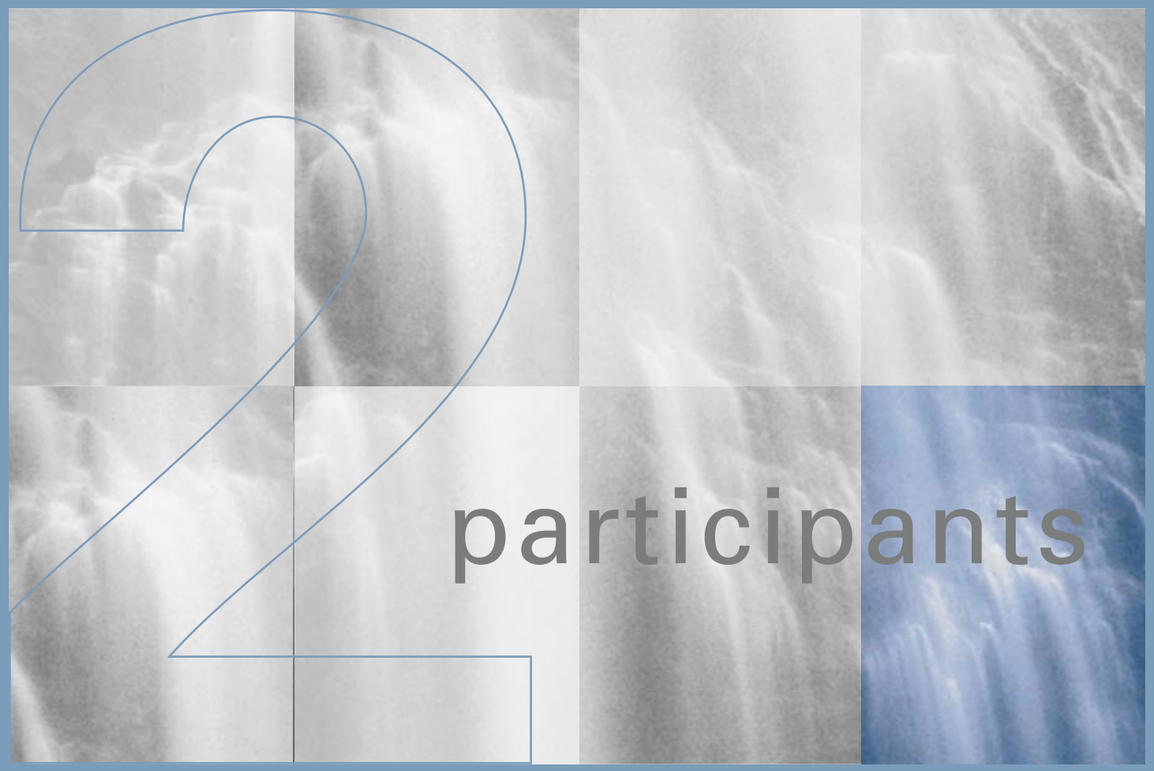
Sustainable Strategies

baseline green

1 SOLAR ORIENTATION FOR PASSIVE SOLAR DESIGN
2 SUNSHADES AND HIGH-PERFORMANCE GLAZING
3 RADIANT SLAB HEATING
4 FLY ASH / SLAG, LOW-CEMENT CONCRETE
5 NATURAL VENTILATION
6 EFFICIENT & EFFECTIVE LIGHT FIXTURES
7 OPTIMIZED, 24" O.C. WOOD FRAMING
8 DUAL-FLUSH TOILETS AND WATERLESS URINALS

living laboratory

9 STEEL ROCKING FRAME
10 BIO-COMPOSITE MATERIALS
11 100% DAYLIT INTERIOR
12 TRIPLE-PANED, DOUBLE LOW-E WINDOWS
13 LIME PLASTER & SALVAGED WOOD
14 FUEL CELL
15 GROUND-SOURCE HEAT PUMP
16 PLUG-IN ELECTRIC VEHICLE FUELING
17 INDOOR AIR MONITORING
18 RAINWATER COLLECTION
19 GREEN ROOF TEST BEDS
20 DOUBLE-PIPING FOR WATER RECYCLING
21 GREYWATER RECYCLING & HEAT RECOVERY
22 MEMBRANE BIOREACTOR
23 PHOTOVOLTAICS TO OFFSET CARBON
24 SOLAR HOT WATER PANELS
25 NET-ZERO STORMWATER DISCHARGE
26 MONITORING OF ALL UTILITY SYSTEMS



participants

Client and User Group

Department of Civil and Environmental Engineering
Sarah Billington
Craig Criddle
Martin Fischer
John Haymaker
Richard Luthy, Chair
Gil Masters
Eduardo Miranda
Sandy Robertson

School of Engineering
Bob Wheeler

Campus Planning and Design
Laura Goldstein, Project Manager
Ruth Todd, Associate Associate Architect
Dave Lenox, University Architect

Stanford Utilities
Susan Kulakowski, Campus Energy Manager

Student Housing
Rodger Whitney
Imogen Hinds
Alicia Restrepo

Student Participants
Jonas Ketterle, Student Representative
Mike Lin
Lauren Dietrich
Mauricio Toledo
John Chachere
Emily Leslie

Design and Construction Team

Architect
EHDD Architecture
Duncan Ballash, Principal
Scott Shell, Director of Sustainable Design
Brad Jacobson, Project Manager

Mechanical Engineer
Taylor Engineering
Allan Daly, Principal
Gwelen Paliaga

Structural Engineer
Tipping Mar + Associates
David Mar, Principal

Civil Engineer
Sherwood Design Engineers
Bry Sarte, Principal
Ken Kortkamp
Dahlia Thompson

Electrical Engineer
Integrated Design Associates (IDeAs)
David Kaneda, Principal
Ryan Stromquist

Cost Estimator
Davis Langdon
Peter Morris, Principal

Contractor
Pankow Builders, Special Projects
Wally Naylor, Principal
Jim Coyle, Project Manager

3 program, site, and building

A 47-unit student row house just steps away from Tresidder Student Union

The ground floor building systems laboratory serves School of Engineering students and faculty

A building oriented towards the sun on a site with unobstructed solar access

An interactive “information center” where residents and visitors can learn about building systems and access and real-time performance

A second floor roof deck supporting experimental green roof, solar panels, and outdoor social space

Program, Site, and Building

Program Summary

The project will house 47 students in a total of 21,150 gross square feet. There are three primary program components:

1) student rooms
2) common spaces
3) building systems laboratory

The initial program was developed by Stanford Land & Buildings in conjunction with the department of Civil and Environmental Engineering faculty and students. Further refinements to this program were made during the Feasibility Study (*see figure 3.1*).

FIGURE 3.1 - GREEN DORM SPACE PROGRAM

Space Type	Count	Occupants	NSF/Room or Occupant	Total NSF	Total GSF
GROUND FLOOR					
Lounge & Seminar Room	1	47	20	940	
Student Rooms	3	1	110	330	
Rec Room	1		300	300	
Kitchen	1		500	500	
Kitchen Pantry	2		125	250	
Dining Room	1	47	16	760	
Office for House Managers	1		100	100	
Computer Cluster and Library	1		300	300	
Closets (Housekeeping+supplies)	1		50	50	
Public Restroom	2		50	100	
Restroom	1	1	75	75	
Open Lab & Bldg Systems	1		2,800	2,800	
Electric vehicle garage	1		350	350	
Porch	1		700/2	350	
Entrance Foyer	1	20	10	200	
Total				7,405	10,552
SECOND FLOOR					
Student Rooms	23	1	110	2,530	
Residence Restrooms	2		200	400	
Alcoves	1	4 to 6	150	150	
Utility Closets	2		30	60	
Laundry	1		200	200	
Storage	1		100	100	
Study	1	10 to 15	150	150	
Total				3,590	5,118
THIRD FLOOR					
Student Rooms	22	1	110	2,420	
Residence Restrooms	2		200	400	
Housekeeping Closets	1		75	75	
Study	1	10 to 15	150	150	
Storage	2		400	800	
Total				3,845	5,479
Efficiency	*70%*				
Total Building Square Feet				14,840	21,150

Student Rooms

47 students will be accommodated in a mix of singles and two-room doubles (*for a full discussion of unit see Appendix)*. A two-room double is essentially two singles with a connection between them. Each dorm room, whether single or one-half of a two-room double, will total 110 NSF. 3 accessible units will be provided on the ground floor -- one may be used as a "demonstration/guest room"-- with the balance on the second and third floors.

Common Spaces

Common spaces will be provided for the students on each floor. On the ground level a lounge will accommodate meetings, parties, and evening programs such as talks on sustainability. A Rec Room may house a pool table or other game tables as well as audio/visual equipment (TV, digital projector, etc.). A Computer Cluster/ Tech Center and Library will serve the entire dorm with access to at least 3 workstations accommodating group work and equipment such as scanners and printers as determined by Stanford Residential Computing. The room will serve as a general library for the dorm as well as a resource for materials on green buildings, sustainable engineering, and environmentalism. Storage will be distributed among all three floors.

Dining facilities will be open to the students at all hours. A dining hall will be sized to serve residents as well as eating associates in a space opening on one side to outdoor dining and on the other to a full-service Kitchen. A chef hired by the students will work out of this kitchen designed for energy efficiency and convenient composting and recycling of wastes.

A foyer shared by residents, researchers and visitors will serve as the "information center" of the project. Users will access information on the design and construction of the building, ongoing research projects, and real-time monitoring results through interactive displays. An office for students managers and a possible "building guru" will be located off of the foyer.

Balancing security with the desire to integrate researchers, residents, and visitors is a primary concern.

FIGURE 3.2 - ROW HOUSE ELEMENTS

ROW-HOUSE DORM ROOM

ROW-HOUSE LOUNGE

ROW-HOUSE KITCHEN

The building must be inviting to visitors and feel like an integrated whole; but privacy and security for residents and researchers is equally important. The entry sequence and circulation will achieve both of these goals by filtering all uses through this entry foyer.

Study lounges will be provided on each of the upper two levels. The second level study lounge will open directly to the roof deck for outdoor studying. Laundry located on the second floor directly over the lab allows for easy plumbing for water recycling. At least one accessible washer and dryer will be provided for the 3 ground level residents.

Communication between the two residential floors is an important design value and may be accommodated with floor openings between the second and third floor with skylights above. Stairs between the second and third floor may be unenclosed pending fire marshal approval to encourage movement and communication between the floors. It will need to be enclosed and fire-rated between the ground and second floors.

Two group restrooms on each floor, with a total of four toilets and four showers, may be used as unisex or separate men's and women's. *(See Chapter VI for further discussion of dorm social life)*

FIGURE 3.3 - INNOVATIVE SPACES: THE ORIGINAL HEWLETT-PACKARD GARAGE, PALO ALTO

Building Systems Laboratory

The Building Systems Laboratory will support the School of Engineering's research in sustainable engineering, including that of Civil and Environmental Engineering and other departments. The lab will allow performance measurement and monitoring of building systems and provide flexibility for development and testing of new technologies. The lab will also accommodate utility and building systems space since most experimentation will involve systems like the water treatment and HVAC systems. The system components will be located for easy access, with ample room for monitoring and reconfiguration for research purposes.

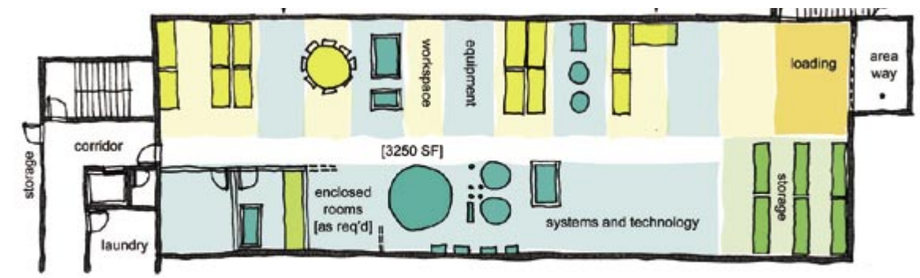
The overall concept is of a workshop space with ultimate flexibility both in terms of spatial configurations and utility hookups (*see figure 3.4*). Since the research program and technology will change over time, a "Plug and Play" concept will guide the design: flexible connections and multiple access points to utilities will allow easy reconfiguration and adaptability.

Features and components:

- Support for short-term experiment setup and long-term data collection
- Loading access for adding and removing large equipment
- Access and accommodation for group tours
- Secure storage for high value components
- A high-quality working environment with daylighting and natural ventilation
- Ventilation required for equipment such as gas chromatographs and reactors, for modest use of reagents (pint-size solvent bottles, reactors that produce or handle methane, etc.), and odor removal. A permanent fume hood is unlikely.
- Adaptable configuration for wiring and plumbing
- Diverse electricity (high power AC and DC) and water (potable, grey, black) feeds
- Workshop-grade benches and sinks
- Electronic prototyping and repair stations
- Tool cabinets
- Racks for long term experiments and other storage
- Electric vehicle recharging and "grid support"

FIGURE 3.4 - BUILDING SYSTEMS LABORATORY SCHEMATICS

LAB CONCEPT SCHEME A



LAB CONCEPT SCHEME B

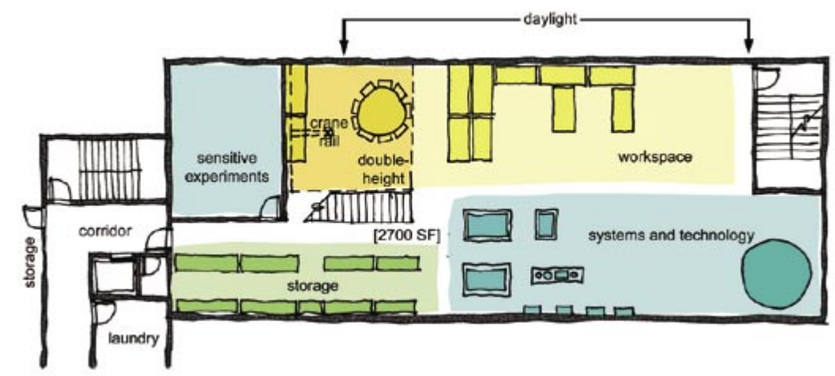


FIGURE 3.5 - SITE PANORAMA

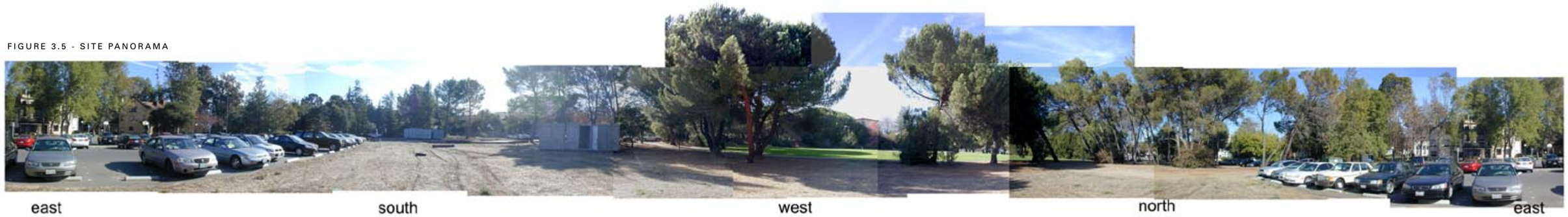
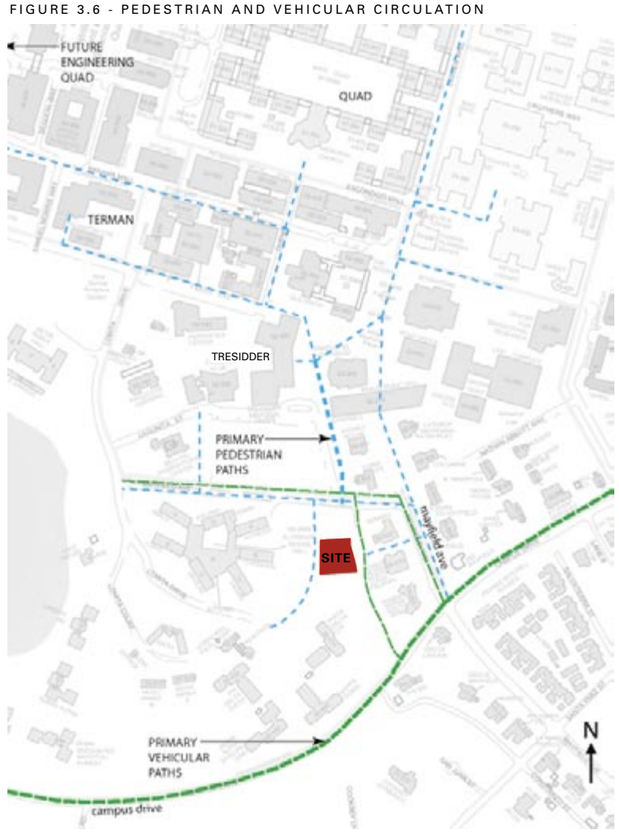


FIGURE 3.6 - PEDESTRIAN AND VEHICULAR CIRCULATION



Site Description

The area selected for the proposed building is appropriately located at the far northern end of "the Row", adjacent to other similarly-sized dorms but very close to the academic core of campus. Mayfield Avenue brackets the site to the north and east while Campus Drive West bounds it to the south. Immediately to the north is an undeveloped lot known for its leaning pine trees while to the west a pedestrian path links students living to the southwest with central campus. Just beyond the path lies Levin Field, a well-maintained playing field. This prominent location directly adjacent to Mayfield Avenue and Tressider parking lot will help increase visibility of the dorm. The rear yards and recreation areas of Xanadu, Casa Italiana, and Robert Moore row houses face the site to the east and offer a potential shared "backyard" territory. Pedestrian distances between "sister" buildings for the research program, such as Terman Engineering (planned for demolition) and the new Engineering quad, are minimized *(see figure 3.6).*

The Project Team was presented with three lot locations on this overall site. Site Three was ruled out due to its distance from central campus and relative lack of amenities. Site One was initially favored due to its prominent location. Building massing studies revealed a bias towards long east and west elevations, which resulted in energy and comfort penalties in our energy model. In addition, Site One is currently undeveloped and many well-loved trees would be felled for construction.

Site Two offers the best of all worlds. Construction of the new building will replace a parking lot and a bare, unlandscaped open space while a forecourt of trees and open space to the north is maintained. Most importantly, Site Two is wider in the east to west direction than Site One, allowing a building massing with primarily north and south facing facades. This provides better sunshading opportunities to keep out the hot summer sun while allowing low winter sun to passively heat interior spaces *(see figure 3.7).*

The building site has unobstructed solar access to the south. The average high temperature for this location is 65 degrees with a record high of 106 degrees. The average low temperature is 49 degrees with a record low of 20 degrees. The prevailing winds are from the west-northwest and there is an annual average rainfall of 20 inches.

Risk Areas

The site is located in an area designated as California Tiger Salamander Management Zone in Stanford's General Use Permit (GUP) agreement with Santa Clara County. This agreement requires that Stanford grant a permanent conservation easement over Lake Lagunita (the primary breeding habitat for the federally listed salamanders) before any development activity is permited in the management zone. Alternatively, Stanford may execute a Habitat Conservation Plan (HCP) with the appropriate federal agencies (USFWS). It is anticipated that the HCP will be approved within the next 9-18 months. Until that

FIGURE 3.7 - SITE ANALYSIS

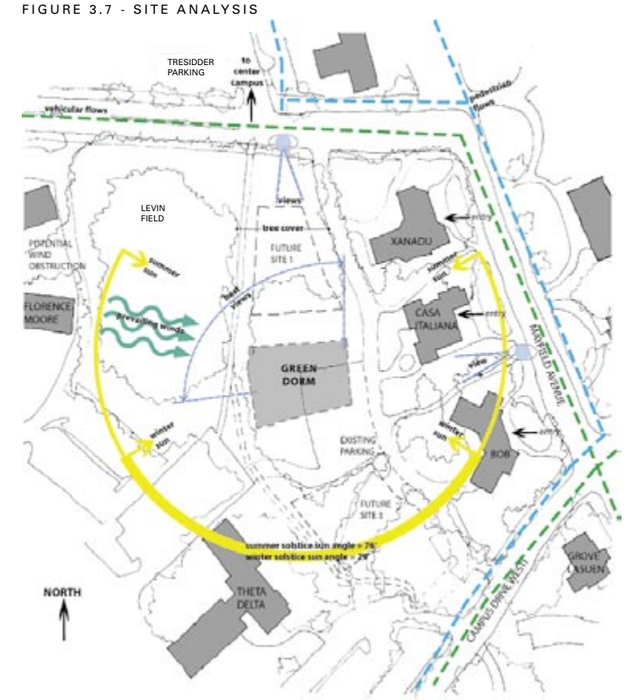


FIGURE 3.8 - SITE AERIAL PHOTO WITH PLANNING GUIDELINES

time, Stanford will not submit for permit for those projects within the California Tiger Salamander management zone.

Site Utilities

Most utilities are located close to this site since the major networks serve the nearby row houses. Public water, irrigation lake water, stormwater sewers, electricity, gas, and communication lines are all currently located below the service road behind Xanadu, Casa Italiana and Bob. The service road will serve the Green Dorm as well, therefore no utility relocation is expected and piping connection distances will be minimal.

As proposed, the Green Dorm will not be connected to the Stanford steam tunnel system located adjacent to the site. The building footprint will not interfere with the existing steam line.

The only major utility that is not located adjacent to the proposed site is the sanitary sewer line. One branch of the sewer system is located below Mayfield Avenue, on the other side of Casa Italiana, and another branch is located below Campus Drive West. It is expected that the sanitary sewer connection will tie in to the Campus Drive West segment, to allow easier sanitary sewer access to future development to the south of the selected site.

The 3-inch diameter irrigation line servicing Levin Field is located below the northwestern corner of the site and will need to be relocated to allow for building construction.

FIGURE 3.9 - SITE PHOTOS

LEVIN FIELD

VIEW NORTH FROM SITE

VIEW OF SITE FROM SOUTHWEST

Site Planning

Site planning guidelines are outlined in the Planning and Design Guidelines provided by Stanford Campus & Design Planning (*see Appendix)*. The Guidelines establish a preference for main entrance facing west toward the open field and existing access path. This main entrance will be shared by residents and researchers and articulated by a porch overlooking the field and path where both sets of users may interact. After studying various options, including splitting residential and research entry points, the project team determined that a shared entry foyer/information center could provide for security beyond while providing for a center point for the overall program *(see figure 3.10)*. Visitors and non-residents will be allowed controlled entry into this space during certain hours. The design will accommodate various levels of security that can be adjusted over time as patterns of use are tested.

A private, outdoor garden/barbeque/seating area will be located immediately to the south of the dining room and lounge. The east side of the building fronts on an access road. All loading and trash/recycling pick-up will occur here. A shared screened trash and recycling enclosure is proposed immediately across the access road to combine functions with Casa Italiana, which currently uses an unscreened trash dumpster. A 10' wide path running along the north side of the building will connect with an existing path running from Mayfield Avenue between Xanadu and Casa Italiana. Screened bike parking will be provided at the northeast corner of the building, along this path and adjacent to the main entry.

Stormwater management will be an important factor in designing the site. Integrative stormwater best management practices (BMPs) will be used to improve stormwater runoff water quality, facilitate infiltration, and act to retain smaller storm events onsite. However, large storms will produce excessive runoff and will be allowed to exit the site as overflow runoff to the Stanford storm drains.

A rainwater harvesting system will capture much of the rainwater falling on the building. Site

FIGURE 3.10 - ENTRY AND ACCESS DIAGRAM

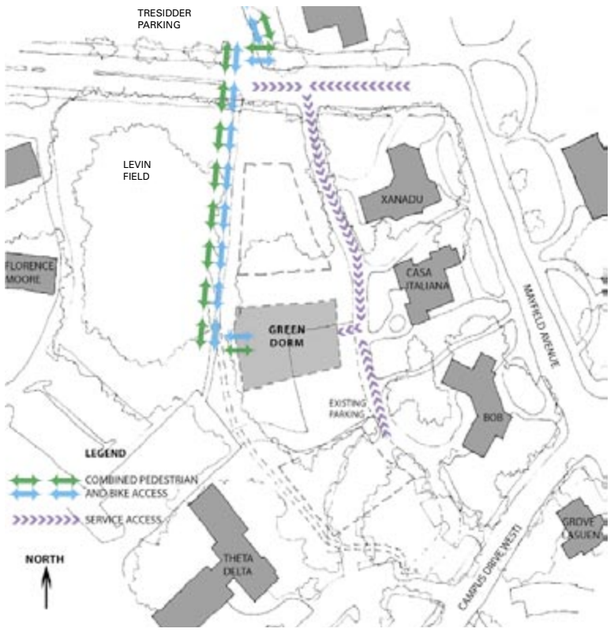


FIGURE 3.11 - ROW-HOUSE NEIGHBORS AND PRECEDENTS

FIGURE 3.12 - CONCEPTUAL PLAN STUDIES (SITE ONE)

U-SHAPED SCHEME, GROUND AND UPPER PLANS

T-SHAPED SCHEME, GROUND AND UPPER PLANS

H-SHAPED SCHEME, GROUND AND UPPER PLANS

housing
common space
service / wc
foyer / horizontal circulation
vertical circulation
research / education
porch / deck

stormwater will be captured by integrated stormwater features, such as bio-infiltration swales, rain gardens, or naturalized swales, or be infiltrated back to the groundwater. Landscaped areas and stormwater features will be planted with native and drought tolerant plantings to reduce irrigation demand. Permeable paving at both the front and back entrances of the building (east and west sides) will help retain and recharge stormwater. Excavated subgrade material will be removed, stockpiled, and reused on site.

Site development must not inhibit future development of the two adjacent row house sites. Solar shading impacts on site one due to development of the Green Dorm on site two were found to be minimal and avoidable with sufficient setbacks.

Site development will require the removal of 56 existing parking spaces. There is an option to replace 34 spaces on both sides of the road leading to the Theta Delt parking lot.

Architectural character

The Stanford row houses contribute a unique character to the residential campus *(see figure 3.11)*. Many of these houses were built in the late 19th and early 20th centuries as fraternities and sororities and have since undergone numerous renovations since being converted to student dorms. Others will built in the 1960's and 1970's as row houses while still others were originally occupied by single families, then were donated to the Univeristy, and absorbed into the electic mix of row houses. The resulting diversity of interior spaces and exterior image is a well-loved feature of these houses and fundamental to their identity. A key goal for the Green Dorm design is to fit into this context and *feel* like a row house to the students who live there. To accomplish this, spatial diversity and the character of a large house will serve as guiding design principles.

Conceptual Building Design

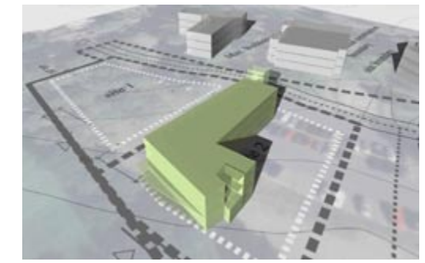
Initial studies

We first examined several different plan configurations on Site One, comparing U-, L-, T- and H-shape buildings for their energy performance and programmatic fit (*see figure 3.12*). Solar orientation—both for energy performance as well as thermal and visual comfort—served as a guiding principle for both massing and programming. The maximum number of student rooms and widely-used common spaces face south. Western exposures are kept to a minimum but open up selectively to admit views and access to Levin Field and the building entry.

Student feedback provided critical insights into preferences for residential layouts and common area orientations and adjacencies. Strong student interest was expressed in a roof deck, more resident exposure to the lab space, a centralized bathroom cluster, and north and south-facing dorm rooms.

Once Site Two was selected, we developed three options based on the feedback received for the Site One schemes (*see figure 3.13*). Option C was selected for further study and forms the basis for the design proposal outlined in this Report.

OPTION A: Long axis oriented to maximize south and north exposure, short leg froms strong entry facade. Outdoor space shaded in afternoon



OPTION B: *Inverted "L" shape. opens to southwest; presents weak facade at entry*

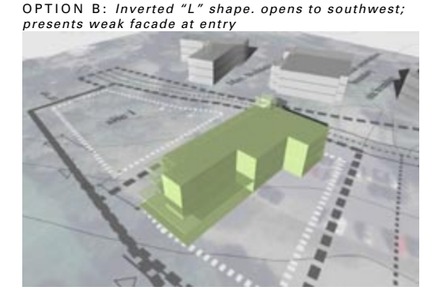
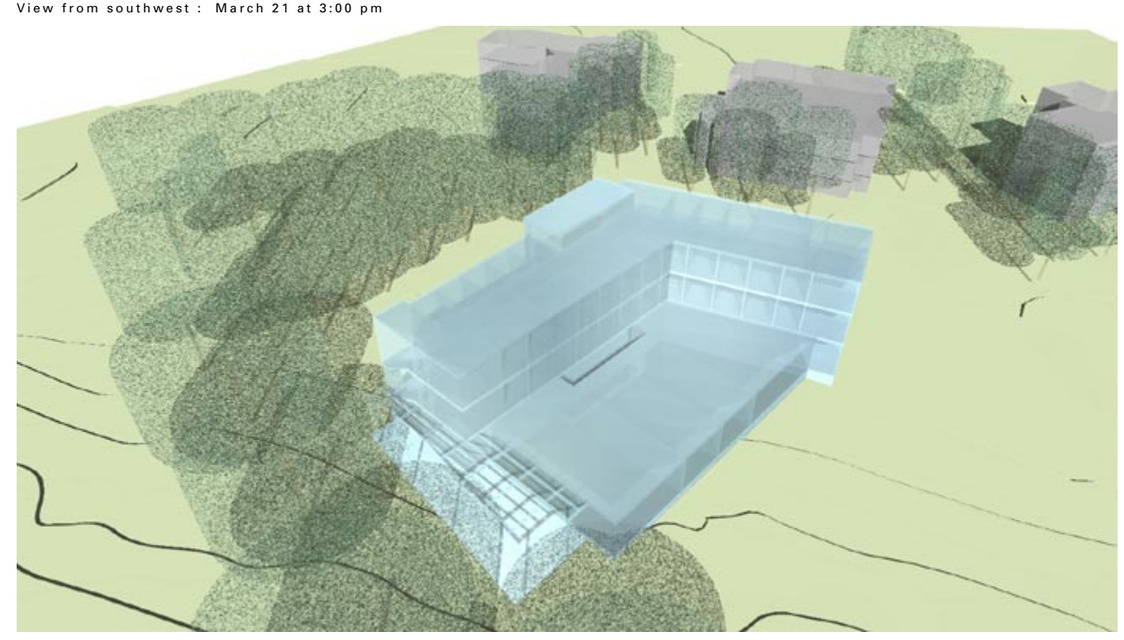


FIGURE 3.13 - BUILDING MASSING STUDIES

OPTION C
View from southwest : March 21 at 3:00 pm



Design proposal

Two stories of housing sit above a larger ground floor footprint containing most dorm common spaces. No basement is required. The initial program suggested that the building systems laboratory would be located in a basement, along with storage and the laundry, for a total of four stories with one below grade (the design guidelines require that the building be a maximum of three stories in height). Further study revealed several advantages to eliminating the basement and locating these elements above grade, including: cost reductions due to elimination of elevator (required for educational program) and subgrade construction; indoor environmental quality of above-grade research space; and multiple uses for roof deck space above expanded first floor. Concerns over loss of exterior space due to larger footprint were mitigated by design studies that showed sufficient exterior dining and garden space on the south and the addition of exterior common space on the roof deck (*see figure 3.14*).

Residents, visitors, and researchers will access the building from the west through a shared foyer/ "information center" featuring real-time information and permanent displays on building features (*see figure 1.0*). This is currently conceived as a widened hallway providing access to the ground floor spaces and stairs to the upper floors. Security details will be addressed further during schematic design but visitor and researcher access will remain limited to the ground floor.

