

THE UNIVERSITY OF ILLINOIS SOLAR DECATHLON
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...An American Icon Reborn



GABLE

2009

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Summary of Changes q

q

Following the review dated 2009-05-29, the Illinois Solar Decathlon Team has implemented a vast q number of changes, including incorporating a new page size and format, updating for all the comments q received, adding details and clarifying code compliance. To list each and every change would be q excessive and confusing. For the sake of this submission, it is relevant to state that every page has q changed. q

q

With regard to the comment regarding 300dpi required for all images. We have incorporated files at the q largest resolution possible. q many cases, our document quality was restricted by the consultant or q company providing the information. The Structural Engineer, for example, was only able to provide 96 q dpi scans of the structural drawings. Other information such as spec. sheets from suppliers or data q exported from engineering calculation programs are similarly limited. For all images that may potentially q be reproduced, we have provided 300dpi. We have also incorporated non-vectorized text into the q construction documents. q

q

In addition, the team has, has directly addressed all of the comments received with regard to the q construction documents and have outlined this below. q

q

Sheet	Revi wer	Comment	Action	Corrected Detail
G-000 q	Harold q Willman q	Tamper-resistant receptacles q must be specified on the q electrical drawings q	Tamper-resistant q receptacles have been q specified q	Updated legend of E-q 001 has new q specification of tamper q resistant receptacles for q symbol q
G-000 q	Carol q Anna q	While detailed narrative explains q the public exhibit and signage q concepts, these designs are q required to include drawings of q event sponsor recognition, team q sponsor recognition, public q exhibit handout, and team q uniform. q	We have included all q data required q	Sheets X-501, X502, X-q 511 & X-521 Show all q signage, uniforms & q handouts that the team q will use q

S-001 j	Tom j Meyers j	SD Building code is based on the j 2006 series of the jnternational j Codes j	We have updated the j notes accordingly j	Sheet S-001 - Notes j
S-001 j	Tom j Meyers j	With 18" maximum embedment j	Added note j	Sheet S-001 - Notes j
S-501 j	Tom j Meyers j	Looks like a good system. You j may need to import fill to do j some minor leveling. Make sure j that the fill material is j restrained... j	Added note j	Keynote 15 / Sheet S-j 501 j
S-502 j	Tom j Meyers j	Please note that the Lamboo j material is still undergoing j evaluation and has not been fully j approved at this point. Approval j is likely, however. j	Addressed any j remaining concerns j and submitted official j IRC R104-11 Request. j	See prior emails and/or j "Unlisted Electrical j Components" section of j the project manual j
S-506 j	Tom j Myers j	You may be advised to provide j maximum limitations for hole j and notch sizes. The jRC j requirements are as follows:.... j	Addressed these j maximum limitations j with general note on j sheet j	S-506 / General Sheet j Notes / 1 j
A-111 j	Tom j Meyers j	Verify 36" width for your j accessible route... and jRC j minimum hall width. j	Has been provided j	Refer to ADA drawing X-j 101 j
A-311 j	Tom j Meyers j	I will need specifications on this j material. The proposed thickness j is more than that proposed by j the code. Please provide j manufacturer's test data to j qualify the thicknesses proposed.	Manuf. Data has been j provided and notes j have been added j clearly stating j maximum thickness j allowed and minimum j thermal barrier j installation to occur. j	See prior emails and/or j "Unlisted Electrical j Components" section of j the project manual j
A-313 j	Tom j Meyers j	What water resistive barrier is j proposed between the siding and j the sheathing? j	We have added notes j stating to provide one j layer of No. 15 asphalt j felt. This shall be j covered with 24g steel j	A-312-315 & A-513 j

			siding panels. The o wo d siding will then o be attached on top, o forming a rain screen. o	
A-513 o	Tom o Meyers o	You will have to produce an ICC-o ES evaluation report or other... o	This material has been o removed. It has been o replaced with a single o layer of No. 15 asphalt o felt covered by steel o siding o	A-312-315 & A-513 o
F-101 o	Tom o Meyers o	Interconnect the alarms o	Updated notations to o interconnect the o alarms. o	F-101 o
-101 o	Tom o Meyers o	Please provide some key notes o	Additional notation has o been provided on all o -series sheets and o descriptions of services o have been defined in o the Engineering o Narrative and "Unlisted o Electrical Components" o	-series, "Unlisted o Electrical Components" o
-101 o	Tom o Meyers o	This suggests that an open o plenum will be used in the attic?? o I would assume that you really o intend to duct at least the supply o air side of the system. See o 1601 o for duct construction criteria o	Updated drawings to o show duct through o ro f cap o	-401 o
E-103 o	hn o Wiles o	None of this was provided. See D-o 3, 10-2 and 11-4. o	Provided Voc o calculations. o	Sheet: E-101/General o Sheet Notes o See 2nd Paragrap, o Electrical Calculations, o E-001 o

E-103 k	John k Wiles k	4 AWG conductor in this circuit k does not meet 690.64(B)(2) k ampacity requirements. 60+ 60= k A x 1.2 A =100 amps. k	Changed to 3 awg k	Specified correctly in k table "Wire Schedule" k of E-601 k
E-103 k	John k Wiles k	Location of PV breaker must be k specified and meet 690.64(B)(7) k requirements. k	Specified location k	Depicted in E-101 as k being in the bottom of k the main panel k
E-103 k	John k Wiles k	Inverters must have dc GEC k terminal connected directly to k ground rod unless you are k following all requirements of k 690.47. k	Added drawing to k comply k	Shown in E-101 as a k conductor coming k through PVC 3/4" k conduit to grounding k rod k
E-104 k	Harold k Willman k	Provide exterior illumination in k compliance with NEC k 210.70(A)(2)(b). k	Per NEC 210.70 k (A)(2)(b) a switched k light has been provided k at both entrances to k the home. In addition, k wall mounted led k lighting will be placed k along the north and k south facades k	Sheet E-103 / k Coordinate E2 & E13 k
E-602 k	John k Wiles k	Need specifications and k calculations for all conductors, k conduits, breakers, etc.. They will k be easy to add to top of this k page. Need temperatures used k and if any conduits are in k sunlight. See 310.15(B)(2) k	Provided specifications k & calculations as k required. k	Sheet E-101 / k Coordinate Q1 k Table "Design Choice k Summary" of E-101 k contains specifications k E-001 - Calculations k No conduit is "Exposed k to sunlight on or above k rooftops" per k 310.5(b)(2) k
E-603 k	Harold k Willman k	Review NEC 210.12(B) for all of k the branch circuits required to be k AFCI protected. k	Reviewed & Updated k	Sheet E-103 / k Coordinate K10 k Specified in table k "Breaker Schedule" k under notes of drawing k

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				E-103 .
E-603 .	Harold . Willman .	E-601 was not provided with the . construction documents. Provide . a panel schedule. . EC 408.4 .	Panel schedule . provided .	Sheet E-103 / . Coordinate K10 . "Breaker Schedule" Dwg . E-103 .
E-605 .	Harold . Willman .	Provide load calculations. NEC . 220.1 through NEC 220.82. .	Provided load . calculations .	Sheet E-001 . "Breaker Schedule" and . "Calculated Load" . drawing E-103 .

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RULES COMPLIANCE CHECKLIST

Rule #	Rule Description	Content Requirement(s)	Drawing Sheet(s)	Coordinate s
4-2	Construction Equipment	Drawing(s) showing the assembly and disassembly sequences and the movement of heavy machinery on the competition site	O-101	All
4-2	Construction Equipment	Specs for heavy machinery	01 50 00	N/A
4-3	Ground Penetration	Drawing(s) showing the locations and depths of all ground penetrations on the competition site	C-103	A1
4-4	Impact on the Turf	Drawing(s) showing the location, contact area, and soil bearing pressure of every component resting directly on the turf	C-103 & Structural Calculations	A1
4-5	Generators	Specifications for generators	01 50 00	Specifications
4-6	Spill Containment	Drawing(s) showing the locations of all equipment, tanks, and pipes that will contain fluids at any point during the event	0-201	A1
4-6	Spill Containment	Specifications for all equipment, tanks, and pipes that will contain fluids at any point during the event	0-201	All
4-7	Lot Conditions	Calculations showing that structural design remains compliant even if 18 in. (45.7 cm) of vertical elevation change exists	Structural Calculations	Specifications
4-7	Lot Conditions	Drawing(s) showing shimming methods and materials to be used if 18 in. (45.7 cm) of vertical elevation change exists on the lot	S-501	A12 & F12
5-2	Solar Envelope Dimensions	Drawing(s) showing the location of all house and site components relative to the solar envelope	A-201 A-202	A1 & K1 A1, A12, K1, K12
5-2	Solar Envelope Dimensions	List of solar envelope exemption requests accompanied by justifications and drawing references	None	None



Rule #	Rule Description	Content Requirement(s)	Drawing Sheet(s)	Coordinates
6-1	Structural Design Approval	List of, or marking on, all sheets in the complete electronic Construction Documents that have been or will be stamped by the structural engineer in the hard-copy, stamped structural submission; the stamped submission shall consist entirely of sheets or pages that also appear in the complete electronic construction document set	S-Series	All
6-2	Maximum Architectural Footprint	Drawing(s) showing all information needed by the Rules Officials to measure the architectural footprint electronically	A117	A1
6-2	Maximum Architectural Footprint	Drawing(s) showing all movable components that may increase the footprint if operated during contest week	N/A	N/A
6-2	Maximum Architectural Footprint	Shading calculations and/or diagrams for components that DO NOT shade the building above its finished floor height between 9 a.m. and 5 p.m. EDT on October 1 (shading calculations and/or diagrams are not necessary for components that are either shorter than finished floor height or obviously do not shade the building)	No exterior shading will occur. Only element above floor level is planters and they are far enough away	N/A
6-3	Minimum Conditioned Space	Drawing(s) showing space conditioning means in primary living spaces	A-116	A1
6-4	Entrance and Exit Routes	Drawing(s) showing the accessible public tour route and the ground surface area that will be covered by organizer-provided walkway material	Walkway: C-104 Tour: X-102	A1 A1
7-1	Placement	Drawing(s) showing the location of all vegetation and, if applicable, the movement of vegetation designed as part of an integrated mobile system	L-101	A1



Rule #	Rule Description	Content Requirement(s)	Drawing Sheet(s)	Coordinate s
7-2	Watering Restrictions	Drawings showing the layout and operation of greywater irrigation systems	No Greywater Used	NA
8-1	PV Technology Limitations	Specifications for photovoltaic components	48 14 13.16	Specifications
8-1	PV Technology Limitations	Retail price quote for photovoltaic components	Project Manual	Project Manual
8-3	Thermal Energy Storage	Drawing(s) showing the location of thermal energy storage components	NA	NA
8-3	Thermal Energy Storage	Specifications for thermal energy storage components	NA	NA
8-3	Thermal Energy Storage	Shading calculations and/or diagrams for thermal energy storage components (if necessary)	NA	NA
8-4	Batteries	Drawing(s) showing the location(s) and quantity of stand-alone, PV-powered devices	NA	NA
8-4	Batteries	Specifications for all stand-alone, PV-powered devices	NA	NA
8-5	Desiccant Systems	Drawing(s) describing the operation of the desiccant system	NA	NA
8-5	Desiccant Systems	Specifications for desiccant system components	NA	NA
8-6	Village Grid	Completed Interconnection Application form.	Project Manual	Project Manual
8-6	Village Grid	Drawing(s) showing the locations of the photovoltaics, inverter(s), terminal box, meter housing, service equipment, and grounding means	C-102 A-514	A1 A1
8-6	Village Grid	Specifications for the photovoltaics, inverter(s), terminal box, meter housing, service equipment, and grounding means	48 14 13.16 48 19 16	Specifications
8-6	Village Grid	One-line electrical diagram	E-101	A1
8-6	Village Grid	Calculation of service/feeder net computed load per NEC 220	E-001	Calculations
8-6	Village Grid	Site plan showing the house, decks, ramps, tour paths, and terminal box	X-101, A-101, C-102	A1

Rule #	Rule Description	Content Requirement(s)	Drawing Sheet(s)	Coordinate s
8-6	Village Grid	Elevation(s) showing the terminal box, meter housing, main utility disconnect, and other service equipment	A-201 & A-202 A-221 & A-222	A1
9-4	Rainwater Collection	Drawing(s) showing the layout and operation of rainwater collection systems	NA	--
9-6	Thermal Mass	Drawing(s) showing the locations of water-based thermal mass systems	NA	NA
9-6	Thermal Mass	Specifications for components of water-based thermal mass systems	NA	NA
10-2	Event Sponsor Recognition	Drawing(s) showing the dimensions, materials, artwork, and content of all communications materials, including signage	X-Series	All sheets
10-3	Team Sponsor Recognition	Drawing(s) showing the dimensions, materials, artwork, and content of all communications materials, including signage	X-501 & X-502	Entire Sheet
11-4	Public Exhibit	Interior and exterior plans showing entire accessible tour route	X-101 & X-102	Entire Sheet
11-4	Public Exhibit	Drawing(s) showing the dimensions, materials, artwork, and content of the handout	X-521	Entire Sheet
11-4	Public Exhibit	Drawing(s) showing the artwork and content of the team uniform	X-511	Entire Sheet



SECTION 01 30 00 - ADMINISTRATIVE REQUIREMENTS

PART 1 - GENERAL

1.1 PROJECT MANAGEMENT AND COORDINATION

- A. Coordinate construction operations included in different Sections of the Specifications to ensure efficient and orderly installation of each part of the Work.
- B. Requests for Information (RFIs): On discovery of the need for additional information or interpretation of the Contract Documents, Contractor shall prepare and submit an RFI. Use AIA Document G716-2004.
- C. Schedule and conduct progress meetings at Project site at weekly intervals. Notify Owner and Architect of meeting dates and times. Require attendance of each subcontractor or other entity concerned with current progress or involved in planning, coordination, or performance of future activities.
 - 1. Architect will record minutes and distribute to everyone concerned, including Owner and Architect.

1.2 SUBMITTAL ADMINISTRATIVE REQUIREMENTS

- A. Coordinate each submittal with fabrication, purchasing, testing, delivery, other submittals, and related activities that require sequential activity.
 - 1. No extension of the Contract Time will be authorized because of failure to transmit submittals enough in advance of the Work to permit processing, including resubmittals.
 - 2. Submit three copies of each action submittal. Architect will return two copies.
 - 3. Submit two copies of each informational submittal. Architect will not return copies.
 - 4. Architect will return submittals, without review received from sources other than Contractor.
- B. Place a permanent label or title block on each submittal for identification. Provide a space approximately 6 by 8 inches on label or beside title block to record Contractor's review and approval markings and action taken by Architect. Include the following information on the label:
 - 1. Project name.
 - 2. Date.
 - 3. Name and address of Contractor.
 - 4. Name and address of subcontractor or supplier.
 - 5. Number and title of appropriate Specification Section.

- C. Identify deviations from the Contract Documents on submittals.
- D. Contractor's Construction Schedule Submittal Procedure: Submit two copies of schedule within 5 days after date established for Commencement of the Work.

PART 2 - PRODUCTS

2.1 ACTION SUBMITTALS

- A. Product Data: Mark each copy to show applicable products and options. Include the following:
 1. Manufacturer's written recommendations, product specifications, and installation instructions.
 2. Wiring diagrams showing factory-installed wiring.
 3. Printed performance curves and operational range diagrams.
 4. Testing by recognized testing agency.
 5. Compliance with specified standards and requirements.
- B. Shop Drawings: Prepare Project-specific information, drawn accurately to scale. Do not base Shop Drawings on reproductions of the Contract Documents or standard printed data. Submit on sheets at least 8-1/2 by 11 inches but no larger than 30 by 42 inches. Include the following:
 1. Dimensions and identification of products.
 2. Fabrication and installation drawings and roughing-in and setting diagrams.
 3. Wiring diagrams showing field-installed wiring.
 4. Notation of coordination requirements.
 5. Notation of dimensions established by field measurement.
- C. Samples: Submit Samples for review of kind, color, pattern, and texture and for a comparison of these characteristics between submittal and actual component as delivered and installed. Include name of manufacturer and product name on label.
 1. If variation is inherent in material or product, submit at least three sets of paired units that show variations.

2.2 INFORMATIONAL SUBMITTALS

- A. Qualification Data: Include lists of completed projects with project names and addresses, names and addresses of architects and owners, and other information specified.
- B. Product Certificates: Prepare written statements on manufacturer's letterhead certifying that product complies with requirements in the Contract Documents.



2.3 DELEGATED DESIGN SERVICES

- A. Performance and Design Criteria: Where professional design services or certifications by a design professional are specifically required of Contractor by the Contract Documents, provide products and systems complying with specific performance and design criteria indicated.
 - 1. If criteria indicated are not sufficient to perform services or certification required, submit a written request for additional information to Architect.
- B. Delegated-Design Submittal: In addition to Shop Drawings, Product Data, and other required submittals, submit three copies of a statement, signed and sealed by the responsible design professional, for each product and system specifically assigned to Contractor to be designed or certified by a design professional.
 - 1. Indicate that products and systems comply with performance and design criteria in the Contract Documents. Include list of codes, loads, and other factors used in performing these services.

2.4 CONTRACTOR'S CONSTRUCTION SCHEDULE

- A. Gantt-Chart Schedule: Submit a comprehensive, fully developed, horizontal Gantt-chart-type schedule within 30 days of date established for commencement of the Work.
- B. Preparation: Indicate each significant construction activity separately. Identify first workday of each week with a continuous vertical line.

PART 3 - EXECUTION

3.1 SUBMITTAL REVIEW

- A. Review each submittal and check for coordination with other Work of the Contract and for compliance with the Contract Documents. Note corrections and field dimensions. Mark with approval stamp before submitting to Architect.
- B. Architect will review each action submittal, make marks to indicate corrections or modifications required, will stamp each submittal with an action stamp and will mark stamp appropriately to indicate action.
- C. Submittals not required by the Contract Documents may not be reviewed and may be discarded.

3.2 CONTRACTOR'S CONSTRUCTION SCHEDULE

- A. Updating: At monthly intervals, update schedule to reflect actual construction progress and activities. Issue schedule one week before each regularly scheduled progress meeting.



1. As the Work progresses, indicate Actual Completion percentage for each activity.
- B. Distribute copies of approved schedule to Owner, Architect, subcontractors, testing and inspecting agencies, and parties identified by Contractor with a need-to-know schedule responsibility. When revisions are made, distribute updated schedules to the same parties.

END OF SECTION 01 30 00

SECTION 01 40 00 - QUALITY REQUIREMENTS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Testing and inspecting services are required to verify compliance with requirements specified or indicated. These services do not relieve Contractor of responsibility for compliance with the Contract Document requirements.
 - 1. Testing and inspecting services shall be performed by independent testing agencies.
- B. Referenced Standards: If compliance with two or more standards is specified and the standards establish different or conflicting requirements, comply with the most stringent requirement. Refer uncertainties to Architect for a decision.
- C. Minimum Quantity or Quality Levels: The quantity or quality level shown or specified shall be the minimum. The actual installation may exceed the minimum within reasonable limits. Indicated numeric values are minimum or maximum, as appropriate, for the context of requirements. Refer uncertainties to Architect for a decision.
- D. Test and Inspection Reports: Prepare and submit certified written reports specified in other Sections. Include the following:
 - 1. Date of issue.
 - 2. Project title and number.
 - 3. Name, address, and telephone number of testing agency.
 - 4. Dates and locations of samples and tests or inspections.
 - 5. Record of temperature and weather conditions at time of sample taking and testing and inspecting.
 - 6. Names of individuals making tests and inspections.
 - 7. Description of the Work and test and inspection method.
 - 8. Complete test or inspection data, test and inspection results, an interpretation of test results, and comments or professional opinion on whether tested or inspected Work complies with the Contract Document requirements.
 - 9. Name and signature of laboratory inspector.
 - 10. Recommendations on retesting and reinspecting.
- E. Permits, Licenses, and Certificates: For Owner's records, submit copies of permits, licenses, certifications, inspection reports, notices, receipts for fee payments, and similar documents, established for compliance with standards and regulations bearing on performance of the Work.



- F. Testing Agency Qualifications: An independent agency with the experience and capability to conduct testing and inspecting indicated; and where required by authorities having jurisdiction, that is acceptable to authorities.
- G. Retesting/Reinspecting: Regardless of whether original tests or inspections were Contractor's responsibility, provide quality-control services, including retesting and reinspecting, for construction that replaced Work that failed to comply with the Contract Documents.
- H. Testing Agency Responsibilities: Cooperate with Architect and Contractor in performance of duties. Provide qualified personnel to perform required tests and inspections.
 - 1. Promptly notify Architect and Contractor of irregularities or deficiencies in the Work observed during performance of its services.
 - 2. Do not release, revoke, alter, or increase requirements of the Contract Documents or approve or accept any portion of the Work.
 - 3. Do not perform any duties of Contractor.
- I. Associated Services: Cooperate with testing agencies and provide reasonable auxiliary services as requested. Provide the following:
 - 1. Access to the Work.
 - 2. Incidental labor and facilities necessary to facilitate tests and inspections.
 - 3. Adequate quantities of representative samples of materials that require testing and inspecting. Assist agency in obtaining samples.
 - 4. Facilities for storage and field curing of test samples.
 - 5. Security and protection for samples and for testing and inspecting equipment.
- J. Coordination: Coordinate sequence of activities to accommodate required quality-assurance and -control services with a minimum of delay and to avoid necessity of removing and replacing construction to accommodate testing and inspecting.
 - 1. Schedule times for tests, inspections, obtaining samples, and similar activities.

PART 2 - PRODUCTS (Not Used)

PART 3 - EXECUTION (Not Used)

END OF SECTION 01 40 00

SECTION 014200 - REFERENCES

PART 1 - GENERAL

1.1 GENRAL REQUIREMENTS

- A. Publication Dates: Comply with standards in effect as of date of the Contract Documents unless otherwise indicated.
- B. Abbreviations and Acronyms: Where abbreviations and acronyms are used in Specifications or other Contract Documents, they shall mean the recognized name of the entities in the following list. Names, telephone numbers, and Web site addresses are subject to change and are believed to be accurate and up-to-date as of the date of the Contract Documents.

AA	Aluminum Association, Inc. (The)
AAADM	American Association of Automatic Door Manufacturers
AABC	Associated Air Balance Council
AAMA	American Architectural Manufacturers Association
AASHTO	American Association of State Highway and Transportation Officials
AATCC	American Association of Textile Chemists and Colorists
ABAA	Air Barrier Association of America
ABMA	American Bearing Manufacturers Association
ACI	American Concrete Institute
ACPA	American Concrete Pipe Association
AEIC	Association of Edison Illuminating Companies, Inc. (The)
AF&PA	American Forest & Paper Association
AGA	American Gas Association
AGC	Associated General Contractors of America (The)
AHA	American Hardboard Association (Now part of CPA)

AHAM	Association of Home Appliance Manufacturers
AI	Asphalt Institute
AIA	American Institute of Architects (The)
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
AITC	American Institute of Timber Construction
ALCA	Associated Landscape Contractors of America (Now PLANET - Professional Landcare Network)
ALSC	American Lumber Standard Committee, Incorporated
AMCA	Air Movement and Control Association International, Inc.
ANSI	American National Standards Institute
AOSA	Association of Official Seed Analysts, Inc.
APA	Architectural Precast Association
APA	APA - The Engineered Wood Association
APA EWS	APA - The Engineered Wood Association; Engineered Wood Systems (See APA - The Engineered Wood Association)
API	American Petroleum Institute
ARI	Air-Conditioning & Refrigeration Institute
ARMA	Asphalt Roofing Manufacturers Association
ASCE	American Society of Civil Engineers
ASCE/SEI	American Society of Civil Engineers/Structural Engineering Institute (See ASCE)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	ASME International (American Society of Mechanical Engineers International)



ASSE	American Society of Sanitary Engineering
ASTM	ASTM International (American Society for Testing and Materials International)
AWCI	Association of the Wall and Ceiling Industry
AWCMA	American Window Covering Manufacturers Association (Now WCMA)
AWI	Architectural Woodwork Institute
AWPA	American Wood Protection Association (Formerly: American Wood Preservers' Association)
AWS	American Welding Society
AWWA	American Water Works Association
BHMA	Builders Hardware Manufacturers Association
BIA	Brick Industry Association (The)
BICSI	BICSI, Inc.
BIFMA	BIFMA International (Business and Institutional Furniture Manufacturer's Association International)
BISSC	Baking Industry Sanitation Standards Committee
BWF	Badminton World Federation (Formerly: IBF - International Badminton Federation)
CCC	Carpet Cushion Council
CDA	Copper Development Association
CEA	Canadian Electricity Association
CEA	Consumer Electronics Association
CFFA	Chemical Fabrics & Film Association, Inc.
CGA	Compressed Gas Association
CIMA	Cellulose Insulation Manufacturers Association



CISCA	Ceilings & Interior Systems Construction Association
CISPI	Cast Iron Soil Pipe Institute
CLFMI	Chain Link Fence Manufacturers Institute
CRRC	Cool Roof Rating Council
CPA	Composite Panel Association
CPPA	Corrugated Polyethylene Pipe Association
CRI	Carpet and Rug Institute (The)
CRSI	Concrete Reinforcing Steel Institute
CSA	Canadian Standards Association
CSA	CSA International (Formerly: IAS - International Approval Services)
CSI	Cast Stone Institute
CSI	Construction Specifications Institute (The)
CSSB	Cedar Shake & Shingle Bureau
CTI	Cooling Technology Institute (Formerly: Cooling Tower Institute)
DHI	Door and Hardware Institute
EIA	Electronic Industries Alliance
EIMA	EIFS Industry Members Association
EJCDC	Engineers Joint Contract Documents Committee
EJMA	Expansion Joint Manufacturers Association, Inc.
ESD	ESD Association (Electrostatic Discharge Association)
ETL SEMCO	Intertek ETL SEMCO (Formerly: ITS - Intertek Testing Service NA)
FIBA	Federation Internationale de Basketball



(The International Basketball Federation)

FIVB	Federation Internationale de Volleyball (The International Volleyball Federation)
FM Approvals	FM Approvals LLC
FM Global	FM Global (Formerly: FMG - FM Global)
FMRC	Factory Mutual Research (Now FM Global)
FRSA	Florida Roofing, Sheet Metal & Air Conditioning Contractors Association, Inc.
FSA	Fluid Sealing Association
FSC	Forest Stewardship Council
GA	Gypsum Association
GANA	Glass Association of North America
GRI	(Part of GSI)
GS	Green Seal
GSI	Geosynthetic Institute
HI	Hydraulic Institute
HI	Hydronics Institute
HMMA	Hollow Metal Manufacturers Association (Part of NAAMM)
HPVA	Hardwood Plywood & Veneer Association
HPW	H. P. White Laboratory, Inc.
IAS	International Approval Services (Now CSA International)
IBF	International Badminton Federation (Now BWF)
ICEA	Insulated Cable Engineers Association, Inc.



ICRI	International Concrete Repair Institute, Inc.
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers, Inc. (The)
IESNA	Illuminating Engineering Society of North America
IEST	Institute of Environmental Sciences and Technology
IGCC	Insulating Glass Certification Council
IGMA	Insulating Glass Manufacturers Alliance
ILI	Indiana Limestone Institute of America, Inc.
ISO	International Organization for Standardization Available from ANSI
ISSFA	International Solid Surface Fabricators Association
ITS	Intertek Testing Service NA (Now ETL SEMCO)
ITU	International Telecommunication Union
KCMA	Kitchen Cabinet Manufacturers Association
LMA	Laminating Materials Association (Now part of CPA)
LPI	Lightning Protection Institute
MBMA	Metal Building Manufacturers Association
MFMA	Maple Flooring Manufacturers Association, Inc.
MFMA	Metal Framing Manufacturers Association, Inc.
MH	Material Handling (Now MHIA)
MHIA	Material Handling Industry of America
MIA	Marble Institute of America



MPI	Master Painters Institute
MSS	Manufacturers Standardization Society of The Valve and Fittings Industry Inc.
NAAMM	National Association of Architectural Metal Manufacturers
NACE	NACE International (National Association of Corrosion Engineers International)
NADCA	National Air Duct Cleaners Association
NAGWS	National Association for Girls and Women in Sport
NAIMA	North American Insulation Manufacturers Association
NBGQA	National Building Granite Quarries Association, Inc.
NCAA	National Collegiate Athletic Association (The)
NCMA	National Concrete Masonry Association
NCPI	National Clay Pipe Institute
NCTA	National Cable & Telecommunications Association
NEBB	National Environmental Balancing Bureau
NECA	National Electrical Contractors Association
NeLMA	Northeastern Lumber Manufacturers' Association
NEMA	National Electrical Manufacturers Association
NETA	InterNational Electrical Testing Association
NFHS	National Federation of State High School Associations
NFPA	NFPA (National Fire Protection Association)
NFRC	National Fenestration Rating Council
NGA	National Glass Association
NHLA	National Hardwood Lumber Association
NLGA	National Lumber Grades Authority



NOFMA	NOFMA: The Wood Flooring Manufacturers Association (Formerly: National Oak Flooring Manufacturers Association)
NOMMA	National Ornamental & Miscellaneous Metals Association
NRCA	National Roofing Contractors Association
NRMCA	National Ready Mixed Concrete Association
NSF	NSF International (National Sanitation Foundation International)
NSSGA	National Stone, Sand & Gravel Association
NTMA	National Terrazzo & Mosaic Association, Inc. (The)
NTRMA	National Tile Roofing Manufacturers Association (Now TRI)
NWWDA	National Wood Window and Door Association (Now WDMA)
OPL	Omega Point Laboratories, Inc. (Now ITS)
PCI	Precast/Prestressed Concrete Institute
PDCA	Painting & Decorating Contractors of America
PDI	Plumbing & Drainage Institute
PGI	PVC Geomembrane Institute
PLANET	Professional Landcare Network (Formerly: ACLA - Associated Landscape Contractors of America)
PTI	Post-Tensioning Institute
RCSC	Research Council on Structural Connections
RFCI	Resilient Floor Covering Institute
RIS	Redwood Inspection Service
SAE	SAE International

SDI	Steel Deck Institute
SDI	Steel Door Institute
SEFA	Scientific Equipment and Furniture Association
SEI/ASCE	Structural Engineering Institute/American Society of Civil Engineers (See ASCE)
SGCC	Safety Glazing Certification Council
SIA	Security Industry Association
SIGMA	Sealed Insulating Glass Manufacturers Association (Now IGMA)
SJI	Steel Joist Institute
SMA	Screen Manufacturers Association
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SMPTE	Society of Motion Picture and Television Engineers
SPFA	Spray Polyurethane Foam Alliance (Formerly: SPI/SPFD - The Society of the Plastics Industry, Inc.; Spray Polyurethane Foam Division)
SPIB	Southern Pine Inspection Bureau (The)
SPRI	Single Ply Roofing Industry
SSINA	Specialty Steel Industry of North America
SSPC	SSPC: The Society for Protective Coatings
STI	Steel Tank Institute
SWI	Steel Window Institute
SWRI	Sealant, Waterproofing, & Restoration Institute
TCA	Tile Council of America, Inc. (Now TCNA)
TCNA	Tile Council of North America, Inc.



TIA/EIA	Telecommunications Industry Association/Electronic Industries Alliance
TMS	The Masonry Society
TPI	Truss Plate Institute, Inc.
TPI	Turfgrass Producers International
TRI	Tile Roofing Institute
UL	Underwriters Laboratories Inc.
UNI	Uni-Bell PVC Pipe Association
USA V	USA Volleyball
USGBC	U.S. Green Building Council
USITT	United States Institute for Theatre Technology, Inc.
WASTEC	Waste Equipment Technology Association
WCLIB	West Coast Lumber Inspection Bureau
WCMA	Window Covering Manufacturers Association
WCSC	Window Covering Safety Council (Formerly: WCMA - Window Covering Manufacturers Association)
WDMA	Window & Door Manufacturers Association (Formerly: NWWDA - National Wood Window and Door Association)
WI	Woodwork Institute (Formerly: WIC - Woodwork Institute of California)
WIC	Woodwork Institute of California (Now WI)
WMMPA	Wood Moulding & Millwork Producers Association
WSRCA	Western States Roofing Contractors Association
WWPA	Western Wood Products Association



PART 2 - PRODUCTS (Not Used)

PART 3 - EXECUTION (Not Used)

END OF SECTION 01 42 00



SECTION 01 50 00 - TEMPORARY FACILITIES AND CONTROLS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Use Charges: Installation and removal of and use charges for temporary facilities shall be included in the Contract Sum unless otherwise indicated.
- B. Water and Electric Power: Available from Owner's existing system without metering and without payment of use charges. Provide connections and extensions of services as required for construction operations. For competition available during construction week.
- C. Electric Service: Comply with NECA, NEMA, and UL standards and regulations for temporary electric service. Install service to comply with NFPA 70.
- D. Accessible Temporary Egress: Comply with applicable provisions in ICC/ANSI A117.1.

PART 2 - PRODUCTS

2.1 MATERIALS

- A. Chain-Link Fencing: Minimum 2-inch, 0.148-inch- thick, galvanized-steel, chain-link fabric fencing; minimum 6 feet high with galvanized-steel pipe posts and top and bottom rails.

2.2 TEMPORARY FACILITIES

- A. Provide field offices, storage and fabrication sheds, and other support facilities as necessary for construction operations. Store combustible materials apart from building.
- B. Provide temporary floor cover and allow for solar decathlon organizer supplied walkway during construction.

2.3 EQUIPMENT

- A. Fire Extinguishers: Portable, UL rated; with class and extinguishing agent as required by locations and classes of fire exposures.
- B. HVAC Equipment: Unless Owner authorizes use of permanent HVAC system, provide vented, self-contained, liquid-propane-gas or fuel-oil heaters with individual space thermostatic control.

- C. Generator: Gas 10KW Generator, Cat-Class 008-0020, AC Voltage 12-240, Continuous Amps: 78.0/39.0. 80.8/40.4, 18 HP Engine, Max./Cont. Watts 9700/8400, 9700/9300
1. Available Products:
 - a. Multiquip GA97HE
 - 1) Manufacturer's Specifications (p. 8):
<http://www.multiquip.com/multiquip/pdfs/product-brochures/generators-welders-0209-brochure.pdf>

PART 3 - EXECUTION

3.1 TEMPORARY UTILITY INSTALLATION

- A. General: Install temporary service or connect to existing service.
 1. Arrange with utility company, Owner, and existing users for time when service can be interrupted, if necessary, to make connections for temporary services.
- B. Sanitary Facilities: Provide temporary toilets, wash facilities, and drinking-water fixtures. Comply with regulations and health codes for type, number, location, operation, and maintenance of fixtures and facilities.
- C. Heating **and Cooling**: Provide temporary heating **and cooling** required for curing or drying of completed installations or for protecting installed construction from adverse effects of low temperatures or high humidity. Select equipment that will not have a harmful effect on completed installations or elements being installed.
- D. Provide temporary lighting with local switching that provides adequate illumination for construction operations, observations, inspections, and traffic conditions.

3.2 SUPPORT FACILITIES INSTALLATION

- A. Install project identification and other signs in locations **[indicated]** **[approved by Owner]** to inform the public and persons seeking entrance to Project.
- B. Waste Disposal Facilities: Provide waste-collection containers in sizes adequate to handle waste from construction operations. Comply with requirements of authorities having jurisdiction.

3.3 SECURITY AND PROTECTION FACILITIES INSTALLATION

- A. Provide protection, operate temporary facilities, and conduct construction as required to comply with environmental regulations and that minimize possible air, waterway, and subsoil contamination or pollution or other undesirable effects.

- B. Provide measures to prevent soil erosion and discharge of soil-bearing water runoff and airborne dust to undisturbed areas and to adjacent properties and walkways, according to erosion- and sedimentation-control Drawings. Maximum pressure on grass to be < 1500PSF for solar decathlon competition.
- C. Furnish and install site enclosure fence in a manner that will prevent people and animals from easily entering site except by entrance gates.
- D. Barricades, Warning Signs, and Lights: Comply with requirements of authorities having jurisdiction for erecting structurally adequate barricades, including warning signs and lighting.
- E. Provide temporary enclosures for protection of construction, in progress and completed, from exposure, foul weather, other construction operations, and similar activities. Provide temporary weathertight enclosure for building exterior.
- F. Provide floor-to-ceiling dustproof partitions to limit dust and dirt migration and to separate areas occupied by Owner from fumes and noise.
- G. Install and maintain temporary fire-protection facilities. Comply with NFPA 241.

3.4 MOISTURE AND MOLD CONTROL

- A. Before installation of weather barriers, protect materials from water damage and keep porous and organic materials from coming into prolonged contact with concrete.
- B. After installation of weather barriers but before full enclosure and conditioning of building, protect as follows:
 - 1. Do not load or install drywall or porous materials into partially enclosed building.
 - 2. Discard water-damaged and wet material and material that begins to grow mold.
 - 3. Allow installed wet materials adequate time to dry before being enclosed.

3.5 OPERATION, TERMINATION, AND REMOVAL

- A. Remove each temporary facility when need for its service has ended, when it has been replaced by authorized use of a permanent facility, or no later than Substantial Completion.

END OF SECTION 01 50 00



SECTION 01 60 00 - PRODUCT REQUIREMENTS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. The term "product" includes the terms "material," "equipment," "system," and terms of similar intent.
- B. Comparable Product Requests:
 1. Submit request for consideration of each comparable product. Do not submit unapproved products on Shop Drawings or other submittals.
 2. Identify product to be replaced and show compliance with requirements for comparable product requests. Include a detailed comparison of significant qualities of proposed substitution with those of the Work specified.
 3. Architect will review the proposed product and notify Contractor of its acceptance or rejection.
- C. Basis-of-Design Product Specification Submittal: Show compliance with requirements.
- D. Compatibility of Options: If Contractor is given option of selecting between two or more products, select product compatible with products previously selected.
- E. Deliver, store, and handle products using means and methods that will prevent damage, deterioration, and loss, including theft. Comply with manufacturer's written instructions.
 1. Schedule delivery to minimize long-term storage at Project site and to prevent overcrowding of construction spaces.
 2. Deliver products to Project site in manufacturer's original sealed container or packaging, complete with labels and instructions for handling, storing, unpacking, protecting, and installing.
 3. Inspect products on delivery to ensure compliance with the Contract Documents and to ensure that products are undamaged and properly protected.
 4. Store materials in a manner that will not endanger Project structure.
 5. Store products that are subject to damage by the elements, under cover in a weathertight enclosure above ground, with ventilation adequate to prevent condensation.
- F. Warranties specified in other Sections shall be in addition to, and run concurrent with, other warranties required by the Contract Documents. Manufacturer's disclaimers and limitations on product warranties do not relieve Contractor of obligations under requirements of the Contract Documents.

PART 2 - PRODUCTS

2.1 PRODUCT SELECTION PROCEDURES

- A. Provide products that comply with the Contract Documents, are undamaged, and are new at the time of installation.
 - 1. Provide products complete with accessories, trim, finish, and other devices and components needed for a complete installation and the intended use and effect.
 - 2. Descriptive, performance, and reference standard requirements in the Specifications establish salient characteristics of products.
- B. Product Selection Procedures:
 - 1. Where Specifications name a single manufacturer and product, provide the named product that complies with requirements.
 - 2. Where Specifications name a single manufacturer or source, provide a product by the named manufacturer or source that complies with requirements.
 - 3. Where Specifications include a list of names of both manufacturers and products, provide one of the products listed that complies with requirements. Comparable products or substitutions for Contractor's convenience will be considered.
 - 4. Where Specifications include a list of names of both available manufacturers and products, provide one of the products listed, or an unnamed product, that complies with requirements. Comply with requirements for "comparable product requests" for consideration of an unnamed product.
 - 5. Where Specifications include a list of manufacturers' names, provide a product by one of the manufacturers listed that complies with requirements. Comparable products or substitutions for Contractor's convenience will be considered.
 - 6. Where Specifications include a list of available manufacturers, provide a product by one of the manufacturers listed, or a product by an unnamed manufacturer, that complies with requirements. Comply with requirements for "comparable product requests" for consideration of an unnamed manufacturer's product.
 - 7. Where Specifications name a single product, or refer to a product indicated on Drawings, as the "basis-of-design," provide the named product. Comply with provisions for "comparable product requests" for consideration of an unnamed product by another manufacturer.
- C. Where Specifications require "match Architect's sample," provide a product that complies with requirements and matches Architect's sample. Architect's decision will be final on whether a proposed product matches.
- D. Unless otherwise indicated, Architect will select color, gloss, pattern, density, or texture from manufacturer's product line that includes both standard and premium items.



PART 3 - EXECUTION (Not Used)

END OF SECTION 01 60 00

SECTION 01 70 00 - EXECUTION AND CLOSEOUT REQUIREMENTS

PART 1 - GENERAL

1.1 CLOSEOUT SUBMITTALS

- A. Record Drawings: Maintain a set of prints of the Contract Drawings as record Drawings. Mark to show actual installation where installation varies from that shown originally.
 - 1. Identify and date each record Drawing; include the designation "PROJECT RECORD DRAWING" in a prominent location.
- B. Operation and Maintenance Data: Submit one copy of manual. Organize data into three-ring binders with identification on front and spine of each binder, and envelopes for folded drawings. Include the following:
 - 1. Manufacturer's operation and maintenance documentation.
 - 2. Maintenance and service schedules.
 - 3. Maintenance service contracts.
 - 4. Emergency instructions.
 - 5. Spare parts list.
 - 6. Wiring diagrams.
 - 7. Copies of warranties.

1.2 CLOSEOUT PROCEDURES

- A. Substantial Completion: Before requesting Substantial Completion inspection, complete the following:
 - 1. Prepare a list of items to be completed and corrected (punch list), the value of items on the list, and reasons why the Work is not complete.
 - 2. Advise Owner of pending insurance changeover requirements.
 - 3. Submit specific warranties, maintenance service agreements, and similar documents.
 - 4. Obtain and submit releases permitting Owner unrestricted use of the Work and access to services and utilities. Include occupancy permits, operating certificates, and similar releases.
 - 5. Submit record Drawings and Specifications, operation and maintenance manuals, and similar final record information.
 - 6. Deliver tools, spare parts, extra materials, and similar items.
 - 7. Make final changeover of permanent locks and deliver keys to Owner.
 - 8. Complete startup testing of systems.
 - 9. Remove temporary facilities and controls.
 - 10. Submit changeover information related to Owner's occupancy, use, operation, and maintenance.



11. Complete final cleaning requirements, including touchup painting.
 12. Touch up and otherwise repair and restore marred exposed finishes to eliminate visual defects.
- B. Submit a written request for inspection for Substantial Completion. On receipt of request, Architect will proceed with inspection or advise Contractor of unfulfilled requirements. Architect will prepare the Certificate of Substantial Completion after inspection or will advise Contractor of items that must be completed or corrected before certificate will be issued.
- C. Request inspection for Final Completion, once the following are complete:
1. Submit a copy of Substantial Completion inspection list stating that each item has been completed or otherwise resolved for acceptance.
 2. Instruct Owner's personnel in operation, adjustment, and maintenance of products, equipment, and systems.
- D. Request reinspection when the Work identified in previous inspections as incomplete is completed or corrected.
- E. Submit a written request for final inspection for acceptance. On receipt of request, Architect will proceed with inspection or advise Contractor of unfulfilled requirements. Architect will prepare final Certificate for Payment after inspection or will advise Contractor of items that must be completed or corrected before certificate will be issued.

PART 2 - PRODUCTS (Not Used)

PART 3 - EXECUTION

3.1 EXAMINATION AND PREPARATION

- A. Before proceeding with each component of the Work, examine substrates, areas, and conditions, with Installer or Applicator present where indicated, for compliance with requirements for installation tolerances and other conditions affecting performance.
1. Verify compatibility with and suitability of substrates.
 2. Examine roughing-in for mechanical and electrical systems.
 3. Examine walls, floors, and roofs for suitable conditions.
- B. Proceed with installation only after unsatisfactory conditions have been corrected.
- C. Take field measurements as required to fit the Work properly. Where portions of the Work are indicated to fit to other construction, verify dimensions of other construction by field measurements before fabrication.
- D. Verify space requirements and dimensions of items shown diagrammatically on Drawings.



3.2 CONSTRUCTION LAYOUT AND FIELD ENGINEERING

- A. Before proceeding to lay out the Work, verify layout information shown on Drawings, in relation to the property survey and existing benchmarks.
- B. Engage a professional engineer to lay out the Work using accepted surveying practices.
- C. Engage a land surveyor prepare a final property survey showing significant features (real property) for Project.
 - 1. At Substantial Completion, have the final property survey recorded by or with authorities having jurisdiction as the official "property survey."

3.3 INSTALLATION

- A. Locate the Work and components of the Work accurately, in correct alignment and elevation, as indicated. Make vertical work plumb and make horizontal work level.
 - 1. Make joints of uniform width. Where joint locations in exposed work are not indicated, arrange joints for the best visual effect. Fit exposed connections to form hairline joints.
 - 2. Conceal pipes, ducts, and wiring in finished areas unless otherwise indicated.
 - 3. Maintain minimum headroom clearance of 96 inches in occupied spaces and 90 inches in unoccupied spaces.
- B. Comply with manufacturer's written instructions and recommendations.
- C. Conduct construction operations so no part of the Work is subjected to damaging operations or loading in excess of that expected during normal conditions of occupancy.
- D. Use products, cleaners, and installation materials that are not considered hazardous.
- E. Provide blocking and attachment plates and anchors and fasteners of adequate size and number to securely anchor each component in place. Obtain and distribute to the parties involved templates for work specified to be factory prepared and field installed.

3.4 CUTTING AND PATCHING

- A. Provide temporary support of work to be cut. Do not cut structural members or operational elements without prior written approval of Architect.
- B. Where existing services/systems are required to be removed, relocated, or abandoned, bypass such services/systems before cutting to minimize interruption to occupied areas.
- C. Patch with durable seams that are as invisible as possible. Provide materials and comply with installation requirements specified in other Sections.

1. Restore exposed finishes of patched areas and extend finish restoration into adjoining construction in a manner that will minimize evidence of patching and refinishing.
2. Where patching occurs in a painted surface, prepare substrate and apply primer and intermediate paint coats appropriate for substrate over the patch, and apply final paint coat over entire unbroken surface containing the patch. Provide additional coats until patch blends with adjacent surfaces.

3.5 CLEANING

- A. Clean Project site and work areas daily, including common areas. Dispose of materials lawfully.
 1. Remove liquid spills promptly.
 2. Where dust would impair proper execution of the Work, broom-clean or vacuum the entire work area, as appropriate.
 3. Remove debris from concealed spaces before enclosing the space.
- B. Complete the following cleaning operations before requesting inspection for certification of Substantial Completion:
 1. Remove labels that are not permanent.
 2. Clean transparent materials, including mirrors. Remove excess glazing compounds. Replace chipped or broken glass.
 3. Clean exposed finishes to a dust-free condition, free of stains, films, and foreign substances. Sweep concrete floors broom clean.
 4. Vacuum carpeted surfaces and wax resilient flooring.
 5. Wipe surfaces of mechanical and electrical equipment. Remove excess lubrication. Clean plumbing fixtures. Clean light fixtures, lamps, globes, and reflectors.
 6. Clean Project site, yard, and grounds, in areas disturbed by construction activities. Sweep paved areas; remove stains, spills, and foreign deposits. Rake grounds to a smooth, even-textured surface.

3.6 DEMONSTRATION AND TRAINING

- A. Engage qualified instructors to instruct Owner's personnel to adjust, operate, and maintain systems, subsystems, and equipment not part of a system. Include a detailed review of the following:
 1. Include instruction for basis of system design and operational requirements, review of documentation, emergency procedures, operations, adjustments, troubleshooting, maintenance, and repairs.

END OF SECTION 01 70 00

SECTION 03 31 00 - CAST-IN-PLACE STRUCTURAL CONCRETE

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data, concrete mix designs and submittals required by ACI 301, "Specification for Structural Concrete for Builders" except where noted in drawings.
- B. Ready-Mixed Concrete Producer Qualifications: ASTM C 94/C 94M.
- C. Comply with ACI 301, "Specification for Structural Concrete"; ACI 117, "Specifications for Tolerances for Concrete Construction and Materials"; and CRSI's "Manual of Standard Practice."

PART 2 - PRODUCTS

2.1 MATERIALS

- A. Reinforcing Bars: ASTM A 615/A 615M, Grade 60, deformed.
- B. Plain Steel Wire: ASTM A 82, as drawn.
- C. Plain-Steel Welded Wire Reinforcement: ASTM A 185, as drawn, flat sheet.
- D. Deformed-Steel Welded Wire Reinforcement: ASTM A 497, flat sheet.
- E. Portland Cement: ASTM C 150, Type I or II.
- F. Fly Ash: ASTM C 618, Type F. Maximum fly ash as a percentage of total weight of cementitious material shall be 25 percent.
- G. Ground Granulated Blast-Furnace Slag: ASTM C 989, Grade 100 or 120.
- H. Aggregates: ASTM C 33, uniformly graded.
 - I. Maximum Aggregate Size for Concrete in Insulating Concrete Forms: as listed per drawings, 1" typical.
 - J. Synthetic Fiber: ASTM C 1116/C 1116M, Type III, polypropylene fibers, 1/2 to 1-1/2 inches long.
 - K. Air-Entraining Admixture: ASTM C 260.

- K. Vapor Retarder: Reinforced sheet, ASTM E 1745, Class A.
- L. Joint-Filler Strips: ASTM D 1751, asphalt-saturated cellulosic fiber, or ASTM D 1752, cork or self-expanding cork.
- M. Moisture-Retaining Cover: ASTM C 171, polyethylene film or white burlap-polyethylene sheet.
- N. Clear, Solvent-Borne, Membrane-Forming Curing and Sealing Compound: ASTM C 1315, Type 1, Class A.

2.2 MIXES

- A. Comply with ACI 301 requirements for concrete mixtures.
- B. Normal-Weight Concrete: Prepare design mixes, proportioned according to ACI 301, as follows:
 - 1. Minimum Compressive Strength: 4500 psi at 28 days.
 - 2. Maximum Water-Cementitious Materials Ratio: 0.50.
 - 3. Slump Limit: slumps shall be within +1 inch and -2 inches of the specified slump per drawings.
 - 4. Air Content: Maintain within range permitted by ACI 301. Do not allow air content of floor slabs to receive troweled finishes to exceed 3 percent.
 - 5. Use fly ash, pozzolan, ground granulated blast-furnace slag, and silica fume as needed to reduce the total amount of portland cement, which would otherwise be used, by not less than 25 percent.
 - 6. For concrete exposed to deicing chemicals, limit use of fly ash to 25 percent replacement of portland cement by weight and granulated blast-furnace slag to 40 percent of portland cement by weight; silica fume to 10 percent of portland cement by weight.
- C. Measure, batch, mix, and deliver concrete according to ASTM C 94/C 94M
 - 1. When air temperature is above 90 deg F, reduce mixing and delivery time to 60 minutes.

PART 3 - EXECUTION

3.1 CONCRETING

- A. Construct formwork according to ACI 301 and maintain tolerances and surface irregularities within ACI 347R limits of Class A, 1/8 inch for concrete exposed to view and Class C, 1/2 inch for other concrete surfaces.
- B. Place vapor retarder on prepared subgrade, with joints lapped 6 inches and sealed.

- C. Comply with CRSI's "Manual of Standard Practice" for fabricating, placing, and supporting reinforcement.
- D. Install construction, isolation, and contraction joints where indicated. Install full-depth joint-filler strips at isolation joints.
- E. Place concrete in a continuous operation and consolidate using mechanical vibrating equipment.
- F. Protect concrete from physical damage, premature drying, and reduced strength due to hot or cold weather during mixing, placing, and curing.
- G. Formed Surface Finish: Smooth-formed finish for concrete exposed to view, coated, or covered by waterproofing or other direct-applied material; rough-formed finish elsewhere.
- H. Slab Finishes: Comply with ACI 302.1R for screeding, restrecting, and finishing operations for concrete surfaces. Do not wet concrete surfaces. Provide the following finishes:
 - 1. Scratch finish for surfaces to receive mortar setting beds.
 - 2. Float finish for interior steps and ramps and surfaces to receive waterproofing, roofing, or other direct-applied material.
 - 3. Troweled finish for floor surfaces and floors to receive floor coverings, paint, or other thin film-finish coatings.
 - 4. Trowel and fine-broom finish for surfaces to receive thin-set tile.
 - 5. Nonslip-broom finish to exterior concrete platforms, steps, and ramps.
- I. Cure formed surfaces by moist curing for at least seven days.
- J. Begin curing concrete slabs after finishing.
- K. Owner will engage a testing agency to perform field tests and to submit test reports.
- L. Protect concrete from damage. Repair surface defects in formed concrete and slabs.

END OF SECTION 03 30 00

SECTION 051200 - STRUCTURAL STEEL FRAMING

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data, Shop Drawings, and Welding Procedure Specifications (WPSs).
- B. Comply with applicable provisions of the following:
 - 1. AISC 303.
 - 2. AISC 341 and AISC 341s1.
 - 3. AISC 360.
 - 4. RCSC's "Specification for Structural Joints Using ASTM A 325 or A 490 Bolts."
- C. All work shall be in accordance with the AISC Specification.
- D. Contractor shall be responsible for coordinating the selection of optional details shown on the drawings. The contractor shall also be responsible for all erection aides that include, but are not limited to erection angles, lift holes, and other aides.

PART 2 - PRODUCTS

2.1 STRUCTURAL STEEL

- A. W-Shapes: ASTM A992, FY=50KSI or ASTM A913, FY=50KSI.
- B. All Angles U.N.O.: ASTM A36, FY = 36KSI.
- C. Square or Rectangular: ASTM A500, Grade B.
- D. Steel Pipe Diameter Less than or equal to 12 inches: ASTM A53 Type E or S, Grade B, FY=36KSI
- E. Material called out on plan as (A36): MASTM A36, FY=36 KSI

2.2 ACCESSORIES

- A. High-Strength Bolts, Nuts, and Washers: ASTM A 325, Type 1, heavy-hex steel structural bolts; ASTM A 563, Grade C, heavy-hex carbon-steel nuts; and ASTM F 436 (Type 1, hardened carbon-steel washers).
- B. Anchor Rods: ASTM F 1554, Grade 36.

1. Configuration: Straight or hooked, refer to drawings.
 2. Nuts: ASTM A 563 heavy-hex carbon steel.
 3. Plate Washers: ASTM A 36/A 36M carbon steel.
 4. Washers: ASTM F 436, Type 1, hardened carbon steel.
- C. Primer: Fabricator's standard lead- and chromate-free, nonasphaltic, rust-inhibiting primer.
- D. Grout: ASTM C 1107, nonmetallic, shrinkage resistant, factory packaged.

2.3 FABRICATION

- A. Structural Steel: Fabricate and assemble in shop to greatest extent possible. Fabricate according to AISC's "Code of Standard Practice for Steel Buildings and Bridges" and AISC 360.
- B. Weld Connections: Comply with AWS D1.1/D1.1M for tolerances, appearances, welding procedure specifications, weld quality, and methods used in correcting welding work.
- C. Shop Priming: Prepare surfaces according to SSPC-SP 2, "Hand Tool Cleaning"; or SSPC-SP 3, "Power Tool Cleaning." Shop prime steel to a dry film thickness of at least 1.5 mils. Do not prime surfaces to be embedded in concrete or mortar or to be field welded.

PART 3 - EXECUTION

3.1 ERECTION

- A. Set structural steel accurately in locations and to elevations indicated and according to AISC 303 and AISC 360.
- B. Base Bearing and Leveling Plates: Clean concrete- and masonry-bearing surfaces of bond-reducing materials, and roughen surfaces prior to setting plates. Clean bottom surface of plates.
 1. Set plates for structural members on wedges, shims, or setting nuts as required.
 2. Weld plate washers to top of base plate.
 3. Snug-tighten and/or Pretension anchor rods after supported members have been positioned and plumbed. Do not remove wedges or shims but, if protruding, cut off flush with edge of plate before packing with grout.
 4. Promptly pack grout solidly between bearing surfaces and plates so no voids remain. Neatly finish exposed surfaces; protect grout and allow to cure.
- C. Align and adjust various members forming part of complete frame or structure before permanently fastening. Before assembly, clean bearing surfaces and other surfaces that will be in permanent contact with members. Perform necessary adjustments to compensate for discrepancies in elevations and alignment.



- D. Do not use thermal cutting during erection unless approved by Architect. Finish thermally cut sections within smoothness limits in AWS D1.1/D1.1M.
- E. High-Strength Bolts: Install high-strength bolts according to RCSC's "Specification for Structural Joints Using ASTM A 325 or A 490 Bolts" for type of bolt and type of joint specified.
 - 1. Joint Type: Snug tightened, Pretensioned, or Slip critical.
- F. Weld Connections: Comply with AWS D1.1/D1.1M for tolerances, appearances, welding procedure specifications, weld quality, and methods used in correcting welding work.

END OF SECTION 051200



MECHANICAL PROPERTIES

Adhesive:

Dynorit SPS (Aerolite UP 4116/A942/H240)

Does not contain any components considered hazardous to the environment, or does not contain any solvents (VOC;s) heavy metals, bactericides, or halogenated organic components.

Formaldehyde Emissions:

a. "traditional" bamboo – 0.0127ppm (per ENV717-1)

Indentation Resistance/Hardness:

Natural Horizontal – avg. 2109

Natural Vertical – avg. 1813

Carbonized Horizontal – avg. 1907

Carbonized Vertical – avg. 1409

Strandwoven Light – 3200

Strandwoven Dark – 3200

Moisture Content:

7.3% (average for all tested samples)

Moisture content of final product will vary based on climate conditions to which the material is warehoused and then installed. It is highly recommended to let all bamboo products acclimate to installed space conditions.

Dimensional Stability:

Stability factor = 0.00144

Flammability:

Class 1 (ASTM E648 – Critical Radiant Panel Test)

Smoke Density:

270 - Flaming Mode (ASTM E622)

300 - Non-flaming mode (ASTM E622)

* Passing is any number below 450.

Compression Strength:

Parallel to grain: 9345 psi (ASTM 3501-86 A)

Perpendicular to grain: 3043 psi (ASTM 3501-86 A)

Tensile Strength:

15300 parallel to grain (ASTM 3500-90)

Bending Strength:

14600 psi (ASTM D3043)

Shear Strength:

789 psi (ASTM D3048)



LAMBOO INC.
1024 Post Rd
Springfield IL.
62712
217-408-4446

Website: www.lamboo.us

E-mail:
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**BAMBOO PANELS AND VENEERS
PRODUCT SPECIFICATION
IN CSI 3-PART FORMAT**

GENERAL NOTES TO SPECIFIER:

PLEASE GO TO www.lamboo.us TO VERIFY THIS IS THE MOST CURRENT VERSION OF THIS SPECIFICATION.

THE FOLLOWING PRODUCT SPECIFICATION LANGUAGE IS INTENDED TO ASSIST DESIGN PROFESSIONALS IN SPECIFYING BAMBOO PLYWOOD IN EXISTING 3-PART SPECIFICATIONS FOR PANELING, CASEWORK, DOORS, AND SIMILAR ARCHITECTURAL WOODWORK.

SAMPLE LANGUAGE IS PROVIDED FOR APPLICABLE ARTICLES IN PART 1-GENERAL AND PART 2-PRODUCTS FOLLOWING THE CONSTRUCTION SPECIFICATION INSTITUTE'S SECTIONFORMAT. BECAUSE OF THE VARIATION IN SPECIFICATION SYSTEMS CURRENTLY IN USE, ARTICLE AND PARAGRAPH NUMBERS AND TITLES MAY DIFFER SOMEWHAT THAN PRESENTED HEREIN. THE SAMPLE LANGUAGE SHOULD BE EDITED ACCORDINGLY TO FIT EACH FIRM'S SPECIFICATIONS.

ARTICLES AND PARAGRAPHS OF THIS PRODUCT SPECIFICATION ASSUME THE PROJECT MANUAL WILL CONTAIN COMPLETE DIVISION 1 DOCUMENTS INCLUDING 01 25 13-PRODUCT SUBSTITUTION PROCEDURES, SECTIONS 01 33 00-SUBMITTAL PROCEDURES, 01 62 00-PRODUCT OPTIONS, 01 66 00-PRODUCT STORAGE AND HANDLING REQUIREMENTS, 01 74 00-CLEANING AND WASTE MANAGEMENT, 01 77 00-CLOSEOUT PROCEDURES, AND 01 78 00-CLOSEOUT SUBMITTALS. CLOSE COORDINATION WITH DIVISION 1 SECTIONS IS REQUIRED. IF THE PROJECT MANUAL DOES NOT CONTAIN THESE SECTIONS, ADDITIONAL INFORMATION MAY BE INCLUDED UNDER THE APPROPRIATE ARTICLES.

NOTES TO THE SPECIFIER ARE IN ALL UPPER CASE TEXT AND ARE CONTAINED WITHIN ROWS OF ASTERISKS.

GREY HIGHLIGHTED GREEN TEXT AND NOTES RELATE TO LEED® PROJECTS AND CAN BE DELETED IF THE PROJECT IS NOT INTENDED TO ATTAIN LEED CERTIFICATION.

OPTIONAL ITEMS REQUIRING SELECTION BY THE SPECIFIER ARE ENCLOSED WITHIN BRACKETS, E.G. [35] [40] [45]. MAKE APPROPRIATE SELECTIONS AND DELETE OTHERS.

PART 1—GENERAL

1.01 SUMMARY

A. Section Includes:

ADD SUBPARAGRAPH IDENTIFYING THE ITEMS MADE WITH BAMBOO PLYWOOD.

B. Related Sections:

INCLUDE ALL DIVISION 01 SECTIONS CONTAINING LEED® REQUIREMENTS.

INCLUDE SECTION 01350 IF THE PROJECT IS A SCHOOL LOCATED IN A DISTRICT USING
“SECTION 01350 – SPECIAL ENVIRONMENTAL REQUIREMENTS”

<http://www.chps.net/manual/index.htm#specs> PREPARED BY THE COLLABORATIVE FOR
HIGH PERFORMANCE SCHOOLS (CHPS).

1.02 REFERENCES

IF THE “REFERENCES” ARTICLE IS USED, INCLUDE THE FOLLOWING IN THE
REFERENCE LIST:

- A. American Society for Testing and Materials (ASTM):
 - 1. ASTM D 1037, Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials.
 - 2. ASTM D 3043 Standard Test Methods for Flexural Structural Panels in Flexure
 - 3. ASTM E 84, Standard Test Method for Surface Burning Characteristics of Building Materials.
 - 4. ASTM D 4442, Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials.
 - 5. ASTM D 3500, Standard Test Method for Structural Panels in Tension
 - 6. ASTM E 1333, Standard Test Method for Determining Formaldehyde Concentrations in Air Emission Rates from Wood Using a Large Chamber
- B. American National Standards Institute/Hardwood Plywood and Veneer Association (ANSI/HPVA): American National Standard for Hardwood and Decorative Plywood, HP-1.
- C. **US Green Building Council’s Leadership in Energy and Environmental Design Green Building Rating System™ (LEED).**

1.03 SUBMITTALS

A. Product Data:

INCLUDE THE FOLLOWING IN THE “PRODUCT DATA” PARAGRAPH:

1. Bamboo plywood manufacturer’s product data.

B. LEED Submittals:

INCLUDE THE FOLLOWING FOR LEED PROJECTS, AS APPLICABLE.

- *****
1. Credit MR 6, Rapidly Renewable Materials: Bamboo manufacturer's product data for each product used, indicating that product(s) are manufactured from a rapidly renewable resource.
- *****

FOLLOWING RELATES ONLY TO ADHESIVES AND FINISHES APPLIED TO UNFINISHED PLYBOO PRODUCTS. REFERENCES TO DATA SHOULD BE SUPPLIED BY THE ADHESIVE, SEALANT, OR FINISH MANUFACTURER

2. Credit EQ 4.1, Low Emitting Materials: Adhesive and/or sealant manufacturer's product data for each product used, indicating adhesive agent contains low voc adhesive.
3. Credit EQ 4.2, Low Emitting Materials: Paints and/or coatings manufacturer's product data for finishes used.

1.07 WARRANTY

INCLUDE THE FOLLOWING SPECIAL WARRANTY:

- A. A Special Warranty for Lamboo Inc. Products referenced at www.lamboo.us

PART 2-PRODUCTS

2.01 MATERIALS

INCLUDE THE FOLLOWING PARAGRAPHS AND SUBPARAGRAPHS FOR BAMBOO PLYWOOD AS APPROPRIATE.

- A. Bamboo Plywood:
 1. Lamboo Inc. Architectural and Structural Bamboo
 - a. Tel: 217-408-4446.
 - b. www.lamboo.us
 2. Species: Moso (*Phyllostachys Pubescens*).

INCLUDE THE FOLLOWING SUBPARAGRAPH IF PRODUCTS ARE USED FOR WALL OR CEILING FINISHES PURSUANT TO IBC SECTION 803.

3. Fire Resistance Classification: [Class A] [Class C].
 - a. Test surface burning characteristics in accordance with ASTM E 84.
4. Type:

SELECT APPROPRIATE TYPE(S) BELOW TO SUIT PROJECT REQUIREMENTS. DELETE THOSE NOT USED. FABRICATION ARTICLE OR DRAWINGS MUST CLEARLY IDENTIFY SPECIFIC USES.

GO TO www.lamboo.us FOR AVAILABLE FACE SIZES.

- a. 7/8 inch thick, 5-ply, [amber flat grain] [natural flat grain].
- b. 3/4 inch thick, 3-ply [amber flat grain] [amber edge grain] [natural flat grain] [natural edge grain] [Dark Strand] [Honey Strand] [Neopolitan].
- c. 3/4 inch thick, solid, [amber edge grain] [natural edge grain]

- d. 1/2 inch thick, 3-ply, [amber flat grain] [amber edge grain] [natural flat grain] [natural edge grain] [Neopolitan].
- e. 1/4 inch thick, 3-ply, [amber flat grain] [amber edge grain] [natural flat grain] [natural edge grain].
- f. 1/8 inch thick, bamboo veneer panel, [amber flat grain] [amber edge grain] [natural flat grain] [natural edge grain].
- g. 4 millimeters, solid, [Honey Strand] [Dark Strand]
- h. 1-1/16 inch thick, 5-ply PlybooSquared [amber end grain] [natural end grain]

5. Physical/Mechanical Properties:

- a. ASTM D 3043 Method D Flexural Strength (MOE/MOR)
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain: 179 MOE/11,371 MOR average
 - ii. $\frac{3}{4}$ inch thick 3-ply Cross Core: 148 MOE/9,109 MOR average
 - iii. $\frac{3}{4}$ inch thick Cross Core Strand: 268 MOE/14,762 MOR average
 - iv. $\frac{3}{4}$ inch flat grain panel Average Modulus of Elasticity:1,324,800psi
- b. ASTM D 1037 Screw Hold
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain
 - a) Face: 261 pounds average
 - b) Back: 233 pounds average
 - c) Edge 1: 513 pounds average
 - d) Edge 2: 636 pounds average
 - ii. $\frac{3}{4}$ inch thick 3-ply Cross Core
 - a) Face: 1009 pounds average
 - b) Back: 681 pounds average
 - c) Edge 1: 361 pounds average
 - d) Edge 2: 670 pounds average
 - iii. $\frac{3}{4}$ inch thick Cross Core Strand
 - a) Face: 742 pounds average
 - b) Back: 831 pounds average
 - c) Edge 1: 980 pounds average
 - d) Edge 2: 759 pounds average
- c. ASTM D 4442 Method A Moisture Content
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain: 4.9 percent average
 - ii. $\frac{3}{4}$ inch thick 3-ply Cross Core: 5.7 percent average
 - iii. $\frac{3}{4}$ inch thick Cross Core Strand: 4.4 percent average
- d. ASTM D 1037 Tensile Strength Parallel
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain: Load 1700 pounds, Strength 7535 psi average
 - ii. $\frac{3}{4}$ inch thick 3-ply Cross Core: Load 892 pounds, Strength 3547 psi average
 - iii. $\frac{3}{4}$ inch thick Cross Core Strand: Load 1732 pounds, Strength 5968 psi average
- e. ASTM D 3500 Tensile Strength Perpendicular
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain: Load 642 pounds, Strength 428 psi average
 - ii. $\frac{3}{4}$ inch thick 3-ply Cross Core: Load 1536 pounds, Strength 1024 psi average
 - iii. $\frac{3}{4}$ inch thick Cross Core Strand: Load 1591 pounds, Strength 1061 psi average
- f. ASTM D 1037 Dimensional Stability at 20% RH
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain
 - a) Linear Expansion: Parallel -0.04 percent; Perpendicular -0.10 percent average
 - b) Thickness Swell: -0.13 percent average

- ii. ¾ inch thick 3-ply Cross Core
 - a) Linear Expansion: Parallel -0.09 percent;
 Perpendicular -0.07 percent
 - b) Thickness Swell: -0.39 percent
 - iii. ¾ inch thick Cross Core Strand
 - a) Linear Expansion: Parallel -0.04 percent,
 Perpendicular -0.07 percent
 - b) Thickness Swell: -0.13 percent
- g. ASTM E 1333 Formaldehyde Emission
- i. ¾ inch thick 1-ply Edge Grain: 0.02 ppm
 - ii. ¾ inch thick 3-ply Cross Core: 0.02 ppm
 - iii. ¾ inch thick Cross Core Strand: 0.02 ppm
- h. ASTM E 84 Surface Burning
- i. ¾ inch thick, 3-ply, edge grain cross core: Class C
 - ii. ¾ inch thick, 3-ply, edge grain cross core Strand: Class C

END OF PRODUCT SPECIFICATION



SECTION 074600 - SIDING

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data, Samples, and ICC-ES evaluation reports.
- B. Warranties: Manufacturer's standard from in which siding manufacturer agrees to repair or replace siding that fails in materials or workmanship within **10** years. Failures include, but are not limited to, cracking, deforming, or otherwise deteriorating beyond normal weathering.

PART 2 - PRODUCTS

2.1 SIDING

- A. Reclaimed Wood Siding:
 - 1. Products:
 - a. Reclaimed Douglas Fir from Barn
 - 2. Horizontal Pattern: 10-1/2" –inch exposure in plain, single board style.
 - 3. Texture: Wood grain.
 - 4. Finish: Cabot Solid State Exterior Stain
 - a. Color: White

2.2 ACCESSORIES

- A. Siding Accessories, General: Provide starter strips, edge trim, outside and inside corner caps, and other items as recommended by siding manufacturer for building configuration.
 - 1. Provide accessories made from same material as adjacent siding unless otherwise indicated.
- B. Decorative Accessories: Provide the following wood decorative accessories as indicated:
 - 1. Door and window casings
 - 2. Entrance and window head pediments.
 - 3. Shutters with paneled faces.
 - 4. Louvers.
 - 5. Lattice.
 - 6. Fasciae.
 - 7. Moldings and trim.



PART 3 - EXECUTION

3.1 INSTALLATION

- A. Install wood siding and related accessories.
 1. Install fasteners no more than 24 inches o.c.

END OF SECTION 074600

SECTION 078413 - PENETRATION FIRESTOPPING

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data and Installer certificates signed by Installer certifying that products have been installed in compliance with requirements.

PART 2 - PRODUCTS

2.1 PENETRATION FIRESTOPPING

- A. Provide penetration firestopping materials that are compatible with one another, substrates, and penetrating items if any.
- B. Penetrations in Fire-Resistance-Rated Walls and Horizontal Assemblies: Provide penetration firestopping with ratings determined per ASTM E 814 or UL 1479, based on testing at a positive pressure differential of 0.01-inch wg.
 - 1. F-Rating at Fire-Resistance-Rated Walls: Not less than that of construction penetrated.
 - 2. F-Rating at Horizontal Assemblies: At least 1 hour, but not less than that of construction penetrated.
 - 3. T-Rating at Horizontal Assemblies: At least 1 hour, but not less than the fire-resistance rating of construction penetrated except for penetrations within the cavity of a wall.
- C. Penetrations in Smoke Barriers: Provide penetration firestopping with ratings determined per UL 1479.
 - 1. L-Rating: Not exceeding 5.0 cfm/sq. ft. of penetration opening at 0.30-inch wg at both ambient and elevated temperatures.
- D. Exposed Penetration Firestopping: Provide products with flame-spread and smoke-developed indexes of less than 25 and 450, respectively, as determined per ASTM E 84.
- E. Accessories: Provide components for each penetration firestopping system that are needed to install fill materials and to maintain ratings required. Use only those components specified by penetration firestopping manufacturer and approved by qualified testing and inspecting agency.



PART 3 - EXECUTION

3.1 INSTALLATION

- A. General: Install penetration firestopping to comply with manufacturer's written installation instructions and published drawings for products and applications indicated.
- B. Identify penetration firestopping with preprinted metal or plastic labels. Attach labels permanently to surfaces adjacent to and within 6 inches of firestopping edge so labels will be visible to anyone seeking to remove penetrating items or firestopping. Include the following information on labels:
 1. The words "Warning - Penetration Firestopping - Do Not Disturb. Notify Building Management of Any Damage."
 2. Designation of applicable testing and inspecting agency.
 3. Manufacturer's name.
 4. Installer's name.
- C. Owner will engage a qualified testing agency to perform tests and inspections.

END OF SECTION 078413

SECTION 079200 - JOINT SEALANTS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data and color Samples.
- B. Environmental Limitations: Do not proceed with installation of joint sealants when ambient and substrate temperature conditions are outside limits permitted by joint-sealant manufacturer or are below 40 deg F

PART 2 - PRODUCTS

2.1 JOINT SEALANTS

- A. Compatibility: Provide joint sealants, joint fillers, and other related materials that are compatible with one another and with joint substrates under service and application conditions.
- B. Sealant for Use in Building Expansion Joints:
 1. Single-component, neutral-curing silicone sealant, ASTM C 920, Type S; Grade NS; [Class 50] [Class 100/50]; for Use NT.
- C. Sealant for General Exterior Use Where Another Type Is Not Specified:
 1. Single-component, nonsag polysulfide sealant, ASTM C 920, Type S; Grade NS; Class 25; for Use NT.
 2. Single-component, neutral-curing silicone sealant, ASTM C 920, Type S; Grade NS; Class 25; for Use NT.
 3. Single-component, nonsag urethane sealant, ASTM C 920, Type S; Grade NS; Class 25; and for Use NT.
- D. Sealant for Use in Interior Joints in Ceramic Tile and Other Hard Surfaces in Kitchens and Toilet Rooms and Around Plumbing Fixtures:
 1. Single-component, mildew-resistant silicone sealant, ASTM C 920, Type S; Grade NS; Class 25; for Use NT; formulated with fungicide.
- E. Sealant for Interior Use at Perimeters of Door and Window Frames:
 1. Acrylic latex or siliconized acrylic latex, ASTM C 834, Type OP, Grade NF.



2.2 MISCELLANEOUS MATERIALS

- A. Provide sealant backings of material that are nonstaining; are compatible with joint substrates, sealants, primers, and other joint fillers; and are approved for applications indicated by sealant manufacturer based on field experience and laboratory testing.
- B. Cylindrical Sealant Backings: ASTM C 1330, of size and density to control sealant depth and otherwise contribute to producing optimum sealant performance.
- C. Bond-Breaker Tape: Polyethylene tape or other plastic tape recommended by sealant manufacturer for preventing sealant from adhering to rigid, inflexible joint-filler materials or joint surfaces at back of joint. Provide self-adhesive tape where applicable.
- D. Primer: Material recommended by joint-sealant manufacturer where required for adhesion of sealant to joint substrates indicated, as determined from preconstruction joint-sealant-substrate tests and field tests.

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Comply with ASTM C 1193.
- B. Install sealant backings to support sealants during application and to produce cross-sectional shapes and depths of installed sealants that allow optimum sealant movement capability.
- C. Install bond-breaker tape behind sealants where sealant backings are not used between sealants and backs of joints.

END OF SECTION 079200

SECTION 081416 - FLUSH WOOD DOORS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Samples for doors.

PART 2 - PRODUCTS

2.1 DOOR CONSTRUCTION, GENERAL

- A. Quality Standard: WDMA I.S.1-A.
- B. Low-Emitting Materials: Provide doors made with adhesives and composite wood products that do not contain urea formaldehyde.

2.2 Acceptable Manufacturer: Optiwin

- A. Doors for Opaque Finish:
 - 1. Exterior Solid-Core Doors: Optiwin Frostkorken Outdoor
 - a. <http://www.optiwin.net/en/produkte>
 - 2. Interior Hollow-Core Doors: Premium grade, three-ply, standard hollow cores with lock blocks on both sides.

2.3 FABRICATION AND FINISHING

- A. Factory fit doors to suit frame-opening sizes indicated and to comply with clearances specified.
- B. Factory machine doors for hardware that is not surface applied. Locate hardware to comply with DHI-WDHS-3.
- C. Cut and trim openings to comply with referenced standards.
 - 1. Trim light openings with moldings indicated.
 - 2. Factory install glazing in doors indicated to be factory finished.
 - 3. Factory install louvers in prepared openings.



- D. Factory finish doors indicated for transparent finish with manufacturer's standard finish complying with WDMA TR-4, conversion varnish and/or WDMA TR-6, catalyzed polyurethane for grade specified for doors.
 - 1. Sheen: Satin
- E. Factory finish doors indicated for opaque finish with manufacturer's standard finish complying with WDMA OP-4, conversion varnish and/or WDMA OP-6, catalyzed polyurethane for grade specified for doors.
 - 1. Sheen: Satin.

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Install doors to comply with manufacturer's written instructions and WDMA I.S.1-A, and as indicated.
 - 1. Install fire-rated doors to comply with NFPA 80.
- B. Align and fit doors in frames with uniform clearances and bevels.
- C. Clearances: As follows unless otherwise indicated:
 - 1. 1/8 inch at heads, jambs, and between pairs of doors.
 - 2. 1/8 inch from bottom of door to top of decorative floor finish or covering.
 - 3. 1/4 inch from bottom of door to top of threshold.
 - 4. Comply with NFPA 80 for fire-rated doors.
- D. Repair, refinish, or replace factory-finished doors damaged during installation, as directed by Architect.

END OF SECTION 081416



SECTION 08 52 00 - WOOD WINDOWS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data, Shop Drawings

PART 2 - PRODUCTS

2.1 WOOD WINDOWS

- A. Products:

- 1. OptiWin 3-Wood Window

- B. Provide prime-painted wood windows.

- C. Window Types: The following types, as indicated on Drawings:

- 1. Tilt-and-Turn (Casement Type)

- 2. Fixed/Picture

- D. Performance Requirements: AAMA/WDMA/CSA 101/I.S.2/A440.

- 1. Thermal Transmittance: Whole-window U-factor not more than 0.11 Btu/sq. ft. x h x deg F wind velocity and winter temperatures.

- 2. Solar Heat-Gain Coefficient: Whole-window SHGC not more than .52

- 3. Soundproof value not to exceed 32dB

- E. Trim: Provide indicated trim, matching material and finish of frame members. Milled edge for windowsill 1 ¼" high.

- F. Wood Species: European Fir, exterior Scotch pine with white finish

- G. Provide gear-type rotary operators for casement windows.

- H. Equip units with aluminum mesh insect screens on operable sashes.

- I. Equip units with removable grilles as indicated, attach to inside face of each lite.

- J. Exterior Color: White

- K. Glaze units with low-e coating, argon-filled, sealed insulating glass, complying with Division 08 Section "Glazing." All units to be triple glass with u-value of 0.11.

- L. Manufacturer's Information: <http://www.optiwin.net/en/produkte>

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Set units level, plumb, and true to line, without warp or rack of frames and panels. Provide proper support and anchor securely in place.
- B. Set sill members in bed of sealant or with gaskets, as indicated, to provide weathertight construction.
- C. Adjust operating panels, screens, and hardware to provide a tight fit at contact points and weather stripping for smooth operation and weathertight closure. Lubricate hardware and moving parts.
- D. Clean glass surfaces immediately after installing windows. Remove nonpermanent labels from glass surfaces.

END OF SECTION 085200

SECTION 08 71 00 - DOOR HARDWARE

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Hardware schedule.
- B. Deliver keys to Owner.
- C. Fire-Resistance-Rated Assemblies: Provide products that comply with NFPA 80 and are listed and labeled by a testing and inspecting agency acceptable to authorities having jurisdiction for applications indicated. On exit devices provide label indicating "Fire Exit Hardware."

PART 2 - PRODUCTS

2.1 HARDWARE

- A. Manufacturers:

- 1. Specialty Doors

- B. Hinges:

- 1. Stainless-steel hinges with stainless-steel pins for exterior.
 - 2. Nonremovable hinge pins for exterior and public interior exposure.
 - 3. Ball-bearing hinges for doors with closers and entry doors.
 - 4. 2 hinges for 1-3/8-inch- thick wood doors.
 - 5. 3 hinges for 1-3/4-inch- thick doors 90 inches or less in height; 4 hinges for doors more than 90 inches in height.

- C. Locksets and Latchsets:

- 1. BHMA A156.2, Series 4000, Grade 1 for bored locks and latches.
 - 2. BHMA A156.3, Grade 1 for exit devices.
 - 3. BHMA A156.5, Grade 1 for auxiliary locks.
 - 4. BHMA A156.12, Series 5000, Grade 1 for interconnected locks and latches.
 - 5. BHMA A156.13, Series 1000, Grade 1 for mortise locks and latches.
 - 6. Knobs on locksets and latchsets
 - 7. Provide trim on exit devices matching locksets.
 - 8. Provide key control system, including cabinet.

- D. Closers:



1. Mount closers on interior side (room side) of door opening. Provide regular-arm, parallel-arm, or top-jamb-mounted closers as necessary.
 2. Adjustable delayed opening (accessible to people with disabilities) feature on closers.
- E. Provide wall stops or floor stops for doors without closers.
- F. Manufacturer's Information: <http://www.specialtydoors.com/barndoorthardware.html>

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Mount hardware in locations recommended by the Door and Hardware Institute unless otherwise indicated.

3.2 HARDWARE SCHEDULE

- A. Four (4) each #8-130 open double wall bracket
- B. Four (4) each #8-051 end cap
- C. Two (2) each #8-132 lock joint double bracket
- D. Four (4) each #8-25-28 top track at 5'11"
- E. Four (4) each #8-344 top roller guide
- F. Two (2) each #97-724 door stop
- G. Two (2) each #97-780 guide
- H. Two (2) each #95-622 door pull
- I. Four (4) each #97-720 door stop
- J. Eight (8) each #66-1-18 bottom track at 5'11"
- K. Four (4) each #70-402 bottom roller

END OF SECTION 08 71 00

SECTION 08 95 00 - VENTS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Provide louvers complying with performance requirements indicated as demonstrated by testing according to AMCA 500-L.

PART 2 - PRODUCTS

2.1 MATERIALS

- A. Aluminum Extrusions: ASTM B 221, Alloy 6063-T5, T-52, or T6.
- B. Aluminum Sheet: ASTM B 209, Alloy 3003 or 5005.
- C. Galvanized-Steel Sheet: ASTM A 653/A 653M, G90 zinc coating.
- D. Stainless-Steel Sheet: ASTM A 240/A 240M, Type 304.
- E. Fasteners: Of same basic metal and alloy as fastened metal or 300 Series stainless steel.

2.2 WALL VENTS

- A. Extruded-aluminum wall vents, of load-bearing construction, 0.125 inch thick, with aluminum insect screening on inside face. Provide with aluminum blade dampers on inside face, operated from exterior.
 - 1. 6" Round Vent

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Provide perimeter reveals of uniform width for sealants and joint fillers, as indicated.
- B. Use concealed anchorages where possible.



- C. Protect metal surfaces from corrosion or galvanic action by applying a heavy coating of bituminous paint on surfaces that will be in contact with concrete, masonry, or dissimilar metals.

END OF SECTION 089000

SECTION 09 62 33 - BAMBOO WOOD FLOORING

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data and material Samples.
- B. Softwood Flooring: Comply with WCLIB grading rules for species, grade, and cut.

PART 2 - PRODUCTS

2.1 BAMBOO WOOD FLOORING

A. Bamboo Flooring:

- 1. Species and Grade: Carbonized Bamboo
- 2. Thickness: 3/4 inch.
- 3. Face Width: 3-1/2 inch.
- 4. Lengths: Lengths required to form pattern indicated on drawings
- 5. Simulated Wood Pegs: Contrasting wood pegs at ends of plank flooring pieces.

B. Lamboo Slats:

- 1. Species and Grade: Lamboo with Carbonized Finish
- 2. Thickness: $\frac{3}{8}$ " Actual Thickness
- 3. Face Width: 3" Slats
- 4. Lengths: Lengths required to form pattern indicated on drawings @ 3/8" spacing
- 5. Simulated Wood Pegs: Contrasting wood pegs at ends of plank flooring pieces.

C. Lamboo Thin Sheets

- 1. Species and Grade: Lamboo
- 2. Thickness:
- 3. Face Width:
- 4. Lengths: Legths required to form patterns indicated on drawings.
- 5. Simulated Wood Pegs: Contrasting wood pegs at ends of sheets.

2.2 FINISHING MATERIALS

- A. Wood Filler: Formulated to fill and repair seams, defects, and open-grain hardwood floors; compatible with finish system components and recommended by filler and finish manufacturers for use indicated. If required to match approved samples, provide pigmented filler.

2.3 ACCESSORY MATERIALS

- A. Vapor Retarder: ASTM D 4397, polyethylene sheet not less than 6.0 mils thick.
- B. Asphalt-Saturated Felt: ASTM D 4869, Type II.
- C. Wood Flooring Adhesive: Mastic recommended by flooring and adhesive manufacturers for application indicated.
- D. Fasteners: As recommended by manufacturer, but not less than that recommended in NWFA's "Installation Guidelines: Wood Flooring."

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Comply with flooring manufacturer's written installation instructions, but not less than applicable recommendations in NWFA's "Installation Guidelines: Wood Flooring."
- B. Provide expansion space at walls and other obstructions and terminations of flooring of not less than 3/4 inch.
- C. Felt Underlayment: Where strip or plank flooring is nailed to solid-wood subfloor, install flooring over a layer of asphalt-saturated felt.
- D. Vapor Retarder: Where wood flooring is nailed to sleepers over concrete, install flooring over a layer of polyethylene sheet with edges overlapped over sleepers and turned up behind baseboards.

END OF SECTION 096400

SECTION 096519 - RESILIENT TILE FLOORING

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data and Samples.
- B. Extra Materials: Deliver to Owner one box for every [50] <Insert number> boxes or fraction thereof, of each type and color of resilient floor tile installed.

PART 2 - PRODUCTS

2.1 MARMOLEUM

- A. Products:
 - 1. Forbo Click 1 Planks
- B. Color and Pattern: Arabian Pearl (53861) and Silver Shadow (63860)
- C. Fire resistance and smoke behavior in accordance with DIN 4102-1: class B2 EN 1399
- D. Size: 12" by 36"
- E. Manufacturer's Specifications:
<http://www.themarmoleumstore.com/default.aspx?menuid=247>

2.2 INSTALLATION ACCESSORIES

- A. Trowelable Leveling and Patching Compounds: Latex-modified, portland cement- or blended hydraulic cement-based formulation provided or approved by flooring manufacturer for applications indicated.
- B. Adhesives: Water-resistant type recommended by manufacturer to suit resilient products and substrate conditions indicated.
- C. Floor Polish: Protective liquid floor polish products as recommended by manufacturer.



PART 3 - EXECUTION

3.1 INSTALLATION

- A. Prepare concrete substrates according to ASTM F 710. Verify that substrates are dry and free of curing compounds, sealers, and hardeners.
- B. Lay out tiles so tile widths at opposite edges of room are equal and are at least one-half of a tile.
- C. Match tiles for color and pattern by selecting tiles from cartons in same sequence as manufactured and packaged. Lay tiles patterns indicated on drawings.

END OF SECTION 09 65 19



SECTION 09 91 00 - PAINTING

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals:
 - 1. Product Data
 - 2. Samples.
- B. Mockups: Full-coat finish Sample of each type of coating, color, and substrate, applied where directed.
- C. Extra Materials: Deliver to Owner **1 gal.** of each color and type of finish coat paint used on Project, in containers, properly labeled and sealed.

PART 2 - PRODUCTS

2.1 PAINT

A. Products:

- 1. Cabot Solid Stains for Exterior Surfaces
 - a. Color to be chosen from Manufacturer's Full Line
 - b. Manufacturer's Specifications: <http://www.cabotstain.com/pdf/PROV0800.pdf>
 - 2. Earthpaint
 - a. Colors to be chosen from Manufacturer's Full Line
 - b. Manufacturer's Specifications:
http://www.earthpaint.net/PDF/Brochures/NewstBrochures/UsageGuide_Interior.pdf
- B. MPI Standards: Provide materials that comply with MPI standards indicated and listed in its "MPI Approved Products List."
 - C. Colors: As scheduled.

PART 3 - EXECUTION

3.1 PREPARATION

- A. Comply with recommendations in MPI's "MPI Architectural Painting Specification Manual" applicable to substrates indicated.



- B. Remove hardware, lighting fixtures, and similar items that are not to be painted. Mask items that cannot be removed. Reinstall items in each area after painting is complete.
- C. Clean and prepare surfaces in an area before beginning painting in that area. Schedule painting so cleaning operations will not damage newly painted surfaces.

3.2 APPLICATION

- A. Comply with recommendations in MPI's "MPI Architectural Painting Specification Manual" applicable to substrates indicated.
- B. Paint exposed surfaces, unless otherwise indicated.
 - 1. Paint surfaces behind movable equipment and furniture same as similar exposed surfaces.
 - 2. Paint surfaces behind permanently fixed equipment or furniture with prime coat only.
 - 3. Paint the back side of access panels.
 - 4. Color-code mechanical piping in accessible ceiling spaces.
 - 5. Do not paint prefinished items, items with an integral finish, operating parts, and labels unless otherwise indicated.
- C. Apply paints according to manufacturer's written instructions.
 - 1. Use brushes only for exterior painting and where the use of other applicators is not practical.
 - 2. Use rollers for finish coat on interior walls and ceilings.
- D. Apply paints to produce surface films without cloudiness, spotting, holidays, laps, brush marks, roller tracking, runs, sags, ropiness, or other surface imperfections. Cut in sharp lines and color breaks.
 - 1. If undercoats or other conditions show through topcoat, apply additional coats until cured film has a uniform paint finish, color, and appearance.
- E. Apply stains and transparent finishes to produce surface films without color irregularity, cloudiness, holidays, lap marks, brush marks, runs, ropiness, or other imperfections. Use multiple coats to produce a smooth surface film of even luster.

END OF SECTION 09 91 00

SECTION 10 14 00 - SIGNAGE

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data, Shop Drawings, and Samples.
 - 1. Submit full-size rubbings for metal plaques.

PART 2 - PRODUCTS

2.1 MATERIALS

- A. Applied Vinyl: Die-cut characters from vinyl film of nominal thickness of 3 mils, suitable for exterior applications.

2.2 SIGNS

- A. Vinyl Signs
 - 1. Finishes and Colors: As selected from manufacturer's full range
 - 2. UV Print to Vinyl.
 - 3. Sign Printed from <http://www.deansgraphics.com/>

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Locate signs where indicated or directed per drawings. Install signs level, plumb, and at heights indicated, with sign surfaces free from distortion and other defects in appearance.

END OF SECTION 10 14 00

SECTION 10 28 00 - TOILET, BATH, AND LAUNDRY ACCESSORIES

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data.

PART 2 - PRODUCTS

2.1 MATERIALS

- A. Stainless Steel: ASTM A 666, Type 304, No. 4 finish (satin), 0.0312-inch minimum nominal thickness unless otherwise indicated.
- B. Brass: ASTM B 19, ASTM B 16, or ASTM B 30.
- C. Aluminum: ASTM B 221, Alloy 6063-T6 or 6463-T6.
- D. Sheet Steel: ASTM A 1008/A 1008M, 0.0359-inch minimum nominal thickness.
- E. Galvanized-Steel Sheet: ASTM A 653/A 653M, G60.
- F. Chromium Plating: ASTM B 456, Service Condition Number SC 2 (moderate service).
- G. Galvanized-Steel Mounting Devices: ASTM A 153/A 153M, hot-dip galvanized after fabrication.
- H. Fasteners: Screws, bolts, and other devices of same material as accessory unit, tamper and theft resistant when exposed, and of galvanized steel when concealed.

2.2 TOILET AND BATH ACCESSORIES

A. Toilet Tissue Dispenser

1. Basis-of-Design Product: Kohler Loure Covered Toilet Tissue Holder, K-11584-CP
2. Type: Double Roll Dispenser
3. Mounting: Surface mounted with concealed anchorage
4. Finish: Polished Chrome
5. Operation: Noncontrol delivery with standard spindle
6. Capacity: Designed for 4-1/2- or 5-inch- diameter-core tissue rolls
7. Manufacturer's Specifications:
http://www.us.kohler.com/onlinecatalog/pdf/1074914_4.pdf

B. Mirror Unit

1. Basis-of-Design Product: Provided by Owner, generic design
2. Dimensions: 24" x 24" Frameless

C. Medicine Cabinet

1. Basis-of-Design Product: Custom Design by University of Illinois – Urbana Champagin Students
2. Mounting: Surface mounted.
3. Materials: Chrysalis Panels and Bamboo

D. Towel Bar

1. Basis-of-Design Product: Kohler Loure 24" Bar, K-11581-CP
2. Description: 3/4-inch- square tube with rectangular end brackets recommended.
3. Mounting: Flanges with **concealed** fasteners.
4. Length: 24"
5. Material and Finish: Polished Chrome
6. Manufacturer's Specifications:
http://www.us.kohler.com/onlinecatalog/pdf/1074914_4.pdf

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Install accessories using fasteners appropriate to substrate indicated and recommended by unit manufacturer. Install units level, plumb, and firmly anchored in locations and at heights indicated.
- B. Adjust accessories for unencumbered, smooth operation and verify that mechanisms function properly. Replace damaged or defective items. Remove temporary labels and protective coatings.

END OF SECTION 10 28 00

SECTION 10 44 16 - FIRE EXTINGUISHERS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data.

PART 2 - PRODUCTS

2.1 FIRE EXTINGUISHERS

- A. Portable Fire Extinguishers NFPA 10, listed and labeled for the type, rating, and classification of extinguisher.

- 1. Products:

- a. First Alert
 - 2. Stored-Pressure Water Type: UL-rated 2-A, 2.5-gal. nominal capacity, in stainless-steel container; with pressure-indicating gage.
 - 3. Stored-Pressure Antifreeze Type: UL-rated 2-A, 2.5-gal. nominal capacity, in stainless-steel container; with pressure-indicating gage.
 - 4. Multipurpose Dry-Chemical Type: UL-rated 3-A:40-B:C, 6-lb nominal capacity
 - 5. Manufacturer's Specification:

http://www.firstalert.com/pdfs/MSDS_Model_FE1A10_FE2A10_FE3A10_FE3A40.pdf

- B. Mounting Brackets: Manufacturer's standard steel, designed to secure fire extinguisher to wall or structure, of sizes required for fire extinguishers indicated, with plated or baked-enamel finish.

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Install mounting brackets in locations indicated at heights acceptable to authorities having jurisdiction.
- B. Install fire extinguishers in mounting brackets where indicated.

END OF SECTION 10 44 16



SECTION 11 31 00 - RESIDENTIAL APPLIANCES

1. GENERAL

1 SECTION REQUIREMENTS

- 1 Submittals: Product Data.
- 2 Regulatory Requirements: Comply with provisions of the following product certifications:
 - 1 NFPA: Provide electrical appliances listed and labeled as defined in NFPA 70, Article 100, by a testing agency acceptable to authorities having jurisdiction, and marked for intended use.
 - 2 UL and NEMA: Provide electrical components required as part of residential appliances that are listed and labeled by UL and that comply with applicable NEMA standards.
 - 3 NAECA: Provide residential appliances that comply with NAECA standards.
- 3 Accessibility: Where residential appliances are indicated to comply with accessibility requirements, comply with ICC/ANSI A117.1.
- 4 Energy Ratings: Provide appliances that qualify for the EPA/DOE ENERGY STAR product labeling program.

2. PRODUCTS

1 RESIDENTIAL APPLIANCES

- 1 Electric Cooktop: 12-inch built-in cooktop with two burner elements, 3600W.
 - 1 Products:
 - 1 Diva De Provence, DDP-2
 - 2 Options: standard options.
 - 3 Manufacturer's Specifications: http://www.divainduction.com/doc/Install_DDP2.pdf
 - 2 Microwave Oven: Built-in microwave oven, 1.6-cu. ft. capacity, 950 W.
 - 1 Products:
 - 1 GE Monogram Built-On Oven, ZSC1201NSS
 - 2 Options: standard options.
 - 3 Color: Stainless Steel
 - 4 Manufacturer's Specifications:
http://products.geappliances.com/MarketingObjectRetrieval/Dispatcher?RequestType=PDF&Name=130316_zsc1201nss_c4.pdf



- 3 Refrigerator/Freezer: Freestanding, frost-free two-door refrigerator with top-mounted freezer, polystyrene interior cabinet liners.
 - 1 Products:
 - 1 Sunfrost Refrigerator/Freezer, RF12
 - 1 Fresh Food Compartment Volume: 8.07 cu. ft.
 - 2 Freezer Compartment Volume: 2.05 cu. ft.
 - 2 Options: standard options.
 - 3 Color: Stainless Steel
 - 4 Manufacturer's Specifications: http://www.sunfrost.com/refrigerator_specs.html
- 4 Dishwasher: Built-in, undercounter, automatic dishwasher, sized to replace 24-inch- base cabinet, 9 wash cycles with hot-air and heat-off drying cycles.
 - 1 Products:
 - 1 Fisher & Paykel, DS605SS
 - 2 Options: standard options.
 - 3 Color: Stainless Steel
 - 4 Manufacturer's Specifications:
<http://www.fisherpaykel.com/dishwashing/index.cfm?productUid=413DD4C6-FCFD-5468-C7CD505FAE8C6253§ion=spec>
- 5 Clothes Washer and Electric Clothes Dryer Combination: Freestanding, top-loading, automatic clothes washer with 2.44 cu. ft. capacity stainless steel tub and 9 wash cycles including normal, delicate, and permanent press; variable speed, direct drive motor.
 - 1 Products:
 - 1 LG Washer/Dryer Combo, WM3431HS
 - 2 Options: standard options.
 - 3 Color: Titanium Finish
 - 4 Manufacturer's Specifications:
http://www.lge.com/us/appliances/pdf/WM3431HW_HSss_v1.pdf

3. EXECUTION

1 INSTALLATION

- 1 Built-in Appliances: Securely anchor to supporting cabinetry or countertops with concealed fasteners. Verify that clearances are adequate for proper functioning and rough openings are completely concealed.
- 2 Freestanding Appliances: Place in final locations after finishes have been completed in each area. Verify that clearances are adequate to properly operate equipment.



- 3 Test each item of residential appliances to verify proper operation. Make necessary adjustments.
- 4 Verify that accessories required have been furnished and installed.

END OF SECTION 113100

SECTION 12 06 00 – SCHEDULES FOR FURNISHINGS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data and color Samples.

PART 2 - PRODUCTS

2.1 INTERIOR FURNISHINGS

- A. Couches:

- 1. Products:
 - a. CB2 Annex Sectional
- 2. Components (1 Each):
 - a. Slate Loveseat
 - b. Slate Chaise
 - c. Slate Sectional Corner
 - d. Slate Chair
- 3. Product Information:
<http://www.cb2.com/family.aspx?c=112&f=3507>

- B. Outdoor Seating:

- 1. Products:
 - a. DWR – Loll Adirondack Collection
- 2. Components:
 - a. Darjeeling Dining Table
Manufacturer's Information:
<http://www.cb2.com/family.aspx?c=112&f=3507>

- C. Dining:

- 1. Products:
 - a. CB2 Darjeeling Dining Table
- 2. Manufacturer's Information: <http://www.cb2.com/family.aspx?c=11020&f=4662>

- D. Chairs



1. Custom Chairs Design by the University of Illinois
 - a. Product Information:
<H:\Documents and Settings\Joe\My Documents\Architecture\Solar Decathlon\night joe c.jpg>
2. CB2 Slim Chair (6)
 - a. Product Information:
<http://www.cb2.com/family.aspx?c=206&f=3426&q=slim+chair&fromLocation=Search&DIMID=400001&SearchPage=1>
3. Herman Miller Caper - WC420P-BK-BK-U5-BK
 - a. Product Information:
http://www.hermanmiller.com/hm/content/product_showroom/shared_assets/files/CP_CAP.pdf

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Install per drawing location, anchoring where necessary.

END OF SECTION 12 06 50

SECTION 12 12 19 – FRAMED PRINTS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data

PART 2 - PRODUCTS

2.1 LIVING ROOM PRINT

- A. Sinsadaugh – 30” Reproduction:
 - 1. Product Information: www.krannert.uiuc.edu

2.2 BEDROOM PRINT:

- A. 30x30 Framed Metal Print by Larry Kanfer
 - Product Information: <http://www.kanfer.com/galleries.htm>

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Locate Stud
- B. Use Proper Anchors/Supports
- C. Do not damage drywall. If damage occurs, patch and repair any markings made.

END OF SECTION 12 12 19



SECTION 12 34 00 – PORTABLE LAMPS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data

PART 2 - PRODUCTS

2.1 DESK LAMP

- A. Aeonic Gooseneck LED Lamp – 11-0214

1. Quantity: 3
 2. Product Information:
- <http://www.realgoods.com/product/home-outdoor/lighting/fixtures/aeonic+gooseneck+led+lamp.do?search=basic&keyword=gooseneck&sortby=bestSellers&page=1>

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Place on desk.
- B. Plug into wall.

END OF SECTION 12 34 00

SECTION 12 42 00 – TABLE ACCESSORIES

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data

PART 2 - PRODUCTS

2.1 PLATES/BOWLS

- A. Goodwill / Habitat restore purchase:
 - 1. Quantity: 8 Sets
 - 2. Product Information: <http://www.habitat.org/env/restores.aspx>

2.2 BAMBOO “PAPER” PLATES:

- A. Bamboo Plate
 - 1. Quantity: 1 Set of 8
 - 2. Product Information:
<http://www.worldmarket.com/Bamboo-Plate-Sets-of-8/lev/4/productId/5276/index.pro>

2.3 FLATWARE

- A. Spudware Set: 14-9377
 - 1. Quantity: 1 Set
 - 2. Product Information:
<http://www.gaiam.com/product/eco-home-outdoor/household/kitchen/spudware--174-forks,+set+of+50.do>
- B. Sets of Utensils from Goodwill / Habitat
 - 1. Quantity: 8 sets
 - 2. Product Information: <http://www.habitat.org/env/restores.aspx>
- C. Glassware Sets from Goodwill / Habitat
 - 1. Quantity: 8 sets
 - 2. Product Information: <http://www.habitat.org/env/restores.aspx>

2.4 NAPERY

- A. Admète Napkin
 - 1. Quantity: 2 sets
 - 2. Product Information: <http://www.ikea.com/us/en/catalog/products/60110958>
- B. Placemat
 - 1. Quantity: 8
 - 2. Product Information: <http://www.ikea.com/us/en/catalog/products/00107812>

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Place on Table.

END OF SECTION 12 42 00



SECTION 12 58 83 – CUSTOM RESIDENTIAL FURNITURE

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data

PART 2 - PRODUCTS

2.1 BED

- A. Custom Design by the University of Illinois – Urbana/Champaign:
 - 1. Materials Used: Lamboo

2.2 DRESSER

- A. Custom Design by the University of Illinois – Urbana/Champaign:
 - 1. Materials Used: Lamboo

2.3 NIGHTSTAND

- A. Custom Design by the University of Illinois – Urbana/Champaign:
 - 1. Materials Used: Lamboo

PART 3 - EXECUTION

3.1 INSTALLATION

- A. See drawings for further details.

END OF SECTION 12 58 83



SECTION 129300 - SITE FURNISHINGS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data and color Samples.

PART 2 - PRODUCTS

2.1 SITE FURNISHINGS

- A. Water Cooler

- 1. Products:

- a. Hinkley Springs Water Cooler (for Public Use during Competition, provided by the DOE)

- 2. Manufacturer's Product Information:

- <http://www.hinckleysprings.com/pages/content/products.jsf - coolers>

PART 3 - EXECUTION

3.1 INSTALLATION

- A. General: Anchor site furnishings securely, positioned at locations and elevations indicated.

END OF SECTION 129300

SECTION 220500 - COMMON WORK RESULTS FOR PLUMBING

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data.

PART 2 - PRODUCTS

2.1 SLEEVES

- A. Mechanical Sleeve Seals: Modular rubber sealing element unit, designed for field assembly, to fill annular space between pipe and sleeve.
- B. Galvanized-Steel Sheet: 0.0239-inch minimum thickness; round tube closed with welded longitudinal joint.
- C. Steel Pipe: ASTM A 53, Type E, Grade B, Schedule 40, galvanized, plain ends.
- D. PVC Pipe: ASTM D 1785, Schedule 40.

2.2 GROUT

- A. Description: ASTM C 1107, Grade B, nonshrink and nonmetallic, dry hydraulic-cement grout.

2.3 MOTORS

- A. Motor Characteristics:

1. Motors 1 HP and Larger: Three phase.
2. Motors Smaller Than 1 HP: Single phase.
3. Frequency Rating: 60 Hz.
4. Voltage Rating: NEMA standard voltage for circuit voltage to which motor is connected.
5. Service Factor: 1.15 for open dripproof motors; 1.0 for totally enclosed motors.
6. Duty: Continuous duty at ambient temperature of 105 deg F and at altitude of 3300 feet above sea level.
7. Capacity and Torque Characteristics: Sufficient to start, accelerate, and operate connected loads at designated speeds, at installed altitude and environment, with indicated operating sequence, and without exceeding nameplate ratings or considering service factor.
8. Enclosure: Unless otherwise indicated, open dripproof.

9. Motors Used with Variable-Frequency Controllers: Ratings, characteristics, and features coordinated with and approved by controller manufacturer.

2.4 HANGERS AND SUPPORTS

- A. Hanger and Pipe Attachments: Factory fabricated with galvanized coatings; nonmetallic coated for hangers in direct contact with copper tubing.
- B. Powder-Actuated Fasteners: Threaded-steel stud, with pull-out and shear capacities appropriate for supported loads and building materials where used.
- C. Mechanical-Expansion Anchors: Insert-wedge-type, zinc-coated steel, with pull-out and shear capacities appropriate for supported loads and building materials where used.

2.5 VIBRATION ISOLATION AND SEISMIC CONTROL DEVICES

- A. Vibration Supports:
 1. Pads: Arranged in single or multiple layers of oil- and water-resistant, neoprene or rubber of sufficient stiffness for uniform loading over pad area, molded with a nonslip pattern and galvanized-steel baseplates, and factory cut to sizes that match supported equipment.
 2. Restrained Mounts: Double-deflection type, with molded, oil-resistant fiberglass, rubber, or neoprene isolator elements with factory-drilled, encapsulated top plate and baseplate. Provide isolator with minimum 0.5-inch static deflection.
 3. Spring Isolators: Freestanding, laterally stable, restrained-spring isolators. Provide isolator with minimum 1-inch static deflection.
- B. Vibration Hangers:
 1. Elastomeric Hangers: Double-deflection type, with molded, oil-resistant rubber or neoprene isolator elements bonded to steel housings with threaded connections for hanger rods. Provide isolator with minimum 0.5-inch static deflection.
 2. Spring Hangers: Combination coil-spring and elastomeric-insert hanger with spring and insert in compression. Provide isolator with minimum 1-inch static deflection.

2.6 PRESSURE GAGES AND TEST PLUGS

- A. Pressure Gages: Direct-mounting, indicating-dial type complying with ASME B40.100. Dry metal case, minimum 2-1/2-inch diameter with red pointer on white face, and plastic window. Minimum accuracy 3 percent of middle half of range. Range two times operating pressure.
- B. Test Plug: Corrosion-resistant brass or stainless-steel body with two self-sealing rubber core inserts and gasketed and threaded cap, with extended stem for units to be installed in insulated piping. Minimum pressure and temperature rating 500 psig at 200 deg F.

PART 3 - EXECUTION

3.1 MOTOR INSTALLATION

- A. Anchor motor assembly to base, adjustable rails, or other support, arranged and sized according to manufacturer's written instructions.

3.2 GENERAL PIPING INSTALLATIONS

- A. Install piping free of sags and bends.
- B. Install fittings for changes in direction and branch connections.
- C. Install sleeves for pipes passing through concrete walls, and concrete floor and roof slabs.
- D. Exterior Wall, Pipe Penetrations: Mechanical sleeve seals installed in steel or cast-iron pipes for wall sleeves.
- E. Comply with requirements in Division 07 Section "Penetration Firestopping" for sealing pipe penetrations in fire-rated construction.
- F. Install unions at final connection to each piece of equipment.
- G. Install dielectric unions and flanges to connect piping materials of dissimilar metals in gas piping.
- H. Install dielectric coupling and nipple fittings to connect piping materials of dissimilar metals in water piping.

3.3 GENERAL EQUIPMENT INSTALLATIONS

- A. Install equipment to allow maximum possible headroom unless specific mounting heights are not indicated.
- B. Install equipment level and plumb, parallel and perpendicular to other building systems and components, unless otherwise indicated.
- C. Install mechanical equipment to facilitate service, maintenance, and repair or replacement of components. Connect equipment for ease of disconnecting, with minimum interference to other installations. Extend grease fittings to accessible locations.
- D. Install equipment to allow right of way for piping installed at required slope.



3.4 BASES, SUPPORTS, AND ANCHORAGES

- A. Anchor equipment to concrete base according to equipment manufacturer's written instructions and according to seismic codes at Project.
 - 1. Construct concrete bases of dimensions indicated, but not less than 4 inches larger in both directions than supported unit.
 - 2. Install dowel rods on 18-inch centers around the full perimeter of the base to connect concrete base to concrete floor.
 - 3. Install epoxy-coated anchor bolts for supported equipment that extend through concrete base, and anchor into structural concrete floor.
 - 4. Place and secure anchorage devices. Use supported equipment manufacturer's setting drawings, templates, diagrams, instructions, and directions furnished with items to be embedded.
 - 5. Use **3000-psi**, 28-day compressive-strength concrete and reinforcement as specified in Division 03 Section "Cast-in-Place Concrete"
- B. Mix and install grout for fire-suppression equipment base bearing surfaces, pump and other equipment base plates, and anchors. Place grout, completely filling equipment bases.

3.5 HANGERS AND SUPPORTS

- A. Comply with MSS SP-69 and MSS SP-89. Install building attachments within concrete or to structural steel.
- B. Install hangers and supports to allow controlled thermal and seismic movement of piping systems.
- C. Install powder-actuated fasteners and mechanical-expansion anchors in concrete after concrete is cured. Do not use in lightweight concrete or in slabs less than 4 inches thick.
- D. Load Distribution: Install hangers and supports so piping live and dead loading and stresses from movement will not be transmitted to connected equipment.
- E. Horizontal-Piping Hangers and Supports: Unless otherwise indicated and except as specified in piping system Specification Sections, install the following types:
 - 1. Adjustable Steel Clevis Hangers (MSS Type 1): For suspension of noninsulated or insulated stationary pipes, NPS 1/2 to NPS 30.
 - 2. Pipe Hangers (MSS Type 5): For suspension of pipes, NPS 1/2 to NPS 4, to allow off-center closure for hanger installation before pipe erection.
 - 3. Adjustable Steel Band Hangers (MSS Type 7): For suspension of noninsulated stationary pipes, NPS 1/2 to NPS 8.
 - 4. Adjustable Band Hangers (MSS Type 9): For suspension of noninsulated stationary pipes, NPS 1/2 to NPS 8.
 - 5. Adjustable Swivel-Ring Band Hangers (MSS Type 10): For suspension of noninsulated stationary pipes, NPS 1/2 to NPS 2.

- F. Vertical-Piping Clamps: Unless otherwise indicated and except as specified in piping system Specification Sections, install the following types:
1. Extension Pipe or Riser Clamps (MSS Type 8): For support of pipe risers, NPS 3/4 to NPS 20.
 2. Carbon- or Alloy-Steel Riser Clamps (MSS Type 42): For support of pipe risers, NPS 3/4 to NPS 20, if longer ends are required for riser clamps.

3.6 VIBRATION ISOLATION AND SEISMIC CONTROL DEVICE INSTALLATION

- A. Adjust vibration isolators to allow free movement of equipment limited by restraints.
- B. Install resilient bolt isolation washers and bushings on equipment anchor bolts.
- C. Install cables so they do not bend across sharp edges of adjacent equipment or building structure.

END OF SECTION 220500



SECTION 223300 - ELECTRIC DOMESTIC WATER HEATERS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data.
- B. Comply with requirements of applicable NSF, AWWA, or FDA and EPA regulatory standards for tasteless and odorless, potable-water-tank linings.
- C. Comply with performance efficiencies prescribed in ASHRAE 90.2, "Energy Efficient Design of New Low-Rise Residential Buildings."
- D. Warranties: Submit a written warranty executed by manufacturer agreeing to repair or replace water heaters that fail in materials or workmanship within five years from date of Substantial Completion. Failures include, but are not limited to, tanks and elements.

PART 2 - PRODUCTS

2.1 WATER HEATERS, GENERAL

- A. Insulation: Suitable for operating temperature and required insulating value. Include insulation material that surrounds entire tank except connections and controls.
- B. Anode Rods: Factory installed, magnesium.
- C. Combination Temperature and Pressure Relief Valve: ASME rated and stamped and complying with ASME PTC 25.3. Include relieving capacity at least as great as heat input and pressure setting less than water heater working-pressure rating. Select relief valve with sensing element that extends into tank.
- D. Drain Valve: Factory or field installed.

2.2 ELECTRIC WATER HEATERS

A. Available Products:

- 1. Rheem Marathon MR50245, 50 Gallon
<http://waterheating.rheem.com:80/content/resources/documents/specsheets/Residential%20Electric/RHElecMarathon.pdf>

- B. Household, Storage, Electric Water Heaters: UL 174, 50-gal. capacity; steel with 150-psig working-pressure rating. Two electric, screw-in, immersion-type heating elements with

adjustable thermostat for each element and wiring arrangement for nonsimultaneous operation with maximum 30-A circuit.

2.3 UNITARY HEAT PUMP BOOSTER

- A. Available Products:
 - 1. Airgenerate Airtap
<http://www.airgenerate.com/products/specs.html>
- B. Factory-assembled and -tested, packaged water-source heat pump complete with controls.
- C. Cabinet and Chassis: Galvanized-steel casing: Access panels for access and maintenance of internal components. Knockouts for electrical and piping connections. Glass-fiber liner, complying with UL 181. Plastic or stainless-steel drain pan pitched per ASHRAE 62.
- D. Water Circuit: Refrigerant-to-water heat exchanger leak tested to 450 psig on refrigerant side.
- E. Refrigerant-to-Air Coil: Copper-tubes with aluminum fins, leak tested to 450 psig.
- F. Refrigerant Circuit Components: Sealed refrigerant circuit rated per ARI-ISO-13256. Service fittings on suction and liquid for charging and testing. ASTM B 743 copper refrigerant piping with wrought-copper fittings and brazed joints. Minimum 3/8-inch-thick, flexible elastomeric insulation on piping exposed to airflow through unit.
 - 1. Compressor: Installed on vibration isolators in an acoustically treated enclosure with anti-recycle timer; high- and low-pressure cutout, or loss of charge switch; and internal thermal-overload protection.
 - a. Freezestat stops compressor if water-loop temperature falls below 35 deg F.
 - b. Condensate overflow switch stops compressor with high condensate level in pan.
- G. Filters: Disposable pleated type.
- H. Basic Unit Controls: Low- and high-voltage protection. Overcurrent protection for compressor and fan motor. Random time delay, three to ten seconds, starts on power-up. Control voltage transformer.
- I. Electrical Connection: Single electrical connection.
- J. Controls in addition to those required for other options.
 - 1. Thermostat Optional Features:
 - a. On-off switch.
 - b. Exposed temperature set-point and indication.
 - c. Deg F indication.



PART 3 - EXECUTION

3.1 INSTALLATION

- A. Install temperature and pressure relief valves and extend to closest floor drain.
- B. Install vacuum relief valves in cold-water-inlet piping.
- C. Install shutoff valves and unions at hot- and cold-water piping connections.
- D. Make piping connections with dielectric fittings where dissimilar piping materials are joined.
- E. Electrically ground units according to authorities having jurisdiction.

END OF SECTION 223300

SECTION 230500 - COMMON WORK RESULTS FOR HVAC

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data.

PART 2 - PRODUCTS

2.1 SLEEVES

- A. Mechanical Sleeve Seals: Modular rubber sealing element unit, designed for field assembly, to fill annular space between pipe and sleeve.
- B. Galvanized-Steel Sheet: 0.0239-inch minimum thickness; round tube closed with welded longitudinal joint.
- C. Steel Pipe: ASTM A 53, Type E, Grade B, Schedule 40, galvanized, plain ends.
- D. PVC Pipe: ASTM D 1785, Schedule 40.

2.2 GROUT

- A. Description: ASTM C 1107, Grade B, nonshrink and nonmetallic, dry hydraulic-cement grout.

2.3 MOTORS

- A. Motor Characteristics:

1. Motors 1 HP and Larger: Three phase.
2. Motors Smaller Than 1 HP: Single phase.
3. Frequency Rating: 60 Hz.
4. Voltage Rating: NEMA standard voltage for circuit voltage to which motor is connected.
5. Service Factor: 1.15 for open dripproof motors; 1.0 for totally enclosed motors.
6. Duty: Continuous duty at ambient temperature of 105 deg F and at altitude of 3300 feet above sea level.
7. Capacity and Torque Characteristics: Sufficient to start, accelerate, and operate connected loads at designated speeds, at installed altitude and environment, with indicated operating sequence, and without exceeding nameplate ratings or considering service factor.
8. Enclosure: Unless otherwise indicated, open dripproof.

9. Motors Used with Variable-Frequency Controllers: Ratings, characteristics, and features coordinated with and approved by controller manufacturer.

2.4 HANGERS AND SUPPORTS

- A. Hanger and Pipe Attachments: Factory fabricated with galvanized coatings; nonmetallic coated for hangers in direct contact with copper tubing.
- B. Powder-Actuated Fasteners: Threaded-steel stud, with pull-out and shear capacities appropriate for supported loads and building materials where used.
- C. Mechanical-Expansion Anchors: Insert-wedge-type, zinc-coated steel, with pull-out and shear capacities appropriate for supported loads and building materials where used.

2.5 VIBRATION ISOLATION AND SEISMIC CONTROL DEVICES

- A. Vibration Supports:
 1. Pads: Arranged in single or multiple layers of oil- and water-resistant, neoprene or rubber of sufficient stiffness for uniform loading over pad area, molded with a nonslip pattern and galvanized-steel baseplates, and factory cut to sizes that match supported equipment.
 2. Restrained Mounts: Double-deflection type, with molded, oil-resistant fiberglass, rubber or neoprene isolator elements with factory-drilled, encapsulated top plate and baseplate. Provide isolator with minimum 0.5-inch static deflection.
- B. Vibration Hangers:
 1. Elastomeric Hangers: Double-deflection type, with molded, oil-resistant rubber or neoprene isolator elements bonded to steel housings with threaded connections for hanger rods. Provide isolator with minimum 0.5-inch static deflection.

2.6 PRESSURE GAGES AND TEST PLUGS

- A. Pressure Gages: Direct-mounting, indicating-dial type complying with ASME B40.100. Dry metal case, minimum 2-1/2-inch diameter with red pointer on white face, and plastic window. Minimum accuracy 3 percent of middle half of range. Range two times operating pressure.
- B. Test Plug: Corrosion-resistant brass or stainless-steel body with two self-sealing rubber core inserts and gasketed and threaded cap, with extended stem for units to be installed in insulated piping. Minimum pressure and temperature rating of 500 psig at 200 deg F.

1. EXECUTION

2.7 MOTOR INSTALLATION

- A. Anchor motor assembly to base, adjustable rails, or other support, arranged and sized according to manufacturer's written instructions.

2.8 GENERAL PIPING INSTALLATIONS

- A. Install piping free of sags and bends.
- B. Install fittings for changes in direction and branch connections.
- C. Install sleeves for pipes passing through concrete walls, and concrete floor and roof slabs.
- D. Exterior Wall, Pipe Penetrations: Mechanical sleeve seals installed in steel or cast-iron pipes for wall sleeves.
- E. Comply with requirements in Division 07 Section "Penetration Firestopping" for sealing pipe penetrations in fire-rated construction.
- F. Install unions at final connection to each piece of equipment.
- G. Install dielectric unions and flanges to connect piping materials of dissimilar metals in gas piping.
- H. Install dielectric coupling and nipple fittings to connect piping materials of dissimilar metals in water piping.

2.9 GENERAL EQUIPMENT INSTALLATIONS

- A. Install equipment to allow maximum possible headroom unless specific mounting heights are not indicated.
- B. Install equipment level and plumb, parallel and perpendicular to other building systems and components, unless otherwise indicated.
- C. Install mechanical equipment to facilitate service, maintenance, and repair or replacement of components. Connect equipment for ease of disconnecting, with minimum interference to other installations. Extend grease fittings to accessible locations.
- D. Install equipment to allow right of way for piping installed at required slope.

2.10 BASES, SUPPORTS, AND ANCHORAGES

- A. Anchor equipment to concrete base according to equipment manufacturer's written instructions and according to seismic codes at Project.

1. Construct concrete bases of dimensions indicated, but not less than 4 inches larger in both directions than supported unit.
 2. Install dowel rods on 18-inch centers around the full perimeter of the base to connect concrete base to concrete floor.
 3. Install epoxy-coated anchor bolts for supported equipment that extend through concrete base, and anchor into structural concrete floor.
 4. Place and secure anchorage devices. Use supported equipment manufacturer's setting drawings, templates, diagrams, instructions, and directions furnished with items to be embedded.
 5. Use 3000-psi 28-day compressive-strength concrete and reinforcement as specified in Division 03 Section "Cast-in-Place Concrete"
- B. Mix and install grout for pump and other equipment base plates, and anchors. Place grout, completely filling equipment bases.

2.11 HANGERS AND SUPPORTS

- A. Comply with MSS SP-69 and MSS SP-89. Install building attachments within concrete or to structural steel.
- B. Install hangers and supports to allow controlled thermal and seismic movement of piping systems.
- C. Install powder-actuated fasteners and mechanical-expansion anchors in concrete after concrete is cured. Do not use in lightweight concrete or in slabs less than 4 inches thick.
- D. Load Distribution: Install hangers and supports so piping live and dead loading and stresses from movement will not be transmitted to connected equipment.
- E. Horizontal-Piping Hangers and Supports: Unless otherwise indicated and except as specified in piping system Specification Sections, install the following types:
 1. Adjustable Steel Clevis Hangers (MSS Type 1): For suspension of noninsulated or insulated stationary pipes, NPS 1/2 to NPS 30.
 2. Pipe Hangers (MSS Type 5): For suspension of pipes, NPS 1/2 to NPS 4 to allow off-center closure for hanger installation before pipe erection.
 3. Adjustable Steel Band Hangers (MSS Type 7): For suspension of noninsulated stationary pipes, NPS 1/2 to NPS 8.
 4. Adjustable Band Hangers (MSS Type 9): For suspension of noninsulated stationary pipes, NPS 1/2 to NPS 8.
 5. Adjustable Swivel-Ring Band Hangers (MSS Type 10): For suspension of noninsulated stationary pipes, NPS 1/2 to NPS 2.
- F. Vertical-Piping Clamps: Unless otherwise indicated and except as specified in piping system Specification Sections, install the following types:



1. Extension Pipe or Riser Clamps (MSS Type 8): For support of pipe risers, NPS 3/4 to NPS 20.
2. Carbon- or Alloy-Steel Riser Clamps (MSS Type 42): For support of pipe risers, NPS 3/4 to NPS 20, if longer ends are required for riser clamps.

2.12 VIBRATION ISOLATION AND SEISMIC CONTROL DEVICE INSTALLATION

- A. Adjust vibration isolators to allow free movement of equipment limited by restraints.
- B. Install resilient bolt isolation washers and bushings on equipment anchor bolts.
- C. Install cables so they do not bend across sharp edges of adjacent equipment or building structure.

END OF SECTION 230500

SECTION 230593 - TESTING, ADJUSTING, AND BALANCING FOR HVAC

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Certified TAB reports.
- B. TAB Firm Qualifications: TABB certified.
- C. TAB Report Forms: Standard TAB contractor's forms approved by Architect.
- D. Perform TAB after leakage and pressure tests on air distribution systems have been satisfactorily completed.

PART 2 - PRODUCTS (Not Used)

PART 3 - EXECUTION

3.1 EXAMINATION

- A. Examine the Contract Documents to become familiar with Project requirements and to discover conditions in systems' designs that may preclude proper TAB of systems and equipment.
- B. Examine the approved submittals for HVAC systems and equipment.
- C. Examine systems for installed balancing devices, such as test ports, gage cocks, thermometer wells, flow-control devices, balancing valves and fittings, and manual volume dampers. Verify that locations of these balancing devices are accessible.
- D. Examine system and equipment installations and verify that field quality-control testing, cleaning, and adjusting specified in individual Sections have been performed.
- E. Examine HVAC equipment and filters and verify that bearings are greased, belts are aligned and tight, and equipment with functioning controls is ready for operation.
- F. Examine terminal units, such as variable-air-volume boxes, and verify that they are accessible and their controls are connected and functioning.
- G. Examine automatic temperature system components to verify the following:
 - 1. Dampers, valves, and other controlled devices are operated by the intended controller.

2. Dampers and valves are in the position indicated by the controller.
 3. Integrity of dampers and valves for free and full operation and for tightness of fully closed and fully open positions. This includes dampers in multizone units, mixing boxes, and variable-air-volume terminals.
 4. Automatic modulating and shutoff valves, including two-way valves and three-way mixing and diverting valves, are properly connected.
 5. Thermostats and humidistats are located to avoid adverse effects of sunlight, drafts, and cold walls.
 6. Sensors are located to sense only the intended conditions.
 7. Sequence of operation for control modes is according to the Contract Documents.
 8. Controller set points are set at indicated values.
 9. Interlocked systems are operating.
 10. Changeover from heating to cooling mode occurs according to indicated values.
- H. Report deficiencies discovered before and during performance of test and balance procedures.

3.2 GENERAL PROCEDURES FOR TESTING AND BALANCING

- A. Perform testing and balancing procedures on each system according to the procedures contained in ASHRAE 111 and in this Section.
- B. Cut insulation, ducts, pipes, and equipment cabinets for installation of test probes to the minimum extent necessary for TAB procedures. After testing and balancing, patch probe holes in ducts with same material and thickness as used to construct ducts. Install and join new insulation that matches removed materials. Restore insulation, coverings, vapor barrier, and finish.
- C. Mark equipment and balancing devices, including damper-control positions, valve position indicators, fan-speed-control levers, and similar controls and devices, with paint or other suitable, permanent identification material to show final settings.
- D. Take and report testing and balancing measurements in inch-pound (IP) and metric (SI) units.

3.3 GENERAL PROCEDURES FOR BALANCING AIR SYSTEMS

- A. Prepare schematic diagrams of systems' "as-built" duct layouts.
- B. For variable-air-volume systems, develop a plan to simulate diversity.
- C. Determine the best locations in main and branch ducts for accurate duct airflow measurements.
- D. Verify that motor starters are equipped with properly sized thermal protection.
- E. Check for airflow blockages.

- F. Check condensate drains for proper connections and functioning.
- G. Check for proper sealing of air-handling unit components.
- H. Check for proper sealing of air duct system.

3.4 TOLERANCES

- A. Set HVAC system airflow and water flow rates within the following tolerances:
 - 1. Supply, Return, and Exhaust Fans and Equipment with Fans: Plus or minus 10 percent.
 - 2. Air Outlets and Inlets: Plus or minus 10 percent.
 - 3. Heating-Water Flow Rate: Plus or minus 10 percent.
 - 4. Cooling-Water Flow Rate: Plus or minus 10 percent.

END OF SECTION 230593



SECTION 230700 - HVAC INSULATION

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data.
- B. Quality Assurance: Labeled with maximum flame-spread index of 25 and maximum smoke-developed index of 50 according to ASTM E 84.

PART 2 - PRODUCTS

2.1 INSULATION MATERIALS

- A. Foam insulation materials shall not use CFC or HCFC blowing agents in the manufacturing process.
- B. Flexible Elastomeric: Closed-cell, sponge- or expanded-rubber materials. Comply with ASTM C 534, Type I for tubular materials and Type II for sheet materials.
- C. Mineral-Fiber Blanket Insulation: Comply with ASTM C 553, Type II and ASTM C 1290, Type I.
- D. Mineral-Fiber Board Insulation: Comply with ASTM C 612, Type IA or Type IB. For equipment applications, provide insulation with factory-applied FSK.
- E. Mineral-Fiber, Preformed Pipe Insulation: Comply with ASTM C 547, Type I, Grade A, with factory-applied FSK.
- F. Mineral-Fiber, Pipe and Tank Insulation: Complying with ASTM C 1393, Type II or Type IIIA Category 2, or with properties similar to ASTM C 612, Type IB; and having factory-applied ASJ jacket. Nominal density is 2.5 lb/cu. ft. or more. Thermal conductivity (k-value) at 100 deg F is 0.29 Btu x in./h x sq. ft. x deg F or less.
- G. Polyolefin Insulation: Unicellular, polyethylene thermal plastic insulation. Comply with ASTM C 534 or ASTM C 1427, Type I, Grade 1 for tubular materials and Type II, Grade 1 for sheet materials.
- H. Flexible Elastomeric and Polyolefin Adhesive: Comply with MIL-A-24179A, Type II, Class I.
- I. Mineral-Fiber Adhesive: Comply with MIL-A-3316C, Class 2, Grade A.
- J. Vapor-Barrier Mastic: Water based; suitable for indoor and outdoor use on below ambient services.



- K. Factory-Applied Jackets: When factory-applied jackets are indicated, comply with the following:
 - 1. ASJ: White, kraft-paper, fiberglass-reinforced scrim with aluminum-foil backing; complying with ASTM C 1136, Type I.
 - 2. FSK Jacket: Aluminum-foil, fiberglass-reinforced scrim with kraft-paper backing; complying with ASTM C 1136, Type II.
- L. ASJ Tape: White vapor-retarder tape matching factory-applied jacket with acrylic adhesive, complying with ASTM C 1136.
- M. FSK Tape: Foil-face, vapor-retarder tape matching factory-applied jacket with acrylic adhesive; complying with ASTM C 1136.

PART 3 - EXECUTION

3.1 INSULATION INSTALLATION

- A. Comply with requirements of the Midwest Insulation Contractors Association's "National Commercial & Industrial Insulation Standards" for insulation installation on pipes and equipment.
- B. Insulation Installation at Interior Wall and Partition Penetrations (That Are Not Fire Rated): Install insulation continuously through walls and partitions.
- C. Insulation Installation at Fire-Rated Wall, Partition, and Floor Penetrations: Install insulation continuously through penetrations. Seal penetrations. Comply with requirements in Division 07 Section "Penetration Firestopping."
- D. Flexible Elastomeric Insulation Installation:
 - 1. Seal longitudinal seams and end joints with adhesive to eliminate openings in insulation that allow passage of air to surface being insulated.
 - 2. Insulation Installation on Pipe Fittings and Elbows: Install mitered sections of pipe insulation. Secure insulation materials and seal seams with adhesive to eliminate openings in insulation that allow passage of air to surface being insulated.
- E. Mineral-Fiber Insulation Installation:
 - 1. Insulation Installation on Straight Pipes and Tubes: Where vapor barriers are indicated, seal longitudinal seams, end joints, and protrusions with vapor-barrier mastic and joint sealant.
 - 2. For insulation with factory-applied jackets on above ambient surfaces, secure laps with outward clinched staples at 6 inches o.c.
 - 3. For insulation with factory-applied jackets on below ambient surfaces, do not staple longitudinal tabs but secure tabs with additional adhesive as recommended by

- insulation material manufacturer and seal with vapor-barrier mastic and flashing sealant.
 - 4. Blanket and Board Insulation Installation on Ducts and Plenums: Secure with adhesive and insulation pins.
 - 5. For ducts and plenums with surface temperatures below ambient, install a continuous unbroken vapor barrier.
- F. Polyolefin Insulation Installation:
- 1. Seal split-tube longitudinal seams and end joints with adhesive to eliminate openings in insulation that allow passage of air to surface being insulated.
 - 2. Insulation Installation on Pipe Fittings and Elbows: Install mitered sections of polyolefin pipe insulation. Secure insulation materials and seal seams with adhesive to eliminate openings in insulation that allow passage of air to surface being insulated.
- G. Plenums and Ducts Requiring Insulation:
- 1. Concealed and exposed supply and outdoor air.
 - 2. Concealed and exposed return air located in nonconditioned space.
 - 3. Concealed and exposed exhaust between isolation damper and penetration of building exterior.
- H. Plenums and Ducts Not Insulated:
- 1. Metal ducts with duct liner.
 - 2. Factory-insulated plenums and casings.
 - 3. Flexible connectors.
 - 4. Vibration-control devices.
 - 5. Factory-insulated access panels and doors.
- I. Piping Not Insulated: Unless otherwise indicated, do not install insulation on the following:
- 1. Drainage piping located in crawlspaces.
 - 2. Underground piping.
 - 3. Chrome-plated pipes and fittings unless there is a potential for personnel injury.

3.2 DUCT AND PLENUM INSULATION SCHEDULE

- A. Concealed duct insulation shall be **one of** the following:
- 1. Flexible Elastomeric: 1 inch thick.
 - 2. Mineral-Fiber Blanket: 3 inches thick and 3-lb/cu. ft. nominal density.
 - 3. Mineral-Fiber Board: 3 inches thick and 3-lb/cu. ft. nominal density.
 - 4. Polyolefin: 1 inch thick.
- B. Exposed duct insulation shall be one of the following:

1. Flexible Elastomeric: 1 inch thick.
2. Mineral-Fiber Blanket: 3 inches thick and 3-lb/cu. ft. nominal density.
3. Mineral-Fiber Board: 3 inches thick and 3-lb/cu. Ft. nominal density.
4. Polyolefin: 1 inch thick.

3.3 HVAC PIPING INSULATION SCHEDULE

- A. Chilled Water: Insulation shall be **one of** the following:
 1. Flexible Elastomeric: 1 inch thick.
 2. Polyolefin: 1 inch thick.
- B. Heating-Hot-Water Supply and Return: Insulation shall be the following:
 1. Mineral-Fiber, Preformed Pipe, Type I: 2 inches.
- C. Piping: Insulation shall be one of the following:
 1. Flexible Elastomeric: 1 inch thick.
 2. Mineral-Fiber, Preformed Pipe Insulation, Type I: 1 inch thick.
 3. Polyolefin: 1 inch thick.
- D. Refrigerant Suction and Hot-Gas Flexible Tubing: Insulation shall be[one of] the following:
 1. Flexible Elastomeric: 1 inch thick.
 2. Polyolefin: 1 inch thick.

END OF SECTION 230700

SECTION 233100 - HVAC DUCTS AND CASINGS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data for fire and smoke dampers and Shop Drawings detailing duct layout and including locations and types of duct accessories, duct sizes, transitions, radius and vaned elbows, special supports details, and inlets and outlet types and locations.
- B. Comply with NFPA 90A, "Installation of Air Conditioning and Ventilating Systems," and with NFPA 90B, "Installation of Warm Air Heating and Air Conditioning Systems."
- C. Comply with NFPA 96 for ducts connected to commercial kitchen hoods.
- D. Comply with UL 181 for ducts and closures.

PART 2 - PRODUCTS

2.1 DUCTS

- A. Galvanized-Steel Sheet: ASTM A 653/A 653M, with G60 hot-dip galvanized coating.
- B. Carbon-Steel Sheets: ASTM A 1008/A 1008M; with oiled, matte finish for exposed ducts.
- C. Stainless Steel: ASTM A 480/A 480M, Type 316, with a No. 2D finish for concealed ducts and No. 4 finish for exposed ducts.
- D. Fibrous-Glass Duct Board: Comply with UL 181, Class 1, 1-inch- thick, fibrous glass with fire-resistant, reinforced foil-scrim-kraft barrier, and having the air-side surface treated to prevent erosion.
- E. Joint and Seam Tape, and Sealant: Comply with UL 181A.
- F. Rectangular Metal Duct Fabrication: Comply with SMACNA's "HVAC Duct Construction Standards - Metal and Flexible."
- G. Fibrous-Glass Duct Fabrication: Comply with SMACNA's "Fibrous Glass Duct Construction Standard."
- H. Fibrous-Glass Liner: Comply with NFPA 90A or NFPA 90B and with NAIMA AH124.
 - 1. Thickness: 1/2 inch.
 - 2. Airstream surface coated with an antimicrobial erosion-resistant coating.



3. Liner Adhesive: Comply with NFPA 90A or NFPA 90B and with ASTM C 916.
4. Mechanical Fasteners: Galvanized steel suitable for adhesive attachment, mechanical attachment, or welding attachment.

2.2 ACCESSORIES

- A. Volume Dampers and Control Dampers: Single-blade and multiple opposed-blade dampers, standard leakage rating, and suitable for horizontal or vertical applications; factory fabricated and complete with required hardware and accessories.
- B. Fire Dampers: Rated and labeled according to UL 555 by an NRTL; factory fabricated and complete with required hardware and accessories.
- C. Ceiling Fire Dampers: Labeled according to UL 555C by an NRTL and complying with construction details for tested floor- and roof-ceiling assemblies as indicated in UL's "Fire Resistance Directory." Provide factory-fabricated units complete with required hardware and accessories.
- D. Smoke Dampers: Labeled according to UL 555S by an NRTL. Combination fire and smoke dampers shall also be rated and labeled according to UL 555. Provide factory-fabricated units complete with required hardware and accessories.
- E. Flexible Connectors: Flame-retarded or noncombustible fabrics, coatings, and adhesives complying with UL 181, Class 1.
- F. Flexible Ducts: Factory-fabricated, insulated, round duct, with an outer jacket enclosing 1-inch- thick, glass-fiber insulation around a continuous inner liner complying with UL 181, Class 1.

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Install ducts according to SMACNA's "HVAC Duct Construction Standards - Metal and Flexible" unless otherwise indicated.
- B. Seal ducts to the following seal classes according to SMACNA's "HVAC Duct Construction Standards - Metal and Flexible":
 1. Outdoor, Supply-Air Ducts: Seal Class A.
 2. Outdoor, Exhaust Ducts: Seal Class C.
 3. Outdoor, Return-Air Ducts: Seal Class C.
 4. Unconditioned Space, Supply-Air Ducts in Pressure Classes 2-Inch wg and Lower: Seal Class B.



5. Unconditioned Space, Supply-Air Ducts in Pressure Classes Higher Than 2-Inch wg: Seal Class A.
 6. Unconditioned Space, Exhaust Ducts: Seal Class C.
 7. Unconditioned Space, Return-Air Ducts: Seal Class B.
 8. Conditioned Space, Supply-Air Ducts in Pressure Classes 2-Inch wg and Lower: Seal Class C.
 9. Conditioned Space, Supply-Air Ducts in Pressure Classes Higher Than 2-Inch wg: Seal Class B.
 10. Conditioned Space, Exhaust Ducts: Seal Class B.
 11. Conditioned Space, Return-Air Ducts: Seal Class C.
- C. Conceal ducts from view in finished and occupied spaces.
- D. Avoid passing through electrical equipment spaces and enclosures.
- E. Support ducts to comply with SMACNA's "HVAC Duct Construction Standards - Metal and Flexible," Ch. 4, "Hangers and Supports."
- F. Install duct accessories according to applicable details in SMACNA's "HVAC Duct Construction Standards - Metal and Flexible" for metal ducts and in NAIMA AH116, "Fibrous Glass Duct Construction Standards," for fibrous-glass ducts.
- G. Install volume and control dampers in lined duct with methods to avoid damage to liner and to avoid erosion of duct liner.
- H. Install fire and smoke dampers according to UL listing.
- I. Install fusible links in fire dampers.
- J. Clean new and existing duct system(s) before testing, adjusting, and balancing.

3.2 TESTING, ADJUSTING, AND BALANCING

- A. Balance airflow within distribution systems, including submains, branches, and terminals to indicated quantities.

END OF SECTION 233100

SECTION 233713 - DIFFUSERS, REGISTERS, AND GRILLES

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data and color charts for factory finishes.

PART 2 - PRODUCTS

2.1 OUTLETS AND INLETS

- A. Diffusers:

1. Available Products:
 - a. Schedule on Drawings.
2. Material: Steel or Aluminum.
3. Finish: Baked enamel, color selected by Architect or Anodized aluminum.
4. Mounting: Duct connection, Surface, Snap in.

- B. Wall and Ceiling Registers:

1. Available Products:
 - a. Schedule on Drawings.
2. Material: Steel or Aluminum.
3. Finish: Baked enamel, color selected by Architect or Anodized aluminum.
4. Mounting: Countersunk screw, Concealed, or Lay in.

- C. Wall and Ceiling Grilles:

1. Available Products:
 - a. Schedule on Drawings.
2. Material: Steel or Aluminum.
3. Finish: Baked enamel, color selected by Architect or Anodized aluminum.
4. Mounting: Countersunk screw, Concealed, or Lay in.

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Install diffusers, registers, and grilles level and plumb.
- B. Ceiling-Mounted Outlets and Inlets: Drawings indicate general arrangement of ducts, fittings, and accessories. Make final locations where indicated, as much as practical. For units installed in lay-in ceiling panels, locate units in the center of panel unless otherwise indicated. Where architectural features or other items conflict with installation, notify Architect for a determination of final location.
- C. After installation, adjust diffusers, registers, and grilles to air patterns indicated, or as directed, before starting air balancing.

END OF SECTION 233713



SECTION 23 72 00 – AIR-TO-AIR ENERGY RECOVERY EQUIPMENT

PART 1 - GENERAL

1.1 DESCRIPTION

This Section specifies rotary air-to-air heat exchanger.

1.2 QUALITY ASSURANCE

- A. Refer to paragraph QUALITY ASSURANCE in specification Section 23 05 11, COMMON WORK RESULTS FOR HVAC AND STEAM GENERATION.
- B. Performance Criteria: Heat recovery equipment shall be provided by a manufacturer who has been manufacturing such equipment and the equipment has a good track record for at least 5 years.
- C. Performance Test: In accordance with PART 3.

1.3 SUBMITTALS

- A. Submit in accordance with Section 01 33 23, SHOP DRAWINGS, PRODUCT DATA, AND SAMPLES.
- B. Manufacturer's Literature and Data:
 1. Rotary Heat Exchanger
Ultimate Air Recuperator Energy Recovery Ventilator
http://ultimateair.com/Ultimate_Air/specifications/house_unit_specs.aspx

1.4 APPLICABLE PUBLICATIONS

- A. The publications listed below form a part of this specification to the extent referenced. The publications are referenced in the text by the basic designation only.
- B. Air Conditioning and Refrigeration Institute (ARI)
ARI 1060-2005 - Performance Rating of Air-to-Air Heat Exchangers for Energy Recovery Ventilation Heat Equipment
- C. American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE):
15-07 - Safety Standard for Refrigeration Systems (ANSI)
52.1-92 - Gravimetric and Dust-Spot Procedures for Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter
52.2-07 - Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size
84-91 - Method of Testing Air-to-Air Heat Exchangers
- D. American Society for Testing and materials (ASTM)
 - a. D635-06 - Standard Test Method for Rate of Burning and/ or Extent and Time of Burning of Plastics in a Horizontal Position
 - b. E84-07 - Standard Test Method for Surface Burning Characteristics of Building Materials
- E. Underwriters Laboratories, Inc (UL)

1812-95 (Rev. 2006) - Standard for Ducted Heat Recovery Ventilators

1815-01 (Rev. 2006) - Standard for Nonducted Heat Recovery Ventilators

PART 2 - PRODUCTS

2.1 ROTARY AIR-TO-AIR HEAT EXCHANGER:

- A. Exchanger Rotor or Wheel: Aluminum transfer media with a flame spread rating of not more than 25 and smoke developed rating of not more than 50 and independently tested in accordance with ASTM standard E-84. Rotor media shall be independently tested in accordance with ASHRAE Standard . It shall allow laminar flow (but not radial) at usual velocities and prevent leakage, bypassing and cross contamination by cross flow within wheel. Size the transfer media to allow passage of 1200 micrometers particles without fouling or clogging. When latent heat transfer is required, treat media with non-degrading silica-gel desiccant coating that is bacteriostatic, non-corroding and non-toxic. No asbestos material will be allowed. Wheel shall not condense water directly or require a condensate drain for summer or winter operation. Performance rating shall be in accordance with ARI Standard 1060.
- B. Rotor: Glass-fiber segmented wheel strengthened with radial spokes impregnated with non-migrating, water-selected, molecular-sieve desiccant coating.
 - 1. Maximum Solid Size for media to pass: 1200micrometers.
- C. Casings shall be sealed on periphery of rotor as well as on duct divider and purge section. Seals shall be adjustable, of extended life materials and effective in limiting air leakage.
- D. Wheel shall be supported by ball or roller bearings and belt driven by a fractional horsepower, totally enclosed, NEMA Standard motor through a close coupled positively lubricated speed reducer, or gear/chain speed reduction.
 - 1. Motors for constant speed wheel shall be an AC motor.
 - 2. Variable-speed exchanger wheels shall have exchanger wheel speed and leaving-air temperature controlled by means of a variable-speed motor controller. Operation shall be from 115/1/60 and by a proportioning temperature controller which shall vary output voltage of a silicon controlled rectifier (SCR) to a rectified power motor which will change speed in proportion to changes of voltage to its armature. Automatic changeover for summer-winter operations shall be controlled by an adjustable thermostwitch. Set point of adjustable proportioning temperature controller and thermostwitch shall be indicated on visible scale. System shall be capable of speed reduction down to 5 percent of capacity while maintaining adequate torque at any point of operation to rotate wheel.
- E. Unit shall be constructed of heavy gage steel to insure rigidity and stability. Casing side panels shall be removable to insure easy access to internal parts and have integral flanges for flanged duct connection and lifting holes or lugs.

- F. Controls starting relay shall be factory mounted and wired, and include a manual motor starter for field wiring. Variable frequency controller shall be factory mounted and wired, permitting input of field connected 4-20 mA or 1-10 V control signal. Variable frequency controller shall be factory mounted and wired, with exhaust-air sensor to vary rotor speed and maintain exhaust temperature above freezing. When exhaust-air temperature is less than outdoor-air temperature rotor shall be a maximum speed.
- G. Filters: Extended-Surface Disposable Panel Filters: Comply with NFPA 90A.
 - 1. Minimum Arrestance: According to ASHRAE 52.1
 - 2. Minimum Efficiency Reporting Value (MERV): According to ASHRAE 52.2.
 - 3. Filter Holding Frames: Arranged for flat or angular orientation, with access doors on both sides of unit. Filters shall be removable from one side or lift out from access plenum.
 - 4. Flat-Panel Type: Factory-fabricated, viscous-coated, 25 mm (1 inch).
 - 5. MERV (According to ASHRAE 52.2): 12
 - 6. Media: Interlaced glass fibers sprayed with nonflammable adhesive and antimicrobial agent.
 - 7. Frame: Galvanized steel with metal grid on outlet side, steel rod grid on inlet side, hinged, and with pull and retaining handles.

2.2 AIR FILTERS

Air Filters: MERV rating of 12.

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Follow the equipment manufacturer's instructions for handling and installation, and setting up of ductwork for makeup and exhaust air steamers for maximum efficiency.
- B. Rotary Air-to-Air Exchanger: Adjust seals as recommended by the manufacturer. Verify correct installation of controls.
- C. Seal ductwork tightly to avoid air leakage.
- D. Install units with adequate spacing and access for cleaning and maintenance of heat recovery coils as well as filters.

3.2 FIELD QUALITY CONTROL

- A. Operational Test: Perform tests as per manufacturers written instructions for proper and safe operation of the heat recovery system.
 - 1. After electrical circuitry has been energized, start units to confirm proper motor rotation and unit operation.
 - 2. Adjust seals and purge.
 - 3. Test and adjust controls and safeties.



- B. Replace damaged and malfunctioning controls and equipment.
- C. Set initial temperature and humidity set points. Set field-adjustable switches and circuit-breaker trip ranges as indicated.

End of Section 23 72 00



SECTION 238143 – AIR-SOURCE UNITARY HEAT PUMP

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data and Shop Drawings, including wall penetrations, and attachments to other work.
- B. Electrical Components, Devices, and Accessories: Listed and labeled as defined in NFPA 70, by a qualified testing agency, and marked for intended location and application.
- C. ASHRAE/IESNA Compliance: Applicable requirements in ASHRAE/IESNA 90.1-2004.

PART 2 - PRODUCTS

2.1 PACKAGED UNITS

- A. Available Products:

1. Variable capacity compressor, Masterflux SIERRA05-0982Y3
<http://www.masterflux.com/products/sierra/?pid=8>.
2. Fin and tube heat exchangers, Modine Manufacturing.
3. Thermostatic expansion valve, Parker EC-A-JW,
<http://www.grainger.com/Grainger/items/1ZRE7>.
4. Reversing valve, Ranco V1-406060-270, 0.4 – 1 ton, 3/8" x 3/8",
<http://www.hvacplus.com/product/v1-406060-270/253380/>.
5. Check valve, Parker CV4-6FS-6FS, 3/8", Ball,
http://www.drillspot.com/products/407727/Parker_CV4-6FS-6FS_Copper_Check_Valve.
6. Electric Resistance Heating Coil, Dayton 1CKA5,
<http://www.grainger.com/Grainger/items/1CKA5>.

- B. Electric refrigeration system, heating, and temperature controls; fully charged with refrigerant and filled with oil; with cord-connected chassis.
- C. Refrigeration System: supply coil with thermostatic expansion valve, hermetically sealed variable capacity scroll compressor with vibration isolation and overload protection. Include the following:

- 1. Exhaust coil.
 - 2. Accumulator.
 - 3. Thermostatic expansion valve.
 - 4. Reversing valve.
 - 5. Check valve.
 - 6. Charge: R-134a.
- D. Supply Fan: Same as supply fan in ERV.
- E. Exhaust Fan: Same as exhaust fan in ERV.
- F. Fan Motors: High efficiency ECM brushless, three-speed motors.
- G. Filters: Washable aluminum mesh and MERV 12.
- H. Electric-Resistance Heating Coil: Nickel-chromium-wire, electric-resistance heating elements with contactor and high-temperature-limit switch.
- I. Condensate Drain: Drain pan piping to direct condensate to building waste and vent piping.
 - 1. All commercially available manufactures
- J. Controls: Home automation and control, adjustable thermostat, off-heat-auto-cool switch, and high-medium-low fan switch. Include the following features:
- 1. Low Ambient Lockout Control: Prevents cooling-cycle operation below 40 deg F outdoor air temperature.
 - 2. Heat-Pump Ambient Control: Field-adjustable switch changes to heat-pump heating operation above 40 deg F and to supplemental heating below plus 25 deg F.
 - 3. Temperature-Limit Control: Prevents occupant from exceeding preset setback or setup temperature.
 - 4. Building Automation System Interface: Allows remote on-off control with setback temperature control.
 - 5. Reverse-Cycle Defrost: Solid-state sensor monitors frost buildup on exhaust coil and reverses unit to melt frost.

2.2 CAPACITIES AND CHARACTERISTICS

- A. Airflow: 70-210.
- B. Outdoor Air-Intake Rate: 70-210 cfm.
- C. Cooling Capacity:
- 1. Total: 3511-15,461 Btu/h.
 - 2. Sensible: 2282-10,050 Btu/h.
 - 3. Energy-Efficiency Ratio: 8-10.
 - 4. Indoor Coil Entering-Air Dry Bulb Temperature: 74.3 deg F.

5. Indoor Coil Entering-Air Wet Bulb Temperature: 60.5 deg F.
 6. Indoor Coil Leaving-Air Dry Bulb Temperature: 55.4 deg F.
 7. Indoor Coil Leaving-Air Wet Bulb Temperature: 52.6 deg F.
 8. Exhaust Coil Entering-Air Temperature: 74 deg F.
- D. Heat-Pump Capacity:
1. Total: 4,996-22,344 Btu/h.
 2. Minimum Outdoor Temperature: 40 deg F.
- E. Electric Heat Capacity: 8,537 Btu/h.
- F. Electrical Characteristics:
1. Volts: 120
 2. Phase: Single.
 3. Hertz: 60.
 4. Full-Load Amperes: 9.
 5. Minimum Circuit Ampacity: 4.4.
 6. Maximum Overcurrent Protection: 20.

2.3 SOURCE QUALITY CONTROL

- A. Unit Performance Ratings: Test to comply with ARI 210/240, "Unitary Air-Conditioning and Air-Source Heat Pump Equipment."

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Install units level and plumb, and anchor.
- B. Connect units to wiring systems and to ground.

END OF SECTION 238113

SECTION 260500 - COMMON WORK RESULTS FOR ELECTRICAL

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Electrical Components, Devices, and Accessories: Listed and labeled as defined in NFPA 70, by a qualified testing agency, and marked for intended location and application.
- B. Comply with NFPA 70.

PART 2 - PRODUCTS

2.1 GROUNDING MATERIALS

- A. Conductors: Solid for No. 8 AWG and smaller, and stranded for No. 6 AWG and larger unless otherwise indicated.
 - 1. Bare, Solid-Copper Conductors: Comply with ASTM B 3.

26 05 26.A1 - GROUNDING ROD

<http://www.grainger.com/Grainger/items/2KXL8>

PART 3 - EXECUTION

3.1 GENERAL ELECTRICAL EQUIPMENT INSTALLATION REQUIREMENTS

- A. Install electrical equipment to allow maximum possible headroom unless specific mounting heights that reduce headroom are indicated.
- B. Install electrical equipment to provide for ease of disconnecting the equipment with minimum interference to other installations.
- C. Install electrical equipment to allow right of way for piping and conduit installed at required slope.
- D. Install electrical equipment to ensure that connecting raceways, cables, wireways, cable trays, and busways are clear of obstructions and of the working and access space of other equipment.



- E. Install required supporting devices and set sleeves in cast-in-place concrete, masonry walls, and other structural components as they are constructed.
- F. Coordinate location of access panels and doors for electrical items that are behind finished surfaces or otherwise concealed. Comply with requirements in Division 08 Section "Access Doors and Frames."
- G. Install sleeve and sleeve seals of type and number required for sealing electrical service penetrations of exterior walls.
- H. Comply with NECA 1.

3.2 RACEWAY AND CABLE INSTALLATION

- A. Outdoor Raceways Applications:

- 1. Boxes and Enclosures: Metallic, NEMA 250, Type 3R or Type 4.

26 05 33 01 - JUNCTION BOX

<http://www.hubbell-wiegmann.com/2004/pdf2004/B2.pdf>

- B. Indoor Raceways Applications:

- 1. Exposed or Concealed: EMT.

26 05 33.A1 - 1" EMT

<http://www.grainger.com/Grainger/wwg/productIndex.shtml?L2=EMT&operator=prodIndexRefinementSearch&originalValue=1%22+EMT+&L1=Conduit%2C>

26 05 33.A3 - 2" EMT

<http://www.grainger.com/Grainger/items/5ZM23>

3.3 GROUNDING

- A. Underground Grounding Conductors:

26 05 26.A1 - GROUNDING ROD



<http://www.grainger.com/Grainger/items/2KXL8>

END OF SECTION 260500



SECTION 26 09 00 – INSTRUMENTATION AND CONTROL FOR ELECTRICAL SYSTEMS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

PART 2 - PRODUCTS

2.1 TERMINAL BOX

26 09 13.A1 - TERMINAL BOX

<http://sine.ni.com/nips/cds/view/p/lang/en/nid/203092EXECUTION>

2.2 GENERAL ELECTRICAL EQUIPMENT INSTALLATION REQUIREMENTS

PART 3 – INSTALLLATION (NOT USED)

END OF SECTION 26 09 00

SECTION 262400 – SWITCHBOARDS AND PANELBOARDS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data.
- B. Electrical Components, Devices, and Accessories: Listed and labeled as defined in NFPA 70, by a qualified testing agency, and marked for intended location and application.
- C. Comply with NEMA PB 1.