The main lounge receives light from south and west exposures with direct access to the porch, field and landscaped areas. The tech center/computer cluster and game room receive well-shaded southern light while the dining hall opens out to a south-facing bbq and outdoor dining area. The building systems laboratory occupies the entire north side of the building, where diffuse northern light and reduced heat gain serve energy and daylighting goals. An "plug-in electric vehicle" garage is attached at the east as a saddlebag to the lab. All other functions which require service,

FLOOR PLANS

FIGURE 3.14A - GROUND FLOOR PLAN

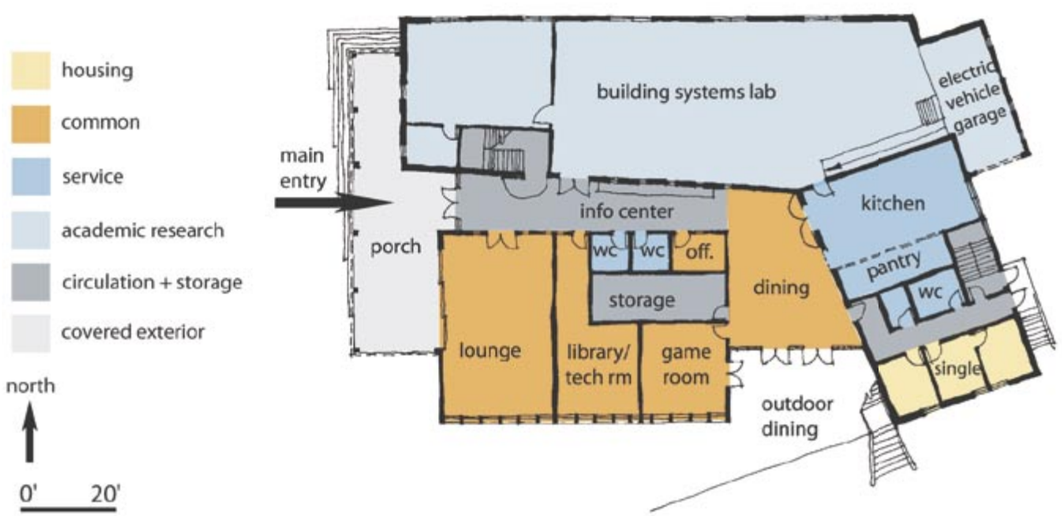


FIGURE 3.14B - THIRD FLOOR PLAN

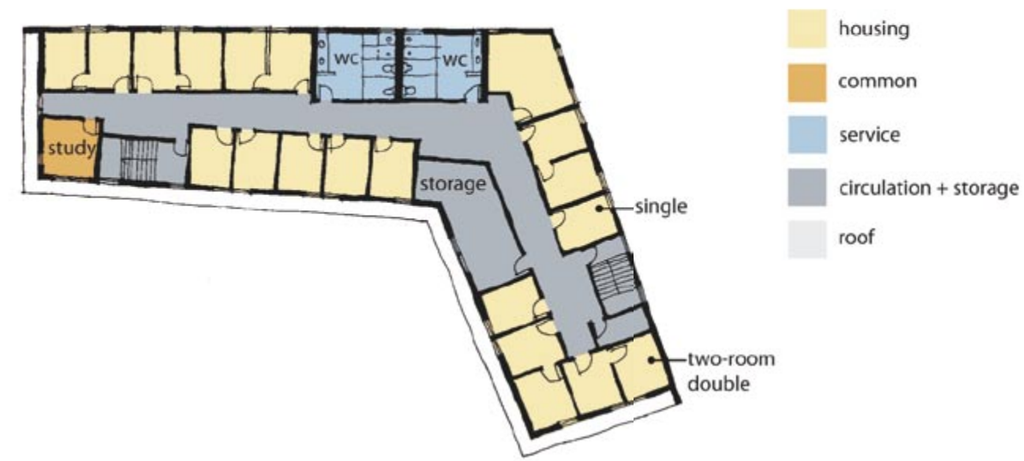


FIGURE 3.14C - SECOND FLOOR PLAN

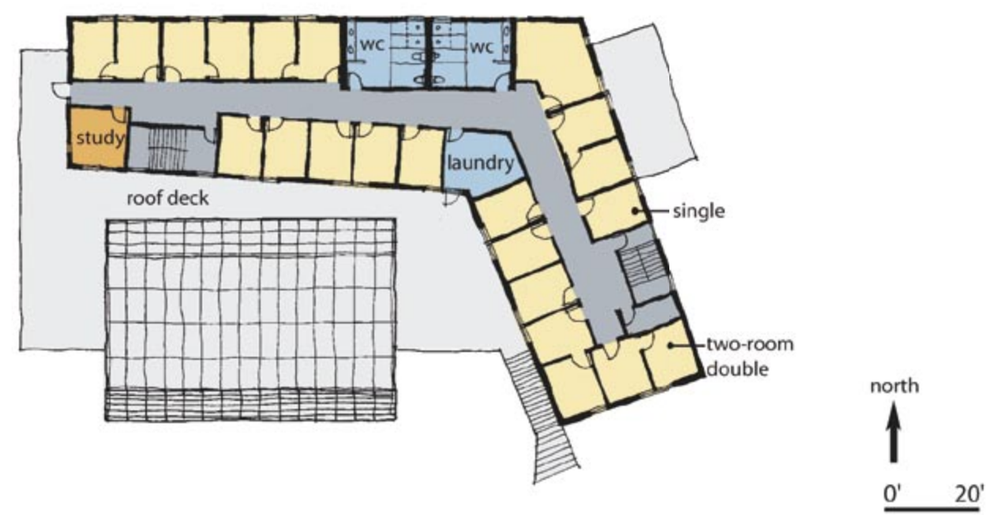
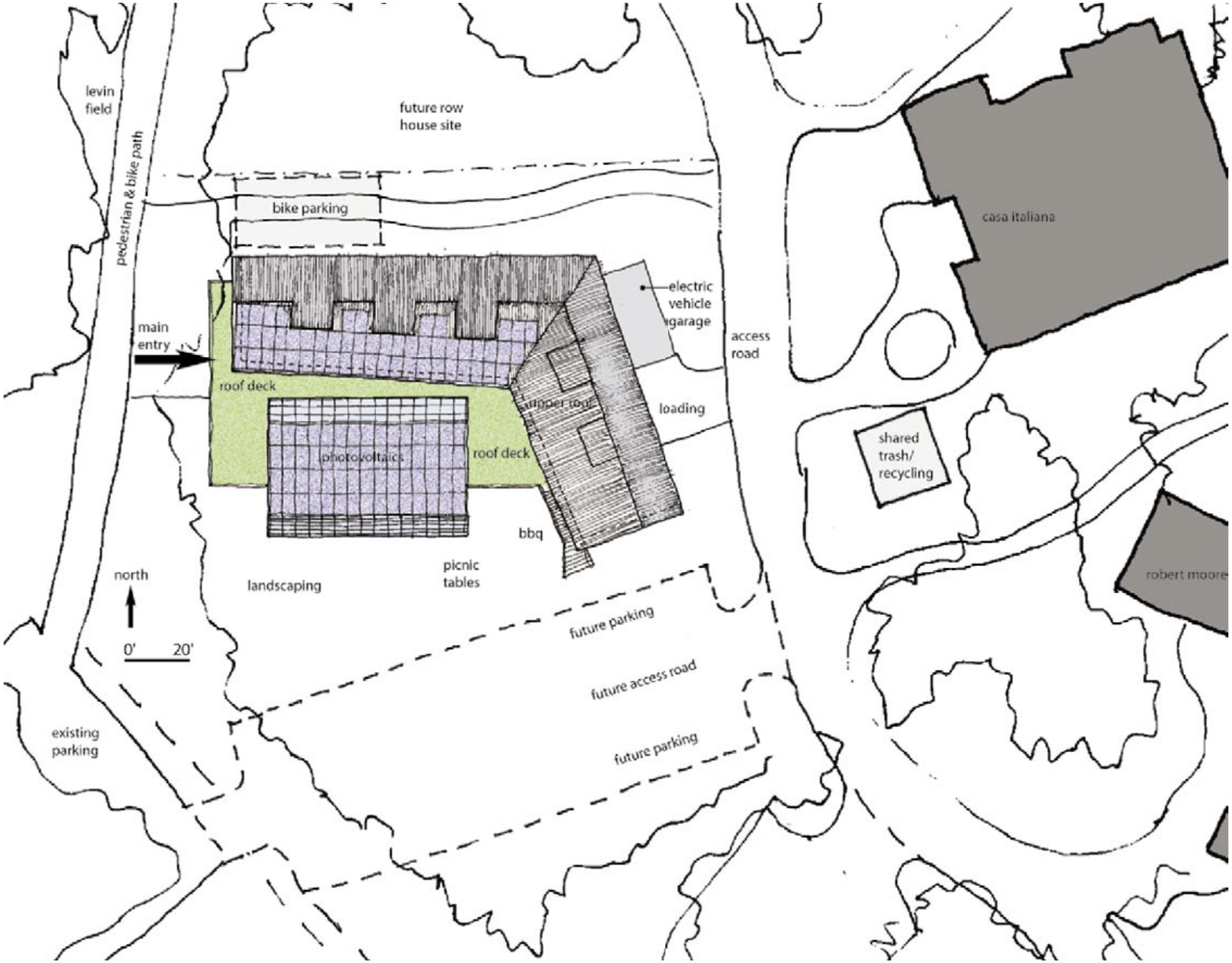


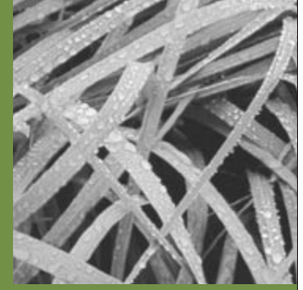
FIGURE 3.15 - SITE AND ROOF PLAN



loading, and car access, including the kitchen and lab, are accessible from the service road to the east *(see figure 3.15)*. Three accessible housing units, an accessible washer and dryer, and accessible bathrooms will be provided on the first level.

The massing of the upper two floors is shaped by solar orientation and the housing unit types. 36 out of 47 dorm rooms receive south or north light, enhancing energy performance and thermal and visual comfort. The unit type choice of singles and two-room doubles results in a narrow building width of 32' to 36' feet, with corridors which widen to accommodate ventilating lightwells, allowing stack ventilation and daylighting through an operable clerestory above. The eastern wing orients parallel to Mayfield avenue and the neighboring row houses, forging a connection with neighbors that is visible to passersby. Study rooms receive abundant light and views on the southwest corner with direct access to the roof deck on the second floor (*see figure 3.14C)*. A main laundry room on the second floor includes solar drying cabinets and access to the roof deck for line drying.

The roof deck will accommodate outdoor social and study space along with experimental green roof plots, photovoltaic panels, and unknown future monitoring devices. An exterior stair will join the outdoor dining and landscaped area to the deck above. The deck space above the west-facing porch should serve as the primary social space while other areas are assigned to PV arrays and green roof. North-facing operable skylights will bring cross-ventilation and balanced daylight down to the information center, dining hall, lounge, office, and restrooms. This unique above-grade, outdoor space should help the Green Dorm forge a unique visual and social character (*see figures 1.5-1.7)*.



a living laboratory for research

A vehicle for ongoing research and learning in sustainable engineering and design

A living case study for School of Engineering coursework and independent studies

Data collection and analysis to test and demonstrate systems and strategies

Built-in adaptability to invite future modifications

A Living Laboratory for Research

Overview

What does it mean to say a building is "living"? All buildings have a life after they are built in which users and uses change, equipment is upgraded and partitions are put up and taken down. Such changes are usually traumatic to the building's physical structure and operating budgets. The difference here lies in the design intent: this "Living Laboratory" is planned to serve as a *vehicle for research and learning* for many years to come.

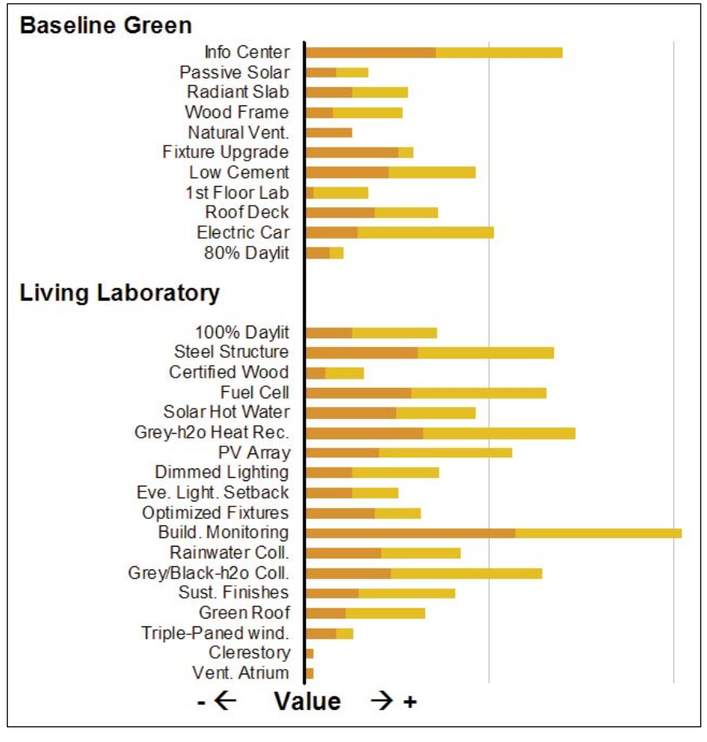
Transformation will occur over the short and long-term. As building monitoring reveals the subtle workings of the building ecosystem, refinements can be made to improve performance; as building technology continues to advance over the next several decades, equipment can be upgraded so that that researchers can always be gathering data on the latest in technology; and as test data verifies the utility and safety of innovative strategies such as water recycling, flexible plumbing systems can allow reconfiguration of water flows.

This ability to alter the building requires built-in adaptability: structural and architectural plans, construction details, plumbing connections, access capabilities, and electrical and data systems must be designed with flexibility in mind to invite future modifications.

The CEE department will be seeking a permanent endowment to fund this ongoing research program.

VALUE OF OPTIONS: RESEARCH & DEMONSTRATION

SEE APPENDIX A FOR MORE INFO



Areas of Experimentation

The department of Civil and Environmental Engineering contains four core groups - Environmental Engineering & Science, Environmental Fluid Mechanics & Hydrology, Construction Engineering & Management, and Structural Engineering & Geomechanics - each of which will incorporate their research projects in the building's lab space. The housing component of this project will serve as the data collection point while the building systems laboratory will be the site of data analysis, equipment testing, and the development of powerful new technologies.

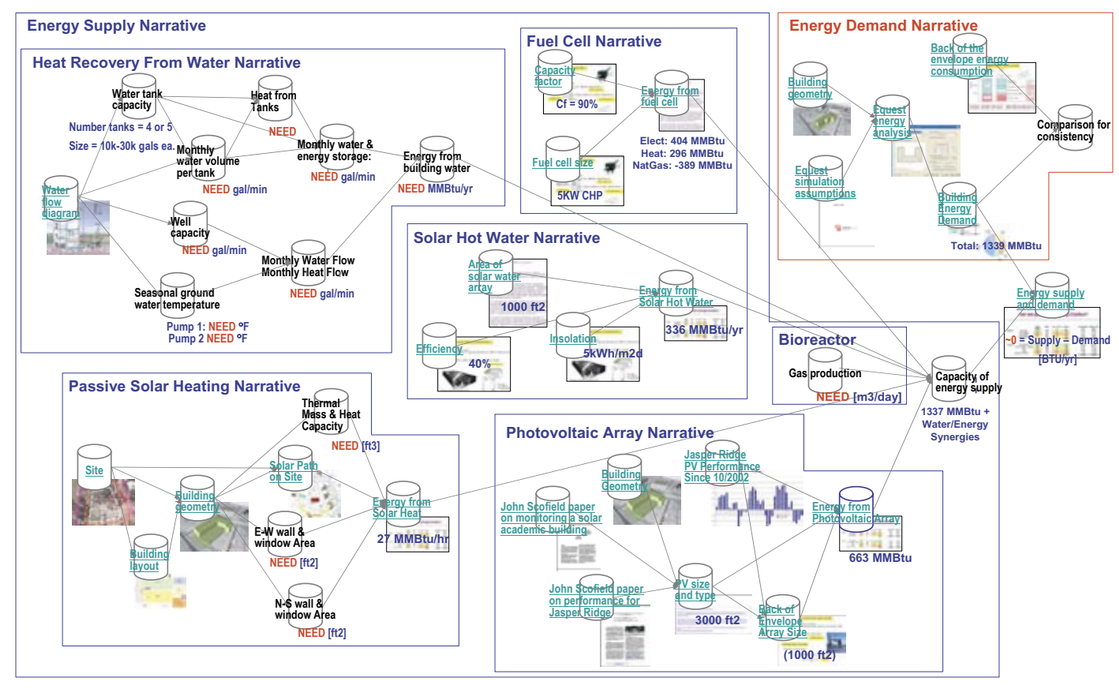
The following research proposals by faculty in CEE and affiliated departments provide a glimpse into the range of critical inquiries for which the Green Dorm would act as host. While the precise subjects of engineering research are certain to evolve over the next 100 years these examples should serve as good benchmarks for the scope of research that will be accommodated in the design.

Design and Construction Process

John Haymaker - *Assistant Professor, Construction Engineering and Management*

Architecture, Engineering, and Construction (AEC) projects require multidisciplinary solutions. Today AEC professionals have formal methods to help them manage and communicate much of a single discipline's information; however, they lack formal methodologies to manage and communicate information and processes among multiple disciplines. As a result, AEC projects have difficulty quickly and accurately achieving their many objectives. Using the Living Laboratory as a case study, we are designing and testing several methodologies to help AEC professionals overcome these difficulties to achieve more successful and sustainable projects. Using our POP methodology we are organizing project information models in terms of the functions, forms, and behaviors of the design and construction products, organizations and processes. Using our Narrative methodology we are communicating and managing the integration of the design and construction processes by defining and controlling the dependencies between information models. Using our Decision Dashboard and MACDADI methodologies, we are considering tradeoffs amongst options and documenting decisions. The scientific purpose of this research is to define and test formal methodologies that help teams manage and communicate relationships and processes between multidisciplinary design and construction information. The practical purpose is to help AEC professionals improve their multidisciplinary projects

FIGURE 4.1 - ENERGY SUPPLY AND DEMAND NARRATIVE: AN EXAMPLE OF PROCESS MODELING FROM THE FEASIBILITY STUDY



Sensing and Monitoring

Anne Kiremidjian - *Professor, Structural and Earthquake Engineering*

Philip Levis - *Assistant Professor, Computer Science and Electrical Engineering*

Dense monitoring of the building presents research and educational opportunities. We imagine a spectrum of monitoring, ranging from interior living spaces (e.g., power draw from each outlet, air quality, water consumption and quality) to structural monitoring (e.g., humidity, vibration, and mold within the walls) (*see figure 4.2 and 4.3*). The computer science research challenges include displaying this dense information, supporting user queries, and a wide range of networking challenges. The structural engineering research challenges include analyzing this dense data to obtain a better understanding of building dynamics, load, and deterioration/durability. This data would inform residents on how their lifestyle affects resource consumption, and the data sets would be excellent educational tools for understanding building, inhabitant and network dynamics. Similarly, projects can be designed around these networks for students to determine the basic understanding of structural behavior and the relationships between loads and structural response as well as to characterize various uncertainties that have become critical in our design process.

Eduardo Miranda - *Assistant Professor, Design/Construction Integration*

We are contemplating various kinds of sensors for structural monitoring in the Green Dorm including: (a) accelerometers; (b) displacement transducers; (c) inclinometers (*see figure 4.4*). One idea that we have talked about is to have a relatively large number of channels available for multi-purpose sensing in the building. Data from all sensors could be remotely viewed/monitored/analyzed. We are interested not only in the structural data itself, but also on research aspects related to wireless sensing networks inside of buildings.

FIGURE 4.2 - WIRELESS STRUCTURAL SYSTEM SENSING DEVICE

FIGURE 4.3 - STRUCTURAL SYSTEM SENSING

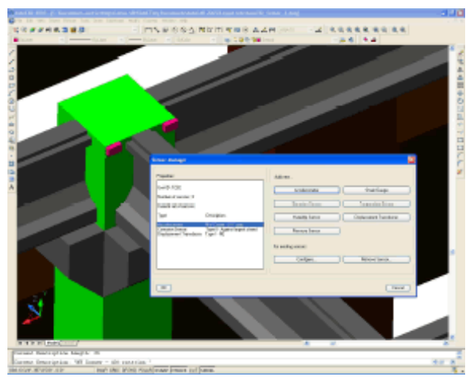


FIGURE 4.4 - INCLINOMETER

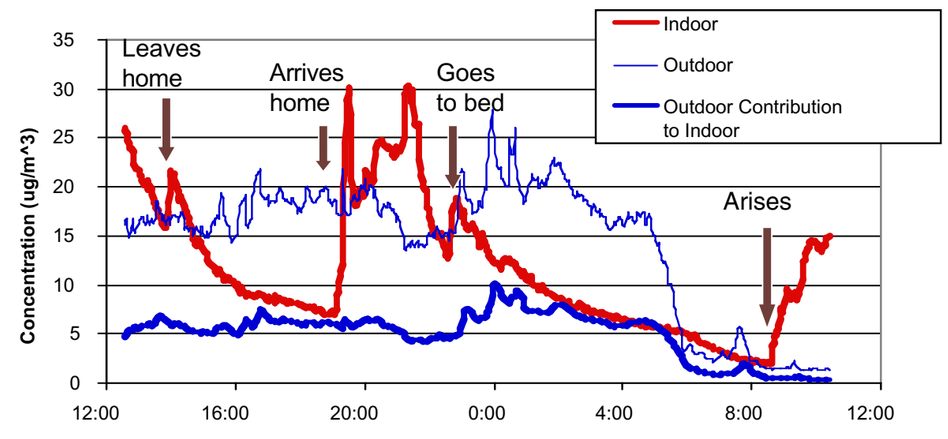
Lynn Hildemann - *Associate Professor , Environmental Engineering and Science*

Sensing Air Pollutant Levels in the Green Dorm

The average California adult spends 89% of the time in indoor environments, where pollutant levels can differ greatly from outdoor levels. As is shown by the graph below, when a person is at home and awake, the levels of airborne particulate matter (PM) indoors greatly increase, often substantially exceeding outdoor levels. Typically, only about 1/3rd of the outdoor PM penetrates indoors (*as can be seen by comparing the heavy and light blue lines in figure 4.5*). Thus, when a person is at home, a very large portion of the total PM indoors originates from indoor sources, such as dust resuspension and cooking activities.

Continuous monitors are now becoming available for measuring levels of PM and other air pollutants as a function of time. Having power and data downloading connections available to discreetly place these monitors in communal areas and the kitchen would allow rich datasets to be collected showing how pollutant levels vary indoors with specific activities and times of day.

FIGURE 4.5 - INTERIOR AIRBORNE PARTICULATE MATTER LEVELS



Water

Craig Criddle - *Professor, Environmental Engineering & Science (EES)*

Proposed Research for Anaerobic Digesters

Facilities for two Green Dorm digesters will provide an opportunity to assess the effects of different operating conditions on small-scale energy recovery from domestic wastewater (black water, potentially including also food scraps). A base configuration of two well-mixed anaerobic digesters is proposed. This configuration would be modifiable: when the reactors are operated without mixing, they become septic tanks; when they are operated with sidestream filtration, they are membrane bioreactors. For each of these systems, a wide variety of operational conditions may be evaluated, including temperature, nature of the feed (± food scraps, ±urine), and levels of buffer addition (pH).

The following are representative research questions:

- What are the rates of hydrolysis of organic polymers (fats, proteins, complex carbohydrates)?
- How do microbial populations shift in response to different operational conditions?
- What is the fate of personal care products and other commonly used household products, such as the perfluorinated organics?
- What are the rates of transformation and biochemical pathways?
- Under what conditions would hydrogen production be practical? Is membrane–coupled fuel cell operation feasible?
- What measures can be taken to facilitate degradation of oil and grease from food processing operations?
- What energy-efficient systems can be used to treat the effluent?
- When the digesters are operated as membrane bioreactors, what operational conditions and membrane types minimize optimal membrane fouling and why?

FIGURE 4.6 - CURRENT ANAEROBIC MEMBRANE BIOREACTOR PROTOTYPE IN TERMAN ENGINEERING LAB

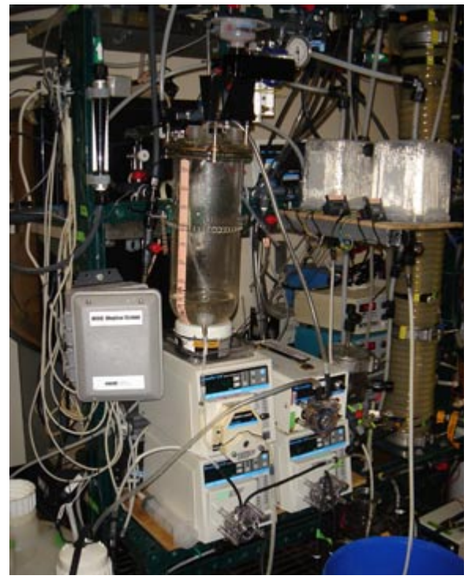


FIGURE 4.7 - PROFESSOR BOEHM GATHERING SAMPLES

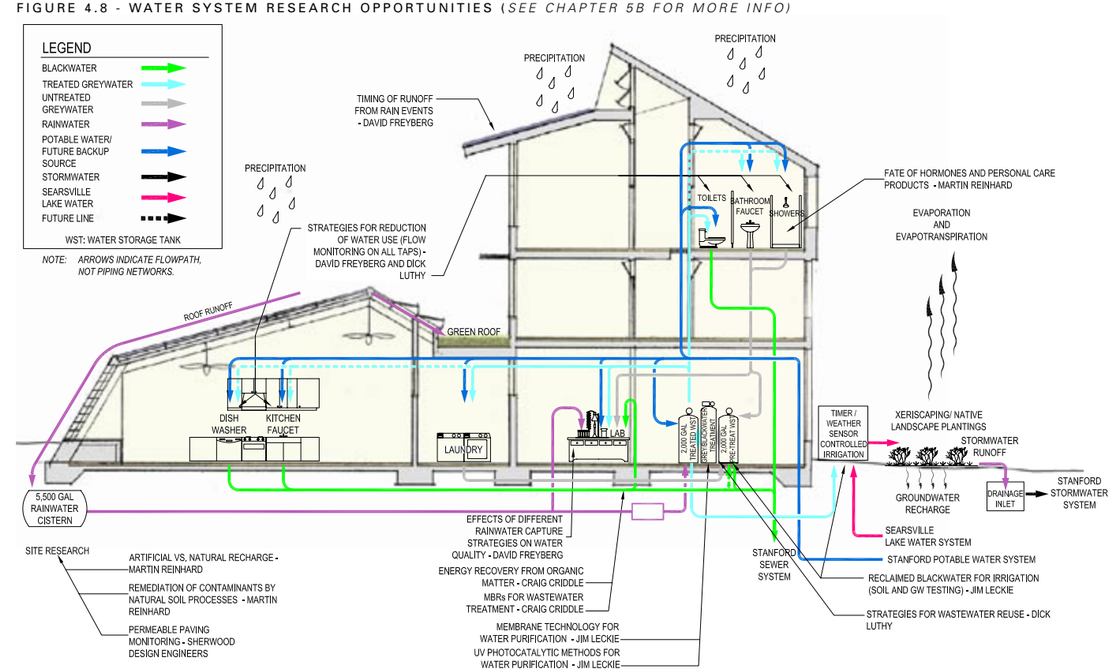
Alexandria B. Boehm - *Assistant Professor, Civil and Environmental Engineering*

Disinfection and Pathogens in Recovered Water

A major public health concern with the use of recovered water is the potential for waterborne illness. Two examples of experiments that could be occur at the Green Dorm are:

1) Recovered water can be tested for fecal indicator organisms or pathogens to assess the feasibility of recovered water for potable use.
2) The effectiveness of various treatment strategies (such as wetlands and UV lights) can be evaluated by measuring concentrations of indicator organisms or pathogens in the recovered water before and after treatment.

FIGURE 4.8 - WATER SYSTEM RESEARCH OPPORTUNITIES (*SEE CHAPTER 5B FOR MORE INFO*)



Richard G. Luthy - *Chair, Civil and Environmental Engineering*

Martin Reinhard - *Professor, Environmental Engineering and Science*

So-called emerging contaminants may be widespread in the environment but until recently have received scant attention due in part to the difficulty in detecting and quantifying these compounds in environmental matrices. Examples include organic compounds used in propellants, pesticides, pharmaceuticals, adhesives, coatings, and detergents. The removal of these compounds by wastewater treatment systems and their fate in recycled water reused for irrigation remains largely unknown.

Some chemicals present in commercial items, consumer goods, and personal care products may comprise a major class of toxicants in aquatic environments and these compounds need to be studied in order to gain public confidence in the safety of wastewater reused for irrigation. Two projects are:

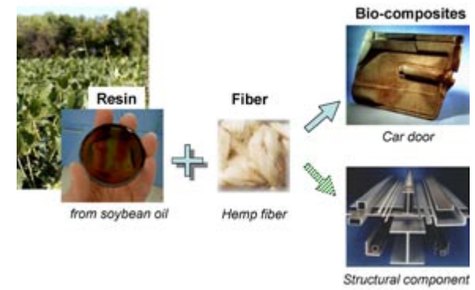
1) Monitoring which emerging contaminants are present in Green Dorm final treated water
2) Evaluating such chemicals in reclaimed water for irrigation using soil tests to determine whether these compounds may leach through soil.

Both projects would inform students about modern analytical measurements employed in water quality engineering and whether every-day products may pose untoward problems for water reuse.

FIGURE 4.9 - EXAMPLES OF CONTAMINANTS: *TRICLOSAN [CLEARASIL], IBUPROFEN[PHARMACEUTICAL], PERFLUORINATED CHEMICALS [SCOTCH-GARD], AND PESTICIDES*

FIGURE 4.10 - GAS CHROMATOGRAPH WITH MASS SPECTROMETER FOR ANALYSIS OF RECLAIMED WATER

FIGURE 4.11 - BIOBASED MATERIALS FOR BUILDING APPLICATIONS



Materials

Sarah Billington - *Associate Professor, Structural and Earthquake Engineering*

Research interests:

- Damage-tolerant fiber-reinforced cement-based materials for durable infrastructure
- Experimentation and simulation of high-performance materials and systems (e.g. self-centering bridge piers)
- Performance-based engineering
- Bio-degradable composites for the building industry

The Green Dorm project presents several opportunities for investigating the application of innovative materials that promote sustainable living. One current research area at Stanford is on the engineering of new materials made from renewable resources (e.g. fiber-reinforced plastics made from plant-based products) could be used in both structural and non-structural applications (*see figure 4.11*). This research is in early stages and samples of materials fabricated in our laboratory could be installed in the dorm (non-structural additions) to allow for monitoring of any in-service degradation (from air, temperature, moisture). The materials could also be investigated for biodegradability with or without initial treatments through on-site composting.

A second area of materials research focuses on the application of traditional cement-based materials that have been re-engineered to achieve properties such as high tensile strength and ductility, resulting in more durable as well as easily demountable and replaceable building components. If an example of such materials could be installed in various locations (such as for seismic resistance or possibly a non-structural application), the long-term response to load, temperature and moisture could be monitored. For all new materials incorporated, collaboration with sensing research would enhance the quality of the data to be obtained.

Structure

Greg Deierlein - *Professor, Structural and Earthquake Engineering, Director of the John A. Blume Earthquake Engineering Center*

Enhanced seismic performance of the Green Dorm

Working in conjunction with the design team, we are applying performance-based design concepts to evaluate the potential benefits of a steel frame alternative to conventional wood shear wall construction. Our strategy is to evaluate the expected damage and losses of alternative systems and components in terms of both direct economics and the broader green design issues. The steel frame alternative employs an innovative post-tensioned rocking frame (*see figure 4.12*), which has self-centering characteristics that can be tuned to optimize building performance to the earthquake hazard. In conjunction with the steel frame, we plan to investigate alternative partition wall designs that are more damage resistant to building drifts due to earthquakes. This aspect of the project may involve construction of testing of mock-up sections of partition walls. The wall testing and associated analytical studies of the enhanced seismic systems would require modest financial support for students and test materials, and commitment by the green dorm design team to collaborate with us on these studies.

While the main thrust of this project would occur during the design phase, we anticipate that a larger impact will be to use this design and an illustrative example to demonstrate the value of performance-based seismic design in the context of green building design.

FIGURE 4.12 - **ROCKING FUSE SYSTEM**: SCHEMATIC DIAGRAM OF INNOVATIVE STEEL BRACED FRAME DESIGN THAT EMPLOYS A CONTROLLED ROCKING MECHANISM TO REDUCE EFFECTS OF LARGE EARTHQUAKES.

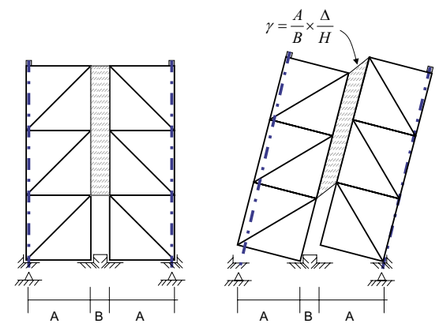


FIGURE 4.13 - RESULTS OF INCREMENTAL DYNAMIC ANALYSIS ON ROCKING STEEL FRAME

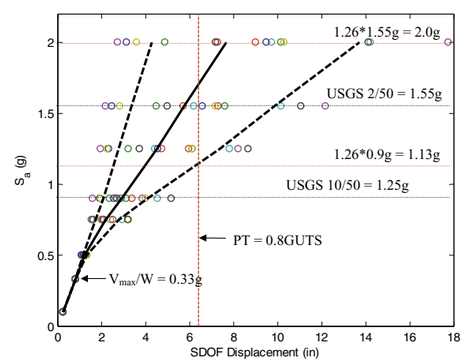


FIGURE 4.14 - WHISPER GEN MICRO-CHP UNIT

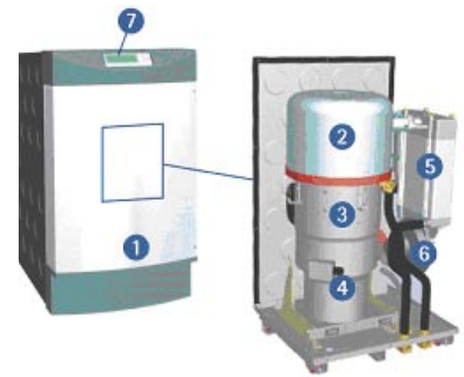
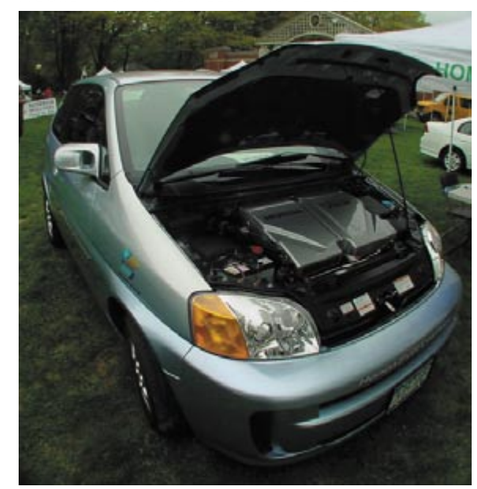


FIGURE 4.15 - HONDA ELECTRIC VEHICLE



Building Energy

Gil Masters - *Professor (Emeritus), Civil and Environmental Engineering*

Research Proposal for a Biogas/Micro-Combined-Heat-and-Power System

Biogas harvested from the wastewater treatment system could power a micro combined-heat-and-power (CHP) system based on an external combustion Stirling engine system manufactured by Whisper Tech of New Zealand. Their Whisper Gen CHP unit is the size of a home dishwasher and produces about 1.2 kW of electricity and 8 kW of heat with an overall efficiency of over 90 percent. (*see figure 4.14*) Research questions include the degree to which biogas must be cleaned to operate the Stirling engine, how well the system performs under varying thermal and electrical load conditions, and how suitable it would be for a home CHP unit.

Vehicle Energy

Gil Masters - *Professor (Emeritus), Civil and Environmental Engineering*

Chris Gerdes - *Assistant Professor, Mechanical Engineering*

Proposal for Vehicle-to-grid research

Vehicle-to-grid (V2G) systems using electric-drive vehicles (battery, fuel cell, or plug-in hybrid) with 2-way energy/information meters to allow buying and selling of power offer an intriguing combination of distributed generation, load management, and energy storage. The advantages of developing V2G include an additional revenue stream for cleaner vehicles, increased stability and reliability of the grid, and eventually, inexpensive storage and backup for intermittent renewable electricity.

With a dedicated vehicle bay, we will be able to determine the potential for electric-drive vehicles to provide load management services for the dorm, shaving peak demands, smoothing the electric load profile, and even providing emergency power for the

"This entire collaboration can ultimately help teach us as housing professionals how to incorporate green technologies and sustainable conservation efforts into our day-to-day Student Housing operations and into our long-term preservation efforts for our valuable residences at Stanford.

ALICIA RESTREPO Z., - *ASSOCIATE DIRECTOR OF HOUSING OPERATIONS, STUDENT HOUSING*

IMOGEN HINDS - *MANAGER OF PLANNED PROJECTS AND ENERGY MANAGEMENT, STUDENT HOUSING*

Equally important, the ever-escalating energy and utility costs are constant reminders of the need to find energy efficient and resource conserving ways to operate our residences. Through careful and creative conservation initiatives generated by this project, we hope to bring innovative operational methods from this prototype residence into our Student Housing residences."

dorm should the campus grid fail. With a soon-to-be-available plug-in hybrid van, we will be able to determine the practicality of providing local student transportation powered almost entirely from the building's fuel-cell, photovoltaic and other on-site electrical generation systems.

Demonstration

The results of Green Dorm research will not be relegated to scientific journals but will be actively demonstrated to the Stanford community and beyond. This central component of the project mission will take several forms:

- CEE curriculum integration during design, construction, and occupation
- Direct, on-site education for visitors and residents
- Replicable strategies for Stanford housing
- Online documentation of design, construction, research and performance
- Test site for building technology

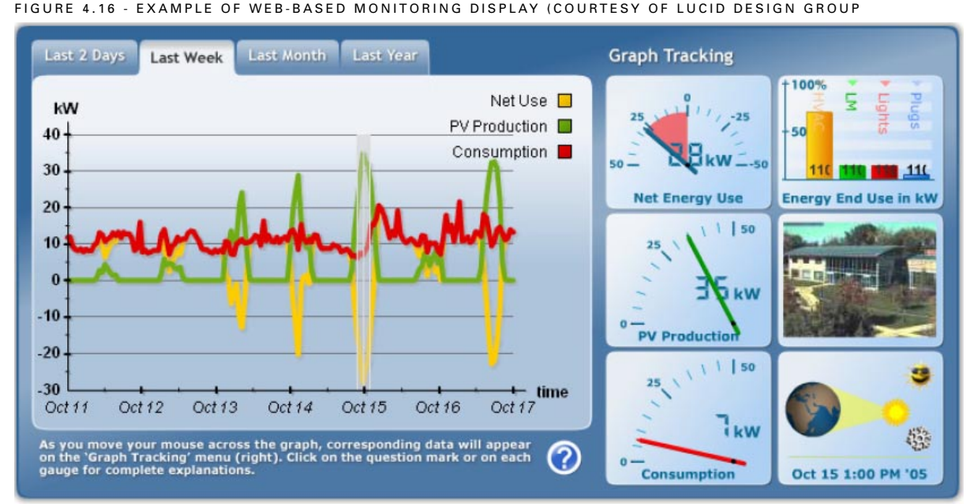
The audience, therefore, is wide-ranging: residents will, of course, get the most exposure and stand to gain the most from the demonstration capabilities (*see chapter 6 for further discussion)*; students in classes utilizing the Green Dorm as a case study are provided with a real-world example to ground their learning; Stanford students, faculty, staff and outside visitors will be able to access information and experience the architecture; and building professionals and academics worldwide will profit from the knowledge gained through ongoing monitoring and study of the building's performance.

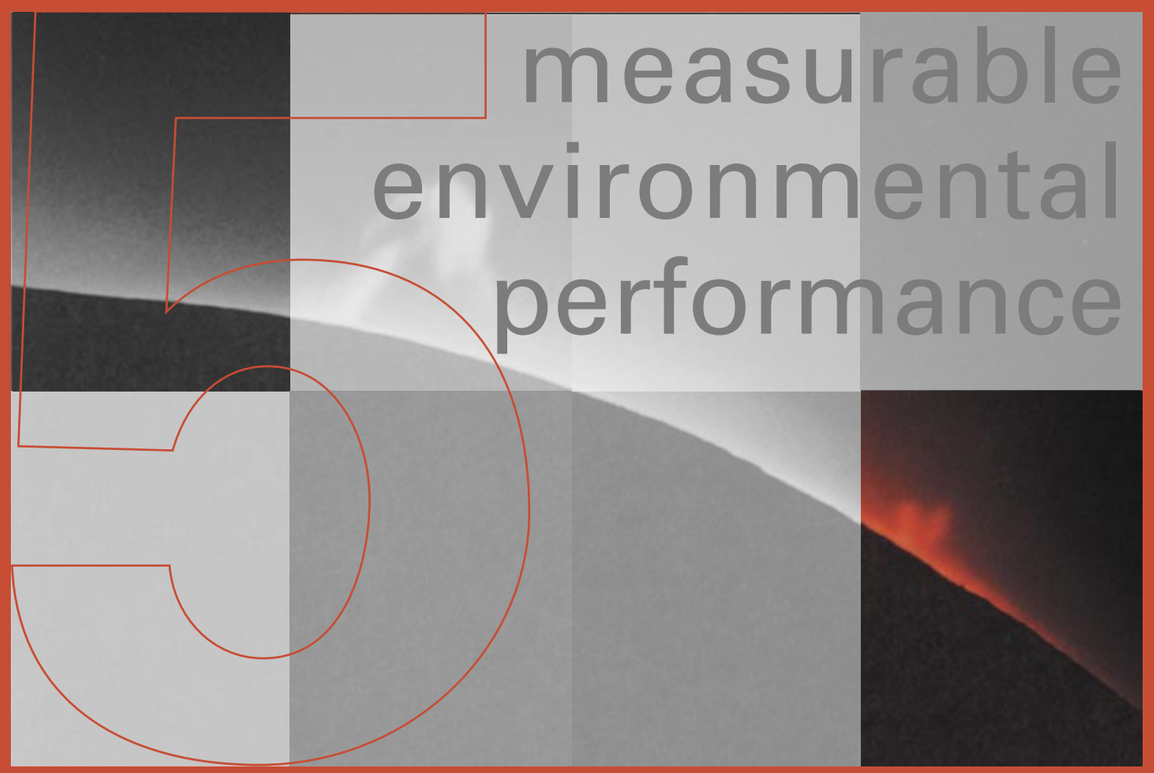
The following project features will figure prominently in this regard:

- *Information center / foyer* : [1] allows controlled view into building lab as well as dorm common spaces; [2] real-time, interactive display of building performance data; [3] computer terminal for access to web portal (*see figure 4.15*); [4] short-term exhibits
- *building systems laboratory*: [1] group tours; [2] class-based demonstrations
- *electric vehicle*: [1] car share program for residents; [2] visibility around campus
- *Roof deck*: [1] solar thermal and photovoltaic panels located for observation; [2] unspecified future equipment or experiments that require controlled exterior application [3] "green roof" performance monitoring
- *Web portal*: [1] information database on design, construction and ongoing research projects; [2] community discussion forum
- *Programs and events*: [1] lectures and discussions held in the lounge; [2] class trips (Stanford students as well as local schools); [3] summer housing for conferences; [4] lifestyle seminars (food, landscaping, design, other)

The Green Dorm project has already contributed in numerous ways to student education and research opportunities. This diversity and power of project-based learning will only expand when the project is built, occupied, and monitored. Many examples of this kind of hands-on education completed or in progress are provided in the Appendix.

FIGURE 4.16 - EXAMPLE OF WEB-BASED MONITORING DISPLAY (COURTESY OF LUCID DESIGN GROUP





measurable environmental performance

Zero Carbon Building

Eliminate net carbon emissions due to operational and embodied energy use over the course of a year

Close the Water Cycle

Reduce water use, capture rainwater, and recycle water within the building to ultimately eliminate the import of potable water and the export of wastewater

Optimizing Material Resources

Cut the embodied energy of building materials in half while reducing earthquake losses through high-performance structural design

Measurable Environmental Performance

Overview

The sustainable design goals of the Green Dorm are a reflection of the project's larger goal—to create the most desirable housing on campus combined with a living lab for research and demonstration—and to do this in a way that provides outstanding and measurable environmental performance. Too often green buildings are an ad hoc collection of fashionable strategies, with no academic rigor quantifying their specific environmental effectiveness or the user experience in the completed buildings. For the Green Dorm we are trying to establish quantifiable goals as far as possible, beginning with modeling and predictions during the design phase, and followed by detailed monitoring and evaluation during occupancy of the completed building.

Three primary sustainable design goals have been established that profoundly affect almost every aspect of the project. These are:

- Design a zero carbon building
- Close the water cycle
- Optimize material resource use

The design should not only strive to meet these goals, but also be a vehicle for demonstrating existing and emerging technologies for their educational and research benefits. With this in mind, the proposed design strategies are influenced by their academic and technical contributions in addition to more conventional considerations of performance and economy.

One of the most interesting challenges of sustainablility is how to combine various design elements in an integrated approach to problem solving. For example, it is no longer adequate for the structure to just support the building, it must also provide thermal mass to increase comfort, use materials more efficiently, include less embodied carbon, and be deconstructable. This integration between disciplines is essential and an area of rich possibility for collaboration across the design team and with University faculty and students.

ZERO CARBON BUILDING

Eliminate net carbon emissions due to operational and embodied energy use over the course of a year

PASSIVE DESIGN GOALS

- **Summer comfort without air conditioning**
- **Passive solar strategies for winter heating**
- **100% daylit interior integrated with electric lighting controls**
- **Radiant heat and natural ventilation for exceptional thermal comfort**
- **Super-efficient windows and envelope on residential floors**

PERFORMANCE TARGETS

- **20% less electricity and natural gas use than the current best row house**
- **On site generation of electricity to offset 100% of carbon impacts of energy consumption**

NOTABLE SYSTEM COMPONENTS

- **46 KW photovoltaic array**
- **475 SF solar hot water array**
- **Shower water heat recovery**
- **Water-source heat pump**
- **Radiant floor slab heat delivery**
- **Potential fuel cell or other "combined heat and power" device**

Zero Carbon Building

FIGURE 5.1 - CARBON EMISSIONS BY SECTOR (BY ED MAZRIA)

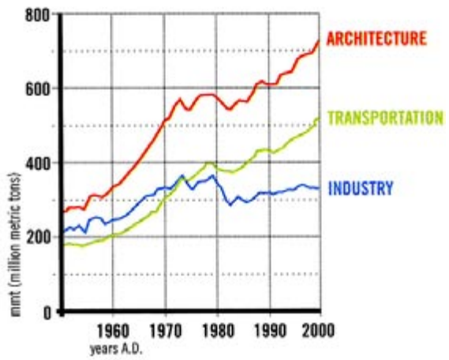
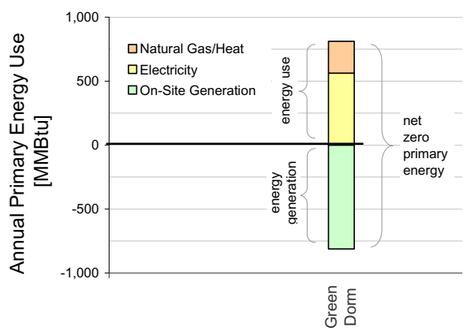


FIGURE 5.2 - PRIMARY ENERGY USE BALANCE



Overview

The first overarching goal of the green dorm is to create a Zero Carbon Building. This goal recognizes the fundamental challenge climate change poses to the global environment, and the major role the built environment plays in releasing carbon into the atmosphere (*see figure 5.1*). By far, the largest source of carbon associated with buildings is the energy they consume. The green dorm will address this issue by first significantly reducing energy use in the building and second, by generating enough energy itself to make the net carbon emissions for the building equal zero. To clarify the analysis, primary energy is used as a proxy for carbon emissions. Primary energy is the total fossil fuel energy use, whether natural gas used directly in the building, or fossil fuels used at a power plant to generate electricity used by the building. A building that has net zero primary energy use also has zero net carbon emissions.

Figure 5.2 shows that the primary energy use balance for the Green Dorm will be zero. Primary energy use is a measure of the non-renewable fuel required to deliver energy to a building and is most significant when considering electricity use. The efficiency of the "grid" is on average 33%, which means that for each 3 units of "primary" fossil fuel energy consumed, only 1 unit of electrical energy makes it to a building.

The bars showing positive values above the zero axis represent energy use in the building, and are broken down into natural gas and heat demands (orange) and electricity demands (yellow). The bar below the zero axis shows electricity that is generated by the photovoltaic (PV) array in the building and exported to the utility grid. The net sum of building energy use and the building energy generation is zero, making it a Zero Carbon Building.

The net zero value represents an annual balance of energy flows. At some times of the year the building will consume more energy than the PV's produce, and during the sunny summer season they will produce much more energy than the building consumes.

Figure 5.3 shows a breakdown of the predicted energy uses in the building shown again in terms of primary energy. The plug load values and the lighting values dominate the total at 41% and 31% respectively making almost three-quarters of the buildings primary energy demand. Both of these are electricity end uses (yellow) and it is largely because of the primary energy conversion factor of 33% efficiency that these values are such a large part of the total.

From a building design standpoint, through integrated design and careful attention to the building envelope and systems application, we have reduced the building heating demands dramatically and also reduced building lighting demands well below typical levels. There are a number of demands shown here, however, that the building design itself has little ability to affect. For example, natural gas used for cooking and "plug loads" connected to computers and other dorm room equipment as well as lighting used at night by students to study are end uses that we cannot design away.

Figures 5.4 and 5.5 present the bar graph data above in a pie chart format. These again make it clear that the heating/natural-gas use is roughly one-quarter of the total while the electricity uses make up much large remaining three-quarters of the pie.

Benchmarking

The strategy used by the Green Dorm to get to zero primary energy use and zero overall carbon impact is to reduce building demands as much as possible and then to generate enough energy on-site to offset the energy that is used.

The demand-side of this equation is critical since it is the driver for how large the expensive photovoltaic array needs to be for the building. We have evaluated a number of significant steps to reduce building energy demands as described in the section on integrated design. One way to gauge the effectiveness of these strategies and their cumulative effect is to compare the Green Dorm to other existing row houses on campus.

Figures 5.6 and 5.7 present actual Stanford Utilities metered electricity and natural gas use data for

FIGURE 5.3 - PRIMARY ENERGY USE BY TYPE AND END USE

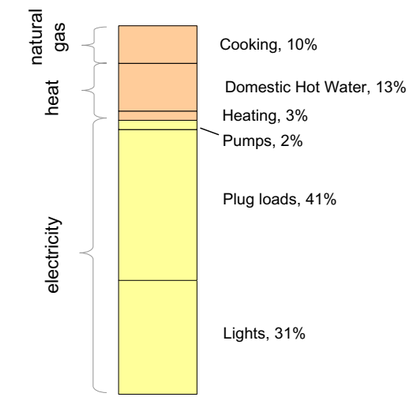


FIGURE 5.4 - PRIMARY ENERGY USE BY TYPE

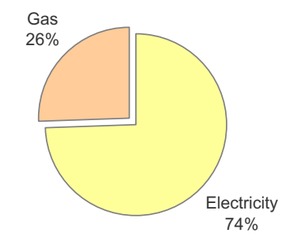


FIGURE 5.5 - PRIMARY ENERGY USE BY END USE

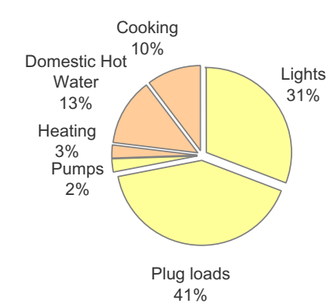
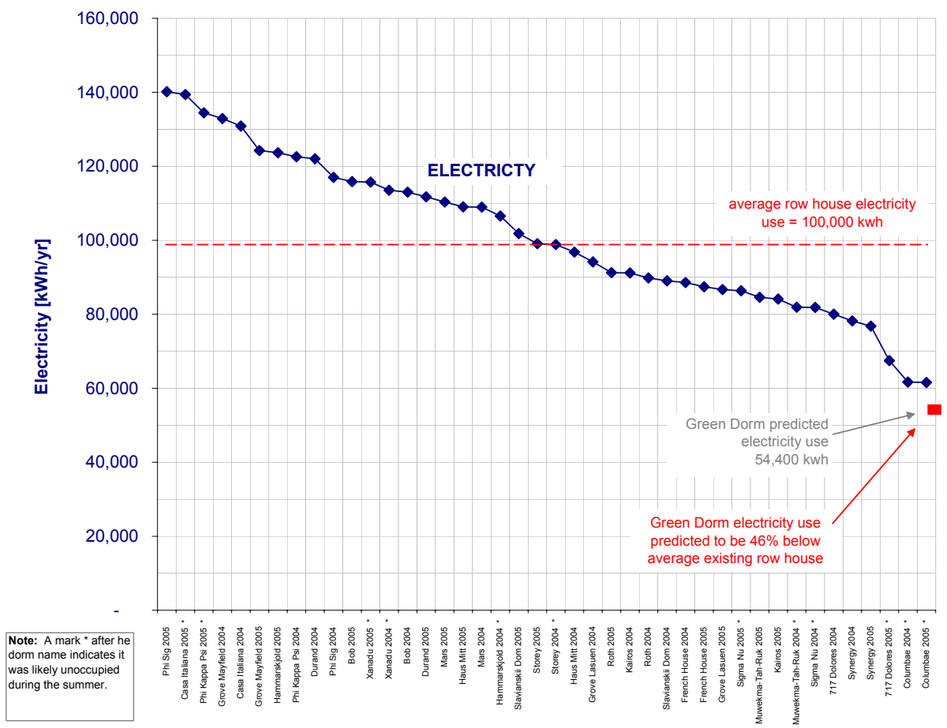
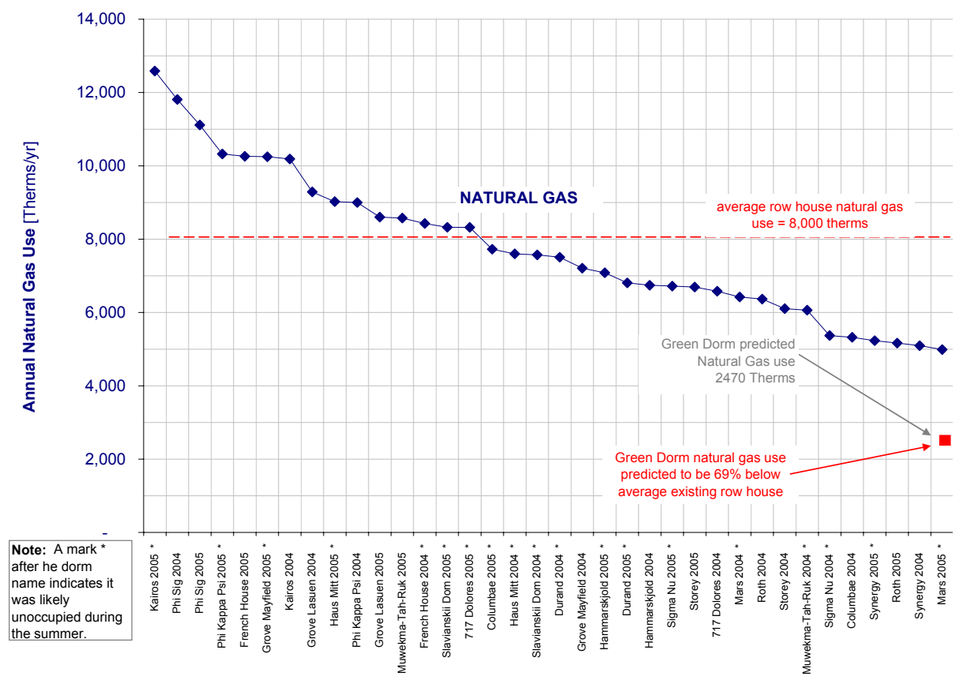


FIGURE 5.6 - ROW HOUSE ELECTRICITY USE FOR 2004 & 2005 (SCALED TO GREEN DORM SIZE AND DENSITY)



Note: A mark * after he dorm name indicates it was likely unoccupied during the summer.

FIGURE 5.7 - ROW HOUSE NATURAL GAS USE FOR 2004 & 2005 (SCALED TO GREEN DORM SIZE AND DENSITY)



Note: A mark * after he dorm name indicates it was likely unoccupied during the summer.

existing row houses at Stanford. Data is presented for both calendar year 2004 and 2005, so each house has two entries along the x axis. The data has all been scaled to match the Green Dorm size and occupant density in order to facilitate an "apples to apples" comparison.

The electricity graph shows that there is significant variation in electricity use among existing row houses. Because this data has been scaled to both dorm size and number of students, it's fair to read the data presented on this graph to say that in some dorms electricity use per student can more than double from one dorm to the next.

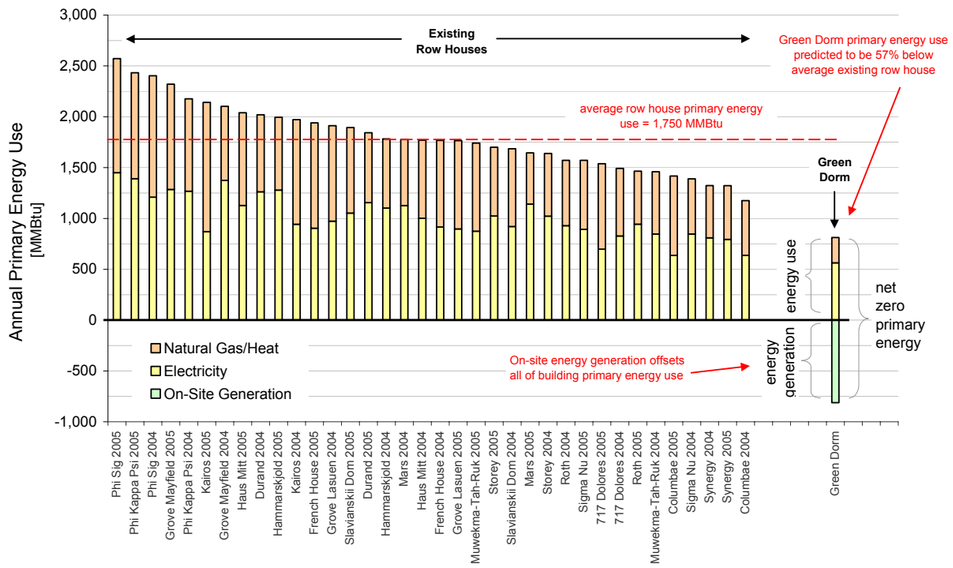
For the Green Dorm, our energy modeling, research, benchmarking, and design strategies point us to predict electricity use for the dorm lower than all existing row houses as can be seen by the red mark on the graph. We expect that the green dorm will be occupied through the summer and that summer occupancy is reflected in this annual estimate. A number of the dorms (marked with an asterisk) are likely unoccupied during the summer, which makes the Green Dorm benchmark even more significant.

The natural gas comparison graph also shows that there is a wide range of natural gas/heating demands across the existing row houses. Due to the integrated design strategies at play in the green dorm as well as providing an excellent thermal envelope, we predict heating/natural gas demands in the Green Dorm will be well below the existing row houses.

The graphs and data above have examined utility use in the existing row houses. Since our goal is to consider the primary energy impact of the building, figure 5.8 (next page) converts natural gas use and electricity use into consistent units of primary energy and incorporates the appropriate primary energy efficiency factors. Primary energy is presented in units of millions of Btu's (MMBtu) for the rest of this section.

Now with the data presented in consistent units, a trend is established showing a building design strategy that significantly reduces primary energy demand relative to other dorms and then makes up that energy with on-site generation to get to zero primary energy use. The far right bar showing Green Dorm "energy use" indicates a 31% reduction in primary energy use beyond the best existing row house and 57% below the average row house. On site electricity generation is sized to generate enough energy to offset the primary energy impact of the real building demands. The energy exported to the utility grid by the excess production from the PV array is shown by the green bar below the zero axis.

FIGURE 5.8 - ROW HOUSE ANNUAL PRIMARY ENERGY USE (ALL VALUES SCALED TO GREEN DORM)



Annual Energy Flows

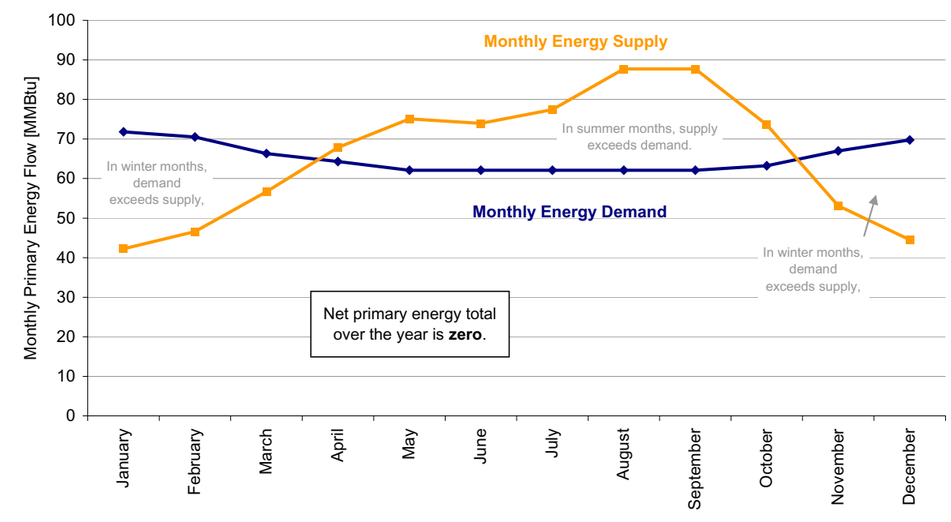
To understand how the Green Dorm will achieve the net-zero goal, it's important to consider the energy flows through the building across the seasons of the year. Figure 5.9 shows the primary energy demands and supplies in the building for each month. Figure 5.10 shows the data as "Total Demand" and "Total Supply" from the table.

In the winter, when days are short, the sun is low, and the weather is cloudy, the PV array generates less electricity. At the same time, heating demand increases. During winter the building is a net consumer and pulls electricity out of the grid. During late spring, summer,

FIGURE 5.9 - ESTIMATED GREEN DORM MONTHLY PRIMARY ENERGY DEMAND AND SUPPLY

	Demand				Supply			Totals		
	Domestic Hot Water	Space Heating	Electricity (Lights, Plugs)	Natural Gas (Cooking)	PV Electricity	Solar Hot Water Collectors	Heat Recovery System	Demand	Supply	Supply - Demand
Units	[MMBtu]	[MMBtu]	[MMBtu]	[MMBtu]	[MMBtu]	[MMBtu]	[MMBtu]	[MMBtu]	[MMBtu]	[MMBtu]
January	9	5	52	7	29	4	9	72	42	-30
February	9	4	52	7	34	5	8	71	47	-24
March	9	2	49	7	46	6	4	66	57	-10
April	9	1	48	7	58	8	2	64	68	4
May	9	0	47	7	67	9	0	62	75	13
June	9	0	47	7	65	9	0	62	74	12
July	9	0	47	7	69	9	0	62	77	15
August	9	0	47	7	79	9	0	62	88	26
September	9	0	47	7	79	9	0	62	88	26
October	9	1	47	7	64	9	0	63	74	10
November	9	2	50	7	43	6	5	67	53	-14
December	9	3	51	7	33	4	7	70	44	-25
Totals	102	18	583	80	667	85	35	783	786	3

FIGURE 5.10 - ESTIMATED GREEN DORM MONTHLY PRIMARY ENERGY DEMAND AND SUPPLY



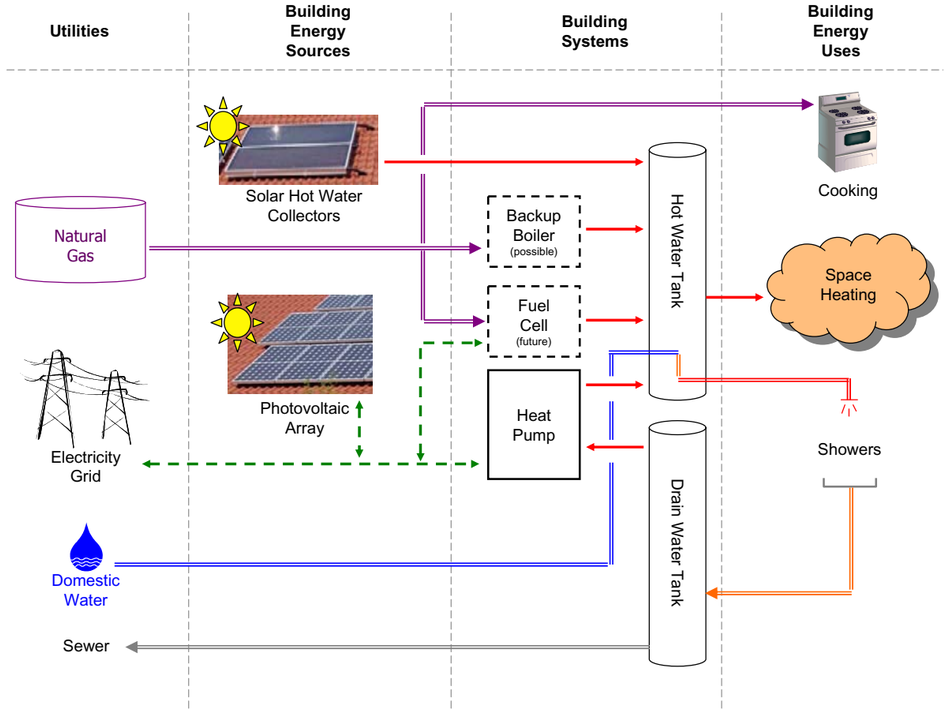
and early fall when the sun is higher, days are longer, and the weather is clearer, the PV array generates much more electricity and the building is a net electricity producer with the excess being exported to the utility grid. Over the course of the year, the "areas under the curve" for both the supply and demand lines equal, indicating that there is a net zero balance of primary energy use.

Building Systems Design Concept

The building systems installed in the Green Dorm make achieving the zero carbon goal possible. These systems move, recover, and generate energy and connect utility and local building sources with the demands of the users and building. The design team has spent much of the feasibility phase of work brainstorming, researching, and evaluating system concepts and strategies that are currently available in order to evaluate if the goal of a zero carbon building is reasonable and achievable.

The feasibility-phase design work suggests thata zero carbon building is an achievable goal, and it is especially so given that integrated design and proactive users allow for the energy demands in the building to be reduced significantly below other similar dorms on campus. The system design that best balances the multiple program elements and achieves project goals is presented in the schematic below (*see figure 5.11*). Plug loads and lighting loads that use electricity are left out of the diagram for clarity. This schematic focuses on the thermal systems in the building.

FIGURE 5.11 - SCHEMATIC BUILDING ENERGY SYSTEM



The proposed Green Dorm system employs a PV array as the primary energy generation source and a solar hot-water collector array as a secondary energy generation source. These are represented in the graphic in the "building energy systems" column. The building is attached to the utility grid with connections to natural gas infrastructure and the electricity grid as well as to domestic water and sewer services. These connections are shown at the left side of the schematic in the "utilities" column.