PART 2 - PRODUCTS

2.1 GENERAL REQUIREMENTS FOR PANELBOARDS

- A. Fabricate and test panelboards according to IEEE 344 to withstand seismic forces defined in Division 26 Section "Common Work Results for Electrical."
- B. Enclosures: Flush
 - 1. Hinged Front Cover: Entire front trim hinged to box and with standard door within hinged trim cover.
- C. Incoming Mains Location: Top.
- D. Phase, Neutral, and Ground Buses: Hard-drawn copper, 98 percent conductivity.
- E. Conductor Connectors: Suitable for use with conductor material and sizes.
 - 1. Material: Hard-drawn copper, 98 percent conductivity.
 - 2. Main and Neutral Lugs: Compression type.
 - 3. Ground Lugs and Bus Configured Terminators: Compression type.
 - 4. Feed-Through Lugs: Compression type, suitable for use with conductor material. Locate at opposite end of bus from incoming lugs or main device.

2.2 DISTRIBUTION PANELBOARDS

- A. Doors: Omit in fused-switch panelboards.
- B. Mains: Circuit breaker.

26 24 16.A1 - 200A MAIN PANEL

http://stevenengineering.com/Tech_Support/PDFs/45174-1.pdf

26 24 16.A2 - 100A SUB-PANEL

http://stevenengineering.com/Tech_Support/PDFs/45174-1.pdf

26 24 00.A3 - SQUARE D SERVICE PAK10C-1

http://stevenengineering.com/Tech_Support/PDFs/45174-1.pdf

2.3 LIGHTING AND APPLIANCE BRANCH-CIRCUIT PANELBOARDS

- A. Mains: Circuit breaker.
- B. Branch Overcurrent Protective Devices: Plug-in circuit breakers, replaceable without disturbing adjacent units.
- C. Doors: Concealed hinges; secured with flush latch with tumbler lock; keyed alike.

2.4 DISCONNECTING AND OVERCURRENT PROTECTIVE DEVICES

- A. Molded-Case Circuit Breaker (MCCB): Comply with UL 489, with interrupting capacity to meet available fault currents.
 - 1. GFCI Circuit Breakers: Single- and two-pole configurations with Class A ground-fault protection (6-mA trip).

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Arrange conductors into groups; bundle and wrap with wire ties.
- B. Create a directory to indicate installed circuit loads and incorporating Owner's final room designations. Obtain approval before installing. Use a computer or typewriter to create directory.

END OF SECTION 262400



SECTION 263000 – FACILITY ELECTRICAL POWER GENERATING AND STORING EQUIPMENT

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

PART 2 - PRODUCTS

2.1 JUNCTION BOX

26 30 00.D1 - TERMINAL BOX

<http://www.hubbell-wiegmann.com/2004/pdf2004/A2.pdf>

PART 3 - EXECUTION

3.1 GENERAL ELECTRICAL EQUIPMENT INSTALLATION REQUIREMENTS

END OF SECTION 263000



SECTION 26 41 13 - LIGHTNING PROTECTION FOR STRUCTURES

1. GENERAL

1 SECTION REQUIREMENTS

- 1 Submittals: Product Data.
- 2 Installer Qualifications: Certified by UL trained and approved for installation of units required for this Project.
- 3 Electrical Components, Devices, and Accessories: Listed and labeled as defined in NFPA 780, "Definitions" Article.

2. PRODUCTS

1 LIGHTNING PROTECTION SYSTEM COMPONENTS

- 1 Comply with UL 96.
- 2 Ground Rods: Copper bonded steel, 5/8 inch in diameter by 8 feet long.
- 3 Acceptable Manufacturer: Grainger, 2KXL8
1 Manufacturer's Specifications: <http://www.grainger.com/Grainger/items/2KXL8>

3. EXECUTION

1 INSTALLATION

- 1 Install lightning protection components and systems according to UL 96A
- 2 Install conductors with direct paths from air terminals to ground connections. Avoid sharp bends and narrow loops. Where indicated, run conductors in nonmetallic raceway.
- 3 Conceal the following conductors:
 - 1 System conductors.
 - 2 Down conductors.
 - 3 Interior conductors.
 - 4 Conductors within normal view of exterior locations at grade within 200 feet of building.
- 4 Cable Connections: Exothermic-welded connections for conductor splices and connections between conductors and other components, except those above single-ply membrane roofing.



- 5 Air Terminals on Single-Ply Membrane Roofing: Comply with adhesive manufacturers' written installation instructions.
- 6 Do not combine materials that can form an electrolytic couple that will accelerate corrosion in the presence of moisture, unless moisture is permanently excluded from the junction of such materials.
- 7 Use conductors with protective coatings where conditions would cause deterioration or corrosion of conductors.

2 FIELD QUALITY CONTROL

- 1 UL Inspection: Meet requirements to obtain a UL Master Label for system.
- 2 LPI System Inspection: Meet requirements to obtain an LPI System Certificate.

END OF SECTION 26 41 13

SECTION 26 31 00 – PHOTOVOLTAIC COLLECTORS

1. GENERAL

1 SECTION REQUIREMENTS

- 1 Submittals: Product data and Shop Drawings
- 2 Contractor to coordinate installation with electrical drawings.
- 3 Electrical Components, Devices, and Accessories: Listed and labeled as defined in NFPA 70, by a qualified testing agency, and marked for intended location and application.
- 4 Comply with IEC 61215 and UL 1703 by UL or CSA, Class C Fire Rating

2. PRODUCTS

1 Photovoltaic Panel

- 1 Acceptable Product: SunPower 225 Solar Panel
 - 1 Efficiency: 18.1%
 - 2 kWs: 4.5
 - 3 Watts: 225
 - 4 Manufacturer's Information:
http://us.sunpowercorp.com/downloads/product_pdfs/residential/SunPower_225bk_res_en_lt_w_ra.pdf

3. EXECUTION

- 1 Install per Manufacturer's Specifications.

END OF SECTION 263000



SECTION 26 50 00 - LIGHTING

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. Submittals: Product Data for each luminaire, including lamps.
- B. Fixtures, Emergency Lighting Units, Electrical Components, Devices, and Accessories: Listed and labeled as defined in NFPA 70, by a qualified testing agency, and marked for intended location and application.
- C. Comply with IEEE C2, "National Electrical Safety Code."
- D. Coordinate ceiling-mounted luminaires with ceiling construction, mechanical work, and security and fire-prevention features mounted in ceiling space and on ceiling.

PART 2 - PRODUCTS

2.1 LIGHTING FIXTURES AND COMPONENTS, GENERAL REQUIREMENTS

- A. Recessed Fixtures: Comply with NEMA LE 4 for ceiling compatibility for recessed fixtures.
- B. Incandescent Fixtures: Comply with UL 1598. Where LER is specified, test according to NEMA LE 5A.
- C. Fluorescent Fixtures: Comply with UL 1598. Where LER is specified, test according to NEMA LE 5 and NEMA LE 5A as applicable.
- D. HID Fixtures: Comply with UL 1598. Where LER is specified, test according to NEMA LE 5B.
- E. Exterior Luminaires: Comply with UL 1598 and listed and labeled for installation in wet locations by an NRTL acceptable to authorities having jurisdiction.
- F. Comply with IESNA RP-8 for parameters of lateral light distribution patterns indicated for luminaires.
- G. Plastic Parts: High resistance to yellowing and other changes due to aging, exposure to heat, and UV radiation.

2.2 BALLASTS

- A. Ballasts for Linear Fluorescent Lamps:

1. Electronic: Comply with ANSI C82.11; programmed-start type.
 - a. Sound Rating: A, except B for T12/HO and T12/Slimline lamp ballasts.
 - b. BF: 0.85 or higher.
 - c. Power Factor: 0.95 or higher.
 2. Electromagnetic: Comply with ANSI C82.1; energy saving, high-power factor, Class P, and having automatic-reset thermal protection.
 3. For Temperatures **Minus 20 Deg F** and Higher: Electromagnetic type designed for use with indicated lamp types.
 4. Low-Temperature Ballast Capability: Rated by its manufacturer for reliable starting and operation of indicated lamp(s) at temperatures **0 deg F** and higher.
 5. Dimmer Controlled: Electronic type.
 - a. Dimming Range: 100 to 5 percent of rated lamp lumens.
 - b. Ballast Input Watts: Can be reduced to 20 percent of normal.
 - c. Compatibility: Certified by manufacturer for use with specific dimming control system and lamp type indicated.
- B. Ballasts for Compact Fluorescent Lamps: Electronic programmed rapid-start type, complying with ANSI C 82.11.
1. Lamp end-of-life detection and shutdown circuit.
 2. Automatic lamp starting after lamp replacement.
 3. Sound Rating: A.
 4. BF: 0.95 or higher unless otherwise indicated.
 5. Power Factor: .95 or higher.
 6. Night-Light Connection: Operate one fluorescent lamp continuously.
 7. Test Push Button and Indicator Light: Visible and accessible without opening fixture or entering ceiling space.
 8. Battery: Sealed, maintenance-free, nickel-cadmium type.
 9. Charger: Fully automatic, solid-state, constant-current type with sealed power transfer relay.
- C. Ballasts for Metal-Halide Lamps:
1. Electromagnetic: Comply with ANSI C82.4 and UL 1029,
 - a. Constant-wattage autotransformer or regulating high-power-factor type.
 2. Electronic:
 - a. Lamp end-of-life detection and shutdown circuit.
 - b. Total Harmonic Distortion Rating: Less than 15 percent.
 - c. Transient Voltage Protection: IEEE C62.41, Category A or better.

- D. Ballasts for High-Pressure Sodium Lamps: Electromagnetic type, with solid-state igniter/starter. Igniter-starter shall have an average life in pulsing mode of 10,000 hours at an igniter/starter-case temperature of 90 deg C.

2.3 LAMPS

- A. Low-Mercury Fluorescent Lamps: Comply with the EPA's toxic characteristic leaching procedure test, and yield less than 0.2 mg of mercury per liter, when tested according to NEMA LL 1.
- B. T8 Rapid-Start Fluorescent Lamps: Rated 32 W maximum, nominal length **48 inches**, 2800 initial lumens (minimum), CRI 75 (minimum), color temperature of 3500 K, and average rated life of 20,000 hours unless otherwise indicated.
- C. T8 Rapid-Start Fluorescent Lamps: Rated 17 W maximum, nominal length of **24 inches**, 1300 initial lumens (minimum), CRI 75 (minimum), color temperature of 3500 K, and average rated life of 20,000 hours unless otherwise indicated.
- D. Compact Fluorescent Lamps: Four pin, low mercury, CRI 80 (minimum), color temperature 3500, average rated life of 10,000 hours at three hours' operation per start, and suitable for use with dimming ballasts unless otherwise indicated.
 - 1. 13 W: T4, double or triple tube, rated 900 initial lumens (minimum).
 - 2. 18 W: T4, double or triple tube, rated 1200 initial lumens (minimum).
 - 3. 26 W: T4, double or triple tube, rated 1800 initial lumens (minimum).
 - 4. 32 W: T4, triple tube, rated 2400 initial lumens (minimum).
 - 5. 42 W: T4, triple tube, rated 3200 initial lumens (minimum).
 - 6. 55 W: T4, triple tube, rated 4300 initial lumens (minimum).
- E. High-Pressure Sodium Lamps: ANSI C78.42, CRI 21 (minimum), color temperature 1900 K, and average rated life of 24,000 hours, minimum.
- F. Metal-Halide Lamps: ANSI C78.1372, with a minimum CRI 65, and color temperature 4000 K.
- G. Pulse-Start, Metal-Halide Lamps: Minimum CRI 65, and color temperature 4000 K.
- H. Ceramic, Pulse-Start, Metal-Halide Lamps: Minimum CRI 80, and color temperature 4000 K.

2.4 RETROFIT KITS FOR FLUORESCENT LIGHTING FIXTURES

- A. Comply with UL 1598 listing requirements.
 - 1. Reflector Kit: UL 1598, Type I. Suitable for two- to four-lamp, surface-mounted or recessed lighting fixtures by improving reflectivity of fixture surfaces.
 - 2. Ballast and Lamp Change Kit: UL 1598, Type II. Suitable for changing existing ballast, lamps, and sockets.

2.5 REQUIREMENTS FOR INDIVIDUAL LIGHTING FIXTURES

A. Fixture:

1. Basis-of-Design Product: Subject to compliance with requirements, provide product indicated on Drawings, Silo Small Silver Single-Lamp Pendant
2. Manufacturer's Specifications: <http://www.alicoindustries.com/details.cfm?id=2153>

B. Fixture:

1. Basis-of-Design Product: Subject to compliance with requirements, provide product indicated on Drawings, Silo Small White Single-Lamp Pendant
2. Manufacturer's Specifications: <http://www.alicoindustries.com/details.cfm?id=2152>

C. Fixture:

1. Basis-of-Design Product: Subject to compliance with requirements, provide product indicated on Drawings, C6H Horizontal Downlight Quad
2. Manufacturer's Specifications:
http://www.junolightinggroup.com/product_detail.asp?ino=7601&Sel_Id=7148&brand=5

D. Fixture :

1. Basis-of-Design Product: Subject to compliance with requirements, provide product indicated on Drawings, PLC Lighting Gimbal Light, Silver
2. Manufacturer's Specifications: http://www.plclighting.com/catalog/crear-pdf.php?nombre=PLC_0453.jpg

E. Fixture:

1. Basis-of-Design Product: Subject to compliance with requirements, provide product indicated on Drawings, eW Flex SLX
2. Manufacturer's Specifications:
<http://www.colorkinetics.com/support/datasheets/ewflexslx.pdf>

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Set units level, plumb, and square with ceiling and walls, and secure.
- B. Air-Handling Fixtures: Install with dampers closed.
- C. Adjust aimable lighting fixtures to provide required light intensities.



- D. Lamping: Where specific lamp designations are not indicated, lamp units according to manufacturer's written instructions.

END OF SECTION 265000



SECTION 265100 – INTERIOR LIGHTING

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

PART 2 - PRODUCTS

2.1 Interior Lighting Equipment

- A. 26 51 00 Refer to schedule of sheet E -102 numbers 1,2,5,6,7,9
 - 1. Alico Silo Chrome PS4500 -16-16
 - 2. PLC Lighting Gimbal #TR-121
 - 3. Progress 6" PG-P86-TG
 - 4. Alico Silo White #PS4500-10-16

PART 3 - EXECUTION

3.1 GENERAL ELECTRICAL EQUIPMENT INSTALLATION REQUIREMENTS

END OF SECTION 265100



SECTION 265600 – EXTERIOR LIGHTING

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

PART 2 - PRODUCTS

2.1 Exterior Lighting Equipment

- A. 26 56 00 Refer to schedule of sheet E-102 numbers 3,4,8,10
 - 1. Progress Lighting #P5641
 - 2. Saturn Exterior Pendant #1902
 - 3. Philips Color Kinetics Clear Flat 2700k
 - 4. Meteor LED Ground Light #SH220C

PART 3 - EXECUTION

3.1 GENERAL ELECTRICAL EQUIPMENT INSTALLATION REQUIREMENTS

END OF SECTION 265600



SECTION 272000 – DATA COMMUNICATIONS

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

PART 2 - PRODUCTS

2.1 Data Logger

A. Data Logger Box

27 20 00.A2 - DATA LOGGER BOX

<http://sine.ni.com/ds/app/doc/p/id/ds-9/lang/en>

PART 3 - EXECUTION (NOT USED)

END OF SECTION 272000

SECTION 28 31 00 - FIRE DETECTION AND ALARM

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

- A. System Description: Noncoded, conventional, hardwired, zoned, 24-V dc loop system.
 - 1. Initiating Device Circuits: NFPA 72, Class B, Style B.
 - 2. Notification Appliance Circuits: NFPA 72, Class B, Style Y.
- B. Submittals: Product Data and system operating description.
- C. Submittals to Authorities Having Jurisdiction: In addition to distribution requirements for submittals, make an identical submittal to authorities having jurisdiction. To facilitate review, include copies of annotated Contract Drawings as needed to depict component locations.
- D. Comply with NFPA 72.
- E. UL listed and labeled.
- F. Electrical Components, Devices, and Accessories: Listed and labeled as defined in NFPA 70, by a qualified testing agency, and marked for intended location and application.

PART 2 - PRODUCTS

2.1 FACP

- A. General: Modular, power-limited design with electronic modules, UL 864 listed.
- B. Transmission to Remote Alarm Receiving Station: Automatically transmit alarm, trouble, and supervisory signals to a remote alarm station through a digital alarm communicator transmitter and telephone lines.
- C. Secondary Power: 24-V dc supply system with 9V batteries and automatic battery charger and an automatic transfer switch.

2.2 ALARM-INITIATING DEVICES

- A. Manual Pull Stations: UL 38 listed, double-action mechanism, red in color with molded, raised-letter operating instructions in contrasting color.
- B. Smoke Detectors: UL 268, 24-V dc, self-restoring, photoelectric type, plug-in arrangement.

- C. Heat Detectors: UL 521 listed, combination 135 deg F fixed-temperature and rate-of-rise unit.

2.3 NOTIFICATION APPLIANCES

- A. Bells: Electric-vibrating type, with 94 dBA at 10 feet.
- B. Low-Level Chimes: Vibrating type with 75 dBA.
- C. High-Level Chimes: Vibrating type with 81 dBA.
- D. Horns: Electric-vibrating-polarized type, 90 dBA at 10 feet.

2.4 WIRE AND CABLE

- A. General: UL listed and labeled as complying with NFPA 70, Article 760.
- B. Signaling Line Circuits: Twisted, shielded pair, size as recommended by system manufacturer.
- C. Non-Power-Limited Circuits: Solid-copper conductors with 600-V rated, 75 deg C, color-coded insulation.
 - 1. Low-Voltage Circuits: No. 16 AWG, minimum.
 - 2. Line-Voltage Circuits: No. 12 AWG, minimum.

2.5 MANUFACTURER'S SPECIFICATIONS

- A. http://www.kiddeus.com/utcfs/ws-384/Assets/PE120E_Sheet.pdf

PART 3 - EXECUTION

3.1 INSTALLATION

- A. Install and test systems according to NFPA 72. Comply with NECA 1.
- B. Wiring Method: Install wiring where indicated.
- C. Ground the FACP and associated circuits; comply with IEEE 1100. Install a ground wire from main service ground to the FACP.

END OF SECTION 283100



SECTION 337100 –ELECTRICAL UTILITY TRANSMISSION AND DISTRIBUTION

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

PART 2 - PRODUCTS

2.1 DC Wiring

A. 10 AWG USE-2/RHH/RHW-2

33 71 53 01 – DC Wiring

<http://tfcable.com/productspecs/PDF%5C2%20Power-Cable-600V-PPC/PPC%201%20RHH-RHW-2-USE2%20600V.pdf>

PART 3 - EXECUTION

3.1 GENERAL ELECTRICAL EQUIPMENT INSTALLATION REQUIREMENTS

END OF SECTION 337100

SECTION 337500 – HIGH VOLTAGE SWITCHGEAR AND PROTECTION DEVICES

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

PART 2 - PRODUCTS

2.1 Disconnects

A. AC Disconnect

33 75 00.A1 AC Disconnect

<http://ecatalog.squared.com/pubs/Electrical%20Distribution/Safety%20Switches/Heavy%20Duty/3110DB0401.pdf>

B. DC Disconnect

33 75 00.A2 DC Disconnect (Built in to Inverter)

http://www.stellarsolar.net/downloads/SPR_2007-08-02SPR-5000m.SPR-6000m&SPR-7000mDataSheet.pdf

PART 3 - EXECUTION

3.1 GENERAL ELECTRICAL EQUIPMENT INSTALLATION REQUIREMENTS

END OF SECTION 337500



SECTION 481900 - ELECTRICAL POWER CONTROL EQUIPMENT

PART 1 - GENERAL

1.1 SECTION REQUIREMENTS

PART 2 - PRODUCTS

2.1 INVERTERS

48 19 16 - SPR-5000M INVERTER

http://us.sunpowercorp.com/downloads/product_pdfs/inverters/SunPower_Inverters567000m_DS.pdf

END OF SECTION 481900

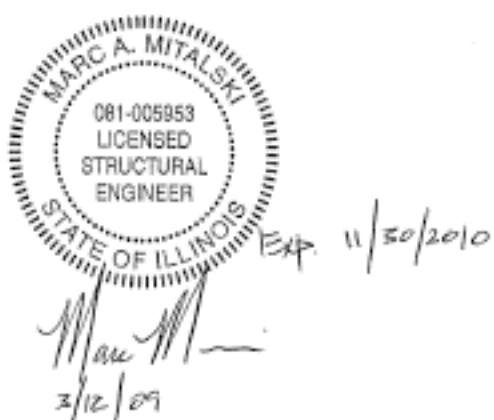
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These calculations prepared under the direct supervision of Marc A. Mitalski





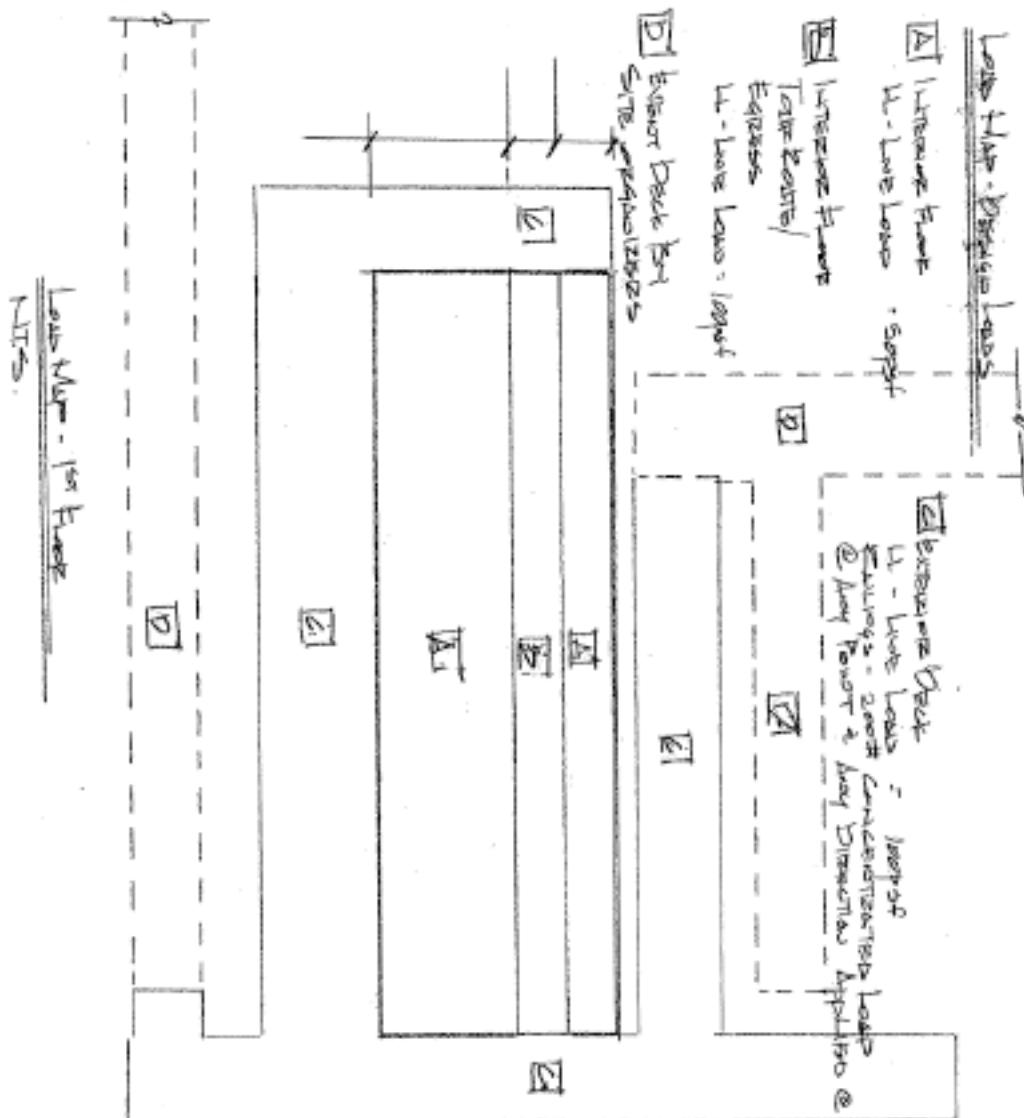
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GRAVITY LOADS



- Floor Loading / Design Criteria

- $9\frac{1}{4}$ " open-web floor trusses manufactured +
Suppliers by themselves - Some General Contractors
Homes for Residential & Shop Drawing Submittals.

Floor Loading Criteria

- Dead Loads - - $3\frac{1}{4}$ " OSB Sub floors = 3psf
 - $9\frac{1}{4}$ " open Web Woods Trusses = 2.25psf
(5# per linear ft @ 16" o.c.) + (Fz. T) Variation
 - Floors floors = 2psf
 - 3" spring floor isolators = 4psf
 - $\frac{1}{2}$ " boards under decks = 2psf
 - Mac/Mac = 10 - floors = 3psf
- Total = 25psf

Top Gables bl - 8psf

Bottom Gables bl - 7psf

Self wt of gables

- Horizontal spacing fl / floors $24'' \times 24'' = 4\frac{1}{4}$

$$\text{Allow loads} = (1,600 \text{ psf}) (4\frac{1}{4}) = 6,000 \text{ #}$$

↑ Allow breaking capacity on floor beams

$444 + .75LL + .75LR + .75W$

- Use Span of $\frac{1}{4}$ foot because we NOT To increase 6,000# capacity

$$\Rightarrow 6,000 \text{ #} / 607.25 \text{ #}/\text{ft}^2 [6.76' \rightarrow \text{the spacing of floors}]$$

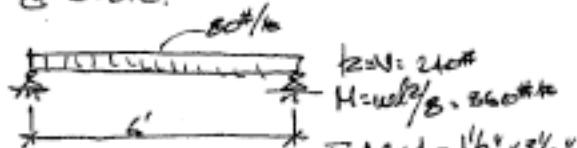
Project:	Solar Decathlon	Seal:
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Date:	12/15/08	
Drawn By:	J. H. A.	
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Roof Design / Joist Design

Span Roofs 8'-0" → 6'-0" @ 24" o.c.
 $(2004 + 2011)(2') = 80\text{#/ft}$



$$f_b = \frac{M/c}{s} = \frac{(80\text{#/ft})(12\text{"})}{5.0625 \times 3} = 1,410.6 \text{ psi}$$

$$\Delta = \frac{(6)(80\text{#/ft})(6)(6)}{(384)(1,600,000\text{psi})(5.36 \times 10^4)} = 0.27"$$

→ 1/245 Torsion Limit Δ

$$f_{zN} = 240\text{#}$$

$$M = wL^2/8 = 860\text{#/ft}$$

$$W = A 2x4 - 1\frac{1}{2} \times 2\frac{1}{2}$$

$$A = 5.28 \text{ in}^2$$

$$S = 3.0625 \text{ in}^3$$

$$I = 5.36 \text{ in}^4$$

∴ A 5'-0" spans U24-2x4 @ 24" o.c.
@ 6'-0" Spans U24-2x6 @ 24" o.c.

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Footing options: $\left\{ \begin{array}{l} \text{option 1 - Tie-forced - un-reinforced fig.} \\ \text{option 2 - Steel tie footing} \end{array} \right.$
 - 6,000# capacity

- AISC 14 Foot Base (Simpson) Uplift Capacity (Wmax) = 2,200#
 Dead Load = 6,665#

Option #1 - Unreinforced - Structural Frame Calc.

- FRC ACI 318-08 § 4.21 - Category F2 - Seismic Condition
- FRC ACI 318-08 Table 4.2.1 - Max W/C = 0.45
- FRC ACI 318-08 § 22.7.4. Min f'c = 4,500psi

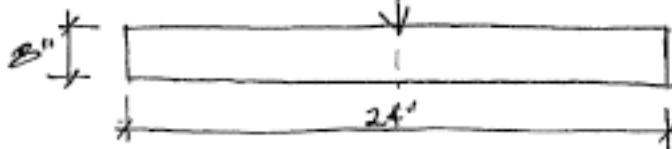
Thickness of Structural Frame Calc

Thickness shall NOT be less than 8"

$$\text{- Approx w/c at } f_{cy} = (8''/12)^2(2') \times 140 \text{ psf} = 388.6 \#$$

$$F_u = (6,000\# + 388.6\#)(1.7) = 10,860\#$$

$$q_{ult} = 10,860\# / (2'' \times 2') = 2,715 \text{ psf}$$



$$M_u = (2,715 \text{ psf})(1')^2(2') / 2 = 2,715 \text{ k-in}$$

$$\text{Slope: } M_u / \phi S_f f'_c = \frac{2,715 \text{ k-in}}{(0.65 \times 5)(4,500)} = \frac{44.44 \text{ in/in}}{67.08}$$

$$h_{max} = \sqrt{\frac{(6)(44.44 \text{ in})^2}{24''}} = 6.11''$$

$$h = h + 2'' = 6.11'' + 2'' \Rightarrow 8'' \text{ ok}$$

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- Option 1 - Concrete Footing Reinforced

Check 2-Way Shear

$$h = 8'' - 2'' = 6''$$

$$b_s = (2)(7'' + 9'') = 34''$$

$$\sqrt{V_{us}} = 10,860\# - (2,715\text{psf} \left(\frac{9'' \times 9''}{144''^2} \right)) = 9,332.8\#$$

$$\phi V_{us} = (0.65) \cdot 2 \left(\sqrt{1.500 \text{psi}} \right) (34'') (6'') = \cancel{26,052\#} \geq 9,332.8\#$$

$\phi \uparrow \quad \uparrow 1.0 \quad \underline{\underline{26,052\#}}$ OK

Check 1-Way Shear

$$V_{us} = (2,715\text{psf}) \left(\frac{6''}{144''^2} \right) (2') = 2,715\#$$

$$\phi V_{us} = (0.65) \cdot 2 \left(\sqrt{1.500 \text{psi}} \right) (2') (6'') \left(\frac{4}{3} \right) = 8,350\# \geq 2,715\#$$

OK

∴ A 24" x 24" x 6" Deep Piano Concr.

OPTION 1 Footing is Adequate for the Imposed
Unfactored Load of 6,000#

$$f'_c = 4,500 \text{psi}$$

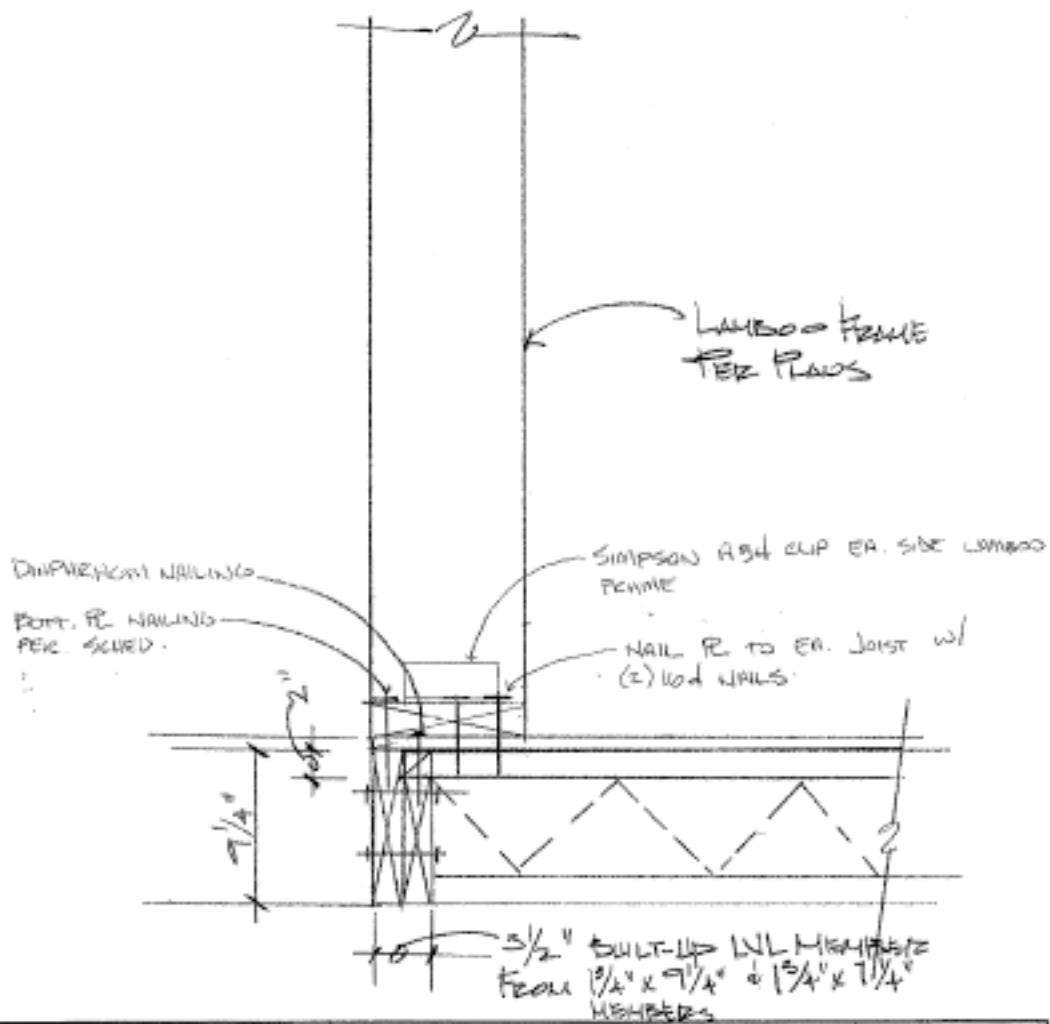
∴ A 6" Concr FTG (24" x 24" x 6") REINFORCED

OPTION 2 14.14" (3) #3 REW BOTTOM is also Adequate

$$f'_c = 4,500 \text{psi}$$

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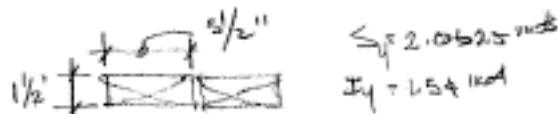


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Exterior Decking - Check

2006 IBC Planers - Calculate Max Span with respect to Live Load



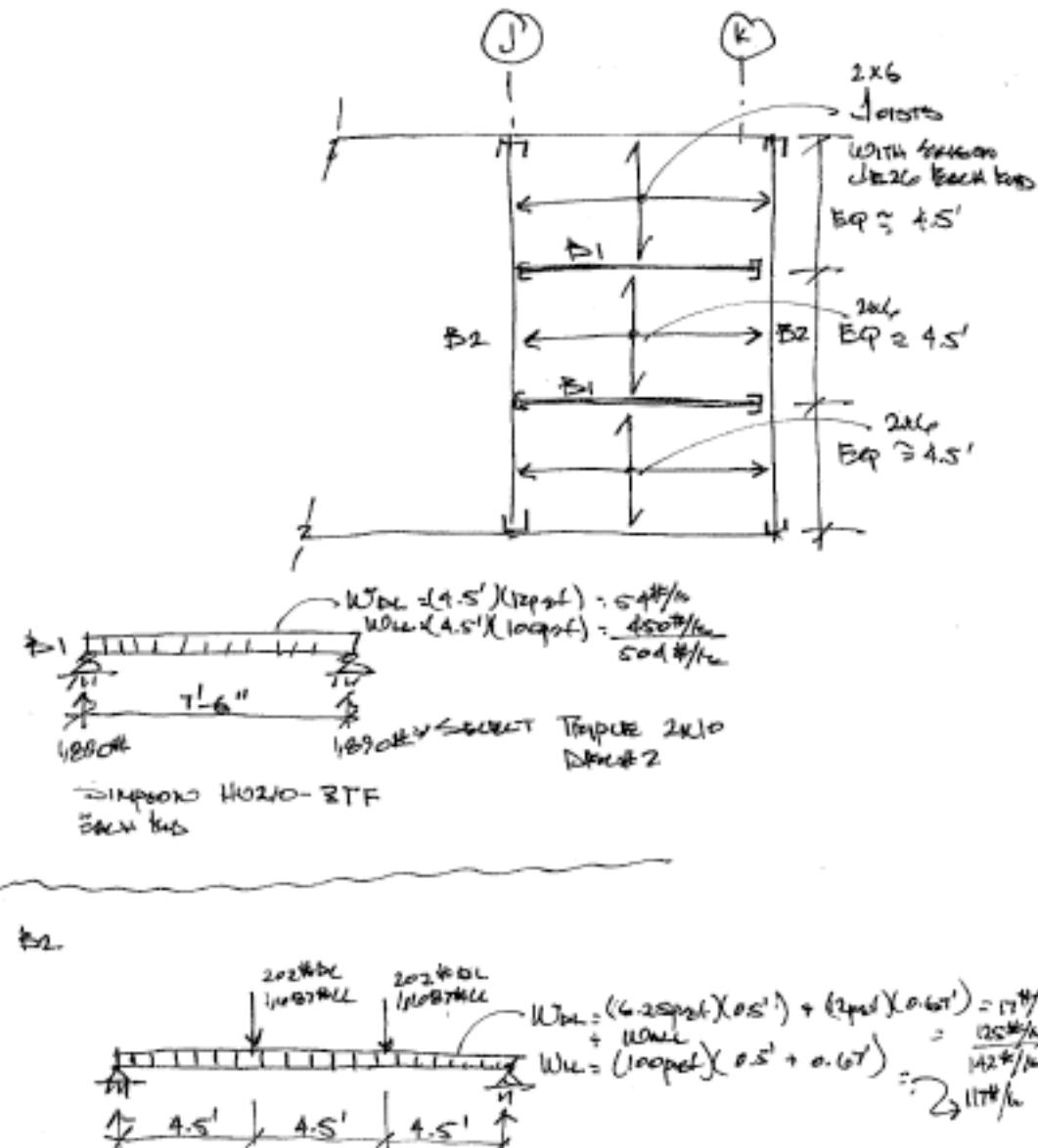
$$\Delta_{LL} = l/260 \Rightarrow$$

$$\text{Trey A } 6\text{'-0"} \text{ span} \Rightarrow W = (\text{Live load}) \cdot \frac{6'}{12} \cdot \frac{l}{260} = 50 \#/\text{ft}$$

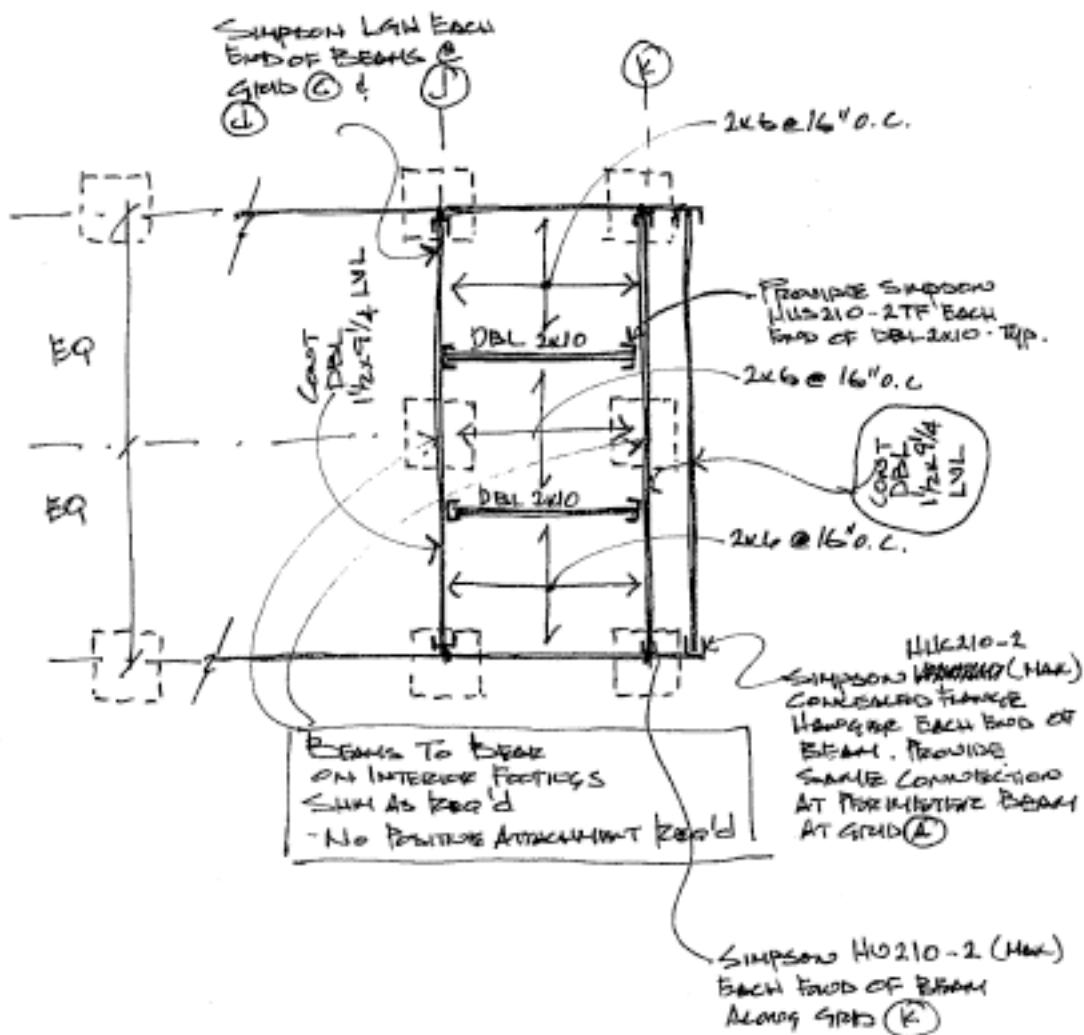
$$W_{MAX} = (50 \#/\text{ft}) \cdot (6')^2 / 8 \cdot 225 \#/\text{in}^2 \cdot \frac{l}{260} = \frac{(225 \#/\text{in}^2) (12') (l/2)}{2.0625 \text{ in}^2} = 1,209 \# \text{--}$$

$$\text{Cover } \Delta = \frac{(5)(800 \#)(6')^2 (l/2)}{(384)(1,400,000 \text{ psi})(1.54 \text{ in}^4)} + 0.6' \leftarrow \\ \Rightarrow l/120$$

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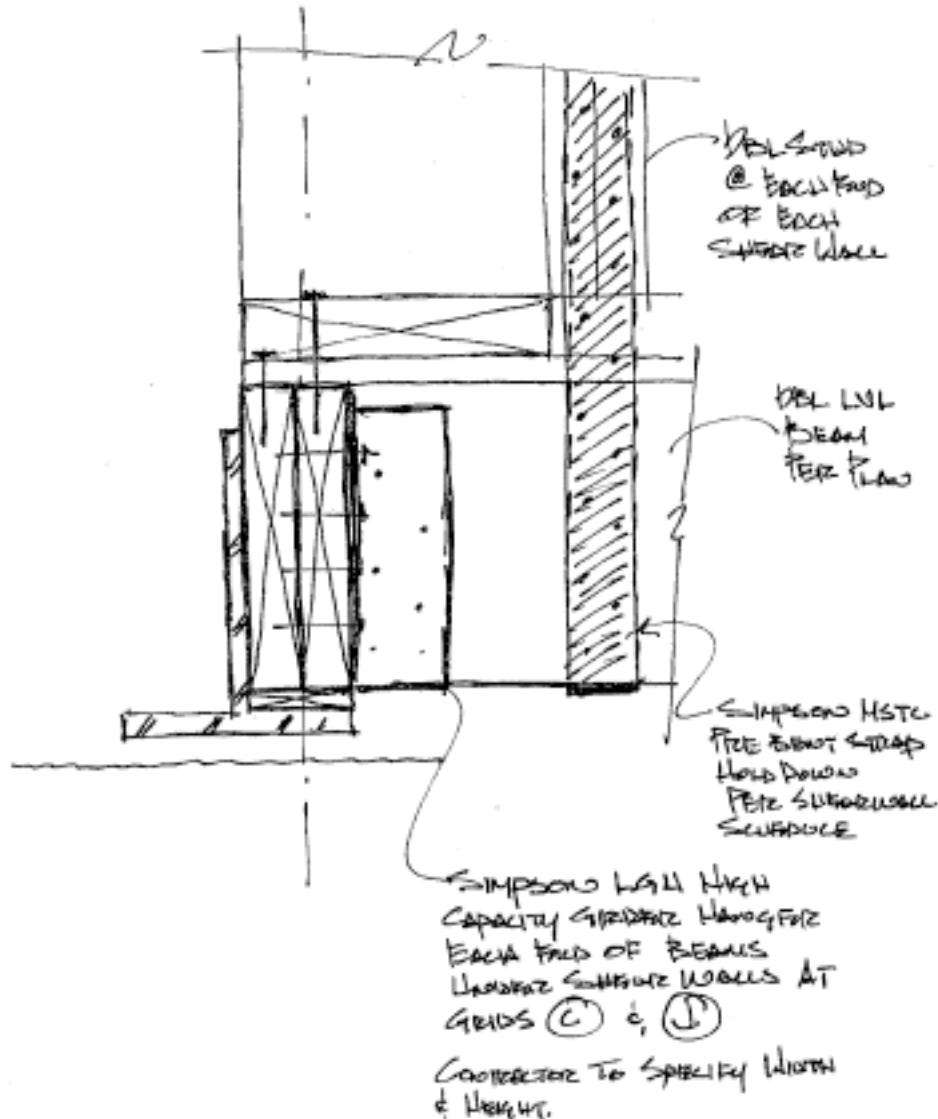


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Framing Detail

Try A 2x6 NCL#2

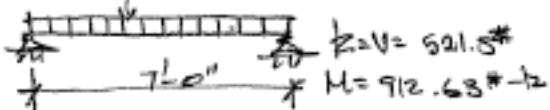
$$\Delta_{eff} = 7.563 \times 10^3$$

$$P_{act} = 20.80 \text{ kip}$$

$$f_b = (912.63 \text{ kip}) (12^4/\text{in}^2) / 7.563 \times 10^3 = 148.1 \text{ psi}$$

$$F_b = (g_{act}) \left(\frac{C_s}{C_d} \right) \left(\frac{C_u}{C_d} \right) = 114 \text{ psi} \geq 1,440 \text{ psi}$$

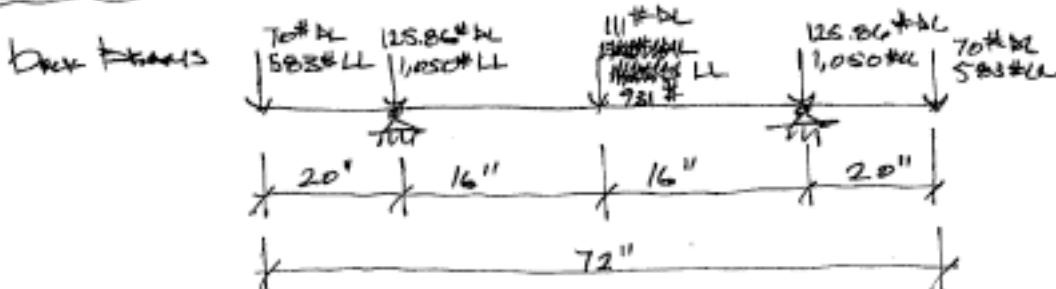
$$(1.53') (112.54) = 174 \text{ ft-lb}$$



⇒ How About A 2x8

$$f_b = (912.63 \text{ kip}) (12^4/\text{in}^2) / 13.14 \text{ in}^2 = 523 \text{ psi}$$

$$\Delta = (5) (145 \text{ ft-lb}) (7') (7') (1728) / (384) (1,600,000)(0.9) (47.65 \text{ in}^4) \\ = 0.117 \Rightarrow L = 717 \text{ in}$$

Brace details → 2x8 (NCL#2) @ 16" o.c. tip

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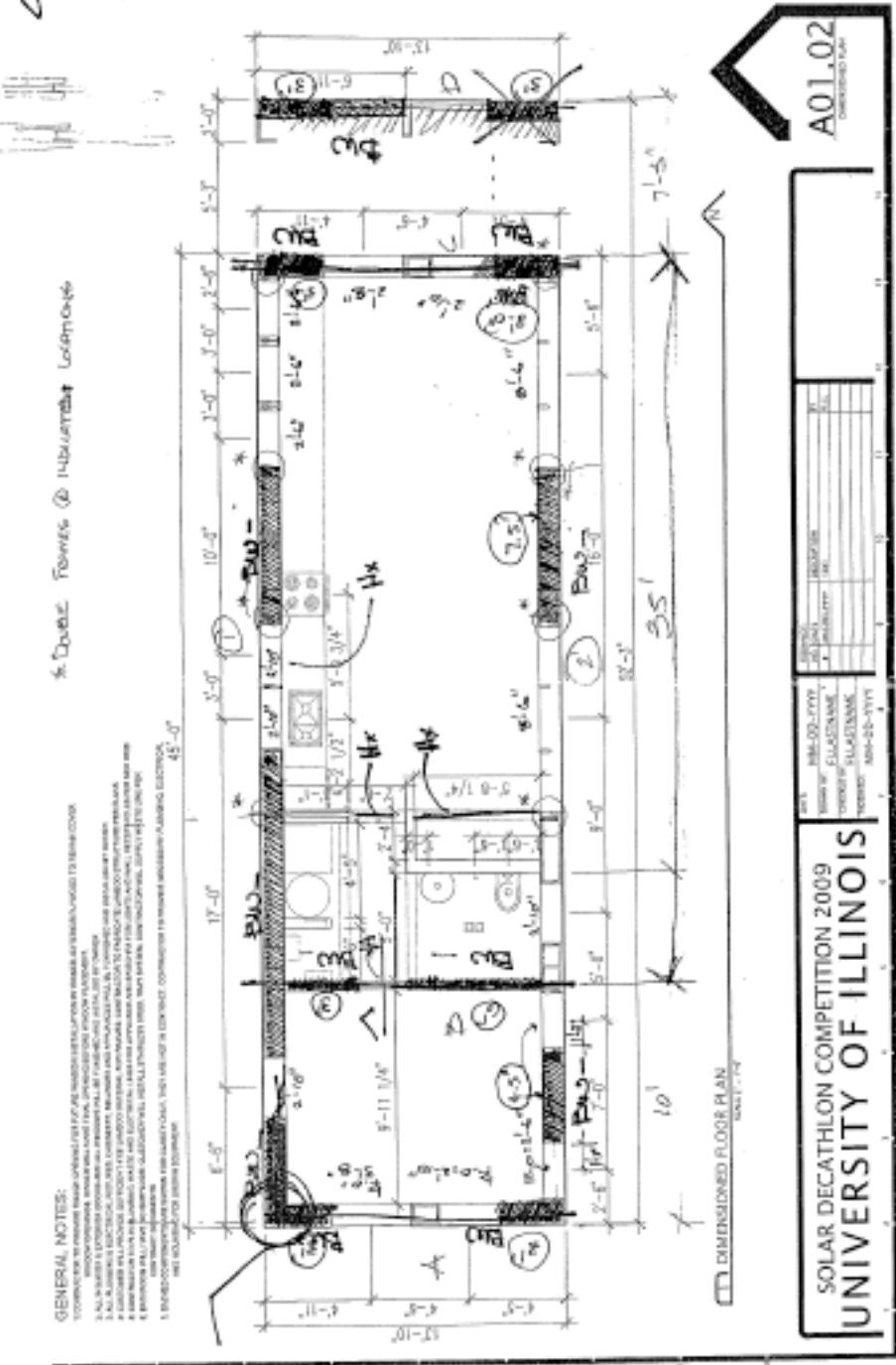
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LATERAL LOADS



Main Wind Force Resisting System - Method 1		$h \leq 60$ ft.
Figure 6-2	Design Wind Pressures	Walls & Roofs
Enclosed Buildings		
<p>Note:</p> <ol style="list-style-type: none"> Pressures shown are applied to the horizontal and vertical projections, for exposure B, at $h=33$ ft (9.1 m), $I=1.0$, and $K_w = 1.0$. Adjust to other conditions using Equation 6-1. The load patterns shown shall be applied to each corner of the building in turn as the reference corner. (See Figure 6-10) For the design of the longitudinal MWFRS are $\theta = 0^\circ$, and locate the zone EF_1/GH boundary in the mid-length of the building. Loud zones 1 and 2 must be checked for $25^\circ < \theta \leq 45^\circ$. Load case 2 at 25° is provided only for interpolation between 25° to 30°. Plus and minus signs signify pressures acting toward and away from the projected surface, respectively. For roof slopes other than those shown, linear interpolation is permitted. The total horizontal load shall not be less than that determined by assuming $p_w = 0$ in zones B & D. The zone pressures represent the following: Horizontal pressure zones—Sum of the windward and leeward net (sum of internal and external) pressures on vertical projection of: A - End zone of wall C - Interior zone of wall B - End zone of roof D - Interior zone of roof Vertical pressure zones—Net (sum of internal and external) pressures on horizontal projection of: E - End zone of windward roof G - Interior zone of windward roof F - End zone of leeward roof H - Interior zone of leeward roof Where zone E or G falls on a roof overhanging on the windward side of the building, use E_{out} and G_{out} for the pressures as the horizontal projection of the overhang. Overhangs on the leeward and side edges shall have the basic zone pressure applied. Notes:<ol style="list-style-type: none"> 10 percent of least horizontal dimension or 0.4 ft, whichever is greater, but not less than either 4% of least horizontal dimension or 3 ft (0.9 m). Mean roof height, in feet (meters), except that eave height shall be used for roof angles $< 10^\circ$. θ: Angle of plane of roof from horizontal, in degrees. 		

- lateral loads bypassing system
- simplified method (use T-0)

Vertical, exposure 'C', + Mean True Height = 11'

$$F_s = 2.0 \text{ kip/in}^2$$

$$\begin{array}{c} 1.0 \\ \downarrow \\ 1.21 \end{array}$$

$$\begin{array}{c} 1.0 \\ \downarrow \\ 1.0 \end{array}$$

From Table 18C use A-7 channel
(Welded Flange Zone & Horizontal at Vertical
Tension).

$$P_s = (1.2)(1.0)(1.0)(F_s) = 2.4 \text{ kip/in}$$

Load Case 1	Horizontal				Vertical				Wind Loadings			
	A	B	C	D	E	F	G	H	I	J	K	L
	0.9	0.8	0.7	0.6	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3
	0.9	0.8	0.7	0.6	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3
	1.56	1.46	1.33	1.21	2.0	1.89	1.76	1.63	1.50	1.39	1.26	1.13
Load Case 2	A	B	C	D	E	F	G	H	I	J	K	L
	0.9	0.8	0.7	0.6	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3
	0.9	0.8	0.7	0.6	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3
	1.56	1.46	1.33	1.21	2.0	1.89	1.76	1.63	1.50	1.39	1.26	1.13

$$P_s = (L)(K_{20})(I)(P_{S20})$$

- calculate 'a' : bias zone

$$10\% \text{ Lateral Horizontal Dimension} = (0.10)(A - c) = 1.4'$$

$$= 0.10(A - 1.0) = 0.4'$$

$$= 0.4$$

$$= (0.4)(1.1') = 0.44'$$

Windzone is complete

↓

but Wind Zones 1.4'

$$4\% \text{ of the Lateral Horizontal Dimension} = (0.04)(A - 1.0) = 0.56'$$

$$= 0.56$$

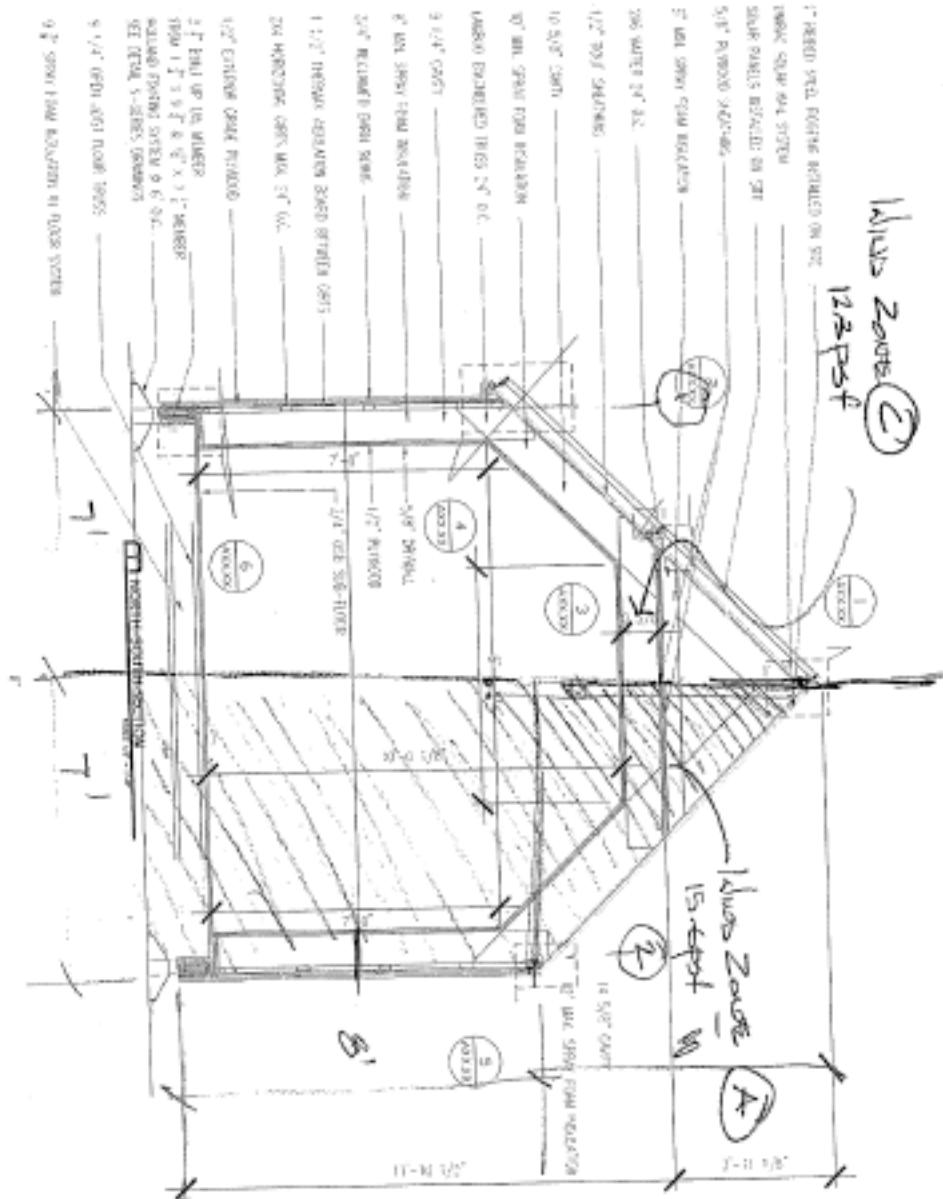
$$= 3'-0"$$

$$a = 3'-0"$$

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Main Wind Lateral Force Resisting System - CONTINUED

- Calculate Forces To TRANSVERSE Walls A, B, C, D

- ① - CALCULATE LWS LOAD ALONG EDGE OF BUILDING DUE TO PRESSURE IN EACH ZONE

$$\text{Zone A} \Rightarrow (15.6 \text{ psf})(8'/2) = 62.4 \text{ #/ft}$$

$$\text{Zone B} \Rightarrow (10.65 \text{ psf})(8') = \frac{85.2 \text{ #/ft}}{147.6 \text{ #/ft}}$$

LWS Load Along
edge of Building.
No Buff Zone
(2a)

$$\text{Zone C} \Rightarrow (12.5 \text{ psf})(8'/2) = 49.2 \text{ #/ft}$$

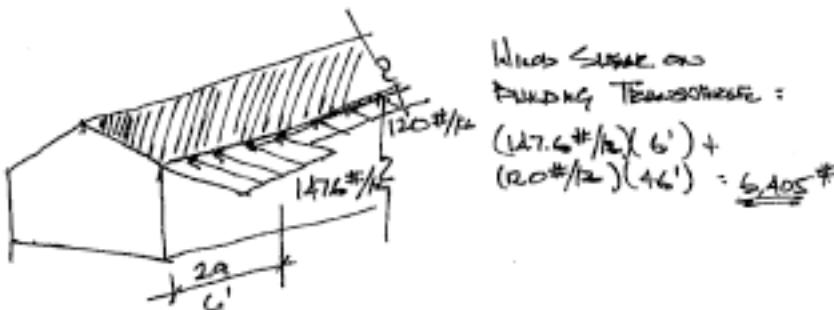
$$\text{Zone D} \Rightarrow (8.47 \text{ psf})(8') = \frac{67.76 \text{ #/ft}}{116.96 \text{ #/ft}}$$

∴ Total Wind Accel \Rightarrow Minimum Wind Pressure
on Turb Structure = 10 psf

\Rightarrow Use 10 psf in Zone C + D for Design

$$\text{Zone C Design} = (10 \text{ psf})(8'/2) = 40 \text{ #/ft}$$

$$\text{Zone D Design} = (10 \text{ psf})(8') = \frac{80 \text{ #/ft}}{120 \text{ #/ft}} \leftarrow \text{Controls}$$



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Main
 Horizontal Load Resistance System Considered

- Calculate Forces To Longitudinal Wall Loads ① + ②

- Wind Loads To Roof Diaphragm Due To Load Pressurization ③

$$\begin{aligned} & (15.6 \text{ psf}) (8'/2) (7') = 436.8 \# \Rightarrow 436.8 \# / 7' = 62.4 \# / \text{ft} [62.4 \# / \text{ft}] \\ & + (15.6 \text{ psf}) \left(\frac{8' \times 7'}{2} \right) = \frac{436.8 \#}{873.6 \#} \end{aligned}$$

- Wind Loads To Roof Diaphragm Due To Load Pressurization ④

$$\begin{aligned} & (12.3 \text{ psf}) (8'/2) (7') = 344.4 \# \\ & (12.3 \text{ psf}) \left(\frac{8' \times 7'}{2} \right) = \frac{344.4 \#}{688.8 \#} \end{aligned}$$

$$\text{Wind Stress} = 1362.4 \# \text{ (Longitudinal directions)}$$

$$\sqrt{\textcircled{1}} = (344.4 \#)(2.5') + (344.4 \#)(4.67') + (456)(1.5') + (436 \#)(7.33') -$$

$$\sqrt{\textcircled{2}}(1') = 0$$

$$\sqrt{1} = 818 \#$$

Wind Considered To Come From Any Horizontal Direction
 - Flexible Diaphragm Analysis \Rightarrow No Tension
 $\sqrt{\textcircled{1}} = \sqrt{\textcircled{2}} = 818 \#$

Project:	Solar Decathlon	Seal	
Address:			
Job No.:			
Date:	1/19/09		
Drawn By:	HAR	Sketch No.	

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- Wall Ledges Concentrators.

- Force To Wall Ledge (A) = $(120\text{#/ft})(4') \times (4'/2) + (147.6\text{#/ft})(5') \times (7')$
 $- k_A(10') = 0$
 $k_A = 716\text{#}$

- Force To Wall Ledge (B) = $1,365.6\text{#} - 716\text{#} = 649.6\text{#}$
 $(120\text{#/ft})(35'/2) = \frac{+ 2,100\text{#}}{[2,749.6\#]}$

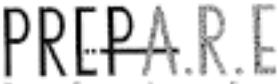
- by inspection

Use Forces to Wall Ledges As follows

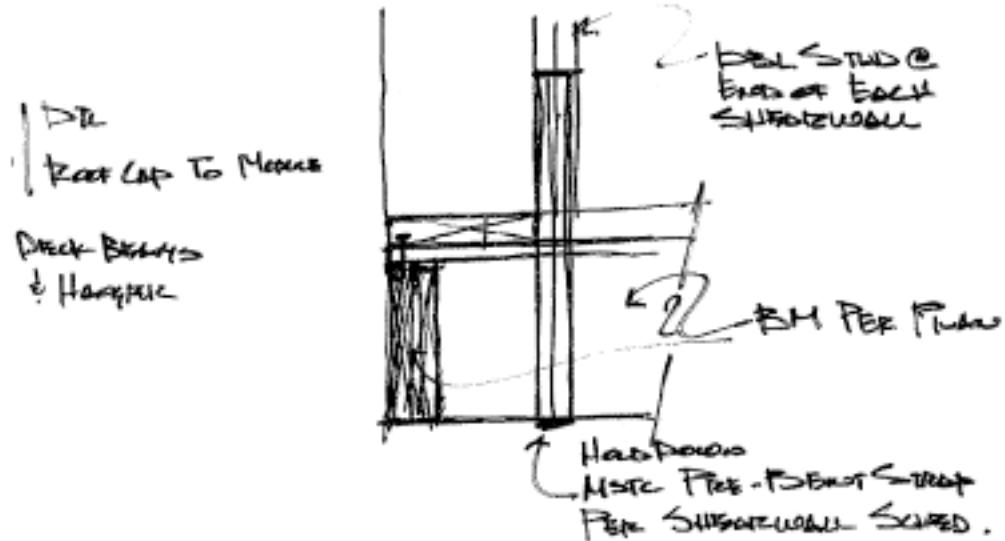
$$\boxed{V_A = V_B = 716\text{#}}$$

$$\boxed{V_B = V_C = 2,749.6\text{#}}$$

Project:	Solar Decathlon	Seal	
Address:			
Job No.:			
Date:	1/21/09		
Drawn By:	Hall		Sketch No.



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Project:			
Address:			
Job No.:			
Date:			
Drawn By:			
PREPARE Planning . Education . Architecture . Engineering 1828 Woodfield Drive, Suite 202, Savoy, IL 61874 Ph: (217) 398-0099 • Fax: (217) 398-0099 www.prepare-il.com		Seal	
		Sketch No.	

Picture of Safety Factor Update & Safety Check

- For the 2009 Solar Decathlon rules §5-2 If The Decathalon Rules were used, You Must Show That There Is No overbearing or uplifting when A factor of safety of 2.

- * For Longitudinal loading (Area 7 - Fig 6-2) - The bottom back is no uplift (Zones B, C, D, H)

$$\begin{aligned} \text{• Uplift Zone } \textcircled{E} &= (7' \times \frac{52'}{2}) (6 \text{ equal}) = 1,101.1\# \\ \text{• " " " } \textcircled{F} &= (7' \times \frac{52}{2}) (4 \text{ psf}) = 655.4\# \\ \text{• " " " } \textcircled{G} &= (7' \times \frac{52}{2}) (5.2 \text{ psf}) = 946.4\# \\ \text{• " " " } \textcircled{H} &= (7' \times \frac{52}{2}) (3.4 \text{ psf}) = \frac{618.8\#}{3,521.7\#} \end{aligned}$$

- Look at Weight of framing $\Rightarrow (2'(2' \times 0.67)) (15 \text{ psf}) = 288.6\#/\text{ft}_q$
Is framing provided $\Rightarrow (18) (288.6\#) = 6,994.8\#$

$$\frac{6,994.8\#}{3,521.7\#} = 1.98 \geq 2 \text{ ok}$$

~~It is the weight of the structure~~
~~at the height of the centerline~~
~~is considered in this~~
~~culation~~

- Look at Local chapter report for Concreting lumber frames
For Temperature temple terms.

$$\text{The temperature drop} = (2'-0") (14'-0") \text{ span} = 284 \Rightarrow \text{the drop} = 20^\circ$$

$$\text{back} > 27 \text{ to } 45^\circ \Rightarrow \text{Zone } \textcircled{1} = (12 \text{ psf})(1.2) = -14.52 \text{ psf}$$

$$\textcircled{2} = (-14.52 \text{ psf})(1.2) = -17.46 \text{ psf}$$

$$\textcircled{3} = (-14.52)(-1.2) = 17.46 \text{ psf}$$

Project: <u>Solar Decathlon</u>	Seal
Address:	
Job No.:	
Date:	
Drawn By: <u>Hilary</u>	Sketch No.
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- Local Uplift Components -

- Use - 17.49 psf Total Uplift of Local/Brackets Components

- Effective Uplift Length of Gable (the Component Forces Add To Total Uplift Vertical To Components) $(\sqrt{7^2+8^2})(2) = 21.2'$

$$\begin{aligned} \text{- Various Uplift resistances} \Rightarrow & \left[\frac{\text{Tens}}{(2')(21.2' \times 17.49\text{psf})} \right] / 2 = 573.12\# \\ & \quad : 3' \quad : 559\# \\ & \quad : 6' \quad : 1,119.36\# \end{aligned}$$

- Use A Simpson H6 Horizontal Tie At Each Lumber Frame/Vertical Member

Walls Frames Are Dovetailed @ Height openings
Use (1) H6 Pier Lumber Vertical at

Project:		
Address:		
Job No.:		
Date:		
Drawn By:		
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		Sketch No.



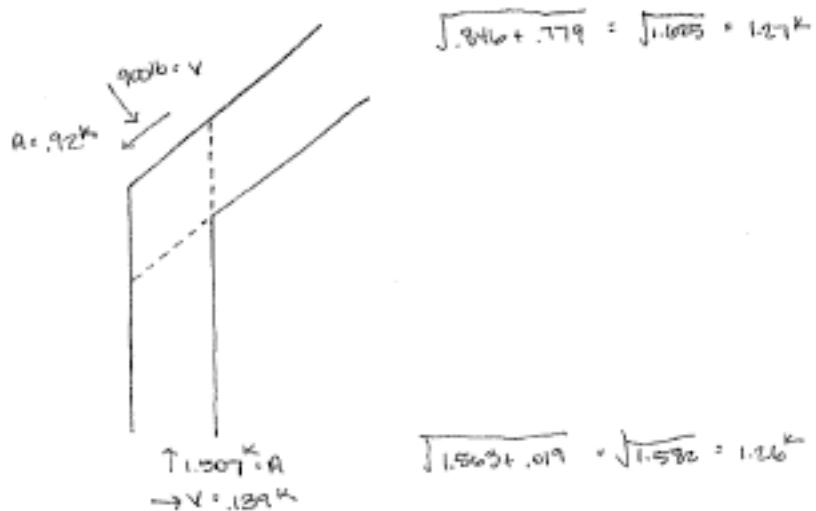
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2009 UIUC Solar Decathlon

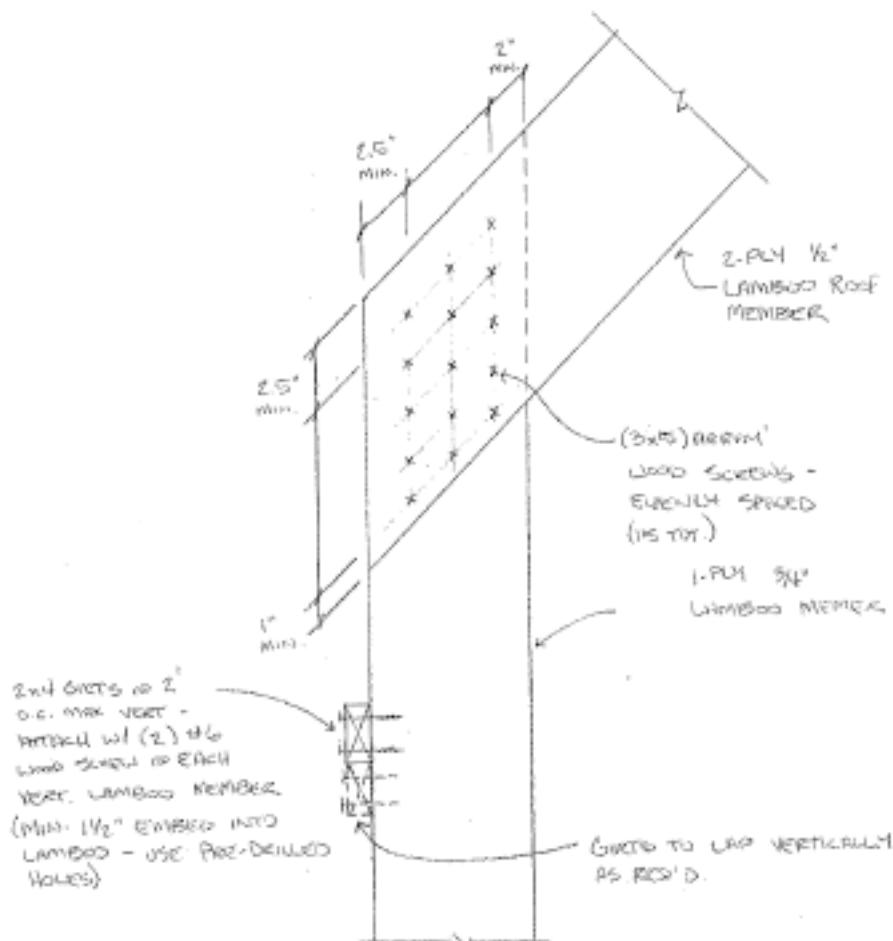
LAMBOO FRAME



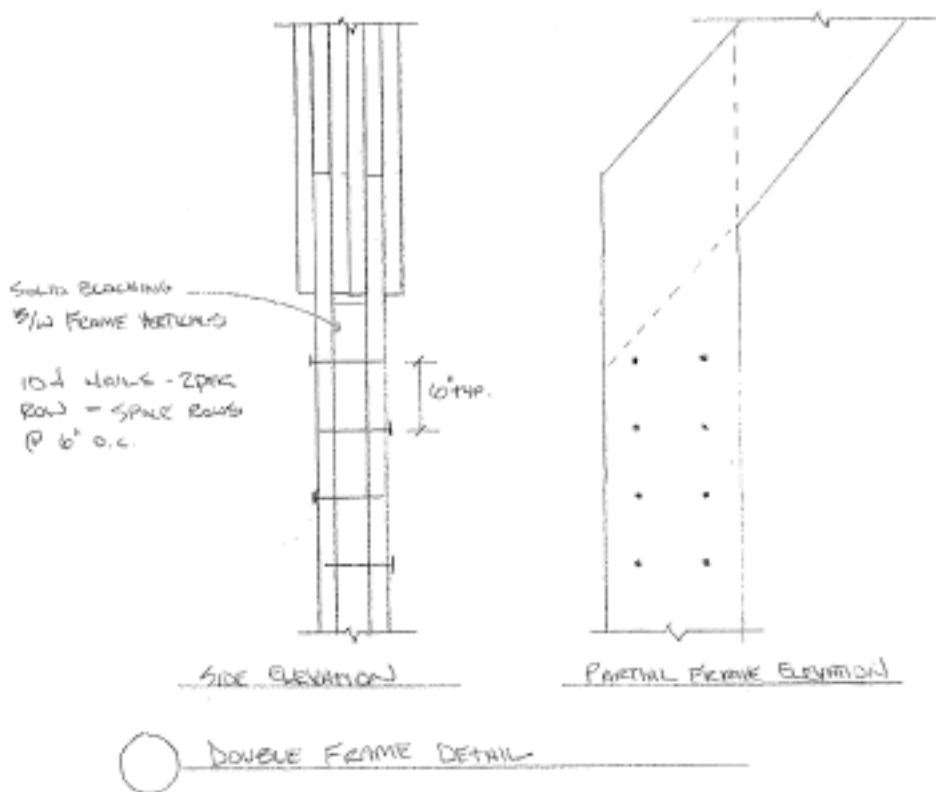
$$\frac{1300 \text{ lb}}{90 \text{ lb}/\text{fastener}} = 14.4 \text{ fasteners} \sim \underline{\underline{15 \text{ min.}}}$$

Project:	Solar Decathlon	Seal
Address:	Laredo Friends	
Job No.:		
Date:		
Drawn By:	JK	Sketch No.

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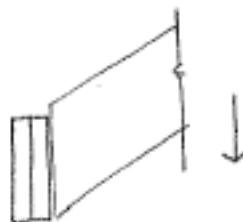


Project:		PREPARE Planning . Educate . Advocate . Engineering <small>1000 University Drive, Suite 200, Champaign, IL 61820 Ph: (217) 398-0088 • Fax: (217) 398-0089 www.prepare-il.org</small>	Seal
Address:			
Job No.:			
Date:			
Drawn By:			Sketch No.



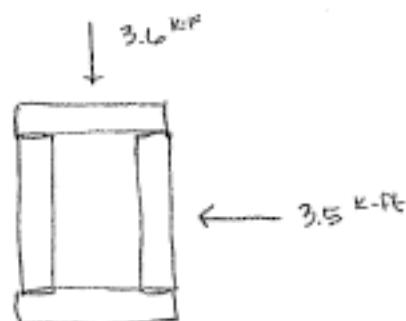
Project:	Solar	Seal:	
Address:	Lambo Frame		
Job No.:			
Date:			
Drawn By:	JK	Sketch No.:	

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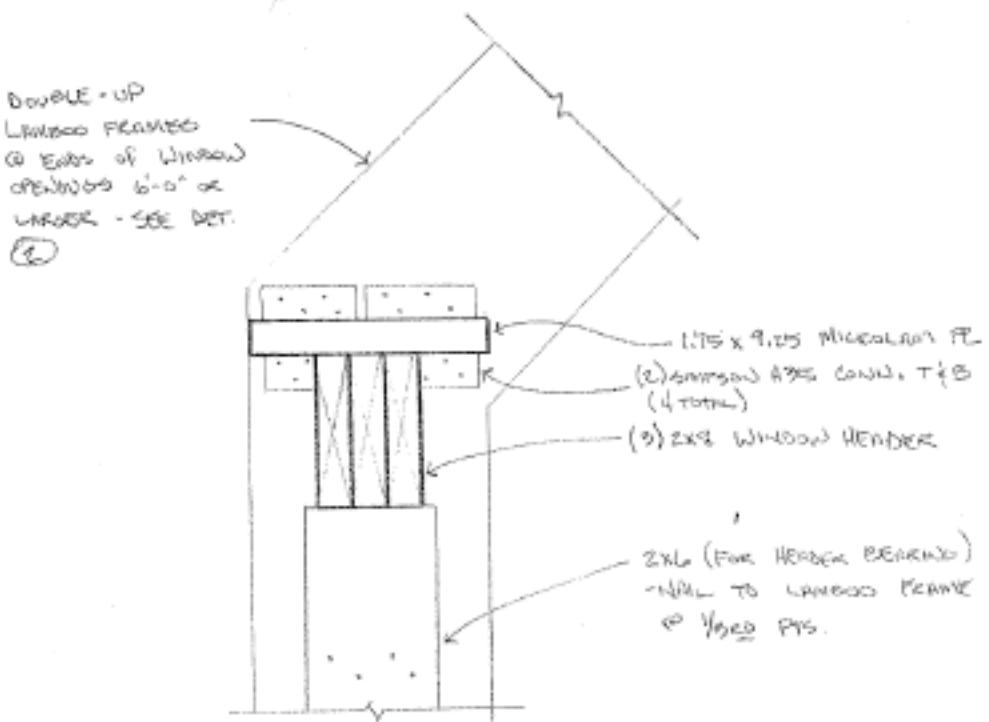
REACTIONS:

WIND: ← 140 lb ↓ 62 lb
 DEAD: ← 521 lb ↓ 664 lb
 LIVE: ← 521 lb ↓ 983 lb



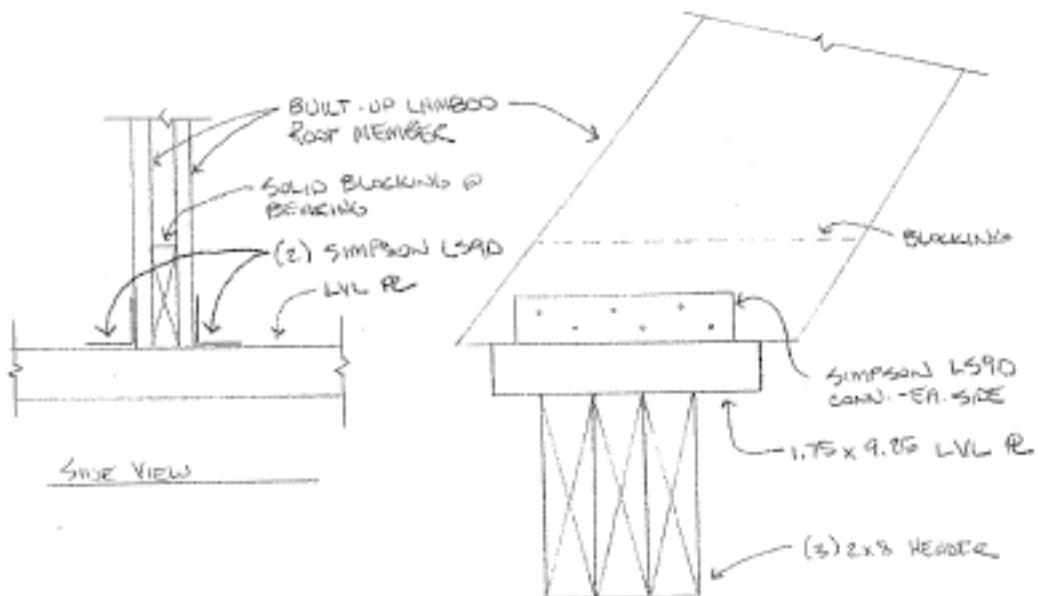
Project:	Solar Decathlon	Seal
Address:	Lorenz House	
Job No.:		
Date:		
Drawn By:	JK	Sketch No.

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① HEADER CONN. DET.
4x10s.

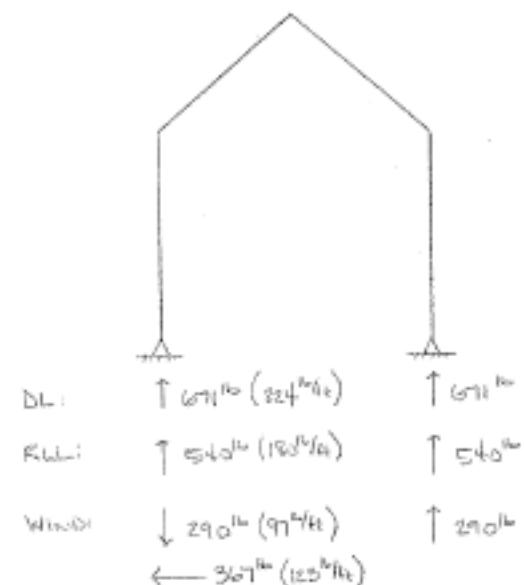
Project:	<i>Solar Decathlon</i>	Address:	<i>Lumbo Frame</i>	Seal	
Job No.:		Date:			
Drawn By:	<i>JK</i>	PREPARE <small>Planning . Education . Architecture . Engineering</small> 1044 Woodfield Drive, Suite 202, Savoy, IL 61874 Ph: (217) 366-0388 • Fax: (217) 355-6295 info@prepare-il.org			Sketch No.



○ Roof Member Bearing Detail (2 window HEADER)
NTS.

Project:	Solne	Seal	
Address:			
Job No.:			
Date:			
Drawn By:		Sketch No.	

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Project:		PREPARE Planning . Education . Architecture . Engineering 1850 Woodfield Drive, Suite 202, Savoy, IL 61874 Ph: (217) 309-0808 - Fax: (217) 309-0808 www.prepare-il.com	Seal
Address:			
Job No.:			
Date:			
Drawn By:			Sketch No.

Detailed Water Budget

Summary

The University of Illinois has calculated the amount of water required for the competition by carefully studying each competition requirement and allowing for wastage minimal additional usage. This study was also used to determine the required size of a heat-pump water heater that will be located in the home. Detailed calculations follow, however, the Illinois Solar Decathlon team estimates that a total of 550 gallons of clean potable water will be required for the competition and has specified water tanks with a total capacity of 600 gallons, allowing for an approximately 10% wastage factor or additional usage. This water will be stored in two 300 gallon potable water tanks resting beneath the south building deck. They are manufactured by "Fol-Da-Tank" and measuring 66" x 84" x 14". In addition, two 300 gallon gray water tanks will be provided to store all the water used during the competition. The team will not attempt to recycle any gray water during the event and will not add any additional water to the system at any time. Each tank will have a 4" diameter fill opening located at the top of the unit and accessible from above after the removable decking slats have been removed.

In accordance with the competition requirements and outline stated in the official Solar Decathlon Rules, the team has allotted for (4) Water Vaporization tests of 5lbs each, 20 Hot Water Draws of 15 gallons each, (5) dishwasher runs utilizing 7 gallons each and (10) clothes washer cycles at 22 gallons per cycle. Usage has been detailed below.

Estimated Hot Water Draws

Day	Hot water draws	Gallons	Dishwasher runs	Gallons	Clothes washer cycles	Gallons	Total gallons per day
8	2	30	1	2.4	1	11	43.4
9	3	45	0	0	2	22	67
10	2	30	1	2.4	0	0	32.4
11	3	45	0	0	0	0	45
12	2	30	0	0	2	22	52
13	3	45	1	2.4	1	11	58.4
14	2	30	1	2.4	2	22	54.4
15	3	45	1	2.4	2	22	69.4
Total	20		5		10	Avg	52.75
						Max	69.4

Day	Time frame
8	52 gallons within 4 hours
9	70 gallons within 6 hours
10	27 gallons within 5 hours
11	20 gallons within 1 hour
12	60 gallons within 6 hours
13	35 gallons within 2.5 hours and 27 gallons within 2.5 hours four hours later
14	77 gallons within 6 hours
15	20 gallons within 1 hour and 67 gallons within 6 hours six hours later

Unlisted Components

The University of Illinois Gable Home team has developed a number of technologies for use within the home that are not explicitly standard practice and recognized by code. Each product, however, has been fully vetted and will not cause any safety concerns or violate any code. We would like to use the following pages to explain each system, its testing, performance, acceptability and reliability. The pages shall serve as our formal request to use the technologies within the home per IRCR104-11, alternate products.

Structurally Laminated Bamboo

Per International Residential Code R104.11: Alternative materials, design and methods of construction and equipment, the Illinois team would like to formally request approval of Lamboo, a structural laminated bamboo product for use as the structure of our home. We have worked with the company, Lamboo Inc and their structural engineers to ensure that our dwelling meets all requirements and will be safe for occupancy while on the National Mall in Washington D.C.

R104.11 states that a request for approval of an alternative material shall show that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material is, for the purpose intended, equivalent of that prescribed in the code.

As a means of showing compliance with the requirements of the code, we have outlined extensive information regarding the manufacture, testing and performance of Lamboo. On the following pages, you will find the testing, engineering and manufacturing that together work to qualify the alternative to the wood construction prescriptively prescribed in the code.

For bamboo certifications, Lamboo, Inc. is working with the PFS Corporation and J. Robert Nelson, a third party certification company. Through this contact, Lamboo is working with Kurt Stochlia for the ICCES Certification. With regard to ASTM, Lamboo, Inc. is working with Borjen Yeh with the APA. There is also a D07 task group for ASTM certification of Lamboo as a structural material.

On Wednesday, June 3, 2009 there will be a meeting to address AC47 – Structural Wood-based products. More information can be found here, under the June 3rd link: http://www.iccs.org/Criteria_Development/0906-pre/index.shtml

We hope that this information is sufficient to qualify the use of Lamboo as a structural product for use in the Illinois Solar Decathlon Project. If there is any additional information that you desire or require, please let us know and we will provide it as quickly as possible. Thank you again for your time and consideration.



L A M B O O

ARCHITECTURAL AND STRUCTURAL

Product Research and Developer:



Lamboo Inc.
510 East Addams
Third Floor
Springfield IL 62701
www.lamboo.us

Manufacturer:



Louisiana Pacific
2706 US Highway 421 N
Wilmington, NC 28401
(910) 762-9878

Louisiana Pacific
800 9th Ave N
Golden, BC V0A 1H0, Canada
(250) 344-8800
www.lpcorp.com

ASTM, ICC-ES Accredited Testing Labs:

St. Louis Testing Laboratories
2810 Clark Ave
St Louis, MO 63103
(314) 531-8080
www.labinc.com

Tekle Technical Services, TTS.
9527 49 Avenue NW
Edmonton, AB T6E 5Z5, Canada
(780) 465-1532
www.ttsfsl.com

LAMBOO, Inc
510 East Addams
Springfield, IL 62701

July 25, 2008
Lab No. 08P-1517
Page 1 of 6

Attention: Luke Schuette

REPORT OF MECHANICAL TESTS

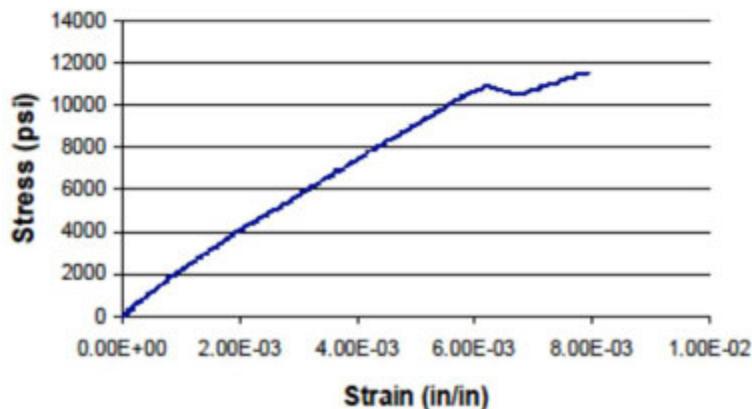
SAMPLE ID: LAMINATED BAMBOO PANEL
 SUBJECT: Flexural Modulus of Rupture and Modulus of Elasticity
 TEST PROCEDURE: In accordance with ASTM D 1037
 TEST INSTRUMENT: SATEC Universal Testing Machine S/N 1269
 TEST SPECIMEN CONDITION: As-Received
 RESULTS:

TEST ORIENTATION	SPECIMEN SIZE	TEST SPAN	AVERAGE MODULUS OF RUPTURE	AVERAGE MODULUS OF ELASTICITY
LONGITUDINAL	46" L x 3.00" W x 1.75" D	42"	14,743 psi	2.86*10 ⁶ psi
TRANSVERSE			1,234 psi	272,432 psi

Karl Schmitz, Director
Materials Testing

KS/rt

Sample #10 (outside)



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 Springfield, IL 62701

July 25, 2008
 Lab No. 08P-1517
 Page 2 of 6

Attention: Luke Schuette

REPORT OF MECHANICAL TESTS

SAMPLE ID: LAMINATED BAMBOO PANEL

SUBJECT: Tension Strength

TEST PROCEDURE: In accordance with ASTM D 198-05 sections 28-35

TEST INSTRUMENT: SATEC Universal Testing Machine S/N 1269 (Wedge Grips)

TEST SPECIMEN CONDITION: As-Received

RESULTS:

SAMPLE ID	TEST ORIENTATION	SPECIMEN SIZE	PEAK LOAD	TENSILE STRENGTH
TENSION 1	Parallel to Grain	1.75" x 1.75 x 14"	19300	14811 psi
TENSION 2	Transverse to Grain	1.75" x 1.75 x 14"	2040	665.5 psi

Parallel Tension



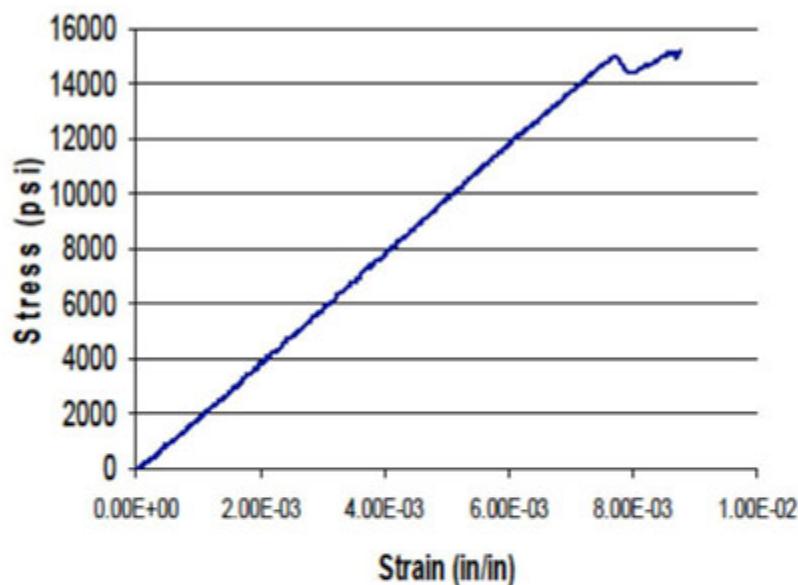
Transverse Tension



Karl Schmitz, Director
 Materials Testing

KS/art

Sample #6 (outside)



Tensile Strength=14811 psi

E=3.17*10^6 psi

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Springfield, IL 62701

July 25, 2008
Lab No. 08P-1517
Page 3 of 6

Attention: Luke Schuette

REPORT OF MECHANICAL TESTS

SAMPLE ID: LAMINATED BAMBOO PANEL

SUBJECT: Compression Strength

TEST PROCEDURE: In accordance with ASTM D 198-05 sections 28-35

TEST INSTRUMENT: SATEC Universal Testing Machine S/N 1269 (W/floating head)

TEST SPECIMEN CONDITION: As-Received

RESULTS:

TEST ORIENTATION	SPECIMEN SIZE	COMPRESSION STRENGTH #1	COMPRESSION STRENGTH #2	COMPRESSION STRENGTH #3
Parallel to Grain	1.75" x 1.75 x 12"	8675 psi	9345 psi	9279 psi
Transverse to Grain	1.75" x 1.75 x 12"	3017 psi	3043 psi	3043 psi

Parallel Compression



Transverse Compression



Karl Schmitz, Director
Materials Testing

LAMBOO, Inc
510 East Addams
Springfield, IL 62701

July 25, 2008
Lab No. 08P-1517
Page 4 of 6

Attention: Luke Schuette

REPORT OF MECHANICAL TESTS

SAMPLE ID: LAMINATED BAMBOO SHEETS

SUBJECT: Hardness

TEST PROCEDURE: In accordance with ASTM D 1037

PENTRANT DIAMETER: 0.444"

TEST SPECIMEN CONDITION: As-Received

RESULTS:

TEST ORIENTATION	*HARDNESS #1	*HARDNESS #2	*AVERAGE HARDNESS
Parallel to Grain	1649 LBS.	1877 lbs.	1778 lbs.
Transverse to Grain	1965 LBS.	2288 lbs.	2127 lbs.

*Load to penetrate one-half ball diameter

Karl Schmitz, Director
Materials Testing

KS/rt

LAMBOO, Inc
510 East Addams
Springfield, IL 62701

July 25, 2008
Lab No. 08P-1517
Page 5 of 6

Attention: Luke Schuette

REPORT OF MECHANICAL TESTS

SAMPLE ID: LAMINATED BAMBOO PANELS

SUBJECT: Falling Ball Impact

TEST PROCEDURE: In accordance with ASTM D 1037 (*with modifications)

TEST SPECIMEN CONDITION: As-Received

RESULTS: *270 Feet Calculated height to visible cracking (1.75" thick specimen)

* Specimen exceeded maximum capability of testing apparatus as described in ASTM D 1037. Used a modified drop weight tester with 2" head x 60.0lb. impactor dropped from a height of 4'6"



Karl Schmitz, Director
Materials Testing

KS/art

LAMBOO, Inc
1024 Post Rd.
Springfield, IL 62712

July 25, 2008
Lab No. 08P-1517
Page 6 of 6

Attention: Luke Schuette

REPORT OF MECHANICAL TESTS

SAMPLE ID: LAMINATED BAMBOO SHEETS

SUBJECT: Water Absorption/Swelling

TEST PROCEDURE: In accordance with ASTM D 1037 (Method A)

TEST SPECIMEN: 12.0" X 12.0" X 1.750"

TEST SPECIMEN CONDITION: As-Received

RESULTS	1 HR SUBMERGED	2+22 HR SUBMERGED
Absorption	+2.6%	+9.2%
Swelling	+0.1%	+0.4%

Karl Schmitz, Director
Materials Testing

KS/rt

LAMBOO, Inc
510 East Addams
Springfield, IL 62701

May 8, 2008
Lab No. 08P-1517
Page 1 of 6

Attention: Luke Schuette

REPORT OF MECHANICAL TESTS

SAMPLE ID: LAMINATED BAMBOO PANELS

SUBJECT: Flexural Strength

TEST PROCEDURE: In accordance with ASTM D 198-05 sections 4-11

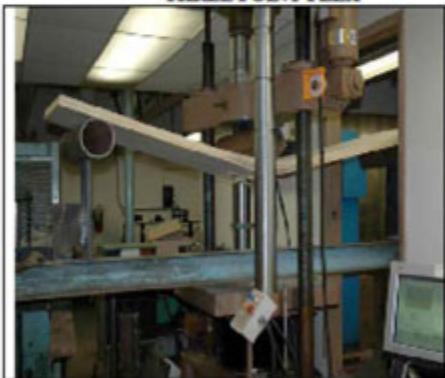
TEST INSTRUMENT: SATEC Universal Testing Machine S/N 1269

TEST SPECIMEN CONDITION: As-Received

RESULTS:

TEST DESCRIPTION	TEST ORIENTATION	SPECIMEN SIZE	TEST SPAN	LOADING SPAN	FLEXURAL MODULUS	FLEXURAL STRENGTH
TWO-POINT LOADING	Parallel to surface plane	96" L x 24" W x 1.75" D	84"	28"	1,317,754 psi	10,458 psi
CENTER-POINT LOADING				NA	1,229,904 psi	14,642 psi

THREE POINT FLEX



FOUR POINT FLEX



LAMBOO INC.

MECHANICAL PROPERTIES SUMMARY

Compression:

Parallel to grain: 9345 psi (ASTM 3501-86 A)

Perpendicular to grain: 3043 psi (ASTM 3501-86 A)

Tensile Strength:

Parallel to grain 15300 psi (ASTM 3500-90)

Perpendicular to grain 665.5 psi (ASTM 3500-90)

Flexural Strength:

14600 psi (ASTM D3043)

Flexural Modulus:

1,317,754 psi (ASTM D3043)

Shear Strength:

789 psi (ASTM D3048)

Modulus of Elasticity:

2.86×10^6 psi or 2.86E (ASTM D 1037)

GENERAL PROPERTIES SUMMARY

Adhesive:

Dynorit SPS (Aerolite UP 4116/A942/H240)

Does not contain any components considered hazardous to the environment, or does not contain any solvents (VOC;s) heavy metals, bactericides, or halogenated organic components.

Formaldehyde Emissions:

a. "traditional" bamboo - 0.0127ppm (per ENV717-1)

Indentation Resistance/Hardness:

Natural Horizontal – avg. 2109

Natural Vertical – avg. 1813

Moisture Content:

7.3% (average for all tested samples)

Moisture content of final product will vary based on climate conditions to which the material is warehoused and then installed. It is highly recommended to let all bamboo products acclimate to installed space conditions.

Dimensional Stability:

Stability factor = 0.00144

Flammability:

Class 1 (ASTM E648 – Critical Radiant Panel Test)

Smoke Density:

270 - Flaming Mode (ASTM E622)

300 - Non-flaming mode (ASTM E622)

* Passing is any number below 450.

Attachment:

GENERAL STRUCTURAL NOTES**BUILDING CODES – APPLICABLE CODES AND STANDARDS****GENERAL**

1. ALL TYPICAL DETAILS AND NOTES SHOWN ON DRAWINGS SHALL APPLY UNLESS NOTED OTHERWISE. TYPICAL DETAILS MAY NOT NECESSARILY BE INDICATED ON THE PLANS BUT SHALL STILL APPLY AS SHOWN OR DESCRIBED IN THE DETAILS. WHERE TYPICAL DETAILS ARE NOTED ON THE DRAWINGS, THE SPECIFIED TYPICAL DETAIL SHALL BE USED. WHERE NO DETAIL IS NOTED, IT SHALL BE THE CONTRACTOR'S RESPONSIBILITY TO CHOOSE THE APPROPRIATE TYPICAL DETAIL FROM THOSE PROVIDED. THE CONTRACTOR SHALL SUBMIT ALL PROPOSED ALTERNATE TYPICAL DETAILS TO THOSE PROVIDED WITH RELATED CALCULATIONS TO THE ENGINEER FOR APPROVAL PRIOR TO SHOP DRAWING PRODUCTION AND FIELD USE.

BUILDING CODE

2. ALL CONSTRUCTION SHALL BE IN ACCORDANCE WITH THE BUILDING CODE. THE PUBLICATIONS LISTED BELOW ARE THE GOVERNING CODES AND STANDARDS AND ARE REFERENCED BY THEIR BASIC DESIGNATION. IN THE CASE OF CONFLICTING REQUIREMENTS, THE BUILDING CODE SHALL GOVERN.

APPLICABLE CODES AND STANDARDS

BUILDING CODE	INTERNATIONAL BUILDING CODE (IBC), 2003 EDITION INTERNATIONAL RESIDENTIAL CODE (IRC), 2003 EDITION SOLAR DECAHTLON BUILDING CODE, LATEST EDITION
AWS D1.1	AMERICAN WELDING SOCIETY D1.1-2000, "STRUCTURAL WELDING CODE – STEEL"
AWS A2.4	AMERICAN WELDING SOCIETY A2.4-98, "SYMBOLS FOR WELDING AND NONDESTRUCTIVE TESTING"
AISI	AMERICAN IRON AND STEEL INSTITUTE, "SPECIFICATIONS FOR THE DESIGN OF COLD-FORMED STEEL STRUCTURAL MEMBERS," 1996 EDITION WITH SUPPLEMENT NO. 1, JULY 30, 1999.
ASTM	AMERICAN SOCIETY FOR TESTING MATERIALS (ASTM INTERNATIONAL)

STEEL**STRUCTURAL STEEL**

1. ALL STEEL SHALL CONFORM TO THE FOLLOWING:

W-SHAPES	ASTM A992, Fy=50 KSI ASTM A913, Fy=50 KSI
ALL ANGLES UNLESS OTHERWISE NOTED	ASTM A36, Fy=36 KSI

SQUARE OR RECTANGULAR STRUCTURAL TUBE	ASTM A500 GRADE B, Fy=46 KSI
STEEL PIPE DIAMETER LESS THAN OR EQUAL TO 12 INCHES	ASTM A53, TYPE E OR S GRADE B, Fy=35 KSI
MATERIAL CALLED OUT ON PLANS AS (A36)	ASTM A36, Fy=36 KSI
MATERIAL CALLED OUT ON PLANS AS (Fy=65 KSI)	ASTM A913, Fy=65 KSI
ALL OTHER STEEL UNLESS OTHERWISE NOTED	ASTM A572, Fy=50 KSI ASTM A588, Fy=50 KSI ASTM A441, Fy=50 KSI

2. GENERAL NOTES FOR STEEL CONNECTIONS SHALL APPLY TO ALL STEEL CONNECTIONS UNLESS NOTED OTHERWISE.

3. ALL WORK SHALL BE IN ACCORDANCE WITH THE AISC SPECIFICATION. SHOP DRAWINGS SHALL BE SUBMITTED AND REVIEWED BY THE ARCHITECT/ENGINEER BEFORE COMMENCING FABRICATION. ALL STEEL ANCHORS AND TIES AND OTHER MEMBERS EMBEDDED IN CONCRETE OR MASONRY SHALL BE LEFT UNPAINTED. DIMENSIONAL TOLERANCE FOR BUILT-UP MEMBERS SHALL BE PER AWS D1.1

4. THE CONTRACTOR SHALL BE RESPONSIBLE FOR COORDINATING THE SELECTION OF OPTIONAL DETAILS SHOWN ON THE DRAWINGS. THE CONTRACTOR SHALL ALSO BE RESPONSIBLE FOR ALL ERECTION AIDS THAT INCLUDE, BUT ARE NOT LIMITED TO, ERECTION ANGLES, LIFT HOLES AND OTHER AIDS.

STRUCTURAL STEEL WELDING

5. STRUCTURAL STEEL SHOP DRAWINGS SHALL SHOW ALL WELDING WITH AWS A2.4 SYMBOLS. ALL WELDING SHALL BE DONE WITH AWS/WABO (WASHINGTON STATE ASSOCIATION OF BUILDING OFFICIALS) CERTIFIED WELDERS AND IN ACCORDANCE WITH AWS D1.1. WELDS SHOWN ON THE DRAWINGS ARE THE MINIMUM SIZES. INCREASE WELD SIZE TO AWS MINIMUM SIZES, BASED ON PLATE THICKNESS. THE MINIMUM WELD SIZE SHALL BE 3/16 INCH. FIELD WELDING SYMBOLS HAVE NOT NECESSARILY BEEN INDICATED ON THE DRAWINGS. WHERE SHOWN, PROPER FIELD WELDING PER AWS D1.1 SHALL BE USED. WHERE NOT FIELD WELDING SYMBOLS ARE SHOWN, IT IS THE CONTRACTOR'S RESPONSIBILITY TO COORDINATE THE USE OF SHOP AND FIELD WELDS. ALL PARTIAL PENETRATION GROOVE WELD SIZES SHOWN ON THE DRAWINGS REFER TO EFFECTIVE THROAT THICKNESS. ALL WELDS SHALL BE MADE USING LOW HYDROGEN ELECTRODES WITH MINIMUM TENSILE STRENGTH PER AWS D1.1 (MINIMUM 70 KSI). LOW HYDROGEN SMAW ELECTRODES SHALL BE USED WITHIN FOUR HOURS OF OPENING THEIR HERMETICALLY SEALED CONTAINERS, OR SHALL BE REFRIED PER AWS D1.1, SECTION 4.5. ELECTRODES SHALL BE REDRIED NO MORE THAN ONE TIE, AND ELECTRODES THAT HAVE BEEN WET SHALL NOT BE USED.

6. ALL WELDING SHALL BE PERFORMED IN STRICT ADHERENCE TO A WRITTEN WELDING PROCEDURE SPECIFICATION (WPS) PER AWS D1.1. ALL WELDING PARAMETERS SHALL BE WITHIN THE ELECTRODE MANUFACTURER'S RECOMMENDATIONS. WELDING PROCEDURES SHALL BE SUBMITTED TO THE OWNER'S TESTING AGENCY FOR REVIEW BEFORE STARTING FABRICATION OR ERECTION. COPIES OF THE WPS SHALL BE ON SITE AND AVAILABLE TO ALL WELDERS AND THE SPECIAL INSPECTOR.

GROUND ANCHORS

7. GROUND ANCHORS SHALL BE 15" X 3" BLADE DIAMETER X 1-1/2" ROD DIAMETER ANCHOR. UPLIFT CAPACITY = 200 LB (BASED ON FIRM DENSE SOIL).

WOOD

FRAMING LUMBER

1. FRAMING LUMBER SHALL BE KILN DRIED OR MC-15, AND GRADED AND MARKED IN CONFORMANCE WITH WEST COAST LUMBER INSPECTION BUREAU STANDARD GRADING RULES FOR WEST COAST LUMBER NO. 16, LATEST EDITION. FURNISH TO THE FOLLOWING MINIMUM STANDARDS:

2x JOISTS AND BUILT-UP MEMBERS	DOUGLAS FIR-LARCH NO.2
3x AND 4x BEAMS AND POSTS	DOUGLAS FIR-LARCH NO. 2
6x AND LARGER BEAMS AND STRINGERS	DOUGLAS FIR-LARCH NO. 1
6x AND LARGER POSTS AND TIMBERS	DOUGLAS FIR-LARCH NO. 1
STUDS, PLATES AND MISC. LIGHT FRAMING	DOUGLAS FIR-LARCH STANDARD GRADE
TOP AND BOTTOM PLATES AT BEARING WALLS	DOUGLAS FIR-LARCH CONSTRUCTION GRADE
BOLTED STUDS, LEDGERS AND PLATES	DOUGLAS FIR-LARCH STANDARD GRADE

LAMINATED VENEER LUMBER (LVL)

2. LAMINATED VENEER LUMBER SHALL BE MANUFACTURED UNDER A PROCESS APPROVED BY THE NATIONAL RESEARCH BOARD. EACH PIECE SHALL BEAR A STAMP OR STAMPS NOTING THE NAME AND PLANT NUMBER OF THE MANUFACTURER, THE GRADE, THE NATIONAL RESEARCH BOARD NUMBER AND THE QUALITY CONTROL AGENCY. ALL LAMINATED VENEER LUMBER SHALL BE MANUFACTURED IN ACCORDANCE WITH THE INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS (ICBO) ER-4979 USING DOUGLAS FIR VENEER GLUED WITH A WATERPROOF ADHESIVE MEETING THE REQUIREMENTS OF ASTM D2559 WITH ALL GRAIN PARALLEL WITH THE LENGTH OF THE MEMBER.

3. ALL MEMBERS SHALL BE WESTERN SPECIES, GRADE 1.8E, FB = 2,600 PSI, FV = 285 PSI.

4. DESIGN SHOWN ON PLANS IS BASED ON LVL MEMBERS MANUFACTURED BY TRUS JOIST, A WEYERHAUSER BUSINESS. ALTERNATE MANUFACTURERS MAY BE USED SUBJECT TO REVIEW AND APPROVAL BY THE ARCHITECT AND STRUCTURAL ENGINEER. ALTERNATE JOIST HANGERS AND OTHER HARDWARE MAY BE SUBSTITUTED FOR ITEMS SHOWN PROVIDED THEY HAVE THE ICBO APPROVAL FOR EQUAL OR GREATER LOAD CAPACITIES. ALL JOIST HANGERS AND OTHER HARDWARE SHALL BE COMPATIBLE IN SIZE WITH THE MEMBERS PROVIDED.

PARALLEL STRAND LUMBER (PSL)

5. PARALLEL STRAND LUMBER SHALL BE MANUFACTURED UNDER A PROCESS APPROVED BY THE NATIONAL RESEARCH BOARD. EACH PIECE SHALL BEAR A STAMP OR STAMPS NOTING THE NAME AND PLANT NUMBER OF THE MANUFACTURER, THE GRADE, THE NATIONAL RESEARCH BOARD NUMBER AND THE QUALITY CONTROL AGENCY. ALL LAMINATED VENEER LUMBER SHALL BE MANUFACTURED IN ACCORDANCE WITH THE ICBO ER-4979 USING DOUGLAS FIR VENEER GLUED WITH A WATERPROOF ADHESIVE MEETING THE REQUIREMENTS OF ASTM D2559 WITH ALL GRAIN PARALLEL WITH THE LENGTH OF THE MEMBER.

6. ALL MEMBERS SHALL BE GRADE 2.0E, FB = 2,900 PSI, FV = 290 PSI.

7. DESIGN SHOWN ON PLANS IS BASED ON PSL MEMBERS MANUFACTURED BY TRUS JOIST, A WEYERHAEUSER BUSINESS. ALTERNATE MANUFACTURERS MAY BE USED SUBJECT TO REVIEW AND APPROVAL BY THE ARCHITECT AND STRUCTURAL ENGINEER. ALTERNATE JOIST HANGERS AND OTHER HARDWARE MAY BE SUBSTITUTED FOR ITEMS SHOWN PROVIDED THEY HAVE ICBO APPROVAL FOR EQUAL OR GREATER LOAD CAPACITIES. ALL JOIST HANGERS AND OTHER HARDWARE SHALL BE COMPATIBLE IN SIZE WITH THE MEMBERS PROVIDED.

TIMBERSTRAND RIM BOARD (LSL)

8. TIMBERSTRAND RIM BOARD SHALL BE MANUFACTURED UNDER A PROCESS APPROVED BY THE NATIONAL RESEARCH BOARD. EACH PIECE SHALL BEAR A STAMP OR STAMPS NOTING THE NAME AND PLANT NUMBER OF THE MANUFACTURER, THE GRADE, THE NATIONAL RESEARCH BOARD NUMBER AND THE QUALITY CONTROL AGENCY. ALL LAMINATED VENEER LUMBER SHALL BE MANUFACTURED IN ACCORDANCE WITH ICBO ER-4979 USING DOUGLAS FIR VENEER GLUED WITH A WATERPROOF ADHESIVE MEETING THE REQUIREMENTS OF ASTM D2559 WITH ALL GRAIN PARALLEL WITH THE LENGTH OF THE MEMBER.

9. ALL MEMBERS SHALL BE GRADE 1.3E, FB = 1,700 PSI, FV = 150 PSI

10. DESIGN SHOWN ON PLANS IS BASED ON LSL MEMBERS MANUFACTURED BY TRUS JOIST, A WEYERHAEUSER BUSINESS. ALTERNATE MANUFACTURERS MAY BE USED SUBJECT TO REVIEW AND APPROVAL BY THE ARCHITECT AND STRUCTURAL ENGINEER.

LAMBOO LVB (LAMINATE VENEER BAMBOO)

11. ALL MEMBERS SHALL BE GRADE S, FB = 7,200 PSI, FV = 450 PSI

12. LAMINATED VENEER BAMBOO SHALL BE MANUFACTURED UNDER A PROCESS APPROVED BY THE NATIONAL RESEARCH BOARD. EACH PIECE SHALL BEAR A STAMP OR STAMPS NOTING THE NAME AND PLANT NUMBER OF THE MANUFACTURER, THE GRADE, THE NATIONAL RESEARCH BOARD NUMBER AND THE QUALITY CONTROL AGENCY. ALL LAMINATED VENEER LUMBER SHALL BE MANUFACTURED IN ACCORDANCE WITH THE INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS (ICBO) ER-4979 USING MOSO GLUED WITH A WATERPROOF ADHESIVE MEETING THE REQUIREMENTS OF ASTM D2559 WITH ALL GRAIN PARALLEL WITH THE LENGTH OF THE MEMBER.

13. ALL MEMBERS SHALL BE MOSO SPECIES, GRADE 2.0E, FB = 7,200 PSI, FV = 450 PSI

14. DESIGN SHOWN ON PLANS IS BASED ON LVB MEMBERS MANUFACTURED BY LAMBOO INC. ALTERNATE MANUFACTURERS MAY BE USED SUBJECT TO REVIEW AND

APPROVAL BY THE ARCHITECT AND STRUCTURAL ENGINEER. ALTERNATE JOIST HANGERS AND OTHER HARDWARE MAY BE SUBSTITUTED FOR ITEMS SHOWN PROVIDED THEY HAVE THE ICBO APPROVAL FOR EQUAL OR GREATER LOAD CAPACITIES. ALL JOIST HANGERS AND OTHER HARDWARE SHALL BE COMPATIBLE IN SIZE WITH THE MEMBERS PROVIDED.

PREFABRICATED CONNECTOR PLATE WOOD ROOF TRUSSES

12. THE CONTRACTOR IS RESPONSIBLE FOR THE DESIGN OF PREFABRICATED CONNECTOR PLATE WOOD ROOF TRUSSES. THESE MEMBERS SHALL BE DESIGNED BY THE MANUFACTURER IN ACCORDANCE WITH THE "DESIGN SPECIFICATION FOR METAL PLATE CONNECTED WOOD TRUSSES," TPI LATEST EDITION, BY THE TRUSS PLATE INSTITUTE FOR THE SPANS AND CONDITIONS SHOWN ON THE PLANS. THE FOLLOWING TRUSS LOADING IS TYPICAL UNLESS NOTED OTHERWISE ON PLANS AND/OR LOAD MAPS.

TOP CHORD LIVE LOAD (SNOW)	25 PSF
TOP CHORD DEAD LOAD	10 PSF
BOTTOM CHORD DEAD LOAD	5 PSF

TOTAL LOAD	40 PSF
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13. FLOOR TRUSS DEFLECTION SHALL MEET THE MINIMUM ICBO REQUIREMENTS UNLESS A MORE STRINGENT CRITERIA IS NOTED ON THE PLANS.

14. WOOD TRUSSES SHALL UTILIZE APPROVED CONNECTOR PLATES (GANGNAIL OR APPROVED EQUAL). SUBMIT SHOP DRAWINGS AND DESIGN CALCULATIONS COMPLETE WITH STRESS DIAGRAMS FOR REVIEW A MINIMUM OF TWO WEEKS PRIOR TO FABRICATION. PROVIDE FOR ALL TEMPORARY AND PERMANENT TRUSS BRACING AND BRIDGING.

PLYWOOD

15. PLYWOOD SHEATHING SHALL BE GRADE C-D EXTERIOR GLUE OR STRUCTURAL II. ORIENTED STRAND BOARD (OSB) OF EQUIVALENT THICKNESS, EXPOSURE RATING AND PANEL INDEX MAY BE USED IN LIEU OF PLYWOOD.

TIMBER CONNECTORS

16. TIMBER CONNECTORS CALLED OUT BY LETTERS AND NUMBERS SHALL BE SIMPSON STRONG -TIE COMPANY, INC, AS SPECIFIED IN THE LATEST EDITION OF THEIR CATALOG. EQUIVALENT DEVICES BY OTHER MANUFACTURERS MAY BE SUBSTITUTED, PROVIDED THEY HAVE ICC-ES APPROVAL FOR EQUAL OR GREATER LOAD CAPCITIES. PROVIDE NUMBER AND SIZE OF FASTENERS AS SPECIFIED BY MANUFACTURER. CONNECTORS SHALL BE INSTALLED IN ACCORDANCE WITH THE MANUFACTURER'S PUBLISHED SPECIFICATIONS. WHERE CONNECTOR STRAPS CONNECT TWO MEMBERS, PLACE HALF OF THE NAILS OR BOLTS IN EACH MEMBER. ALL BOLTS IN WOOD MEMBERS SHALL CONFORM TO ASTM A307. PROVIDE WASHERS UNDER THE HEADS AND NUTS OF ALL BOLTS AND LAG SCREWS BEARING ON WOOD. UNLESS NOTED OTHERWISE, ALL NAILS SHALL BE COMMON. ALL SHIMS SHALL BE SEASONED AND DRIED AND THE SAME GRADE (MINIMUM) AS MEMBERS CONNECTED. ALL SINGLE, DOUBLE AND TRIPLE JOISTS SHALL BE CONNECTED WITH "U" SERIES JOIST HANGERS.

WOOD FRAMING DETAILS

17. THE FOLLOWING APPLY UNLESS OTHERWISE SHOWN ON THE PLANS:

1. AT JOIST AREAS: PROVIDE CROSS-BRIDGING AT 8'-0" ON CENTER MAXIMUM. PROVIDE SOLID BLOCKING OR CONTINUOUS RIM AT ALL BEARING POINTS. PROVIDE SOLID BLOCKING UNDER ALL BEARING WALLS ABOVE.
2. PROVIDE DOUBLE JOISTS UNDER ALL PARALLEL PARTITIONS THAT EXTEND OVER MORE THAN HALF THE JOIST LENGTH. PROVIDE DOUBLE JOISTS EACH SIDE OF ALL OPENINGS IN FLOORS AND ROOFS UNLESS DETAILED OTHERWISE. COORDINATE SIZE AND LOCATION OF ALL OPENINGS WITH ARCHITECTURAL AND MECHANICAL DRAWINGS.
3. PROVIDE TWO 2x10 HEADERS OVER AND DOUBLE STUDS EACH SIDE OF ALL OPENINGS IN STUD BEARING WALLS UNLESS NOTED OTHERWISE.
4. PROVIDE SOLID BLOCKING AT FLOORS FOR WOOD COLUMNS AND MULTIPLE STUD POSTS TO PASS THROUGH.
5. PROVIDE CONTINUOUS SOLID BLOCKING AT MID-HEIGHT OF ALL STUD WALLS OVER 10'-0" IN HEIGHT.
6. UNLESS NOTED OTHERWISE, ALL STRUCTURAL STUD WALLS SHOWN ON THE PLANS SHALL BE 2x6 AT 16 INCHES ON CENTER. ALL NON-STRUCTURAL WALLS SHALL BE 2X4 AT 16 INCHES ON CENTER.
7. USE FULL LENGTH STUDS (BALLOON FRAME) ON EXTERIOR WALLS AT STAIRWAYS AND AT VAULTED CEILINGS.
8. PLYWOOD WALL SHEATHING SHALL HAVE SOLID BLOCKING AT ALL PANEL EDGES. PROVIDE THE FOLLOWING MINIMUM NAILING UNLESS NOTED OTHERWISE ON PLANS:

8d AT 6 INCHES ON CENTER AT SHEET EDGES (PANEL EDGES)

8d AT 12 INCHES ON CENTER AT INTERMEDIATE FRAMING

9. UNLESS OTHERWISE NOTED ON THE PLANS, ALL WOOD STUD WALLS SHALL HAVE THEIR LOWER WOOD PLATED ATTACHED TO THE WOOD FRAMING BELOW WITH 16d NAILS AT 6 INCHES ON CENTER STAGGERED OR BOLTED TO CONCRETE WITH 5/8 INCH DIAMETER ANCHOR BOLTS AT 8'-0" ON CENTER WITH A MINIMUM EMBEDMENT OF 7 INCHES IN CONCRETE.

STRUCTURAL DESIGN DATA

STRUCTURAL DESIGN DATA

FLOOR LIVE LOADS: SHALL BE IN ACCORDANCE WITH THE LOAD DIAGRAMS AND GENERAL STRUCTURAL NOTES.

ROOF LIVE LOADS: 20 P.S.F., PER THE SOLAR DECATHLON RULES

WIND LOADS: 60 M.P.H., EXP. C, I = 1.0, PER THE SOLAR DECATHLON RULES

FOUNDATIONS**FOUNDATIONS**

- ALLOWABLE BEARING PRESSURE: 1,500 PSF (PER SOLAR DECATHLON RULES)

NON-LOAD BEARING PARTITIONS

1. FRAMING FOR INTERIOR PARTITIONS SHALL CONSIST OF WOOD STUD TYPE FRAMING. PARTITIONS SHALL BE CONNECTED TO THE STRUCTURE SO AS TO ALLOW FOR BOTH VERTICAL AND LATERAL DEFORMATIONS OF THE STRUCTURE.

SEQUENCING CONSTRUCTION AND LATERAL STABILITY

2. THE STRUCTURAL COMPONENTS BY THEMSELVES ARE A NON-SELF SUPPORTING STRUCTURE. LATERAL FORCES DUE TO WIND, EARTHQUAKE, OR SOIL ARE CARRIED BY THE ROOF AND FLOOR DIAPHRAGMS TO THE LATERAL SYSTEM. CERTAIN ELEMENTS SHOWN ON THE STRUCTURAL DRAWINGS (SUCH AS SHEARWALLS, SLABS ON GRADE AND ROOF DIAPHRAGM) ARE REQUIRED FOR OVERALL STABILITY OF OTHER ELEMENTS (SUCH AS BEAMS, COLUMNS AND WALLS). IF, DUE TO SEQUENCING OF CONSTRUCTION, THESE STABILITY ELEMENTS ARE NOT IN PLACE, THE CONTRACTOR SHALL RETAIN A LICENSED STRUCTURAL ENGINEER WHO SHALL INVESTIGATE WHERE TEMPORARY SHORING / BRACING IS REQUIRED, AND SHALL DESIGN THIS TEMPORARY SHORING / BRACING. THE CONTRACTOR SHALL PROVIDE THIS SHORING / BRACING UNTIL THE REQUIRED STRUCTURAL ELEMENTS AND THEIR CONNECTIONS HAVE BEEN INSTALLED AND REACH THEIR FINAL DESIGN STRENGTHS.

INSPECTION**SHOP DRAWINGS**

1. SHOP DRAWINGS FOR OPEN WEB WOOD TRUSSES SHALL BE SUBMITTED FOR REVIEW PRIOR TO FABRICATION OF THESE ITEMS.
2. DIMENSIONS AND QUANTITIES ARE NOT REVIEWED BY THE ENGINEER OF RECORD; THEREFORE THEY SHALL BE VERIFIED BY THE CONTRACTOR. CONTRACTOR SHALL REVIEW AND STAMP DRAWINGS PRIOR TO REVIEW BY THE ENGINEER OF RECORD. CONTRACTOR SHALL REVIEW DRAWINGS FOR CONFORMANCE WITH THE MEANS, METHODS, TECHNIQUES, SEQUENCES, AND OPERATIONS OF CONSTRUCTION, AND ALL SAFETY PRECAUTIONS AND PROGRAMS INCIDENTAL THERETO. SUBMITTALS SHALL INCLUDE ONE REPRODUCIBLE AND ONE COPY; REPRODUCIBLE WILL BE MARKED AND RETURNED.
3. SHOP DRAWING SUBMITTALS PROCESSED BY THE ENGINEER ARE NOT CHANGE ORDERS. THE PURPOSE OF SHOP DRAWING SUBMITTALS BY THE CONTRACTOR IS TO DEMONSTRATE TO THE ENGINEER THAT THE CONTRACTOR UNDERSTANDS THE DESIGN CONCEPT, BY INDICATING WHICH MATERIAL IS INTENDED TO BE FURNISHED AND INSTALLED, AND BY DETAILING THE INTENDED FABRICATION AND INSTALLATION METHODS. IF DEVIATIONS, DISCREPANCIES, OR CONFLICTS BETWEEN THE SHOP DRAWING SUBMITTALS AND THE CONTRACT DOCUMENTS ARE DISCOVERED EITHER PRIOR TO OR AFTER THE SHOP DRAWING SUBMITTALS ARE PROCESSED BY THE

ENGINEER, THE DESIGN DRAWINGS AND SPECIFICATIONS SHALL CONTROL AND SHALL BE FOLLOWED.

4. SHOP DRAWINGS OF DESIGN BUILD COMPONENTS INCLUDING STAIRS BY OTHERS SHALL INCLUDE THE DESIGNING PROFESSIONAL ENGINEER'S STAMP, AND SHALL BE APPROVED BY THE COMPONENT DESIGNER PRIOR TO THE CURSORY REVIEW BY THE ENGINEER OF RECORD FOR LOADS IMPOSED ON THE BASIC STRUCTURE. THE COMPONENT DESIGNER IS RESPONSIBLE FOR CODE CONFORMANCE AND ALL NECESSARY CONNECTIONS NOT SPECIFICALLY CALLED OUT ON ARCHITECTURAL OR STRUCTURAL DRAWINGS. SHOP DRAWINGS SHALL INDICATE MAGNITUDE AND DIRECTION OF ALL LOADS IMPOSED ON BASIC STRUCTURE. DESIGN CALCULATIONS SHALL BE INCLUDED IN THE SUBMITTAL.

MISCELLANEOUS

5. REFER TO ARCHITECTURAL, MECHANICAL, ELECTRICAL, CIVIL, ELEVATOR, OR OTHER SPECIALTY ENGINEERING DRAWINGS FOR DIMENSIONS NOT SHOWN, INCLUDING BUT NOT LIMITED TO: SIZE AND LOCATION OF CURBS, EQUIPMENT HOUSEKEEPING PADS, WALL AND FLOOR OPENINGS, BLOCKOUTS, FLOOR DEPRESSIONS, SUMPS, DRAINS, ANCHOR BOLTS, EMBEDDED ITEMS, ARCHITETURAL TREATMENT, ETC. CONTRACTOR SHALL VERIFY DIMENSIONS AND RESOLVE DISCREPANCIES OR CONFLICTS PRIOR TO CONSTRUCTION.

6. WHERE SECTIONS ARE INDICATED ON THE PLAN BY A NUMBER AND A DRAWING THUS, 1/S1, THE INDICATED SECTION (1) IS SHOWN ON THE STRUCTURAL DRAWING S1.



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**BAMBOO PANELS AND VENEERS
PRODUCT SPECIFICATION
IN CSI 3-PART FORMAT**

GENERAL NOTES TO SPECIFIER:

PLEASE GO TO www.lamboo.us TO VERIFY THIS IS THE MOST CURRENT VERSION OF THIS SPECIFICATION.

THE FOLLOWING PRODUCT SPECIFICATION LANGUAGE IS INTENDED TO ASSIST DESIGN PROFESSIONALS IN SPECIFYING BAMBOO PLYWOOD IN EXISTING 3-PART SPECIFICATIONS FOR PANELING, CASEWORK, DOORS, AND SIMILAR ARCHITECTURAL WOODWORK.

SAMPLE LANGUAGE IS PROVIDED FOR APPLICABLE ARTICLES IN PART 1-GENERAL AND PART 2-PRODUCTS FOLLOWING THE CONSTRUCTION SPECIFICATION INSTITUTE'S SECTIONFORMAT. BECAUSE OF THE VARIATION IN SPECIFICATION SYSTEMS CURRENTLY IN USE, ARTICLE AND PARAGRAPH NUMBERS AND TITLES MAY DIFFER SOMEWHAT THAN PRESENTED HEREIN. THE SAMPLE LANGUAGE SHOULD BE EDITED ACCORDINGLY TO FIT EACH FIRM'S SPECIFICATIONS.

ARTICLES AND PARAGRAPHS OF THIS PRODUCT SPECIFICATION ASSUME THE PROJECT MANUAL WILL CONTAIN COMPLETE DIVISION 1 DOCUMENTS INCLUDING 01 25 13-PRODUCT SUBSTITUTION PROCEDURES, SECTIONS 01 33 00-SUBMITTAL PROCEDURES, 01 62 00-PRODUCT OPTIONS, 01 66 00-PRODUCT STORAGE AND HANDLING REQUIREMENTS, 01 74 00-CLEANING AND WASTE MANAGEMENT, 01 77 00-CLOSEOUT PROCEDURES, AND 01 78 00-CLOSEOUT SUBMITTALS. CLOSE COORDINATION WITH DIVISION 1 SECTIONS IS REQUIRED. IF THE PROJECT MANUAL DOES NOT CONTAIN THESE SECTIONS, ADDITIONAL INFORMATION MAY BE INCLUDED UNDER THE APPROPRIATE ARTICLES.

NOTES TO THE SPECIFIER ARE IN ALL UPPER CASE TEXT AND ARE CONTAINED WITHIN ROWS OF ASTERISKS.

GREY HIGHLIGHTED GREEN TEXT AND NOTES RELATE TO LEED® PROJECTS AND CAN BE DELETED IF THE PROJECT IS NOT INTENDED TO ATTAIN LEED CERTIFICATION.

OPTIONAL ITEMS REQUIRING SELECTION BY THE SPECIFIER ARE ENCLOSED WITHIN BRACKETS, E.G. [35] [40] [45]. MAKE APPROPRIATE SELECTIONS AND DELETE OTHERS.

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PART 1—GENERAL

1.01 SUMMARY

A. Section Includes:

ADD SUBPARAGRAPH IDENTIFYING THE ITEMS MADE WITH BAMBOO PLYWOOD.

B. Related Sections:

INCLUDE ALL DIVISION 01 SECTIONS CONTAINING LEED® REQUIREMENTS.

INCLUDE SECTION 01350 IF THE PROJECT IS A SCHOOL LOCATED IN A DISTRICT USING "SECTION 01350 – SPECIAL ENVIRONMENTAL REQUIREMENTS"
<http://www.chps.net/manual/index.htm#specs> PREPARED BY THE COLLABORATIVE FOR HIGH PERFORMANCE SCHOOLS (CHPS).

1.02 REFERENCES

IF THE "REFERENCES" ARTICLE IS USED, INCLUDE THE FOLLOWING IN THE REFERENCE LIST:

A. American Society for Testing and Materials (ASTM):

1. ASTM D 1037, Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials.
2. ASTM D 3043 Standard Test Methods for Flexural Structural Panels in Flexure
3. ASTM E 84, Standard Test Method for Surface Burning Characteristics of Building Materials.
4. ASTM D 4442, Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials.
5. ASTM D 3500, Standard Test Method for Structural Panels in Tension
6. ASTM E 1333, Standard Test Method for Determining Formaldehyde Concentrations in Air Emission Rates from Wood Using a Large Chamber

B. American National Standards Institute/Hardwood Plywood and Veneer Association (ANSI/HPVA): American National Standard for Hardwood and Decorative Plywood, HP-1.

C. US Green Building Council's Leadership in Energy and Environmental Design Green Building Rating System™ (LEED).

1.03 SUBMITTALS

A. Product Data:

INCLUDE THE FOLLOWING IN THE "PRODUCT DATA" PARAGRAPH:

1. Bamboo plywood manufacturer's product data.

B. LEED Submittals:

INCLUDE THE FOLLOWING FOR LEED PROJECTS, AS APPLICABLE:

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- *****
1. Credit MR 6, Rapidly Renewable Materials: Bamboo manufacturer's product data for each product used, indicating that product(s) are manufactured from a rapidly renewable resource.

FOLLOWING RELATES ONLY TO ADHESIVES AND FINISHES APPLIED TO UNFINISHED PLYBOO PRODUCTS. REFERENCES TO DATA SHOULD BE SUPPLIED BY THE ADHESIVE, SEALANT, OR FINISH MANUFACTURER.

2. Credit EQ 4.1, Low Emitting Materials: Adhesive and/or sealant manufacturer's product data for each product used, indicating adhesive agent contains low voc adhesive.
3. Credit EQ 4.2, Low Emitting Materials: Paints and/or coatings manufacturer's product data for finishes used.

1.07 WARRANTY

INCLUDE THE FOLLOWING SPECIAL WARRANTY:

- A. A Special Warranty for Lamboo Inc. Products referenced at www.lamboo.us

PART 2-PRODUCTS

2.01 MATERIALS

INCLUDE THE FOLLOWING PARAGRAPHS AND SUBPARAGRAPHS FOR BAMBOO PLYWOOD AS APPROPRIATE.

- A. Bamboo Plywood:
1. Lamboo Inc. Architectural and Structural Bamboo
a. Tel: 217-408-4446.
b. www.lamboo.us
2. Species: Moso (*Phyllostachys Pubescens*).

INCLUDE THE FOLLOWING SUBPARAGRAPH IF PRODUCTS ARE USED FOR WALL OR CEILING FINISHES PURSUANT TO IBC SECTION 803.

3. Fire Resistance Classification: [Class A] [Class C].
a. Test surface burning characteristics in accordance with ASTM E 84.
4. Type:

SELECT APPROPRIATE TYPE(S) BELOW TO SUIT PROJECT REQUIREMENTS. DELETE THOSE NOT USED. FABRICATION ARTICLE OR DRAWINGS MUST CLEARLY IDENTIFY SPECIFIC USES.

GO TO www.lamboo.us FOR AVAILABLE FACE SIZES.

- a. 7/8 inch thick, 5-ply, [amber flat grain] [natural flat grain].
b. 3/4 inch thick, 3-ply [amber flat grain] [amber edge grain] [natural flat grain] [natural edge grain] [Dark Strand] [Honey Strand] [Neopolitan].
c. 3/4 inch thick, solid, [amber edge grain] [natural edge grain]

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- d. 1/2 inch thick, 3-ply, [amber flat grain] [amber edge grain] [natural flat grain] [natural edge grain] [Neopolitan].
 - e. 1/4 inch thick, 3-ply, [amber flat grain] [amber edge grain] [natural flat grain] [natural edge grain].
 - f. 1/8 inch thick, bamboo veneer panel, [amber flat grain] [amber edge grain] [natural flat grain] [natural edge grain].
 - g. 4 millimeters, solid, [Honey Strand] [Dark Strand]
 - h. 1-1/16 inch thick, 5-ply PlybooSquared [amber end grain] [natural end grain]
5. Physical/Mechanical Properties:
- a. ASTM D 3043 Method D Flexural Strength (MOE/MOR)
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain: 179 MOE/11,371 MOR average
 - ii. $\frac{3}{4}$ inch thick 3-ply Cross Core: 148 MOE/9,109 MOR average
 - iii. $\frac{3}{4}$ inch thick Cross Core Strand: 268 MOE/14,762 MOR average
 - iv. $\frac{3}{4}$ inch flat grain panel Average Modulus of Elasticity: 1,324,800psi
 - b. ASTM D 1037 Screw Hold
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain
 - a) Face: 261 pounds average
 - b) Back: 233 pounds average
 - c) Edge 1: 513 pounds average
 - d) Edge 2: 636 pounds average
 - ii. $\frac{3}{4}$ inch thick 3-ply Cross Core
 - a) Face: 1009 pounds average
 - b) Back: 681 pounds average
 - c) Edge 1: 361 pounds average
 - d) Edge 2: 670 pounds average
 - iii. $\frac{3}{4}$ inch thick Cross Core Strand
 - a) Face: 742 pounds average
 - b) Back: 831 pounds average
 - c) Edge 1: 980 pounds average
 - d) Edge 2: 759 pounds average
 - c. ASTM D 4442 Method A Moisture Content
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain: 4.9 percent average
 - ii. $\frac{3}{4}$ inch thick 3-ply Cross Core: 5.7 percent average
 - iii. $\frac{3}{4}$ inch thick Cross Core Strand: 4.4 percent average
 - d. ASTM D 1037 Tensile Strength Parallel
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain: Load 1700 pounds, Strength 7535 psi average
 - ii. $\frac{3}{4}$ inch thick 3-ply Cross Core: Load 892 pounds, Strength 3547 psi average
 - iii. $\frac{3}{4}$ inch thick Cross Core Strand: Load 1732 pounds, Strength 5968 psi average
 - e. ASTM D 3500 Tensile Strength Perpendicular
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain: Load 642 pounds, Strength 428 psi average
 - ii. $\frac{3}{4}$ inch thick 3-ply Cross Core: Load 1536 pounds, Strength 1024 psi average
 - iii. $\frac{3}{4}$ inch thick Cross Core Strand: Load 1591 pounds, Strength 1061 psi average
 - f. ASTM D 1037 Dimensional Stability at 20% RH
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain
 - a) Linear Expansion: Parallel -0.04 percent; Perpendicular -0.10 percent average
 - b) Thickness Swell: -0.13 percent average

Lamboo Panel 07/09/08

- ii. $\frac{3}{4}$ inch thick 3-ply Cross Core
 - a) Linear Expansion: Parallel -0.09 percent;
Perpendicular -0.07 percent
 - b) Thickness Swell: -0.39 percent
- iii. $\frac{3}{4}$ inch thick Cross Core Strand
 - a) Linear Expansion: Parallel -0.04 percent,
Perpendicular -0.07 percent
 - b) Thickness Swell: -0.13 percent
- g. ASTM E 1333 Formaldehyde Emission
 - i. $\frac{3}{4}$ inch thick 1-ply Edge Grain: 0.02 ppm
 - ii. $\frac{3}{4}$ inch thick 3-ply Cross Core: 0.02 ppm
 - iii. $\frac{3}{4}$ inch thick Cross Core Strand: 0.02 ppm
- h. ASTM E 84 Surface Burning
 - i. $\frac{3}{4}$ inch thick, 3-ply, edge grain cross core: Class C
 - ii. $\frac{3}{4}$ inch thick, 3-ply, edge grain cross core Strand: Class C

END OF PRODUCT SPECIFICATION

Lamboo Panel 07/09/08



1800 Woodfield Drive, Suite 202 • Savoy, IL 61874 • Ph:(217) 356-0600 • Fax:(217) 356-0088 • www.prepareinc.us

May 22, 2009

Mr. Mark Taylor, Assistant Professor
University of Illinois at Urbana – Champaign
College of Fine and Applied Arts, School of Architecture
117 Temple Hoyne Buell Hall
611 Lorado Taft Drive
Champaign, IL 61820

Subject: Solar Decathlon

Re: Lamboo Engineering Values

Dear Professor Taylor,

The purpose of this letter is to outline the engineering values that PREPARE, Inc. (PREPARE) used in its calculations for the Lamboo material as it applies to the University of Illinois' Solar Decathlon House.

PREPARE, INC. was provided a list of material properties by Lamboo, Inc. PREPARE applied a factor of safety of five (5) to the values provided to obtain the allowable stress design values used in the structural design of all Lamboo members and assemblies containing the Lamboo material. Please find attached this aforementioned document that shows both the base values provided by Lamboo, Inc. and those values used for structural design by PREPARE.

Sincerely,
PREPARE, INC.

A handwritten signature in blue ink, appearing to read "Marc A. Mitalski".

Marc A. Mitalski, P.E., S.E.
President



MECHANICAL PROPERTIES

Adhesive:

Dynorit SPS (Acrolite LP 4116/A942/H240)

Does not contain any components considered hazardous to the environment, or does not contain any solvents (VOC's) heavy metals, bactericides, or halogenated organic components.

Formaldehyde Emissions:

a. "traditional" bamboo – 0.0127ppm (per ENV717-1)

Indentation Resistance/Hardness:

Natural Horizontal – avg. 2109

Natural Vertical – avg. 1813

Carbonized Horizontal – avg. 1907

Carbonized Vertical – avg. 1409

Strandwoven Light – 3200

Strandwoven Dark – 3200

Moisture Content:

7.3% (average for all tested samples)

Moisture content of final product will vary based on climate conditions to which the material is warehoused and then installed. It is highly recommended to let all bamboo products acclimate to installed space conditions.

Dimensional Stability:

Stability factor = 0.00144

Flammability:

Class I (ASTM E648 – Critical Radiant Panel Test)

Smoke Density:

270 - Flaming Mode (ASTM E622)

300 - Non-flaming mode (ASTM E622)

* Passing is any number below 450.

Compression Strength:

$F_{c\parallel}$ Parallel to grain: 9345 psi (ASTM 3501-86 A) →

$F_{c\perp}$ Perpendicular to grain: 3043 psi (ASTM 3501-86 A) →

Tensile Strength:

F_T 15300 parallel to grain (ASTM 3500-90) →

Bending Strength:

F_b 14600 psi (ASTM D3043) →

Shear Strength:

F_v 789 psi (ASTM D3048) →

DESIGN VALUES

F.S. = 5 APPLIED

$F_{c\parallel} = 1869 \text{ psi}$

$F_{c\perp} = 609 \text{ psi}$

$F_T = 3060 \text{ psi}$

$F_b = 2920 \text{ psi}$

$F_v = 158 \text{ psi}$



Closed-cell Foam Insulation

The University of Illinois Solar Decathlon Team will be using NFCI Insulstar closed cell foam insulation in the walls and ceiling of our home to a maximum thickness of 8 and 12 inches respectively. As this exceeds standard allowable thicknesses per code requirements without additional testing, we have attached additional testing information to this letter to prove that the home will remain safe and effective during the public tours on the National Mall and into the future. It shows compliance with both the flame spread index and shows the alternate testing method required per code when the thickness exceeds 4". The walls and ceiling containing insulation will be protected from the home with 5/8" gypsum board, exceeding the ½" requirement. We hope that this information is sufficient to qualify the use of NFCI Insulstar as the insulation of choice for the Illinois Solar Decathlon Project.

Insulstar ES Report ESR-1615 – Subject: Spray Applied Polyurethane Insulation

http://www.icc-es.org/reports/pdf_files/ICC-ES/ESR-1615.pdf

NCFI Limitations of Insulstar Insulation Thickness Point Paper

<http://www.insulstar.com/uploads/Point%20Paper%20Limits%20on%20Thickness.pdf>

**Technical
Bulletin**
April, 2008

InsulStar® High Performance Insulation

InsulStar® ICC Evaluation Services Report Complies with 2006 Codes

The ESR-1615 Report from ICC Evaluation Service, Inc., acknowledges that InsulStar High Performance Closed-Cell Polyurethane Foam Insulation is in compliance with the 2006 IBC, IRC AND IECC. This includes being the only closed-cell spray foam evaluated for use in unvented attics per the 2006 IRC. InsulStar has the highest performance over the widest range of applications by providing insulation, moisture vapor control, air barrier, and water barrier in a single product.

**INSULSTAR MEETS
THE FOLLOWING
2006 IRC
REQUIREMENTS**



- > Allows unvented attic application
- > Normally requires no additional vapor retarder
- > 8 inches maximum thickness in wall assembly
- > 12 inches maximum thickness in ceiling
- > Lists R-values to the maximum installed thickness
- > Job-site certification provided for installer
- > Allows exposed SPF on floors of vented attics
- > Permits ignition barrier coating

**HIGHER R-VALUE
REDUCES REQUIRED
INSULATION
THICKNESS**



The high R-value per inch thickness allows the builder to install the necessary insulation in a thinner wall or roof cavity without sacrificing energy savings, thereby maximizing the space inside the thermal envelope. Using smaller studs and rafters requires less lumber and fewer trees. InsulStar complies with the IECC for applications of reduced R-values in attics/ceilings.

**INSULSTAR®
HAS HIGHEST
R-VALUE**



InsulStar is a spray-applied cellular polyurethane foam plastic insulation that is installed in cavities of roofs, ceilings, floors, crawl spaces and stud wall assemblies. The foam plastic is a two-component, closed-cell, one-to-one by volume spray foam system with a nominal density of 2 pcf. InsulStar insulation may be used for application to wood, metal, concrete and masonry and gypsum board surfaces.

**NCFI GOLD STAR™
CERTIFIED
CONTRACTORS
ASSURE PROPER
INSTALLATION
OF INSULSTAR®**

**InsulStar® POLYURETHANE FOAM
TYPICAL PHYSICAL PROPERTIES**

R-Value @ 3.5"	22
Compressive strength	27 psi
Moisture vapor perm @ 2"	0.7
Air permeability @ 1"	0.000
Odor emission	Pass
Water penetration @ 56 ft	0.0
FEMA flood resistance	Class 4

Florida Product Approval for roof deck wind uplift resistance.

For more information on InsulStar, please contact your NCFI representative or call us toll free at 866-678-5283 or visit us at InsulStar.com.



NCFI Polyurethanes, A Division of BMC, P.O. Box 1528, Mount Airy, NC 27030
NCFI.com, Phone: 800.346.8229, Fax: 336.789.9586, E-mail: moreinfo@ncl.net



Illinois HVAC System

The Illinois design intent is to have an integrated unit with ventilation, heating and cooling. We will be using an UltimateAir RecoupAerator ERV for both ventilation needs and to supply the forced air for our heating and cooling. For the heating and cooling, we are going to use a heat pump system which will be ducted.

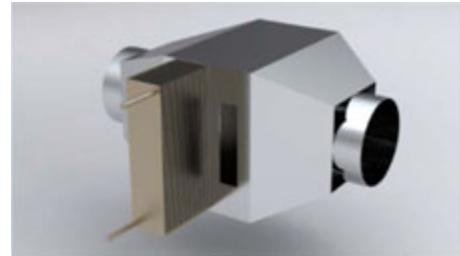
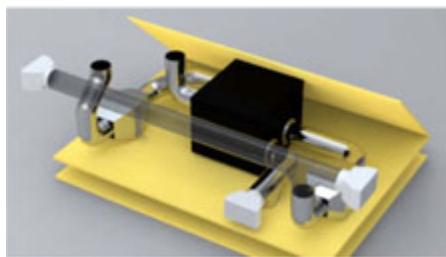
The system will include a number of components, including a transition from the 6" duct to the heat exchanger and back to the 6" duct manufactured by the University metal shop and a drip pan under both heat exchangers with a nipple to drain the condensate.

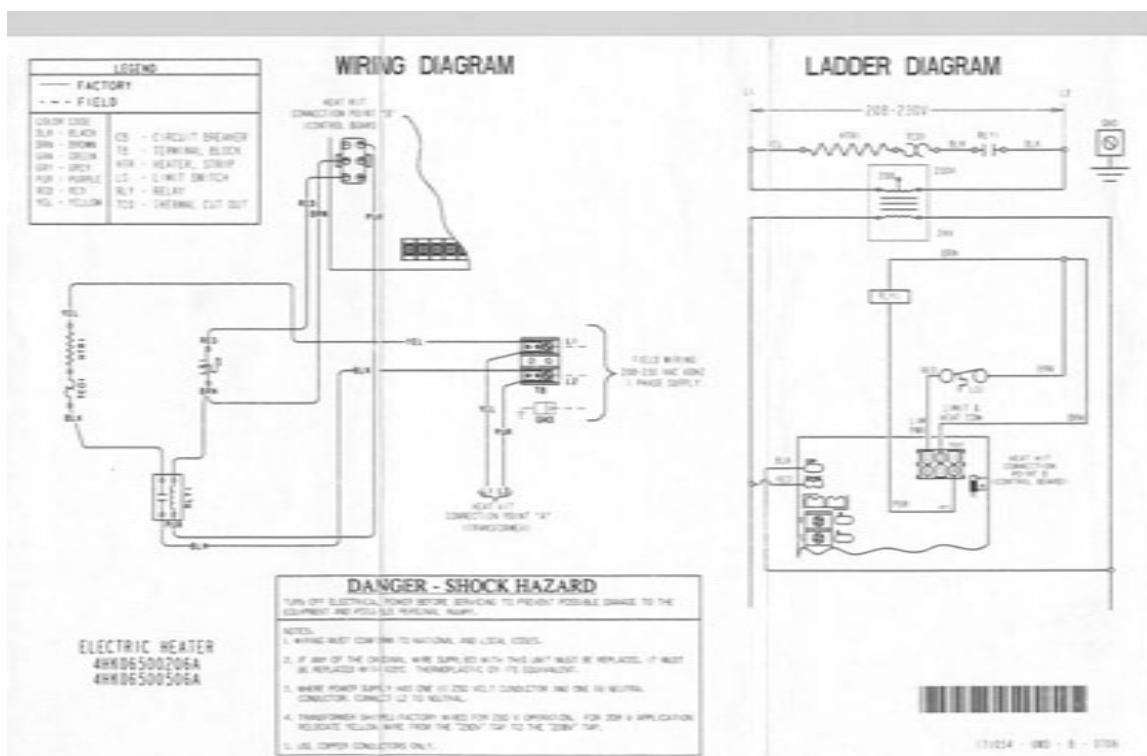
The purchased electric resistance heating element has a thermal cut out included in the wiring. This will cut off electricity to the unit if the temperature goes above the preset limit inside the duct. Then using either "RLY1" in the included wiring diagram or a different relay wired in series with the ERV to cut power to the heating element when the fans in the ERV are not running. So looking at the wiring diagram, instead of the relay going to the controls for the standard furnace, it will now go to our ERV. We will then connect the BLK and YEL through the FIELD WIRING to our home control system to control when the heater will go on and off.

We are going to stress test the unit once it is constructed in a high temp/high humidity setting. We will run the unit at various capacities and then for an extended period of time, such as a few days, at the highest capacity and air flow to make sure it will be reliable on the Mall. After this, if we can get access to an environmental chamber where we can precisely control the temperature and humidity conditions, we will test the unit by ARI 210/240 to determine the SEER and HSPF rating of the unit. If we can not control the outside conditions then we will still test the unit and note the conditions it was tested at to determine the SEER and HSPF. We will also test the unit to make sure the control system is working correctly as well as the relay cut out for the electric resistance heater.

With this text, we have submitted a wiring diagram for the product and a rendering of the system for clarification.

The refrigerant for the system will be R-134a. We are going to braze as many connections as possible and when required, will use Swagelock fittings. The alternate solution to this method described above, following failed tests when described above or other unforeseen safety concerns will be to use an off the shelf mini-split system. As discussed above, the team will follow all code requirements with regard to testing for safety, minimum efficiency and stress testing for reliability.





11124 - 080 - 2 - 0706



Illinois Hot water Desuperheater System

The Illinois Team will also create a custom DHW system. The team will use a Marathon water heater (MR50245 – See Specifications) and will attach a heat pump to the top of the tank. The attached drawings and documents show the fittings and other hardware that will be used. The cold water inlet has been moved to the bottom of the tank where the drain valve is located to accommodate the larger diameter piping of the heat pump at the top of the unit. The tank will still include a pressure release valve and the suction valve that is installed by the manufacturer. In this system, the heat exchange will be with the copper coil extending into the tank. The system will comply with P2902.5.2 Heat Exchangers.

Finally, with regard to the Gosselin ratting of R-22, it has an acceptable Gosslien rating of 1. Since the product is Chlorodifluoromethane (R22), a hydrofluorocarbon refrigerant, it will fall under Gosselin rating of 1. It is per the definition: ESSENTIALLY NONTOXIC TRANSFER FLUIDS. Fluids having a Gosselin rating of 1, including propylene glycol; mineral oil, polydimethylsiloxane; hydrochlorofluorocarbon, chlorofluorocarbon and hydrofluorocarbon refrigerants; and FDA-approved boiler water additives for steam boilers. The MSDS data for safety and toxicity can be found at <http://complyplus.grainger.com/grainger/msds.asp?sheetid=3125728> This report states: Ingestion: no hazards to be specifically mentioned.

IRC R104.11 Request

In summary, we submit this documentation as proof of compliance of these systems and to ensure the safety of everyone involved with the Illinois Solar Decathlon project. Through IRC R104.11, we would like to request approval to use these systems. If you have any questions, please feel free to contact us at any time.

ENGINEERING NARRATIVE

Introduction

The UIUC engineering effort was carried out by faculty and students from the College of Engineering at the UIUC and in collaboration with students and faculty from many disciplines across campus. Most of the engineering students participated in a two-semester course sequence known as ENG 491 “Solar Home Design” and ENG 491 “Solar Home Laboratory.” This course sequence had between twenty and thirty students. In addition, several students participated through senior design courses in their respective academic departments. Finally, several graduate students participated as volunteers or as part of their ongoing research efforts.

The engineering efforts were coordinate through smaller teams, each addressing particular subsystems in the house. This delegation occurred with the clear understanding that these systems are interdependent, requiring regular coordination between students within engineering and across campus to architecture and industrial design. The major subsystems discussed in this report are as follows: Electrical, Heating, Ventilation, and Air Conditioning (HVAC), Hot Water, Appliances and Home Entertainment, and Building Automation and Control. These subsystems are discussed at length below.

Some of the guiding principles of our engineering design are as follows

- 1) Electricity is the most versatile form of energy since it can be converted efficiently to other forms of energy and excess electrical energy can always be sourced back into the electric grid. From a subsystem perspective, electrically-powered solutions are not always the most efficient, but the system-level advantage of flexibility generally results in a system-level optimal trade-off. Therefore, our design decisions favored electrically-powered solutions.
- 2) It is always beneficial to have a backup plan. While we worked on several innovative designs for “Plan A,” we always had a “Plan B” ready to go so that timelines could be preserved and risk could be mitigated.
- 3) In real-life engineering, 90% is failure. While practicing engineers understand this, students that are accustomed to grades where “90% = A” may still need to learn this. As such, a guiding

principle was that no decisions were made without extensive simulation, discussion, and whenever possible, experimentation. Our students were required to present their ideas and data to the whole team for design review. Frequently, errors and untenable assumptions were discovered in this process.

- 4) Keeping an open mind is a key. Every idea was “put through the ringer” and no idea was automatically squashed. The guiding principle was teamwork, where the entire team takes credit or blame for whatever happens.
- 5) System-level thinking is a must. A common problem in engineering is that different teams optimize their different subsystems individually, only to find out that the optimized systems are far from optimal when placed in the full system. This guiding principle was kept in mind during all meetings so that the subsystem teams were always conscious of efforts of other teams and didn’t lose the big picture focus and waste effort on minor issues.

Electrical

The electrical system consists of two major components. First, there is the ordinary household wiring and safety mechanisms, which are routine and in compliance with the NEC. Second, there is the solar photovoltaic (PV) power system. The PV system was designed from both a power generation and an aesthetic standpoint and is the subject of most of this narrative section.

From a power generation standpoint, a minimal design would ensure that the energy used by the house would be at most zero kilowatt-hours but with minimal upfront cost. From an aesthetic standpoint, the team preferred to blend the PV system into the building design without sacrifice of architectural objectives.

The UIUC team conducted several meetings of a period of months to arrive at the final design, which places the PV modules at nearly the optimal angle for solar harvest, fills the southern roof space, and provides far more than enough power to balance the building energy. This approach required the architectural design team to “work around” the limitations of PV systems. For example, numerous types of rooflines are possible and desirable for various reasons, but they all came with cost or performance sacrifices that would reduce the marketability of the house. As such, the final design was the product of many back-and-forth tradeoffs on roof size, PV peak power capability, roof pitch, cost analysis, energy analysis, PV module technology, and ease of installation. The following sections describe the resulting PV system in detail.

Ambient Temperature

Temperature data obtained from the National Climatic Data Center (www.ncdc.noaa.gov), for National Arboretum DC, MD suggests that the design temperature for the house ranges from -10°F to 104°F (-23°C to 40°C). Additionally, the operating temperature of the PV modules can reach up to 75°C.