The building energy uses are shown at the far right, and include cooking, space heating, and showers/domestic hot water demand. A number of building systems connect the energy sources with the energy demands, and these are represented in the "building systems" column of the schematic.

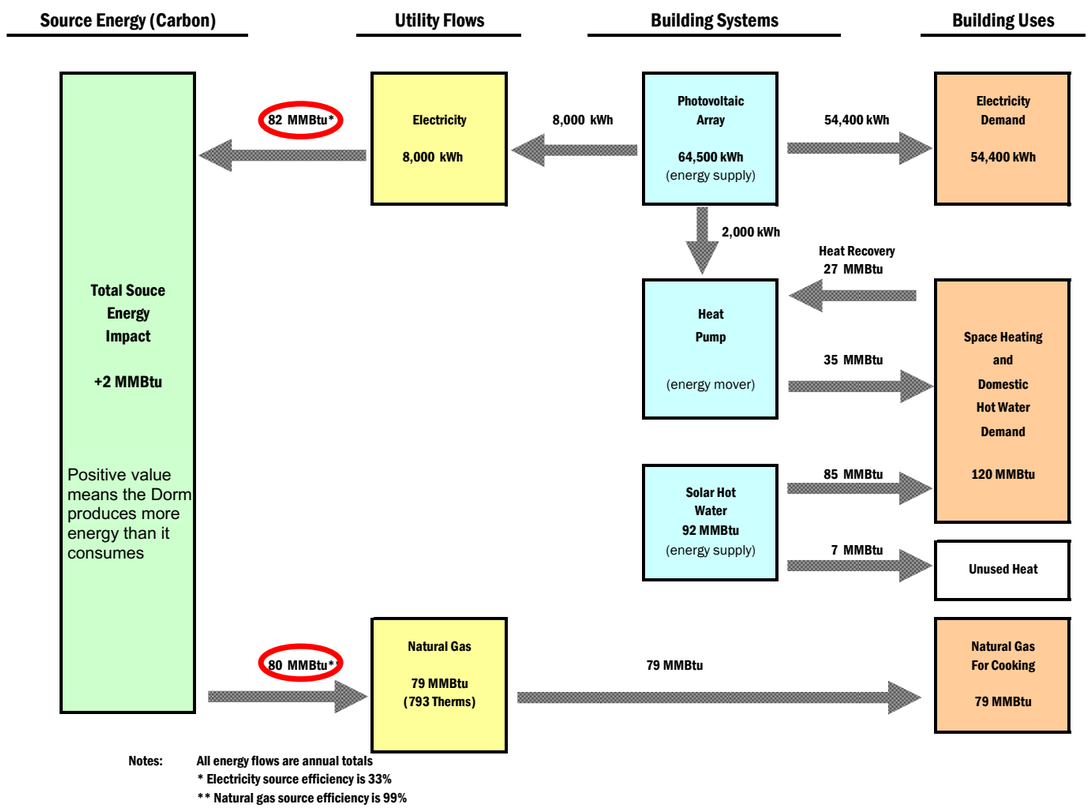
The basic building systems concept is one large thermal energy storage and distribution system with a series of sources and demands that balance out. Schematically, this is represented by a large hot water tank that will receive and store thermal energy for use when needed. This thermal storage tank and associated piping systems will be designed to facilitate a "plug and play" future where new technologies can be connected to the system as they become available and form part of the research program in the building. On the schematic, the fuel cell indicated with a dashed box represents one of may possible future technologies that can be incorporated.

Another important piece of the building energy balance is the domestic drain-water heat recovery system. Drain water is going to be collected as part of the gray water recovery system in the building, and the building energy systems will take advantage of this large tank of warm water by recovering heat from this water via a heat pump and then sending it back into the thermal storage tank. The "drain water tank" and "heat pump" indicated in the schematic represent the

JONAS KETTERLE
SOPHMORE
MECHANICAL ENGINEERING

"Over the past few months, I've excitedly watched the growing number of student research projects and the growing community involvement from alumni to staff to faculty. This widespread excitement has kept me busier than ever coordinating research, working on publicity, and refining the green dorm vision, but this is what I want to do: while my learning with the green dorm can't be measured in units or grades, it is a life altering experience that will guide me far beyond Stanford."

FIGURE 5.12 - NET ZERO ENERGY BALANCE



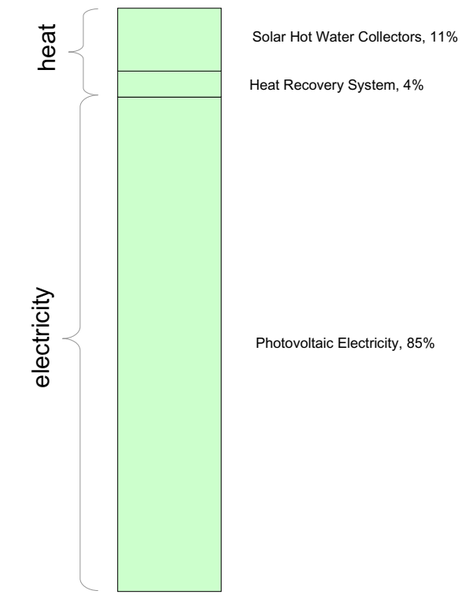
major components of this system.

The building system concept described above has been modeled and analyzed in this stage of design in order to test its feasibility and to evaluate the required component sizes for the purposes of cost estimating. Figure 5.12 presents that annual total energy flow-or net zero energy balance-through each major component of the system.

Another way to look at the system performance is to consider how the "supply" bar (the green bar) of the energy balance graphic first presented in this section is broken out. Figure 5.13 presents this data.

The PV array does the bulk of the work generating energy for the building. The solar hot water collectors and the heat recovery system together provide about 15% of the energy demand in the building. Although these elements are small, they are worth keeping for several reasons. First, these components are much less expensive than the PV array, so it's a cost benefit to the project to employ direct thermal generation/recovery where possible. Second, these components form an important part of the research and demonstration program for the Green Dorm.

FIGURE 5.13 - PRIMARY ENERGY SUPPLY



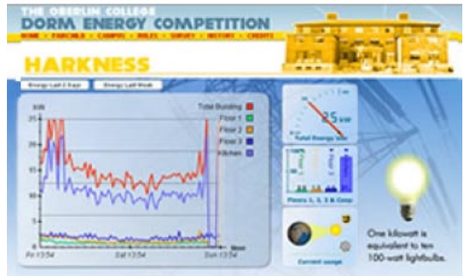
Controls and Monitoring

The last element in the building systems design for the Green Dorm is a controls system that will make all the individual system components work together in an integrated fashion. At the same time, this system will also act as a monitoring and data collection system to allow researchers and others to gauge whether or not the building has met its goals.

The Green Dorm controls and monitoring system will be a sophisticated, programmable, computerized system that will continuously control and measure all building systems. The system will be designed to comply with Stanford facility guidelines for other campus buildings so the building can be effectively integrated into the larger campus energy systems.

Data from this system provides academic research value, educational opportunities, and can provide feedback to the occupants that will allow them to understand how their behavior affects energy use. Building

FIGURE 5.14 - EXAMPLE OF MONITORING INTERFACE



energy research and real-world experience indicate that there are tremendous inefficiencies in conventional building operations. By "inefficiency" we mean energy that is not being put to useful work. For example, heating and cooling systems are running when buildings are empty or lighting is on in unoccupied spaces or when adequate daylight is present. It is our belief that building monitoring and operations advancements provide as much energy savings potential in the near term as any specific advanced technology.

Similar monitoring and feedback systems have been installed at other universities, such as the system by Lucid Design Group at Oberlin College where several dormitories entered into an energy competition based on their monitored energy use. Figure 5.14 shows an example of this web-based monitoring display.

The Green Dorm can make use of similar technologies, or, more likely, will build up its own interface to the building monitoring data that can come out of a student or faculty research project.

Integrated Design

A key goal of the Green Dorm is to achieve its ambitious energy targets while also creating an exceptionally comfortable and desirable living environment. To do this will require thoughtfully integrated design and a synergistic relationship with the natural energy flows at the site. This section focuses on proposed integrated design solutions that are primarily passive, all of which have significant architectural implications.

Integrated design takes a holistic approach to the multiple and often competing building needs. Solutions seek not to optimize a single variable, but to find a synergistic response optimized for the whole. This requires a design approach that bridges across the traditional disciplines, which too often address architectural design, structures, heating, cooling, and lighting using a sequential rather than an integrated process. From the very earliest stages of design for Green Dorm, the entire team including the client, students, housing, architects, and the complete engineering team have worked closely to try and identify and optimize synergies between the various systems and components.

This integrated solution should also rely as much as possible on the natural energy flows at the site, in particular solar energy for heat and light, along with breezes for natural ventilation, and day-to-night temperature swings for passive cooling. These strategies can dramatically reduce energy use, while actually improving comfort if done well. Giving occupants personal control of their environment with operable windows and access to natural ventilation significantly expands their comfort range. Occupants strongly prefer this connection to the outside, fresh air, and natural light if it stays within a reasonable comfort range. How to accomplish this is the subject of this section.

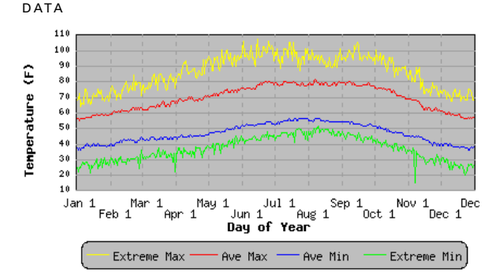
Summer Comfort

Until recently, none of the student housing at Stanford had air-conditioning (AC). Maintaining thermal comfort during peak conditions has been an issue at some dorms, and two recent graduate housing projects have included AC. The challenge for the Green Dorm is to provide exceptional levels of thermal comfort without AC in order to meet its aggressive energy targets.

The average daily maximum temperature in Palo Alto tops out at 80 degrees, moderate enough that mechanical cooling is not required most of the year (*see figure 5.15*). However, the peaks, or extreme maximum temperatures, can be much higher. The Green Dorm uses a number of strategies to maintain comfort during these peak conditions.

The largest source of heat gain for the Green Dorm is direct solar gain through its windows. To control this windows are properly oriented, carefully shaded, not oversized, and use spectrally selective glazing. The peak overheating conditions occur in summer and fall, from the middle of the day to late afternoon. During the middle of the day, the sun

FIGURE 5.15 - PALO ALTO HISTORICAL TEMPERATURE DATA



is high in the sky to the south, where sunshades can effectively shade the windows. Late in the day the sun is from the west and low in the sky making sunshades less effective. For this reason, the building's long facades face north and south. The south facing windows on the third floor are shaded by a continuous roof overhang, and on the first and second floor by sunshades that will be designed for each window.

Spectrally selective glass coatings block most of the infrared portion of the spectrum that contains much of the sun's heat, while admitting the visible light portion of the spectrum. The final glazing for the Green Dorm has not yet been selected, but PPG's new Solarban 70xl would be a good candidate. It admits 63% of visible light (Tvis) but only 27% of the heat (SHGC), over 60% less heat gain compared to clear double glazing. When combined with sunshades, the resulting direct solar gain is a small fraction of a conventional design.

The Palo Alto climate data also shows that the average nighttime low temperature in summer is around 55 degrees F. This cool night air can be used to help cool the Green Dorm at night so it doesn't overheat the following day. To take advantage of this day to night temperature swing, thermal mass is needed to absorb excess heat during the day, which is then released to the cool night air. One of the major advantages of the proposed steel and concrete structure, is that unlike a lightweight wood structure, it provides enough thermal mass to make this possible. The initial concept is to expose the underside of the concrete filled metal deck in the building so it is available for this heat exchange. The cool surface temperature of the thermal mass further improves comfort by lowering the mean radiant temperature.

During the early stages of the feasibility study, the building site was narrower and facing primarily east and west. A comfort analysis was done using ASHRAE Thermal Comfort Software (*see figure 5.16*) to see if west facing dorm rooms could be kept comfortable per ASHRAE standard 55. The analysis showed that the thermal mass present in our current structural scheme could absorb enough heat to keep these rooms comfortable. The final scheme's south facing dorm rooms will perform much better than these west facing rooms because of the higher sun angles and ease of shading.

Another strategy to maintain comfort in hot weather is natural ventilation, both to encourage air movement and remove excess heat. Unfortunately, the building code requires fire rated corridors, which makes true cross ventilation very difficult. It is often possible to do a "tunnel" corridor, in which the hallway ceiling is fire rated, with a ventilation plenum provided above the ceiling. This warrants further investigation as the design proceeds. The window configuration within a room can also make a difference, with casements or double hung windows that allow warm air near the ceiling to be exhausted being preferred to single hung windows in which only the bottom half opens. Additional air movement using electric fans can also significantly expand the comfort conditions. Where and how these may be incorporated into the design will be investigated in future design phases.

Winter Heating

Two distinct concepts are planned to minimize mechanical heating needs in the Green Dorm. The first, Passive Solar Gain, uses direct solar gain through glazing to heat a space with excess heat stored in exposed thermal mass. The second we're calling "the Passiv Haus" approach, after the German Institute that developed it. It relies not primarily on solar gains, but on the internal heat gains from people, lights, computers, and so forth combined with an excellent building envelope.

The Passive Solar Gain approach is planned for the first floor public spaces of the green dorm, with the Passive Haus approach for the upper floor dorm rooms.

Passive Solar Gain

In winter months around 90% of the available solar heat occurs between 9:00 am and 3:00 pm, primarily striking the south facade. The design challenge is to gather and store this heat so it is can be used for the remaining hours of the day, without causing overheating during these peak collection hours. The most common means of doing this is to have the sun directly hit thermal mass so it is absorbed and stored, rather than raising the internal air temperature.

This is the design approach for the south facing public spaces on the first floor, including the Lounge and Dining spaces. They are fairly large spaces with ample opportunity for glazing along the south wall. The floor inside these windows will receive lots of direct sun, and are appropriate locations for tile, terrazzo, or polished concrete, which can provide the thermal mass needed to store the heat for use at night. These spaces are not as sensitive to glare and privacy as the individual dorm rooms, so the blinds are more likely to be open during the key mid-day solar collection hours.

To ensure good solar gain to these spaces, external sunshades should be sized to block the sun during hot months and admit it during cold months. This can be a challenge in northern California, where September can have very hot days, while March, the solar equivalent in Spring, remains cool. Another option to consider is operable external shades that can be adjusted daily or seasonally as needed.

In contrast to the glazing described in the summer comfort section above, the glazing for passive solar gain should admit as much heat as possible. Most glazing used in commercial buildings has a low emissivity coating that reduces heat gain (low SHGC), and improves thermal insulation (low U-value). These glazings are not ideal for passive solar heating since they block much of the solar heat gain. Passive solar design calls for "high gain" low emissivity coatings, used mostly in colder climates, that let a lot of solar heat gain pass while retaining low U-values so the heat is not lost at night (*see figure 5.17*).

This Passive Solar Gain approach was initially proposed for the entire project. It was only after some investigation that a different approach was chosen for the dorm rooms. The rooms are arranged on each side of a double loaded corridor for cost reasons, so even in the best case only half of the rooms have south facing solar access. One of the key challenges of Passive Solar Gain is the need for the sun to

FIGURE 5.16 - ASHRAE THERMAL COMFORT ANALYSIS

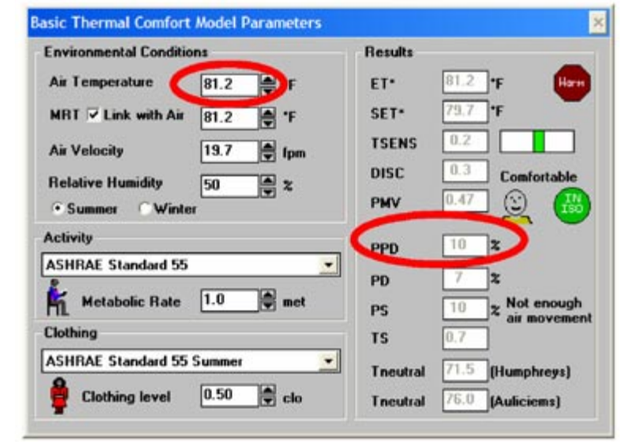
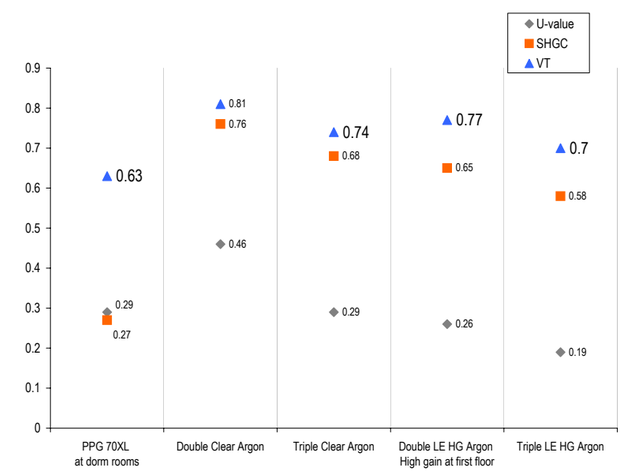


FIGURE 5.17 - GLASS TYPES AND PERFORMANCE



directly strike the thermal mass to avoid overheating, especially in small rooms. A physical scale model of a typical room was used with a box sundial to see which surfaces direct sun would hit. Due to the compact size of the rooms and the closely spaced partitions and furniture, for most of the key solar collection hours the sun would strike either lightweight gypsum board walls or furniture, rather than the thermal mass on the floor. These elements cannot store the heat, so the air temperature would rise quickly leading to overheating during peak conditions, and inadequate stored heat for release at night.

Even the floor is problematic since the preferred flooring in the rooms is carpet for comfort and acoustic reasons, rather than tile or exposed concrete, which could provide thermal mass. In addition, the window blinds would also need to be open to admit direct sun at the appropriate times, which may not be desirable due to glare, privacy, or later student sleeping schedules. For these reasons, the Passive Solar Gain approach was limited to the public spaces, and the Passiv Haus approach applied to the dorm rooms.

Passiv Haus Approach

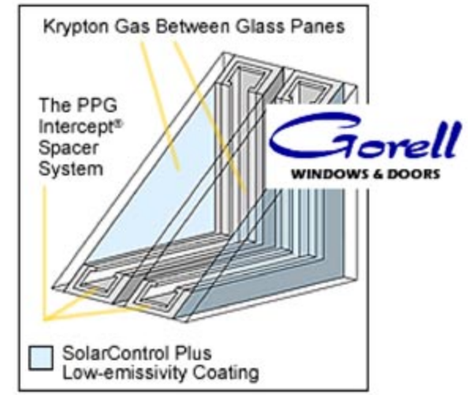
Zero energy home researchers at the Passiv-Haus Institute in Germany have developed a number of successful projects that use highly insulating envelopes that lose so little heat that internal loads such as lights, appliances, computers, and people can supply most of the heat needed. This design strategy contrasts significantly with the passive solar design approach described above. Rather than trying to collect and store heat, the goal here is to create a highly insulated envelope to keep the internally generated heat inside the building.

Windows are typically the weak link in the envelope, and perform poorly at retaining heat at night compared to well-insulated walls. A typical window has an R value of 2.3 while a wall has an R value of 19, more than 8 times betters. The Passivhaus approach uses triple pane, "super windows" which are sized as needed for views and daylight, rather than oversized for passive solar gain. An example of these windows produced by Gorrell is shown in figure 5.18. It has a center of glass U-value of 0.10 and a whole window U-value of 0.17 (R5.8), far better than a conventional window. Detailed analysis during the design phases will quantify the performance benefits and life cycle cost of various window options.

Also important to achieving the high performance envelope are eliminating air leaks by detailing continuous air seals, and eliminating thermal bridging. Metal studs in particular cause severe thermal bridging, conducting heat through the studs and bypassing the insulation. Metal studs reduce the whole wall insulation value by about 50%. The most common strategy for addressing this problem is to sheath the exterior of the wall with 1"-2" of continuous rigid insulation.

This Passiv-Haus high efficiency envelope strategy is a good fit for the individual dorm rooms, whether facing north or south. Rather than trying to balance solar gain in winter and shading in summer, it allows these rooms to receive generous sun shading and spectrally selective glazing to reduce solar gain for improved summer comfort. This approach will also be applied to the north facing lab spaces, which will likely have higher internal heat gains provided by mechanical and other equipment.

FIGURE 5.18 - GORELL TRIPLE-GLAZED WINDOWS



Daylighting

The basic building organization and orientation are designed to optimize access for solar gain and daylight. The goal is to provide adequate daylighting so electric lighting is not required during most daylight hours for virtually all spaces. As noted above, the large public spaces most appropriate for passive solar gain are located on the south. The generous windows on the south elevation for passive solar gain will admit lots of daylight, which can be balanced by light from skylights in the roof to control glare in these spaces. The lab was originally planned for the basement, but has been moved up to the ground floor in part to make daylighting more feasible. Its north exposure will provide indirect light to the lab, a light quality better suited for this working environment

than for the dining and lounge spaces where the warm light of direct sun in winter is desirable.

On the upper floors, the dorm rooms are only 12' deep making them very simple to daylight. The challenge here is controlling glare so students don't close their blinds and then turn on the electric lights. The rooms that face north won't have a glare problem, and the overhangs and sunshades on the south facing rooms will control glare for much of the year when the sun is high in the sky. A range of glare control options for south facing rooms in winter should be investigated during the design phase, including adjustable blinds, light shelves, and blinds that admit a controlled amount of daylight.

Lighting

To ensure the daylighting design leads to actual energy savings, the electric lighting will be equipped with a dimmable lighting system. Lighting controls will measure the daylight available in each space, and automatically adjust the amount of electric light as needed. The control system will also include occupancy sensors to make sure lights are turned out when spaces are unoccupied. These will be set to "manual on/auto off" and provided in the dorm rooms, lounge, dinging room, kitchen, lab, support spaces, and storage areas.

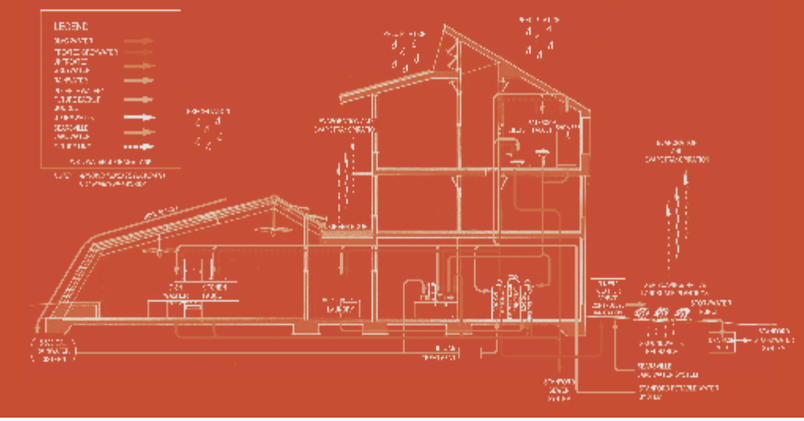
As described in the energy section above, plug loads and lighting are the two largest energy users in the building. Plug loads includes any portable lamps the students bring into the spaces, and Lighting includes any permanent built in fixtures. Student surveys in existing dorms have provided some useful information about the types of lighting students prefer, and their motivation for bringing in additional lights--often inefficient halogen or incandescent fixtures. Most commonly cited were the cold, unattractive, ceiling mounted direct fluorescent fixtures, and their lack of control for different lighting needs.

The green dorm team hopes to continue working with students to try out a number of different lighting options to see what they prefer and how to make that energy efficient. Initial design ideas are that the multiple uses of a dorm room call for a dynamic system that can accommodate the various needs. This could include bright light for individual or group study session, general ambient lighting for general purpose use, or lower lighting levels for socializing or watching TV or a computer screen. A dimmable fluorescent uplight (dimmable down to 10% of light output), either wall mounted or ceiling hung, could provide most of this functionality. Since this is such a large part of the energy pie, and closely related to student use and preferences, we recommend testing alternatives during the design phase.

The most energy efficient way to light a space is generally to use a task/ambient approach, where a low level of general, overall lighting is provided in the space as ambient light, and separate light is applied locally, such as a desk lamp, to increase light levels where needed. Since student provided task lights are often inefficient, it would be beneficial from an energy perspective to provide LED or other high performance task lights as part of the furniture in each room.

The physical and chemical state of the eye plays a large roll in the perception of a room's brightness. When an individual is in a dark environment, the eye adapts to low light levels by opening the pupil and activating rods on the retina to maximize the available light for adequate vision. Likewise, in a bright environment, the pupil constricts and cones are used for most of the visual work. In practical terms this means that at night people need, and in fact prefer, lower light levels. Since much of the lighting in the Green Dorm will already be equipped with dimming capability, it could readily include evening and late night setbacks to achieve these lower light levels.

CLOSE THE WATER CYCLE



Reduce water use, capture rainwater, and recycle water within the building to ultimately eliminate the import of potable water and the export of wastewater

REDUCE WATER USE

Low-flow bathroom fixtures
Non-potable irrigation water
Efficient kitchen facilities design

CAPTURE RAINWATER

5,500 gallon underground storage tank
Filter and use for toilets, irrigation, and laundry
Test and monitor for future potable use

GREYWATER RECYCLING

Treat and use for toilets, irrigation, and laundry
Test and monitor for future potable use

BLACKWATER RECYCLING

In-situ application of faculty research projects
Long-term monitoring of treatment samples

Close the Water Cycle

Overview

The value of clean water and the environmental costs of wastewater treatment are increasing daily, regardless of where you live. But in an arid climate like Stanford, the urgency of these concerns is magnified. In the Green Dorm, we seek to demonstrate an integrated approach to the complete water cycle with the ultimate goal that all the water used in the building is collected and recycled on site so that outside water inputs are eliminated. In addition, we intend to treat all of our wastewater on site in order to reduce and eventually eliminate the pollution associated with municipal wastewater treatment operations. These are ambitious goals, for which all aspects of the water cycle need to be addressed: from water use efficiency, to rainwater collection, to wastewater treatment, to water reuse.

These goals are, in truth, a few steps ahead of what is currently possible, based on existing codes and mainstream technologies. Faculty-led research in various dimensions of the water cycle will be instrumental in developing solutions to our global water problems as well as allowing this project to reach its ultimate closed-loop water goal in the near future.

The following section describes the strategies that will be used to "close the water cycle" and will explain the process by which this will be achieved over time, through applied research and experimentation.

Water efficiency

Showers

Surprisingly, showers are both the largest water user and the largest energy user in the green dorm, so optimizing water efficiency in the showers has a major double benefit. We began by assembling samples of low flow showerheads with the highest consumer ratings (*see figures 5.19 and 5.20*). All showerheads are required by law to be "low flow", which equals a maximum of2.5 gallons per minute. At flow rates lower than this most heads sacrifice performance. But a few showerheads were found with lower flow rates and excellent performance, including Bricor "Elite" and Niagara "Earth" with flow rates between 1.5 and 2.0 gpm. At the time of this writing, these showerheads are being tested by Stanford students for performance and preference.

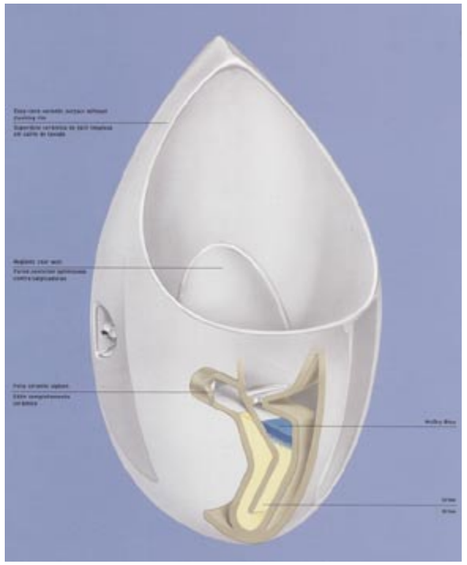
FIGURE 5.19 - BRICOR "ELITE" SHOWERHEAD

FIGURE 5.20 - NIAGARA "EARTH" SHOWERHEAD

Bathroom Fixtures

For water closets we recommend the Caroma dual flush wall hung toilets, with in-wall tanks. This model has two buttons, one for a full flush at 1.6 gallons and another for a half flush at 0.8 gallons for liquids only. Waterless urinals will be installed in the men's bathrooms on each floor (the student occupants will ultimately determine how the bathrooms will be shared). These use a lighter than urine "blue fluid" to seal the trap and prevent odors (*see figure 5.21*). Having urinals will facilitate collection or urine for potential use as an excellent source of nitrogen. There has been some discussion of experimenting with urine diverting toilets, so appropriate drain lines will be installed to facilitate this research. Lavatories will be equipped with manual single lever faucets with 1.0 gpm laminar flow controls, such as by Omni Products.

FIGURE 5.21 - DURAVIT WATERLESS URINAL



Kitchen

Dishwashing in the kitchen is expected to draw the second largest use of hot water in the Green Dorm. The design team will work with the PG&E Food Service Technology Center to optimize water use in the kitchen. Recommended strategies include pre-rinse spray valves rated at 1.6 gpm, and specifying the most efficient dishwashing equipment that include the recycling of the hot water from the final rinse cycle for the following first wash cycle of the following load.

Laundry

University Housing currently provides free laundry to all dorms. This is provided by contract with Web Laundry, and includes high quality Maytag Neptune front load washers. The Neptune is a highly regarded efficient machine, with a maximum modified energy factor (MEF) of 1.84. The MEF includes the energy

FIGURE 5.22 - LG COMBINATION WASHER/DRYER

used in running the machine, hot water used by the appliance, and dryer energy based on water remaining after the final spin. Other manufacturers make machines with MEF ratings up to 2.5, including some interesting new technologies such as LG's new combination washer/dryer that has a very low energy condensing dryer (*see figure 5.22*). These alternatives should be considered during the design phase.

Solar Clothes Drying

The conceptual design for the Green Dorm also includes two solar/air drying options for laundry. The laundry room is located adjacent to the second floor roof deck, where a clothes line would be more secure and less visible than if located on grade. Also, we envision a clothes drying "greenhouse" on the south edge of the laundry room, simply an enclosed indoor handling area for clothes, with south facing windows and passive stack ventilation to remove the moisture. We plan to work with mechanical engineering student to optimize the design for different weather conditions.

Water Capture and Recycling

The following systems describe the turnkey conditions for the Living Laboratory Scenario (see figure 5.24). Anticipated future developments with regards to the building water system are discussed in the Future Phasing section. For comparison purposes, the Baseline Green option without water reuse and recycling is shown in figure 5.23.

Rainwater Reuse

One way to reduce dependency on the ecosystem is to install a rainwater harvesting system that will collect stormwater runoff along the roof and roof decks. This will help the building achieve its sustainability goal by offsetting building water use with rainwater. Rainwater is commonly captured and stored for irrigation but this project aims to capture water for internal building use as well. Initially, the filtered and disinfected water would be used for non-potable uses (toilets and laundry). At a later stage, this reclaimed water could potentially substitute for potable water.

Nearly all roof runoff will be diverted into a 5,500-gallon underground rainwater cistern sized to store approximately two weeks of rainfall during the rainy season. Water from the cistern will be treated as required prior to discharging into a 2,000-gallon treated water storage tank (treated WST) located in the laboratory. Possible treatment would consist of simple filtration and in-line UV disinfection. Sample taps before and after the rainwater filtration and treatment will be installed to allow researchers in the laboratory to take pre- and post-treated rainwater samples.

Treated greywater will also be stored in this treated WST as discussed later in this section.

Greywater recycling

Greywater is typically defined as washwater that includes all wastewater other than toilet and food wastes. In this project, greywater will consist of water from bathroom sinks, shower drains, and the laundry facility. In general, greywater contains fewer harmful pathogens than blackwater (water from the toilets and kitchen) and can therefore be recycled more easily. Upon proper treatment, greywater will be reused for toilet, irrigation, and potentially laundry water.