Electrical System Block Diagram

Figure 1 depicts the one-line diagram of the electrical system (Detailed schematic attached, E-101). In Fig. 1, each Photovoltaic (PV) sub-array consists of 20 Sunpower SPR-225-BLK modules. The 20 modules are arranged as 2 parallel strings of 10 series-connected modules. This constrains the current and voltage of each string below 21 A (the inverter DC maximum input current) and 600 V (the inverter DC maximum input voltage), respectively. More precisely, at the minimum ambient temperature (-23°C), employing the published temperature coefficient of voltage, (-0.1325 V/°C), the worst-case value of the

expected string voltage is $(10 \text{ series modules}) \left(V_{oc} - 0.1325 \frac{\text{V}}{\text{C}} (-23^\circ\text{C} - 25^\circ\text{C}) \right) = 581.7 \text{ V}$, where V_{oc} is the rated open-circuit voltage at 25°C . Also, at the maximum ambient temperature, (40°C), employing the temperature coefficient of current, ($3.5 \text{ mA}/^\circ\text{C}$), the worst-case value of expected string current is $\left(I_{sc} + 3.5 \frac{\text{mA}}{\text{C}} (40^\circ\text{C} - 25^\circ\text{C}) \right) = 6.178 \text{ A}$, where I_{sc} is the short-circuit current at 25°C .

Each subarray is connected to a SunPower 5000m inverter. The inverter eliminates the need for combiner boxes by accepting inputs from four strings (of which only two are used in our design, one for each subarray) and also provides integrated DC disconnects for the PV strings.

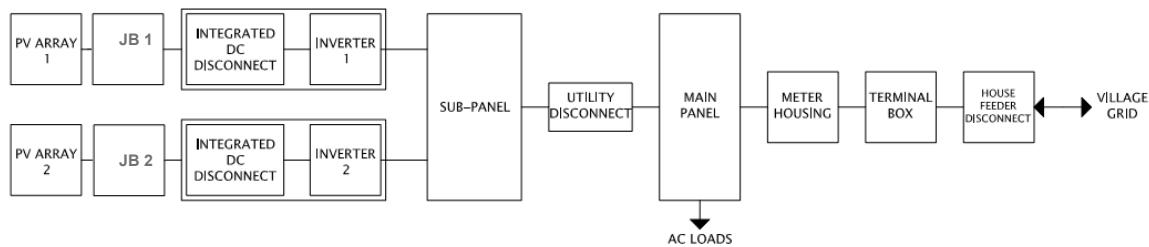


Figure 1: One-Line Diagram of Electrical System

The numbers attached in parentheses for each conductor correspond to the tags in E-101.

PV Modules to Junction Boxes (1)

Conductor Sizing

The short-circuit current of the SPR-225-BLK module is 5.87 A, which implies a continuous current rating of 7.34 A ($5.87 \text{ A} \times 1.25$). The 80% operation current rating is 9.18 A ($7.34 \text{ A} \times 1.25$). Therefore, the DC conductors from the modules should hence have a 30°C ampacity of 9.18 A.

Note that while these cables will be installed in free air, they will be in contact with the back of the PV modules, reaching temperatures of up to 75°C . The following conductors could be used for this application [NEC 310.17].

- 10 AWG USE-2/RHH/RHW-2: Ampacity in free air at 75°C : 22.55 A (55×0.41)
- 12 AWG USE-2/RHH/RHW-2: Ampacity in free air at 75°C : 16.4 A (40×0.41)
- 14 AWG USE-2/RHH/RHW-2: Ampacity in free air at 75°C : 14.35 A (35×0.41)

Voltage Drop Calculations

It is generally suggested that the maximum voltage drop at full power from the PV source to the inverter be limited to 3%. We will assume a DC bus voltage of 410 V for each sub-array (Number of series modules x Rated Voltage = $10 \times 41\text{ V} = 410\text{ V}$). This means that the voltage drop in the conductors should be less than or equal to 12.3 V.

The maximum length wire run from the PV sub-array to the inverter is approximately equal to 13.21 m. The DC resistance of 10 AWG conductors is $3.27 \times 10^{-3}\text{ } \Omega / \text{m}$. Assuming rated current, this implies that the maximum voltage drop experienced is, $5.49\text{ A} \times 3.27 \times 10^{-3}\text{ } \Omega / \text{m} \times 13.21\text{ m} = 2.37\text{ V}$. This is much lesser than 3%-limit.

Conductor chosen

Based on the considerations presented above and a general desire to provide high efficiency, we use a 10 AWG conductor for this run.

Junction Boxes to Inverters (2)

NEMA-3R rain-proof junction boxes will be employed to source the conduit runs into the interior of the house. The conductors from the PV source circuit will be spliced together with the cable in the conduit using approved means [NEC 300.15].

Conductor Sizing

Note that the 30°C ampacity of these conductors should still be 9.18 A or higher. The only other corrective factors that need to be accommodated are for conduit fill. Assuming an ambient temperature of 40°C , the temperature correction factor for THHN/THWN-2 cables in conduit is 0.91. In addition, the ampacity is derated by a factor of 0.8 [NEC 310.15] to accommodate the fact that each conduit will contain five conductors (4 PV output conductors and 1 Equipment Grounding Conductor).

We will use 10 AWG THHN/THWN-2 cable for this portion of the run for uniformity and to reduce voltage drops. The derated ampacity of 10 AWG cable [NEC 310.16] is $29.12\text{ A} = (40\text{ A} \times 0.91 \times 0.8)$, which is well above the required ampacity of 9.18 A.

Conduit Selection

The conductors in this portion of the electrical system will be enclosed in a 3/4" EMT conduit. The conduit will begin at the junction box and terminate in the interior of the house at the inverter (for each sub-array).

NEC Table C-1 (Appendix) indicates that up to ten 10 AWG conductors can be routed through a 3/4" EMT conduit. We are well within this limit as only five 10 AWG conductors will be routed in each conduit (four PV output conductors and one Equipment Grounding Conductor for each sub-array).

Equipment Grounding Conductor (3/4)

Based on the calculations presented above, we will employ a 10 AWG conductor to realize the Equipment Grounding Conductor. As depicted in the Electrical Schematic (E-103), up to the junction box (tag: 3), a bare Copper conductor is utilized, and for the run between the junction box and the inverter (tag: 4), 10 AWG THHN/THWN-2 is utilized.

Inverter output circuits (5)

We refer the conductor runs between each inverter and the electrical subpanel as the inverter output circuits. Note that the conductors will be routed through EMT conduit.

Conductor Sizing

The maximum inverter output current is 20.8 A (5000 W / 240 V). Ampacity requirements dictate a current of 26 A (20.8 A x 1.25). The required circuit breaker for each inverter is 30 A. To keep voltage drops reasonably small, we will employ 10 AWG THWN conductors for the inverter output circuits. Note that the ampacity of these conductors [NEC 310.17] at an assumed ambient temperature of 40°C is 44 A (50 A x 0.88) hence serving this application well.

Conduit Selection

In accordance with NEC Table C-1, we will employ a 1" EMT conduit for this part of the system.

Subpanel design

As depicted in the schematic (E-101), a subpanel is used to combine the output of the two inverters.

Breaker Sizing

In the previous section, it was pointed out that a 30 A circuit breaker is required for each inverter. The subpanel main breaker will be rated for 60 A ($2 \times 20.8 \text{ A} \times 1.25 = 52 \text{ A}$, round up to 60 A).

Subpanel Rating

To size the subpanel, we refer to NEC 690.64(B)(2) and denote the minimum rating as y . Given 30-A circuit breakers for the inverters and a 60-A sub-panel main breaker,
$$1.2y = (2 \times 30 \text{ A}) + (60 \text{ A}) \rightarrow y = 100 \text{ A}$$
. Thus, the sub-panel will be rated for 100 A.

Sub-panel to Main-Panel (7)

Note that these conductors will be routed in conduit from the subpanel through a disconnect switch that will be installed in the exterior of the house and back into the house and terminate at the main panel.

Conductor Sizing

Note that the conductors in this run are also subject to constraints imposed by NEC 690.64(B)(2). Denoting the allowed ampacity of the conductors as z ,

$$1.2z = (2 \times 60 \text{ A}) \rightarrow z = 100 \text{ A}$$
.

The ampacity of 3 AWG THWN conductors at an assumed ambient temperature of 40°C is 127.6 A (145 A $\times 0.88$) [NEC 310.17], which enables their utilization for this run.

Conduit Selection

In accordance with NEC Table C-1, we will employ a 1" EMT conduit for this part of the system.

AC Disconnect Switch

NEC 690.64(B)(2) will dictate the rating of the AC Disconnect Switch. Denoting the minimum rating of the switch as z , $1.2z = (2 \times 60 \text{ A}) \rightarrow z = 100 \text{ A}$. Thus, the AC Disconnect Switch will be rated for 100 A.

Main-Panel design

Breaker Sizing

The main panel includes a 60 A back-fed PV breaker and a 150 A main-breaker. Note that this breaker will be placed at the bottom of the main panel.

Main-panel Rating

To size the Main panel, we refer to NEC 690.64(B)(2) and denote the minimum allowed rating as y . Given the sizes of the breakers installed, $1.2y = 60 \text{ A} + 150 \text{ A} \rightarrow y = 175 \text{ A}$. Thus, the Main-panel will be rated for 200 A.

AC Side Equipment Grounding (6)

To appropriately ground the equipment on the AC side of the system, we employ NEC 250.122, which governs the size of the equipment-grounding conductor based on the rating of the over-current device protecting the relevant circuit.

Note that 30-A and 60-A circuit breakers are employed in this portion of the system (refer design of subpanel and main panel). From Table 250.122, we note that 10 AWG bare Cu suffices at these current levels. Thus, the Equipment Grounding Conductors for the Inverters, Disconnect switch, sub- and main panels will consist of 10 AWG Bare Cu conductor. This will be routed through conduit as appropriate.

Grounding Electrode Conductor (10)

NEC 250.66 dictates limits on the Grounding Electrode Conductor based on the size of the largest ungrounded service-entrance conductor. Assuming that 2/0 AWG conductors will be employed to service the house, Table 250.66 indicates that the Grounding Electrode Conductor should be 4 AWG Bare Cu. As dictated by the rules, we will employ an 8' ground rod driven at a 45° angle into the earth.

Ground Bonding Conductor (8)

This conductor is used to connect the grounding point in the inverter to the grounding bus bar in the main electrical panel. This conductor originates from the grounding point of one of the inverters and terminates at the grounding rod. The other inverter's grounding point is spliced irreversibly to this conductor as depicted in the electrical schematic. The conductors will be enclosed in $\frac{3}{4}$ " PVC conduit up to the point of floor penetration.

NEC 690.47(C)(2) dictates that the bonding conductor between the DC and AC systems should be sized as the larger of the DC requirement (in accordance with NEC 690.45) and the Inverter alternating current over-current device rating [NEC 250.122]. In addition, NEC 690.47(C)(4) indicates that a bonding conductor that serves multiple inverters shall be sized based on the sum of applicable currents used in NEC 690.47(C)(2).

The data sheet of the SPR 5000m inverter indicates that the maximum permissible DC current is 21 A. In addition, 30-A circuit breakers are installed on the AC output of each inverter. Denoting the minimum ampacity of the bonding conductor as z , to satisfy the postulates of NEC 690.47(C)(2) and NEC 690.47(C)(4), $z = 2(21 \text{ A}) + 2(30 \text{ A}) = 102 \text{ A}$.

Based on NEC 250.122, we will employ a 6 AWG Cu conductor to realize the ground bonding conductor. For quick reference, the design choices are tabulated in Table 1:

Table 1: Design Choices Summary

Branch	Continuous Current (A)	80% Operation (A)	Conductor	Derated Ampacity (A)	Circuit Breaker Rating (A)	Grounding Conductor (A)	Conduit
PV Sub-arrays to	7.34	9.18	10 AWG USE-2/RHH/RHW-	22.55	None	10 AWG Solid, Bare Cu	None



PV Sub-arrays to Junction boxes	7.34	9.18	10 AWG USE-2/RHH/RHW-2	22.55	None	10 AWG Solid, Bare Cu	None
Junction boxes to Inverters	7.34	9.18	10 AWG THHN/THWN-2	22.72	Integrated with Inverter	10 AWG THHN/THWN-2	3/4" EMT
Inverter to Sub-panel	20.8	26	10 AWG THWN	44	30	10 AWG Solid, Bare Cu	1" EMT
Sub-panel to Main-	100	N/A	3 AWG THWN	127.6	60	10 AWG Solid, Bare Cu	1" EMT

Other PV System Components

Our research and analysis concluded that the SunPower 225-W panels would be ideal for the PV system requirements of the Gable Home. These modules have the highest efficiency of available silicon modules and have reasonable cost. Furthermore, due to SunPower's proprietary production methods, they have a nearly solid black appearance that is aesthetically pleasing compared to conventional PV modules, which tend to have visible metallization and a degree of purplish tint.

Having finalized the solar panel choice, the quantity of panels required needed to be determined. It was determined that to achieve energy balance, the DC power rating of the PV system needed to be at least 6000 W. There will be a meter that measures and keeps track of the amount of power being drawn from the grid and the amount being fed into the grid.

From the data obtained from the panel spec sheets and the roof dimension from the latest drawings, the calculations below were made. This resulted in having 40 panels on the south facing roof of the house. The details of the panel layout and operation are given below.

Panel Orientation

The system contains (40) SPR-225 panels and (2) 5000m inverters in the following configuration. Each subarray consists of ten modules in a series string, with two strings in parallel. Each subarray will employ its own inverter.

Power Generation

The DC-rated peak power production of the PV modules is 9000 W. The CEC PTC rating is only 8284 W, accounting primarily for temperature drop. Using the online tool PVWatts, energy production can be estimated from the peak power rating, location, and other system details. This tool uses historical data captured from the NREL database and is a good proxy for the actual expected performance on an average basis. Based on our system design using Springfield, IL as a location (nearest to Champaign, IL, which is the final location for the house), the system is estimated to produce 11,528 kWh/yr.

System Costs

The cost per panel is \$949.50 for a total module cost of \$37,980.00. The inverters are SPR 5000m units with a total cost of $\$2,850.00 \times 2 = \$5,700.00$. The system also comprises several smaller balance-of-plant components such as racking mounts (discussed below), conduit, wiring, breakers. These components are numerous but small in cost, and total less than a few thousand dollars.

Inverters

The panels and the inverter have both arrived and once the house is ready with all the electrical connections, the panels can be mounted. After an in-depth research and taking into account different consideration during last semester and at the beginning of this semester it was decided that two 5000-W SunPower inverters are to be used for our system. SunPower 5000m inverters were selected for their power output capacity, high reliability, grid-tie capability and excellent efficiency. Furthermore, SunPower modules have a special “negative ground,” which requires the use of their inverters bearing their brand name. Two SunPower 5000m inverter were ordered at the beginning of the semester along with the solar panels. At the time of this report, the inverters have not yet been installed and tested, however, the appropriate mounts and wiring connections have been made.

Module Mounting

After a thorough analysis, it was initially determined that we would purchase a Unirac system through SunPower, including rails that would penetrate into a composite asphalt roof. However, after further discussions with architecture team members, the roof details were put back up for discussion. It was determined that a solid metal roof would function best for the solar house. The deciding factor for this decision was that the roof life would meet or exceed the life of the PV system (25 years or more), avoiding the need to take down the PV system to fix the roof after about fifteen years. Furthermore, we discovered a mounting system that is compatible with metal roofs and should be easier to manage, as it does not require punctures of the roof.

With the introduction of a metal standing seam roof for the entire house, the possibility of using nonpenetrating clips was revisited. Clips manufactured by S-5! were closely examined and we returned to analyzing the potential performance of this racking solution. We had adequate discussions with S-5! to determine the suitability for our application. After a few weeks of discussion, S-5! agreed to fully donate all the necessary racking materials, plus a significant amount of extra parts and tools.

We have received the S-5! clips and will be conducting the installation in mid-June, 2009.

The following is installation details were provided by S-5!:

"The key to frequency and spacing of attachment points for PV is to distribute loads to the metal standing seam panels in a manner that is consistent with the intended distribution of loads from the roof panels into the building structure. With very few exceptions, the attachment of a single S-5 clamp (even the "mini") to the seam will be stronger than a single point of attachment of the seam to the building structure. Hence the "weak link" is not the S-5 clamp, but the attachment clips that hold the metal panels to the building structure, or the beam strength of the roof panel seam, itself."

S-5-PV Kit

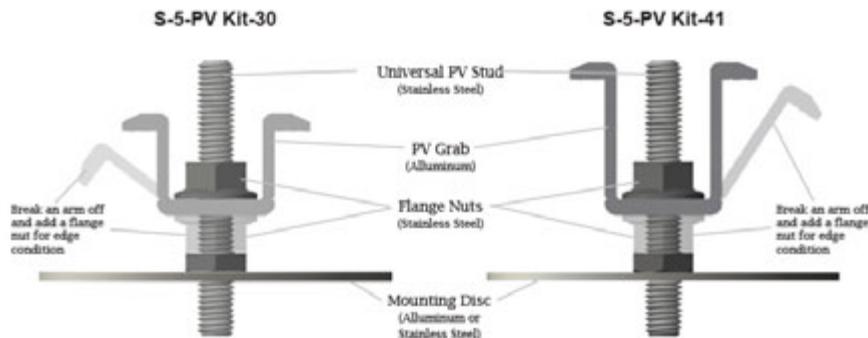


Figure 2: Diagram of S-5! clamps.

"The most conservative approach to the spacing/frequency of PV attachment to the roof is to determine the spacing/frequency of the roof's attachment to the building structure; then duplicate it at minimum. Determining panel attachment spacing in one axis is very simple: Standing seam panels' attachment will be made using concealed hold-down clips within the seam area of the panel. So, in that axis, the clip spacing is the same as the seam spacing. The location of the clips along the seam (in the other axis) can be determined by a) consultation with the roof system manufacturer or installer, b) checking from the

underside or, c) close examination from the topside along the seam. There will usually be a slight, but detectable, deformation of the seam at the clip location visible from the roof's topside. Many standing seam roofing systems are installed on "pre-engineered steel" buildings. The attachment spacing in that industry is typically 5'-0" and is readily apparent by inspecting the structural purlins to which the panel clips are attached from the roof underside (interior of the building)."

"With this in mind, our proposed solution was checked both with the architecture team and Dustin Haddock of S-5!. We have confirmation that PV Kits combined with the S-5-U Mini clamps will properly support our PV system in the proposed arrangement. Specific information on the S-5-U Mini clips is also provided below. These clips attach the PV kits to the roof."

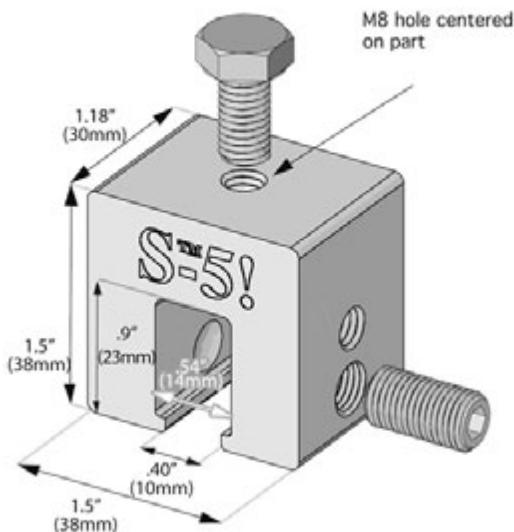


Figure 3: Detailed diagram of clamp.

"Installation is as simple as placing the clamp on the seam and tightening the patented round-point setscrew to the specified tension. Then, affix ancillary items using the bolt provided. Go to www.S-5.com/tools for information and tools available for properly attaching and tensioning S-5!TM clamps. Thanks to our patented round-tip setscrews, S-5!TM clamps do not pierce metal roof paneling, thereby protecting roof coatings and weather tightness warranties."



Figure 4: Brief overview of clamp installation procedure.

HVAC System

Background

The design for our 2009 Solar Decathlon entry is rooted in Midwestern tradition bringing the old barn look and feel to a modern and technologically advanced building. One of the major design features to save energy, especially on the HVAC side, is the pursuance of Passive House certification. A Passive House is a distinctly unique way of thinking of how to build a house. This standard and design comes from Germany, the PassivHaus Institute. The crux of the design is to build a super insulated, air tight home to reduce the heating load to the lowest possible value. A few years ago, this design concept was brought to the US from Germany and the Passive House Institute was born in the US. Katrin Klingenburg heads the US initiative and actually built the first Passive House certified home in the US here in Urbana in 2003 and currently resides there. The reason for building the home in this climate is to really test the design concept in a very harsh climate with wide temperature and humidity difference throughout the year. Thus if the design can work in this location, then it can work anywhere in the US. This also provided validation that they design can work in an environment with a large cooling load, which is important because the climate of Germany is very temperate and does not have as high of cooling loads in the summer as most places in the US. The Passive House standard has a limit for the amount of kWh/m²/year used by the home for both heating and cooling, which is 15 kWh/m²/year for both.

Thus to achieve such a low power consumption per year, Passive Houses rely on conditioning the air of the home using a heat recovery ventilator, HRV, or an energy recovery ventilator, ERV. By using these ventilators, these homes are able to maintain the minimum ventilation requirements set by ASHRAE; however, they are conserving the heat and moisture, for an ERV, of the exhausting air by preconditioning the fresh intake air. By transferring the heat and moisture from the stale exhaust air to the fresh intake air, an ERV is able to drastically reduce the load seen by the cooling unit in the summer and heating unit in the winter.

Now this mechanical ventilation only gives these amazing savings on conditioning the space when the natural infiltration is as close to 0 as possible. To make sure homes employ the best possibly air tightening practices, the Passive House standard imposes a maximum of 0.6 pressurized air changes per hour, ACH, which means when the house is under a 50 Pascal pressurization this is how many times the air should be changed per hour. This number is determined in a built Passive House by using a blower door test. If you convert the pressurized ACH to natural ACH then it is ~0.033 ACH from infiltration. This is well below the minimum required by ASHRAE, who requires a minimum of 0.35 ACH. This means the Passive House needs constant mechanical ventilation to maintain the necessary minimum ventilation requirement.

The next major necessity to reduce the HVAC load is to make the envelope of the home super insulated. To make a home super insulated usually means at least R-70 ceilings, R-50 walls and low-e coated, argon-filled, triple-paned windows with insulated frames reducing thermal bridges among other improvements. The goal of this is to limit heat transfer to the environment from the house so the

temperature inside does not fluctuate wildly during a 24-hour period. Also, the most windows are placed on the south facing wall to maximize solar heat gain during the winter while limiting the number of windows on the other three walls.

With the combinations of all these extreme building practices, the HVAC loads are drastically reduced, requiring only minimal power input.

Competition

Since the house and HVAC unit are designed for a competition, there are certain rules and limitations imposed because of this. The rules state during the week of competition the indoor air temperature must be between 72-76 degrees Fahrenheit to get full points and humidity needs to be between 40% and 55% to get full points. These two readings and points make up 100 of the 1000 total points for the competition, meaning this is not a trivial amount of points and impact.

Design

Our design went through several different iterations over the semester. The major design goals were to make a compact unit which heats, cools, dehumidifies, and ventilates as well as to try and heat and cool only with the ventilation air flow rate. The first design involved a heat pump in a similar configuration as a typical air conditioner; however there were various ducts and dampers to control the air flow supplied to the house over the evaporator or condenser depending if heating or cooling is needed. This design can be seen in the Figure 5.

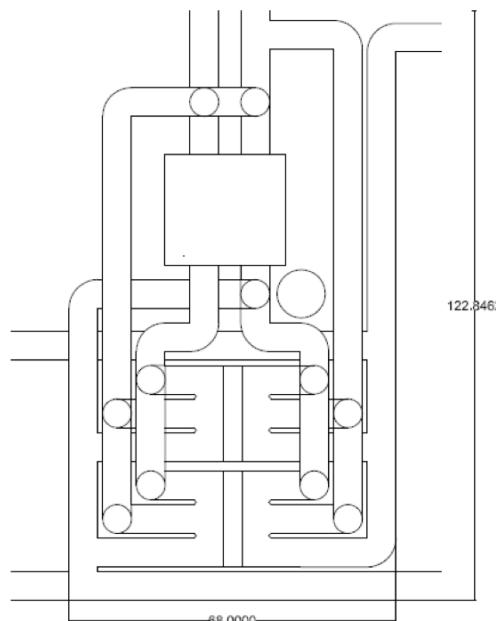




Figure 5: Initial concept or HVAC system.

The dimensions of this unit are 122" long by 68" wide. This is small enough to fit in the space allotted to the HVAC unit in our house design. The various ducts and dampers in this design allow maximum control over the temperature and humidity depending on whether the air is fresh air, fresh air through ERV, or re-circulated air. This setup will also require additional fans for the cases when the ERV is not used. This setup is the best setup for conditioning control; however it is very large and expensive. This setup would require 18 dampers and 2 extra fans and much more ducting. Since I wanted to use electronic dampers the total cost for just the dampers alone would be about \$2000, at \$110 a piece, which is a lot of money for only dampers. Another disadvantage of this idea is the amount of static pressure in the system will be high due to the many turns, tees, and ducting lengths. This will increase the fan power for a given air flow rate. So with this information we redesigned the system.

The new design eliminates the extra ducting and uses a heat pump with a reversing valve instead. Using a heat pump with a reversing valve allows the evaporator and condenser to change roles depending on the refrigerant flow direction. So now there only needs to be one duct, greatly reducing complexity. The new design can be seen below in both a top and side view.

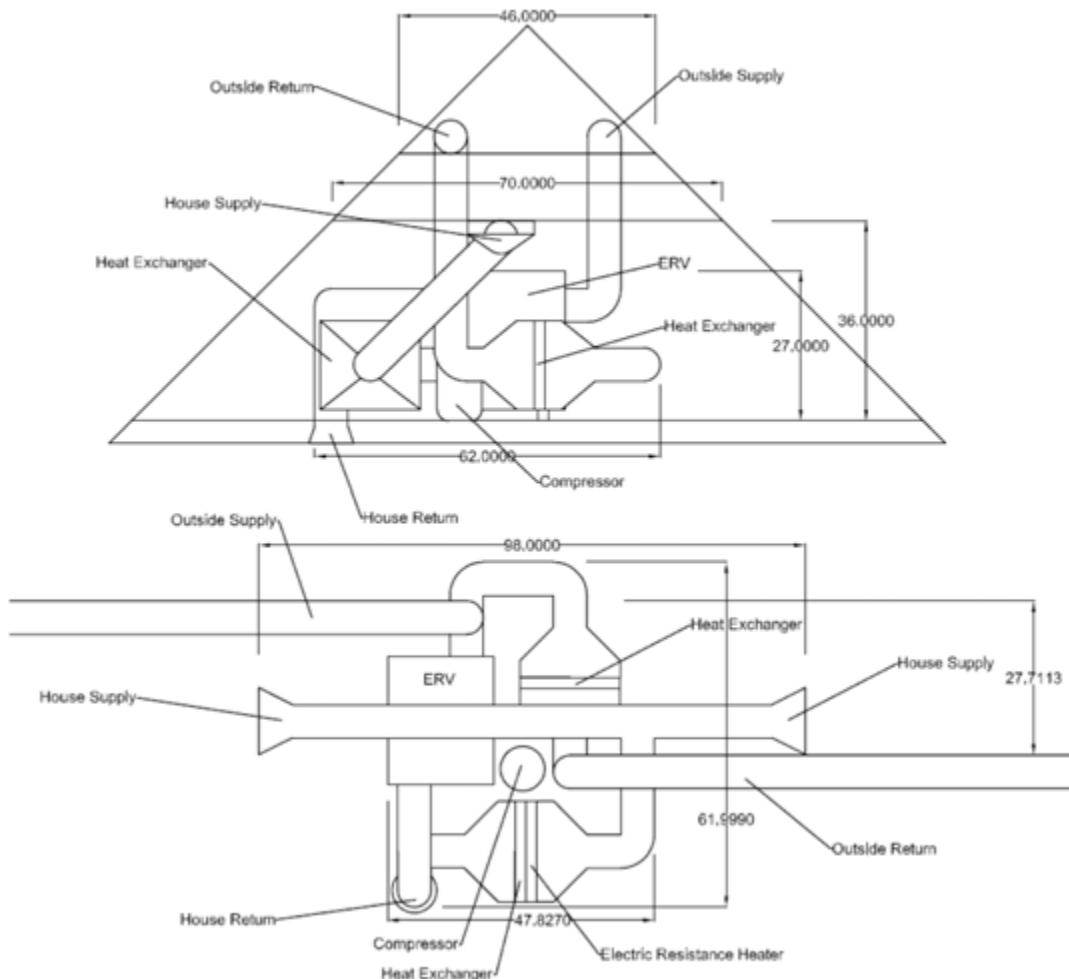


Figure 6: Second revisions of HVAC design concept.

The side view is in the actual space in the house, which is in a little “attic” space above the bathroom. This space is still inside the conditioned space so I do not need to worry about insulating ducting except for the outside air intake and exhaust. So with this design there is already greatly reduced ducting and thus size of the system. It is almost half as long and the width is almost two feet less. With this design there are few bends and short ducting lengths so the static pressure will be less. An electric resistance heater was added for the times when the temperature outside is below the operating temperature of the heat pump, usually 45°F or less. The resistance heater is also there for the times when the heat pump needs to defrost. The major difference with the unit is for the unit to heat or cool it needs to draw in fresh air. This differs from the previous design where we could re-circulate the air if ventilation was not needed at that time. This is the most compact unit possible with only marginal gains making it even smaller with tighter ducting runs. This compactness comes at a price though and the unit would be difficult to work on to make repairs at the competition, especially since it will be in a raised space. Also the filters for the ERV are replaced from the top of the unit in this configuration meaning the ERV would

need to be removed from the raised space to replace the filters. As a result of this and the desire to make possible repairs easier on the team, we redesigned this system to one which is more serviceable.

The new design, as seen below, allows for the filters of the ERV to be changed while still in the raised space since they now are changed on the right side of the ERV from the top view.

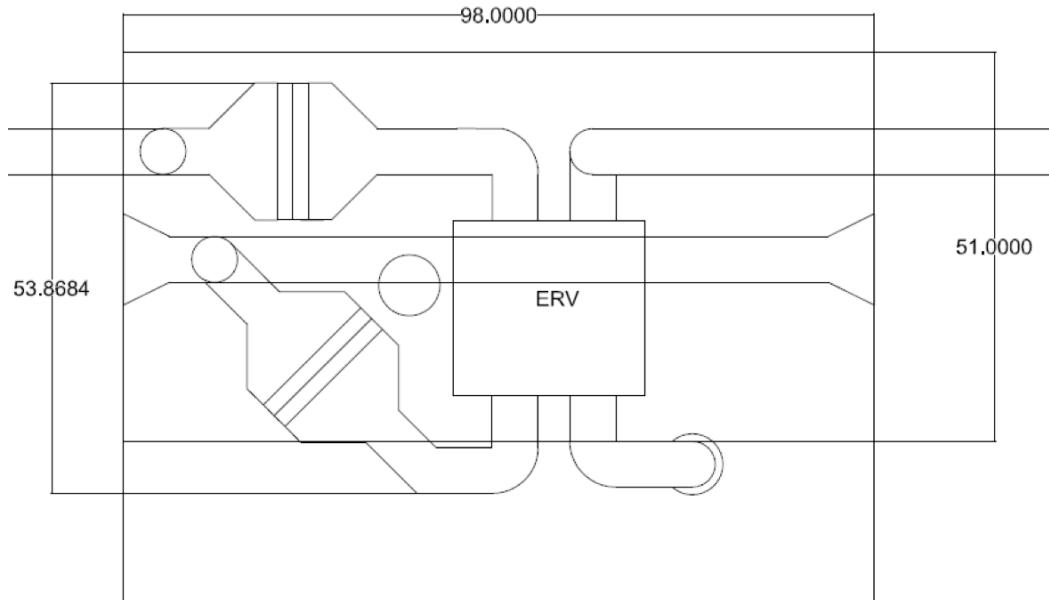


Figure 7: Third version of the HVAC concept.

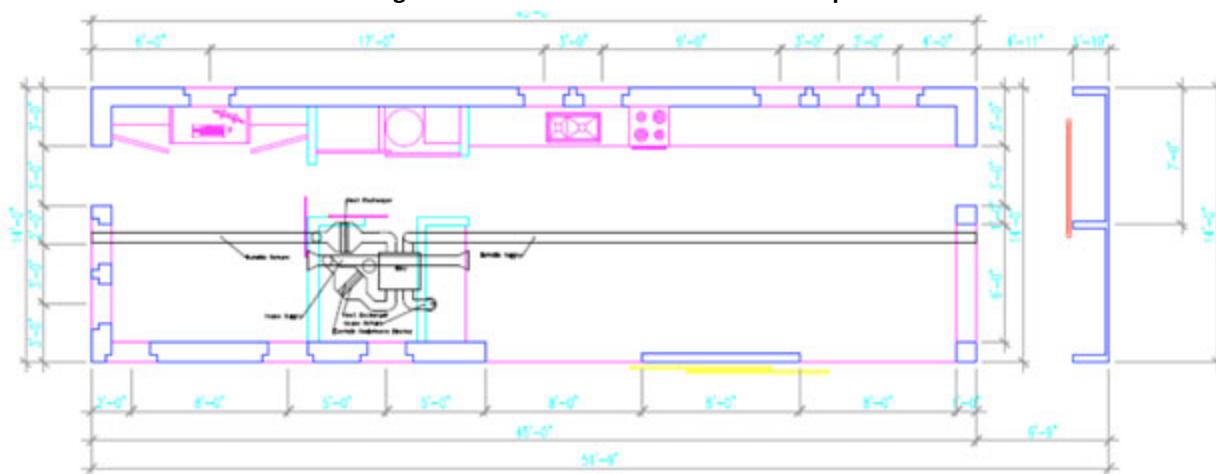


Figure 8: Third version of HVAC as shown against floor plan.

Also, it has slightly better access to the heat exchangers and compressor. Another driving factor for the redesign was the architecture team's desire to take what was once a completely enclosed space above the bathroom, hallway and mechanical/electrical closets and make the hallway go the full height to the vaulted ceiling. This means we no longer had an 8' by 12' floor space to work with but instead it is now 8' by 7'. So now the unit will be closer to the sloping ceiling of this raised space, which can be seen in the side view of the first design. While this design is an improvement in the serviceability of the HVAC unit,

we decided to take it one step further and make the access to the heat pump equipment easier since those will be the items most likely to fail during the competition.

This third redesign (fourth version overall) is now the plan of record. It includes all the necessary pieces to operate while having excellent serviceability as seen below.

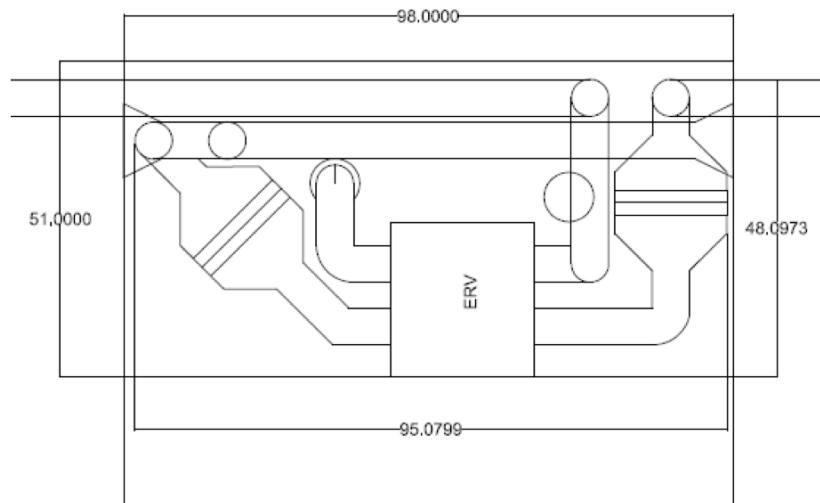


Figure 9: Fourth version of HVAC concept.

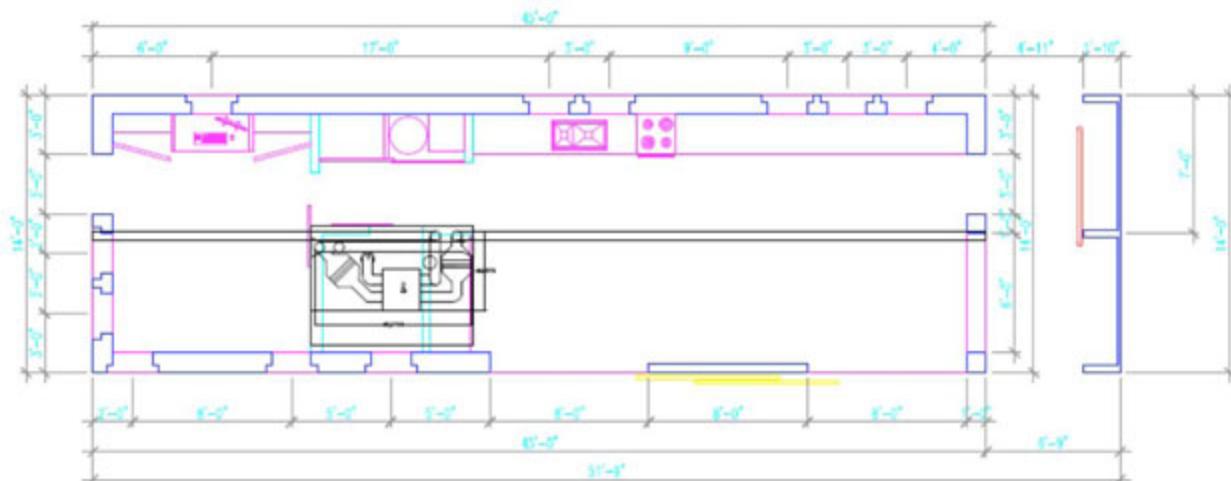


Figure 10: Fourth HVAC concept as shown against floor plan.

This design has slightly longer refrigerant lines than the other designs but the gains in the other aspects of this design greatly outweigh this minor fact. The north wall of the raised space, adjacent to the hallway, will, for now, be open to the hallway allowing access to the HVAC unit but also to incorporate the HVAC unit into the public tour of the house for the competition.

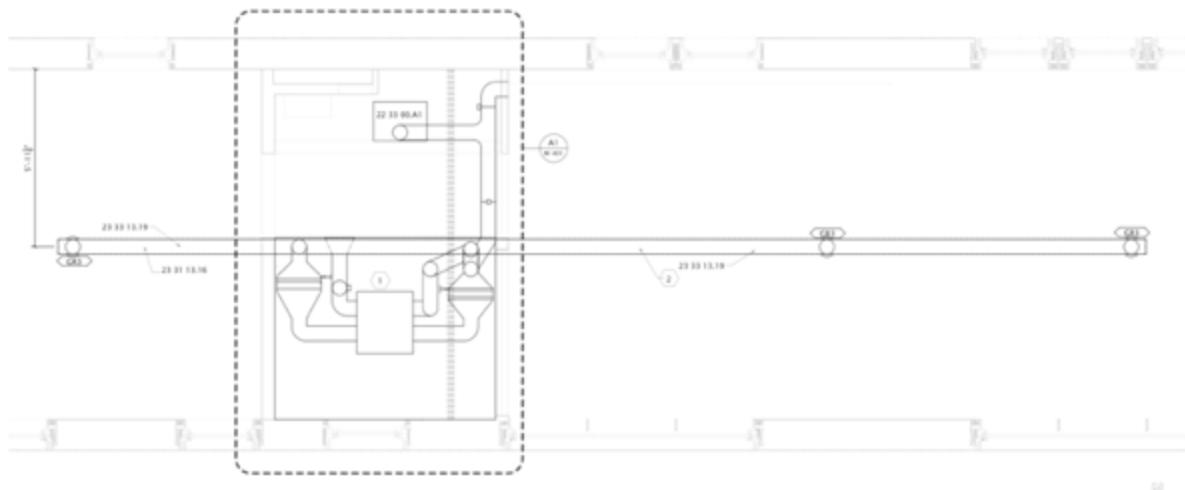


Figure 10: Final (fifth) version of the HVAC concept.

The final revision, shown above in Figure 10, is slightly modified to accurately reflect the physical space constraints. There are now going to be exposed ducts traveling the length of the living room and bedroom instead of throwing the air across the space. This was done to allow for proper air mixing in the two spaces since the return for the system is in the hallway. There is also a connection from the heat pump hot water heater so during the winter the cold air from the heat pump will be diverted to the exhaust air stream, but when the extra cooling will help during the summer it will be diverted to the inside. Refer to the figures below.

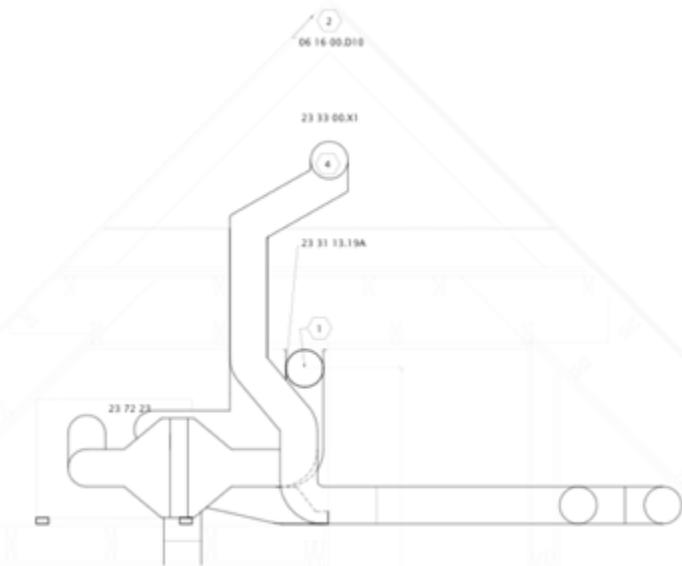


Figure 11: Additional detail of HVAC concept.

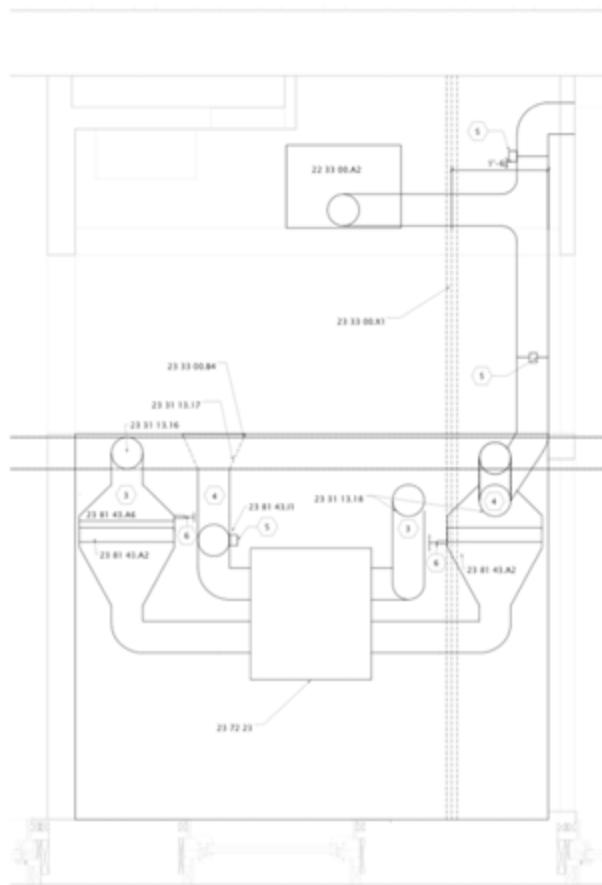


Figure 12: Another additional HVAC drawing.

There will be an electronic damper on the house return located in the bathroom so that when there is an occupant in the bathroom, the damper will be open. This was done so that the extra humidity from a shower or for various other reasons, the bathroom air will be directly exhausted to the outside. This was not needed for our house by code since we have a large enough operable window in the bathroom for those reasons, however, this defeats the purpose of the passive house design and the airtight nature of the home. There is an electric resistance heating coil on the supply side of the system for when the outside air is below 40° F and the heat pump heating system will not function.

The current design will use a variable capacity compressor, which will help to reduce electricity consumption of the system. This will be accomplished through the ability to lower the capacity and fan speed during partial load conditions. These partial load conditions are the majority of the situations for heating and cooling in the home as shown below in the Trace 700 analysis.

SYSTEM LOAD PROFILES

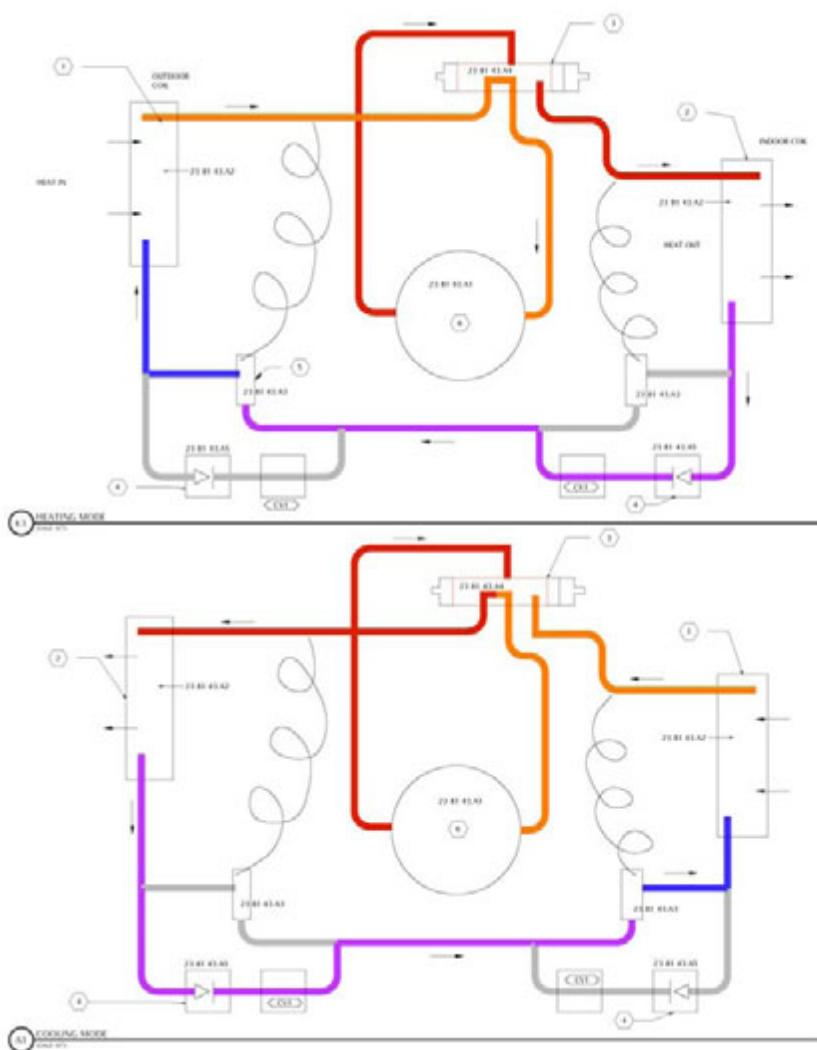
By DEMO

System - 001

Percent Design Load Cooling Load Heating Load Cooling Airflow Heating Airflow		
	Cap. (Tons)	Hours (%)	Hours	Cap. (Btu/h)	Hours (%)	Hours	Cap. (Cfm)	Hours (%)	Hours	Cap. (Cfm)	Hours (%)	Hours
0 - 5	0.0	10	762	-3002	15	60	12.0	0	0	0.0	0	0
5 - 10	0.1	11	891	-500.4	53	209	24.0	0	0	0.0	0	0
10 - 15	0.1	18	1,383	-900.8	32	124	36.0	0	0	0.0	0	0
15 - 20	0.1	11	902	-1,200.8	0	0	48.0	0	0	0.0	0	0
20 - 25	0.1	2	177	-1,501.0	0	0	60.1	0	0	0.0	0	0
25 - 30	0.2	1	68	-1,801.2	0	0	72.1	0	0	0.0	0	0
30 - 35	0.2	2	125	-2,101.4	0	0	84.1	58	5,078	0.0	0	0
35 - 40	0.2	5	402	-2,401.6	0	0	96.1	0	0	0.0	0	0
40 - 45	0.3	2	172	-2,701.8	0	0	108.1	0	0	0.0	0	0
45 - 50	0.3	5	416	-3,002.0	0	0	120.1	42	3,602	0.0	0	0
50 - 55	0.3	11	829	-3,302.2	0	0	132.1	0	0	0.0	0	0
55 - 60	0.3	14	1,054	-3,602.4	0	0	144.1	0	0	0.0	0	0
60 - 65	0.4	7	631	-3,902.6	0	0	156.1	0	0	0.0	0	0
65 - 70	0.4	1	64	-4,202.8	0	0	168.1	0	0	0.0	0	0
70 - 76	0.4	0	0	-4,603.0	0	0	180.2	0	0	0.0	0	0
76 - 80	0.4	0	0	-4,803.2	0	0	192.2	0	0	0.0	0	0
80 - 85	0.5	0	0	-5,103.4	0	0	204.2	0	0	0.0	0	0
85 - 90	0.5	0	0	-5,403.6	0	0	216.2	0	0	0.0	0	0
90 - 95	0.5	0	0	-5,703.8	0	0	228.2	0	0	0.0	0	0
95 - 100	0.5	0	0	-6,004.0	0	0	240.2	0	0	0.0	0	0
Hours Off	0.0	0	904	0.0	0	8,367	0.0	0	0.0	0	0	8,760

Figure 13: Results of load Trace 700 calculations.

While the numbers may not be truly indicative of the actual hours at the partial loads, the overall trends are what are important for the consideration of the variable capacity compressor. As seen in the analysis, much of the time for cooling is at much lower loads than the peak load of 0.5 tons. This means the variable capacity compressor will be greatly beneficial to the system as a whole. This will allow for potential savings up to 10-30% according to various literature on this subject.



GENERAL SHEET NOTES	
THESE GENERAL NOTES APPLY TO ALL DRAWINGS.	
1.1) NOT TO SCALE DRAWINGS, USE FIELD MEASUREMENTS.	
NOTES ON DRAWINGS WILL APPLY TO ALL DRAWINGS, WHETHER THEY ARE REFERENCED OR NOT.	
INCLUDES ALL TRIM, PIPING, ELECTRICAL, CONDUIT, TEMPERATURE CONTROLS, AND ANY OTHER COMPONENTS WHICH ARE ATTACHED TO THE EQUIPMENT.	
THE WORK AND DRAWINGS ARE FOR THE EQUIPMENT INDICATED ON THE DRAWINGS. THE CONTRACTOR SHALL BE RESPONSIBLE FOR ADAPTING THE EQUIPMENT TO THE SPECIFICATIONS TO THE WORK PRESCRIBED, BUT NOT NECESSARILY LIMITED TO ELECTRICAL, MECHANICAL, MEASUREMENT, AND CONTROL, AS WELL AS ANY OTHER FEATURES SUCH AS CEILINGS, DOORS AND FRAMES, CHANROPS, ETC., REQUIRED BY THE CONTRACTOR TO MAKE THE EQUIPMENT OTHER THAN THAT INDICATED ON THE DRAWINGS.	
REFERENCE KEYNOTES	
SECTION 20 - HEATING, VENTILATING, AND AIR CONDITIONING (HVAC)	
21.B1.80	DEEPVAPORIZED UNITARY HVAC EQUIPMENT
21.B1.41.A1	VARIABLE CAPACITY COMPRESSOR
21.B1.41.A2	PIPE AND TUBE HE EXCHANGERS
21.B1.41.A3	TERMOSTATIC EXPANSION VALVE
21.B1.41.A4	REVERSING VALVE
21.B1.41.A5	CHECK VALVE
SHEET KEYNOTES	
①	EVAPORATOR
②	CONDENSER
③	REVERSING VALVE
④	CHECK VALVE
⑤	TERMOSTATIC EXPANSION VALVE
⑥	COMPRESSOR
PIPING LEGEND	
21.B1.41	REFL. RADIATION
21.B1.41.A1	HIGH PRESSURE LIQ.
21.B1.41.A2	HIGH PRESSURE GAS
21.B1.41.A3	LOW PRESSURE LIQ.
21.B1.41.A4	LOW PRESSURE GAS
21.B1.41.A5	LOW TEMP/REFRIGERANT LIQ.

Figure 14: Refrigerant loops of the heat pump system.

The diagram in Figure 14 above is for the refrigerant loops of the heat pump system used for heating and cooling. This shows the different paths of the refrigerant flow for heating and cooling.

Load Modeling

The first load modeling done was by the architecture students using the Passive House Planning Package, or PHPP. The results of this modeling can be seen on the next page. This program takes many low energy specific design principles into consideration when defining the house. However, since this program was developed for the specific environment in Germany where there is little cooling needed, the cooling load numbers might not be correct for the US. This is why we modeled the home in Trane Trace as well to verify the numbers from PHPP.

Building:	University of Illinois 2009 Solar Decathlon Entry		
Location and Climate:	Peoria		
Street:			
Postcode/City:	Urbana, Illinois		
Country:	USA		
Building Type:	Residential Prototype		
Home Owner(s) / Client(s):	University of Illinois		
Street:			
Postcode/City:			
Architect:	U of I Solar Decathlon Team		
Street:			
Postcode/City:			
Mechanical System:	U of I Engineering Department		
Street:			
Postcode/City:			
Year of Construction:	2008-2009		
Number of Dwelling Units:	1		
Enclosed Volume V _e :	147.6	m ³	Interior Temperature: 20.0 °C
Number of Occupants:	2.0 Internal Heat Gains: 2.1 W/m ²		
Specific Demands with Reference to the Treated Floor Area			
Treated Floor Area:	46.6 m ²	Applied: Monthly Method	PH Certificate:
Specific Space Heat Demand:	15 kWh/(m ² a)	15 kWh/(m ² a)	Fulfilled? Yes
Pressurization Test Result:	0.6 h ⁻¹	0.6 h ⁻¹	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	119 kWh/(m ² a)	120 kWh/(m ² a)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	64 kWh/(m ² a)		
Specific Primary Energy Demand (Energy Conservation by Solar Electricity):	129 kWh/(m ² a)	15 kWh/(m ² a)	
Heating Load:	23 W/m ²	over 25 °C	
Frequency of Overheating:	%		
Specific Useful Cooling Energy Demand:	2 kWh/(m ² a)		Yes
Cooling Load:	13 W/m ²		

Figure 15: PHPP Software screen shot.

Trane Trace 700 is a HVAC sizing software developed by Trane. Typically this software is used for commercial scale projects, but it can also be adapted for residential use. Using Trace, the worst case heating and cooling loads were determined. First, the necessary information about the house had to be entered into the program such as wall insulation levels, types of windows, heating and cooling systems, and more. The information was obtained from the architecture students so as to have the most accurate data possible for the software. The more accurate the inputs, the more accurate the outputs will be. The software is relatively simple for residential since there are few inputs needed compared to commercial projects. Once the inputs are correctly entered into the program the software can run the calculations to determine the worst case heating and cooling loads. The worst case cooling load is the hottest, most humid day of the summer with full occupancy and internal generation. For the heating load, it is during the night of the coldest day in the winter with no occupancy and no internal generation.

System Checksums									
System - 001									
COOLING COIL PEAK					CLG SPACE PEAK				
Peaked at Time: M/H: 8/15 Outside Air: OADD/WB/HR: 89.74/105					M/H: Sum of OADD: Peaks				
Space Sens. + Lat. Btu/h	Pleum. Btu/h	Net Total Btu/h	Percent (%)	Sensible OffTotal Btu/h	Space Sens. Btu/h	Percent (%)	Space Peak Btu/h	CoilPeak Btu/h	Percent (%)
Envelope Loads					Envelope Loads				
Skyline Solar	0	0	0	0	Skyline Solar	0	0	0	0.00
Skyline Cond.	0	0	0	0	Skyline Cond.	0	0	0	0.00
Roof Cond.	85	0	85	1	Roof Cond.	-815	-815	8.62	
Glass Solar	2,493	0	2,493	43	Glass Solar	0	0	0	0.00
Glass Cond.	212	0	212	4	Glass Cond.	-1,279	-1,279	21.30	
Wall Cond.	434	0	434	1	Wall Cond.	-855	-855	14.90	
Partition	0	0	0	0	Partition	0	0	0	0.00
Exposed Floor	22	0	22	0.00	Exposed Floor	-733	-733	12.21	
Infiltration	133	0	133	2	Infiltration	-268	-268	3.45	
Sub Total =>	3,379	0	3,379	68	Sub Total =>	-3,632	-3,632	60.45	
Internal Loads					Internal Loads				
Light	352	0	352	6	Light	0	0	0.00	
People	700	0	700	12	People	0	0	0.00	
Mac	1,067	0	1,067	18	Mac	0	0	0.00	
Sub Total =>	2,109	0	2,109	36	Sub Total =>	0	0	0.00	
Ceiling Load	0	0	0	0	Ceiling Load	0	0	0.00	
Ventilation Load	0	0	282	6	Ventilation Load	-2,372	-2,372	39.61	
Adj Air Trans Heat	0	0	0	0	Adj Air Trans Heat	0	0	0.00	
Dehumid. On Sizing	0	0	0	0	Ov/Undr Sizing	0	0	0.00	
Ov/Undr Sizing	0	0	0	0	ExhaustHeat	0	0	0.00	
ExhaustHeat	0	0	0	0	OA Preheat Diff.	0	0.00	0.00	
Sup. Fan Heat	0	62	62	1	RA Preheat Diff.	0	0.00	0.00	
Ret. Fan Heat	0	0	0	0	RA Preheat Diff.	0	0.00	0.00	
DuctHeatPump	0	0	0	0	Additional Reheat	0	0.00	0.00	
ReheatAt Design	0	0	0	0					
Grand Total =>	6,487	0	6,841	100.00	Grand Total =>	-3,632	-6,004	100.00	No. People 2
COOLING COIL SELECTION					HEATING COIL SELECTION				
Total Capacity ton	Sens Cap. M/s	Coil Airflow cfm	Enter DB WB/HR °F	Leave DB WB/HR °F	Capacity M/s	Coil Airflow cfm	Ent °F	Lv°F	
Main Clg 0.5	5.6	53	261.5	74.3	50.5	59.2	55.4	52.5	55.3
Aux Clg 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OptVent 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total 0.5	5.6	53	261.5	74.3	50.5	59.2	55.4	52.5	55.3
AREAS					HEATING COIL SELECTION				
Floor	Gross Total ft ²	Glass ft ² (%)			Main Htg	-5.0	291.5	55.5	85.8
Part	0	0			Aux Htg	0.0	0	0	0
Extr	538	0			Preheat	0.0	0	0	0
Roof	515	0			Humidif	0.0	0	0.0	0.0
Wall	842	154	10		OptVent	0.0	0	0.0	0.0
Total	-5.0				Total	-5.0			

Project Name: TRACE6700 v5.1.3 calculated at 08:03 PM on 12/14/2008
Dataset Name: C:\CDS\TRACE6700\Projects\00House.dz
Alternative=1 System Checksums Report Page 1 of 1

Figure 16: Sample calculations from Trane Trace.

Figure 16 above shows the results of the calculations, giving information regarding the needed size of the system and other more detailed information about the suggested system. For our uses, the information of importance is the total capacity for cooling and to a less extent the capacity of the heating. The cooling capacity is especially important because the competition will be during the month of October which normally still requires cooling versus heating. Also due to the design of our house, cooling will be much more difficult compared to heating. The things which help to reduce the heating load in the winter raise the cooling load in the summer: people, solar heat gain, electronics, refrigerator, etc. According to the results, our peak cooling load will be 5,841 Btu/hr, or 0.5 tons. This requires very little, even for something as small as a window air conditioner. Finding a window unit which is also a heat pump will therefore prove to be very difficult.

The biggest loads for the cooling peak are the solar gains from the windows. This high load can be largely offset with proper shading of the windows during the high solar times. This will dramatically reduce the cooling load needed for the house to about 0.25 tons. However, the downside of this is the greater need for indoor lighting to make up the difference in available light in the home.

Indoor Air Quality

Due to the level of natural infiltration into these airtight homes, the indoor air quality becomes an important consideration. One major determiner for indoor air quality, or IAQ, is CO₂ levels. The easiest way to reduce the CO₂ level in a home is to increase ventilation rate. With a Passive House, it is so air tight it would take about 25.5 hours for one complete air exchange of the home from natural infiltration alone. This infiltration level is too slow compared to the generation levels of CO₂ from four people, for example. Using the equation below from *Indoor Air Quality and HVAC Systems* with a generation of 0.011 cfm/person from *ASHRAE Fundamentals*, after one hour in the airtight home the CO₂ level inside should be 687 ppm.

$$C_{indoor} = \frac{F \times 10^6}{V_{eff} I} (1 - e^{-I t}) + C_{outdoor}$$

Where:

C_{indoor} – CO₂ concentration indoor, ppm

F – Generation rate of CO₂, 0.011 cfm/person

V_{eff} – Effective volume, ft³

I – Ventilation rate, air changes per hour

t – Time, hours

$C_{outdoor}$ – CO₂ concentration outdoor, ppm

Now for this infiltration, the CO₂ will reach steady state in 151.5 hours, or 6.3 days, at a level of 8077 ppm as seen in table below.

Table 2: Air infiltration calculations.

	Airtight	Minimum
	0.033 ACH	0.35 ACH
Time (hr)	C_{inside} (ppm)	C_{inside} (ppm)
0.5	563	553
1	687	651
5	1607	1036

10	2599	1140
50	6652	1162
100	7846	1162
150	8075	1162
151.5	8077	1162
200	8119	1162
720	8129	1162

This is well above the acceptable range for CO₂, which has a threshold limit value for a time-weighted average of 5,000 ppm. This level of CO₂ begins to have serious adverse effects on the human body. Now, if the air exchange per hour is 0.35 instead the 0.033 through mechanical ventilation then the steady state level of CO₂ will be 1162 ppm. This value is the limit for what is acceptable for CO₂ concentrations in a home as ASHRAE recommends levels below 1000 ppm, which is why 0.35 is the minimum level of acceptable ACH. This comparison shows why mechanical ventilation is required for proper indoor air quality with regards to CO₂. Without the mechanical ventilation, the inhabitants will begin to feel the adverse effects of high CO₂ concentration in as few as 10 hours. The best way to reduce CO₂ in the house is more ventilation. Since you are continuously mechanically ventilating the house, an airtight home will have more uniform air change as opposed to the infiltration of fresh air in a conventional home. This means the airtight home will exchange more stale air for fresh air, lowering the CO₂ concentration level in the home.

Ventilation Rates:

Calculations were also made to determine if the HVAC system could provide enough dehumidification to eliminate the moisture in the incoming fresh air. This is an essential part of cooling during the summer. Since the ERV will exchange moisture between air streams, the humidity ratio for both the outgoing air stream and incoming air stream were determined in kg water/kg air and then multiplied by the efficiency of the ERV. The amount of dehumidification capable of the proposed heat pump is 1.7 pints/hour. Then by varying the outside air temperature and relative humidity, the maximum airflow rate can be determined. For any flow rate higher than this value, the supply air will actually humidify the interior, which is not acceptable. This only presents a problem at high outside temperatures and relative humidity. A graph of these flow rates at different temperatures and relative humidity can be seen below.

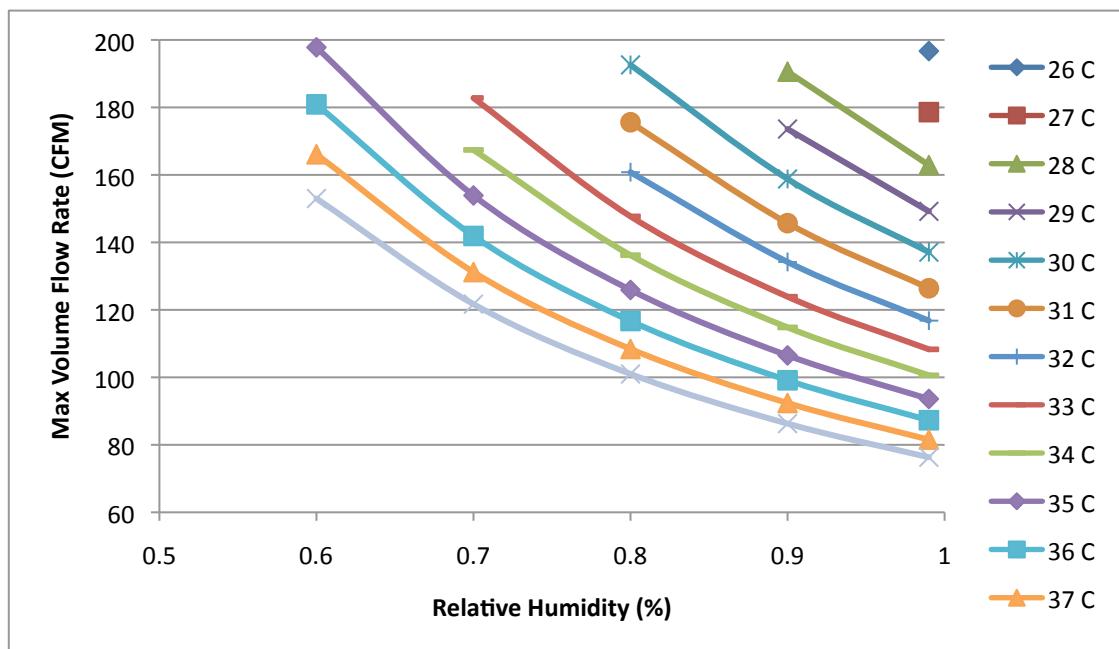


Figure 17: Max ventilation flow rate given outside Temp & RH %, A/C Dehumid (without water heater)

At these high temperatures and relative humidity, extra dehumidification is needed for higher flow rates than indicated. The extra dehumidification can come from the heat pump hot water unit, which provides 1 quart/day of dehumidification or 0.1667 pints/hr. With the extra dehumidification of the hot water heater, the ventilation unit can now have a higher flow rate to provide sufficient cooling without humidifying the indoor air. The adjusted maximum flow rates, taking the additional dehumidification into account, can be seen in the figure below.

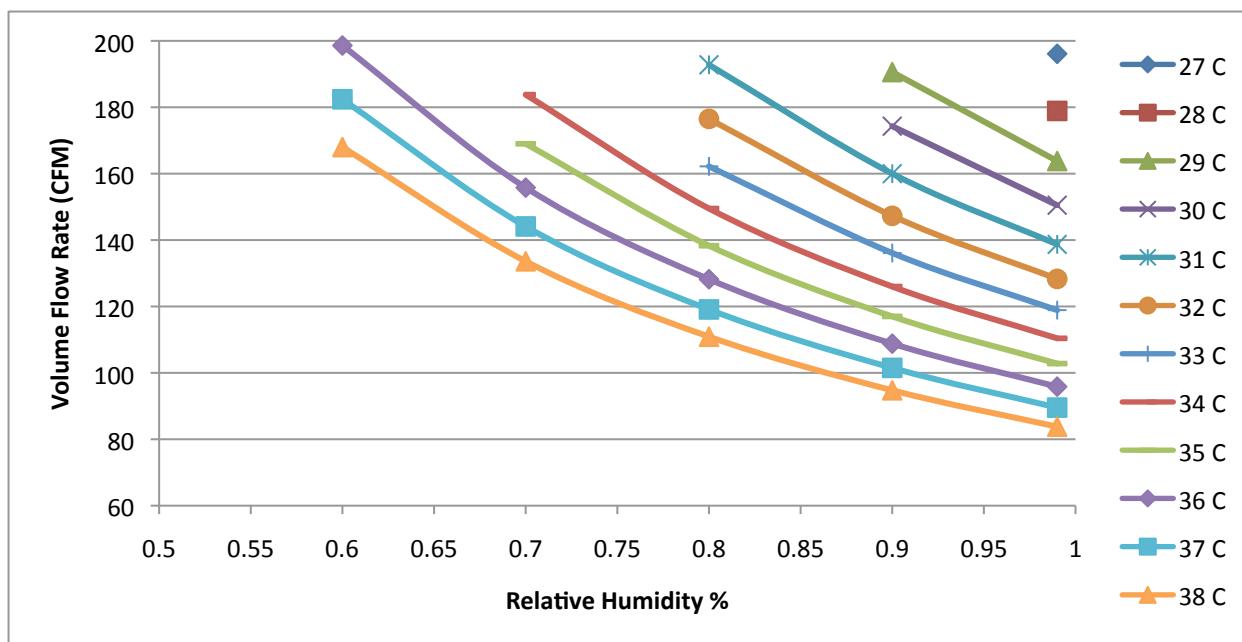


Figure 18: Max ventilation CFM given outside Temp & RH %, A/C Dehumid w/ Water Heater

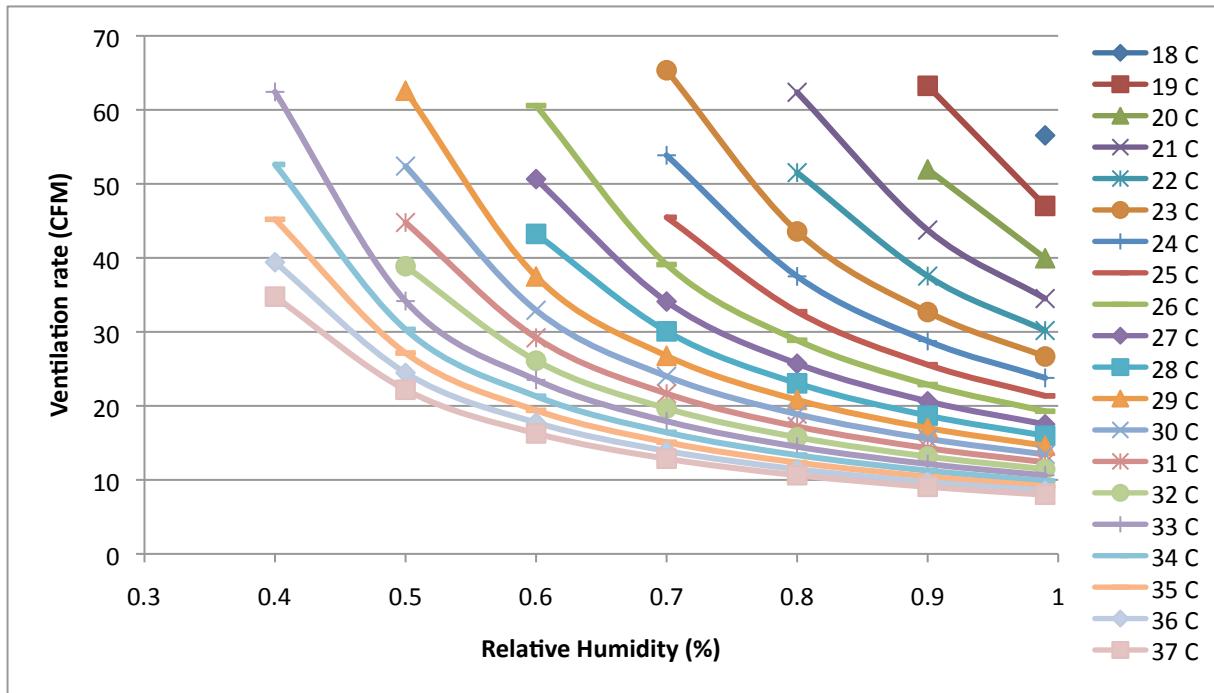


Figure 19: Max ventilation CFM given outside Temp & RH %, Water Heater only

Weather records indicate that the average high temperature and humidity in Washington D.C. in October are 20.6° C and 80%, respectively. Looking at the previous three figures, at a humidity of 80% the temperature must be greater than 30-31° C to necessitate additional dehumidification beyond the AC system and heat pump water heater. In fact, at a low ventilation rate, the hot water heater provides enough dehumidification for the minimum required ventilation at 21° C and 80% RH which is just above the average high for Washington D.C. This means that during the competition we will not have a problem with dehumidifying the incoming fresh air at any airflow rate and may not have to dehumidify the air at all with the AC system dependent on the outside conditions.

The downside to this much dehumidifying is the opposite case when the temperature and humidity are low and we need to humidify. Since we have to maintain a tight temperature and humidity range, we need to consider both sides of the equation. Looking at weather records, the average high and low temperatures are 20.6° C and 10° C respectively. The average morning and afternoon relative humidities are 80% and 53% respectively. So at 10° C, there may be a need for humidification but future work would need to be done to determine if this is true and the extent of the humidification.

Construction



The current idea to construct the unit is to take a purchased ERV and then build the heat pump around that item. The ERV picked out is the Ultimate Air Recouperator and it has an airflow range of ~70-200 CFM which was used as the limiting factors for the ventilation analysis. The heat pump equipment will be compiled from individual components purchased or donated from various companies. This means we will be using UL listed components then combining them ourselves to create our heat pump system. This is more difficult than taking a current off the shelf system and using it in the house because we have to specify all and purchase all components for the system, some of which are very difficult to find for our small system. In the end though, this will allow for a custom system specifically tailored for our home and its specific characteristics.

Backup Plan

A backup plan has also been prepared, in the event that the self-contained unit does not work as planned. In this case we would use a ductless mini split system. The condenser would go outside the home on the south wall right near the bathroom so the refrigerant line is very short and the evaporator unit would be placed on the west wall in the main room. We would use an off the shelf Daikin mini split system because it has a variable capacity compressor so the capacity can go as low as 0.25 tons, while the nominal value is 0.75 tons. With this approach, we are confident that the heating and cooling loads would be met with little trouble. It would be easy to install and control, but it would not provide any points for innovation.



Hot Water

For the domestic hot water system, research was conducted in order to compare the variety of available types of systems. A thorough cost analysis was performed that, along with certain physical restrictions, allowed us to choose the most reliable and cost-effective system for the house. Extended hot water tests ensured that this system would meet the hot water demands of the competition.

System Selection

Like in any residence, the domestic hot water system in the Gable Home is critical to its success as a viable house. Toward reaching a perfect score in hot water, the team spared no effort in choosing and testing the best system to do the job. Before purchasing any materials an analysis was performed to compare possible solutions. These included solar thermal water heating, an electric resistance heater, and a heat pump system. Ultimately a heat pump was chosen as the most economically and practically viable option. Parts were then purchased and thorough experimentation was carried out to demonstrate the system's effectiveness. Detailed here are the steps taken toward accomplishing this goal, as well as what work remains to be completed before the competition.

Table 3 Domestic hot water project budget possibilities.

Component	Quantity	Amount	Total per component
Tankless hot water heater	1	\$700	\$700

Heat pump hot water system components			
Water tank (40gal)	1	\$400	\$400
Heat pump hot water heater	1	\$700	\$700
Electronic damper	2	\$75	\$150
Subtotal			\$1,250

Solar Thermal hot water system components			
Evacuated tubes	2	\$1,100	\$2,200
Wall mounting kit	2	\$170	\$340
Circulation pump	2	\$220	\$440
Solar thermal tank (50gal)	1	\$550	\$550
Propylene glycol (antifreeze)	6	\$20/gallon	\$120
Subtotal			\$3,650

There are three different types of hot water draws that will be demanded during competition week. One is the general hot water draw, which requires that fifteen gallons of water be drawn within a ten-minute period with an average temperature greater than 110°F. Two appliances will also use hot water. When running the clothes washer four gallons will be drawn, also at a temperature of 110°F. The dishwasher requires four gallons as well, only it must reach a temperature of 120°F during its cycle. In short, this means that the water system of the Gable Home must be able to provide water at 120°F on demand. The carefully selected system of an Airgenerate Airtap heat pump in conjunction with a Rheem Marathon tank meets those demands.

Before settling on the heat pump system, alternative options were seriously considered. A breakdown of the costs of these systems can be seen in Table 3. One of these is the use of evacuation tubes on the south wall of the house to provide solar thermal heating. This is an expensive system to install, but its benefits are considerable. No electricity is required to heat, making it extremely efficient. Architectural design limitations, however, prevented this from being an option. Another option, electric resistance heaters are able to heat water extremely quickly, but they consume massive amounts of power to operate. By opting to use a heat pump and a water tank, hot water will be available in adequate volumes while consuming relatively little electricity.

Experimental setup

The heat pump system is advantageous not only for its efficiency, but also its size and shape. It will fit comfortably in a closet in the Gable Home, situated as shown in Figure 20. It was not, however, designed to work with the round-topped water tank made by Rheem. The refrigerant coils were unable to fit into the hot water outlet of the tank, where they customarily enter. Instead the coils were fed through the cold water inlet, and the cold water was attached to feed into the drain located at the bottom of the tank. See Figure 22 for a photo of the setup. Figure 22 shows the temperature of the water in the tank over a twenty-hour period. The losses are strikingly minimal, which is due to the excellent polyurethane insulation with a factor of R-20.

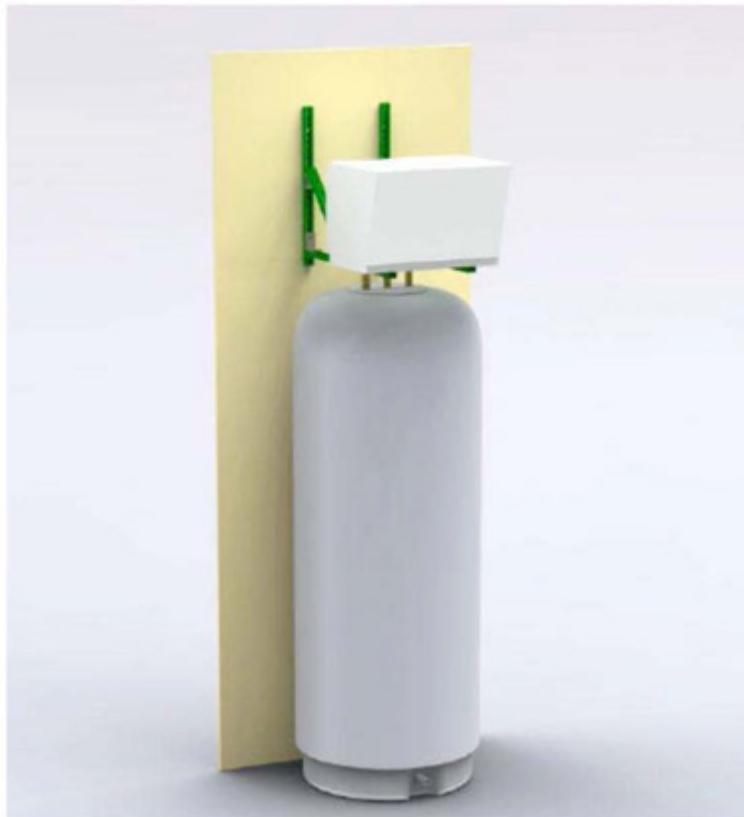


Figure 20 Rendering of Hot Water System in Final Configuration

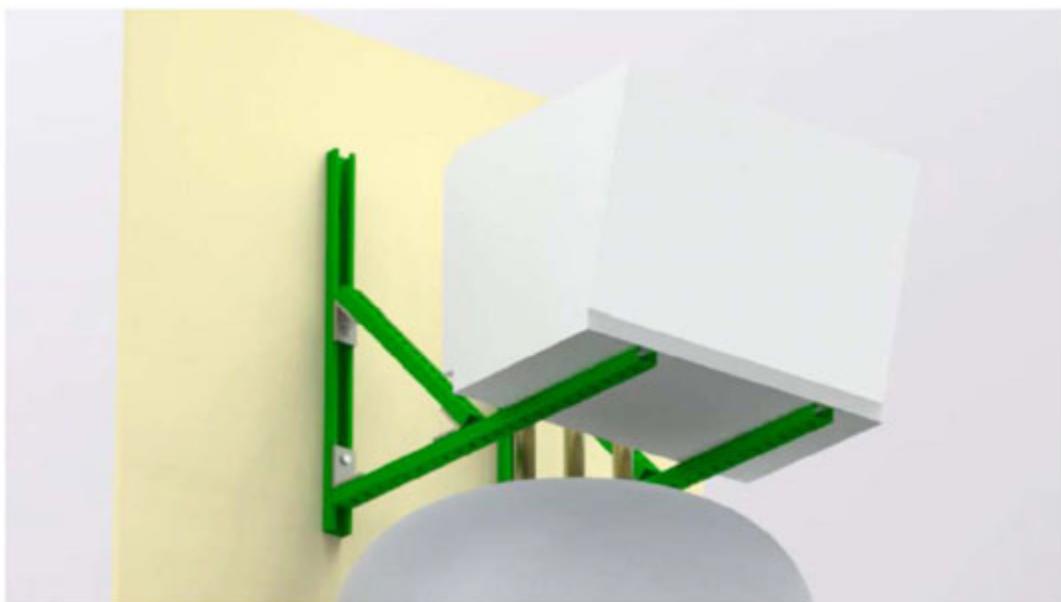


Figure 21 Rendering of AirTap Unistrut mount



Figure 22 Heat pump mounted on top of water tank.

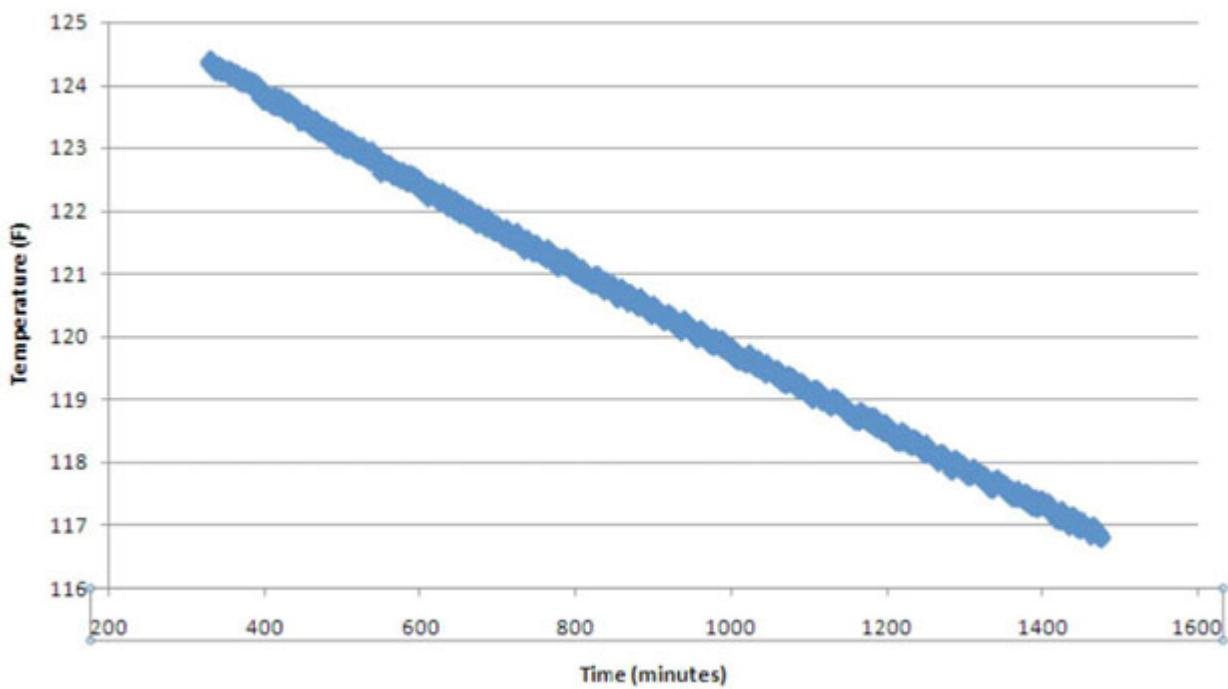


Figure 23 Temperature versus time for water tank.

The Airtap required a custom mounting solution because of the low amount of space in utility closet and the curvature at the top of the water tank. The curved top was a problem because the Airtap unit was designed for a water tank with a flat top. Figure 21 is a rendering of the Airtap mount design. The frame is constructed using 1-5/8" and 3/4" Unistrut metal framing. A complete list of components is shown in Table 5. The vertical 1-5/8" Unistrut will be mounted to the wall using four 1/2" screws and fender washers through the slots in the Unistrut. The horizontal and diagonal members are attached using angle fittings, channel nuts and 3/8"-16 3/4" bolts. The diagonal members are included for support because the weight of the Airtap is concentrated at the front of the unit. The final assembly will have a clean design that is mostly hidden from view once installed in the utility closet.

Table 5: Airtap mount Unistrut components

Table A-3: Airtap mount Unistrut components

Model Number	Description
A3300	1-1/4" x 3/4" 14 gage channel
P1100	1-5/8" x 1-5/8" 14 gage channel
A3008	3/8-16" channel nut
P1008	3/8-16" channel nut

To prove the reliability of the hot water system, it was installed in a laboratory and subject to lengthy tests. Type T thermocouples were placed at the top of the tank, the bottom of the tank, the hot water outlet, the exhaust vent of the heat pump, and in the ambient air. A power transducer measured the electricity being drawn by the heat pump. A digital rotometer measured the hot water flow rate by emitting a square wave that was measured by an oscilloscope. Temperature and power were monitored using a data logger and recorded on a PC using Agilent Datalogger Pro.

The competition schedule shown in Table 4 was obtained from the Solar Decathlon website in order to simulate the demands on the system. This schedule was used to simulate the loads expected during the course of the week, and tests were performed accordingly. Figures 24, 25, and 26 show tank temperature and power versus time graphs for three days of the competition. The periods with increased power consumption correspond with the heat pump being on. The heat pump draws an average of 0.8 kW-hr of electricity each time it turns on. This tended to occur any time a fifteen gallon water draw was made. Day 9, therefore, will most likely use the most energy of any day because the three water draws are spread out over the course of the day, requiring the heater to be turned on each time.

Table A-2 Water demands during the competition schedule.



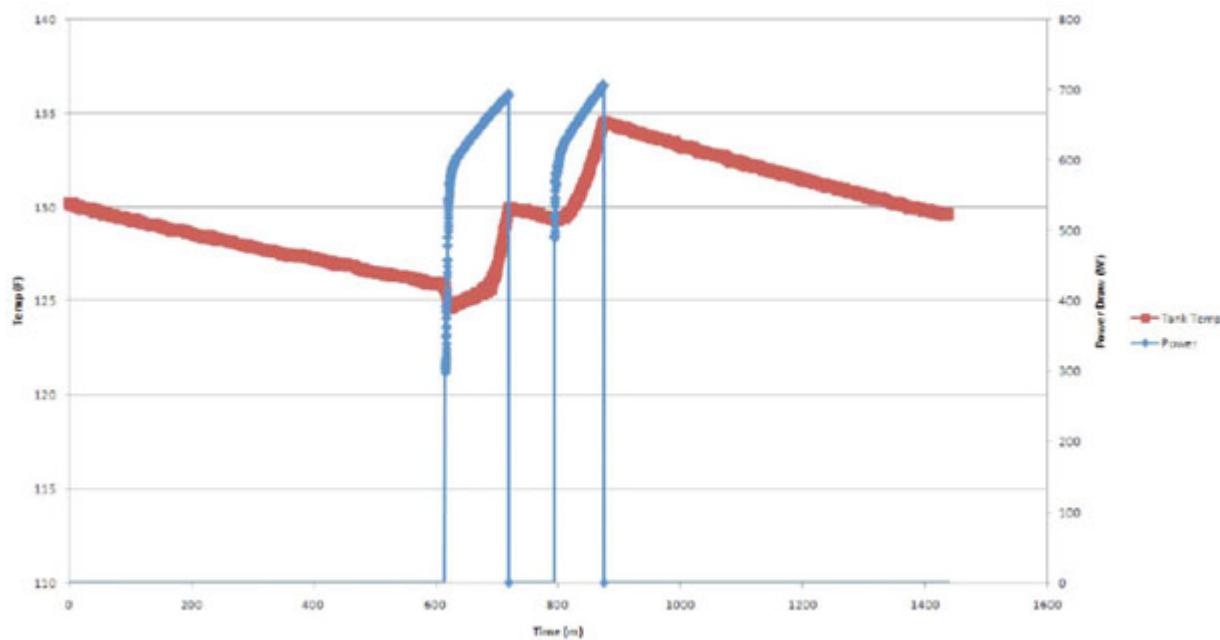


Figure 24 Competition day-1 simulation, tank temperature vs. time.

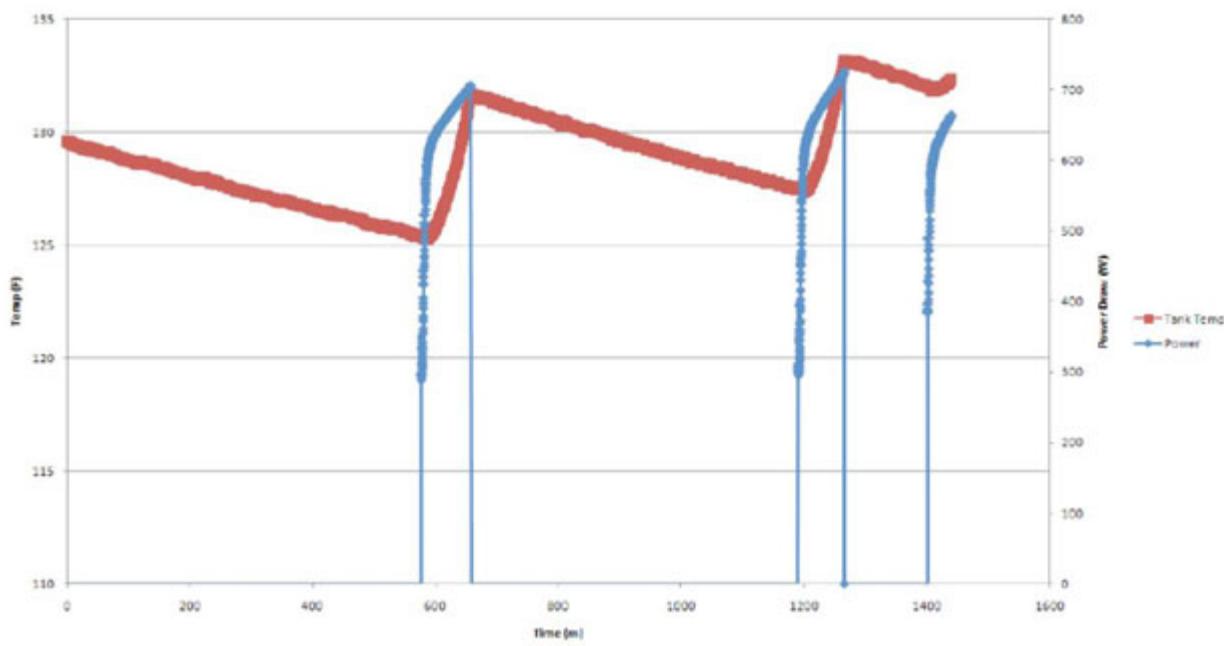


Figure 25 Competition day-2 simulation, tank temperature vs. time.

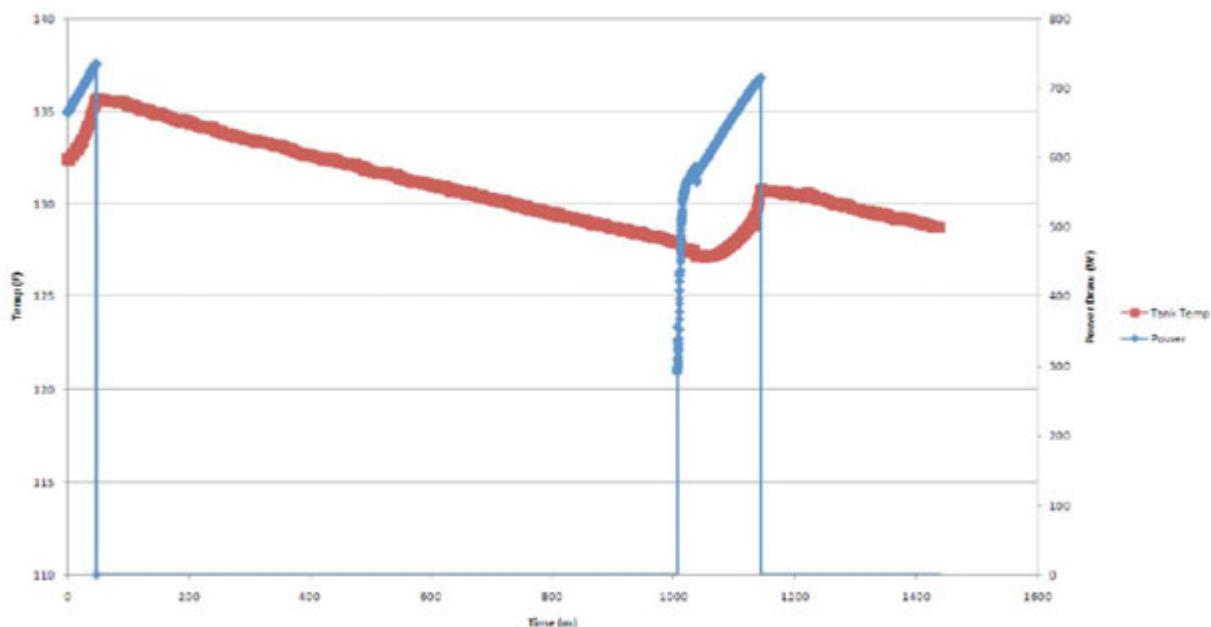


Figure 26 Competition day-3 simulation, tank temperature vs. time.

The energy consumption was calculated by numerically integrating the power versus time curve using a trapezoidal approximation. Also of interest was finding a coefficient of performance for the heat pump. This was accomplished by drawing water at a rate slow enough for the system to reach steady state and measuring the power. Then the equation $\dot{Q} = \dot{m}C_p\Delta T$ was used to find the amount of heat being added to the water in the tank, which was divided by the work done by the heat pump. This yielded a reasonable COP value of 4.5 using the equation $COP = (\dot{Q}_{water} / \dot{W}_{compressor})$. The mass flow rate was found by assuming a heat value equivalent to the rated heat capacity of 7000 Btu/hr. Flow was then adjusted until the tank temperature ceased changing with time. It should also be noted that losses from the tank were neglected in this calculation. More importantly, this COP value itself will change during operation, as the temperature rises and falls. This value is presented only as an indication of the heat pump's effectiveness during steady state conditions.

With such a high rated heat capacity, it stands to reason that the heat pump's cooling capacity would be substantial. The extremely low temperature of the air it exhausted confirmed this. In order to maintain a constant ambient temperature, a duct was added to direct the exhaust air out of the house. Subsequently it was decided that the cooling could be used to help reduce air conditioning loads during the summer. Electronic dampers were then added to the duct such that the cold air would be directed outside during the winter and inside during the summer. A photo of the setup is shown in Figure 27.

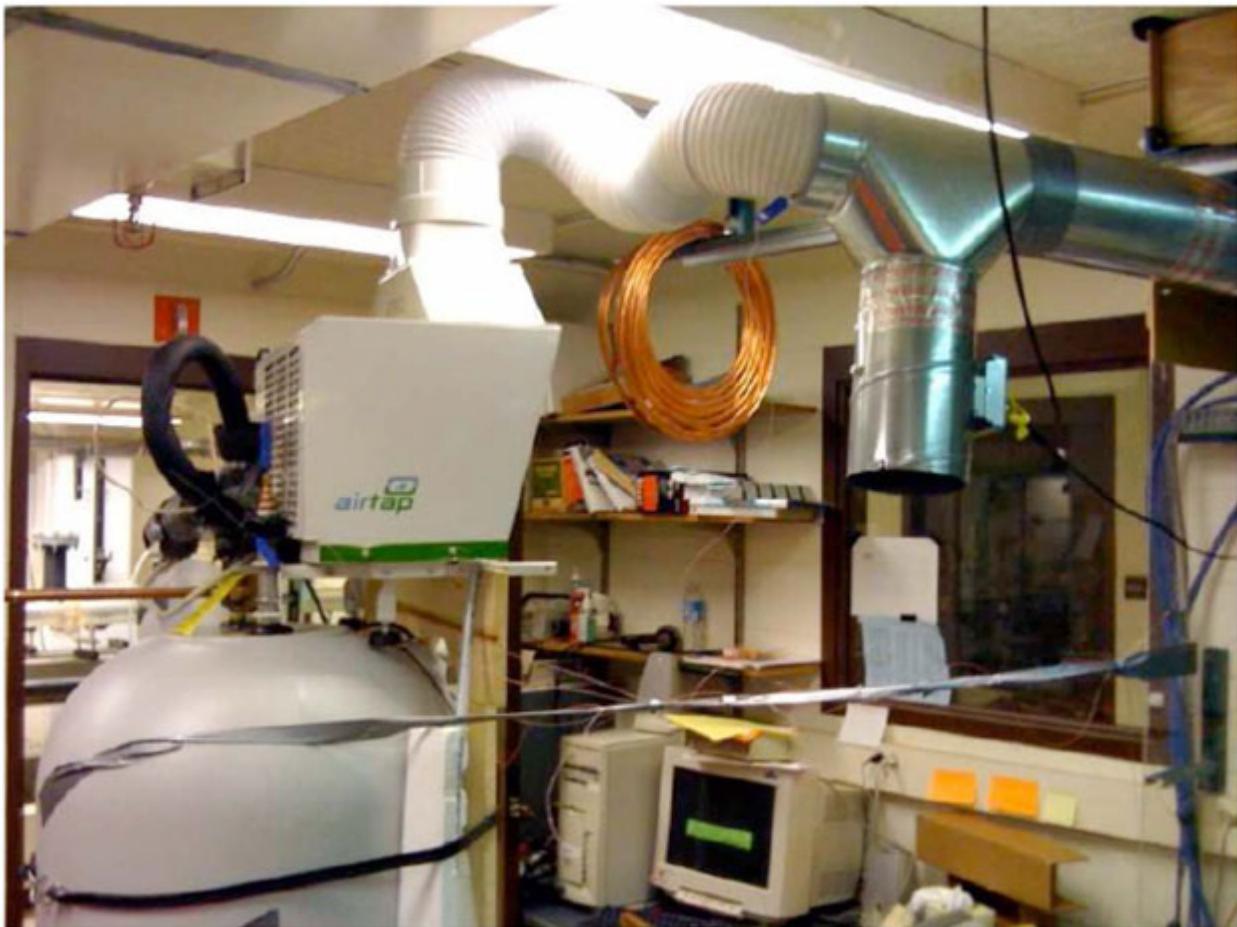


Figure 27 Rerouting of the cold air heat pump exhaust.

During experimentation, it was discovered that the built-in temperature controls for the hot water system needed much improvement. When first set up, the heat pump detected the water temperature with its built-in thermostat. This was observed to be very inaccurate, as the heat pump would be set for 120°F but would not turn on until the tank temperature was 100°F. The heat pump thermostat was then disconnected and wired to the built-in thermostat at the bottom of the water tank. This made it so that the heat pump would recognize the temperature of the cold inlet water whenever the faucet was on, leading to preemptive heating, thus preventing the water temperature to ever fall below 120°F. This can, however, lead to excessive energy consumption because often the water is heated to temperatures higher than is necessary. Optimal control would involve thermocouples in the tank being read by the central control system. The heat pump would turn on whenever the bottom thermocouple read temperatures below 115°F, and turn off whenever the top thermocouple read temperatures above 125°F.



Another concern that presented itself regards the dishwasher cycle. Maximum points are awarded if water reaches a temperature of 120°F. The competition effectively requires that “off the shelf” products be used as appliances. The dishwasher selected is programmed to boost the temperature to 130°F during its normal cycle. In an effort to avoid using electricity by the dishwasher it was requested that the thermostat be disabled. Unfortunately, the competition forbids such tampering with the appliances. As of now the dishwasher will have to boost the temperature, as maintaining a hot water temperature in the tank of 130°F is excessive. The energy usage of the dishwasher is currently unknown, and testing cannot begin until the appliances are delivered during the summer of 2009.

The tests run in the lab convincingly demonstrate that the selected domestic hot water system will meet the demands of the Solar Decathlon. It heats water quickly and efficiently, while consuming only 5% of the photovoltaic energy production on an average day.

Appliances and Home Entertainment

Television (TV)

Based on our initial analysis, a 42" Philips 42PFL5603D based on its ratings for low energy. As it stands, that TV has the lowest power rating out of all the HDTVs on Cnet's review site³. This television also has a modest screen size and an impressive power-to-square-inch of screen space ratio. It is second only to Samsung's HL series which uses Texas Instruments's (TI's) DLP technology.

However, despite our initial inclination toward the Philips 42", TI was willing to donate a 61" Samsung HL61A750. The Samsung HL lineup that has better power to square inch of screen space ratio than the Philips 42". From an entertainment score standpoint, the Samsung 61" TV would perform very well and its total power consumption was impressive. Unfortunately, however, this TV was too large for the given space.

According to TI's DLP information website, the most efficient TV (namely the Samsung HL series) use LED backlights which is why their efficiency is so impressive. The other TVs that use DLP technology do not have that same efficiency but come in smaller sizes. The smallest size is a 50" Samsung television which only stands 3" higher than the Philips 42". The Samsung 61" was rejected because it did not sit below the windows but it is possible that the 50" will sit lower than the windows. After further discussions with TI and in consideration of aesthetics and power management, we were able to obtain a 50" version of the Samsung free of charge.

The TV is simply one aspect of the entertainment system that will be judged by the other contestants. Of course, a great TV will help with the score but picture quality, sound quality, and atmosphere will also have an impact on the score. If a high-definition TV (HDTV) is used, a DVD player will have decent picture quality but a BluRay player may provide the best picture quality. The team initially considered adding a BluRay player to our computer to minimize cost as BluRay players are less expensive in the form of computer DVD drives. We could then run a cable from the computer to the TV to use our computer as the TV's BluRay player. Unfortunately however, the laptop area does not seem to be in reasonable range of the TV unit, making the connection from the laptop to the TV rather difficult to make. With this connection out of the question for now, it will have to be determined if buying a standalone BluRay player will have a large enough impact on the home entertainment experience to warrant the extra cost.

Sound quality is another important movie theater aspect that should be taken into consideration. Bose has offered to sponsor the University and it is possible to obtain a high quality sound system from a well known and respected audio company such as Bose. On the other hand however, Bose products tend to consume a fairly large amount of power. The interior design team has found a set of speakers that has a particularly high audio output in terms of decibel per watt of power. Our industrial design team is also supposedly designing the entertainment center to incorporate these speakers. The speakers are from Lowther USA and they were most compatible with the industrial design that was already underway. Price-wise, they are not all that different from Bose speakers and area much more efficient. We are attempting to obtain the Lowther speakers by donation.

The last topic for the entertainment system is the computer. According to the rules, it must have a display size of at least 17" that can be independently operated from the TV. Due to their substantially lower power consumption we are currently looking into laptops that have 17" screens. The power consumption of the laptop is not as clear cut as some of the other appliances. Laptops have a power supply but not really a power rating. A lot of the power consumption is controlled from the power settings with the laptop software. The monitor is a major source of power consumption and a few laptop companies have started using LED backlights. These will probably be the most efficient laptops. The two laptops proposed last fall were the MacBook Pro and the Dell Studio 17. Since the Dell laptop is much less expensive than the MacBook and because the we plan to use a Dell laptop for building automation and control, it was decided that the Dell Studio 17 is used.

Building Automation and Control

The concept of resource monitoring and control systems is fairly simple, but can quickly become more complicated in implementation especially for something as comprehensive as a house. Resource monitoring keeps track of energy usage, leading to smarter decision making, and can actually perform intelligent analysis and determine specifically which electrical components are wasteful and which are not. It does so through a series of sensors which are attached to not only electrical circuits, but also heating and air conditioning connections, as well as water.

Control system on the other hand provides automation and encompassing controller to the house. We can control everything in the house from just a single panel or we can just tell the system our desired setting of the house and let the system do the rest. The system combined with monitoring allow for intelligent energy saving decisions that in turn, can command the control system to make changes in order to implement these decisions.

At the electrical circuits, we are able to monitor power usage at each of the receptacles which ultimately educate us on the energy usage by the house appliances. Combining the knowledge of the house complete circuit and the monitoring system software, it is possible to detect what appliances is consuming the most energy and thus help us minimize energy waste. The energy monitor also keeps track of the power production by the solar panels. This way we can compare our energy production to our energy usage and project how much savings we are able to make, along with encouraging towards efficient energy usage.

There are various methods of displaying these results, from touch screen panels to web-based interfaces; we are combining both. With a computer that is loaded with monitoring and control software, a touch screen panel, internet connection, resources sensors and electrical sensors, we can control the house on site and remotely. A web-based interface can be set using the house touch screen panel or any computer in the world with internet to provide conditioning for the house or just to keep an eye on what appliances we forgot to turn off through the monitoring system.

Two major power consumers in a house are the lighting and the HVAC system. Thus it is essential to be able to control both to ensure efficient energy usage. HVAC system lighting should be conditioned according to house occupancy, the time of the day and types of activity that is going on in the house. For example, in the middle of the night in winter, when everyone is sleeping, the system will automatically switch off all the light except the night light perhaps, and minimizes the heating. However as the morning is approaching, the heat is increased little by little to the preset condition.

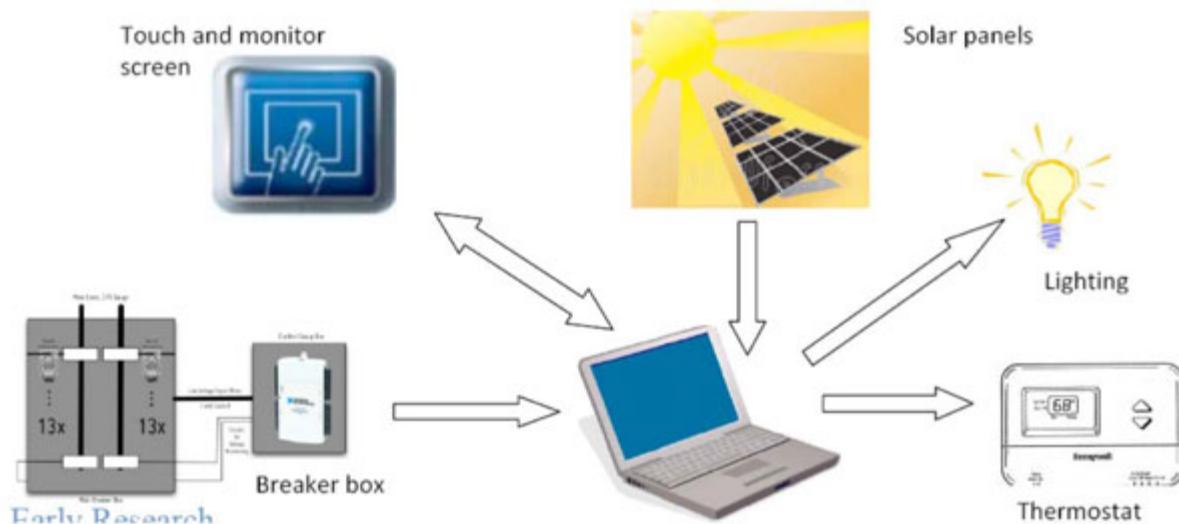


Figure 28: Overview of building control system.

Early Research

Resource Monitoring and Control Systems Companies

There are several companies that manufacture and install products and software that accomplishes the necessary tasks. A few of them have systems that are all-inclusive, whereas some of the systems work on a component-by-component basis. The following companies seemed the most fitting for the needs of the Solar House:

Lucid Design

Lucid Design Group is a company that deals in something called Dashboard. It is essentially a web-based software that monitors resource usage and displays the information via the Internet. It breaks down energy usage and consumption and offers the user the ability to see where energy usage is at the highest, and thus where it may be able to be lowered. It also involves features such as Gas, HVAC, Water, and other utilities that might be needed to be taken into account. Lastly, it has a tool allowing comparisons between the building in question and other buildings in the area. This would be convenient not only as a benchmark for our Solar House, but as a way to show others how efficient our house may be.

Agilewaves

Agilewaves is very similar to Lucid Design Group in their company goals. They have a web-based system that monitors all forms of energy consumption throughout the house and displays it in a format allowing quick and easy decision making regarding energy usage. (See Fig. 29)

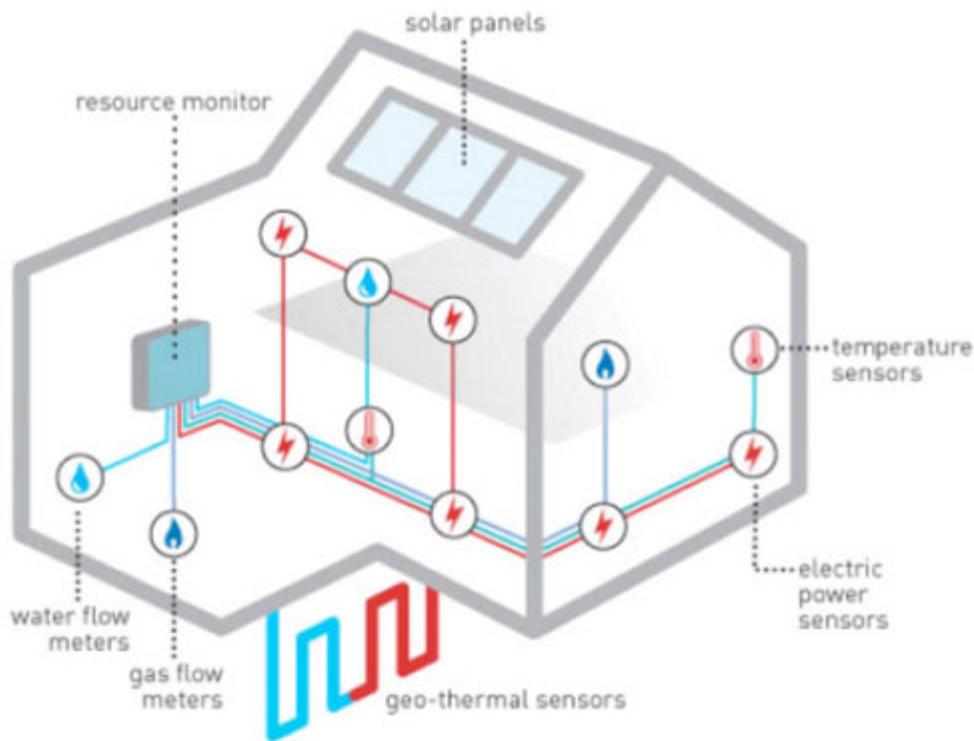




Figure 29: An illustration of various forms of monitoring allowed by Agilewaves.

Though there are subtle differences, Agilewaves and Lucid Design Group are both very comprehensive systems, keeping track of nearly everything one would need to make smart and efficient energy decisions. The main difference here is that Agilewaves “bridges the gap between monitoring and automation” as they put it. This is just a creative way of illustrating their partnership with Crestron, an automation company. Through this partnership, not is resource consumption tracked and monitored, but the information gathered can be used to control aspects of the house, everything from turning off lights automatically when no one is home to opening windows automatically to lower HVAC energy usage.

Crestron

Crestron was the first automation company that we looked into, and seems to be one of the most comprehensive. Though their system can basically control anything, it can also be highly customizable to what needs to be controlled. The problem comes from the system almost being too much; simple tasks like turning on or off electronics seem far too simplistic to make Crestron worth the cost. However, there is no doubt that Crestron transforms a normal house into something much more convenient and efficient. Whether the system will truly be of use is going to depend on the criteria with which the Solar Houses are graded. Although the automation is nice, it doesn't come particularly cheap, so if the money is spent on areas that are awarded more points, it may be one of the first aspects to be cut.

Mile High Automation

Mile High Automation is another company that offers fairly comprehensive packages, but also has options for bare-bones systems that provide us with cost savings. The most interesting system for our purposes is the Value System, which provides the automation panel, door and window security contacts, a smart thermostat, dimmer switches and a scene controller, LCD keypads, CAT 5e cable, software and support, for \$3,500. While we can probably find most of the parts separately for less, what is nice about the system is the guaranteed compatibility and support we would receive, which we agreed makes a decent plan B.

Smarthouse/Insteon

This was one of the last aspects to be considered, but may actually be the best option. Instead of a system that contains monitoring and automation for every aspect in the entire house, these companies

sells components that you simply apply to a given electrical device. A central controlling device also must be purchased, and then the given devices can be controlled and monitored remotely. The advantages of this are fairly obvious; buying by components allows the flexibility to control what needs to be controlled and stay under a reasonable budget. However, there are more limitations in this system, and it can be more complicated, because there are many different formats of communication, and it must be ensured that they will be compatible. Even so, this seems like perhaps the most logical option, and will definitely be looked into more before a final decision is made.

Custom Designed System

If we were to build our own system, the following would be the elements we would be looking to control.

Temperature Control

This is the largest and most important task of the automation group. There is a potentially a lot of energy that can be saved by automating the thermostat efficiently to achieve a desired temperature and humidity. A big unknown still remains, though, and that is the windows. Depending on which windows open and close, and how they do so, we would like to be able to automate them to open and close a method of heating and cooling the house. By comparing the outside temperature and humidity with the energy cost of using the HVAC system to achieve the desired temperature and humidity, we can make a decision to turn on the HVAC based on the following inequality:

$$(P_{HVAC}t_{HVAC}) + (P_{humidifier\ or\ dehumidifier}) < 2E_{servos} + (P_{humidifier\ or\ dehumidifier}) \text{ OR } 2E_{servos} + (P_{HVAC}t_{HVAC})$$

Where P is the power consumed by a system and t is the time it would have to run to achieve the desired. The servo energy, E_{servos} , is required to move the windows and is multiplied by two to take into consideration that they will eventually be closed. It should be noted that to do this, we would want to use a custom system to avoid high costs.

Lighting

While our ability to influence energy saving through automation is diminished both by the use of compact fluorescence and our inability to dim lights based on rules, timing control of lights can avoid wasteful use of energy through. Syncing control of the lights and possibly shades with sunrise and sunset could be a nice effect and prevent unnecessary electric lighting. This should be fairly straightforward, no matter which type of system we decide to go with.

Security

While not incredibly necessary, a security system could help improve marketability. Sensors on doors and windows can be set to alert police or send texts to a cell phone, while CO and fire detectors can alert other emergency authorities. Sensors can be placed around the home as needed, in places like medicine cabinets or desks. Besides alarms, these entries can be logged into a database for later review. This system should also be fairly straightforward to produce.

Energy control

Monitoring the usage of energy on each circuit could be a big help in conscious energy conservation. Just visualizing a breakdown of what is using the most energy might help the user save money. In terms of the competition, we could automate the circuits to ensure that we are never using too much energy at a time. In a practical sense, the system could be used to help control the energy of a user with a set energy budget. However, so far we have been unable to find a system with a price low enough to justify the cost savings. A device proposed earlier, the energy detective, is unfeasible in both monetary and practical standpoints. The only situation in which it would be practical would be to track the amount of energy output from the solar panels.

Appliances

The automation of appliances is almost purely for convenience. Having the coffee maker be on before waking up is a neat trick, but if the appliances don't get used, they're a waste of energy. Some higher end appliances already have these functions, so it may be worth it to just upgrade the appliances rather than automate them. However, we should carefully examine whether or not they will actually be used before spending the extra money.

Research Summary

Table 6: Summary of control system research

Company Name	Pros	Cons	Conclusion
Agilewaves	<ul style="list-style-type: none"> • Comprehensive resource monitoring • Helps make intelligent energy saving decisions • Works easily with Crestron to 	<ul style="list-style-type: none"> • Cost: approx \$5,000 • Gives more information than perhaps is necessary (overkill?) • Installation must 	If we decide a comprehensive and all-inclusive monitoring system is desired, Agilewaves works very well, and combines nicely with an excellent

	automate system	be considered during construction	automation system.
Lucid Design	<ul style="list-style-type: none"> • Comprehensive resource monitoring • Helps make intelligent energy saving decisions 	<ul style="list-style-type: none"> • Cost: approx \$5,000 • Gives more information than perhaps is necessary (overkill?) • Does not integrate as well with Crestron • Installation must be considered during construction 	If we choose a comprehensive system, and Agilewaves doesn't work out, Lucid Design is a good alternative, but doesn't seem to offer much than Agilewaves does not.
Crestron	<ul style="list-style-type: none"> • Very smart and convenient automation system • Automation can be applied to nearly anything in the solar house • Works well with Agilewaves 	<ul style="list-style-type: none"> • Cost: approx \$5,000 • Again, might be more comprehensive than needed (i.e. how important is it to be able to control every aspect of house) • Installation must be considered during construction 	If we are going with a comprehensive system, Crestron can likely do anything and everything we need. The biggest question is if the additional cost is worth the benefits it gives.
Mile High Automation	<ul style="list-style-type: none"> • Moderately priced • Guaranteed support • Well reviewed software 	<ul style="list-style-type: none"> • Self installed • Some features might go unused • Would be better to install during construction 	More basic, not as professional. A good fallback plan
Smarthouse	<ul style="list-style-type: none"> • Cost: as low as \$100 per component • Installation is easy and can be changed if necessary • Can easily be customized to only include electric devices that really benefit the solar 	<ul style="list-style-type: none"> • Not comprehensive, components must be selected separately • Resource monitoring can be difficult, especially for power generated and power to/from the grid 	Almost 180 degrees from Agilewaves and Lucid Design with Crestron. If we are going with an affordable and customizable system, Smarthouse makes a lot of sense. It can easily be adapted to fit whatever the solar house needs, even

	<ul style="list-style-type: none"> house • Offers different brands and services 	<ul style="list-style-type: none"> • Must ensure all components are compatible • Require separate resources to monitor (personal computer) 	after construction.
Insteon	<ul style="list-style-type: none"> • Cost: as low as \$100 per component • Installation is easy and can be changed if necessary • Can easily be customized to only include electric devices that really benefit the solar house 	<ul style="list-style-type: none"> • Not comprehensive, components must be selected separately • Resource monitoring can be difficult, especially for power generated and power to/from the grid • Require separate resources to monitor (personal computer) 	Similar to Smarthouse, but Insteon makes a single line of products, so compatibility is not an issue. However, this sacrifices some freedom of choice, and could be slightly more expensive and/or less flexible. Still a good option though.

Software Considerations

There were many options available to choose from for our software, so narrowing down the field was our first task. We decided to use an Insteon compatible system to control lighting and outlets, so that was the first thing we looked for in our software. The systems we originally looked at included the ISY-99i from universal devices, the Home Control Assistant 8 from Advanced Quonset Technology, the Artemis V2 from South Coast Logic, mControl from Imbedded Automation, Indigo 3.0 from Perceptive Automation, and SmartLinc from Smarthome.

The Artemis V2, while initially very promising, turned out to be specifically designed for lighting controls. While it still would have been able to perform other tasks, the high price tag for lighting features that we would not be able to take advantage of ruled it out. We were able to rule out Indigo 3.0 because it was specifically designed for Macs, since we anticipated other elements of our project needing to be windows compatible. After much debate and research, the Home Control Assistant 8 and mControl we dismissed because of their interfaces and ease of use. In the end, we decided to use a

combination of the ISY-99i and the SmartLinc. The ISY-99i will be used to control systems that are on timers, and the entire behind the scenes aspect of the control system.

Specifically, the ISY-99i was chosen because it was compatible with a security system that we strongly considered purchasing. The SmartLinc on the other hand, will be the face of the system. It has a straightforward interface, allows for easy control from wireless devices such as an iPod touch, and gives us the internet capabilities that we require for remote use. Also, it should be simple to tailor the interface to include other features such as power monitoring. Once we had decided on this software package, the decision for the operating system was made simple, as Windows XP was the preferred system of both pieces of software. While we originally considered using Windows Vista as our operating system, no one on our team is very familiar with it, and we did not want to have to work around any unexpected complications from using a new operating system.

Power Monitoring

Monitoring the usage of energy on each circuit could be a big help in conscious energy conservation. Just visualizing a breakdown of what is using the most energy might help the user save money. In terms of the competition, we could automate the circuits to ensure that we are never using too much energy at a time. In a practical sense, the system could be used to help control the energy of a user with a set energy budget. Many off the shelf options were available for the purpose of monitoring energy use. For instance, Sunpower has a monitor designed for the specific inverters we chose. Also, P3 International's kill-a-watt is a full line of individual monitoring devices. However, both of these solutions are not enough for our needs. Our goal is to monitor each individual outlet and have many *variables* on screen. For example, to monitor each outlet we could use multiple KAW's. However, using KAW's would be expensive, given the number of items we wanted (32) to monitor. In addition, this solution would just allow us to see the energy/power use on individual basis, and not the system as a whole. On the other hand, Sunpower's inverter monitor does present the energy monitoring of the whole house but it cannot do it for individual items of the house. Trying to merge both solutions would be difficult and expensive. Furthermore, it would be difficult to add features we may need in the future. Therefore, we decided to create our own solution. This will allow us to accomplish the aforementioned objectives, and to have an easily expandable system.

The Solution

Our design allows us to monitor the power and energy use in real-time. It is also flexible enough to allow for easy updates such as internet streaming of the power used. In order to accommodate for these needs our solution must be robust and precise. Below is a breakdown of each component to be used.

Current

- A split ring current transformer will be placed around each circuit in the main panel and the lines coming from each inverter
- A resistor will be placed across the leads of each current transformer to produce the desired +/- 5V output per the

Datasheet

- CR Magnetics CR3110-3000
- Digi-key Product Page
- UL Listed, XODW2.E235509
- 30 units should be purchased to accommodate extra circuits. At a per-unit cost of \$11.83, the total cost sums to
\$354.90

Voltage

- A circuit from each of the mains will be fed into the control group's box from which both 120V legs can be monitored while the 240V created by combining both 120V legs can also be monitored
- Inside the box, a monitor will be created that can be plugged directly into a standard wall socket. From this connection, a power transformer will be used to step down the voltage to a level readable by the DAQ
- Power transformer: Hammond 166F5, Datasheet
- Mouser Product Page
- UL Listed
- 5 units should be purchased to allow for replacement parts. At a per-unit cost of \$17.87, the total cost sums to
\$89.35

Data Acquisition



- Data from the above-described current and voltage monitoring methods will be acquired using a 32-input DAQ

supplied from NI

- DAQ will communicate with the computer via a USB connection

- NI USB-6218, Datasheet

- NI Product Page

- UL Listed, 61010-1

- Data will be analyzed to determine real power, power factor, etc. using LabView from which it will be exported to a

medium that can be easily read other softwares such as a web page, likely export formats are MySQL database or TXT file

- Retail cost is \$1249, however we are currently in contact with National Instruments to arrange for sponsorship

Software

-Labview

Future Features

The following features are potentially to be added in the future:

- Stream live view of power and energy usage. This view may be embedded on 491sd uiuc website, to allow visitors to see our performance.
- Automated control of individual outlets based on profiles. i.e. power saving, vacation, out for work.
- Energy/power usage based on kw-h price.

Lighting Control

While lighting is explained in some detail elsewhere in the project manual, we touch on it here with respect to control. Due to the high efficiency provided by the LED, the lighting group has decided to use LEDs to provide light to the interior of the house. Controlling the LED light fixture is essential

since it allows an efficient placement of luminous power throughout the house, therefore reducing the overall power consumption used in lighting the house. However, the amount of control we have on these light fixtures is limited considering diming is not possible with LED light fixtures. As a result, our control is limited to the switching of the LEDs between the on and off states.

The switching is controlled by a series of INSTEON relay switches, which function only as on/off switches. More specifically, twelve 2476S Insteon light switches are to be installed to control the lights placed in the interior edges of the house. The on and off switching will be controlled by the user via a computer (see software/computer annex. These switches were chosen over other brands based on the following criteria:

- The INSTEON relay switches have a quieter built in relay, which allows control of the lighting without disturbing the ambient noise.
- Other switches use semiconductors which absorb a considerable amount of power. The design of this switch uses a relay, which runs cooler and allows the full voltage to dissipate through the load. This points to an increase in the amount of energy saved.
- This switch is fully INSTEON compatible, allowing us to control the switches from a central INSTEON controller.
- The settings for the SwitchLinc Relay are stored in non-volatile memory and are not lost during power failures. In the event of a power outage, the SwitchLinc Relay will return to its last on/off state when the power is restored.

Figure 30 shows a flowchart of the lighting control.

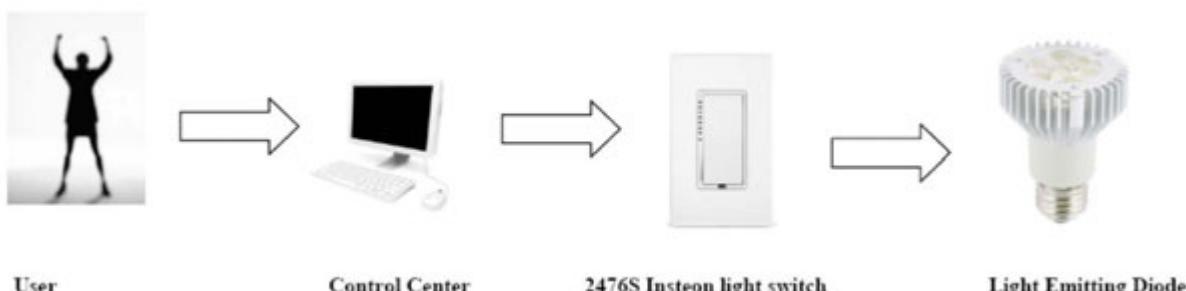


Figure 30 Flowchart of lighting control.

HVAC Control

The following is a list of inputs/outputs that needed to be controlled by the HVAC team.

- 7 inputs
- 0-5v out
- 0-10v out
- 120 or 240v on/off
- 240v on/off
- 120v on/off
- 3-24v on/off
- Reversing valve
- Maybe 2 expansion valves

Because of the complexity of this system, including at least 6 different output voltages, our options for controlling the HVAC system were expensive and somewhat complicated. The following parts would work, but barring some donations or discounts, appears to be slightly more expensive than would be preferred.

Again, the reason the parts are so expensive is because of the variation in outputs that need to be available.

Table 7: Data acquisition boards for building control.

	Vendor	Item	Item Number	Price per Unit	#	Total Cost	Link
	National Instruments	Analog Current Output Module	777318-200	\$629.00	1	\$629.00	http://sine.ni.com/nips/cds/view/p/lang/en/nid/11592
	National Instruments	Controller Interface	777317-2200	\$1449.00	1	\$1449.00	http://sine.ni.com/nips/cds/view/p/lang/en/nid/11570
	National Instruments	Backplane	778617-04	\$429.00	1	\$429.00	http://sine.ni.com/nips/cds/view/p/lang/en/nid/11609

The Analog Current Output Module features eight 4 mA to 20 mA or 0 mA to 20 mA current outputs, so one can control the 6 or so different output voltages that were required. The wiring diagram of the

device is pictured below. As it is necessary to be fairly complex, the item does not come cheap, but there are few other options to control as many different outputs as we were given.

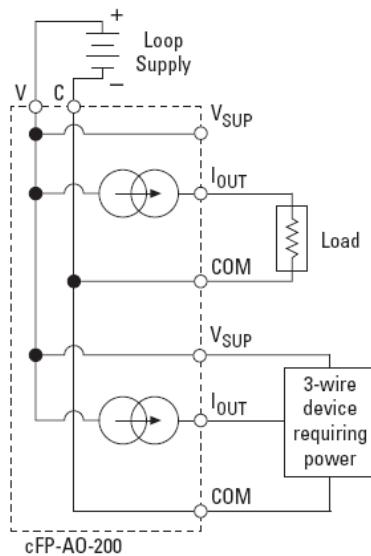


Figure 31: Wiring diagram for analog current output module.

The controller interface is similarly complex, and thus expensive, and is required to be able to read and log the data that we are obtaining regarding the HVAC system. This controller has the benefit of using LabView for the data gathering process, which is the same software we are using to monitor power and resource usage. LabView makes it very simple to take inputs and use algorithms to manipulative them into useful data to either be displayed or used in some type of system control. The following is just a small sample of the simplistic graphical interfaces that can be created.

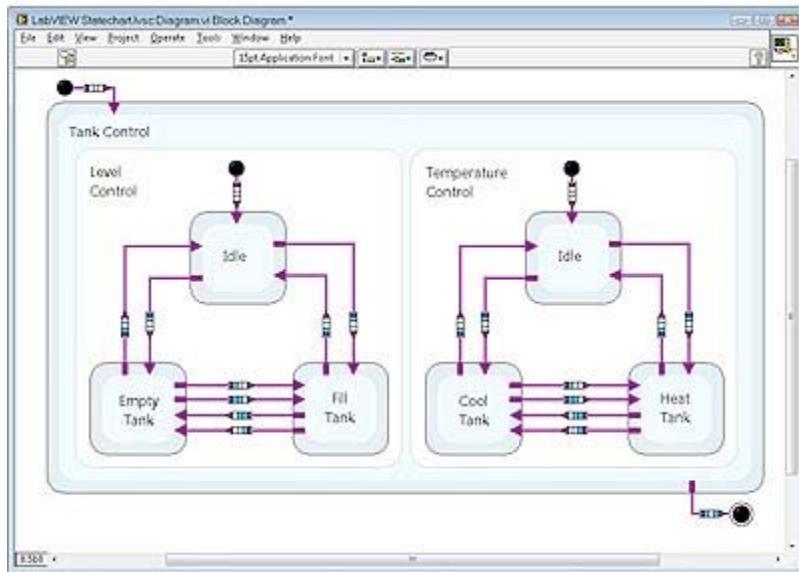


Figure 32: An example of LabView graphical interface.

Lastly the backplane is required in order to properly mount the I/O and control modules that we will use. Since saving space is an obvious concern for our house this is absolutely essential despite the cost.

The system totals over \$2500.00, which seems too expensive for one aspect of the control system. However, for our own budget purposes, National Instruments has already agreed to donate a DAQ for the power monitoring aspect of our system. If there were to donate or reduce the price on any of these parts, the system would become a much more viable option.

If this is not the case, another option we have considered for controlling the HVAC system would be the use of a programmable logic controller, or PLC. These devices are essentially single input/output controllers that are used very similarly to the control module we were looking at. The biggest downfall of using PLCs is the programming can be considerably more complex than the programming using LabView, and the system would essentially be completely in our hands. Nevertheless, this is an important option to consider if the cost of our intended system is too high.

Control Computer and Touch Screen Monitor

Control Computer



To control the resources at the SD house, we decided to have a separate control computer than the home computer. The system that we had chosen is the Dell Mini 9. It is a power efficient laptop with compact size and great usability which fits our purpose. The following the specification of the laptop:

- OPERATING SYSTEM: Genuine Windows® XP Home Edition
- MEMORY: 1GB DDR2 at 533MHz
- HARD DRIVE: 8GB Solid State Drive
- BLUETOOTH OPTION: Built-in Bluetooth 2.1 capability

We decided on using Windows XP due to its compatibility with INSTEON software that we've chosen.

Touch Screen Monitor

We also decided to have a touch screen monitor which will be the main control interface for the SD Home residents. It will show the condition of the house from time to time to see its performance and allows the residents to control the appliances and power usage of the SD Home. Since the main interface for control is the touch screen, the setting done on the laptop will not be easily accessed by public users and can be limited to admin only for security reasons.

The touch screen monitor model that we have chosen is a 19-inch GVISION P19BH-AB-459G Black.

- Touchscreen Type : 5-wire Resistive
- Panel: Active Matrix, TFT LCD
- Screen Size: 19"
- Display Type: SXGA
- Maximum Resolution: 1280 x 1024
- Recommended Resolution: 1280 x 1024

The monitor will be recessed in the depth of the wall because we are tight on width for ADA requirements. The center of the monitor will be placed 4'6" off the floor.



Summary and the Way Forward

This narrative has described the most important subjects of the engineering effort. The Gable House is nearly ready for delivery to the UI campus and most of the engineering equipment has been ordered or has already arrived. This will enable the summer to be used for installation, testing, and refinement of the subsystems, as well as the system as a whole. This work will enable us to develop a competition strategy based on different weather scenarios. In addition, this summer we will focus on getting our work 100% right in preparation for the competition.



Retail PV Price Quote

Modules	Price (\$ / Watt)	Price (\$ / unit)
SPR-215-WHT-U	\$4.02	\$864.30
SPR-225-BLK-U	\$4.22	\$949.50

Standalone Mounting Rail Kits				
Description	Qty	UOM	Part Number	Price / Box
Solar Mount Kit (2 Rails, 3 Grounding Lugs, 6 Grounding Clips, 1 Splice Bar)	1	Each	SPR-SM-4	\$241.09
Solar Mount Light Kit (2 Rails, 3 Grounding Lugs, 6 Grounding Clips, 1 Splice Bar)	1	Each	SPR-SML-4	\$203.27
SunFrame Kit (Single Rail, 1 Splice Bar)	1	Each	SPR-SF-4	\$166.11

Smart Mount Accessories				
Description	Qty / Box	UOM	Part Number	Price / Box
SPR-Comp Shims	100	Each	SPR-SH	\$23.64
SPR-Comp Alignment Tool	1	Each	SPR-AT	\$381.43
SPR-Comp Screws	1500	Each	SPR-CS	\$136.36
SPR-Comp Electrical Flashing	5	Each	SPR-ELF	\$209.82
SPR-230-WHT-U	\$4.22	\$970.60		

These Smart Mount Accessories are required as minimum inventory before Smart Mount installations

Mounting Accessories ²			
Description	Qty / Box	Part Number	Price / Box
Mid Clamp Kit	20	MIDC	\$33.00
End Clamp Kit	20	ENDCF	\$33.00
Stand Off 4"	12	STO-4	\$138.00
Stand Off 7"	12	STO-7	\$153.00
Flashings, 12" x 18" Black.	12	FLA-12	\$157.00
Splice Bars for SPR-SM and SPR-SF Rails	20	SBAR-SM	\$70.00
Splice Bars for SPR-SML Rails	20	SBAR-SML	\$46.00
L Footings with hardware	20	LF	\$55.00
Grounding Clips	100	GC-4	\$57.00
Grounding Lugs	10	GL-4	\$69.00

² Minimum order quantity for Mounting Accessories: \$2000 total (any combination of parts)

Inverters	Price (\$ / unit)
SPR-3000m	\$1,850.00
SPR-3300x	\$1,800.00
SPR-4000m	\$2,300.00
SPR-4000x	\$2,200.00
SPR-5000m	\$2,850.00
SPR-5000x	\$2,750.00
SPR-5200	\$3,000.00
SPR-6000m	\$3,050.00
SPR-7000m	\$3,330.00



SUMMARY OF RECONFIGURABLE FEATURES

The Gable Home design incorporates a few moveable or reconfigurable features that may be demonstrated or used during the course of the competition in Washington, D.C. Consequently, they have been outlined below.

The Gable Home features a few pieces of furniture that have reconfigurable parts in order to serve multiple functions. These components are the bedroom desk, the living room coffee table and the outdoor hammock. The bedroom desk expands like a typical dining table; it pulls apart in one direction and the leaf stored underneath the table fits in the separated space. The expandable surface will allow the desk to pull over the bed so that the users can use a computer, eat breakfast, or do other work while sitting up in bed. The coffee table in the living room is made of two joined chairs that rest on their side. The two chairs can separate from each other when the users wish to accommodate more guests for dinner or other entertainment activities. The hammock will be a standard hammock, with two legs and a fabric support between, but this fabric can be removed and replaced with guide wires that will act as a clothes line for natural drying of our towels. hangs over the deck via guide wires. The hammock can be removed so that the guide wire can be used as a clothes line for natural drying.

In addition, the home will feature a large set of shading devices, mounted like doors, on the south façade of our home. The south shading device is a dual track system that provides for the manipulation of two independent shades. Each shade is fully supported by a rail mounted to the deck and stabilized by two more rails mounted to the overhang of the house. Each shade is free to move independently of the other and they are spaced to allow them to overlap. There are two 8-foot wide windows installed on the south side of the house. These two windows are spaced 8 feet apart, creating an 8 foot wide module repeated three times (window, wall, window). This means that there is a multitude of shading possibilities available at any one time. For instance, one window can be shaded while the other fully exposed, both windows can be fully shaded or both windows can be fully exposed. The freedom of movement in the shading devices allows for any range of shading configurations, thereby allowing the team to carefully monitor our solar gains.

Interconnection Application Form

04-Dec-2008

Solar Decathlon 2009
INTERCONNECTION APPLICATION FORM

UIUC , LOT NUMBER 120

team name and lot number

PV SYSTEMS

Module Manufacturer	Short Description of Array	DC Rating of Array (sum of the DC ratings)
SUNPOWER CORP.	2 SUB-ARRAYS OF SPR-125-BLK	9000 W
	MODULES. EACH SUB-ARRAY HAS 2 PARALLEL CONNECTED SERIES OF 10 PV MODULES	

Total DC power of all arrays is 9 kW (in tenths).

XXXXXXXXXXXXXXXXXXXXXXXXXXXX

INVERTERS

Inverter Manufacturer	Model Number	Voltage	Rating (kVA or kW)	Quantity
SUNPOWER CORP.	SP000-01	240 VAC	5 KW	2

Total AC power of all inverters is 10 kVA or kW (in whole numbers).

XXXXXXXXXXXXXXXXXXXXXXXXXXXX

Please include the following in the Project Manual:

- 1) One-line electrical schematic – the loads do not have to be detailed.
- 2) Calculations of service/feeder net computed load and neutral load (NEC 220)
- 3) Plan view of the lot showing the house, decks, ramps, tour paths and the service point.
- 4) Elevation view(s) showing the terminal box (contains the service point), meter, and other service equipment (such as the distribution panel or load center).

XXXXXXXXXXXXXXXXXXXXXXXXXXXX

Provide the Team's "Electrical Engineer" contact info in the "Team Officer Contact Info" database on the Yahoo Group. See Rule 3-2.

Please see the "Grid Interconnection Process for Teams" file on the Yahoo Group for more details on the interconnection process and the Terminal Box Mounting Panel.



Energy Analysis Results and Discussions

For the 2009 U.S. Department of Energy Solar Decathlon, Team Illinois recognized the merit of conserving energy and resources rather than overproducing to overcome shortfalls in design or construction. In order to reduce the need for energy as much as possible, Team Illinois turned to using passive house principles including orientation, form, detailing, and finishing choices. Through the integration of both materials and detailing, Team Illinois was able to design and build a certified Passive House, which uses 90% less energy than typical construction. This idea of conserving, instead of focusing on production, should help Team Illinois in the 2009 Solar Decathlon net energy competition because it is much easier to produce many times more than what is consumed when very little energy is used. To this end, the University of Illinois Solar Decathlon Team has used many forms of energy analysis and modeling, including full house modeling and single aspect modeling, to help inform design decisions.

The basis of all energy analysis for the Gable Home begins with the Passive House Planning Package 2007 (PHPP) which is developed and distributed by the German Passive House Institute led by Dr. Wolfgang Feist. Not only was the PHPP software useful in the design process, it is also a necessary component of the certification process for achieving Passive House Certification from the Passive House Institute US. Team Illinois began using the PHPP software as a design tool shortly after the original concept was developed during the spring of 2008. From this time on, PHPP software has been utilized as a tool which helps the team balance energy conservation with both real world experiences and aesthetic concerns. The PHPP software has helped the team in many ways including helping to determine the wall u-values and make up of our innovative wall design as well as the materials used within the wall itself. The software has also allowed the team to think about different aspects and construction details which ultimately impact the energy requirements of a building. Both thermal bridging and air tightness are examples of small aspects of construction which are often overlooked, but have huge impacts on the energy viability of a building and consequently are covered in detail through the PHPP software.

The verification page of the program allows users to easily see how the changes they put into the building affect the overall outcome. For instance, if extra insulation is added in the wall, or better performing windows are used instead, on the verification page, the user can quantify how much lower the energy demand is instantly as the building details are updated. The verification page also allows for an initial check for certification purposes. If all boxes are fulfilled and the rest of the program is filled out accurately than the PHPP file is certification ready.

Specific Demands with Reference to the Treated Floor Area			
Treated Floor Area:	45.3 m ²	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	14 kWh/(m ² a)	15 kWh/(m ² a)	Yes
Pressurization Test Result:	0.6 h ⁻¹	0.6 h ⁻¹	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	57 kWh/(m ² a)	120 kWh/(m ² a)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	10 kWh/(m ² a)		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	492 kWh/(m ² a)		
Heating Load:	25 W/m ²		
Frequency of Overheating:	%		
Specific Useful Cooling Energy Demand:	5 kWh/(m ² a)	15 kWh/(m ² a)	Yes
Cooling Load:	21 W/m ²		

Passive House Planning

U-VALUES OF BUILDING ELEMENTS

Building: [University of Illinois 2009 Solar Decathlon Entry](#) Still Air Spaces -> Secondary Calculation to the Right

1 Exterior Wall					
Assembly No. Building Assembly Description					
			Heat Transfer Resistance [m ² K/W]	interior R _{si} :	0.13
				exterior R _{se} :	0.04
1.	Gypsum Board	0.250	Area Section 2 (optional)	λ [W/(mK)]	Total Width
2.	OSB	0.130			Thickness [mm]
3.	Foam	0.025	Lamboo	0.200	16
4.	AIR	0.194			13
5.	Rigid EPS	0.029			203
6.	Plywood	0.130			32
7.					38
8.					16
			Percentage of Sec. 2	Percentage of Sec. 3	Total
			3.1%	6.3%	31.7 cm
U-Value: 0.114 W/(m ² K)					

The u-value page allows the user to input custom wall designs and calculates a u-value for each assembly. A unique point to the u-value pages is the ability to calculate basic thermal bridging through the assembly. For instance, this particular wall has an R-value of 50 with thermal bridging factored in, but without thermal bridging, the R-value of the assembly is 57. These values are typical of Passive House designs and are determined through the program by analyzing conductance values and material thicknesses.

Quantity	Description	Deviation from North	Angle of Inclination from the Horizontal	Orientation	Window Rough Openings		Installed		Glazing		Frame	
					Width	Height	in Area in the Areas worksheet	Nr.	Select glazing from the WinType worksheet	Nr.	Select window from the WinType worksheet	Nr.
		Degrees	Degrees		m	m	Select:		Select:		Select:	
3	North	0	90	North	0.864	0.857	North Wall 1	1	Optiwin Advanc	7	OPTIWIN - Dre	52
3	North	0	90	North	0.781	0.778	North Wall 1	1	Optiwin Advanc	7	optiwin fixed	10
1	East	90	90	East	0.864	0.857	East Wall 1	2	Optiwin Advanc	7	OPTIWIN - Dre	52
1	South	180	90	South	2.607	2.013	South Wall 1	3	Optiwin Advanc	7	optiwin fixed	10
2	South	180	90	South	0.778	1.448	South Wall 1	3	Optiwin Advanc	7	optiwin fixed	10
1	South	180	90	South	0.864	0.857	South Wall 1	3	Optiwin Advanc	7	OPTIWIN - Dre	52
1	South	180	90	South	2.607	2.057	South Wall 1	3	Optiwin Advanc	7	optiwin fixed	10
1	West	270	90	West	0.857	0.864	West Wall 1	4	Optiwin Advanc	7	OPTIWIN - Dre	52
								0		0		0

Climate:	Peoria												
Window Area Orientation	Global Radiation (Cardinal Points)	Shading	Dirt	Non-Perpendicular Incident Radiation	Glazing Fraction	g-Value	Reduction Factor for Solar Radiation	Window Area	Window U-Value	Glazing Area	Average Global Radiation	Transmission Losses	Heat Gains Solar Radiation
maximum:	kWh/(m ² a)							m ²	W/(m ² K)	m ²	kWh/(m ² a)	kWh/a	kWh/a
North	165	0.91	0.95	0.85	0.529	0.53	0.39	4.04	0.84	2.1	165	294	138
East	337	0.89	0.95	0.85	0.474	0.53	0.34	0.74	0.83	0.4	337	53	45
South	613	0.94	0.95	0.85	0.801	0.53	0.61	13.60	0.67	10.9	613	791	2692
West	349	0.75	0.95	0.85	0.474	0.53	0.29	0.74	0.83	0.4	349	54	39
Horizontal	571	0.75	0.95	0.85	0.000	0.00	0.00	0.00	0.00	0.0	571	0	0
Total or Average Value for All Windows.						0.53	0.54	19.13	0.72	13.7		1192	2914

Windows have some of the largest impacts on energy for a Passive House. To start modeling windows, the size orientation, the assembly where they are located, the window type, and the glazing type must all be chosen. Also, typical install values must be obtained for the custom assemblies many Passive Houses use. PHPP then provides the information shown which culminates in the transmission losses due to the window openings and the heat gains due to the solar radiation the windows provide. On the Gable Home, the large south windows provide much needed solar gain during the winter. Losses were minimized by downsizing the windows to smaller efficient square windows on the other three sides of the home. With this in mind, the loss to gain ratio for Gable Home is almost 3:1 due to the extreme efficiency of the windows used.

SPECIFIC ANNUAL HEAT DEMAND

Climate: **Peoria**
 Building: **University of Illinois 2009 Solar Decathlon Entry**
 Location:

Interior Temperature: **20.0** °C
 Building Type/Use: **Residential Prototype**
 Treated Floor Area A_{TFA}: **45.3** m²

Building Element	Temperature Zone	Area m ²	U-Value W/(m ² K)	Temp. Factor f _t	G _t kKh/a	per m ² kWh/a
1. Exterior Wall - Ambient	A	78.1	* 0.114	* 1.00	* 87.0	= 775
2. Exterior Wall - Ground	B		*	* 0.55		
3. Roof/Ceiling - Ambient	A	71.1	* 0.086	* 1.00	* 87.0	= 530
4. Floor Slab	B	58.5	* 0.074	* 0.55	* 87.0	= 206
5.	A		*	* 1.00		
6.	A		*	* 1.00		
7.	X		*	* 0.75		
8. Windows	A	19.1	* 0.716	* 1.00	* 87.0	= 1192
9. Exterior Door	A	4.8	* 0.635	* 1.00	* 87.0	= 267
10. Exterior TB (length/m)	A		*	* 1.00		
11. Perimeter TB (length/m)	P		*	* 0.55		
12. Ground TB (length/m)	B		*	* 0.55		

Total of All Building Envelope Areas

231.7

kWh/(m²a)

Total **2971**

65.5

Transmission Heat Losses Q_T

$$A_{TFA} \text{ m}^2 * \text{Clear Room Height m} = \text{Volume m}^3$$

$$45.3 * 2.50 = 113.3$$

Ventilation System: Effective Air Volume, V_v

Effective Heat Recovery Efficiency of Heat Recovery η_{eff}

Efficiency of Subsoil Heat Exchanger η_{SHX}

$$\text{Energetically Effective Air Exchange } n_v = 0.423 (1 - 0.81) + 0.044 = 0.124$$

$$V_v \text{ m}^3 * n_v \text{ 1/h} * C_{Air} \text{ Wh/(m}^3\text{K)} * G_t \text{ kKh/a} = \text{kWh/a}$$

kWh/(m²a)

8.9

Ventilation Heat Losses Q_V

$$113 * 0.124 * 0.33 * 87.0 = 402$$

Reduction Factor
Night/Weekend

Total Heat Losses Q_L

$$(\boxed{2971} + \boxed{402}) \times \boxed{1.0} = \boxed{3374} \text{ kWh/a}$$

 Orientation
of the Area

1. North
2. East
3. South
4. West
5. Horizontal

 Reduction Factor
See Windows Sheet

0.39
0.34
0.61
0.29
0.40

 g-Value
(perp. radiation)

0.53
0.53
0.53
0.53
0.00

Area

m ²
4.04
0.74
13.60
0.74
0.00

Radiation HP

kWh/(m ² a)
165
337
613
349
571

 kWh/(m²a)

74.4

 kWh/(m²a)

64.3

Available Solar Heat Gains Q_S

 Total 2914
Internal Heat Gains Q_I

$$0.024 \text{ kh/d} \times \boxed{205} \text{ d/a} \times \boxed{2.10} \text{ W/m}^2 \times \boxed{45.3} \text{ m}^2 = \boxed{467} \text{ kWh/a}$$

 kWh/(m²a)

10.3

 Free Heat Q_F

 Q_S + Q_I = 3381

kWh/a

74.6

 Ratio of Free Heat to Losses Q_F / Q_L = 1.00

 Utilisation Factor Heat Gains η_G

$$(1 - (Q_F / Q_L)^5) / (1 - (Q_F / Q_L)^6) = \boxed{83\%}$$
Heat Gains Q_G

$$\eta_G \times Q_F = \boxed{2815} \text{ kWh/a}$$

 kWh/(m²a)

62.1

Annual Heat Demand Q_H

$$Q_L - Q_G = \boxed{559} \text{ kWh/a}$$

kWh/a

12

 Limiting Value 15

 Requirement met? Yes (Yes/No)

The Heat Demand sheet takes the heat losses from all the building assemblies including the walls, floors, ceilings, windows, and even ventilation and infiltration. All of this loss is summed together with the heat gained from solar gain to create the average loss. This loss is then calculated in terms of how much heating is needed per square meter of the treated floor area to get the annual heat demand.



S U M M E R

Climate: Peoria
Building: University of Illinois 2009 Solar Decathlon Entry
Location:
c. Capacity: 132 Wh/K pro m² TFA
Overheating Limit: 25 °C Area U-Value Red. Fa

Interior Temperature:	20	°C
Building Type/Use:	Residential Prototype	
Treated Floor Area A _{TFA} :	45.3	m ²

Building Element	Temperature Zone	m ²	W/(m ² K)	Red. Factor f _{T,Summer}	H _{Summer} Heat Conductance
1. Exterior Wall - Ambient	A	78.1	* 0.114	* 1.00	= 8.9
2. Exterior Wall - Ground	B		*	* 1.00	=
3. Roof/Ceiling - Ambient	A	71.1	* 0.086	* 1.00	= 6.1
4. Floor Slab	B	58.5	* 0.074	* 1.00	= 4.3
5.	A		*	* 1.00	=
6.	A		*	* 1.00	=
7.	X		*	* 0.75	=
8. Windows	A	19.1	* 0.716	* 1.00	= 13.7
9. Exterior Door	A	4.8	* 0.635	* 1.00	= 3.1
10. Exterior TB (length/m)	A		*	* 1.00	=
11. Perimeter TB (length/m)	P		*	* 1.00	=
12. Ground TB (length/m)	B		*	* 1.00	=

Exterior Thermal Transmittance, H_{T_e}

Ground Thermal Transmittance, $H_{T,g}$

Heat Recovery Efficiency

81%

Effective	A_{TFA} m ²	Clear Room Height m		m ³
Air Volume V_v	45.3	*	2.50	= 113

SHX Efficiency

0%

The summer sheet calculates conductance of all of the assemblies much in the same way the heating sheet does. The summer sheet takes into account ventilation and heat exchanger efficiency as well as natural ventilation if applicable. With this data, the summer sheet is able to show the percent chance of overheating above the limit as well as the total temperature swing due to the solar load.

Summer Ventilation

continuous ventilation to provide sufficient indoor air quality

Air Change Rate by Natural (Windows & Leakages) or Exhaust-Only Mechanical Ventilation, Summer: 0.23 1/h

Mechanical Ventilation Summer: 0.40 1/h with HR (check if applicable)

$$\text{Energetically Effective Airchange Rate } n_v = \frac{n_{L,nat}}{1/h} + \frac{n_{V,system}}{1/h} * (1 - \frac{\Phi_{HR}}{0.000}) + \frac{n_{V,Rest}}{1/h} = \frac{0.230}{1/h} + \frac{0.400}{1/h} * (1 - \frac{0.000}{0.000}) + \frac{0.000}{1/h} = \frac{0.630}{1/h}$$

Ventilation Transm. Ambient $H_{V,e}$	$\frac{V_V}{m^3}$	$n_{V,equi,fraction}$ 1/h	$\frac{C_{Air}}{Wh/(m^3K)}$		
Ventilation Transm. Ground $H_{V,g}$	113	0.630	0.33	23.6	W/K
	113	0.000	0.33	0.0	W/K

Additional Summer Ventilation for Cooling Temperature Amplitude Summer 10.8 K

Select: x Window Night Ventilation, Manual

Corresponding Air Change Rate 0.40 1/h

(for window ventilation: at 1 K temperature difference indoor - outdoor)

Minimum Acceptable Indoor Temperature 22.0 °C

Orientation of the Area	Angle Factor Summer	Shading Factor Summer	Dirt	g-Value (perp. radiation)	Area m ²	Portion of Glazing	Aperture m ²
1. North	0.9	*	0.91	*	0.95	*	0.9
2. East	0.9	*	0.96	*	0.95	*	0.2
3. South	0.9	*	0.28	*	0.95	*	1.4
4. West	0.9	*	1.00	*	0.95	*	0.2
5. Horizontal	0.9	*	1.00	*	0.95	*	0.0
6. Sum Opaque Areas				*	0.00	*	0.0

Solar Aperture

Total 2.6 m^{2/m²} 0.06

Internal Heat Gains Q_i

$$\text{Spec. Power } q_i = \frac{A_{TFA}}{m^2} * \frac{W}{m^2} = \frac{2.10}{45} * \frac{W}{m^2} = \frac{95}{2.1} W/m^2$$

Frequency of Overheating $h_{\theta \geq \theta_{max}}$

7.3%

at the overheating limit $\theta_{max} = 25^\circ C$

If the "frequency over 25°C" exceeds 10%, additional measures to protect against summer heat waves are necessary.

$$\text{Daily Temperature Swing due to Solar Load} = \frac{\text{Solar Load}}{kWh/d} * \frac{1/k}{1000} / (\frac{\text{Spec. Capacity}}{Wh/(m^3K)} * \frac{A_{TFA}}{m^2}) = \frac{12.1}{132} * \frac{1}{1000} / (\frac{45}{2.0}) = \frac{2.0}{45} K$$

Passive House Planning

ELECTRICITY DEMAND

Building: University of Illinois 2009 Solar Deca

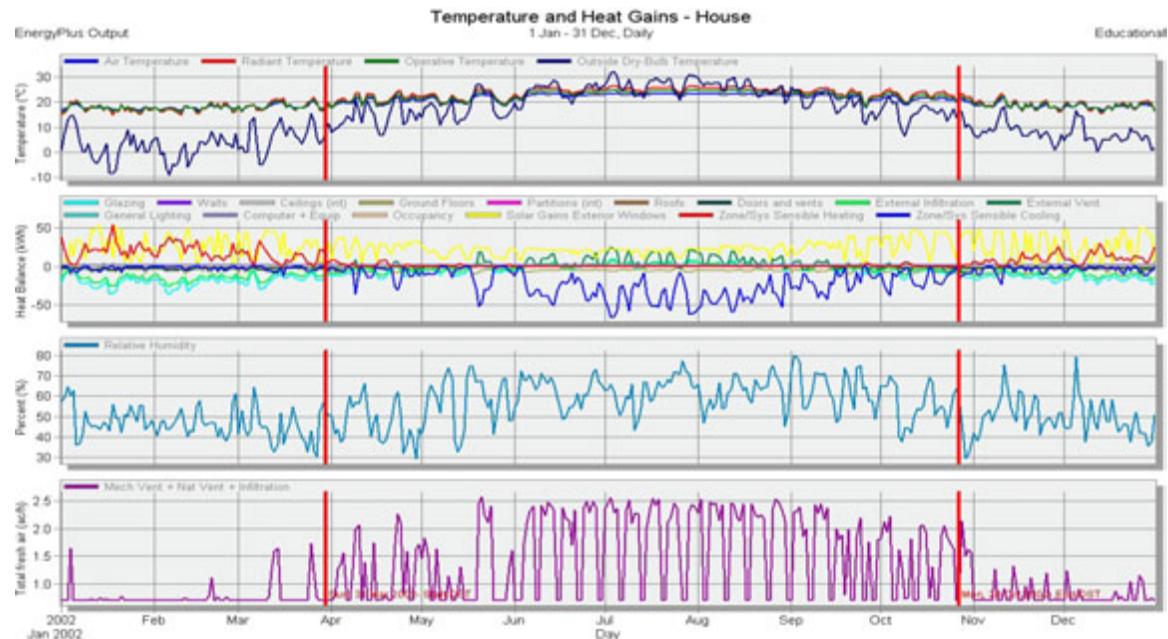
Column Nr.	Application	# Households	1 HH	Solar Fraction of DHW Wash&Dish	0%	Prim. Energy Factors:	Electricity 2.7	kWh/kWh
		Persons	1.3 P				Natural Gas 1.1	
		Living Area	45 m ²	Marginal Performance Ratio Heating	0%	Energy Carrier for Space Heating/DHW:	0.7	0.7
1	Used ? (1/0)	2	Within the Thermal Envelope? (1/0)	3	Norm Demand	4	Utilization Factor	5
Dishwashing	[1] [1] 1.20 kWh/Use			*	1.00	*	65 / (P*a)	*
DHW Connection	[1] [1] 1.10 kWh/Use			*	1.00	*	57 / (P*a)	*
Clothes Washing								
DHW Connection								
Clothes Drying with:	[1] [1] 3.50 kWh/Use			Residual dampness	0.60		57 / (P*a)	*
Clothesline								
Energy Consumed by Evaporation	[1] [1] 3.13 kWh/Use							
Refrigerating	[0] [1] 0.50 kWh/d			*	0.60	*	57 / (P*a)	*
Freezing	[0] [1] 0.50 kWh/d			*	1.00	*	365 d/a	*
or Combined Unit	[1] [1] 0.50 kWh/d			*	1.00	*	365 d/a	*
Cooking with:								
Electricity	[1] [1] 0.25 kWh/Use			*	1.00	*	500 / (P*a)	*
Lighting	[1] [1] 60 W			Percentage CFLs	0%			
Consumer Electronics	[1] [1] 80 W			*	1.00	*	2.90 kh/(P*a)	*
Small Appliances, etc	[1] [1] 50 kWh			*	1.00	*	0.55 kh/(P*a)	*
Total Aux. Electricity				*	1.00	*	1.00 / (P*a)	*
Other:								
Total							0	0
Specific Demand							0	0
Recommended Maximum Value							0	0
							1181 kWh	0
							955 kWh	2578 kWh
							21.1 kWh/(m ² a)	56.9 kWh/(m ² a)
							104 kWh/(m ² a)	0.0 kWh/(m ² a)
							2.3 kWh/(m ² a)	18 kWh/(m ² a)
							0.0 kWh/(m ² a)	50 kWh/(m ² a)
							DHW Non-Electric - Wash&Dish	
							Non-Renewable Non-Electric DHW Wash&Dish	

A secondary portion of the PHPP software deals with every source of energy usage and specifically the amount of electricity necessary to power the entire home and everything in it. This demand must be under certain limits per square meter to pass the Passive House certification.