Greywater piping from building uses will be directed to the laboratory and tie into a 2,000-gallon pre-treatment water storage tank (pre-treatment WST). The pre-treatment WST is designed to hold a week of rainfall runoff during the peak wet season. A water-source heat pump will be attached to this storage tank for greywater heat recovery (see figure 5.xinzerocarbon)). Stored greywater will then be fed into a typical, proprietary package treatment system which will produce effluent at a tertiary level of treatment as required by the state code for reuse. Treated effluent will be discharged into the same 2,000-gallon treated WST as the filtered rainwater. The supply water piping to the toilets, irrigation system, and possibly laundry

FIGURE 5.23 - BASELINE WATER SYSTEM SCHEMATIC

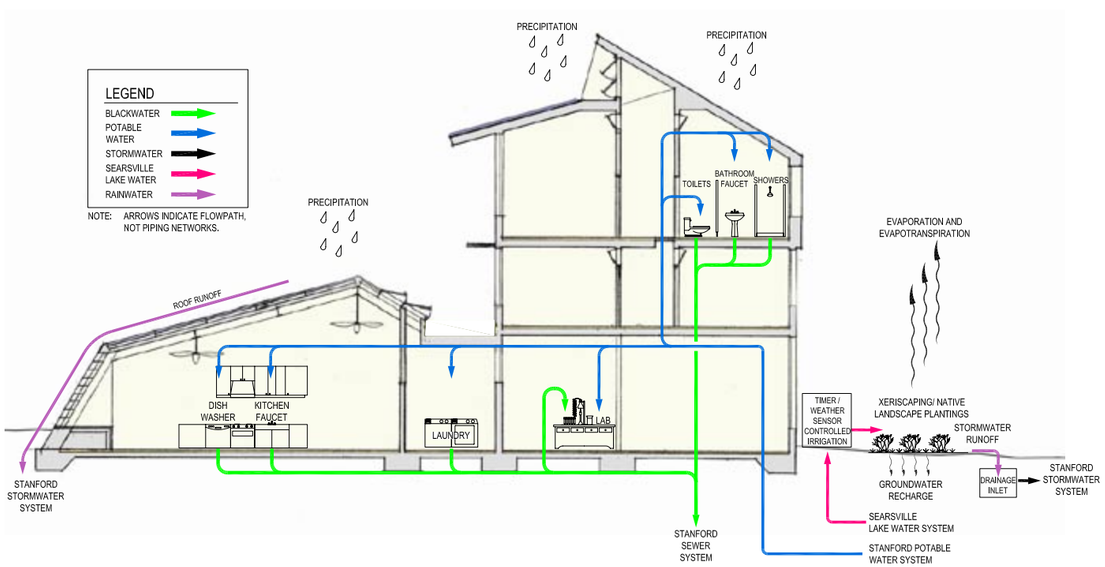
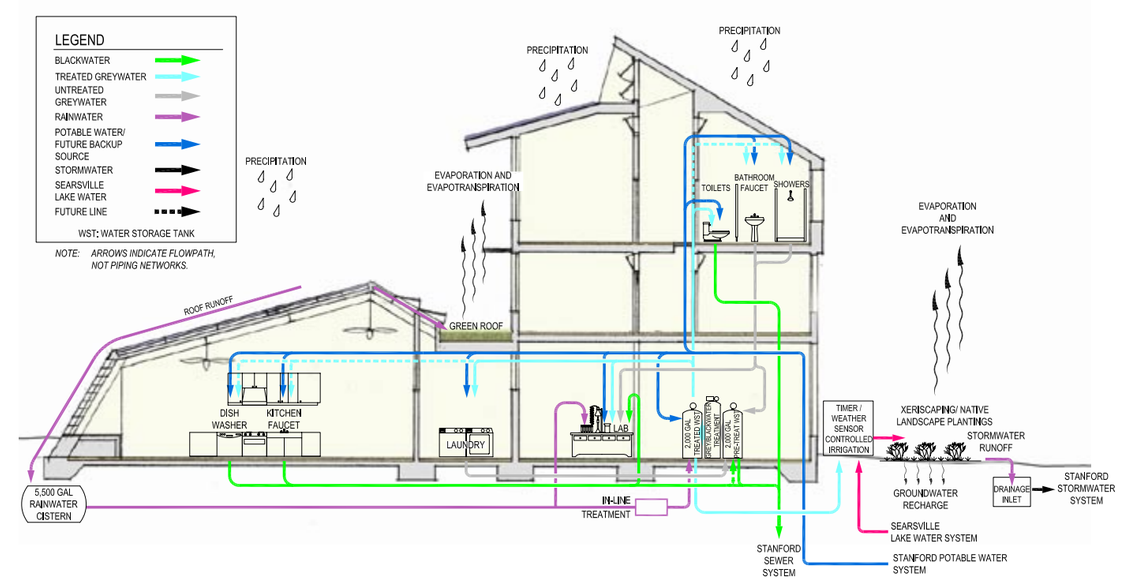


FIGURE 5.24 - LIVING LABORATORY WATER SYSTEM SCHEMATIC



facilities will be supplied by this 2,000-gallon treated WST.

Greywater will be supplemented by potable water on an 'as-needed' basis. In order to minimize double piping to the laundry and toilets, a public supplied potable water connection to a set of control valves at the distribution side of the treated WST will be installed. This allows the balance of potable public water and recycled water to be regulated by researchers and campus facilities staff based on maintenance and research needs. These controls will be protected to prevent accidental impairment of the building's potable water. The potable water will also be provided as a fail safe should the treated greywater not meet local water quality standards after treatment or if the volume of greywater and rainwater does not meet the building's water needs.

Both the pre-treatment WST and treated WST will be fitted with a sampling port located within the laboratory for quality control and experimental purposes. A greywater bypass to the Stanford sanitary sewer line will be provided should the treatment system effluent not meet regulated water quality. The bypass will be needed during routine treatment system downtime due to typical maintenance.

Blackwater recycling

Recycling and treating blackwater can further enhance the overall goal of closing the water loop. Recycling blackwater is a research goal of Stanford faculty in itself, as they explore technology to provide safe drinking water for the advancement of sustainability in developing nations, and is necessary to achieve a net-zero water use goal for the building.

Blackwater is comprised of water that typically comes from toilets, kitchen sinks, and dishwashers. Grease from the stovetops will be collected separately in a grease collection system and will not be combined with the blackwater. Initially, all blackwater will be routed to the Stanford sewer system. Blackwater treatment and recycling will be tested via bench-scale experiments in the laboratory, such as testing an anaerobic digester hooked up to a Sterling engine to generate power from the gas produced by the digester (more details on the research can be found in chapter IV). The main sanitary sewer line for the building will be routed through the laboratory and fitted with a sample tap to provide researchers the capability of obtaining the blackwater for experimentation and chemical and biological water quality testing.

Start-up conditions

When the green dorm initially opens, all potable water (water to sinks, showers, and dishwasher) will be supplied by Stanford's potable water system. In addition, the existing Stanford potable water system will serve as a backup source for the treated rainwater and greywater, the toilet, and laundry. The Stanford water system relies primarily on water from Hetch Hetchy, through an agreement between Stanford and the City of San Francisco. A series of deep wells around campus supplement this water supply and serve as an emergency backup for the campus should the Hetch Hetchy pipeline fail.

Other potential water sources

During the design process potable water wells were considered to serve as a primary drinking water source for the Green Dorm, but were ultimately abandoned in favor of utilizing rainwater to close the water cycle. One reason is that the dorm does not lie in a favorable location from the aquifer standpoint – the wells the campus operates are already in the ideal locations for well efficiency. Another is that though a well might be able to supply enough potable water for the Green Dorm, the aquifers in the region do not have the capacity to be used as a primary source of potable water for the campus. Finally, wells can be expensive, in large part due to high costs for application fees and an annual usage charge levied by Santa Clara County as a way to protect against over-pumping.

While a well could be used to temporarily close the water cycle for the building until greywater and blackwater recycling is refined, a better cause for educational purposes would be to limit the amount of water entering the stormwater system as much as possible by capturing rainwater and infiltrating runoff on site. Captured rainwater could eventually be used as potable water and help make up for natural losses in the water cycle within the building. Infiltrating stormwater runoff on site instead of sending it through the stormwater system to the San Francisco Bay can help rehabilitate the aquifer. These are techniques that, if successful, can be easily implemented into other buildings on campus.

Stormwater

Stormwater management is an often forgotten yet critical component of green building design. It is therefore proposed to create a site that matches the sustainable values of the building by implementing stormwater strategies that divert 100% of non-critical storm event water from the sewer system (see chapter III, "Site planning"). The Green Dorm will devote a portion of the roof to be used as green roof. In addition to aesthetic enhancement of the building, the green roof will also help retain stormwater on the roof and delay roof runoff time, therefore helping to minimize on-site flooding during large storm events and reducing the runoff contribution to the campus system.

Monitoring and Phasing

Testing and Monitoring

Understanding the quality of all streams of water within the building is critical to the documentation and experimentation of future treatment systems. The internal plumbing of all water network systems will therefore be routed through the laboratory space and fitted with multiple sampling taps for monitoring purposes. It is proposed that a real-time, online monitoring program be installed to test physical, chemical, and biological water quality. This system would be similar to monitoring programs currently used by Professor Craig Criddle on some of his research projects.

Other research potentials exist within the site and building and are shown on the Research Opportunities diagram (*see figure 4.8*).

Code Advancement and Permitting

California Code of Regulations states that recycled water can be used for irrigation, commercial laundry, and toilet water, but cannot be used for potable water uses. Whereas recycled water in the code refers to domestic wastewater (both grey- and blackwater), not rainwater. Currently, there are no state codes relating specifically to the reuse of rainwater within a building.

Therefore, it is assumed that the usage of treated recycled water will be approved for the residential laundry and toilet needs. One goal of the Green Dorm and its associated faculty is to develop a strategy to achieve state approval for the use of recycled water in residential buildings. Since rainwater is cleaner than greywater, it is anticipated that treating collected rainwater to potable water standards and using it for potable water may be approved before the approval of recycled water for potable water sources.

Currently this technology has been proven on a few buildings within the state, yet still quite rare in residential systems. A recent residential project in Sausalito, CA was approved to utilize filtered and disinfected rainwater for use in laundry. In Santa Monica,UC Santa Barbara, and elsewhere some non-residential building projects have utilized reclaimed greywater.

In addition, the building will be separating blackwater and greywater, so there is hope that recycled greywater may be approved for potable water uses more readily than recycled blackwater.

Future Phasing

Blackwater
Expansion to building-scale blackwater treatment is anticipated in the future after initial sampling and testing. If and when code authorities approve the treated water quality, blackwater piping will be disconnected from the Stanford sewer system and connected

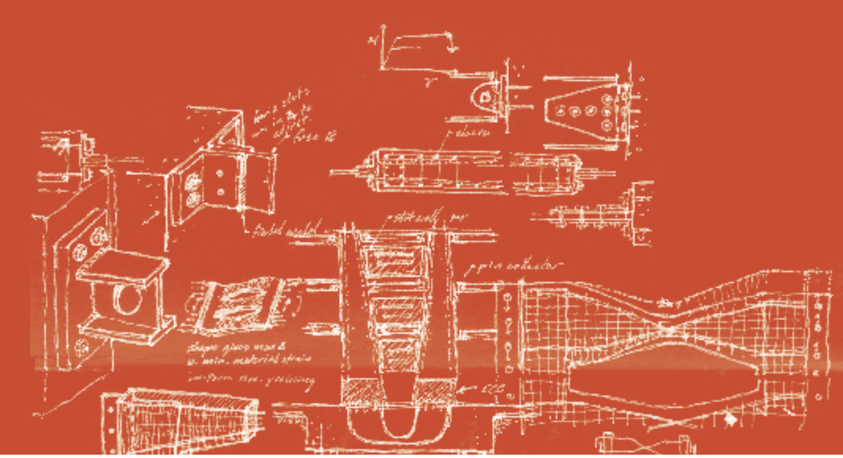
to the building-scale treatment system located in the laboratory area. The building cost estimate takes into account all internal piping to the laboratory and the Stanford sewer system. The bench-scale system that is expected to be used during the start-up stage of the building will be paid for through research grants. Future piping modifications and full-scale treatment system costs are not included in the budgetary cost estimate of this project.

Potable Water

Rainwater, recycled greywater, and blackwater may be treated and disinfected to high enough quality to be used as potable water, pending future code approval. The pipes to the potable water streams will have valves that can be opened in the future to switch the water source from the external potable water system to the treated WST when code authority approval is secured. In the event that treated rainwater is approved before the use of treated greywater for potable uses, a bypass will be supplied tying the rainwater supply directly to the potable water piping without mixing with grey-water.

Currently, state code prohibits using recycled water for potable uses, regardless of its source. It is the hope of this project to create a dialog with regulators and initiate the process of revising some of the more restrictive codes. Upon code evolution and updates, the complete conversion of recycled building waste-water into potable waters for building-wide uses will be possible.

OPTIMIZING MATERIAL RESOURCES



Cut the embodied energy of building materials in half while reducing earthquake losses through high-performance structural design

ANALYTICAL DESIGN PROCESS

Life cycle cost analysis and Structural System Matrix used to analyze and select structural systems

HIGH-PERFORMANCE SEISMIC DESIGN

Self-centering "rocking steel frame" limits earthquake damage losses, reducing long-term landfill, CO_2, and monetary costs

LOW EMBODIED ENERGY MATERIALS

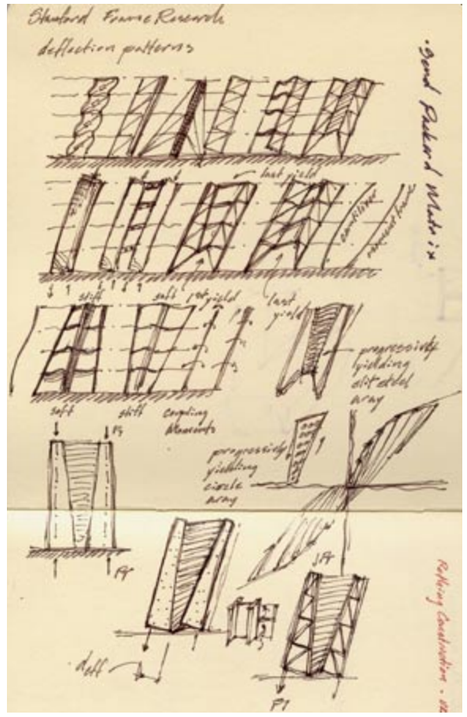
Industrial waste products such as fly ash or slag to replace over 50% of energy-intensive cement use in concrete mixes

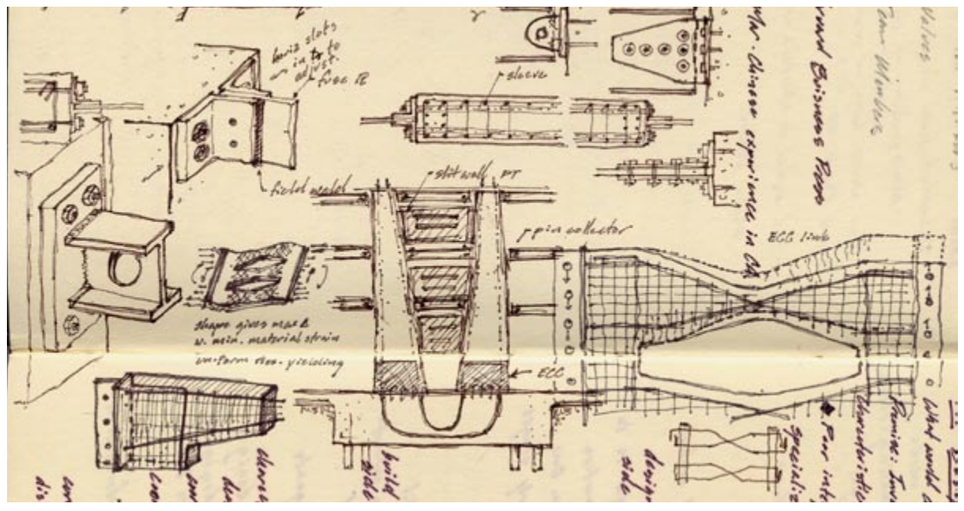
PROJECT-BASED RESEARCH

Faculty-led seismic and material research integrated into system selection process and design

Optimizing Material Resources

FIGURE 5.25 - NOTES FROM STRUCTURAL BRAINSTORMING SESSION BY FACULTY WITH DAVID MAR





Introduction

Under the LEED green building rating system, buildings are rewarded with credits for selecting environmentally-friendly materials. However, these credits tend to focus on interior finishes, rather than the overall material flows for buildings, which are dominated by structural materials. There is no established system of credit for reducing embodied energy or carbon in concrete and other materials used in the structure of a building, nor is there is any credit for designing for advanced seismic performance, durability or deconstructability.

The Green Dorm design team is intent on cutting the embodied energy of the structural materials in half while selecting and designing a structural system using sesimic, life-cycle analysis as a fundamental criteria.

The design team analyzed several structural materials for the structure, including steel, wood, concrete, concrete masonry units (cmu) and straw-bale. After quantitative analysis summarized in the Building System Matrix (see figure 5.38) the design team chose two schemes to explore. The wood scheme was selected for the Baseline Green design. Reducing the building's initial carbon impact is a priority, and wood has a significantly lower impact since the material stores carbon. It is suitable for the program and has the lowest first cost. It would likely be the standard, market structural system selected for this building type.

However, an aspect of sustainable building design that is often overlooked is the impact of future damage due to natural hazards, and the life cycle costs associated with the major repairs that may be required. In the seismically active San Francisco Bay Area (*see figure 5.26*), initial investment in the seismic safety of a building would significantly reduce life cycle costs – both environmental and financial – over the lifespan of the building. The design team, working with structural engineering faculty Professors Greg Deierlein, Eduardo Miranda and Sarah Billington and Ph.D. student Paul Cordova, quantified the effects of local seismicity through life cycle cost analysis. The initial structural performance investment, or cost premium, of the steel scheme over the wood scheme is $230,000. However, the savings of the steel scheme over the wood scheme is $1,964,869, based on the life cycle cost analysis. The work is based on the site specific earthquake hazards, performance-based design of the structure, and loss estimation tools developed by CEE structural faculty. The building's earthquake performance, in conjunction with initial cost, shows that the steel structure is much more durable and cost effective. Its long-term benefits outweigh the higher initial dollar and embodied energy costs, and it was therefore selected for the Living Laboratory Design.

FIGURE 5.26 - PROBABILITIES OF EXPERIENCING AN EARTHQUAKE WITH MAGNITUDE OF 6.5 OR LARGER IN BAY AREA WITHIN 50 YEARS

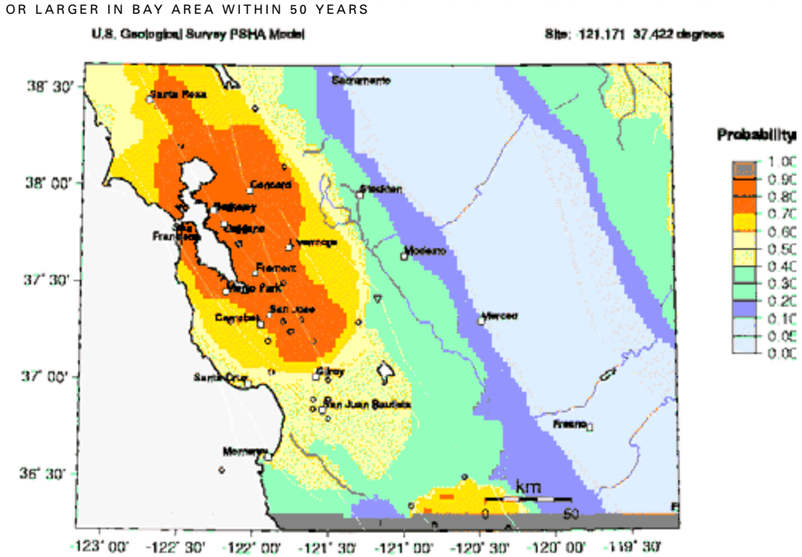


FIGURE 5.27 -EMBODIED CARBON OF MAJOR MATERIALS

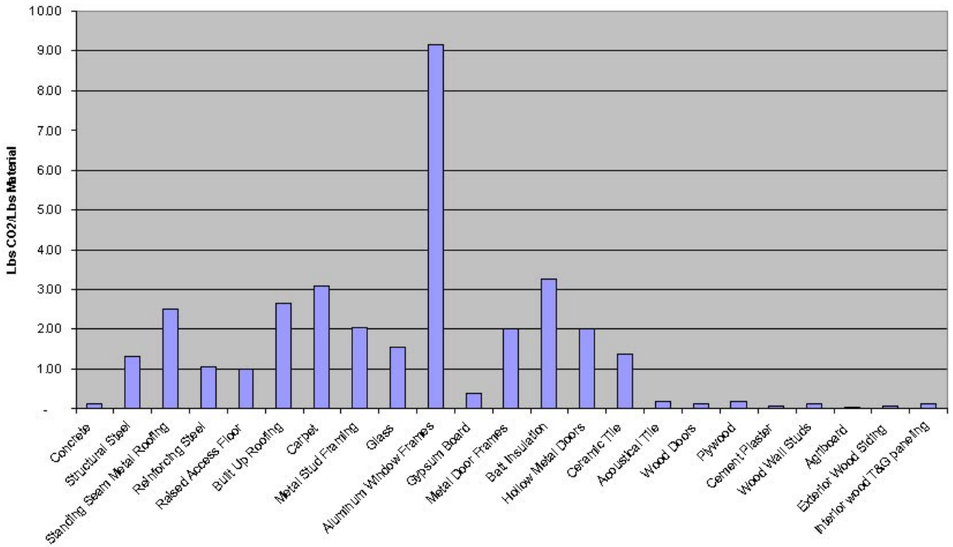


FIGURE 5.28 -PREDOMINANCE OF STRUCTURAL MATERIALS IN BUILDINGS

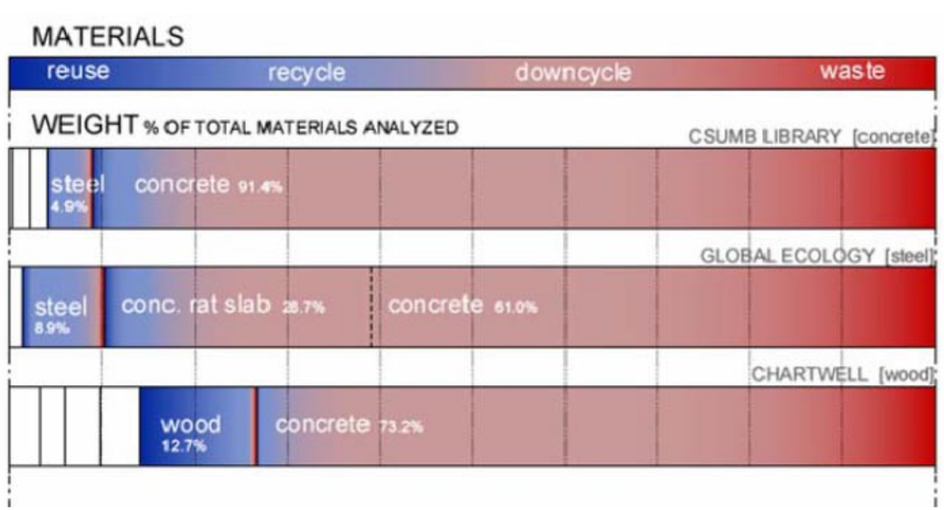
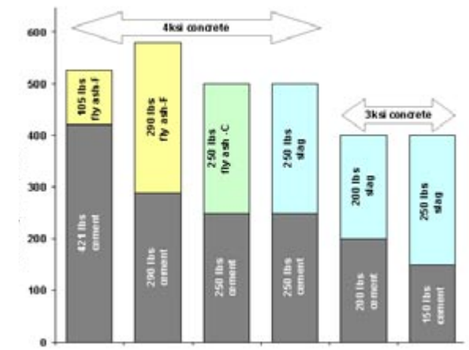


FIGURE 5.29 -CONCRETE MIX DESIGN AND STRENGTH



Initial Environmental Impact

A building's initial carbon impact is driven by the amount of carbon in the structural materials. To assess this impact for the Green Dorm, the embodied carbon of all the major materials was quantified, using data extracted from the ATHENA LCA software database (*see figure 5.27*).

Even though aluminum has a very high embodied carbon per pound, its total weight in the building is minimal. On the other hand, concrete has low embodied carbon per pound, but so dominates the weight of building materials that it is usually the largest carbon material (*see figure 5.28*). Thus, the Green Dorm's initial carbon impact is driven by the amount of concrete in the structure.

Major efforts will therefore be made to reduce the amount of concrete in the design and to make the concrete only as strong as needed. In addition, we also propose to work with the CEE structural facility to optimize low cement concrete mixes. Using supplementary cementitious materials, such as slag or fly ash, reduces cement use and can lower the total embodied energy in concrete by over 50% (*see figure 5.29*).

A building's embodied energy can be defined as the carbon load on the environment needed to produce the building. For example, the carbon impact of every yard of concrete used can be measured as the sum of CO_2 produced in making and transporting the cement and other ingredients. Thermal mass and insulation also contribute to the net carbon impact, since these two factors affect the carbon quantities produced from operations over the building's lifetime.

As was stated before, wood has a significantly lower carbon impact because it stores carbon and has much lower embodied energy. However, the steel scheme has a higher expected thermal mass because it has concrete slab over metal deck, and it will have no finished ceilings. The exposed slab above the rooms and the concrete for the floors will provide exposed thermal mass to help regulate temperatures. The wood scheme will have only thin concrete or gypcrete topping slabs on the floors. For both options, carpeting will reduce the usefulness of the thermal mass. The insulation for each scheme is expected to be similar.

Although the steel scheme has better mass, it is not expected to contribute significantly to reducing the operation costs because of the area's mild climate. Much of the value of the thermal mass will be felt through passive cooling in the summer, when no air conditioning is provided in any case. However, there are potentially significant benefits to thermal comfort, which is a qualitative value based on the occupants' comfort from high mass which reduces the likelihood for overheating.

FIGURE 5.30 - CONVENTIONAL CODE SEISMIC DESIGN PROTECTS LIFE SAFTEY (EX. CONCRETE SHEAR WALL)

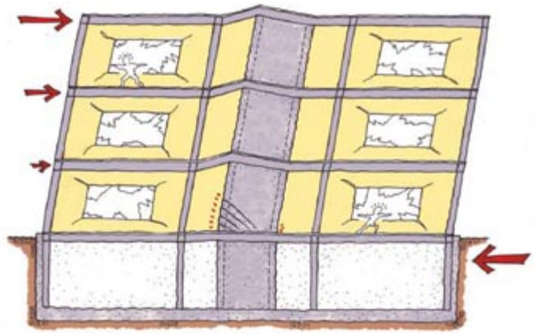


FIGURE 5.31 - MEDIUM PERFORMANCE SEISMIC DESIGN PROTECTS STRUCTURAL FRAME (EX. BUCKLING RESTRAINED BRACE)

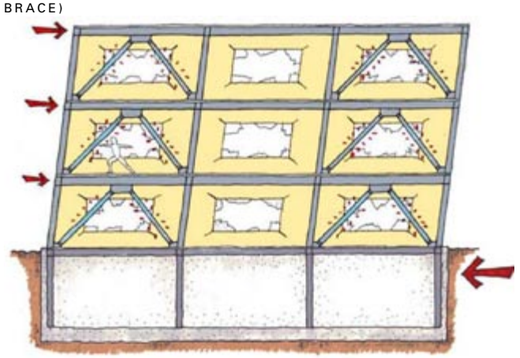
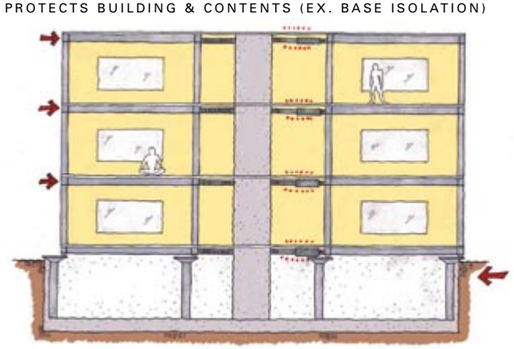


FIGURE 5.32 - HIGH PERFORMANCE SEISMIC DESIGN PROTECTS BUILDING & CONTENTS (EX. BASE ISOLATION)



Life Cycle Protection

Building with life cycle protection in mind can drastically reduce the carbon impact of a building over its lifetime. The devastation of New Orleans caused by levee breaks during Hurricane Katrina is a prime example of a massive rebuilding effort that could have been averted through pre-disaster mitigation. The tremendous expenditure of natural resources used to repair the damage could have been significantly reduced, or completely avoided.

Seismic loss studies indicate that buildings designed to meet but not exceed current building codes are likely to sustain damage of approximately 15-50% of their value (construction cost) under the cumulative effect of the seismic hazard. This stems from the fact that modern building codes are only meant to ensure life-safety during large earthquakes, not necessarily to control damage to the building structure or the architecture (*see figure 5.30 through 5.32*). The aggregate expected damage is significant and the associated repairs and rebuilding should be considered when evaluating design attributes for the Green Dorm.

In specific terms, the life cycle costs are made up of initial construction costs, the costs of implementing the seismic system, and the possible damages and repairs resulting from earthquake damage (*see figure 5.33*). While costs for enhanced, high-performance seismic systems are premiums above conventional construction costs, they should be thought of as investments against future losses. Examples of enhancements include additional strength and specially-detailed frames which have self-centering systems and replaceable fusible elements.

Future earthquake losses are comprised of architectural damage, structural damage, content damage and loss of use, all of which are caused by building drift and accelerations. When earthquakes occur, the structure deforms and drift is the measure of lateral distortion between floors. Excessive drift causes architectural damage, such as when the skin, windows and partitions break, which is the direct EQ loss. Similarly, the structural walls or frames typically sustain damage and require repair. The loss of function and loss of rents is a secondary EQ loss. Content damage occurs when the building's accelerations act on equipment or other stuff within the building, causing it to tip over or otherwise break.

The steel scheme excels in long term performance for better seismic durability. The lateral strength in the wood scheme comes from plywood-sheathed shearwalls, distributed throughout the building, which are tough and inexpensive. However, under high seismic loads, the wood walls will sustain damage that can be extensive and expensive the repair. In particular, plywood shearwalls will experience some type of damage at interstory drifts (relative horizontal displacement between two consecutive floors) as small as ½" and will suffer significant amount of damage requiring replacement at interstory drifts in the order of 2 inches.

The steel scheme can be designed to sustain minimal structural damage and lower levels of non-structural damage. The lateral system can have frames made to stay elastic, except for discrete yielding elements that can be replaced after an earthquake. The frames can also have self-centering capabilities to reduce permanent drifts (*see figure 5.34*).

Analysis

A life cycle cost analysis was conducted on the following three systems:

1. Wood scheme with lateral resisting system consisting of plywood shearwalls and using conventional partitions.
2. Steel scheme with a lateral resisting system consisting of a self-centering rocking brace system in combination with conventional partitions.
3. Steel scheme with a lateral resisting system consisting of a self-centering rocking brace system in combination with improved partitions with special detailing to delay their damage.

A summary of initial costs, expected annual losses from earthquake damage, and annualized life-cycle costs for the three schemes are summarized in figure 5.35.

FIGURE 5.33 - FINANCIAL-BASED STRUCTURAL ENGINEERING

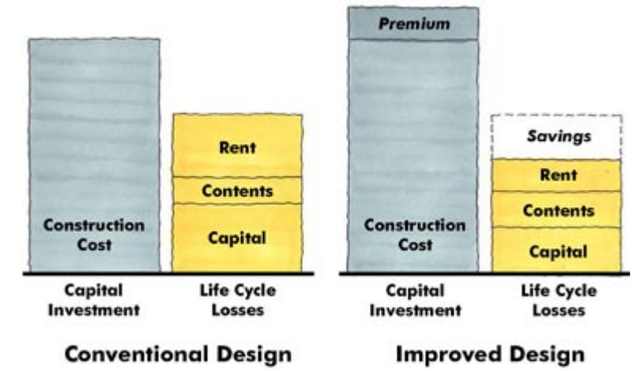


FIGURE 5.34 -STEEL ROCKING FRAME

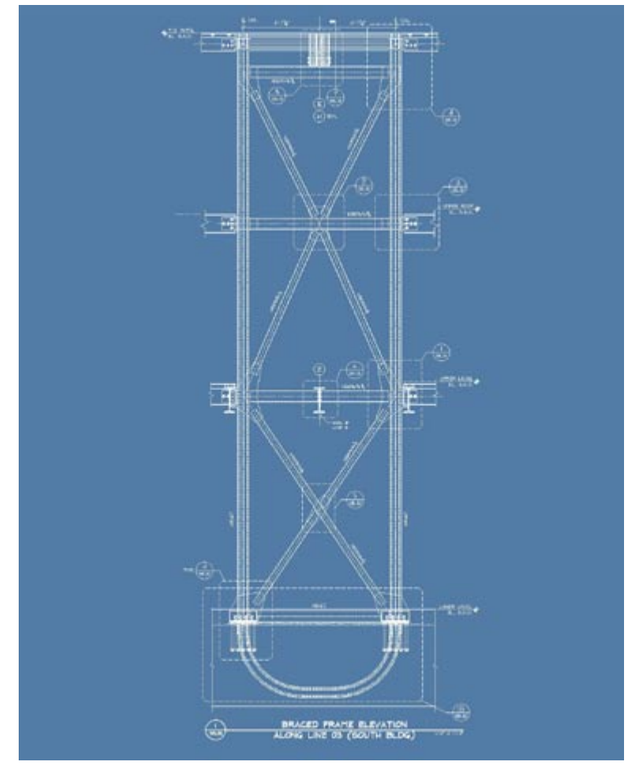


FIGURE 5.35 - STRUCTURAL SYSTEM LIFE CYCLE COST ANALYSIS SUMMARY

SCHEME	Initial construction cost	Cost Premium	Expected Annual Loss from Earthquake Damage	Annualized Lifecycle Cost
Wood with conventional partitions	$6,375,000	$0	$72,141	$199,641
Steel with conventional partitions	$6,605,000	$230,000	$28,244	$160,344
Steel with improved partitions	$6,700,000	$325,000	$22,258	$156,258

The first scheme is the one with the smallest initial cost, but it is the most flexible system and the one that sustains the largest amount of damage. The third scheme is the most expensive but the one that sustains in smallest amount of damage. As shown in the last column the option with the smallest annualized life cycle cost is the steel structure using improved partitions. It should be noted that here we have assumed that special detailing to allow for some relative motion between the interior partitions and exterior facades relative to the slabs is $95,000. Details of the structural performance life cycle cost analysis is presented in the Appendix.