The United States Department of Energy's EnergyPlus software, through the DesignBuilder interface, was used as a verification and backup resource to the PHPP software. Team Illinois found the use of a third party interface, DesignBuilder, worthwhile when working with EnergyPlus due to the ease of using a graphical model over a text only modeling system. Like PHPP, EnergyPlus was used for its many capabilities and its ability to model everything from heating, cooling, ventilation, lighting, and other building design elements. While PHPP was used more for design, EnergyPlus with DesignBuilder was used more for competition programming due to its sub-hourly readings and output. This programming was also backed with the use of weather data from October in Washington D.C. in congruence with the weather data used in the PHPP software.

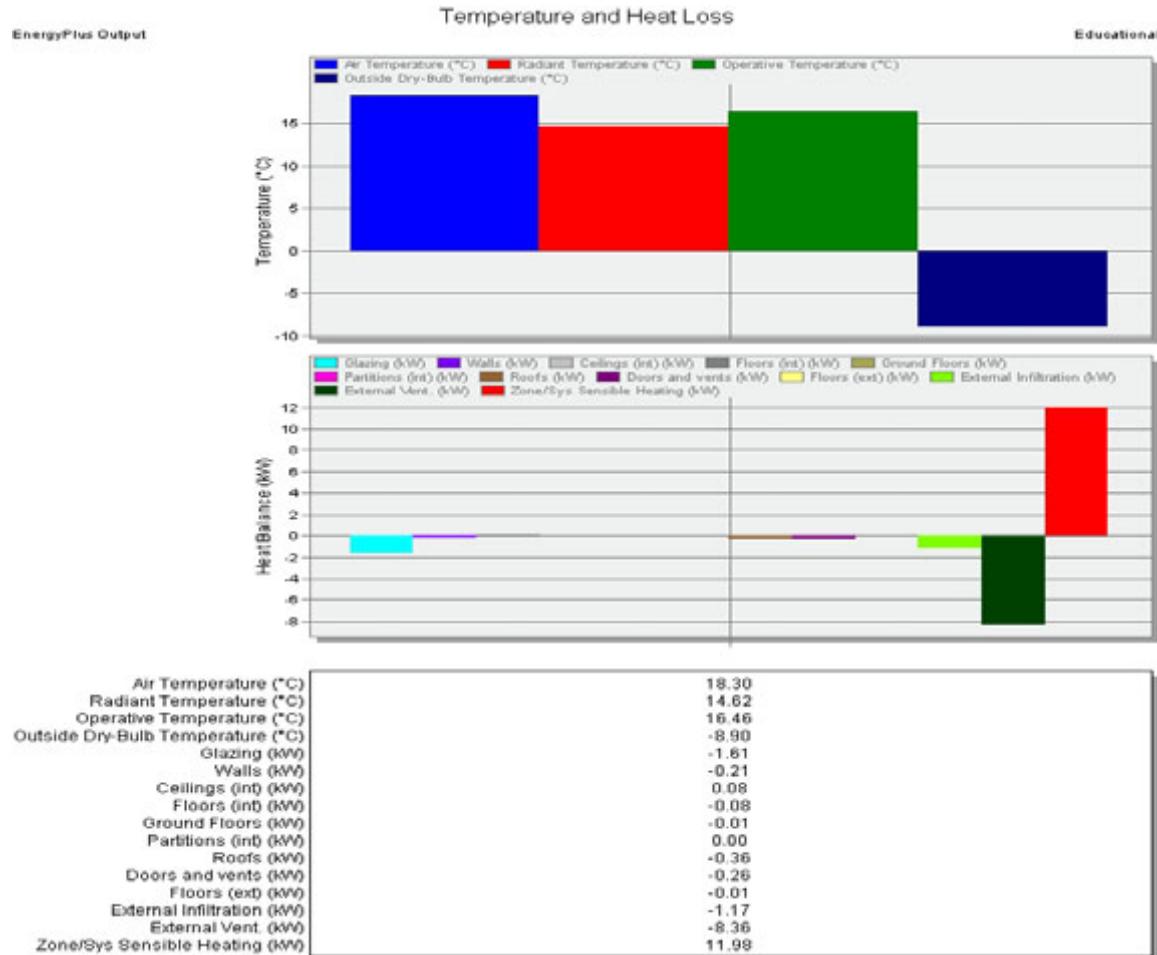
Shown below are graphs representing calculations of both heating in cooling loads over both sub-hourly, daily, and monthly intervals in accordance with the ASHRAE approved "heat balance" method utilized by the EnergyPlus and DesignBuilder software.

Trial Simulation - Annual-Daily Results



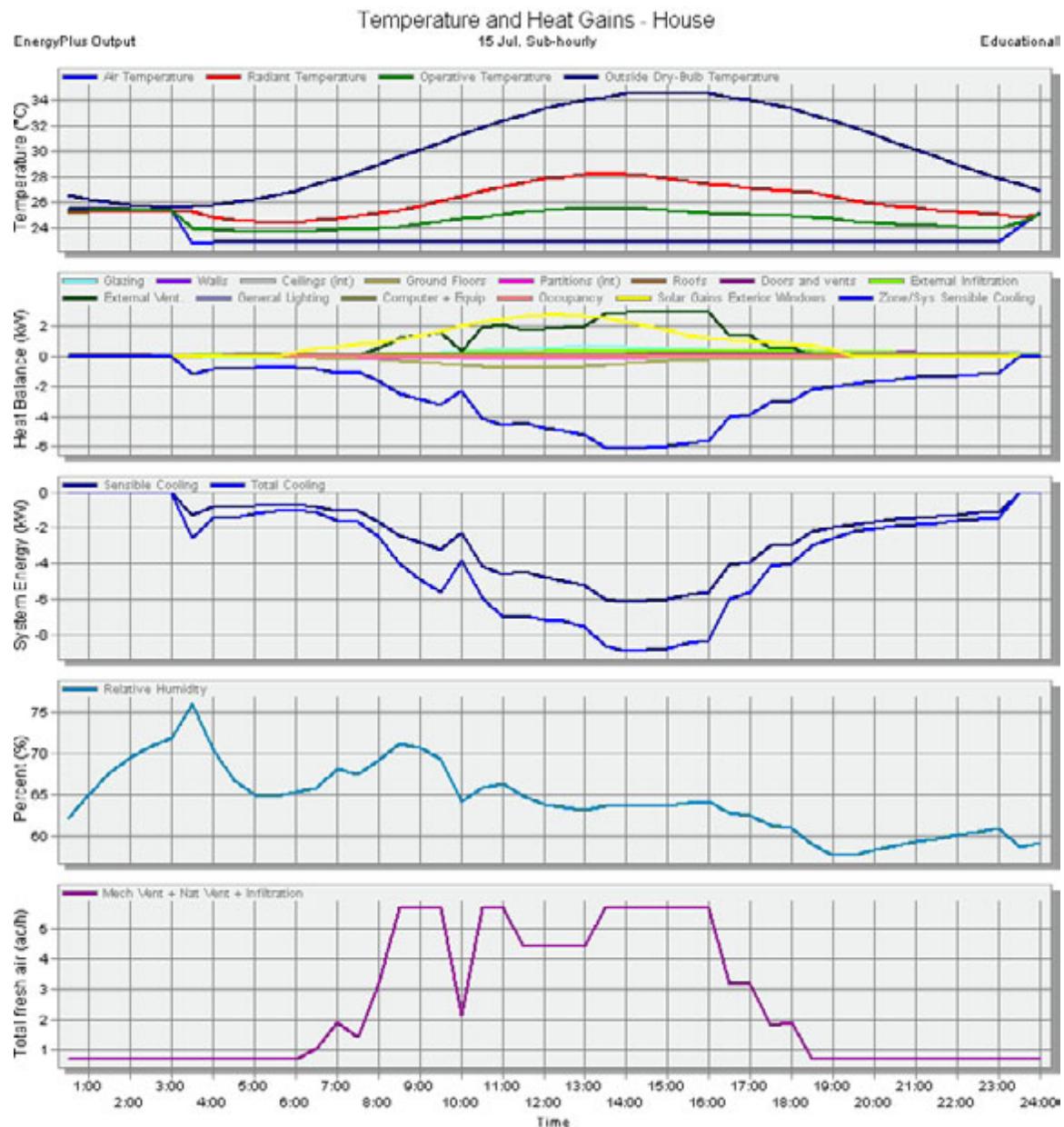
Annual results calculated per each day are a more detailed and accurate reflection of the data and explanation found for the following three figures.

Temperature and Heat Loss for Heating Design Calculations

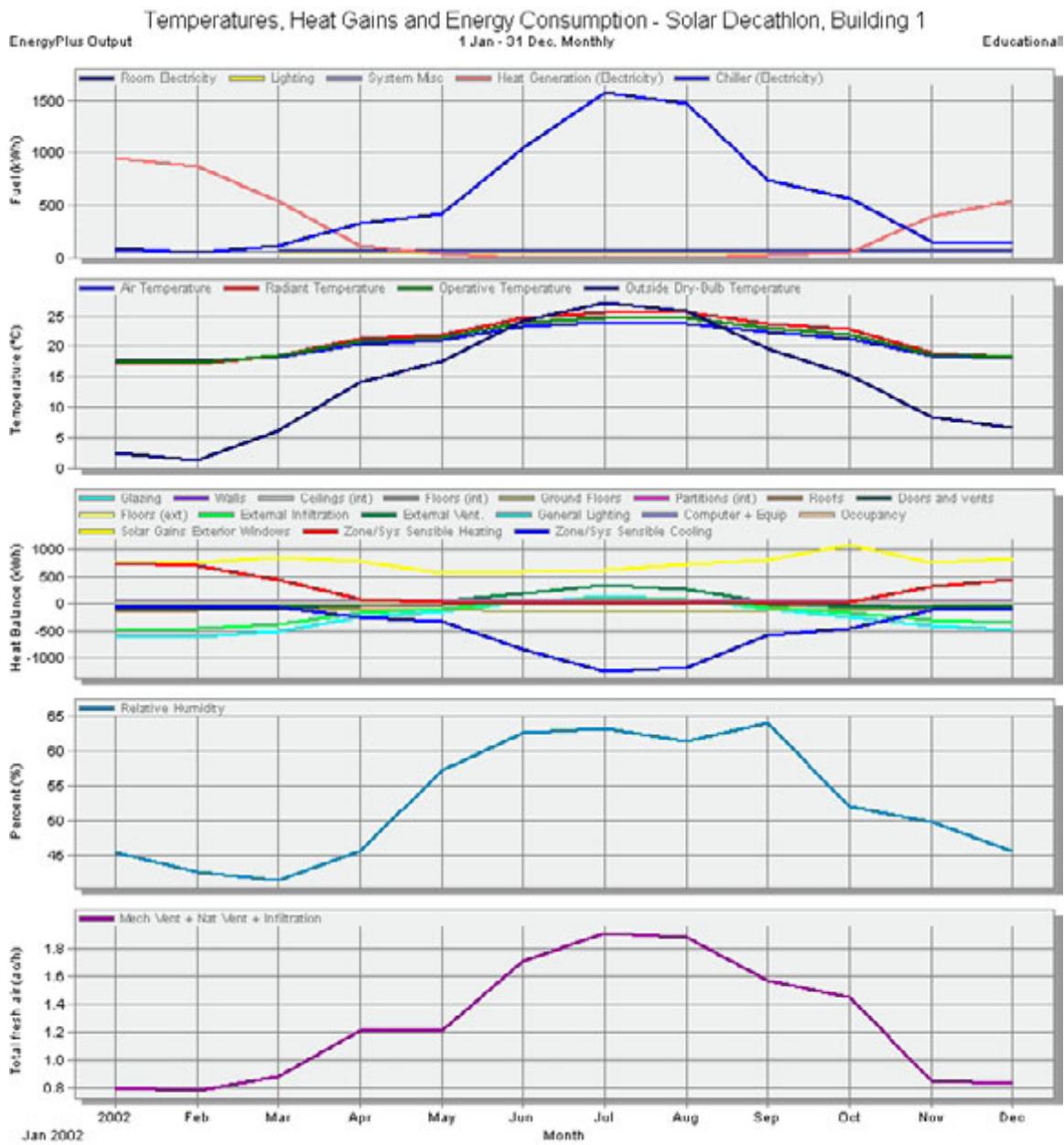


The first temperature and heat loss output is helpful because it shows how the temperature related to the heat loss and gain of the different building elements. This breakdown, much like the PHPP breakdown is helpful when designing so that the weaker areas of the design can be more easily pinpointed.

Temperature and Heat Gains for Cooling Design Calculations



The above graph shows the temperature and heat gains for July 15th (which should be an average hot summer day). This allows the user to see how much cooling is needed at different times of the day as well as what the peak cooling load will be.



Along with a daily readout, yearly readouts are also available along with more typical monthly readouts. The annual readout has the ability to show energy consumption in the terms of fuel as well as consumption in terms of demand.

Grid-Connected System: Simulation parameters

Project :	Grid-Connected Project at Chicago		
Geographical Site	Chicago	Country	USA
Situation Time defined as	Latitude 41.6°N Legal Time Time zone UT+6 Albedo 0.20	Longitude 87.4°W Altitude 177 m	
Meteo data :	Chicago , synthetic hourly data		
Simulation variant :	Simulation variant		
	Simulation date 12/03/09 16h14		
Simulation parameters			
Collector Plane Orientation	Tilt 45°	Azimuth 0°	
Horizon	Free Horizon		
Near Shadings	No Shadings		
PV Array Characteristics			
PV module	Si-mono	Model SPR-225-WHT-I	
Number of PV modules	Manufacturer SunPower	In series 10 modules	In parallel 4 strings
Total number of PV modules		Nb. modules 40	Unit Nom. Power 225 Wp
Array global power	Nominal (STC) 9.0 kWp	At operating cond.	8.2 kWp (50 °C)
Array operating characteristics (50°C)	U mpp 376 V	I mpp	22 A
Total area	Module area 49.8 m ²		
PV Array loss factors			
Heat Loss Factor => Nominal Oper. Coll. Temp. (800 W/m ² , Tamb=20°C, wind 1 m/s)	k ₀ (const) 29.0 W/m ² K	k _v (wind) 0.0 W/m ² K / m/s	
Wiring Ohmic Loss	Global array res. 559.4 mOhm	NOCT 45 °C	
Serie Diode Loss	Voltage Drop 0.7 V	Loss Fraction 3.1 % at STC	
Module Quality Loss		Loss Fraction 0.2 % at STC	
Module Mismatch Losses		Loss Fraction 3.0 %	
Incidence effect, ASHRAE parametrization	IAM = 1-bo (1/cos i - 1)	Loss Fraction 2.0 % at MPP	
		bo Parameter 0.05	
System Parameter			
Inverter	System type Grid-Connected System		
	Model Sunny Boy SB 5000 US		
Inverter Characteristics	Manufacturer SMA		
Inverter pack	Operating Voltage 250-480 V	Unit Nom. Power 5 kW AC	Total Power 10 kW AC
User's needs :	Unlimited load (grid)		

Grid-Connected System: Main results

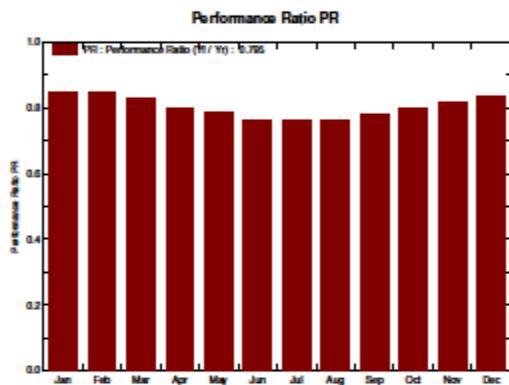
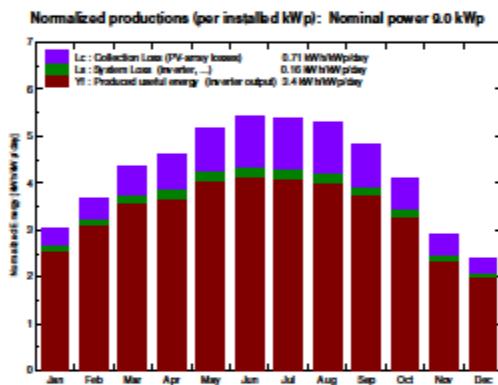
Project : Grid-Connected Project at Chicago

Simulation variant : Simulation variant

Main system parameters	System type	Grid-Connected		
PV Field Orientation	tilt	45°	azimuth	0°
PV modules	Model	SPR-225-WHT-I	Pnom	225 Wp
PV Array	Nb. of modules	40	Pnom total	9.0 kWp
Inverter	Model	Sunny Boy SB 5000 US	Pnom	5.0 kW ac
Inverter pack	Nb. of units	2	Pnom total	10 kW ac
User's needs	Unlimited load (grid)			

Main simulation results

System Production	Produced Energy	11.16 MWh/year	Specific	1240 kWh/kWp/year
	Performance Ratio PR	79.5 %		



Simulation variant Balances and main results

	GlobHor kWh/m ²	T Amb °C	Globinc kWh/m ²	GlobEff kWh/m ²	EArray kWh	EOutInv kWh	EffArrR %	EffSysR %
January	57.0	-5.20	93.8	91.5	753	718	16.13	15.38
February	74.0	-2.90	103.3	100.6	822	785	15.99	15.26
March	110.0	2.80	135.1	131.3	1052	1004	15.64	14.94
April	137.0	10.00	138.2	133.7	1043	995	15.17	14.47
May	178.0	15.40	160.7	154.9	1188	1134	14.86	14.18
June	190.0	20.80	163.2	157.1	1177	1123	14.49	13.83
July	190.0	23.30	167.1	161.0	1198	1143	14.41	13.75
August	168.0	22.40	163.5	158.0	1178	1125	14.48	13.83
September	127.0	18.20	144.8	140.4	1064	1017	14.77	14.12
October	94.0	12.00	127.1	123.6	969	915	15.17	14.47
November	55.0	4.70	87.2	85.1	673	640	15.50	14.75
December	45.0	-2.40	74.3	72.5	587	557	15.88	15.06
Year	1425.0	9.99	1558.3	1509.8	11693	11156	15.08	14.39

Legend: GlobHor Horizontal global irradiation
T Amb Ambient Temperature
Globinc Global Incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings

EArray Effective energy at the output of the array
EOutInv Available Energy at Inverter Output
EffArrR Eff. Eout array / rough area
EffSysR Eff. Eout system / rough area

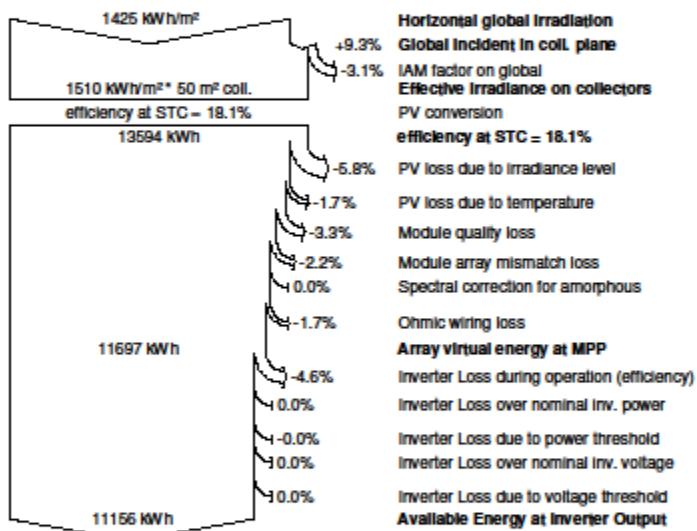
Grid-Connected System: Loss diagram

Project : Grid-Connected Project at Chicago

Simulation variant : Simulation variant

Main system parameters	System type	Grid-Connected		
PV Field Orientation	tilt	45°	azimuth	0°
PV modules	Model	SPR-225-WHT-I	Pnom	225 Wp
PV Array	Nb. of modules	40	Pnom total	9.0 kWp
Inverter	Model	Sunny Boy SB 5000 US	Pnom	5.0 kW ac
Inverter pack	Nb. of units	2	Pnom total	10 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



Grid-Connected System: Simulation parameters

Project :	Grid-Connected Project at Washington		
Geographical Site	Washington	Country	USA
Situation Time defined as	Latitude 39.1°N Legal Time Time zone UT+5 Albedo 0.20	Longitude 76.5°W Altitude 5 m	
Meteo data :	Washington , synthetic hourly data		
Simulation variant :	Simulation variant		
	Simulation date 12/03/09 15h57		
Simulation parameters			
Collector Plane Orientation	Tilt 45°	Azimuth 0°	
Horizon	Free Horizon		
Near Shadings	No Shadings		
PV Array Characteristics			
PV module	Si-mono	Model SPR-225-WHT-I	
Number of PV modules	Manufacturer SunPower	In series 10 modules	In parallel 4 strings
Total number of PV modules	Nb. modules 40	Unit Nom. Power 225 Wp	
Array global power	Nominal (STC) 9.0 kWp	At operating cond.	8.2 kWp (50 °C)
Array operating characteristics (50°C)	U mpp 376 V	I mpp	22 A
Total area	Module area 49.8 m ²		
PV Array loss factors			
Heat Loss Factor => Nominal Oper. Coll. Temp. (800 W/m ² , Tamb=20°C, wind 1 m/s)	k ₀ (const) 29.0 W/m ² K	k _v (wind) 0.0 W/m ² K / m/s	
Wiring Ohmic Loss	Global array res. 559.4 mOhm	NOCT 45 °C	
Serie Diode Loss	Voltage Drop 0.7 V	Loss Fraction 3.1 % at STC	
Module Quality Loss		Loss Fraction 0.2 % at STC	
Module Mismatch Losses		Loss Fraction 3.0 %	
Incidence effect, ASHRAE parametrization	IAM = 1-bo (1/cos i - 1)	Loss Fraction 2.0 % at MPP	
		bo Parameter 0.05	
System Parameter			
Inverter	System type Grid-Connected System		
	Model Sunny Boy SB 5000 US		
Inverter Characteristics	Manufacturer SMA		
Inverter pack	Operating Voltage 250-480 V	Unit Nom. Power 5 kW AC	
	Number of Inverter 2 units	Total Power 10 kW AC	
User's needs :	Unlimited load (grid)		

Grid-Connected System: Main results

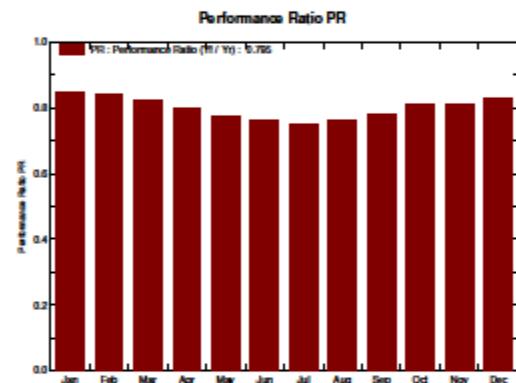
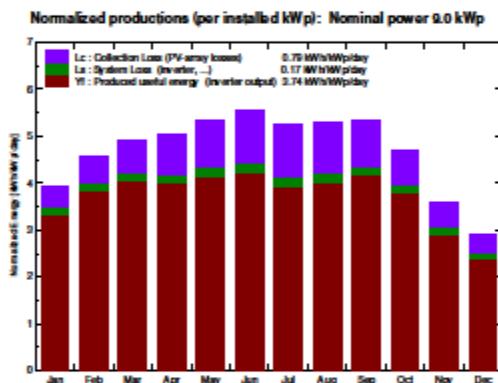
Project : Grid-Connected Project at Washington

Simulation variant : Simulation variant

Main system parameters	System type	Grid-Connected		
PV Field Orientation	tilt	45°	azimuth	0°
PV modules	Model	SPR-225-WHT-I	Pnom	225 Wp
PV Array	Nb. of modules	40	Pnom total	9.0 kWp
Inverter	Model	Sunny Boy SB 5000 US	Pnom	5.0 kW ac
Inverter pack	Nb. of units	2	Pnom total	10 kW ac
User's needs	Unlimited load (grid)			

Main simulation results

System Production	Produced Energy	12.27 MWh/year	Specific	1363 kWh/kWp/year
	Performance Ratio PR	79.5 %		



Simulation variant Balances and main results

	GlobHor kWh/m ²	T Amb °C	Globinc kWh/m ²	GlobEff kWh/m ²	EArray kWh	EOutInv kWh	EffArrR %	EffSysR %
January	71.0	-0.10	122.1	119.3	975	934	16.05	15.37
February	87.0	1.50	127.8	124.6	1006	964	15.82	15.16
March	129.0	7.00	152.7	148.4	1177	1126	15.49	14.83
April	153.0	12.00	150.5	145.4	1129	1080	15.08	14.42
May	189.0	17.50	165.8	159.5	1213	1158	14.70	14.04
June	198.0	22.10	165.9	159.6	1193	1139	14.45	13.80
July	189.0	24.80	162.2	156.1	1152	1098	14.27	13.61
August	174.0	23.70	163.8	158.2	1174	1122	14.40	13.76
September	144.0	19.80	160.4	155.6	1179	1129	14.77	14.14
October	110.0	13.30	145.6	141.8	1105	1058	15.25	14.61
November	69.0	8.10	108.1	105.5	827	790	15.38	14.68
December	57.0	2.50	90.4	88.2	706	672	15.70	14.95
Year	1570.0	12.74	1715.2	1662.2	12836	12270	15.04	14.38

Legend: GlobHor Horizontal global irradiation
 T Amb Ambient Temperature
 Globinc Global Incident in coll. plane
 GlobEff Effective Global, corr. for IAM and shadings

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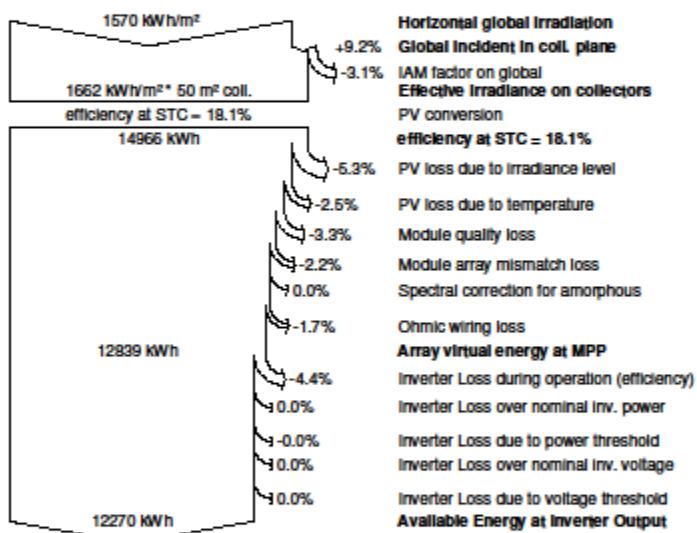
Grid-Connected System: Loss diagram

Project : Grid-Connected Project at Washington

Simulation variant : Simulation variant

Main system parameters	System type	Grid-Connected		
PV Field Orientation	tilt	45°	azimuth	0°
PV modules	Model	SPR-225-WHT-I	Pnom	225 Wp
PV Array	Nb. of modules	40	Pnom total	9.0 kWp
Inverter	Model	Sunny Boy SB 5000 US	Pnom	5.0 kW ac
Inverter pack	Nb. of units	2	Pnom total	10 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



When the energy consumption of the house was minimized and optimized as much as possible with our primary design software, more detailed modeling was completed for the photovoltaic array by the program PVsyst, a software suite designed by the University of Geneva. The information gained was then used in conjunction with the PHPP software to help determine net energy simulations for the entire year. The climates for both Washington D.C. and Champaign, IL were simulated with the energy use in PHPP and energy gain in PVsyst. PHPP is also able to compute this into a carbon dioxide amount which is eliminated through the use of photovoltaic panels.

Data for Champaign, IL

Heating, Cooling, DHW, Auxiliary and Household Electricity	21.1	56.9	14.3
Total PE Value	56.9	kWh/(m ² a)	
Total Emissions CO₂-Equivalent	14.3	kg/(m ² a)	(Yes/No)
Primary Energy Requirement	120	kWh/(m ² a)	Yes
Heating, DHW, Auxiliary Electricity (No Household Applications)	3.7	10.0	2.5
Specific PE Demand - Mechanical System	10.0	kWh/(m ² a)	
Total Emissions CO₂-Equivalent	2.5	kg/(m ² a)	
Solar Electricity	kWh/a	PE Value (Savings)	CO ₂ -Emission Factor
Planned Annual Electricity Generation	Separate Calculation	11156	kWh/kWh
		0.7	250
Specific Demand	246.1	172.2	61.5
PE Value: Conservation by Solar Electricity	kWh/(m ² a)		
CO ₂ -Emissions Avoided Due to Solar Electricity	105.8	kg/(m ² a)	

Data for Washington D.C.

Heating, Cooling, DHW, Auxiliary and Household Electricity	39.1	105.4	26.6
Total PE Value	105.4	kWh/(m ² a)	
Total Emissions CO₂-Equivalent	26.6	kg/(m ² a)	(Yes/No)
Primary Energy Requirement	120	kWh/(m ² a)	Yes
Heating, DHW, Auxiliary Electricity (No Household Applications)	19.4	52.4	13.2
Specific PE Demand - Mechanical System	52.4	kWh/(m ² a)	
Total Emissions CO₂-Equivalent	13.2	kg/(m ² a)	
Solar Electricity	kWh/a	PE Value (Savings)	CO ₂ -Emission Factor
Planned Annual Electricity Generation	Separate Calculation	12270	kWh/kWh
		0.7	250
Specific Demand	270.6	189.4	67.7
PE Value: Conservation by Solar Electricity	kWh/(m ² a)		
CO ₂ -Emissions Avoided Due to Solar Electricity	116.4	kg/(m ² a)	

ARCHITECTURE NARRATIVE

Gable Home Design Philosophy

Illinois' strong agricultural heritage is evident in the thousands of aging barns, silos and farmhouses scattered across the landscape. Although they were not designed by trained architects, these simple, vernacular structures have nonetheless become a symbol of Midwestern practicality and work ethic. For the 2009 U.S. Department of Energy Solar Decathlon, the University of Illinois team envisioned a home that unites this vernacular architecture with principles of sustainability. Gable Home is the achievement of this vision through the creative adaptation of vernacular building vocabulary, the use of materials reclaimed from demolished farm structures, the preference for environmentally conscious materials, and the utilization of innovative technology. Combining vernacular architecture with contemporary materials, technology, and design creates a synergetic relationship through which both aesthetics and functionality are enhanced. The result is a familiar, yet improved home that relates to Illinois' symbolic vernacular architecture, as well as its commitment to a sustainable future.

Midwestern Vernacular

Gable Home adopts a vernacular building vocabulary distinctive to many Illinois barns, the most apparent of which is the use of a steeply pitched gable roof that spans the entire length of the house. This feature satisfies both functional and environmentally conscious goals by effectively shedding rain water and reducing snow loads while also providing an efficient 45 degree surface for solar panel arrays. The solar panels designed for the Gable Home will generate vastly more energy than its annual demand. The large, sliding, exterior shading devices on the southern façade are reminiscent of typical sliding barn doors. The frequent use of sliding doors inside the home continues this reference while also allowing the interior spaces to be condensed.

Whenever possible, reusing existing material was preferred to the production of new material. Therefore, the traditional barn siding aesthetic was created through the use of siding reclaimed from a barn that was slated



Figure 1 - Image of barn from which barn siding was reclaimed

for demolition in Rockford, Illinois. Also, dimensional lumber was salvaged from the deconstruction of a grain elevator in Champaign, Illinois and reused for the exterior decking of the house. The reuse of these materials not only represents a conservative, sustainable approach to material usage, but also establishes a direct relationship between the Gable Home and vernacular farm structures.

Environmentally Driven

The team incorporated quality, environmentally conscious materials whenever reuse was not an option. For example, the material for the structural frame of the house was made of laminated bamboo, a rapidly renewable material, all of which fit onto a single shipping pallet. Each frame element is just $\frac{3}{4}$ of an inch thick, which significantly reduces thermal bridging. The standing-seam steel roof has an estimated lifespan of 50 years, which means that it will last longer than the solar panels, thereby minimizing long-term costs and maximizing the value of the panels. Additional advantages of the roof are the material recyclability, and the elimination of roof penetrations as the solar panels can be attached solely to the steel. Most of the lighting fixtures in the home employ energy efficient LED bulbs. The home also features low-VOC paint, linseed oil stain, natural resin panels for doors, recyclable tiles, cabinetry made of rapidly renewable and recyclable materials, natural linens, and flooring made from renewable materials and ecologically responsible pigments.

Designing quality passive systems for Gable Home was crucial to achieving energy-efficiency. Therefore, the University of Illinois team created a small but comfortable one bedroom, one bath home that meets Passive House standards. Passive House certification requires a tightly constructed building envelope with quality, energy-efficient windows. The envelope uses a combination of spray-foam and rigid insulation, minimizing heat transfer through thermally broken construction. In addition to architectural concerns, the use of energy analysis software helped to determine the optimum placement and size of each window. The windows are triple-paned with thermally broken frames, and involve an air-tight



installation process, which helps maintain a tight building envelope. The result is a design that allows ample daylight while maintaining a comfortable indoor temperature.

Clean, Simple, Modern

The intent to use reclaimed barn siding came early in the design process and became the primary element of the clean and simple aesthetics of the house. The placement of the siding at a consistent spacing of 12 inches on center established a rhythm that influenced many other areas of design. Most notably, the width of each window was designed to fit seamlessly into the siding. Also, the decking boards are spaced at six inches on center and the seams of the roof are spaced at 12 inches on center in order to align with the siding boards and thus preserve clean and continuous lines.

The steep gable roof allows for vaulted ceilings in the home which provide a spacious feeling to the interior, despite the fact that the home has just 550 square feet of living space. The furniture is modern and elegant, and in many cases can be adapted to the user's needs. The sitting furniture in the living room is modular and can be arranged in a variety of ways. The bedroom desk is movable and expands so that it can be used over the bed or in other spaces if desired. The house features a modern wet bathroom with bamboo flooring and a unique draining system. The bedroom is secluded from the more public kitchen and living areas, and also has a private exit to the exterior deck.

Toward Future Sustainability

By using vernacular building vocabulary, reclaimed materials, environmentally conscious materials, and innovative technology, the University of Illinois team created a sustainable home that relates to and preserves the symbolic, vernacular architecture of the Midwest. The synergetic relationship that



exists between this vernacular architecture and new technology allowed for the creation of a home that will lead to a more sustainable future.

Figure 3 - Rendering of home as viewed from the south-west

MARKET VIABILITY:

The Illinois Solar Decathlon Team approached the U. S. Department of Energy Solar Decathlon competition with the goal of creating a practical home based on the synergy between vernacular forms and materials with modern innovations in technology. The designed evolution of the vernacular into a modern housing solution has allowed the University of Illinois team to design and build a home that is not only distinctly Illinois, but also viewed as a home which typical home buyers would feel comfortable living. With these ideals in mind, Gable Home and our target market were born.

Target Market Description:

Simplified Target Market Description

Location	Gibson City, Illinois
Number of Occupants	Two
Occupant Demographic	Self-reliant Couple
Household Income	\$80,000
Number of Bedrooms and Bathrooms	One Bed / One Bath

The Illinois Solar Decathlon team designed this particular home based on a target market of a self-reliant couple living without children in Gibson City, Illinois with a household income of \$80,000 per year. This target market was important to the team for many reasons all of which begin with the location in Illinois. Distinctly Midwestern, the couple embodies the characteristics typical of the area – hardworking, practical, and honest. Choosing to locate in a relatively small but well-established town, Gibson City, IL, the couple enjoys the comforts of society while minimizing urban commotion and waste. The couple seeks a design that does not misrepresent; one that reflects history while simultaneously leading the world with regard to sustainability, energy conservation, and quality design. With a combined income of \$80,000 per year, the couple is able to live comfortably in a home that meets all their desires and goals while refraining from any unnecessary opulence. Overall, the target homeowner is a typical American couple looking for the comforts of the present in a home for the future.



With this target market chosen, a specific set of requirements for the home was derived. We realized the couple would need the basic necessities of a modern home including a bedroom, bathroom, and kitchen in order to perform everyday functions. When designing for this couple and their basic needs, we realized there were other tasks which the target market would also deem as a necessity such as a desk with a computer, a living area for home entertainment, and a way to combine all of these spaces to allow more people to also enjoy the home. For example, the ability to expand the coffee table into two chairs for a dinner party is one way in which the house was designed for two people, but can still accommodate the couple's guests. To allow for the possibility that the homeowner may work from home, we designed the living spaces large enough to be a home office or to host client meetings. Other areas, such as the bedroom desk are also convertible to allow for larger work surfaces and increased functionality. We envision our target market as those who desire the modern amenities while wanting to lead the way in regard to a sustainable, valuable, and overall efficient design.

Application to Target Market:

Energy:

Team Illinois' Gable Home has been designed to meet Passive House standards for both the climate in Gibson City and Washington D.C. Passive House certification - a growing standard in the United States and one that is fully established in much of Europe - means the building uses ninety percent less energy than a comparable sized building constructed by typical construction practices. Obtaining Passive House certification, which requires limiting both heating and cooling demands to under 15 kWh / m² and air infiltration to less than .6 air changes per hour, can add significant value to a new home. While this is extremely admirable with regard to energy and sustainability, it also represents a significant draw for our target market. Due to the low cost to operate, owners will not have to worry about variations in energy bills or increases in utility costs. The high performance of the home will also help the house to retain significant value as time progresses.

Along with conserving as much energy as possible, the integration of many different design technologies also contribute to the value of the home. The Gable Home only requires solar panels on one half of our available roof surface to power the home and generate vast amounts of electricity to feed back into the grid. Consequently, the Illinois Solar Decathlon home is expected to produce much more power than the annual energy demand, resulting in a net gain for the owner each year the home stays in operation. While many solar homes are forced to use their entire flat or sloped roof, the Illinois team hopes to demonstrate that achieving a net-zero energy house is possible when using a pitched gable roof typical of today's housing market. We also are able to show that a highly insulated, energy conscious home does not need to be dark and enclosed but can enjoy significant views and natural



daylight by utilizing well made windows and balancing aesthetics with solar gain and heat loss. Significantly reducing and in even eliminating utility bills is one of the largest strengths of the Gable Home.

Value:

To realize the goal of developing the Gable Home, Team Illinois chose to use a modular homebuilder to help build the shell of the home. Modular also appeals to our target market as a way for them to build with ease and convenience on the part of the couple. Advantages of modular over typical construction practices include an increase of speed, which means a quicker and less stressful build and move period for the couple. The second advantage of modular construction is price. Modular often comes in below the price of on site construction due to the availability of common materials, the ability to shift the workforce in between different units to keep them working, the lack of weather related work stoppages, and the efficiency of the manufacturing line process. Another important aspect of modular construction is the ability to have thorough quality control over all aspects of the construction process. The modular home manufacture used to construct Gable Home employs a permanent quality control officer who checks for code compliance as well as defects in workmanship as the building is assembled. Any consumer, including the couple named as the target market, appreciates a quick, cheap, and error free product, which is what modular construction provides. The efficiency of the construction process when using a modular homebuilder in a controlled environment utilizes less waste, less material overall, and less time designing since the same details can be replicated over and over therefore lowering cost, increasing speed, and increasing quality of the final construction.

Practical:

The Gable Home is a practical solution to the climate of our target market and has been tested in similar forms for over a hundred years. Readapting forms from local vernacular architecture allows Gable Home to function as a climate responsible home should. For example, a pitched gable roof has been determined over time to be a foundation of construction due to its abilities to shed rain and heavy snow loads. In the Gable Home, the pitch is practical for another reason: It optimizes the angle of the solar panel array and also integrates the panels seamlessly to the structure. Shading devices, blinds, and a partially covered deck all sprang from climate responsive ideals. Throughout time, many pieces of the home have been utilized in one way or another. However, the difference in Gable Home is that all of these vernacular details have been revamped into the component parts of a completely innovative home for contemporary America.

In terms of the feasibility and ease of construction, Gable Home relies on the use of acceptable and readily available materials. Besides some very custom components, the materials used in the Gable Home can be easily found throughout Illinois. Furthermore, all of the exterior cladding and decking originated in Illinois and has been reclaimed from a barn and grain elevator respectively. This ability to reuse materials that are frequent throughout Illinois in the form of abandoned and outdated farming structures is a key to Gable Home. Also, locally manufactured and recyclable roofing material, bathroom finishes, and flooring material were used along with local labor throughout the construction process, whether students or the modular homebuilder. Both materials and labor were uniquely Midwestern just like the rest of Gable Home.

Innovative:

Throughout the design, both old and new technologies are introduced that together work to enhance the design and improve overall market viability of the design. The extremely efficient windows work cooperatively with a thermally broken exterior wall construction. The wall utilizes both rigid and foamed in place insulation while also fitting in a structurally sound bamboo frame and resting on an open web joist system. Much of these construction details are built with energy and rapidly renewable materials in mind. For instance, a heat pump water heater captures energy from within the house and efficiently conditions the entire space. With a window to area ratio of nearly 27 percent, Gable Home becomes more than a simple super-insulated cube. Instead, the home displays the opportunities for superior energy design with an appealing aesthetic through the use of large open spaces and pleasant natural daylight. Within the home, a fully-integrated computer control system allows for continuous monitoring and modification of lighting, heating, cooling and forecasting. This ability to control features independent of each other gives the ability for customized living settings to the user. Each feature located in Gable Home was chosen for a specific purpose and works to improve the function of the home and the comfort of the residents.

Desirable:

Gable Home is a comfortable and inviting environment to live in due to the interior spaces which emerged from the design and spatial layout. A person enters into the home through an entry porch which sets the stage for and acts as a transition to the rest of the house. Gable Home is based on an open floor plan which still retains the privacy of a distinct bath and bedroom. These types of plans where the rooms can blend together to become multifunctional, entertainment spaces are popular among our target market. With an open and variable plan, Gable Home adapts to the many different lifestyles and behaviors of the couple may share. With a self-reliant couple projected as our target market it is important to showcase the possibilities of two people with varying interests and goals through the use of space.

ENGINEERING NARRATIVE

Introduction

The UIUC engineering effort was carried out by faculty and students from the College of Engineering at the UIUC and in collaboration with students and faculty from many disciplines across campus. Most of the engineering students participated in a two-semester course sequence known as ENG 491 “Solar Home Design” and ENG 491 “Solar Home Laboratory.” This course sequence had between twenty and thirty students. In addition, several students participated through senior design courses in their respective academic departments. Finally, several graduate students participated as volunteers or as part of their ongoing research efforts.

The engineering efforts were coordinate through smaller teams, each addressing particular subsystems in the house. This delegation occurred with the clear understanding that these systems are interdependent, requiring regular coordination between students within engineering and across campus to architecture and industrial design. The major subsystems discussed in this report are as follows: Electrical, Heating, Ventilation, and Air Conditioning (HVAC), Hot Water, Appliances and Home Entertainment, and Building Automation and Control. These subsystems are discussed at length below.

Some of the guiding principles of our engineering design are as follows

- 1) Electricity is the most versatile form of energy since it can be converted efficiently to other forms of energy and excess electrical energy can always be sourced back into the electric grid. From a subsystem perspective, electrically-powered solutions are not always the most efficient, but the system-level advantage of flexibility generally results in a system-level optimal trade-off. Therefore, our design decisions favored electrically-powered solutions.
- 2) It is always beneficial to have a backup plan. While we worked on several innovative designs for “Plan A,” we always had a “Plan B” ready to go so that timelines could be preserved and risk could be mitigated.
- 3) In real-life engineering, 90% is failure. While practicing engineers understand this, students that are accustomed to grades where “90% = A” may still need to learn this. As such, a guiding

principle was that no decisions were made without extensive simulation, discussion, and whenever possible, experimentation. Our students were required to present their ideas and data to the whole team for design review. Frequently, errors and untenable assumptions were discovered in this process.

- 4) Keeping an open mind is a key. Every idea was “put through the ringer” and no idea was automatically squashed. The guiding principle was teamwork, where the entire team takes credit or blame for whatever happens.
- 5) System-level thinking is a must. A common problem in engineering is that different teams optimize their different subsystems individually, only to find out that the optimized systems are far from optimal when placed in the full system. This guiding principle was kept in mind during all meetings so that the subsystem teams were always conscious of efforts of other teams and didn’t lose the big picture focus and waste effort on minor issues.

Electrical

The electrical system consists of two major components. First, there is the ordinary household wiring and safety mechanisms, which are routine and in compliance with the NEC. Second, there is the solar photovoltaic (PV) power system. The PV system was designed from both a power generation and an aesthetic standpoint and is the subject of most of this narrative section.

From a power generation standpoint, a minimal design would ensure that the energy used by the house would be at most zero kilowatt-hours but with minimal upfront cost. From an aesthetic standpoint, the team preferred to blend the PV system into the building design without sacrifice of architectural objectives.

The UIUC team conducted several meetings of a period of months to arrive at the final design, which places the PV modules at nearly the optimal angle for solar harvest, fills the southern roof space, and provides far more than enough power to balance the building energy. This approach required the architectural design team to “work around” the limitations of PV systems. For example, numerous types of rooflines are possible and desirable for various reasons, but they all came with cost or performance sacrifices that would reduce the marketability of the house. As such, the final design was the product of many back-and-forth tradeoffs on roof size, PV peak power capability, roof pitch, cost analysis, energy analysis, PV module technology, and ease of installation. The following sections describe the resulting PV system in detail.

Ambient Temperature

Temperature data obtained from the National Climatic Data Center (www.ncdc.noaa.gov), for National Arboretum DC, MD suggests that the design temperature for the house ranges from -10°F to 104°F (-23°C to 40°C). Additionally, the operating temperature of the PV modules can reach up to 75°C.

Electrical System Block Diagram

Figure 1 depicts the one-line diagram of the electrical system (Detailed schematic attached, E-101). In Fig. 1, each Photovoltaic (PV) sub-array consists of 20 Sunpower SPR-225-BLK modules. The 20 modules are arranged as 2 parallel strings of 10 series-connected modules. This constrains the current and voltage of each string below 21 A (the inverter DC maximum input current) and 600 V (the inverter DC maximum input voltage), respectively. More precisely, at the minimum ambient temperature (-23°C), employing the published temperature coefficient of voltage, (-0.1325 V/°C), the worst-case value of the

expected string voltage is $(10 \text{ series modules}) \left(V_{oc} - 0.1325 \frac{\text{V}}{\text{C}} (-23^\circ\text{C} - 25^\circ\text{C}) \right) = 581.7 \text{ V}$, where V_{oc} is the rated open-circuit voltage at 25°C . Also, at the maximum ambient temperature, (40°C), employing the temperature coefficient of current, ($3.5 \text{ mA}/^\circ\text{C}$), the worst-case value of expected string current is $\left(I_{sc} + 3.5 \frac{\text{mA}}{\text{C}} (40^\circ\text{C} - 25^\circ\text{C}) \right) = 6.178 \text{ A}$, where I_{sc} is the short-circuit current at 25°C .

Each subarray is connected to a SunPower 5000m inverter. The inverter eliminates the need for combiner boxes by accepting inputs from four strings (of which only two are used in our design, one for each subarray) and also provides integrated DC disconnects for the PV strings.

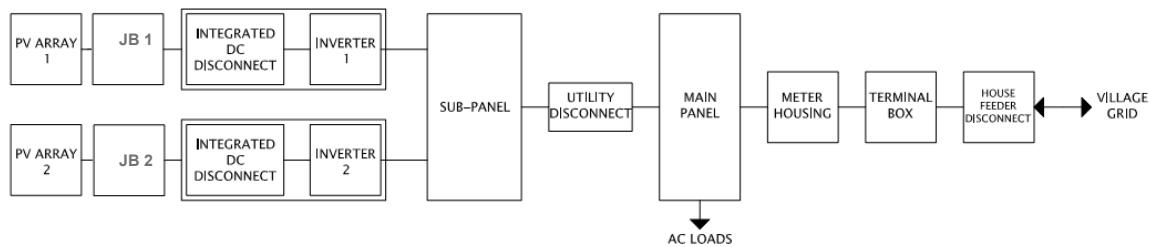


Figure 1: One-Line Diagram of Electrical System

The numbers attached in parentheses for each conductor correspond to the tags in E-101.

PV Modules to Junction Boxes (1)

Conductor Sizing

The short-circuit current of the SPR-225-BLK module is 5.87 A, which implies a continuous current rating of 7.34 A ($5.87 \text{ A} \times 1.25$). The 80% operation current rating is 9.18 A ($7.34 \text{ A} \times 1.25$). Therefore, the DC conductors from the modules should hence have a 30°C ampacity of 9.18 A.

Note that while these cables will be installed in free air, they will be in contact with the back of the PV modules, reaching temperatures of up to 75°C . The following conductors could be used for this application [NEC 310.17].

- 10 AWG USE-2/RHH/RHW-2: Ampacity in free air at 75°C : 22.55 A (55×0.41)
- 12 AWG USE-2/RHH/RHW-2: Ampacity in free air at 75°C : 16.4 A (40×0.41)
- 14 AWG USE-2/RHH/RHW-2: Ampacity in free air at 75°C : 14.35 A (35×0.41)

Voltage Drop Calculations

It is generally suggested that the maximum voltage drop at full power from the PV source to the inverter be limited to 3%. We will assume a DC bus voltage of 410 V for each sub-array (Number of series modules x Rated Voltage = $10 \times 41\text{ V} = 410\text{ V}$). This means that the voltage drop in the conductors should be less than or equal to 12.3 V.

The maximum length wire run from the PV sub-array to the inverter is approximately equal to 13.21 m. The DC resistance of 10 AWG conductors is $3.27 \times 10^{-3}\text{ } \Omega / \text{m}$. Assuming rated current, this implies that the maximum voltage drop experienced is, $5.49\text{ A} \times 3.27 \times 10^{-3}\text{ } \Omega / \text{m} \times 13.21\text{ m} = 2.37\text{ V}$. This is much lesser than 3%-limit.

Conductor chosen

Based on the considerations presented above and a general desire to provide high efficiency, we use a 10 AWG conductor for this run.

Junction Boxes to Inverters (2)

NEMA-3R rain-proof junction boxes will be employed to source the conduit runs into the interior of the house. The conductors from the PV source circuit will be spliced together with the cable in the conduit using approved means [NEC 300.15].

Conductor Sizing

Note that the 30°C ampacity of these conductors should still be 9.18 A or higher. The only other corrective factors that need to be accommodated are for conduit fill. Assuming an ambient temperature of 40°C , the temperature correction factor for THHN/THWN-2 cables in conduit is 0.91. In addition, the ampacity is derated by a factor of 0.8 [NEC 310.15] to accommodate the fact that each conduit will contain five conductors (4 PV output conductors and 1 Equipment Grounding Conductor).

We will use 10 AWG THHN/THWN-2 cable for this portion of the run for uniformity and to reduce voltage drops. The derated ampacity of 10 AWG cable [NEC 310.16] is $29.12\text{ A} = (40\text{ A} \times 0.91 \times 0.8)$, which is well above the required ampacity of 9.18 A.

Conduit Selection

The conductors in this portion of the electrical system will be enclosed in a 3/4" EMT conduit. The conduit will begin at the junction box and terminate in the interior of the house at the inverter (for each sub-array).

NEC Table C-1 (Appendix) indicates that up to ten 10 AWG conductors can be routed through a 3/4" EMT conduit. We are well within this limit as only five 10 AWG conductors will be routed in each conduit (four PV output conductors and one Equipment Grounding Conductor for each sub-array).

Equipment Grounding Conductor (3/4)

Based on the calculations presented above, we will employ a 10 AWG conductor to realize the Equipment Grounding Conductor. As depicted in the Electrical Schematic (E-103), up to the junction box (tag: 3), a bare Copper conductor is utilized, and for the run between the junction box and the inverter (tag: 4), 10 AWG THHN/THWN-2 is utilized.

Inverter output circuits (5)

We refer the conductor runs between each inverter and the electrical subpanel as the inverter output circuits. Note that the conductors will be routed through EMT conduit.

Conductor Sizing

The maximum inverter output current is 20.8 A (5000 W / 240 V). Ampacity requirements dictate a current of 26 A (20.8 A x 1.25). The required circuit breaker for each inverter is 30 A. To keep voltage drops reasonably small, we will employ 10 AWG THWN conductors for the inverter output circuits. Note that the ampacity of these conductors [NEC 310.17] at an assumed ambient temperature of 40°C is 44 A (50 A x 0.88) hence serving this application well.

Conduit Selection

In accordance with NEC Table C-1, we will employ a 1" EMT conduit for this part of the system.

Subpanel design

As depicted in the schematic (E-101), a subpanel is used to combine the output of the two inverters.

Breaker Sizing

In the previous section, it was pointed out that a 30 A circuit breaker is required for each inverter. The subpanel main breaker will be rated for 60 A ($2 \times 20.8 \text{ A} \times 1.25 = 52 \text{ A}$, round up to 60 A).

Subpanel Rating

To size the subpanel, we refer to NEC 690.64(B)(2) and denote the minimum rating as y . Given 30-A circuit breakers for the inverters and a 60-A sub-panel main breaker,
 $1.2y = (2 \times 30 \text{ A}) + (60 \text{ A}) \rightarrow y = 100 \text{ A}$. Thus, the sub-panel will be rated for 100 A.

Sub-panel to Main-Panel (7)

Note that these conductors will be routed in conduit from the subpanel through a disconnect switch that will be installed in the exterior of the house and back into the house and terminate at the main panel.

Conductor Sizing

Note that the conductors in this run are also subject to constraints imposed by NEC 690.64(B)(2). Denoting the allowed ampacity of the conductors as z ,

$$1.2z = (2 \times 60 \text{ A}) \rightarrow z = 100 \text{ A}.$$

The ampacity of 3 AWG THWN conductors at an assumed ambient temperature of 40°C is 127.6 A (145 A $\times 0.88$) [NEC 310.17], which enables their utilization for this run.

Conduit Selection

In accordance with NEC Table C-1, we will employ a 1" EMT conduit for this part of the system.

AC Disconnect Switch

NEC 690.64(B)(2) will dictate the rating of the AC Disconnect Switch. Denoting the minimum rating of the switch as z , $1.2z = (2 \times 60 \text{ A}) \rightarrow z = 100 \text{ A}$. Thus, the AC Disconnect Switch will be rated for 100 A.

Main-Panel design

Breaker Sizing

The main panel includes a 60 A back-fed PV breaker and a 150 A main-breaker. Note that this breaker will be placed at the bottom of the main panel.

Main-panel Rating

To size the Main panel, we refer to NEC 690.64(B)(2) and denote the minimum allowed rating as y . Given the sizes of the breakers installed, $1.2y = 60 \text{ A} + 150 \text{ A} \rightarrow y = 175 \text{ A}$. Thus, the Main-panel will be rated for 200 A.

AC Side Equipment Grounding (6)

To appropriately ground the equipment on the AC side of the system, we employ NEC 250.122, which governs the size of the equipment-grounding conductor based on the rating of the over-current device protecting the relevant circuit.

Note that 30-A and 60-A circuit breakers are employed in this portion of the system (refer design of subpanel and main panel). From Table 250.122, we note that 10 AWG bare Cu suffices at these current levels. Thus, the Equipment Grounding Conductors for the Inverters, Disconnect switch, sub- and main panels will consist of 10 AWG Bare Cu conductor. This will be routed through conduit as appropriate.

Grounding Electrode Conductor (10)

NEC 250.66 dictates limits on the Grounding Electrode Conductor based on the size of the largest ungrounded service-entrance conductor. Assuming that 2/0 AWG conductors will be employed to service the house, Table 250.66 indicates that the Grounding Electrode Conductor should be 4 AWG Bare Cu. As dictated by the rules, we will employ an 8' ground rod driven at a 45° angle into the earth.

Ground Bonding Conductor (8)

This conductor is used to connect the grounding point in the inverter to the grounding bus bar in the main electrical panel. This conductor originates from the grounding point of one of the inverters and terminates at the grounding rod. The other inverter's grounding point is spliced irreversibly to this conductor as depicted in the electrical schematic. The conductors will be enclosed in $\frac{3}{4}$ " PVC conduit up to the point of floor penetration.

NEC 690.47(C)(2) dictates that the bonding conductor between the DC and AC systems should be sized as the larger of the DC requirement (in accordance with NEC 690.45) and the Inverter alternating current over-current device rating [NEC 250.122]. In addition, NEC 690.47(C)(4) indicates that a bonding conductor that serves multiple inverters shall be sized based on the sum of applicable currents used in NEC 690.47(C)(2).

The data sheet of the SPR 5000m inverter indicates that the maximum permissible DC current is 21 A. In addition, 30-A circuit breakers are installed on the AC output of each inverter. Denoting the minimum ampacity of the bonding conductor as z , to satisfy the postulates of NEC 690.47(C)(2) and NEC 690.47(C)(4), $z = 2(21 \text{ A}) + 2(30 \text{ A}) = 102 \text{ A}$.

Based on NEC 250.122, we will employ a 6 AWG Cu conductor to realize the ground bonding conductor. For quick reference, the design choices are tabulated in Table 1:

Table 1: Design Choices Summary

Branch	Continuous Current (A)	80% Operation (A)	Conductor	Derated Ampacity (A)	Circuit Breaker Rating (A)	Grounding Conductor (A)	Conduit
PV Sub-arrays to	7.34	9.18	10 AWG USE-2/RHH/RHW-	22.55	None	10 AWG Solid, Bare Cu	None



PV Sub-arrays to Junction boxes	7.34	9.18	10 AWG USE-2/RHH/RHW-2	22.55	None	10 AWG Solid, Bare Cu	None
Junction boxes to Inverters	7.34	9.18	10 AWG THHN/THWN-2	22.72	Integrated with Inverter	10 AWG THHN/THWN-2	3/4" EMT
Inverter to Sub-panel	20.8	26	10 AWG THWN	44	30	10 AWG Solid, Bare Cu	1" EMT
Sub-panel to Main-	100	N/A	3 AWG THWN	127.6	60	10 AWG Solid, Bare Cu	1" EMT

Other PV System Components

Our research and analysis concluded that the SunPower 225-W panels would be ideal for the PV system requirements of the Gable Home. These modules have the highest efficiency of available silicon modules and have reasonable cost. Furthermore, due to SunPower's proprietary production methods, they have a nearly solid black appearance that is aesthetically pleasing compared to conventional PV modules, which tend to have visible metallization and a degree of purplish tint.

Having finalized the solar panel choice, the quantity of panels required needed to be determined. It was determined that to achieve energy balance, the DC power rating of the PV system needed to be at least 6000 W. There will be a meter that measures and keeps track of the amount of power being drawn from the grid and the amount being fed into the grid.

From the data obtained from the panel spec sheets and the roof dimension from the latest drawings, the calculations below were made. This resulted in having 40 panels on the south facing roof of the house. The details of the panel layout and operation are given below.

Panel Orientation

The system contains (40) SPR-225 panels and (2) 5000m inverters in the following configuration. Each subarray consists of ten modules in a series string, with two strings in parallel. Each subarray will employ its own inverter.

Power Generation

The DC-rated peak power production of the PV modules is 9000 W. The CEC PTC rating is only 8284 W, accounting primarily for temperature drop. Using the online tool PVWatts, energy production can be estimated from the peak power rating, location, and other system details. This tool uses historical data captured from the NREL database and is a good proxy for the actual expected performance on an average basis. Based on our system design using Springfield, IL as a location (nearest to Champaign, IL, which is the final location for the house), the system is estimated to produce 11,528 kWh/yr.

System Costs

The cost per panel is \$949.50 for a total module cost of \$37,980.00. The inverters are SPR 5000m units with a total cost of $\$2,850.00 \times 2 = \$5,700.00$. The system also comprises several smaller balance-of-plant components such as racking mounts (discussed below), conduit, wiring, breakers. These components are numerous but small in cost, and total less than a few thousand dollars.

Inverters

The panels and the inverter have both arrived and once the house is ready with all the electrical connections, the panels can be mounted. After an in-depth research and taking into account different consideration during last semester and at the beginning of this semester it was decided that two 5000-W SunPower inverters are to be used for our system. SunPower 5000m inverters were selected for their power output capacity, high reliability, grid-tie capability and excellent efficiency. Furthermore, SunPower modules have a special “negative ground,” which requires the use of their inverters bearing their brand name. Two SunPower 5000m inverter were ordered at the beginning of the semester along with the solar panels. At the time of this report, the inverters have not yet been installed and tested, however, the appropriate mounts and wiring connections have been made.

Module Mounting

After a thorough analysis, it was initially determined that we would purchase a Unirac system through SunPower, including rails that would penetrate into a composite asphalt roof. However, after further discussions with architecture team members, the roof details were put back up for discussion. It was determined that a solid metal roof would function best for the solar house. The deciding factor for this decision was that the roof life would meet or exceed the life of the PV system (25 years or more), avoiding the need to take down the PV system to fix the roof after about fifteen years. Furthermore, we discovered a mounting system that is compatible with metal roofs and should be easier to manage, as it does not require punctures of the roof.

With the introduction of a metal standing seam roof for the entire house, the possibility of using nonpenetrating clips was revisited. Clips manufactured by S-5! were closely examined and we returned to analyzing the potential performance of this racking solution. We had adequate discussions with S-5! to determine the suitability for our application. After a few weeks of discussion, S-5! agreed to fully donate all the necessary racking materials, plus a significant amount of extra parts and tools.

We have received the S-5! clips and will be conducting the installation in mid-June, 2009.

The following is installation details were provided by S-5!:

"The key to frequency and spacing of attachment points for PV is to distribute loads to the metal standing seam panels in a manner that is consistent with the intended distribution of loads from the roof panels into the building structure. With very few exceptions, the attachment of a single S-5 clamp (even the "mini") to the seam will be stronger than a single point of attachment of the seam to the building structure. Hence the "weak link" is not the S-5 clamp, but the attachment clips that hold the metal panels to the building structure, or the beam strength of the roof panel seam, itself."

S-5-PV Kit

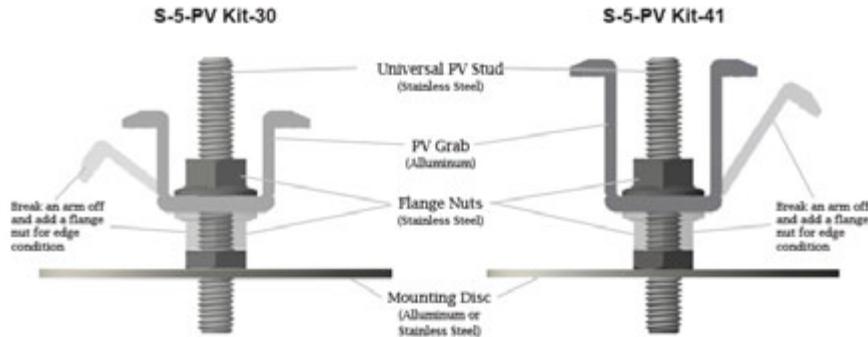


Figure 2: Diagram of S-5! clamps.

"The most conservative approach to the spacing/frequency of PV attachment to the roof is to determine the spacing/frequency of the roof's attachment to the building structure; then duplicate it at minimum. Determining panel attachment spacing in one axis is very simple: Standing seam panels' attachment will be made using concealed hold-down clips within the seam area of the panel. So, in that axis, the clip spacing is the same as the seam spacing. The location of the clips along the seam (in the other axis) can be determined by a) consultation with the roof system manufacturer or installer, b) checking from the

underside or, c) close examination from the topside along the seam. There will usually be a slight, but detectable, deformation of the seam at the clip location visible from the roof's topside. Many standing seam roofing systems are installed on "pre-engineered steel" buildings. The attachment spacing in that industry is typically 5'-0" and is readily apparent by inspecting the structural purlins to which the panel clips are attached from the roof underside (interior of the building)."

"With this in mind, our proposed solution was checked both with the architecture team and Dustin Haddock of S-5!. We have confirmation that PV Kits combined with the S-5-U Mini clamps will properly support our PV system in the proposed arrangement. Specific information on the S-5-U Mini clips is also provided below. These clips attach the PV kits to the roof."

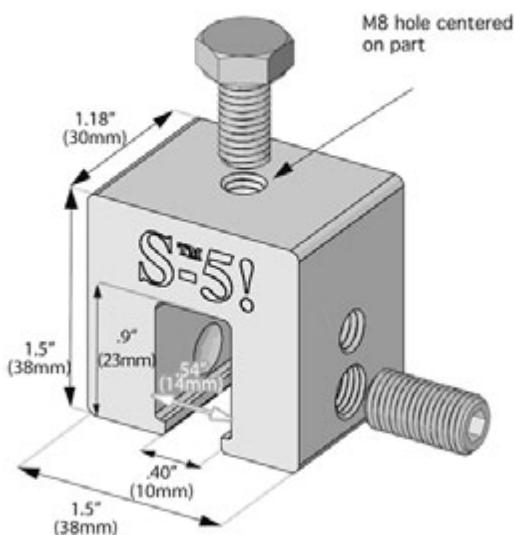


Figure 3: Detailed diagram of clamp.

"Installation is as simple as placing the clamp on the seam and tightening the patented round-point setscrew to the specified tension. Then, affix ancillary items using the bolt provided. Go to www.S-5.com/tools for information and tools available for properly attaching and tensioning S-5!TM clamps. Thanks to our patented round-tip setscrews, S-5!TM clamps do not pierce metal roof paneling, thereby protecting roof coatings and weather tightness warranties."



Figure 4: Brief overview of clamp installation procedure.

HVAC System

Background

The design for our 2009 Solar Decathlon entry is rooted in Midwestern tradition bringing the old barn look and feel to a modern and technologically advanced building. One of the major design features to save energy, especially on the HVAC side, is the pursuance of Passive House certification. A Passive House is a distinctly unique way of thinking of how to build a house. This standard and design comes from Germany, the PassivHaus Institute. The crux of the design is to build a super insulated, air tight home to reduce the heating load to the lowest possible value. A few years ago, this design concept was brought to the US from Germany and the Passive House Institute was born in the US. Katrin Klingenburg heads the US initiative and actually built the first Passive House certified home in the US here in Urbana in 2003 and currently resides there. The reason for building the home in this climate is to really test the design concept in a very harsh climate with wide temperature and humidity difference throughout the year. Thus if the design can work in this location, then it can work anywhere in the US. This also provided validation that they design can work in an environment with a large cooling load, which is important because the climate of Germany is very temperate and does not have as high of cooling loads in the summer as most places in the US. The Passive House standard has a limit for the amount of kWh/m²/year used by the home for both heating and cooling, which is 15 kWh/m²/year for both.

Thus to achieve such a low power consumption per year, Passive Houses rely on conditioning the air of the home using a heat recovery ventilator, HRV, or an energy recovery ventilator, ERV. By using these ventilators, these homes are able to maintain the minimum ventilation requirements set by ASHRAE; however, they are conserving the heat and moisture, for an ERV, of the exhausting air by preconditioning the fresh intake air. By transferring the heat and moisture from the stale exhaust air to the fresh intake air, an ERV is able to drastically reduce the load seen by the cooling unit in the summer and heating unit in the winter.

Now this mechanical ventilation only gives these amazing savings on conditioning the space when the natural infiltration is as close to 0 as possible. To make sure homes employ the best possibly air tightening practices, the Passive House standard imposes a maximum of 0.6 pressurized air changes per hour, ACH, which means when the house is under a 50 Pascal pressurization this is how many times the air should be changed per hour. This number is determined in a built Passive House by using a blower door test. If you convert the pressurized ACH to natural ACH then it is ~0.033 ACH from infiltration. This is well below the minimum required by ASHRAE, who requires a minimum of 0.35 ACH. This means the Passive House needs constant mechanical ventilation to maintain the necessary minimum ventilation requirement.

The next major necessity to reduce the HVAC load is to make the envelope of the home super insulated. To make a home super insulated usually means at least R-70 ceilings, R-50 walls and low-e coated, argon-filled, triple-paned windows with insulated frames reducing thermal bridges among other improvements. The goal of this is to limit heat transfer to the environment from the house so the

temperature inside does not fluctuate wildly during a 24-hour period. Also, the most windows are placed on the south facing wall to maximize solar heat gain during the winter while limiting the number of windows on the other three walls.

With the combinations of all these extreme building practices, the HVAC loads are drastically reduced, requiring only minimal power input.

Competition

Since the house and HVAC unit are designed for a competition, there are certain rules and limitations imposed because of this. The rules state during the week of competition the indoor air temperature must be between 72-76 degrees Fahrenheit to get full points and humidity needs to be between 40% and 55% to get full points. These two readings and points make up 100 of the 1000 total points for the competition, meaning this is not a trivial amount of points and impact.

Design

Our design went through several different iterations over the semester. The major design goals were to make a compact unit which heats, cools, dehumidifies, and ventilates as well as to try and heat and cool only with the ventilation air flow rate. The first design involved a heat pump in a similar configuration as a typical air conditioner; however there were various ducts and dampers to control the air flow supplied to the house over the evaporator or condenser depending if heating or cooling is needed. This design can be seen in the Figure 5.

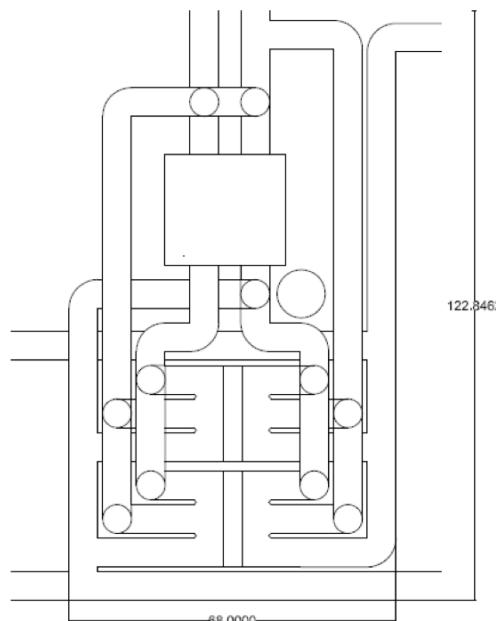




Figure 5: Initial concept or HVAC system.

The dimensions of this unit are 122" long by 68" wide. This is small enough to fit in the space allotted to the HVAC unit in our house design. The various ducts and dampers in this design allow maximum control over the temperature and humidity depending on whether the air is fresh air, fresh air through ERV, or re-circulated air. This setup will also require additional fans for the cases when the ERV is not used. This setup is the best setup for conditioning control; however it is very large and expensive. This setup would require 18 dampers and 2 extra fans and much more ducting. Since I wanted to use electronic dampers the total cost for just the dampers alone would be about \$2000, at \$110 a piece, which is a lot of money for only dampers. Another disadvantage of this idea is the amount of static pressure in the system will be high due to the many turns, tees, and ducting lengths. This will increase the fan power for a given air flow rate. So with this information we redesigned the system.

The new design eliminates the extra ducting and uses a heat pump with a reversing valve instead. Using a heat pump with a reversing valve allows the evaporator and condenser to change roles depending on the refrigerant flow direction. So now there only needs to be one duct, greatly reducing complexity. The new design can be seen below in both a top and side view.

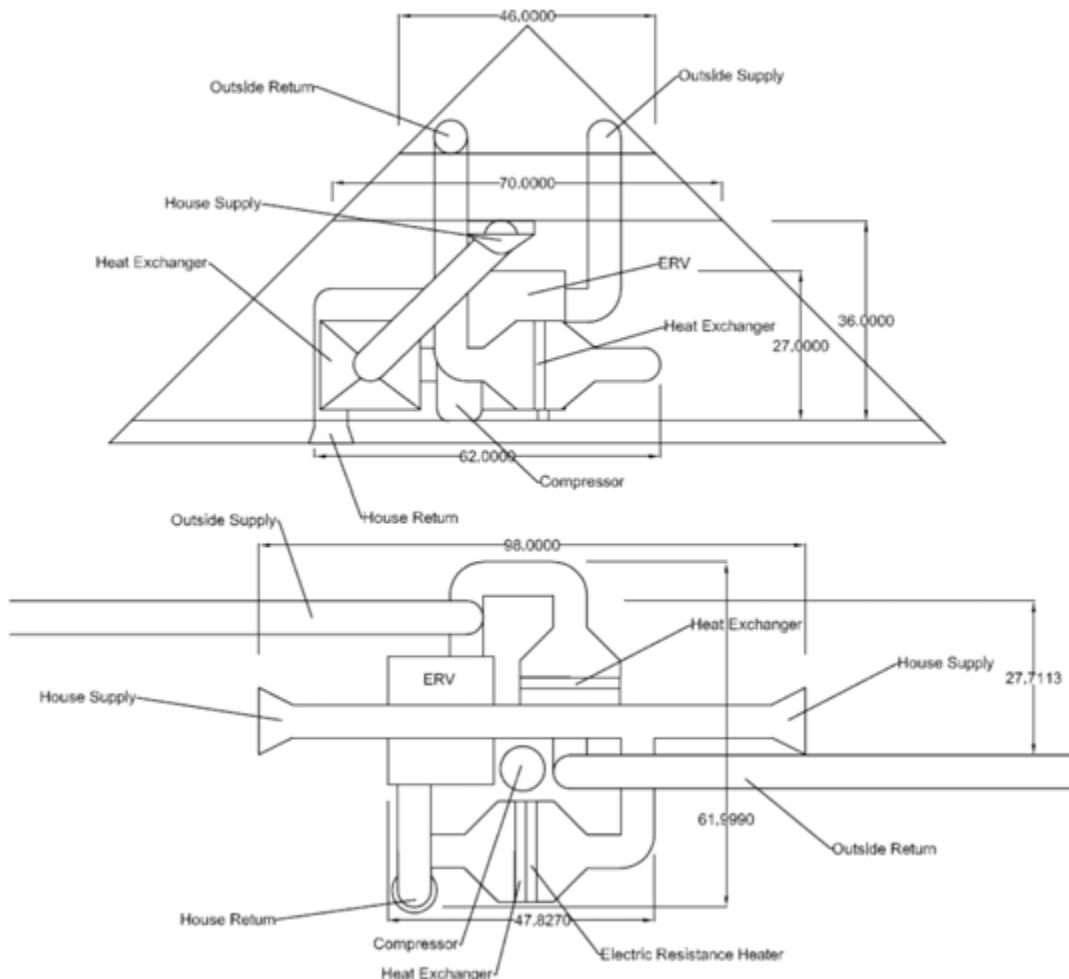


Figure 6: Second revisions of HVAC design concept.

The side view is in the actual space in the house, which is in a little “attic” space above the bathroom. This space is still inside the conditioned space so I do not need to worry about insulating ducting except for the outside air intake and exhaust. So with this design there is already greatly reduced ducting and thus size of the system. It is almost half as long and the width is almost two feet less. With this design there are few bends and short ducting lengths so the static pressure will be less. An electric resistance heater was added for the times when the temperature outside is below the operating temperature of the heat pump, usually 45°F or less. The resistance heater is also there for the times when the heat pump needs to defrost. The major difference with the unit is for the unit to heat or cool it needs to draw in fresh air. This differs from the previous design where we could re-circulate the air if ventilation was not needed at that time. This is the most compact unit possible with only marginal gains making it even smaller with tighter ducting runs. This compactness comes at a price though and the unit would be difficult to work on to make repairs at the competition, especially since it will be in a raised space. Also the filters for the ERV are replaced from the top of the unit in this configuration meaning the ERV would

need to be removed from the raised space to replace the filters. As a result of this and the desire to make possible repairs easier on the team, we redesigned this system to one which is more serviceable.

The new design, as seen below, allows for the filters of the ERV to be changed while still in the raised space since they now are changed on the right side of the ERV from the top view.