FIGURE 5.36 - HYSTERETIC RESPONSE FOR THE 1ST STORY OF THE WOOD SCHEME

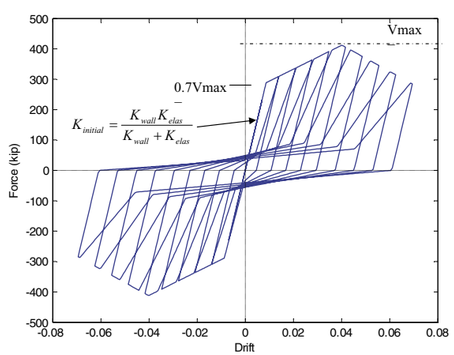
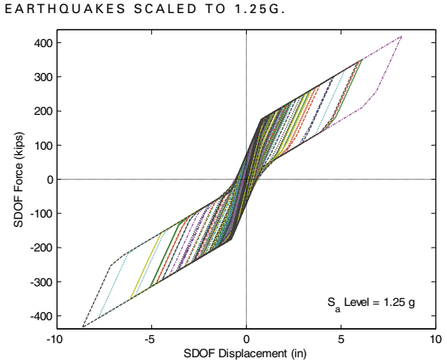


FIGURE 5.37 - SAMPLE OF THE HYSTERETIC RESPONSE OF THE SDOF OSCILLATOR FOR ALL 14 EARTHQUAKES SCALED TO 1.25G.



Structural System Options and Analysis

The design team—including the architect, structural engineer and contractor—developed a Structural System Matrix of seven building systems in order to select some for further study and rule out others for consideration (*see figure 5.38*). This Matrix was then reviewed by members of the structural engineering faculty, and formed the basis of selection of the wood system for the Baseline Green model and the structural steel system for the Living Laboratory model.

The Matrix is an extremely efficient tool, and allowed the design team to explore and compare the various parameters of interest. These parameters were Embodied Energy, Mass, Insulation, First Cost, Construction Speed, EQ Losses, Research Value, Thermal Comfort, Deconstructability and Flexibility. After weighting the parameters, each version of the building was given an overall score.

Weighting System

The weighting is greatest for First Cost with 5 on a 1 - 5 scale, which reflects the cost constraints of the project. Earthquake Losses, which can be defined as costs, have the next largest weight with 3, as the effects of local seismicity are clearly an issue in the Bay Area. Construction Speed is given a weight of 1.

Maintenance/ Durability is given a weight of 1. These four parameters together account for the building's Life Cycle Cost, with an overall effective weight of 10.

Embodied Energy has a relatively large weight of 3, in order to recognize the environmental impact of constructing the dorm and lab. Mass and Insulation are given a weight of 1 each. These relatively low values reflect the minor beneficial impact that added mass and insulation have on the operating costs of the project in this mild climate. The cumulative Carbon

FIGURE 5.38 - STRUCTURAL SYSTEM MATRIX

		CO^2 Impact			Life Cycle Costs										
		Embodied Energy	Mass	Insulation	First Costs	Construction Speed	EQ Losses	Maintenance/Durability	Research Value	Thermal Comfort	Deconstructability	Flexibility	Total (Weighted)	Life Cycle Costs	CO^2 Impact
Dorms/ Common Lab Space	**weight (1-5)**	3	1	1	5	1	3	2	4	2	1	1			
1. Wood Bearing Wall [1,2,3,4]		5	2	3	5	3	1	3	1	3	3	2	**69**	**34**	**20**
2. Steel Frame/Mtl Deck/Conc Topping [7,8,9]		2	4	3	3	5	4	5	4	4	4	5	**83**	**37**	**13**
3. Wood Post and Beam [1,3,4,9]		5	2	3	3	3	2	3	1	3	4	4	65	27	20
4. Metal Stud Bearing Wall [3,4,10]		2	2	3	4	3	2	5	1	3	1	2	58	34	11
5. Concrete Slab and Walls [3,4,10]		1	5	3	1	2	4	5	4	5	1	4	66	24	11
6. CMU Bearing Wall/Wood Floor [1,2,3,10,11]		3	4	3	3	1	2	4	2	2	2	2	58	26	16
7. Straw-Bale/Wood Frame [1,2,3,4,13]		4	4	5	3	3	1	3	2	5	3	1	67	24	21

notes

1. FSC certified wood
2. Resource Efficient Framing
3. Plywood Shearwalls
4. 1.5" concrete or gypcrete topping
5. Steel under discontinuous walls
6. Low cement concrete (70% slag, 30% cement)
7. Rocking & restoring systems w. replaceable fuses (PT cables, steel fuses, ECC fuses)
8. Moment frames w. dampers
9. Structural insulated panel (SIP) skins
10. Plywood floor diaphragm
11. Rigid insulation (3") on exterior walls
12. Rocking & restoring systems w. PT cable reinforcement
13. Lime plaster skins

Impact weight, made up of these two parameters, is 5.

Research Value in this matrix refers to the research potential for the design, construction and performance monitoring of the structure itself by the structural engineering faculty and students. It has a weight of 4, reflecting the priorities of the Civil Engineering Department. Thermal comfort, which is the qualitative benefit to students due to the building mass' moderating the effects of overheating, was assigned a weight of 2. Flexibility and Deconstructability are each given a low weight of 1, since both are benefits that can only be realized in the distant future.

The weighting factors reflect the collective values of the design team and members of the structural engineering faculty. They can be subject to further discussion and adjustment as needed. After the weights were assigned, the wood bearing wall system, Scheme 1, had the second best total score of 69 and was chosen for the Baseline Green scheme. The steel frame system, Scheme 2, had the best total score at 83 and was selected for the Living Laboratory scheme.

The wood scheme scored well for Life Cycle Cost at 34, with the steel scheme at a slightly higher 37 due to lower EQ Losses and Construction Speed offsetting higher initial costs. However, for this project, there may be a first cost threshold value, beyond which the project is not viable.

Research Value

Since part of the mission of the Green Dorm is to be a learning tool, a significant factor in favor of the steel structure is that it presents much richer opportunities for research for the structural engineering faculty than the wood scheme. The first area of study relates to the process of selection of the structural system, which was produced by the design team with significant faculty input. It is an innovative method of rationally selecting a building's lateral system based on cost over time, as well as initial costs. Another area of research will be the design and evaluation of the cost effectiveness of a damage resistant building skin and partitions. Finally, the frame system itself is a source of innovation through the potential use of self centering systems, replaceable yielding elements and new high-performance structural materials. These types of frames are currently being studies by Stanford Faculty with assistance from Tipping Mar + associates.

Flexibility

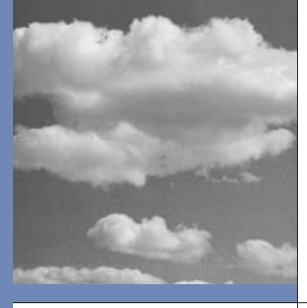
The steel scheme is a post and beam system that is extremely flexible with a widely spaced grid and few discrete frames. This leaves the plan relatively open for reconfiguring the internal spaces. The steel framed system can accommodate future reconfiguration of the walls, spaces and their functions.

The wood scheme is relatively inflexible. Almost all of the room walls are shearwalls and most will be bearing walls. This means that any future alterations would be difficult and expensive.

Deconstruction

The steel scheme is somewhat better than the wood scheme for potential deconstruction and reuse of the frame. The beams and columns will all be bolted together and can be easily disassembled. The concrete over metal deck cannot be reused without down cycling.

The wood scheme is more difficult to deconstruct because of all the nailing. The plywood sheathing on the floors and shearwalls will most likely be destroyed as will the concrete topping. The framing members can be used again if the nails are removed.



6 the most desirable housing on campus

a popular row-house that aims to place at the top of the housing draw

a design balancing privacy and community

access to programs and research contributes to the goals of residential education

building feedback loops encourage sustainable lifestyles as students monitor the impacts of their choices

designed to the highest standards of thermal comfort, occupant health, lighting and acoustic quality

The Most Desirable Housing on Campus

Overview

The target residents for the Stanford Green Dorm project are average Stanford students from the general population that represent the school's diversity of people and interests. While the project goals include building cutting edge sustainable housing for the campus, it should not feel as though the students are part of an experiment, or need to make sacrifices in their daily lives. As such, one of the main goals is to design student housing that incorporates sustainable strategies and technology but also is among the most comfortable and desirable housing options on campus. By achieving this goal it is hoped that the Green Dorm project will demonstrate that sustainable design results in housing that is more comfortable and improves the quality of daily life for its residents as compared to what has been typically built on our campuses.

FIGURE 6.1 - ROW HOUSE RESIDENT CHARLIE DAVIS IN HIS DORM ROOM

Privacy and Community

Building Population

Students who choose the Green Dorm will be looking to be a part of a community that integrates them into campus life. Based on surveys and campus experience the ideal size for a row house to develop this goal of communal living is between thirty five and fifty students. Once the number of students reaches sixty there is the risk of losing the community atmosphere central to the residential program. To maximize both this community atmosphere as well as efficiency, it was decided that forty seven students would be the programmed size of the project. This is in keeping with many of the other row houses on campus.

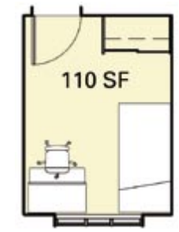
Room Types

Since student rooms occupy the largest proportion of the building area, their occupancy type and form are critical determinants of overall building form. In addition, room type plays a large role in the balancing of privacy and community. Therefore establishing the unit type mix was a critical early decision.

The design team developed a decision matrix to evaluate the relative merits of singles, doubles, two-room doubles, triples, quads, and suites. A combination of singles and two-room doubles was chosen as the unit type mix (*see figure 6.2 & 6.3*). By providing both of these room types, the Project Team felt the future residents would have the best balance of choices for privacy and opportunities to foster roommate relationships. Two-room doubles are essentially two singles with a door connecting them. While singles afford more privacy, two-room doubles are very popular due to the flexibility it allows as students can choose to arrange them as two singles or with one bedroom and one living room. A crucial factor was the fit with the campus Housing Master Plan, which promotes singles, two-room doubles, and smaller suites as the ideal student beedroom types. These unit types also work well for summer program housing.

Since suites are a poor match with a row house, Student Housing supports singles and two-room doubles for this project.

FIGURE 6.2 - TYPICAL SINGLE



TYPICAL TWO-ROOM DOUBLE

FIGURE 6.3 - ANALYSIS OF UNIT TYPE OPTIONS (SEE APPENDIX FOR CRITERIA DISCUSSION)

UNIT TYPE MATRIX 1 = WORST 5 = BEST

ROOM TYPE	NSF / BED (& FACTOR)	EFFICIENCY (materials & energy)	SOCIAL INTERACTION	PRIVACY	FUTURE FLEXIBILITY	POPULARITY	FIT W/CAMPUS HOUSING PLAN	APPROPRIATE FOR ROW HOUSE	SCORE
SINGLES	110 (1.0)	2	4	4	4	4	4	5	27
DOUBLES	100 (1.1)	3	5	2	4	3	2	5	24
DIVIDED DOUBLES	110 (1.0)	2	5	3	5	4	3	5	27
TRIPLES	95 (1.16)	4	1	1	4	1	0	4	15
QUADS	90 (1.22)	4	4	1	4	1	1	4	19
SUITES	135 (0.82)	1	3	5	1	5	5	2	22

Social Spaces

In addition to such programmed communal spaces as the lounge, dining hall and game room *(see page xx for full description)*, the project should strive to create additional areas, both large and small, for residents to congregate. This will help foster a communal atmosphere as well as make the house more comfortable. Spaces identified by the feasibility committee are a west-facing porch, a roof deck, outdoor dining patio or deck, and a demonstration garden. All of these will help give the house a strong connection to the outdoors and the surrounding site and neighborhood.

A west-facing porch is one of the most popular and used areas of the other row houses. Providing such a space would create a welcoming entry point as well as an active, social hub.

Another popular common space at the other row houses are outdoor dining areas. These typically include not only tables and chairs, but a barbeque area, lighting and a direct connection to the indoor dining room. Ideally the outdoor dining space should be south facing to be comfortable for the longest amount of time.

In addition to being a great communal space for sunbathing, reading, talking etc., a roof deck could incorporate many sustainable building systems and strategies. These could include a green roof, solar or hot water panels, line clothes drying and other strategies. By placing them on a roof deck they will be more visible to the residents and more integrated into their lives.

The demonstration garden could also fit with the sustainable goals and message of the project, and help make that transparent to the larger community of Stanford.

In addition to formal community spaces, circulation spaces such as stairs and hallways should be designed to allow for spontaneous gathering of small groups of residents. This may simply involve scaling spaces such as landings or alcoves to accommodate such gatherings or providing built-in or movable furniture for longer gatherings.

"I see this building as a vehicle for transforming our understanding of sustainability, sending a clear message that sustainability is no longer just about hippy co-ops and alternative lifestyles. Luxurious solar heated showers, clean energy, and delicious and healthy sustainable meals will lay claim to rave reviews by every student on campus. I am thrilled by the prospect that there will be a place on campus that embodies Stanford's values of education and stewardship and empowers its residents to conduct forward-thinking research on water, energy and sustainable living."

MIKE LIN - *MASTERS OF SCIENCE, MECHANICAL ENGINEERING*

FIGURE 6.4 - **SCENES FROM THE ROW**

ROW-HOUSE EXTERIOR DINING

PICKING FRUIT AT TERRA HOUSE

SPECIAL DINNER AT THETA CHI

LINE DRYING AT SYNERGY HOUSE

COOKING AT TERRA HOUSE

"EIGHT-MINUTE ABS" AT YOST

Adjacencies

At the outset of this study we studied program adjacencies and entry sequences (*see figure 6.5*). The favored layout included a common entry foyer on the east connecting to a west and south facing lounge and dining hall with service functions facing the access road on the east, as shown in the top diagram. The general concept for building layout is to have the common areas, including dining, recreation, the lab, building lobby etc. with needed support spaces (bathrooms, kitchen) on the first level, and the bedrooms, floor bathrooms, study areas and lounges on the upper floors. This arrangement will provide for the maximum amount of privacy and security for the bedroom areas of the building. The exception to this diagram is some accessible units on the first level. One of these units, planned as a demonstration/guest room, should have a separate outside entrance for increased privacy.

The group felt the entry sequence and relationship for the houses common areas, upper floors and lab space is critical both for privacy and security. Although a common entrance that could double as an information center was preferred, opportunities for securing, or separating the house functions and the lab functions are critical. The students should feel a sense of ownership of their house, and not feel like they are living in a campus common building. The balance between resident privacy and interest in visiting the Green Dorm will need to be solved both architecturally and through appropriate policies.

Direct outside access to the lab and kitchen will be critical for them to function efficiently. Thought needs to be given for vehicular access to these spaces for deliveries.

Although separation is critical between the common areas and the sleeping floors, a strong connection is also important in creating the sense of community. Through the use of a grand stair, light wells or other architectural devices, there should be some connection between all levels of the house.

ADJACENCY AND ENTRY STUDIES

FIGURE 6.5A - ENTRY FROM EAST, SOUTH-FACING COMMONS

FIGURE 6.5B - ENTRY FROM EAST & WEST, WEST-FACING COMMONS

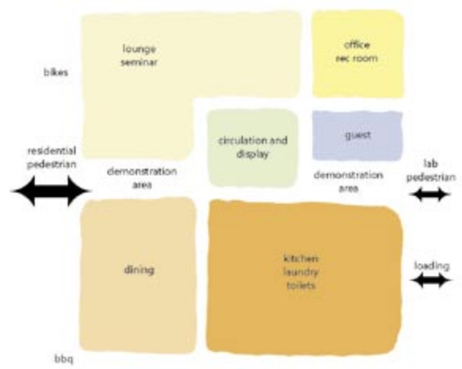
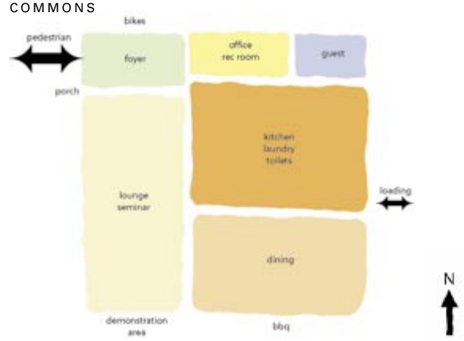


FIGURE 6.5C - ENTRY FROM NORTHEAST, L-SHAPED COMMONS



Living and Learning

Access to Programs and Research

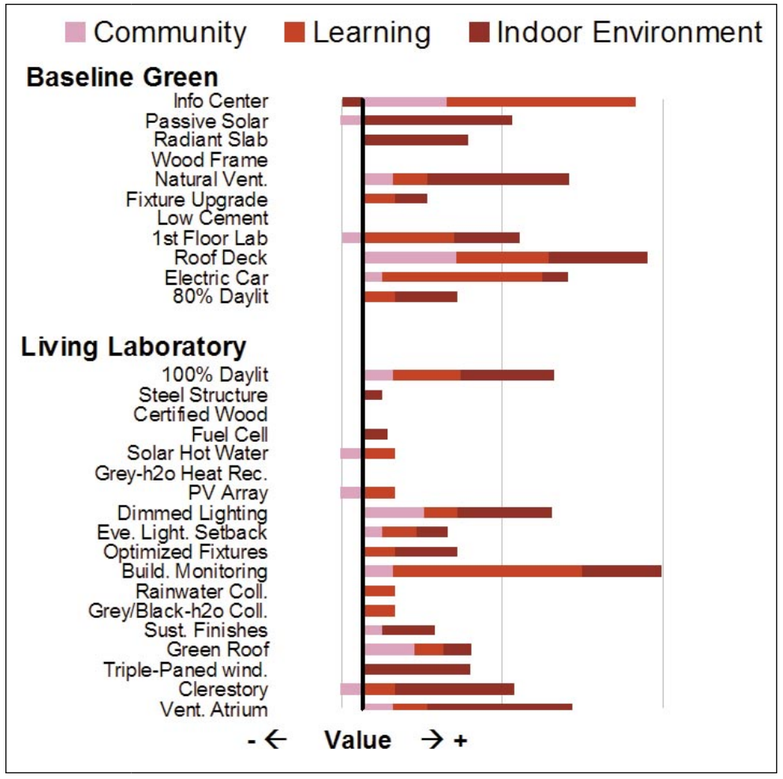
In addition to creating comfortable, sustainably-designed housing there is the opportunity with this project to increase the living and learning experience for the student residents. Both the lab and support spaces will bring information, technology, research space and programs to where the students live. This will create a living learning experience in sustainable design and lifestyles that could not be duplicated in the classroom or in campus labs. Programs and lectures held in the lounge will explore sustainable research at the house, on campus and in the world at large.

An important learning aspect to the Green Dorm will be the monitoring of resident's resource consumption. Continuous feedback loops will help students understand the environmental impacts of their living habits. Monitoring will provide feedback on lighting use, laundry, showers and other water usage, plug and vampire load use, recycling, and so on.

The entry foyer will be designed as an "information center" where real-time building data will be accessible. By utilizing signage, computer access, monitoring, and other displays, students and visitors will receive real-time information on the building's energy and water usage, comfort levels, and the story behind the project. This interpretive component can also be extended beyond the lobby to the lab and to points within the house and grounds. For example, monitoring of energy consumption by floor or even by room could inspire even greater energy savings and help to educate

VALUE OF OPTIONS: MOST DESIRABLE HOUSING

SEE APPENDIX A FOR MORE INFO



LAUREN DIETRICH - *MASTERS STUDENT IN CONSTRUCTION MANAGEMENT*

"I hope we develop a facility that will celebrate multiple layers of involvement. Student residents will have the capacity to: scientifically analyze resource relationships; understand how basic resource systems impact their comfort and how their actions impact the health of these broader systems; and reflect on how behavioral changes that alter resource use patterns influence other aspects of their lives."

residents about the impacts of energy consumption. At other college campuses, such as Oberlin College, similar programs have helped to reduce dorm energy consumption dramatically. The goal is not to require lifestyle sacrifices but to provide students with the information they need to make informed lifestyle choices.

Recycling

Recycling will be an important part of the lifestyle of living at the Green Dorm. A program should be set up to allow the residents to recycle, compost and properly handle all materials. This should extend beyond the residents use to the building materials and construction practices.

To support recycling, it is important that space is assigned on each building floor for the collection of recyclabes. In addition, a recycling center on site will be provided that allows proper sorting and storage and is convenient for deposit and collection. One proposal is to build a new, common trash and recycling enclosure which would be shared with Casa Italiana (*see site plan, figure 2.x)*. The design could incorporate didactic elements which teach about resource flows and the recycling process.

The project specifications will call for a comprehensive recycling program during construction that is documented for verification.

FIGURE 6.6 - STANFORD RECYCLING AT WORK

Indoor Environmental Quality

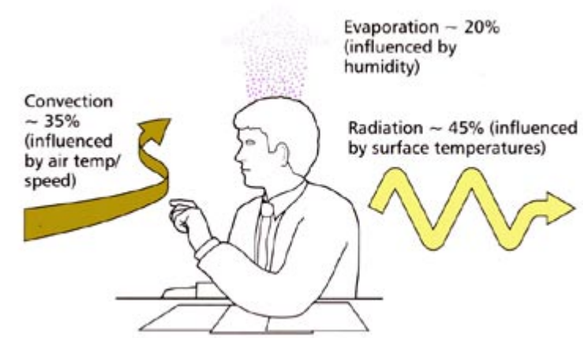
Thermal Comfort

Thermal comfort during cooling and heating seasons can be achieved without relying on energy-intensive mechanical systems. Some fundamental design decisions already made will make this job easier. For example, proper solar orientation--meaning long east-west building facades--will limit the number of rooms with west or east-facing windows, for which solar control is difficult while properly-sized roof overhangs and sunshades will keep the hot sun out in the summer while allowing passive solar gain during the winter. (*Chapter V further details the Zero Carbon goal and the methods to be used to achieve it).* While these basic design strategies will simply and effectively provide for high levels of comfort during the winter months with modest energy penalties, summer cooling is a little more challenging.

Per campus standards, no air-conditioning will be provided for cooling the housing-related spaces. In the past six years, six new studio apartment buildings were built for graduate students without air conditioning. High insulation levels, sub-optimal solar shading, and the lack of cross-ventilation has led to some problems with overheating. As our building envelopes become more air tight (and therefore more efficient in winter), and our building codes divide up our building into smaller fire safety zones, air flow is impeded. A challenge for the Green Dorm design will be to effectively ventilate student rooms and corridors while complying with the relevant building and fire codes. While maintaining summer comfort without air-conditioning is a challenge, it is certainly achievable in Stanford's arid climate.

Thermal comfort is not just a question of the air temperature (convection) of a space but instead is a complex question of human perception. Radiative and evaporative comfort play a large role in determining how comfortable people feel (*see figure 6.7*). In recognition of this fact, radiant floors will supply heating in the winter months while a combination of effective thermal mass and natural ventilation will provide

FIGURE 6.7 - COMPONENTS OF PERCEIVED THERMAL COMFORT



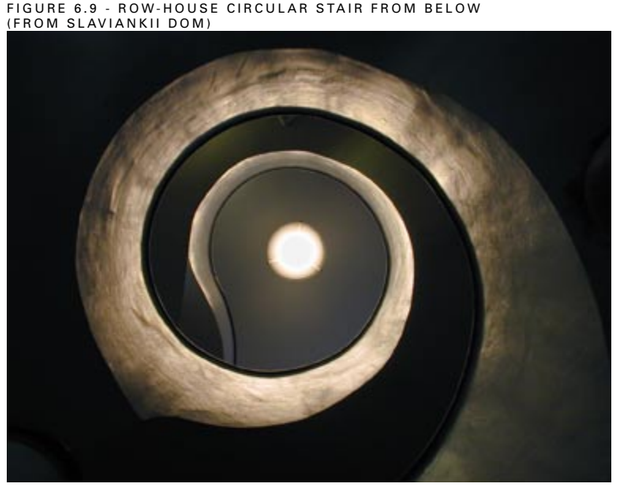
comfort in the summer.

While thermal comfort is hard to measure objectively, sophisticated occupant surveying tools developed by the Center for the Built Environment at UC Berkeley (CBE) indicate the heating and cooling complaints are the most common sources of disatisfaction in the buildings surveyed. The design team plans on using the CBE survey to gauge student comfort in existing dorms and to then compare that to the completed Green Dorm. To this end we have started discussions with CBE about creating new survey modules that apply to dormitories because the existing survey is focused on office buildings.

In summary, thermal comfort is an area in which, with good design, energy-efficiency and improved living standards go hand-in-hand. A critical goal of this project is to show that sustainable housing can be more comfortable than typical housing even while drastically reducing energy consumption.

FIGURE 6.8 - BALANCED DAYLIGHTING IN THE CARY HOUSE
(EHDD ARHITECTURE, 196O)

FIGURE 6.9 - ROW-HOUSE CIRCULAR STAIR FROM BELOW
(FROM SLAVIANKII DOM)



Lighting Quality

In order for the Green Dorm row house to be both comfortable and energy efficient, lighting design--both natural and electric-will be a high priority.

Natural daylighting has been shown to improve occupant productivity and satisfaction in studies covering various building types. When viewed in conjunction with the energy-savings due to reduction in electric lighting, naturally daylight interior can be one of the most cost-effective and robust sustainable strategies.

One of the project goals is daylight 100% of the interior spaces. Creating window openings and skylights to the outside within all spaces is obviously one key compenent, but the quality of this light is determined by several other design components including: proper solar orientation to reduce glare from east and west-facing windows; sunshading and light shelves to control direct sun; light colored surfaces for light reflection; glazing selection; and window placement to ensure balanced daylight from multiple sources (*see figure 6.8)*.

Although natural lighting is preferred, artificial lighting will be required for some tasks and during nighttime (*see figure 6.9*). Appropriate fixture selection and lighting design is critical for the artificial lighting to be both efficient and pleasant. Care needs to be taken in selecting direct or indirect lighting strategies based on a spaces needs. Fixtures need to be evaluated both for energy efficiency as well as lighting quality. The lighting solutions should also allow for a great deal of user control. This is critical not only for comfort but energy-efficiency. When designing, it is critical to think of the light that will escape the house at night, and to insure it has minimum impact on the neighborhood. Outdoor lighting should utilize cutoff fixtures to minimize light pollution. Finally security concerns need to be considered in the lighting design to provide a safe living environment.

Acoustics

One of the most critical design concerns with high density housing is good acoustical quality, including both privacy and acoustic performance. Great care should be taken to design acoustical separation between bedrooms, between floors, and from such spaces as bathrooms and the lab. Through careful detailing, material selection, specification and utilization of building mass, the house will be designed to provide acoustical privacy.

In addition to acoustic separation, care should be taken in designing for acoustical quality, especially of the larger public spaces. The design should control reverberation, and fine tune the "liveliness" of different spaces to the intended use. This can be achieved through the material selectio, spatial form, and scale.

RODGER WHITNEY -
EXECUTIVE DIRECTOR OF STUDENT HOUSING

"The concept of a true living/learning green residence for students is really exciting for all of us in Student Housing. A green Row House will provide a new and rich housing option for Stanford students, and it is really gratifying to be working in close partnership with academic departments in Engineering to help make this a reality. This new residence, in addition to modeling the latest "green" and "sustainable" technology, also aims to meet the goals of the 2005 Student Housing Master Plan by helping create premier (private) spaces for upper class students, reduce our room occupancies across the housing system to provide more desirable housing, and create exciting residential programs for upperclass students tied to their educational pursuits. As such, I am very supportive of this project and plan to dedicate necessary Student Housing resources to help effect this new house and its exciting new program. This house has the potential to become the most popular, sought-after residence in the Draw over time. The entire housing system will benefit from the data generated by a model dedicated to energy and water conservation and sustainability. Ultimately, keeping energy and utility costs down helps us keep room rates down."

FIGURE 6.10 - OUR FUTURE?

FIGURE 6.11 - ZERO-VOC PAINT

Healthy air and materials

Americans spend 85% of their time indoors on average. While occupant safety is a fundamental tenet of good building design, sustainable design takes that charge one step further by seeking to protect occupants from health risks associated with building materials and air quality. Health problems such as sick building syndrome and aggravated asthma can be eliminated through effective product specification, ventilation effectiveness, monitoring, and building maintenance.

The following goals and strategies will ensure that Green Dorm residents and visitors find that their time indoors is time well spent.

Construction IAQ Management Plan

Construction management strategies can minimize building contamination and installer health risks. The General Contractor will be required to institute and follow an IAQ Management Plan which protects absorptive materials from moisture, HVAC systems from contamination, and cleans up any contamination which occurs during construction.

Low-emitting Materials

Specifying materials that release fewer and contain less harmful contaminants can radically increase occupant satisfaction. For example, VOCs are chemical compounds commonly used in paints, sealants, and adhesives which contribute to smog and air pollution and impact the health of building occupants. Alternative products can be specified with negligible differences in product performance. This project will comply at minimum with the following standards: paints and coatings meeting chemical component limits of Green Seal requirements; carpets exceeding the Carpet and Rug Institute Green Label Indoor Air Quality Test Program; low-VOC adhesives and sealants; zero-VOC interior and low-VOC exterior paints (*see figure 6.11*); wood and agrifiber products produced without urea-formaldehyde.

Ventilation Effectiveness

Natural ventilation strategies utilize operable windows to develop building airflows through cross-ventilation (horizontally) and stack effects (vertically). Careful design will ensure effective air distribution and flow to all areas (*see figure 6.12*). Any exhausts from research activities will be directed away from operable windows.

Vinyl, PVC, Urea-Formaldehyde, and Other Toxins

Dioxin and three other chemicals targeted for elimination under international treaties can be traced in significant quantity to the production and use of vinyl and PVC. Where possible, alternatives to these sturdy and prevalent construction materials will be specified.

No PVC was used in the construction of the Sydney 2000 Olympic stadium seating, cabling, floor coverings, wall finishes or plumbing. The Green Dorm can achieve similar goals through the substitution of renewable materials, like wood, or less environmentally damaging plastics (*see figure 6.13*).

Urea-formaldehyde is a common agent used for adhering composite wood together to make plywood, in insulation, and other building products. Formaldehyde gas is a known carcinogen which is liberated during the manufacture and use of such products. Many manufacturers are now producing replacements with more benigh resins. No products with urea-formaldehyde will be specified for the Green Dorm.

Maintenance and Cleanliness

The impacts from the maintenance of buildings over their life times are often overlooked. Building maintenance activities like cleaning and repairs are often the chief causes of complaints from building occupants. Non-toxic janitorial supplies and techniques (*see figure 6.14*), as are currently used by Student Housing, can mitigate these impacts as can the inclusion of building elements such as permanent entryway systems to capture dirt and particulates, which reduce the amount of contaminants entering the building and reduce the need for cleaning.

FIGURE 6.12 - EFFECTIVE CROSS-VENTILATION

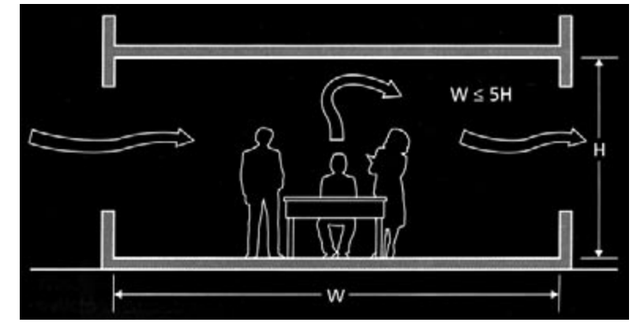
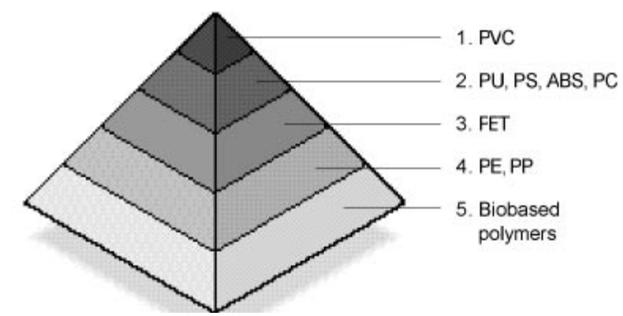


FIGURE 6.13 - **PYRAMID OF PLASTICS** : A RANKING OF PLASTICS ACCORDING TO THEIR HAZARDOUS CHARACTERISTICS. PVC, THE MOST PROBLEMATIC PLASTIC, IS AT THE TOP OF THE PYRAMID, AND BIO-BASED PLASTICS, THE LEAST POLLUTING OF THE PLASTICS, ARE AT THE PYRAMID'S BASE. (COURTESY OF GREENPEACE)



FIGUR 6.14 - BIO-BASED CLEANING PRODUCTS

7 economic sustainability

$12.2 million project cost for Living Laboratory model supports research, educational, environmental performance, and housing goals described in the Report

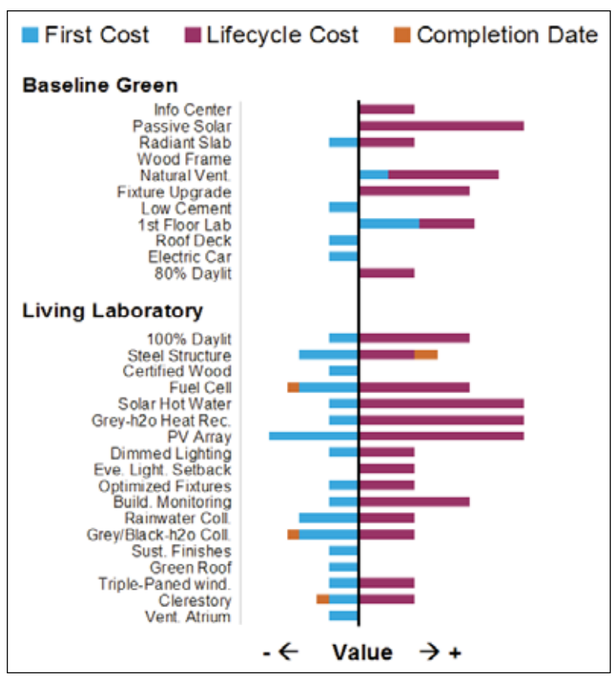
$9.65 million project cost for Baseline Green model is equal in first cost to Stanford's benchmark, demonstrating that sustainable housing at Stanford can be first cost neutral

Life cycle cost analysis shows 30-year payback for Living Laboratory with immediate and ongoing payback for Baseline Green

Economic Sustainability

VALUE OF OPTIONS: ECONOMIC SUSTAINABILITY

SEE APPENDIX A FOR MORE INFO



Overview

The primary goal of this study was to determine the project scope and estimated cost to build the full vision of a "Living Laboratory" student residence. A secondary goal was to test the feasibility of building a "Baseline Green" model of sustainable student housing at Stanford that would be comparable in first cost to a project benchmark. The conclusion reached is that first cost neutral, sustainable housing is viable but that the first cost of building a unique, integrated research facility as described in this Report is indeed higher. Life cycle cost analysis results indicate that a 30-year payback can be expected using reasonable assumptions for the Living Laboratory model; meanwhile, the Baseline Green model pays back immediately and continues to save operating costs over its lifetime.

The Feasibility Report as a whole demonstrates the Green Dorm's potential contribution to the University's housing, educational, and research goals. In this section we describe the results of the cost estimate and analyze the cost differences between the Baseline Green and Living Laboratory models.

Building cost estimate

The "Living Laboratory" total project costs are estimated at $12.2 million or $577/sf. See "Project Costs" below for breakdown of project costs and "Construction Costs" on page 105 for breakdown of construction costs. This amount would support the full building program, including research, environmental performance, and student housing goals, and would include innovative elements such as photovoltaic panels, wastewater treatment, and high-performance structural systems. These types of systems and technologies are uncommon in typical construction and therefore command a cost premium.

However, many of the sustainable building features central to the Living Laboratory proposal do not increase first costs but do add substantially to the quality of the living environment and environmental performance. This aggregation of smart building practices—such as enhanced thermal mass, increased daylighting, and careful solar orientation—are contained within the "Baseline Green" building model, which is the armature upon which the Living Laboratory model is built. While this model does not meet the full research, educational, and performance program of the Green Dorm project, it does represent a compelling model for sustainable housing at Stanford, and was therefore estimated for comparison purposes.

The Baseline Green total project costs are estimated at $9.65 million or $456/sf. This building package is equal in first cost to Stanford's benchmark cost for this project. It is evident from this exercise that it is possible to substantially improve the environmental performance of student housing without increasing first costs.

The difference in construction cost between the two building models is $1.9 million. "Line Item Cost Analysis" on pages 114 and 115 itemizes this cost delta and provides shorthand descriptions of the elements that distinguish one model from the other. See also the "Sustainable Strategies" drawing in the Executive Summary for a graphic depiction of these differences.

PROJECT COSTS

	Baseline Green		Living Laboratory	
	$	$/sf	$	$/sf
Construction	$ 6,300,000	298	$ 8,200,000	388
Other Construction	$ 164,000	8	$ 200,000	9
		0		0
Architect	$ 600,000	28	$ 750,000	35
Other Consultants	$ 185,000	9	$ 225,000	11
Furniture	$ 350,000	17	$ 350,000	17
Internal Costs	$ 255,000	12	$ 275,000	13
Permits	$ 50,000	2	$ 60,000	3
Activation	$ 150,000	7	$ 110,000	5
SIP	$ 430,000	20	$ 550,000	26
Financing	$ -	0	$ -	0
Contingency	$ 662,000	31	$ 824,000	39
Escalation (2007 buyout 8% of construction)	$ 504,000	24	$ 656,000	31
Total Project Cost	$ 9,650,000	$ 456	$ 12,200,000	$ 577

Benchmarks and estimating assumptions

Stanford's Department of Project Management developed a benchmark cost model for this project against which the cost estimates are compared. The benchmark cost is a target budget that is derived from a database of historical project costs collected from several peer Universities. The average cost is derived by selecting for project type, indexed for time and location. For the Green Dorm, the benchmark is a composite of residential and lab benchmark costs prorated based on square foot of each type of space in the building. The Baseline Green model is compared against this benchmark cost.

The budgets for both Baseline Green and Living Laboratory models have been developed from building narratives, conceptual building massing, and extensive discussions with the project team. Cost models were developed independently by Pankow Special Projects and Davis Langdon, and then reconciled to develop a recommended budget for construction. The budgets include allowances and a design contingency to reflect the current level of planning, and to accommodate the design risk within the project. The costs are based on the construction work being performed as a single negotiated bid.

The budgets do not include any allowance for cost escalation from the date of the report to the date of bidding. Escalation has been very volatile over the past two years, and the region has seen dramatic increases in construction cost. The indications are that both the volatility and the current high escalation are likely to continue for the coming year, and that this is the most significant area of cost risk. We would recommend that an allowance of 10% per annum be made to cover likely cost escalation between now and bid day. We would also recommend development of a bid contingency to address the possible volatility in the bid market. The contingency should be in the form of an additional allowance, or bid alternates. We would recommend a bid contingency of 5%.

CONSTRUCTION COSTS

	STANFORD BENCHMARK	BASELINE GREEN	LIVING LAB	DELTA
GROSS AREA (GA)---->	21,150	21,150	21,150	
RENTABLE AREA (RA)---->	0	0	0	
NO. OF UNITS---->	48	48	48	
DIV # NO. OF CARS---->	0	0	0	
01 GENERAL CONDITIONS (SEE CHCKLST)	$494,828	$565,158	$628,158	$63,000
01 GENERAL REQUIREMENTS	$120,969	$95,175	$95,175	$0
02 SITEWORK		$345,353	$394,604	$49,251
03 CONCRETE		$234,817	$380,974	$146,157
04 MASONRY		$0	$0	$0
05 METALS		$184,001	$795,214	$611,213
06 WOOD AND PLASTICS		$780,253	$289,656	($490,597)
07 THERMAL AND MOISTURE PROTECTION		$256,953	$313,335	$56,382
08 DOORS AND WINDOWS		$281,756	$361,102	$79,346
09 FINISHES		$908,180	$1,045,056	$136,876
10 SPECIALTIES		$62,652	$62,652	$0
11 EQUIPMENT		$158,910	$158,910	$0
12 FURNISHINGS		$9,465	$12,500	$3,035
13 SPECIAL CONSTRUCTION		$0	$0	$0
14 CONVEYING SYSTEMS		$0	$0	$0
15 MECHANICAL		$748,931	$1,176,467	$427,536
16 ELECTRICAL/ CONTROLS		$644,800	$1,142,230	$497,430
	$5,084,079			
TOTAL COST OF WORK	$5,699,876	$5,276,404	$6,856,033	$1,579,629
BONDS	$51,196	$0	$0	$0
INSURANCE	$39,867	$103,059	$136,228	$0
TAXES	$0	$0	$0	$0
ESCALATION (0.00%)	$0	$0	$0	$0
TOTAL COST	$5,790,939	$5,379,463	$6,992,261	$1,612,798
FEE 7.00%	$313,500	$367,311	$488,704	$121,393
SUBTOTAL	$6,104,439	$5,746,774	$7,480,965	$1,734,191
CONTRACTOR'S CONTINGENCY 10.00%	$199,059	$574,679	$748,097	$173,418
TOTAL PRICE	**$6,303,498**	**$6,321,453**	**$8,229,062**	**$1,907,609**
$/GA---->	$298.04	$298.89	$389.08	$90.19
$/RA---->	N/A	N/A	N/A	N/A
$/UNIT---->	$131,323	$131,697	$171,439	$39,742
$/CAR---->	N/A	N/A	N/A	N/A

LIVING LABORATORY - CONSTRUCTION COST ESTIMATE

	Description	Quantity	"B"	"C"	"D"	Unit	Unit Price	Baseline	Living Lab	Extension	$/SF	Scope of Work (Exhibit B)
	DIVISION 1- GENERAL REQUIREMENTS							***$95,175***	***$0***	***$95,175***	***$4.50***	
	General Requirements							*$95,175*	*$0*	*$95,175*	*$4.50*	
1	General Requirements	1	0	0	0	wk	95,175.00	95,175	0	95,175	4.50	
	DIVISION 2- SITE WORK							***$345,353***	***$49,251***	***$394,604***	***$18.66***	
	Demolition							*$22,870*	*$0*	*$22,870*	*$1.08*	
1	Clear and Grub	22870	0	0	0	sf	1.00	22,870	0	22,870	1.08	Remove existing landscape/ paving/ curbs
	Earthwork							*$72,069*	*$28,295*	*$100,364*	*$4.75*	
1	Structural Earthwork & Backfill	534	626	0	0	cyds	45.20	24,137	28,295	52,432	2.48	Balanced site (no export/import).
2	Rough Grade	22870	0	0	0	sf	1.00	22,870	0	22,870	1.08	
3	Fine Grade	9374	0	0	0	sf	1.50	14,061	0	14,061	0.66	Fine grade at building and walks only.
4	Utility Trenching (On Site)	1	0	0	0	ls	7,000.00	7,000	0	7,000	0.33	Allowance
5	Drain Pipe/ Aggregate	200	0	0	0	lf	20.00	4,000	0	4,000	0.19	Per pipe/ crushed rock at partial 2 sides.
6	Shoring	1	0	0	0	ls	1.00	1	0	1	0.00	None
	Site Utilities							*$100,000*	*$0*	*$100,000*	*$4.73*	
1	Site Utility Allowance	1	0	0	0	al	100,000.00	100,000	0	100,000	4.73	Allowance. Scope not determined yet.
	Site Concrete & Paving							*$43,104*	*$20,956*	*$64,060*	*$3.03*	
1	Asphalt Paving	416	0	0	0	sf	5.00	2,080	0	2,080	0.10	Patch between site and existing road.
2	Pervious Paving	400	900	0	0	sf	15.00	6,000	13,500	19,500	0.92	Driveway/ Expanded Driveway and Ped Entr.
3	Curb & Gutter - Concrete	208	0	0	0	lf	25.00	5,200	0	5,200	0.25	Curb at existing road only (not parking)
4	Sidewalk - Concrete	8	2	0	0	sf	3,728.00	29,824	7,456	37,280	1.76	Concrete/ Upgrade to pervious concrete
	Sitework							*$107,310*	*$0*	*$107,310*	*$5.07*	Does not include areas beyond curbline (parking)
1	Fences and Gates	1	0	0	0	ls	15,000.00	15,000	0	15,000	0.71	Allowance for enclosure around xfmr and other pads
2	Bike Racks	42	0	0	0	ea	200.00	8,400	0	8,400	0.40	Galv metal rack style (not enclosed)
3	Plantings/ Irrigation - Turf	6760	0	0	0	sf	5.00	33,800	0	33,800	1.60	Allowance
4	Plantings/ Irrigation - Plantings	2611	0	0	0	sf	10.00	26,110	0	26,110	1.23	Alllowance
5	Trees: 24" Box	16	0	0	0	ea	1,500.00	24,000	0	24,000	1.13	Common species
	DIVISION 3- CONCRETE							***$234,817***	***$146,155***	***$380,974***	***$18.01***	
	Concrete Reinforcing							*$42,300*	*$10,575*	*$52,875*	*$2.50*	
1	Reinforcing Steel	2	0.5	0	0	sf	21,150.00	42,300	10,575	52,875	2.50	
	Concrete							*$192,517*	*$135,580*	*$328,099*	*$15.51*	
1	F/P/S - Foundations	85	125.8	0	0	cyds	450.00	38,250	56,624	94,874	4.49	
2	F/P/S - SOG	9374	0	0	0	sf	5.50	51,557	0	51,557	2.44	
3	Misc/ Curbs/ Tank Pads	10000	15000	0	0	ls	1.00	10,000	15,000	25,000	1.18	
4	Gypcrete Floors	12650	-12650	0	0	sf	2.00	25,300	-25,300	1	0.00	Maxxon floor underlayment
5	Moisture Barrier	7742	0	0	0	sf	5.00	38,710	0	38,710	1.83	4" aggregate/ 6mil poly/ 2" sand
6	Foundation Adjustment	1	-1	0	0	ls	7,700.00	7,700	-7,700	1	0.00	
7	Retaining Walls	840	0	0	0	sf	25.00	21,000	0	21,000	0.99	Between garage/lab.
8	Slab on Metal Deck	0	22052	0	0	sf	3.00	0	66,156	66,156	3.13	
9	Rocker Frame Foundations	0	4	0	0	ls	7,700.00	0	30,800	30,800	1.46	
	DIVISION 4- MASONRY							***$1***	***$0***	***$1***	***$0.00***	
1	Sub Quote	1	0	0	0	ls	1.00	1	0	1	0.00	See Concrete
	DIVISION 5- METALS							***$184,001***	***$611,213***	***$795,214***	***$37.60***	
1	Structural Steel	20	106	0	0	tns	4,000.00	80,000	424,000	504,000	23.83	
2	Interior Metal Stairs	0	4	0	0	ea	12,500.00	0	50,000	50,000	2.36	Basic 5-line Sharon Stair or similar, metal tread
3	Railing - Exterior	250	0	0	0	lf	150.00	37,500	0	37,500	1.77	Porches step railing
4	Railing - Interior	50	0	0	0	ls	150.00	7,500	0	7,500	0.35	Between garage/ lab
5	Miscellaneous Metals	1	0	0	0	ea	10,000.00	10,000	0	10,000	0.47	
6	Exterior Stair - Large	1	0	0	0	ls	25,000.00	25,000	0	25,000	1.18	Metal tread, galvanized
7	Exterior Stair - Small	2	0	0	0	ls	7,000.00	14,000	0	14,000	0.66	Metal tread, galvanized
8	Additional Allowance for Rocker Frames	0	4	0	0	ea	6,750.00	0	27,000	27,000	1.28	Brace frames
9	Metal Decking	0	22050	0	0	sf	4.25	0	93,713	93,713	4.43	

	Description	Quantity	"B"	"C"	"D"	Unit	Unit Price	Baseline	Living Lab	Extension	$/SF	Scope of Work (Exhibit B)
10	Ships Ladder	1	0	0	0	ls	10,000.00	10,000	0	10,000	0.47	
11	Solar Array Support	1	0	0	0	ls	1.00	1	0	1	0.00	
12	Clerestory Structure	0	3	0	0	tns	5,500.00	0	16,500	16,500	0.78	
DIVISION 6- ROUGH/ FINISH CARPENTRY								***$780,253***	***-$490,600***	***$289,656***	***$13.70***	
	Rough Carpentry							*$740,252*	*-$490,600*	*$249,655*	*$11.80*	
1	Framing	21150	-21150	0	0	ls	30.50	645,075	-645,075	1	0.00	2x6 Exterior walls, 2x4/2x6 interior, 2x10 joists, 1/2" she
2	Stairwell Framing	1	0	0	0	ls	1.00	1	0	1	0.00	Wood, including in Baseline
3	Porch Construction	1	0	0	0	ls	1.00	1	0	1	0.00	See Concrete (part of SOG)
4	FSC Premium	6	-6	0	0	ls	21,150.00	116,325	-116,325	1	0.00	Use FSC Certified wood for all framing
5	OVE Premium	21150	-21150	0	0	ls	-1.00	-21,150	21,150	1	0.00	Allowance (pending review of resource effic detailing)
6	Wood Siding - General	0	8340	0	0	ls	25.00	0	208,500	208,500	9.86	Salvaged wood siding (base on nearby/available source)
7	Wood Siding - Clerestory	0	800	0	0	ls	25.00	0	20,000	20,000	0.95	Salvaged wood siding (base on nearby/available source)
8	Miscellaneous Carpentry	0	21150	0	0	ls	1.00	0	21,150	21,150	1.00	Use FSC Certified wood for all framing
	Finish Carpentry							*$40,001*	*$0*	*$40,001*	*$1.89*	
1	Finish Carpentry	1	0	0	0	ls	1.00	1	0	1	0.00	
1	Casework	80	0	0	0	sf	500.00	40,000	0	40,000	1.89	Allowance
DIVISION 7- THERMAL & MOISTURE PROTECTION								***$256,953***	***$56,381***	***$313,335***	***$14.81***	
	Waterproofing							*$27,030*	*$0*	*$27,030*	*$1.28*	
1	Subgrade Waterproofing	840	0	0	0	sf	7.00	5,880	0	5,880	0.28	Bituthane membrane; 2-6 up vertical inside face only
2	Joint Sealants	21150	0	0	0	gsf	1.00	21,150	0	21,150	1.00	Allowance
	Insulation							*$76,543*	*$56,542*	*$133,085*	*$6.29*	
1	Thermal - Fiberglass Ceiling Batt (R30)	6033	0	0	0	sf	1.25	7,541	0	7,541	0.36	
2	Thermal - Fiberglass Wall Batt (R19)	15080	2200	0	0	sf	1.00	15,080	2,200	17,280	0.82	
3	Sound - Fiberglass Ceiling Batt	10776	0	0	0	sf	0.75	8,082	0	8,082	0.38	
4	Sound - Fiberglass Wall Batt	24000	0	0	0	sf	0.75	18,000	0	18,000	0.85	
5	Tapered EPS	4640	6177	0	0	sf	6.00	27,840	37,062	64,902	3.07	At flat roofs
6	Exterior EPS	0	17280	0	0	ls	1.00	0	17,280	17,280	0.82	1", at building exterior for Living Lab
	Roof & Sheet Metal							*$153,380*	*-$161*	*$153,220*	*$7.24*	
1	Roof Deck Membrane	3620	0	0	0	sf	10.00	36,200	0	36,200	1.71	American Hydrotech 6125
2	Asphalt Shingle Roofing	7300	-7300	0	0	sf	8.00	58,400	-58,400	1	0.00	Standard 3-tap composition shingle roof
3	Miscellaneous Flashing	1	0	0	0	ls	21,200.00	21,200	0	21,200	1.00	Allowance
4	Gutters	1	0	0	0	ls	5,000.00	5,000	0	5,000	0.24	Allowance
5	Deck Pavers	3620	-1310	0	0	sf	9.00	32,580	-11,790	20,790	0.98	Deck set (non-pedastel)
6	Built-Up Roofing	0	7197	0	0	ea	7.00	0	50,379	50,379	2.38	GAF 4-ply BUR or similar
7	Green Roof	0	1310	0	0	lf	15.00	0	19,650	19,650	0.93	American Hydrotech Extensive Garden Roof (4" +/-)
DIVISION 8 - DOORS/FRAMES/HARDWARE								***$281,756***	***$79,345***	***$361,102***	***$17.07***	
	Doors, Frames & Hardware							*$185,001*	*$8,100*	*$193,101*	*$9.13*	
	FURNISH & INSTALL							$185,001	$8,100	$193,101		
	*** FURNISH DOORS**							$185,001	$8,100	$193,101		
1	Elevator Smoke Doors	1	0	0	0	ea	1.00	1	0	1	0.00	None
2	Single Interior - Dorm	48	0	0	0	ea	1,400.00	67,200	0	67,200	3.18	WD Solid core, paint grade, KD frame
3	Single Interior - Standard	29	0	0	0	ea	1,400.00	40,600	0	40,600	1.92	WD Solid core, paint grade, KD frame
4	Single Exterior	8	0	0	0	ea	1,700.00	13,600	0	13,600	0.64	Metal door/ frame
5	Double Interior	2	0	0	0	ea	1,800.00	3,600	0	3,600	0.17	Metal door/ frame
6	Double Exterior	6	0	0	0	ea	5,000.00	30,000	0	30,000	1.42	Standard storefront entrance
7	Garage	2	0	0	0	ea	15,000.00	30,000	0	30,000	1.42	
8	FSC Certified Doors	0	81	0	0	ea	100.00	0	8,100	8,100	0.38	Upgrade for FSC certification in wood doors
	Glass & Glazing							*$96,755*	*$71,245*	*$168,001*	*$7.94*	
1	Windows	1893	-1893	0	0	sf	35.00	66,255	-66,255	1	0.00	Millguard classic vinyl
2	Skylights	140	0	0	0	sf	150.00	21,000	0	21,000	0.99	Allowance
3	Mirrors	1	0	0	0	ls	5,500.00	5,500	0	5,500	0.26	1/4", polished edges, J-bar supported

	Description	Quantity	"B"	"C"	"D"	Unit	Unit Price	Baseline	Living Lab	Extension	$/SF	Scope of Work (Exhibit B)
4	Windows: Interior	1	0	0	0	ls	4,000.00	4,000	0	4,000	0.19	Wire glass if required for FR
5	Windows - Triple Glazed/ General	0	1893	0	0	ls	55.00	0	104,115	104,115	4.92	Allowance (Gorell does not ship to west coast)
6	Windows - Triple Glazed/ Clerestory	0	607	0	0	ls	55.00	0	33,385	33,385	1.58	Allowance (Gorell does not ship to west coast)
DIVISION 9 - FINISHES								***$908,180***	***$136,875***	***$1,045,056***	***$49.41***	
	Lath & Plaster							*$256,360*	*-$53,720*	*$202,641*	*$9.58*	
1	Plaster System	15080	-15080	0	0	sf	14.00	211,120	-211,120	1	0.00	3-coat, D-paper, med sand finish
2	Lime Plaster System	0	7540	0	0	sf	20.00	0	150,800	150,800	7.13	Allowance (no contractors have performed)
3	Scaffold System	15080	2200	0	0	sf	3.00	45,240	6,600	51,840	2.45	
	Drywall & Metal Stud Framing							*$317,250*	*$152,078*	*$469,328*	*$22.19*	
1	Drywall & Taping	12	-2	0	0	gsf	21,150.00	253,800	-42,300	211,500	10.00	1-layer 5/8"
2	Premium for 2nd Layer	3	-0.75	0	0	gsf	21,150.00	63,450	-15,863	47,588	2.25	1-layer 5/8", Level-4 finish
3	Interior Metal Framing	0	24000	0	0	sf	3.00	0	72,001	72,001	3.40	3-5/8"/25ga framing
4	Exterior Metal Framing	0	15080	0	0	ls	8.00	0	120,640	120,640	5.70	4"/16-18ga. Framing, dens glass
5	Clerestory Ext Metal Framing	0	2200	0	0	ls	8.00	0	17,600	17,600	0.83	4"/16-18ga. Framing, dens glass
	Tile							*$70,336*	*$0*	*$70,336*	*$3.33*	
1	Ceramic Floor Tile	1892	0	0	0	sf	15.00	28,380	0	28,380	1.34	Dal 2x2 standard
2	Floor Prep, W/P	1892	0	0	0	lf	8.00	15,136	0	15,136	0.72	
3	Ceramic Wall Tile	1788	0	0	0	lf	15.00	26,820	0	26,820	1.27	Dal 2x2 standard
	Flooring							*$153,164*	*$14,152*	*167,316*	*$7.91*	
1	Carpet - Common	4	1	0	0	sf	3,335.00	13,340	3,335	16,675	0.79	30oz cut pile/ 32oz. Loop
2	Carpet - Rooms	3.5	1	0	0	sf	4,076.00	14,266	4,076	18,342	0.87	30oz cut pile/ 32oz. Loop
3	Cork	12	0	0	0	sf	7,788.00	93,456	0	93,456	4.42	Expanko Cork
4	Linoleum	5	0	0	0	sf	1,052.00	5,260	0	5,260	0.25	
5	Sealed Concrete	5	0	0	0	sf	3,009.00	15,045	0	15,045	0.71	
6	Base	1.75	1	0	0	lf	6,741.00	11,797	6,741	18,538	0.88	4" rubber
	Painting							*$111,070*	*$24,365*	*$135,435*	*$6.40*	
1	Interior Paint	3	0.5	0	0	gsf	21,150.00	63,450	10,575	74,025	3.50	Low/No VOC
2	Exterior Paint	1.5	0.5	0	0	sf	15,080.00	22,620	7,540	30,160	1.43	Low/No VOC
3	Wall Coverings	1	0.25	0	0	ls	25,000.00	25,000	6,250	31,250	1.48	
DIVISION 10- SPECIALTIES								***$62,652***	***$0***	***$62,652***	***$2.96***	
	Miscellaneous Specialties							*$62,652*	*$0*	*$62,652*	*$2.96*	
1	Toilet Partitions	9	0	0	0	ea	850.00	7,650	0	7,650	0.36	Painted metal.
2	Toilet Specialties	11	0	0	0	ea	500.00	5,500	0	5,500	0.26	
3	Signage - Code	1	0	0	0	ls	1.00	1	0	1	0.00	
4	Signage - Exterior	1	0	0	0	ls	1.00	1	0	1	0.00	
5	Awnings	36	0	0	0	ea	1,000.00	36,000	0	36,000	1.70	
6	Shower Units	9	0	0	0	ea	1,500.00	13,500	0	13,500	0.64	
DIVISION 11- EQUIPMENT								***$158,910***	***$0***	***$158,910***	***$7.51***	
1	Ktichen Hood	1	0	0	0	ls	50,000.00	50,000	0	50,000	2.36	Hood, grease duct, ansul, installation
2	Complete Kitchen	752	0	0	0	sf	80.00	60,160	0	60,160	2.84	Allowance
3	Lab Equipment	1	0	0	0	ls	48,750.00	48,750	0	48,750	2.30	Allowance
DIVISION 12- FURNISHINGS								***$9,465***	***$3,035***	***$12,500***	***$0.59***	
1	Window Treatment	1893	607	0	0	sf	5.00	9,465	3,035	12,500	0.59	Allowance
DIVISION 14- CONVEYING SYSTEMS								***$1***	***$0***	***$1***	***$0.00***	
1	Elevator	1	0	0	0	ls	1.00	1	0	1	0.00	None
DIVISION 15- MECHANICAL								***$748,931***	***$427,536***	***$1,176,467***	***$55.62***	
	Fire Protection							*$95,175*	*$5,000*	*$100,175*	*$4.74*	
1	Fire Protection	21150	0	0	0	gsf	4.50	95,175	0	95,175	4.50	Semi-recessed heads.
2	Clerestory	0	1	0	0	ls	5,000.00	0	5,000	5,000	0.24	
	Plumbing							*$548,006*	*$354,895*	*$902,901*	*$42.69*	

	Description	Quantity	"B"	"C"	"D"	Unit	Unit Price	Baseline	Living Lab	Extension	$/SF	Scope of Work (Exhibit B)
1	Plumbing - General Building	1	0	0	0	ls	257,000.00	257,000	0	257,000	12.15	11 w/c, 11 lavy, 9swr, 2 sink, 4 washer, 2 mop sink, 5 FD
2	Plumbing - Lab	1	0	0	0	ls	25,000.00	25,000	0	25,000	1.18	
3	Heating - Baseboard/ Radiant	0.75	0.25	0	0	ls	336,000.00	252,000	84,000	336,000	15.89	
4	Greywater System	0.11	0.89	0	0	ls	122,000.00	14,006	107,994	122,000	5.77	
5	Greywater System - Heat Recovery	0	1	0	0	ea	12,000.00	0	12,000	12,000	0.57	
6	Blackwater System - Hookups	0	1	0	0	ls	25,000.00	0	25,000	25,000	1.18	
7	Potable Water Connection	0	1	0	0	ls	1,500.00	0	1,500	1,500	0.07	
8	Rainwater Harvest	0	1	0	0	ea	124,400.00	0	124,400	124,400	5.88	
9	Boiler	0	1	0	0	ls	1.00	0	1	1	0.00	Allowance; possible trench drain in lieu of relocates.
	HVAC							*$105,750*	*$67,641*	*$173,391*	*$8.20*	
1	HVAC Budget	21150	2950	0	0	gsf	5.00	105,750	14,750	120,500	5.70	
2	Boiler (Back-Up Heat)	0	1	0	0	ls	1.00	0	1	1	0.00	200,000 Btu - Included in Radiant Heating
3	Solar Hot Water	0	615	0	0	sf	86.00	0	52,890	52,890	2.50	
	DIVISION 16- ELECTRICAL							***$399,400***	***$442,630***	***$842,030***	***$39.81***	
	Basic Electrical							*$399,400*	*$24,847*	*$424,247*	*$20.06*	
1	Power, Lighting & Fire Alarm	16	1.2	0	0	ls	21,150.00	338,400	24,847	363,247	17.17	Allowance. Quote pending.
2	Sitework/ Power Hook-Up	1.2	0	0	0	ls	21,150.00	24,999	0	24,999	1.18	
3	Fire Alarm	1	0	0	0	ls	1.00	1	0	1	0.00	
4	Individual Circuit Monitoring	8	0	0	0	ls	4,500.00	36,000	0	36,000	1.70	Supply & hook-up of house power; starter b/o.
	Photovoltaics							*$0*	*$417,783*	*$417,783*	*$19.75*	
1	Solar Power System	0	47	0	0	kw	8,889.00	0	417,783	417,783	19.75	
	DIVISION 17- LV & CONTROLS							***$245,400***	***$54,800***	***$300,192***	***$14.19***	
1	Tel/ Data Budget	1	0	0	0	gsf	57,200.00	57,200	0	57,200	2.70	
1	MEP General Monitoring/ Controls	0.7	0.3	0	0	ls	116,000.00	81,200	34,800	116,000	5.48	
2	Fire Alarm/ Sprinkler Monitoring	1	0	0	0	ls	107,000.00	107,000	0	107,000	5.06	
3	Branch Circuit Monitoring	0	1	0	0	ls	10,000.00	0	10,000	10,000	0.47	
4	Additional Miscellaneous Monitorin	0	1	0	0	ls	10,000.00	0	10,000	10,000	0.47	
							SUBTOTAL	***$4,711,248***	***$1,516,621***	***$6,227,869***	***$294.46***	
							GENERAL CONDITIONS	*$565,158*	*$63,000*	*$628,158*	*Incl.*	
							SUBCONTRACTOR BONDS	*$103,059*	*$33,176*	*$136,235*	*$6.44*	
							SUBTOTAL	*$5,379,464*	*$1,612,797*	*$6,992,261*	*$330.60*	
							FEE	*$367,311*	*$121,393*	*$488,704*	*$23.11*	
							TOTAL PRICE	***$5,746,775***	***$1,734,190***	***$7,480,966***	***$353.71***	
							CONTINGENCY (Add to Total Price)	*$574,678*	*$173,419*	*$748,097*	*$35.37*	**OK**
							TOTAL PRICE w/ CONTINGENCY	***$6,321,453***	***$1,907,609***	***$8,229,062***	***$389.08***	
							$/SF	***$298.89***	***$90.19***	***$389.08***		

LINE ITEM COST ANALYSIS

NO.	DESCRIPTION	DIFFERENCE BETWEEN "BASELINE" AND "LIVING LAB"	$/SF
1	ROCKING STEEL FRAME	234,983	$ 11.06
	a. Baseline: Basic 3-story wood frame construction consisting of 2x6 exterior walls, 2x4/2x6 interior walls, 2x10 floor joists, 3/4" CDX floor plywood, 1/2" CDX shear/wall plywood, and 2x12 cut/stacked roof w/ 1/2" OSB. Includes FSC certified wood, and assumes credit for OVE (resource efficient) framinq. Includes 2-layers of drywall on walls and		
	b. Living Lab: Steel framed structure, with concrete slabs on metal decking. Steel frame braced with rocker-frames, with allowance for post-tensioned cable installation. Interior and exterior framing is light gauge metal stud, with dens-qlass/ 1" EPS exterior.		
	c. Summary: Premium is for using steel frame structure in lieu of wood frame structure. Includes allowances for PT cable, earthwork/foundation upgrades and credits for exposed ceilings.		
2	SUSTAINABLE EXTERIOR MATERIALS	221,041	$ 10.40
	a. Baseline: Buildling cladding - standard cement plaster. Sitework - standard concrete paving (sidewalks, driveways).		
	b. Living Lab: Cladding - 50% lime plaster (St.Austier hydraulic lime, or similar), 50% salvaged wood siding (from local source). Sitework - paving based on pervious paving.		
	c. Summary: Premium for the following exterior materials: 1) lime plaster/ salavaged wood in lieu of standard cement plaster (Baseline), 2) pervious concrete paving in lieu of standard concrete paving (Baseline).		
3	TRIPLE-PANED WINDOWS AND IMPROVED DAYLIGHTING	47,620	$ 2.24
	a. Baseline: Window based on Milguard Classic Vinyl series dual glazed windows.		
	b. Living Lab: Based on allowance for triple glazed windows.		
	c. Summary: Premium is for providing triple-glazed window in lieu of dual glazed windows.		
4	GREEN ROOF	9,886	$ 0.47
	a. Baseline: Direct set (not pedastal set) paving system throughout entire 2nd floor deck. Pavers would sit on top of a standardized waterproofing membrane (Hydroteck 6125, or similar).		
	b. Living Lab: Replace approximately 1310sf of roof pavers with Hyrotech Extensive Garden Roof, consisting mainly of vegetation with shallow root system, resistance to direct radiation, regenerative, and drought, frost and wind		
	c. Cost Premium Summary: Garden roof in lieu of roof pavers.		
5	ROOF UPGRADE Replace 3-tab for BUR & additional insulation	36,528	$ 1.72
	a. Baseline: Conventional aspalt shingle (30yr.) roofing, over building paper, over plywood sheathing, over wood trusses (gabled/ sloped roof).		
	b. Living Lab: High reflective built-up roof, over tapered polyiso (foam) insulation, over concrete slab on metal deck (with exposed bottom/interior).		
	c. Cost Premium Summary: Using tapered polyiso insulation, in lieu of fiberglass batt insulation. This allows for exposed ceilings in interiors, providing better thermal mass benefits, and further, deleting drywall from ceilings (credit value in STEEL STRUCTURE PREMIUM). This cost premium also involves increasing R-Value of roof insulation.		
6	CLERESTORY	131,214	$ 6.17
	a. Baseline: No clerestory. Roof is a conventional sloped roof made from pre-fabricated trusses.		
	b. Living Lab: Clerestory projects from main roof to allow. Windows in clerestory allow for solar gain in northern top floor rooms. Clerestory assumed to be approximately 128lf long x 14 wide, and containing approximately 600sf of window.		
	c. Cost Premium Summary: Cost premium is for the additional structure required (steel vertical support) required to create the clerestory. In addition, the exterior cladding (assumed to be salvaged wood siding), temporary access required for this work (scaffold) and interior wall finish (drywall/ paint). Roofing and insulation impacts for clerestory, contain in Baseline, are assumed to be negligible.		
7	SUSTAINABLE INTERIOR FINISH MATERIALS	58,635	$ 2.76
	a. Overview: Interior finish materials included in this group are paint, flooring and doors.		
	b. Baseline: Paint is low VOC. Carpet is standard commercial grade. Doors are standard wood (where wood).		
	c. Living Lab: Paint is no VOC and/or natural based paint (depending on performance). Carpet has recycled content, and is recyclable, while maintaining performance. Wood doors are FSC certified.		
	d. Cost Premium Summary: Cost premium is to use sustainable interior finish materials in lieu of conventional materials.		
8	RADIANT FLOOR HEATING	105,655	$ 4.97
	a. Baseline: Radiant baseboard heating, consisting of a central boiler, radiators in each room, and 3-4 zones on each floor.		
	b. Living Lab: Radiant floor heating (PEX tubing) with central boiler, pumps and 25 zones.		
	c. Summary: Cost premium is for additional piping required for radiant floor heating, and additional controls, piping and wiring required for additional heating zones.		

NO.	DESCRIPTION	DIFFERENCE BETWEEN "BASELINE" AND "LIVING LAB"	$/SF
9	SOLAR HOT WATER	66,525	$ 3.13
	a. Baseline: None		
	b. Living Lab: Solar hot water system consisting of 615sf of solar panels, 1000gal pressurized storage tank, heat exchanger, pumps and controls.		
	c. Summary: Cost premium is for addition of solar hot water system.		
10	GREYWATER COLLECTION	142,124	$ 6.69
	a. Baseline: None		
	b. Living Lab: Installation of 2000gal greywater storage tank, heat exchanger and piping, double contained piping, piping to 2000 gal filtered water storage tank, filtration equipment, connection piping to conventional blackwater		
	c. Summary: Cost premium is for addition of greywater collection system.		
11	GREYWATER HEAT RECOVERY	15,094	$ 0.71
	a. Baseline: None		
	b. Living Lab: Heat exchanger and piping added to greywater collection system.		
	c. Summary: Cost premium is for addition of heat recovery system to greywater collection system.		
12	BLACKWATER SYSTEM/ POTABLE WATER HOOK-UPS	39,621	$ 1.86
	a. Baseline: Conventional sewer system in baseline concept.		
	b. Living Lab: Double contained piping for blackwater system, stubbed to lab space for future filtration system. Includes connection to 2000 gal tank for potable water.		
	c. Summary: Cost premium is for addition of blackwater recovery piping.		
13	RAINWATER HARVEST	162,759	$ 7.66
	a. Baseline: None. Baseline concept includes rainwater leaders to storm drain.		
	b. Living Lab: 5500 gallon underground storage tank, piping to 5500 tank (in addition to storm drain connections), filter, 2000 gallon filtered water tank, piping to 2000 gallon tank, connection to irrigation system, pumps and controls.		
	c. Summary: Cost premium is for addition of a rainwater harvest system.		
14	SOLAR PHOTOVOLTAICS	525,487	$ 24.73
	a. Baseline: None (all electrical from grid).		
	b. Living Lab: 47kw (approximately 4000sf) solar panel array, with roof support, including inverter, connection to panel, and remote monitoring.		
	c. Summary: Cost premium is for addition of a photovoltaic system.(note: see rebate info under "alternates")		
15	ADDITIONAL HVAC COMMISSIONING	18,553	$ 0.87
	a. Baseline: Basic start-up, air-balance and commissioning.		
	b. Living Lab: Detailed start-up and commissioning.		
	c. Summary: Cost premium is for additional time and equipment required for additional and extended monitoring of HVAC equipment.		
16	HIGH-PERFORMANCE LIGHTING PACKAGE	31,253	$ 1.47
	a. Baseline: Standard fluoresent fixtures, ballasts, and switches.		
	b. Living Lab: High performance fluorescent lighting, high performance (dimmer compatible) electronic ballasts, dimmer switching (where possible), timers/ stepped power (day/evening lighting set-backs in public spaces).		
	c. Summary: Cost premium is for upgraded electrical equipment that will provided improved light quality, and long term energy savings.		
17	MONITORING OF ALL UTILITY SYSTEMS	60,628	$ 2.85
	a. Baseline: No monitoring.		
	b. Living Lab: Monitoring of energy consumption from various zones: electrical consumption (per circuit), water consumption (4-6 zones), gas consumption (1 zone). Provide temperature in all heated zones. Information would		
	c. Summary: Cost premium is for providing sensors, wiring and terminal equipment to monitor various energy consumption at more detailed levels than conventional structures.		
	SUBTOTAL	**1,907,609**	**$90/sf**
X	ALTERNATES		$ -
	a. Potential PV Credit/Rebate (47Kw x $2500/Kw)	(117,500)	$ (5.53)
	b. Fuel Cell Installation (5kw system, includes replacement stack for approximate 5-yr lifespan)	105,000	$ 4.94
	SUBTOTAL	1,895,109	

Life Cycle Cost Analysis

The goal of life-cycle cost analysis (LCCA) is to understand the cost implications of different system options over the entire life of a project, looking beyond simply the initial costs required to construct a building.

LCCA takes into account both initial costs and recurring costs, including energy, routine maintenance, and system replacement values.

LCCA is particularly important on the Green Dorm project because a number of the options under consideration include energy generating systems. It we look only at the purchase and construction costs of these systems we do not see the whole story since we would miss the value of the energy these systems produce.

This section presents LCCA for the Green Dorm system options in three interrelated sections.

1. "By the book" – The system options for the Green Dorm are analyzed strictly using the LCCA procedure established in the Stanford LCCA Guidelines. This analysis only considers the "hard numbers" and conventional dollar values the systems would entail.
2. "Soft factors" – There are a number of factors that are worth considering beyond the hard numbers presented in the first section. These are listed and discussed in this section.
3. "What if?" – In the conclusion, the LCC analysis established in section (1) is extended to take a first pass at including some of the factors discussed in section (2).

In general it is the goal of this LCCA section in the feasibility report to examine the life-cycle cost impacts of the various system options we have investigated in the feasibility stage of design.

System Options

We investigated a number of system options for the Green Dorm project with the goal of providing data across a wide range of choices. These options span from looking at the LCC performance of what a conventional "standard new row house" might look like all the way to two different options that accomplish the "zero carbon" program goals.

The list below presents a short description of each run along with a number designation and short name for each. These names and numbers are used throughout the rest of the LCCA section.

Run 0 – Standard Row House
To set a baseline context for what CEE is trying to accomplish with the Green Dorm, we established this case to be a "standard" new dorm that might be built somewhere else on campus, without the integrated design concepts and demand reduction that will be present in the Green Dorm. Energy use for this case is assumed to be at the bottom quartile for both natural gas use and electricity use based on actual Stanford Utilities data for all row houses from years 2004 and 2005. Choosing data from the bottom quartile means that the dorm would use energy at a rate just below the highest three-quarters of the existing dorms.

Runs 1A and 1B – the "Baseline" and "Target" Green Dorm
Run 1A is what we consider to be the "Baseline" Green Dorm. This is the case where the building is designed with strong integrated design concepts to reduce energy use related to building design, but this case does not incorporate significant energy demand reductions due to user behavior. Run 1B then takes 1A a step further to include the effect of demand reduction by proactive users. 1A is titled "Baseline Green Dorm" and 1B is titled "Target Green Dorm" sometimes referred to as TGD.

Run 2 – Target Green Dorm with Solar Hot Water Collection System
This run adds in a solar hot water heating system to the Target Green Dorm scenario. The solar system is sized to meet the monthly peak demand in the spring and fall with a solar array sized with 475 square feet of collector. During winter, this array does not produce enough heat to serve the building demands – sizing it large enough to meet this demand would make the array much larger, resulting in excess heat production at all other times of the year. This scenario does not meet the zero carbon program goal.

Run 3 – Target Green Dorm with Solar Hot Water and Drain-water Heat Recovery
This scenario adds a drain-water heat recover system to the components from Run 2. This heat recovery system takes heat out of the waste drain water and with a heat-pump sends it back into the building to be reused. This scenario does not meet the zero carbon program goal.

Runs 4A and 4B – Target Green Dorm with Solar Hot Water, Drain-water Heat Recovery, and a Photovoltaic Array
Both of these runs are the first options that meet the zero carbon program goal. By adding in a photovoltaic (PV) array to the components from Run 3, the building produces enough electricity to offset the energy used in the building, with the result being a net zero primary energy demand and a net zero carbon impact on the environment. System size analysis puts the PV array at 46 kW to generate enough electricity over the course of the year. Run 4A examines the economics of this scenario without any self-generation rebates. Run 4B adds in the value of a $2.50/watt.

Runs 5A and 5B – Target Green Dorm with a Fuel Cell and PV array
These runs present a different approach to a project that reaches the net zero carbon goal. Instead of the components from Run 4, these runs use a 3.5 kW fuel cell coupled with a 44 kW PV array and do not use a solar hot water array. Run 5A does not employ rebates and Run 5B adds in a $2.50/watt rebate for the PV array and a $3/watt rebate for the fuel cell.

Life Cycle Cost Analysis Calculation Parameters

The following values are used as a basis for the Life-Cycle Cost (LCC) calculations. All calculations here are consistent with the Stanford LCC Analysis (LCCA) Guidelines.

FIGURE 7.1 - CALCULATION PARAMETERS

General Analysis Parameters

Study Life	50 years
General Inflation Rate	3.0%
Owner Discount Rate (Nominal)	7.0%
Real Discount Rate	3.9%

Annual Escalation Rates

	Nominal	Real
Maintenance	4.0%	0.97%
Materials	4.0%	0.97%
Fuel	4.0%	0.97%
Electricity	4.0%	0.97%

First Costs and Maintenance Costs

Working with the design team's cost consultant, an independent contractor hired to give constructability and cost advice, and Stanford staff/students/faculty, cost estimates were developed for each of the options described above. We also created estimates for a simple maintenance and replacement schedule for the equipment associated with each iteration. *Please see Appendix Chapter H for figures and text which describe the first (construction) and maintenance costs of the variety of options under study.*

Annual Energy Use and Cost

For each of the cases described above, we predict the annual energy use using a combination of historical Stanford Utilities data, DOE-2 energy modeling, and spreadsheet analysis. The results of the annual energy cost calculations are presented in the Figure 7.2.

FIGURE 7.2 - LCCA UTILITY USE AND COST

Run	Name	Natural Gas Use [therms]	Natural Gas Cost [$]	Electricity Use [kWh]	Electricity Cost [$]
0	Standard Row House	6,500	$ 10,205	85,000	$ 9,180
1A	Baseline Green Dorm	3,088	$ 4,848	68,016	$ 7,346
1B	Target Green Dorm (TGD)	2,470	$ 3,879	54,413	$ 5,877
2	TGD + Solar Hot Water (HW)	1,293	$ 2,046	54,423	$ 5,878
3	TGD + Solar HW +Heat Recovery	801	$ 1,253	56,611	$ 6,114
4A	TGD + Solar HW + Heat Recovery + PV	801	$ 1,253	-7,820	$ -
5A	TGD + Combined Heat and Power + PV	4,156	$ 6,507	-40,574	$ -

"By the Book" LCCA Results

Figure 7.3 summarizes the input values for the LCCA calculations. Electricity and fuel costs are taken from the table above. Maintenance and construction costs are also drawn from earlier tables in this section. Replacement costs are added in to the analysis as appropriate for each system where the systems differ from each other. Only differences are considered here since the analysis ranks each case relative to the others. In runs 0 and 1, no replacement costs are assumed

FIGURE 7.3 - INPUT VALUES FOR LCCA CALCULATIONS

Run	Description	Fuel Cost [$]	Electricity Cost [$]	Maintenance Cost [$]	First Cost [$]
0	Standard Row House	$10,205	$9,180	$150	$287,564
1A	Baseline Green Dorm	$4,848	$7,346	$150	$287,564
1B	Target Green Dorm (TGD)	$3,879	$5,877	$150	$327,000
2	TGD + Solar Hot Water (HW)	$2,046	$5,878	$750	$367,311
3	TGD + Solar HW +Heat Recovery	$1,253	$6,114	$1,200	$382,311
4A	TGD + Solar HW + Heat Recovery + PV	$1,253	$0	$1,500	$750,954
4B	Photovoltaic +3 with rebates	$1,253	$0	$1,500	$635,954
5A	TGD + Combined Heat and Power + PV	$6,507	$0	$1,350	$710,724
5B	Combined Heat and Power with rebates	$6,507	$0	$1,350	$588,724

FIGURE 7.4 - "BY THE BOOK" LCCA CALCULATION RESULTS

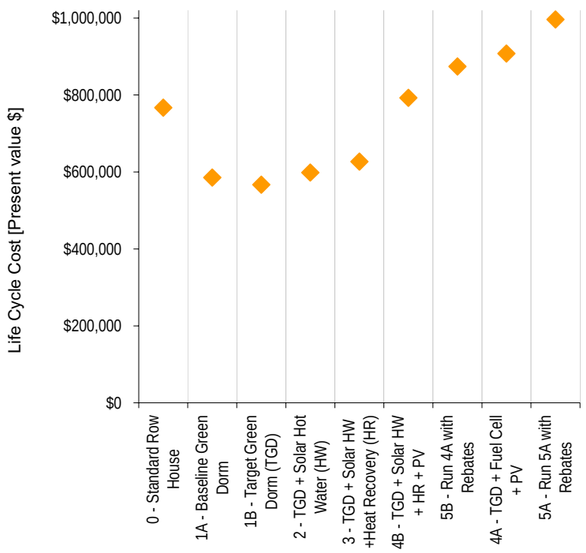
Run	Description	Life Cycle Cost [present dollars] [15 years]	Life Cycle Cost [present dollars] [25 years]	Life Cycle Cost [present dollars] [50 years]	Rank [50 yrs]
0	Standard Row House	$517,927	$619,466	$767,037	5
1A	Baseline Green Dorm	$432,679	$495,683	$585,541	2
1B	Target Green Dorm (TGD)	$443,815	$494,554	$566,961	1
2	TGD + Solar Hot Water (HW)	$476,529	$531,447	$598,384	3
3	TGD + Solar HW +Heat Recovery	$495,492	$552,110	$627,000	4
4A	TGD + Solar HW + Heat Recovery + PV	$802,158	$855,167	$907,609	8
4B	Photovoltaic +3 with rebates	$687,158	$740,167	$792,609	6
5A	TGD + Combined Heat and Power + PV	$821,558	$906,778	$996,131	9
5B	Combined Heat and Power with rebates	$699,558	$784,778	$874,131	7

since the systems in this base case are present in all the cases. In the runs with a solar HW system, a major system maintenance is assumed at 25 years. In runs with the heat recovery system, a major system maintenance is also assumed at 25 years. In runs with a PV array, an inverter replacement is calculated every 20 years. In runs with the fuel cell, a major system replacement is assumed at 25 years.

Figure 7.4 summarizes the LCCA calculation results. The values shown in the "Life Cycle Cost" column are shown in present value dollars and include the "time value of money" effect of including the escalation and discount rates listed above.

Figure 7.5 presents the same data as shown in the LCCA results table. At far left the LCC of the "standard row house" is shown with a 50-year cost of near $800,000. Run 1A, which represents the "baseline

FIGURE 7.5 - "BY THE BOOK" LCCA CALCULATION RESULTS TABLE OVER 50-YEAR LIFE CYCLE



dorm" including integrated design features has a much lower LCC of roughly $600,000. Run 1B includes the demand reductions by the building occupants. The next two options, runs 2 and 3, have a similar overall life-cycle cost. Moving to the right, runs 4A and 5A are the zero carbon options that do not incorporate rebates. Runs 4B and 5B are the zero carbon options that do include rebates. Of course the runs without rebates have a higher LCC than the runs with rebates. What is notable about the LCC for runs 4B and 5B is that while they have a higher LCC than runs 1 through 3, they have a very similar LCC to the "standard" row house.

In other words, if we consider the costs over the life of the building, creating a zero-carbon dormitory incorporating integrated design and demand reduction by the users can cost a similar amount to Stanford as a "standard" dormitory. This is a significant result and shows the power of integrated design and innovative systems.

Figure 7.6 presents the same data again, showing the cumulative LCC performance of each option over a 50 year study. Because the Run 4B line (purple) and the Run 0 line (red) end close together at the right side of the graph, these options have similar overall life-cycle costs even though their initial costs are much different.

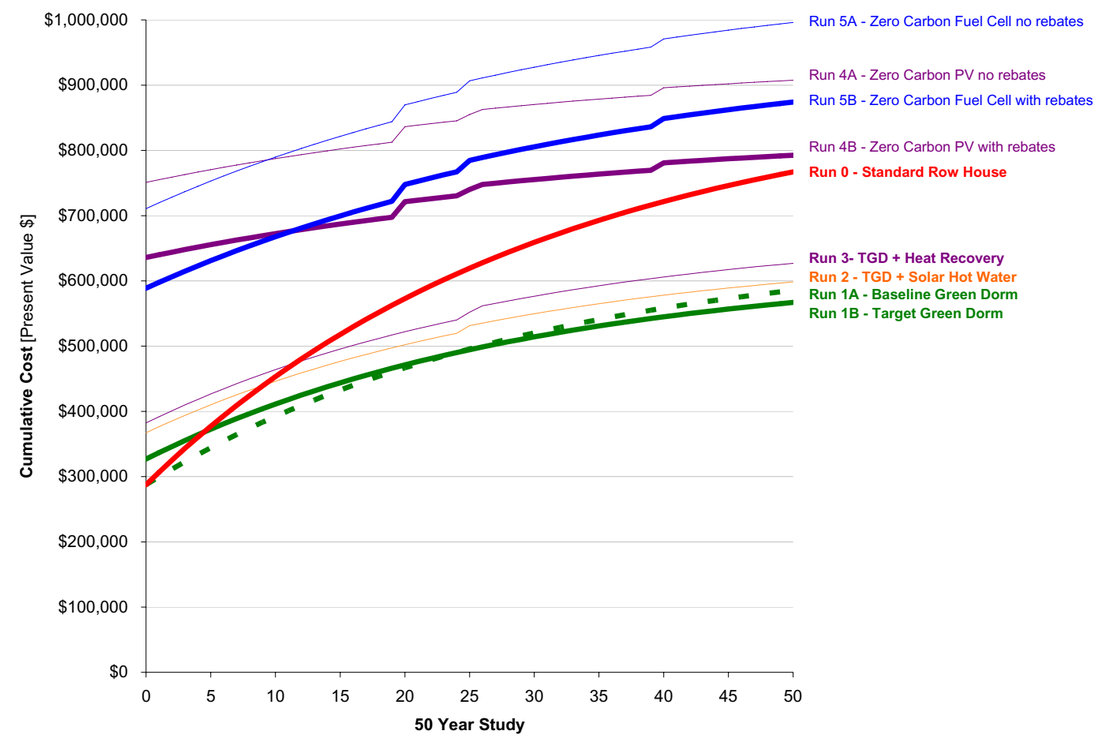
"Soft Factors"

There are a couple factors not incorporated in the data presented above that are worth considering.

Gross Metering

The first we have termed "gross metering." In the analysis performed so far, we followed the rules for valuation of electricity generated on-site established by the Stanford Utilities group. These rules are similar to those in effect today by most utilities like Pacific Gas and Electric where a building is only given full dollar credit for the electricity used by a building itself, and that excess electricity given back to the grid has no value. At the end of the year, if a building generates as much or more electricity than it uses, the electricity bill can be a net zero, but no credit will be given beyond this.

FIGURE 7.6 - "BY THE BOOK" LCCA CALCULATION RESULTS OVER 50-YEAR STUDY PERIOD



Gross metering is a concept where the Green Dorm would be given full value for the excess electricity it generates. While we do not expect that any check would ever be written to the Green Dorm, certainly if the building produced more electricity than it uses, that electricity will flow to other campus buildings and eliminate the need to buy power from Cardinal Cogen. From there, Cardinal Cogen will be able to sell more power to grid and increase the eventual revenue to Stanford. While the Green Dorm will not get the value for the excess electricity it generates, Stanford eventually will.

The next section of the report presents some LCC results including the value of electricity as though it was valued on a "gross metering" basis.

Time-Of-Use Electricity Rates

Another factor to consider is that electricity is much more valuable at some times of day than others, namely from noon to 6pm electricity costs are at their peak. While Stanford does not charge buildings based on the time of day when energy is used, most other utilities do have such "time of use" (TOU) rates. Figure 7.7 summarizes the A-10 time of use rates from PG&E in effect in March 2006.

The next section of the report presents LCC data for the Green Dorm as though electricity generated by the PV array is valued at 13.5¢/kwh and that electricity purchased by the Green Dorm is valued at 9.5¢/kwh. This is a very rough approximation of the TOU value of electricity, but aims to capture the fact that in a dorm most electricity use used at night (off peak) and the PV array would generate electricity mostly during the day (on peak).

Carbon Tax

The last factor to be considered beyond the "by the book" analysis is the value of possible future carbon tax. As discussed elsewhere in the report, CO_2 is a greenhouse gas and is contributing to global climate change. In other parts of the world, a charge or tax is allocated to energy use based on how much CO_2 is generated to deliver that energy.

CO_2 is assumed to be generated according to the Figure 7.8, with appropriate costs and credits allocated to systems based on their energy use / generation totals.

FIGURE 7.7 - PG&E A-10 TIME OF USE RATES, 3/2006

	Summer	Winter
Peak	14.6	-
Part-Peak	13.5	10.6
Off Peak	11.2	8.9
Stanford 2006 Flat Rate	10.8	

FIGURE 7.8 - CO_2 EMISSIONS ASSUMPTIONS

National Average lbs CO_2/delivered per kwh	1.63	
lbs CO_2/1000 ft^3 delivered natural gas	11.6	
1 therm =	100	ft^3 natural gas
lbs CO_2/therm delivered natural gas	1.16	
Carbon Tax on CO_2	$25	/ton

Conclusions

While there is a significant construction cost increase to the zero carbon options, when these are considered in light of their life-cycle cost even a standard "by the book" analysis comparing a zero-carbon dorm to the performance of a "standard" dorm shows that the zero-carbon dorm looks good over a 50 year study. When other reasonable soft factors are considered beyond this basic analysis, the LCC performance of either zero-carbon Green Dorm system option starts to look quite attractive.

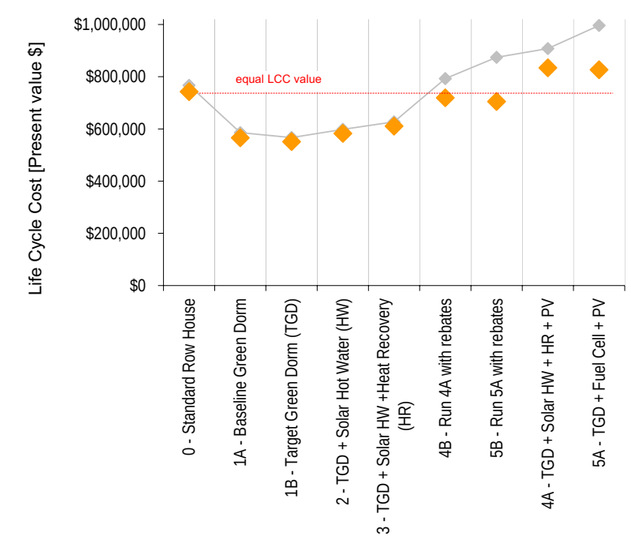
Figure 7.9 shows the "What If?" effect of incorporating both the carbon tax as well as the TOU rates and gross metering. The "By The Book" analysis results are presented in gray and a line is shown connecting those options. That data becomes the background on top of which we can consider the impact of the soft factors.

An "equal value" line corresponding to the life-cycle cost of a "standard" dorm is included as well. The base case scenarios have their LCC relatively unchanged while the zero-carbon system options start to really pay back due to the higher value given to carbon emissions and electricity generated on peak.

Overall, the effect of the carbon tax is not that significant at the assumed $25/ton of CO_2 trading rate. But when we consider the effect of changing the electric utility rates to both a "gross metering" arrangement and a time-of-use valuation system,, the zero-carbon options (all the 4 and 5 runs) end up with a significantly lower LCC due to the fact that the building is not receiving credit for all the excess electricity it generates as well as increased value for that electricity since it is produced on peak. The LCC of the base case options goes down a little since we assumed that the dorm primarily uses electricity when the rates are lower.

In this scenario, the fuel cell options start to perform very well due to the large quantity of excess

FIGURE 7.9 - "WHAT IF?" LCCA VALUES FOR EACH OPTION

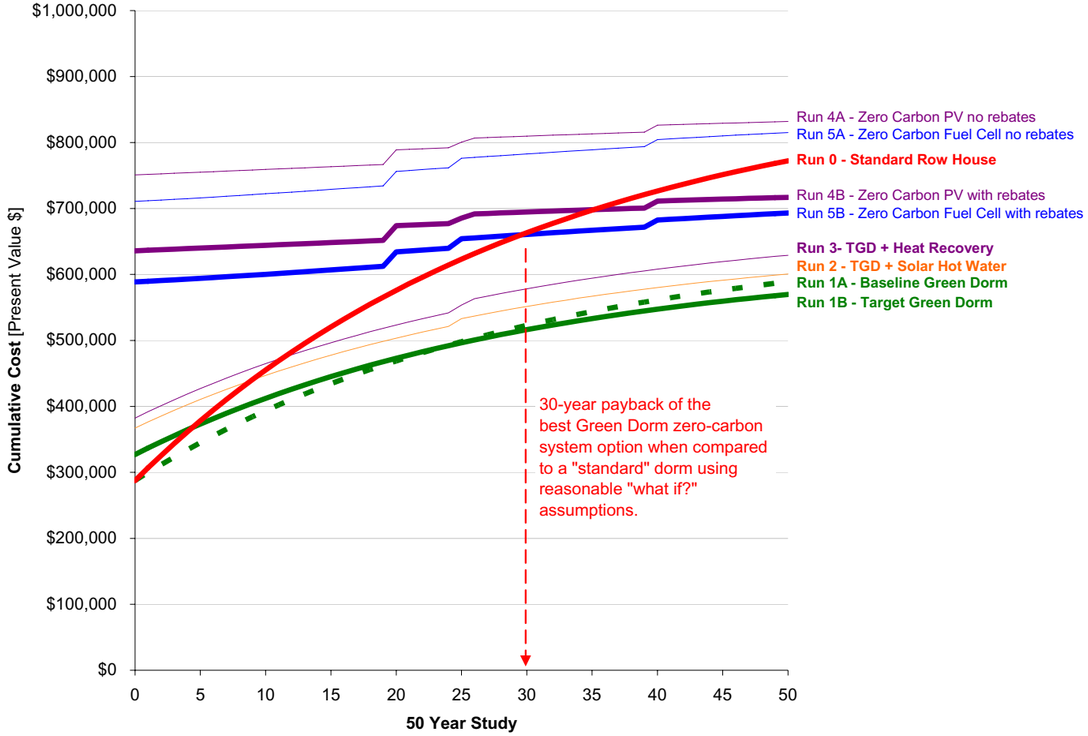


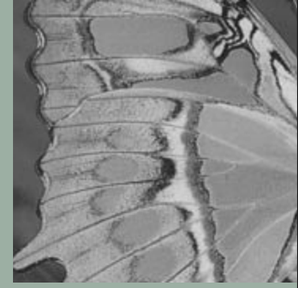
electricity that is generated. (This large amount of electricity is needed to offset the natural gas use by the fuel cell.

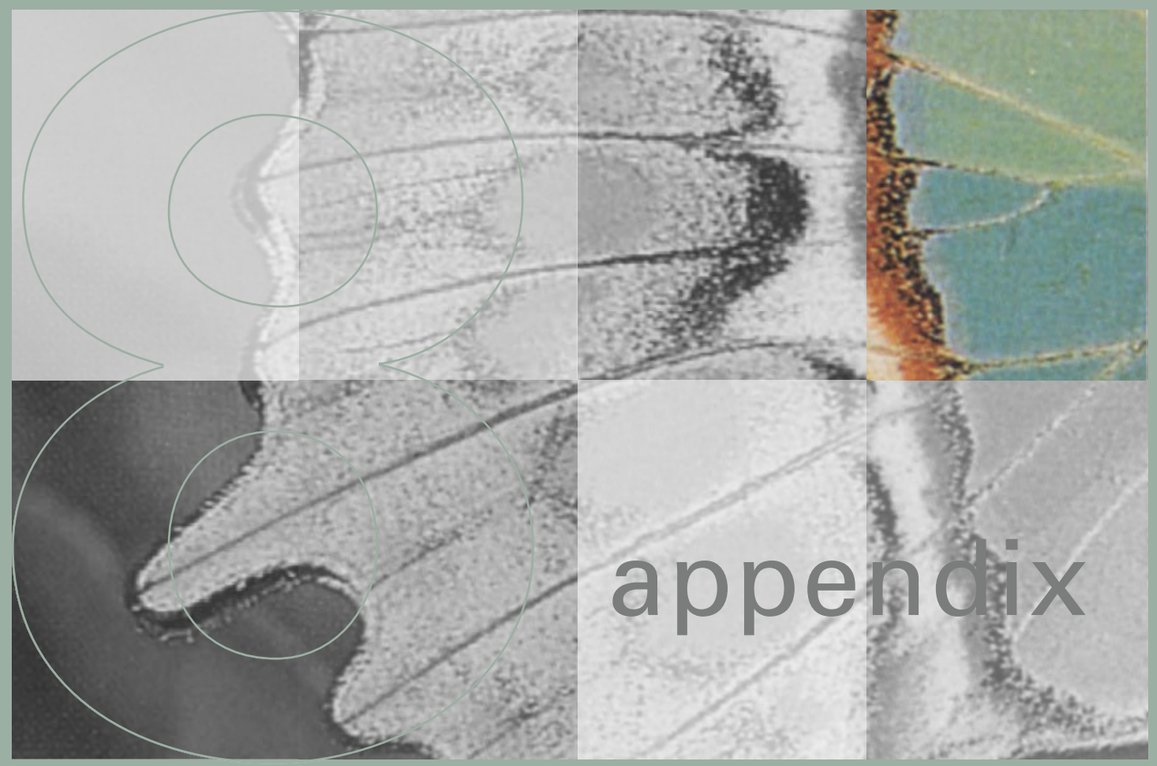
The graph below shows the performance of the system options over the life of the project using the optimistic "what if?" factors under discussion. The red line represents the "standard" dorm performance and the blue and purple lines show the performance of the zero-carbon options. Where the "standard" line crosses the first "zero-carbon" line can be considered the point at which the extra initial investment pays back. In this case that comes out to be a roughly a 30-year period.

When currently available rebates are added into a Green Dorm design scenario that incorporates significant integrated design strategies, aggressive demand reduction by building occupants, and innovative system design, this "what if" analysis shows that a zero-carbon system pays back in about 30-years time and that over 50 years the total life-cycle cost of a zero-carbon Green Dorm can be significantly less than that of a conventional row house.

FIGURE 7.10 - "WHAT IF?" LCCA PAYBACK RESULTS







appendix

a. the macdadi process

b. housing matrix criteria

c. curriculum and student research

d. planning and design guidelines

e. geotech report

f. meeting notes

g. structural life cycle cost analysis

h. energy LCCA: first and maintenance costs