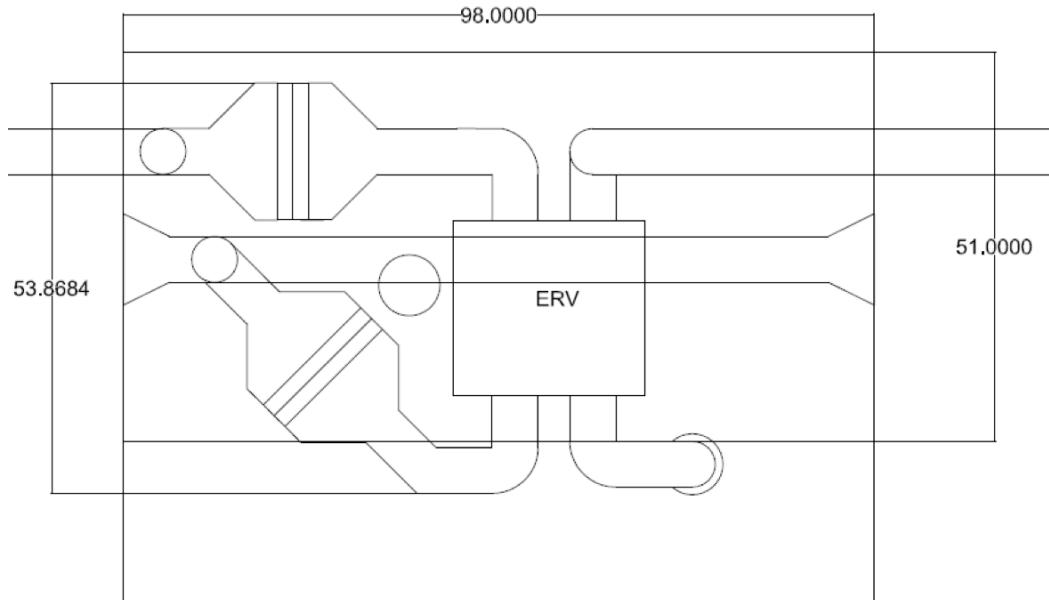


Figure 7: Third version of the HVAC concept.

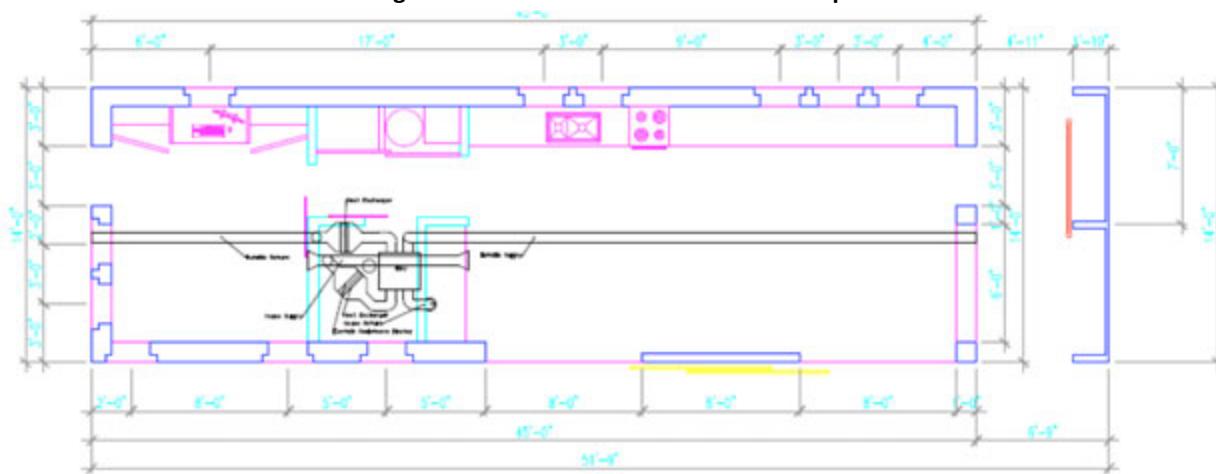


Figure 8: Third version of HVAC as shown against floor plan.

Also, it has slightly better access to the heat exchangers and compressor. Another driving factor for the redesign was the architecture team's desire to take what was once a completely enclosed space above the bathroom, hallway and mechanical/electrical closets and make the hallway go the full height to the vaulted ceiling. This means we no longer had an 8' by 12' floor space to work with but instead it is now 8' by 7'. So now the unit will be closer to the sloping ceiling of this raised space, which can be seen in the side view of the first design. While this design is an improvement in the serviceability of the HVAC unit,

we decided to take it one step further and make the access to the heat pump equipment easier since those will be the items most likely to fail during the competition.

This third redesign (fourth version overall) is now the plan of record. It includes all the necessary pieces to operate while having excellent serviceability as seen below.

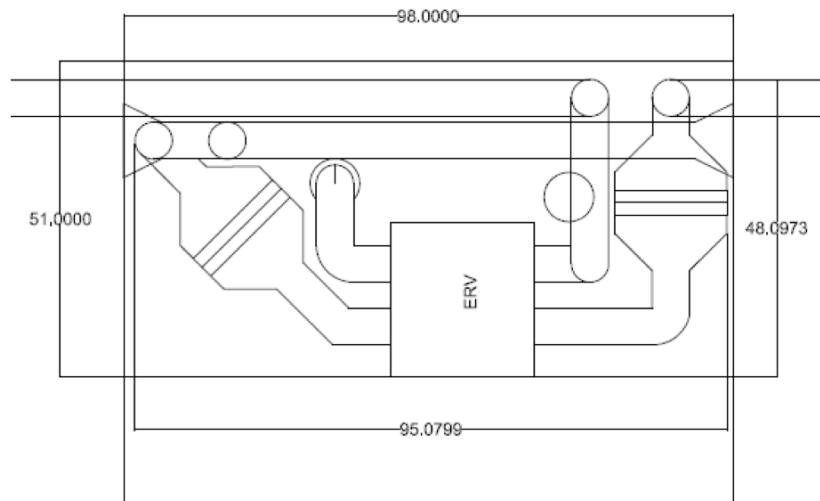


Figure 9: Fourth version of HVAC concept.

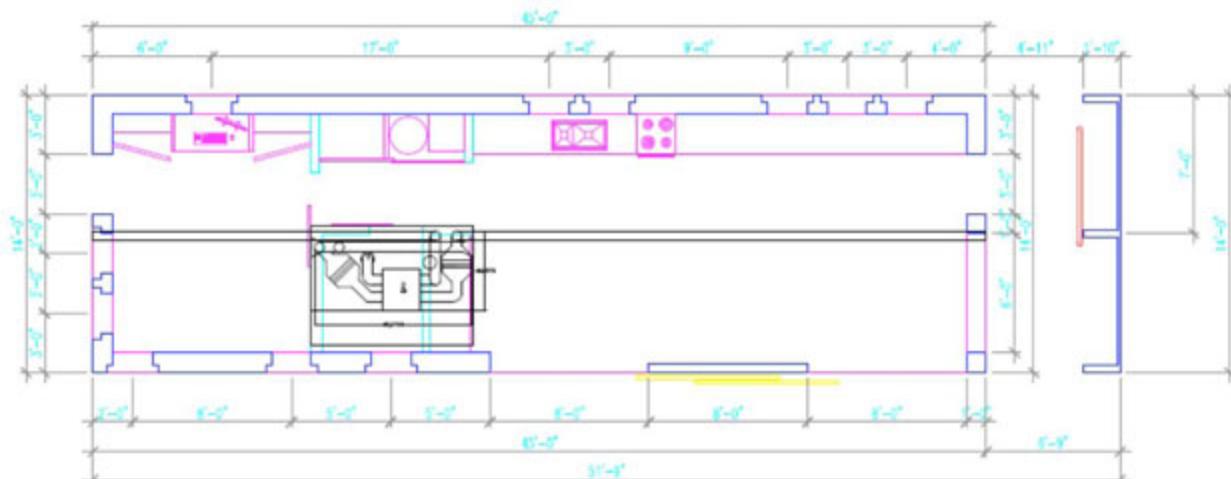


Figure 10: Fourth HVAC concept as shown against floor plan.

This design has slightly longer refrigerant lines than the other designs but the gains in the other aspects of this design greatly outweigh this minor fact. The north wall of the raised space, adjacent to the hallway, will, for now, be open to the hallway allowing access to the HVAC unit but also to incorporate the HVAC unit into the public tour of the house for the competition.

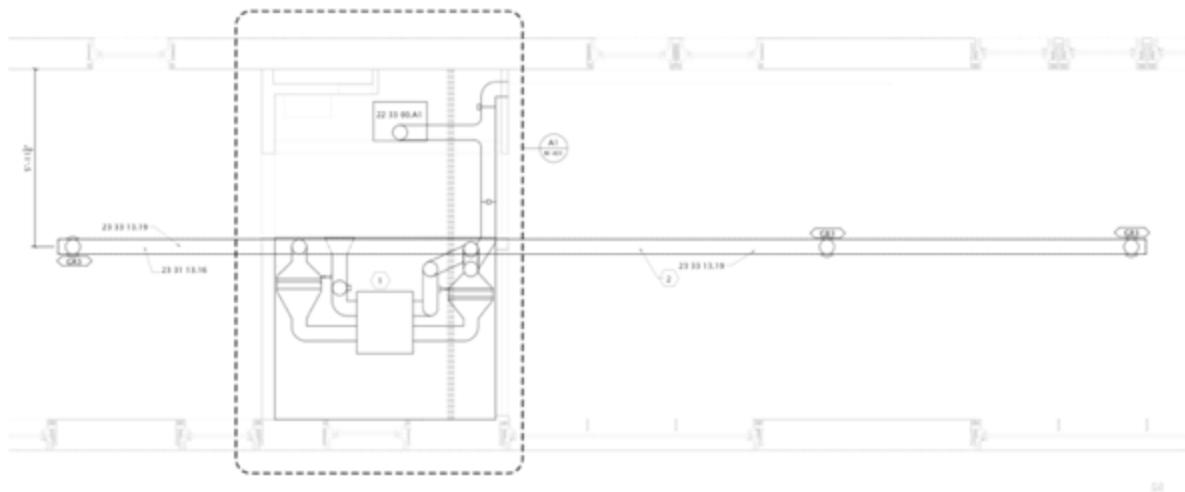


Figure 10: Final (fifth) version of the HVAC concept.

The final revision, shown above in Figure 10, is slightly modified to accurately reflect the physical space constraints. There are now going to be exposed ducts traveling the length of the living room and bedroom instead of throwing the air across the space. This was done to allow for proper air mixing in the two spaces since the return for the system is in the hallway. There is also a connection from the heat pump hot water heater so during the winter the cold air from the heat pump will be diverted to the exhaust air stream, but when the extra cooling will help during the summer it will be diverted to the inside. Refer to the figures below.

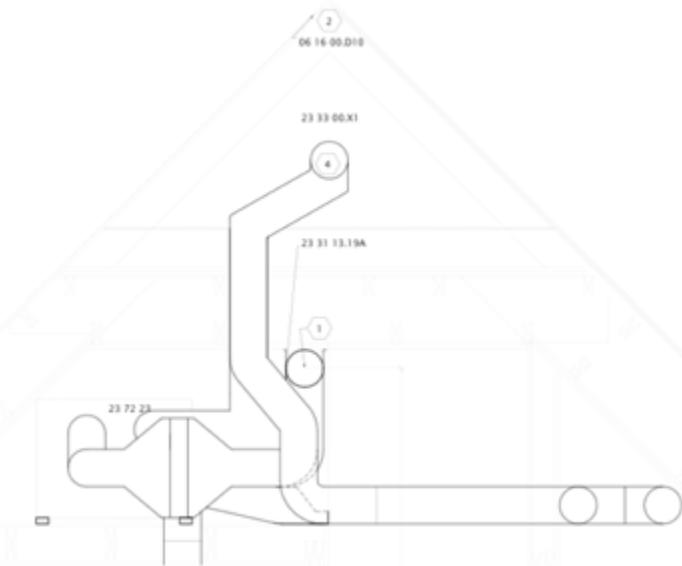


Figure 11: Additional detail of HVAC concept.

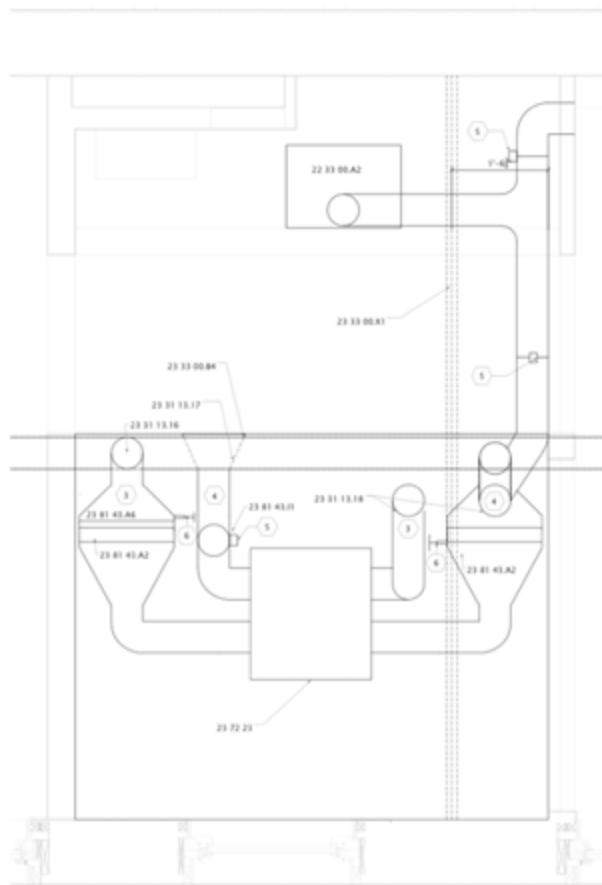


Figure 12: Another additional HVAC drawing.

There will be an electronic damper on the house return located in the bathroom so that when there is an occupant in the bathroom, the damper will be open. This was done so that the extra humidity from a shower or for various other reasons, the bathroom air will be directly exhausted to the outside. This was not needed for our house by code since we have a large enough operable window in the bathroom for those reasons, however, this defeats the purpose of the passive house design and the airtight nature of the home. There is an electric resistance heating coil on the supply side of the system for when the outside air is below 40° F and the heat pump heating system will not function.

The current design will use a variable capacity compressor, which will help to reduce electricity consumption of the system. This will be accomplished through the ability to lower the capacity and fan speed during partial load conditions. These partial load conditions are the majority of the situations for heating and cooling in the home as shown below in the Trace 700 analysis.

SYSTEM LOAD PROFILES

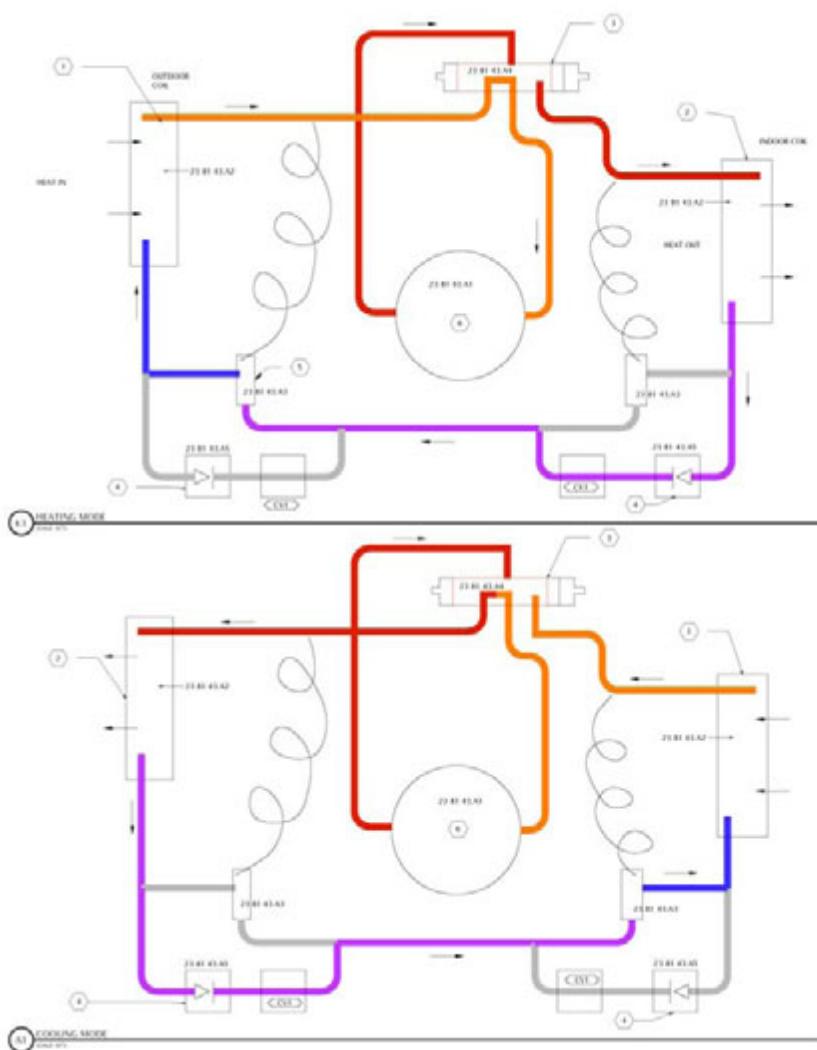
By DEMO

System - 001

Percent Design Load Cooling Load Heating Load Cooling Airflow Heating Airflow		
	Cap. (Tons)	Hours (%)	Hours	Cap. (Btu/h)	Hours (%)	Hours	Cap. (Cfm)	Hours (%)	Hours	Cap. (Cfm)	Hours (%)	Hours
0 - 5	0.0	10	762	-3002	15	60	12.0	0	0	0.0	0	0
5 - 10	0.1	11	891	-500.4	53	209	24.0	0	0	0.0	0	0
10 - 15	0.1	18	1,383	-900.8	32	124	36.0	0	0	0.0	0	0
15 - 20	0.1	11	902	-1,200.8	0	0	48.0	0	0	0.0	0	0
20 - 25	0.1	2	177	-1,501.0	0	0	60.1	0	0	0.0	0	0
25 - 30	0.2	1	68	-1,801.2	0	0	72.1	0	0	0.0	0	0
30 - 35	0.2	2	125	-2,101.4	0	0	84.1	58	5,078	0.0	0	0
35 - 40	0.2	5	402	-2,401.6	0	0	96.1	0	0	0.0	0	0
40 - 45	0.3	2	172	-2,701.8	0	0	108.1	0	0	0.0	0	0
45 - 50	0.3	5	416	-3,002.0	0	0	120.1	42	3,602	0.0	0	0
50 - 55	0.3	11	829	-3,302.2	0	0	132.1	0	0	0.0	0	0
55 - 60	0.3	14	1,054	-3,602.4	0	0	144.1	0	0	0.0	0	0
60 - 65	0.4	7	631	-3,902.6	0	0	156.1	0	0	0.0	0	0
65 - 70	0.4	1	64	-4,202.8	0	0	168.1	0	0	0.0	0	0
70 - 76	0.4	0	0	-4,603.0	0	0	180.2	0	0	0.0	0	0
76 - 80	0.4	0	0	-4,803.2	0	0	192.2	0	0	0.0	0	0
80 - 85	0.5	0	0	-5,103.4	0	0	204.2	0	0	0.0	0	0
85 - 90	0.5	0	0	-5,403.6	0	0	216.2	0	0	0.0	0	0
90 - 95	0.5	0	0	-5,703.8	0	0	228.2	0	0	0.0	0	0
95 - 100	0.5	0	0	-6,004.0	0	0	240.2	0	0	0.0	0	0
Hours Off	0.0	0	904	0.0	0	8,367	0.0	0	0.0	0	0	8,760

Figure 13: Results of load Trace 700 calculations.

While the numbers may not be truly indicative of the actual hours at the partial loads, the overall trends are what are important for the consideration of the variable capacity compressor. As seen in the analysis, much of the time for cooling is at much lower loads than the peak load of 0.5 tons. This means the variable capacity compressor will be greatly beneficial to the system as a whole. This will allow for potential savings up to 10-30% according to various literature on this subject.



GENERAL SHEET NOTES	
THESE GENERAL NOTES APPLY TO ALL DRAWINGS.	
1.1) NOT TO SCALE DRAWINGS. USE FIELD MEASUREMENTS.	
NOTES ON DRAWINGS WILL APPLY TO ALL DRAWINGS, WHETHER THEY ARE REFERENCED OR NOT.	
INCLUDES LINES, TUBES, PIPES, ETC., AND THEIR LENGTHS, DIA., THICKNESS, MATERIAL, TEMPERATURE COEFFICIENTS, AND ALLOWABLE STRESSES.	
COMPONENTS SHOULD BE SHOWN AS STYLIZED COLOR AS SHOWN IN THE LEGEND.	
THE WORK AND PARTS ATTACHED FOR THE EQUIPMENT INDICATED ON THIS DRAWING ARE THE CONTRACTOR'S RESPONSIBILITY. THE CONTRACTOR SHALL BE RESPONSIBLE FOR ALL DESIGN, CONSTRUCTION, AND SPECIFICATIONS TO THE WORK PROVIDED, BUT NOT NECESSARILY LIMITED TO ELECTRICAL, MECHANICAL, INDUSTRIAL, AND ARCHITECTURAL FEATURES SUCH AS CEILINGS, DOORS AND FRAMES, CHIMNEYS, ETC. INSPECTED BY THE CONTRACTOR AND APPROVED BY OTHER THAN THE CONTRACTOR, IF APPLIED ON THE DRAWINGS.	
REFERENCE KEYNOTES	
SECTION 20 - HEATING, VENTILATING, AND AIR CONDITIONING (HVAC)	
21.B1.80	DEEPVAPORIZED UNITARY HVAC EQUIPMENT
21.B1.41.A1	VARIABLE CAPACITY COMPRESSOR
21.B1.41.A2	PIPE AND TUBE HE EXCHANGERS
21.B1.41.A3	TERMOSTATIC EXPANSION VALVE
21.B1.41.A4	CHECK VALVE
21.B1.41.A5	CHECK VALVE
SHEET KEYNOTES	
①	EVAPORATOR
②	CONDENSER
③	REFRIGERANT
④	CHECK VALVE
⑤	TERMOTHERMATIC EXPANSION VALVE
⑥	COMPRESSOR
PIPING LEGEND	
21.B1.41	HIGH PRESSURE LIQ
21.B1.41.G1	HIGH PRESSURE LIQUID
21.B1.41.G2	LOW PRESSURE LIQUID
21.B1.41.G3	LOW PRESSURE GAS
21.B1.41.G4	HIGH PRESSURE GAS
21.B1.41.G5	LOW TEMPERATURE LIQUID

Figure 14: Refrigerant loops of the heat pump system.

The diagram in Figure 14 above is for the refrigerant loops of the heat pump system used for heating and cooling. This shows the different paths of the refrigerant flow for heating and cooling.

Load Modeling

The first load modeling done was by the architecture students using the Passive House Planning Package, or PHPP. The results of this modeling can be seen on the next page. This program takes many low energy specific design principles into consideration when defining the house. However, since this program was developed for the specific environment in Germany where there is little cooling needed, the cooling load numbers might not be correct for the US. This is why we modeled the home in Trane Trace as well to verify the numbers from PHPP.

Building:	University of Illinois 2009 Solar Decathlon Entry		
Location and Climate:	Peoria		
Street:			
Postcode/City:	Urbana, Illinois		
Country:	USA		
Building Type:	Residential Prototype		
Home Owner(s) / Client(s):	University of Illinois		
Street:			
Postcode/City:			
Architect:	U of I Solar Decathlon Team		
Street:			
Postcode/City:			
Mechanical System:	U of I Engineering Department		
Street:			
Postcode/City:			
Year of Construction:	2008-2009		
Number of Dwelling Units:	1		
Enclosed Volume V _e :	147.6	m ³	Interior Temperature: 20.0 °C
Number of Occupants:	2.0 Internal Heat Gains: 2.1 W/m ²		
Specific Demands with Reference to the Treated Floor Area			
Treated Floor Area:	46.6 m ²	Applied: Monthly Method	PH Certificate:
Specific Space Heat Demand:	15 kWh/(m ² a)	15 kWh/(m ² a)	Fulfilled? Yes
Pressurization Test Result:	0.6 h ⁻¹	0.6 h ⁻¹	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	119 kWh/(m ² a)	120 kWh/(m ² a)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	64 kWh/(m ² a)		
Specific Primary Energy Demand (Energy Conservation by Solar Electricity):	129 kWh/(m ² a)	15 kWh/(m ² a)	
Heating Load:	23 W/m ²	over 25 °C	
Frequency of Overheating:	%		
Specific Useful Cooling Energy Demand:	2 kWh/(m ² a)		Yes
Cooling Load:	13 W/m ²		

Figure 15: PHPP Software screen shot.

Trane Trace 700 is a HVAC sizing software developed by Trane. Typically this software is used for commercial scale projects, but it can also be adapted for residential use. Using Trace, the worst case heating and cooling loads were determined. First, the necessary information about the house had to be entered into the program such as wall insulation levels, types of windows, heating and cooling systems, and more. The information was obtained from the architecture students so as to have the most accurate data possible for the software. The more accurate the inputs, the more accurate the outputs will be. The software is relatively simple for residential since there are few inputs needed compared to commercial projects. Once the inputs are correctly entered into the program the software can run the calculations to determine the worst case heating and cooling loads. The worst case cooling load is the hottest, most humid day of the summer with full occupancy and internal generation. For the heating load, it is during the night of the coldest day in the winter with no occupancy and no internal generation.

System Checksums									
System - 001									
COOLING COIL PEAK					CLG SPACE PEAK				
Peaked at Time: M/H: 8/15 Outside Air: OADD/WB/HR: 89.74/105					M/H: Sum of OADD: Peaks				
Space Sens. + Lat. Btu/h	Pleum. Btu/h	Net Total Btu/h	Percent (%)	Sensible OffTotal Btu/h	Space Sens. Btu/h	Percent (%)	Space Peak Btu/h	CoilPeak Btu/h	Percent (%)
Envelope Loads					Envelope Loads				
Skyline Solar	0	0	0	0	Skyline Solar	0	0	0	0.00
Skyline Cond.	0	0	0	0	Skyline Cond.	0	0	0	0.00
Roof Cond.	85	0	85	1	Roof Cond.	-815	-815	8.62	
Glass Solar	2,493	0	2,493	43	Glass Solar	0	0	0	0.00
Glass Cond.	212	0	212	4	Glass Cond.	-1,279	-1,279	21.30	
Wall Cond.	434	0	434	1	Wall Cond.	-855	-855	14.90	
Partition	0	0	0	0	Partition	0	0	0	0.00
Exposed Floor	22	0	22	0.00	Exposed Floor	-733	-733	12.21	
Infiltration	133	0	133	2	Infiltration	-268	-268	3.45	
Sub Total =>	3,379	0	3,379	68	Sub Total =>	-3,632	-3,632	60.45	
Internal Loads					Internal Loads				
Light	352	0	352	6	Light	0	0	0.00	
People	700	0	700	12	People	0	0	0.00	
Mac	1,067	0	1,067	18	Mac	0	0	0.00	
Sub Total =>	2,109	0	2,109	36	Sub Total =>	0	0	0.00	
Ceiling Load	0	0	0	0	Ceiling Load	0	0	0.00	
Ventilation Load	0	0	282	6	Ventilation Load	-2,372	-2,372	39.61	
Adj Air Trans Heat	0	0	0	0	Adj Air Trans Heat	0	0	0.00	
Dehumid. On Sizing	0	0	0	0	Ov/Undr Sizing	0	0	0.00	
Ov/Undr Sizing	0	0	0	0	ExhaustHeat	0	0	0.00	
ExhaustHeat	0	0	0	0	OA Preheat Diff.	0	0.00	0.00	
Sup. Fan Heat	0	62	62	1	RA Preheat Diff.	0	0.00	0.00	
Ret. Fan Heat	0	0	0	0	RA Preheat Diff.	0	0.00	0.00	
DuctHeatPump	0	0	0	0	Additional Reheat	0	0.00	0.00	
ReheatAt Design	0	0	0	0					
Grand Total =>	6,487	0	6,841	100.00	Grand Total =>	-3,632	-6,004	100.00	No. People 2
COOLING COIL SELECTION					HEATING COIL SELECTION				
Total Capacity ton	Sens Cap. M/s	Coil Airflow cfm	Enter DB WB/HR °F	Leave DB WB/HR °F	Capacity M/s	Coil Airflow cfm	Ent °F	Lv°F	
Main Clg 0.5	5.6	53	261.5	74.3	50.5	59.2	55.4	52.5	55.3
Aux Clg 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OptVent 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total 0.5	5.6	53	261.5	74.3	50.5	59.2	55.4	52.5	55.3
AREAS					HEATING COIL SELECTION				
Floor	Gross Total ft ²	Glass ft ² (%)			Main Htg	-5.0	291.5	55.5	85.8
Part	0	0			Aux Htg	0.0	0	0	0
Extr	538	0			Preheat	0.0	0	0	0
Roof	515	0			Humidif	0.0	0	0.0	0.0
Wall	842	154	10		OptVent	0.0	0	0.0	0.0
Total	-5.0				Total	-5.0			

Project Name: TRACE6700 v5.1.3 calculated at 08:03 PM on 12/14/2008
Dataset Name: C:\CDS\TRACE6700\Projects\00House.dz
Alternative=1 System Checksums Report Page 1 of 1

Figure 16: Sample calculations from Trane Trace.

Figure 16 above shows the results of the calculations, giving information regarding the needed size of the system and other more detailed information about the suggested system. For our uses, the information of importance is the total capacity for cooling and to a less extent the capacity of the heating. The cooling capacity is especially important because the competition will be during the month of October which normally still requires cooling versus heating. Also due to the design of our house, cooling will be much more difficult compared to heating. The things which help to reduce the heating load in the winter raise the cooling load in the summer: people, solar heat gain, electronics, refrigerator, etc. According to the results, our peak cooling load will be 5,841 Btu/hr, or 0.5 tons. This requires very little, even for something as small as a window air conditioner. Finding a window unit which is also a heat pump will therefore prove to be very difficult.

The biggest loads for the cooling peak are the solar gains from the windows. This high load can be largely offset with proper shading of the windows during the high solar times. This will dramatically reduce the cooling load needed for the house to about 0.25 tons. However, the downside of this is the greater need for indoor lighting to make up the difference in available light in the home.

Indoor Air Quality

Due to the level of natural infiltration into these airtight homes, the indoor air quality becomes an important consideration. One major determiner for indoor air quality, or IAQ, is CO₂ levels. The easiest way to reduce the CO₂ level in a home is to increase ventilation rate. With a Passive House, it is so air tight it would take about 25.5 hours for one complete air exchange of the home from natural infiltration alone. This infiltration level is too slow compared to the generation levels of CO₂ from four people, for example. Using the equation below from *Indoor Air Quality and HVAC Systems* with a generation of 0.011 cfm/person from *ASHRAE Fundamentals*, after one hour in the airtight home the CO₂ level inside should be 687 ppm.

$$C_{indoor} = \frac{F \times 10^6}{V_{eff} I} (1 - e^{-I t}) + C_{outdoor}$$

Where:

C_{indoor} – CO₂ concentration indoor, ppm

F – Generation rate of CO₂, 0.011 cfm/person

V_{eff} – Effective volume, ft³

I – Ventilation rate, air changes per hour

t – Time, hours

$C_{outdoor}$ – CO₂ concentration outdoor, ppm

Now for this infiltration, the CO₂ will reach steady state in 151.5 hours, or 6.3 days, at a level of 8077 ppm as seen in table below.

Table 2: Air infiltration calculations.

	Airtight	Minimum
	0.033 ACH	0.35 ACH
Time (hr)	C_{inside} (ppm)	C_{inside} (ppm)
0.5	563	553
1	687	651
5	1607	1036

10	2599	1140
50	6652	1162
100	7846	1162
150	8075	1162
151.5	8077	1162
200	8119	1162
720	8129	1162

This is well above the acceptable range for CO₂, which has a threshold limit value for a time-weighted average of 5,000 ppm. This level of CO₂ begins to have serious adverse effects on the human body. Now, if the air exchange per hour is 0.35 instead the 0.033 through mechanical ventilation then the steady state level of CO₂ will be 1162 ppm. This value is the limit for what is acceptable for CO₂ concentrations in a home as ASHRAE recommends levels below 1000 ppm, which is why 0.35 is the minimum level of acceptable ACH. This comparison shows why mechanical ventilation is required for proper indoor air quality with regards to CO₂. Without the mechanical ventilation, the inhabitants will begin to feel the adverse effects of high CO₂ concentration in as few as 10 hours. The best way to reduce CO₂ in the house is more ventilation. Since you are continuously mechanically ventilating the house, an airtight home will have more uniform air change as opposed to the infiltration of fresh air in a conventional home. This means the airtight home will exchange more stale air for fresh air, lowering the CO₂ concentration level in the home.

Ventilation Rates:

Calculations were also made to determine if the HVAC system could provide enough dehumidification to eliminate the moisture in the incoming fresh air. This is an essential part of cooling during the summer. Since the ERV will exchange moisture between air streams, the humidity ratio for both the outgoing air stream and incoming air stream were determined in kg water/kg air and then multiplied by the efficiency of the ERV. The amount of dehumidification capable of the proposed heat pump is 1.7 pints/hour. Then by varying the outside air temperature and relative humidity, the maximum airflow rate can be determined. For any flow rate higher than this value, the supply air will actually humidify the interior, which is not acceptable. This only presents a problem at high outside temperatures and relative humidity. A graph of these flow rates at different temperatures and relative humidity can be seen below.

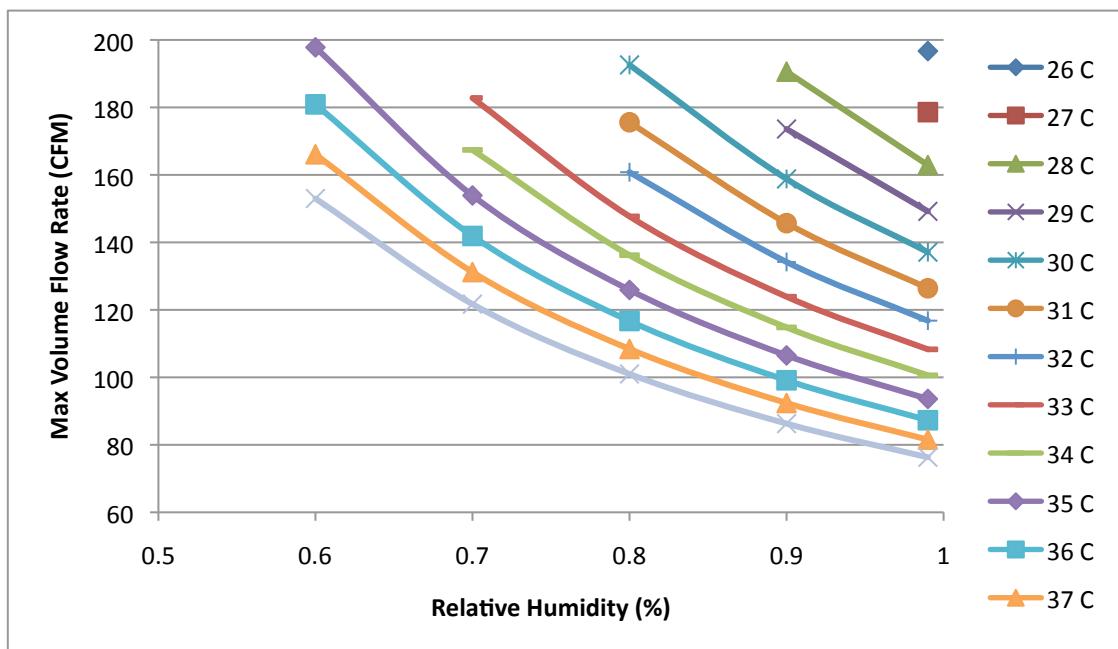


Figure 17: Max ventilation flow rate given outside Temp & RH %, A/C Dehumid (without water heater)

At these high temperatures and relative humidity, extra dehumidification is needed for higher flow rates than indicated. The extra dehumidification can come from the heat pump hot water unit, which provides 1 quart/day of dehumidification or 0.1667 pints/hr. With the extra dehumidification of the hot water heater, the ventilation unit can now have a higher flow rate to provide sufficient cooling without humidifying the indoor air. The adjusted maximum flow rates, taking the additional dehumidification into account, can be seen in the figure below.

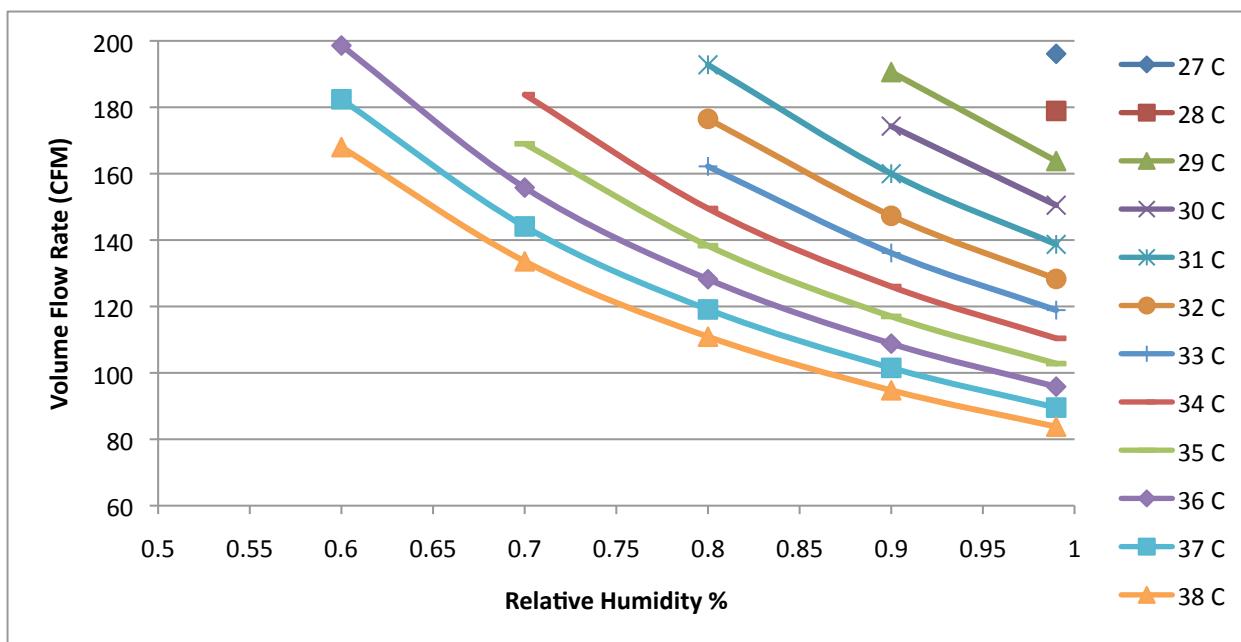


Figure 18: Max ventilation CFM given outside Temp & RH %, A/C Dehumid w/ Water Heater

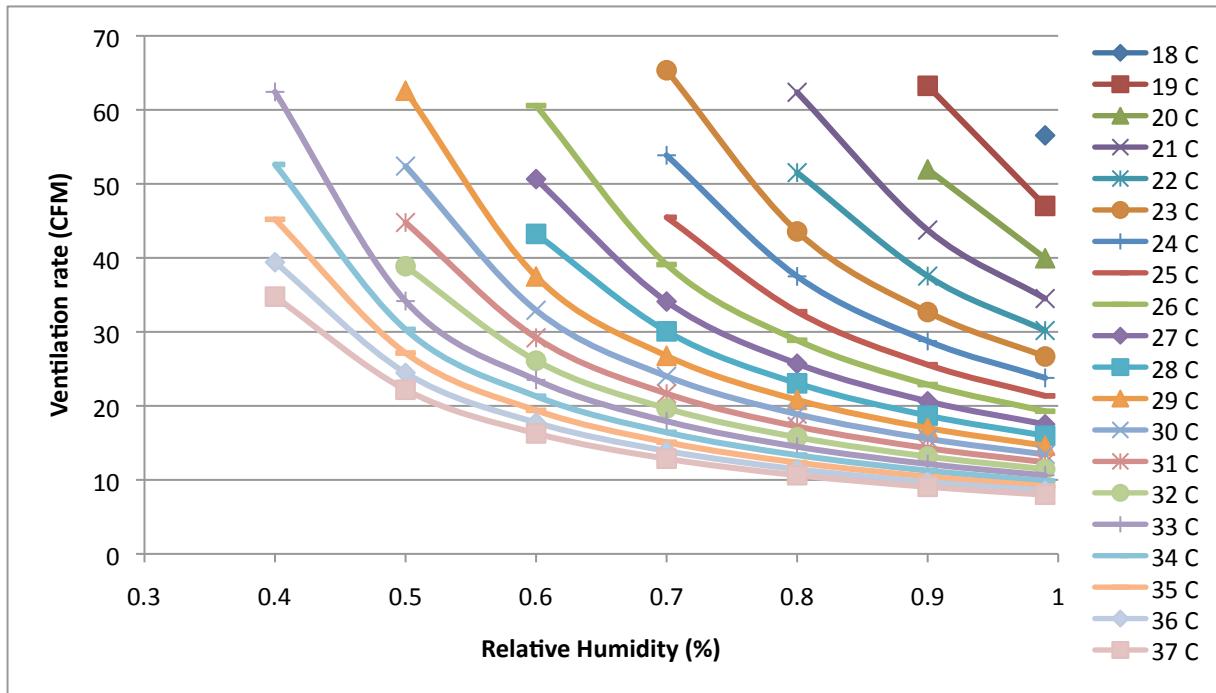


Figure 19: Max ventilation CFM given outside Temp & RH %, Water Heater only

Weather records indicate that the average high temperature and humidity in Washington D.C. in October are 20.6° C and 80%, respectively. Looking at the previous three figures, at a humidity of 80% the temperature must be greater than 30-31° C to necessitate additional dehumidification beyond the AC system and heat pump water heater. In fact, at a low ventilation rate, the hot water heater provides enough dehumidification for the minimum required ventilation at 21° C and 80% RH which is just above the average high for Washington D.C. This means that during the competition we will not have a problem with dehumidifying the incoming fresh air at any airflow rate and may not have to dehumidify the air at all with the AC system dependent on the outside conditions.

The downside to this much dehumidifying is the opposite case when the temperature and humidity are low and we need to humidify. Since we have to maintain a tight temperature and humidity range, we need to consider both sides of the equation. Looking at weather records, the average high and low temperatures are 20.6° C and 10° C respectively. The average morning and afternoon relative humidities are 80% and 53% respectively. So at 10° C, there may be a need for humidification but future work would need to be done to determine if this is true and the extent of the humidification.

Construction



The current idea to construct the unit is to take a purchased ERV and then build the heat pump around that item. The ERV picked out is the Ultimate Air Recouperator and it has an airflow range of ~70-200 CFM which was used as the limiting factors for the ventilation analysis. The heat pump equipment will be compiled from individual components purchased or donated from various companies. This means we will be using UL listed components then combining them ourselves to create our heat pump system. This is more difficult than taking a current off the shelf system and using it in the house because we have to specify all and purchase all components for the system, some of which are very difficult to find for our small system. In the end though, this will allow for a custom system specifically tailored for our home and its specific characteristics.

Backup Plan

A backup plan has also been prepared, in the event that the self-contained unit does not work as planned. In this case we would use a ductless mini split system. The condenser would go outside the home on the south wall right near the bathroom so the refrigerant line is very short and the evaporator unit would be placed on the west wall in the main room. We would use an off the shelf Daikin mini split system because it has a variable capacity compressor so the capacity can go as low as 0.25 tons, while the nominal value is 0.75 tons. With this approach, we are confident that the heating and cooling loads would be met with little trouble. It would be easy to install and control, but it would not provide any points for innovation.



Hot Water

For the domestic hot water system, research was conducted in order to compare the variety of available types of systems. A thorough cost analysis was performed that, along with certain physical restrictions, allowed us to choose the most reliable and cost-effective system for the house. Extended hot water tests ensured that this system would meet the hot water demands of the competition.

System Selection

Like in any residence, the domestic hot water system in the Gable Home is critical to its success as a viable house. Toward reaching a perfect score in hot water, the team spared no effort in choosing and testing the best system to do the job. Before purchasing any materials an analysis was performed to compare possible solutions. These included solar thermal water heating, an electric resistance heater, and a heat pump system. Ultimately a heat pump was chosen as the most economically and practically viable option. Parts were then purchased and thorough experimentation was carried out to demonstrate the system's effectiveness. Detailed here are the steps taken toward accomplishing this goal, as well as what work remains to be completed before the competition.

Table 3 Domestic hot water project budget possibilities.

Component	Quantity	Amount	Total per component
Tankless hot water heater	1	\$700	\$700

Heat pump hot water system components			
Water tank (40gal)	1	\$400	\$400
Heat pump hot water heater	1	\$700	\$700
Electronic damper	2	\$75	\$150
Subtotal			\$1,250

Solar Thermal hot water system components			
Evacuated tubes	2	\$1,100	\$2,200
Wall mounting kit	2	\$170	\$340
Circulation pump	2	\$220	\$440
Solar thermal tank (50gal)	1	\$550	\$550
Propylene glycol (antifreeze)	6	\$20/gallon	\$120
Subtotal			\$3,650

There are three different types of hot water draws that will be demanded during competition week. One is the general hot water draw, which requires that fifteen gallons of water be drawn within a ten-minute period with an average temperature greater than 110°F. Two appliances will also use hot water. When running the clothes washer four gallons will be drawn, also at a temperature of 110°F. The dishwasher requires four gallons as well, only it must reach a temperature of 120°F during its cycle. In short, this means that the water system of the Gable Home must be able to provide water at 120°F on demand. The carefully selected system of an Airgenerate Airtap heat pump in conjunction with a Rheem Marathon tank meets those demands.

Before settling on the heat pump system, alternative options were seriously considered. A breakdown of the costs of these systems can be seen in Table 3. One of these is the use of evacuation tubes on the south wall of the house to provide solar thermal heating. This is an expensive system to install, but its benefits are considerable. No electricity is required to heat, making it extremely efficient. Architectural design limitations, however, prevented this from being an option. Another option, electric resistance heaters are able to heat water extremely quickly, but they consume massive amounts of power to operate. By opting to use a heat pump and a water tank, hot water will be available in adequate volumes while consuming relatively little electricity.

Experimental setup

The heat pump system is advantageous not only for its efficiency, but also its size and shape. It will fit comfortably in a closet in the Gable Home, situated as shown in Figure 20. It was not, however, designed to work with the round-topped water tank made by Rheem. The refrigerant coils were unable to fit into the hot water outlet of the tank, where they customarily enter. Instead the coils were fed through the cold water inlet, and the cold water was attached to feed into the drain located at the bottom of the tank. See Figure 22 for a photo of the setup. Figure 22 shows the temperature of the water in the tank over a twenty-hour period. The losses are strikingly minimal, which is due to the excellent polyurethane insulation with a factor of R-20.

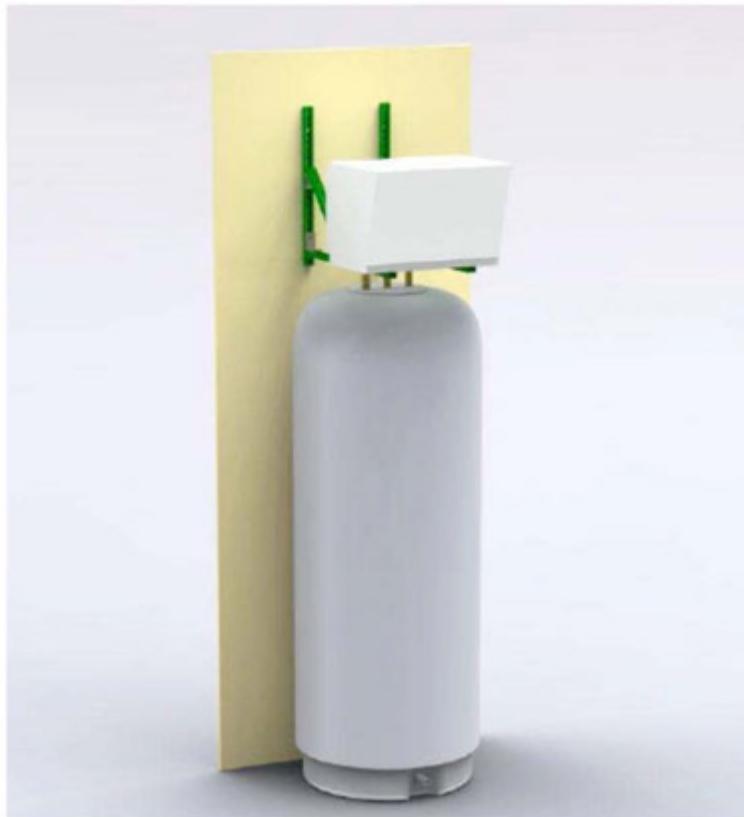


Figure 20 Rendering of Hot Water System in Final Configuration

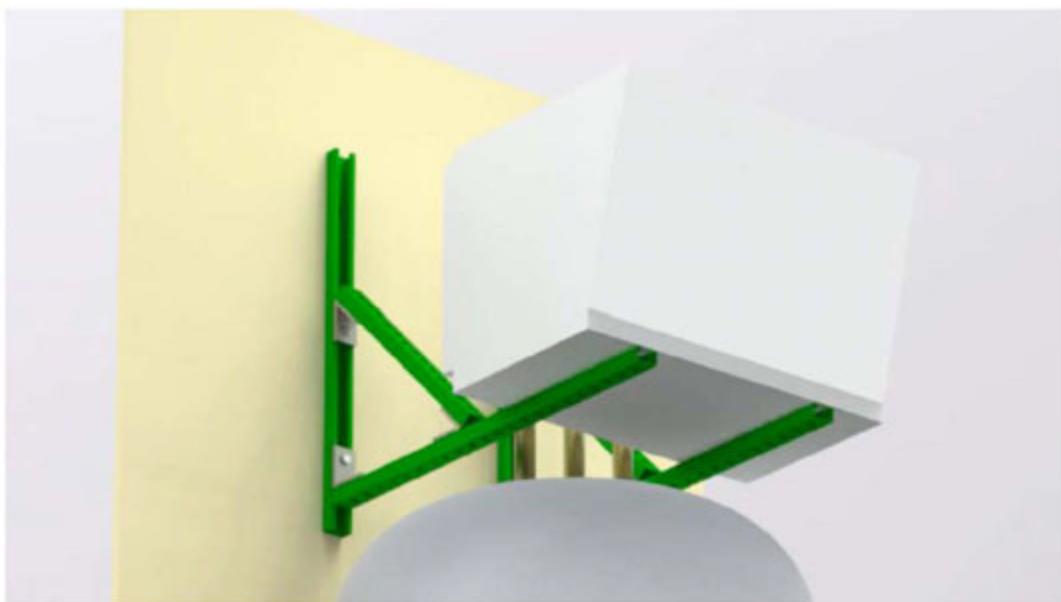


Figure 21 Rendering of AirTap Unistrut mount



Figure 22 Heat pump mounted on top of water tank.

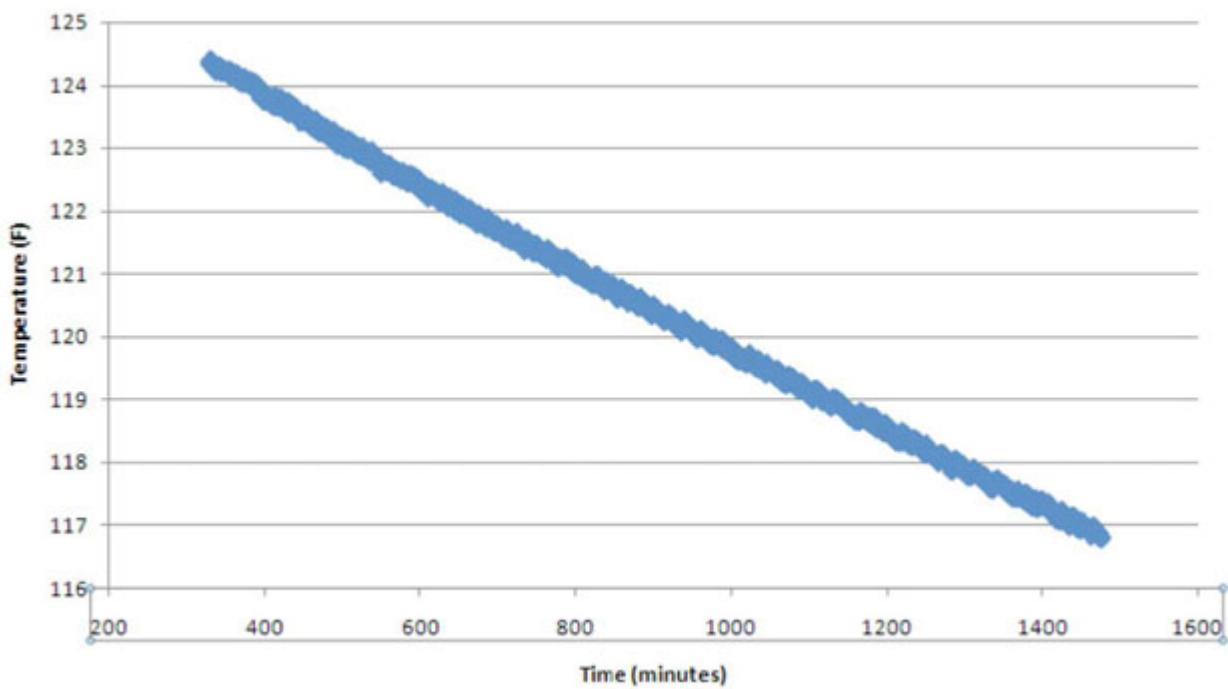


Figure 23 Temperature versus time for water tank.

The Airtap required a custom mounting solution because of the low amount of space in utility closet and the curvature at the top of the water tank. The curved top was a problem because the Airtap unit was designed for a water tank with a flat top. Figure 21 is a rendering of the Airtap mount design. The frame is constructed using 1-5/8" and 3/4" Unistrut metal framing. A complete list of components is shown in Table 5. The vertical 1-5/8" Unistrut will be mounted to the wall using four 1/2" screws and fender washers through the slots in the Unistrut. The horizontal and diagonal members are attached using angle fittings, channel nuts and 3/8"-16 3/4" bolts. The diagonal members are included for support because the weight of the Airtap is concentrated at the front of the unit. The final assembly will have a clean design that is mostly hidden from view once installed in the utility closet.

Table 5: Airtap mount Unistrut components

Table A-3: Airtap mount Unistrut components

Model Number	Description
A3300	1-1/4" x 3/4" 14 gage channel
P1100	1-5/8" x 1-5/8" 14 gage channel
A3008	3/8-16" channel nut
P1008	3/8-16" channel nut

To prove the reliability of the hot water system, it was installed in a laboratory and subject to lengthy tests. Type T thermocouples were placed at the top of the tank, the bottom of the tank, the hot water outlet, the exhaust vent of the heat pump, and in the ambient air. A power transducer measured the electricity being drawn by the heat pump. A digital rotometer measured the hot water flow rate by emitting a square wave that was measured by an oscilloscope. Temperature and power were monitored using a data logger and recorded on a PC using Agilent Datalogger Pro.

The competition schedule shown in Table 4 was obtained from the Solar Decathlon website in order to simulate the demands on the system. This schedule was used to simulate the loads expected during the course of the week, and tests were performed accordingly. Figures 24, 25, and 26 show tank temperature and power versus time graphs for three days of the competition. The periods with increased power consumption correspond with the heat pump being on. The heat pump draws an average of 0.8 kW-hr of electricity each time it turns on. This tended to occur any time a fifteen gallon water draw was made. Day 9, therefore, will most likely use the most energy of any day because the three water draws are spread out over the course of the day, requiring the heater to be turned on each time.

Table A-2 Water demands during the competition schedule.



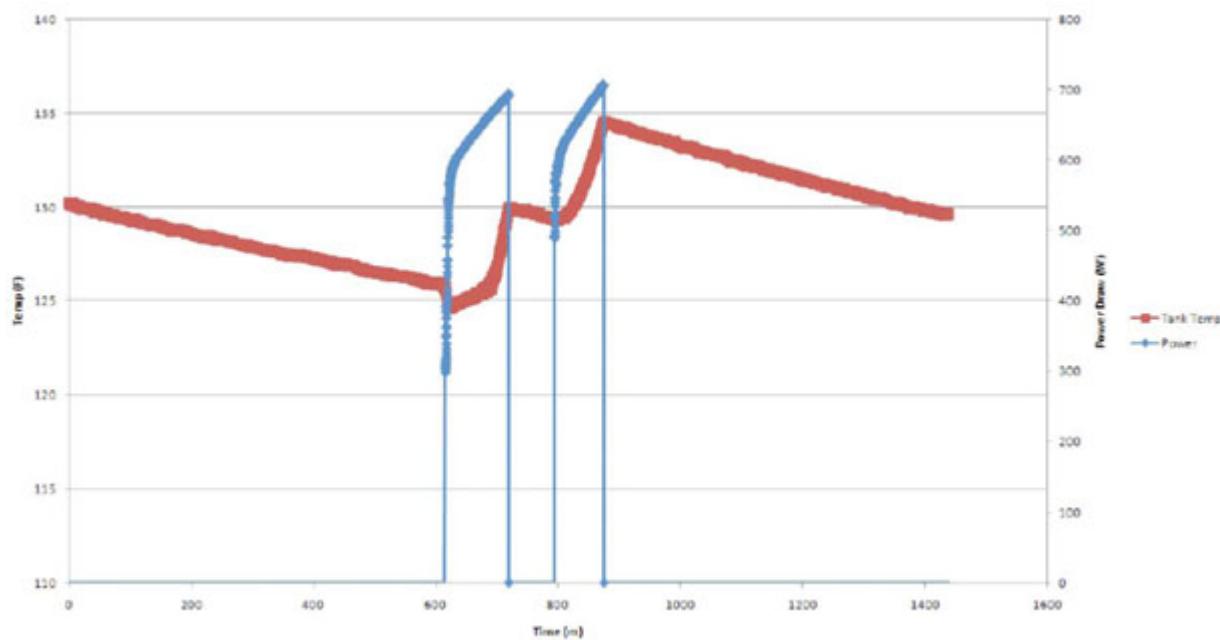


Figure 24 Competition day-1 simulation, tank temperature vs. time.

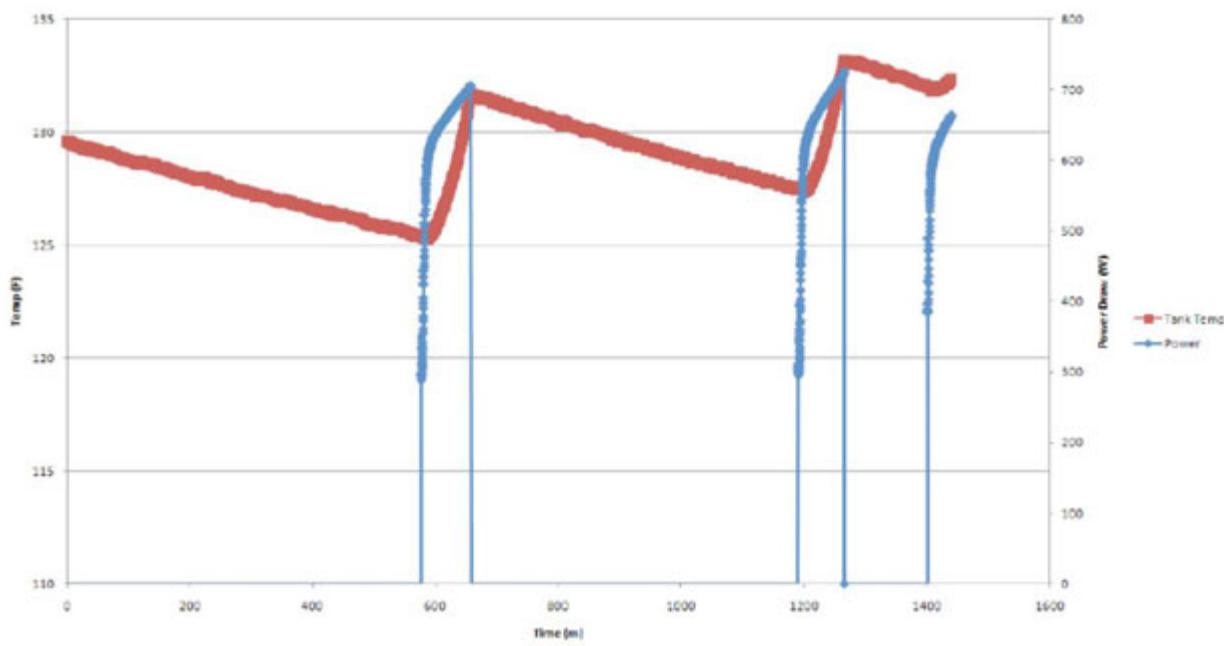


Figure 25 Competition day-2 simulation, tank temperature vs. time.

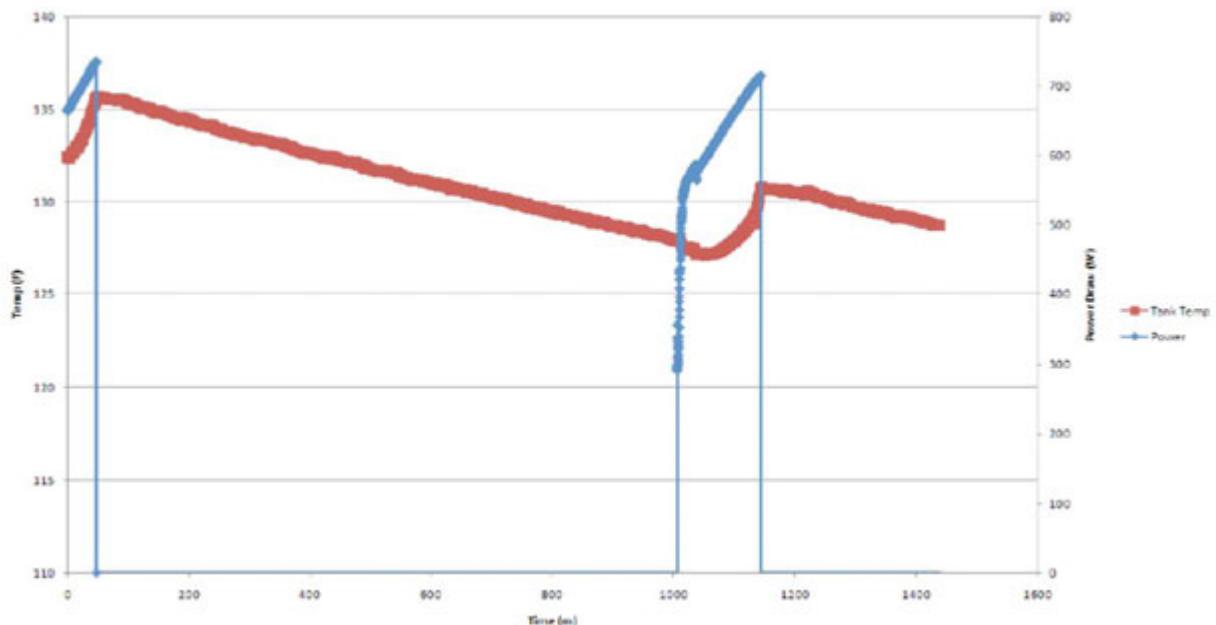


Figure 26 Competition day-3 simulation, tank temperature vs. time.

The energy consumption was calculated by numerically integrating the power versus time curve using a trapezoidal approximation. Also of interest was finding a coefficient of performance for the heat pump. This was accomplished by drawing water at a rate slow enough for the system to reach steady state and measuring the power. Then the equation $\dot{Q} = \dot{m}C_p\Delta T$ was used to find the amount of heat being added to the water in the tank, which was divided by the work done by the heat pump. This yielded a reasonable COP value of 4.5 using the equation $COP = (\dot{Q}_{water} / \dot{W}_{compressor})$. The mass flow rate was found by assuming a heat value equivalent to the rated heat capacity of 7000 Btu/hr. Flow was then adjusted until the tank temperature ceased changing with time. It should also be noted that losses from the tank were neglected in this calculation. More importantly, this COP value itself will change during operation, as the temperature rises and falls. This value is presented only as an indication of the heat pump's effectiveness during steady state conditions.

With such a high rated heat capacity, it stands to reason that the heat pump's cooling capacity would be substantial. The extremely low temperature of the air it exhausted confirmed this. In order to maintain a constant ambient temperature, a duct was added to direct the exhaust air out of the house. Subsequently it was decided that the cooling could be used to help reduce air conditioning loads during the summer. Electronic dampers were then added to the duct such that the cold air would be directed outside during the winter and inside during the summer. A photo of the setup is shown in Figure 27.

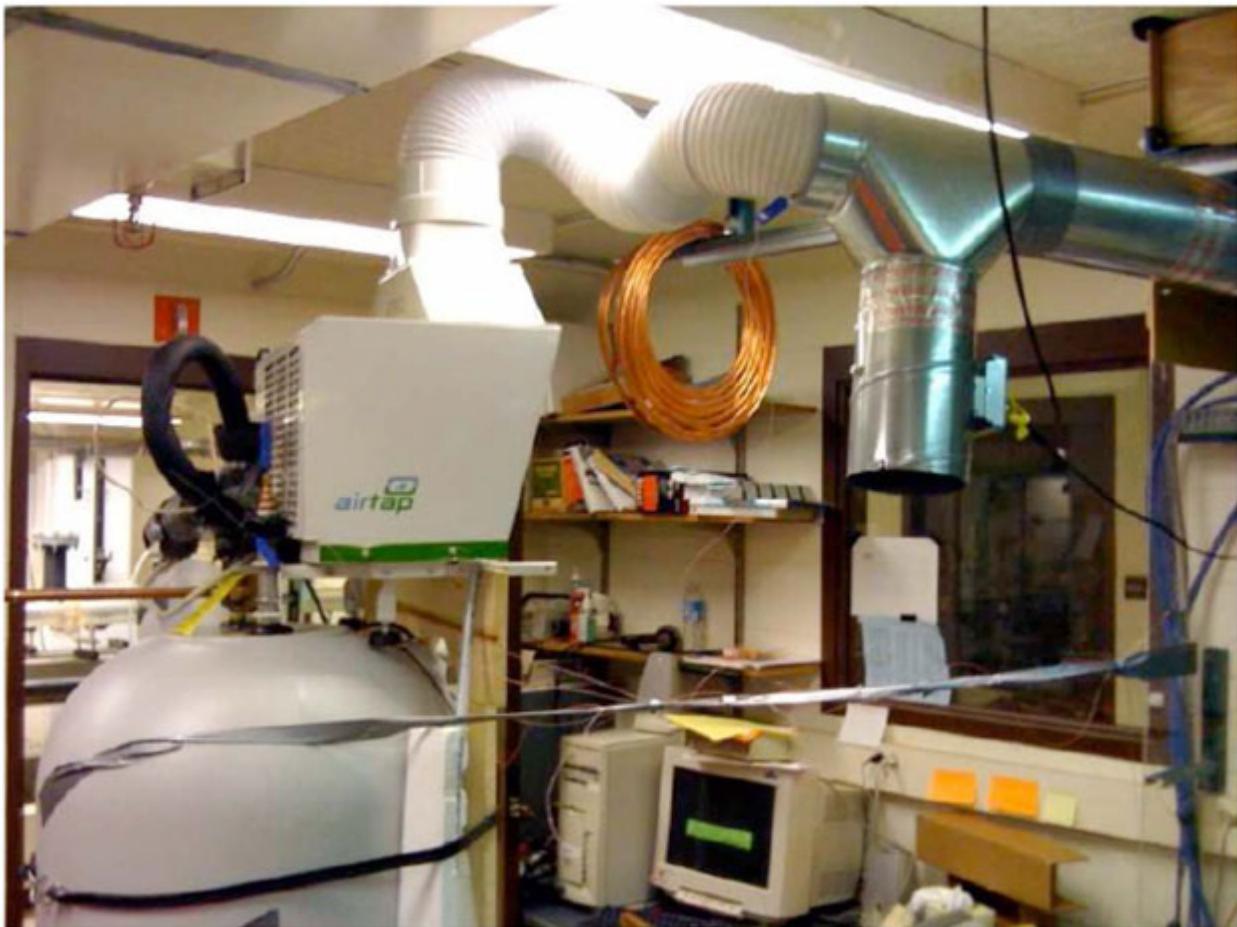


Figure 27 Rerouting of the cold air heat pump exhaust.

During experimentation, it was discovered that the built-in temperature controls for the hot water system needed much improvement. When first set up, the heat pump detected the water temperature with its built-in thermostat. This was observed to be very inaccurate, as the heat pump would be set for 120°F but would not turn on until the tank temperature was 100°F. The heat pump thermostat was then disconnected and wired to the built-in thermostat at the bottom of the water tank. This made it so that the heat pump would recognize the temperature of the cold inlet water whenever the faucet was on, leading to preemptive heating, thus preventing the water temperature to ever fall below 120°F. This can, however, lead to excessive energy consumption because often the water is heated to temperatures higher than is necessary. Optimal control would involve thermocouples in the tank being read by the central control system. The heat pump would turn on whenever the bottom thermocouple read temperatures below 115°F, and turn off whenever the top thermocouple read temperatures above 125°F.



Another concern that presented itself regards the dishwasher cycle. Maximum points are awarded if water reaches a temperature of 120°F. The competition effectively requires that “off the shelf” products be used as appliances. The dishwasher selected is programmed to boost the temperature to 130°F during its normal cycle. In an effort to avoid using electricity by the dishwasher it was requested that the thermostat be disabled. Unfortunately, the competition forbids such tampering with the appliances. As of now the dishwasher will have to boost the temperature, as maintaining a hot water temperature in the tank of 130°F is excessive. The energy usage of the dishwasher is currently unknown, and testing cannot begin until the appliances are delivered during the summer of 2009.

The tests run in the lab convincingly demonstrate that the selected domestic hot water system will meet the demands of the Solar Decathlon. It heats water quickly and efficiently, while consuming only 5% of the photovoltaic energy production on an average day.

Appliances and Home Entertainment

Television (TV)

Based on our initial analysis, a 42" Philips 42PFL5603D based on its ratings for low energy. As it stands, that TV has the lowest power rating out of all the HDTVs on Cnet's review site³. This television also has a modest screen size and an impressive power-to-square-inch of screen space ratio. It is second only to Samsung's HL series which uses Texas Instruments's (TI's) DLP technology.

However, despite our initial inclination toward the Philips 42", TI was willing to donate a 61" Samsung HL61A750. The Samsung HL lineup that has better power to square inch of screen space ratio than the Philips 42". From an entertainment score standpoint, the Samsung 61" TV would perform very well and its total power consumption was impressive. Unfortunately, however, this TV was too large for the given space.

According to TI's DLP information website, the most efficient TV (namely the Samsung HL series) use LED backlights which is why their efficiency is so impressive. The other TVs that use DLP technology do not have that same efficiency but come in smaller sizes. The smallest size is a 50" Samsung television which only stands 3" higher than the Philips 42". The Samsung 61" was rejected because it did not sit below the windows but it is possible that the 50" will sit lower than the windows. After further discussions with TI and in consideration of aesthetics and power management, we were able to obtain a 50" version of the Samsung free of charge.

The TV is simply one aspect of the entertainment system that will be judged by the other contestants. Of course, a great TV will help with the score but picture quality, sound quality, and atmosphere will also have an impact on the score. If a high-definition TV (HDTV) is used, a DVD player will have decent picture quality but a BluRay player may provide the best picture quality. The team initially considered adding a BluRay player to our computer to minimize cost as BluRay players are less expensive in the form of computer DVD drives. We could then run a cable from the computer to the TV to use our computer as the TV's BluRay player. Unfortunately however, the laptop area does not seem to be in reasonable range of the TV unit, making the connection from the laptop to the TV rather difficult to make. With this connection out of the question for now, it will have to be determined if buying a standalone BluRay player will have a large enough impact on the home entertainment experience to warrant the extra cost.

Sound quality is another important movie theater aspect that should be taken into consideration. Bose has offered to sponsor the University and it is possible to obtain a high quality sound system from a well known and respected audio company such as Bose. On the other hand however, Bose products tend to consume a fairly large amount of power. The interior design team has found a set of speakers that has a particularly high audio output in terms of decibel per watt of power. Our industrial design team is also supposedly designing the entertainment center to incorporate these speakers. The speakers are from Lowther USA and they were most compatible with the industrial design that was already underway. Price-wise, they are not all that different from Bose speakers and area much more efficient. We are attempting to obtain the Lowther speakers by donation.

The last topic for the entertainment system is the computer. According to the rules, it must have a display size of at least 17" that can be independently operated from the TV. Due to their substantially lower power consumption we are currently looking into laptops that have 17" screens. The power consumption of the laptop is not as clear cut as some of the other appliances. Laptops have a power supply but not really a power rating. A lot of the power consumption is controlled from the power settings with the laptop software. The monitor is a major source of power consumption and a few laptop companies have started using LED backlights. These will probably be the most efficient laptops. The two laptops proposed last fall were the MacBook Pro and the Dell Studio 17. Since the Dell laptop is much less expensive than the MacBook and because the we plan to use a Dell laptop for building automation and control, it was decided that the Dell Studio 17 is used.

Building Automation and Control

The concept of resource monitoring and control systems is fairly simple, but can quickly become more complicated in implementation especially for something as comprehensive as a house. Resource monitoring keeps track of energy usage, leading to smarter decision making, and can actually perform intelligent analysis and determine specifically which electrical components are wasteful and which are not. It does so through a series of sensors which are attached to not only electrical circuits, but also heating and air conditioning connections, as well as water.

Control system on the other hand provides automation and encompassing controller to the house. We can control everything in the house from just a single panel or we can just tell the system our desired setting of the house and let the system do the rest. The system combined with monitoring allow for intelligent energy saving decisions that in turn, can command the control system to make changes in order to implement these decisions.

At the electrical circuits, we are able to monitor power usage at each of the receptacles which ultimately educate us on the energy usage by the house appliances. Combining the knowledge of the house complete circuit and the monitoring system software, it is possible to detect what appliances is consuming the most energy and thus help us minimize energy waste. The energy monitor also keeps track of the power production by the solar panels. This way we can compare our energy production to our energy usage and project how much savings we are able to make, along with encouraging towards efficient energy usage.

There are various methods of displaying these results, from touch screen panels to web-based interfaces; we are combining both. With a computer that is loaded with monitoring and control software, a touch screen panel, internet connection, resources sensors and electrical sensors, we can control the house on site and remotely. A web-based interface can be set using the house touch screen panel or any computer in the world with internet to provide conditioning for the house or just to keep an eye on what appliances we forgot to turn off through the monitoring system.

Two major power consumers in a house are the lighting and the HVAC system. Thus it is essential to be able to control both to ensure efficient energy usage. HVAC system lighting should be conditioned according to house occupancy, the time of the day and types of activity that is going on in the house. For example, in the middle of the night in winter, when everyone is sleeping, the system will automatically switch off all the light except the night light perhaps, and minimizes the heating. However as the morning is approaching, the heat is increased little by little to the preset condition.

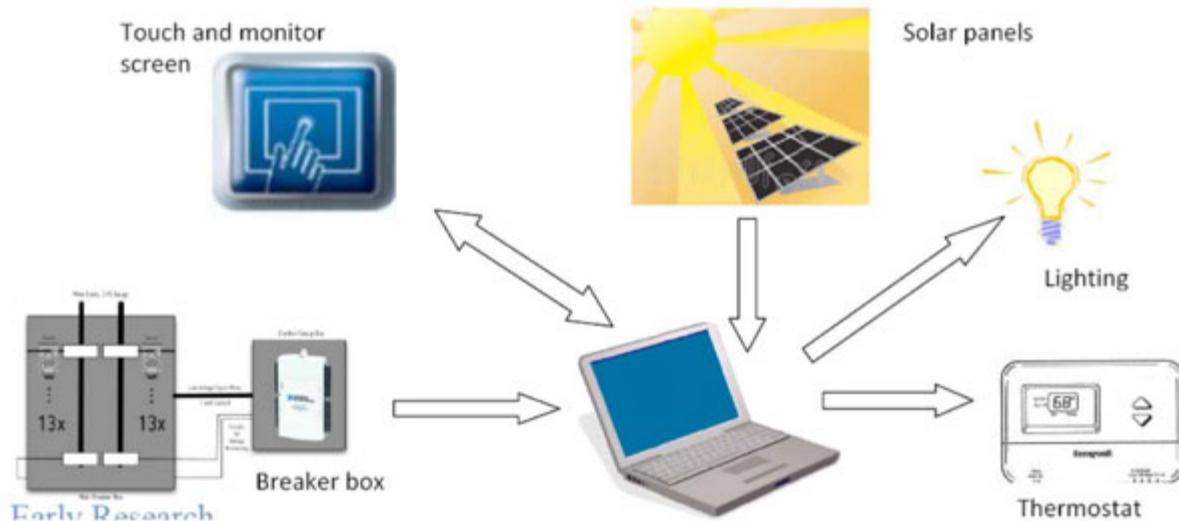


Figure 28: Overview of building control system.

Early Research

Resource Monitoring and Control Systems Companies

There are several companies that manufacture and install products and software that accomplishes the necessary tasks. A few of them have systems that are all-inclusive, whereas some of the systems work on a component-by-component basis. The following companies seemed the most fitting for the needs of the Solar House:

Lucid Design

Lucid Design Group is a company that deals in something called Dashboard. It is essentially a web-based software that monitors resource usage and displays the information via the Internet. It breaks down energy usage and consumption and offers the user the ability to see where energy usage is at the highest, and thus where it may be able to be lowered. It also involves features such as Gas, HVAC, Water, and other utilities that might be needed to be taken into account. Lastly, it has a tool allowing comparisons between the building in question and other buildings in the area. This would be convenient not only as a benchmark for our Solar House, but as a way to show others how efficient our house may be.

Agilewaves

Agilewaves is very similar to Lucid Design Group in their company goals. They have a web-based system that monitors all forms of energy consumption throughout the house and displays it in a format allowing quick and easy decision making regarding energy usage. (See Fig. 29)

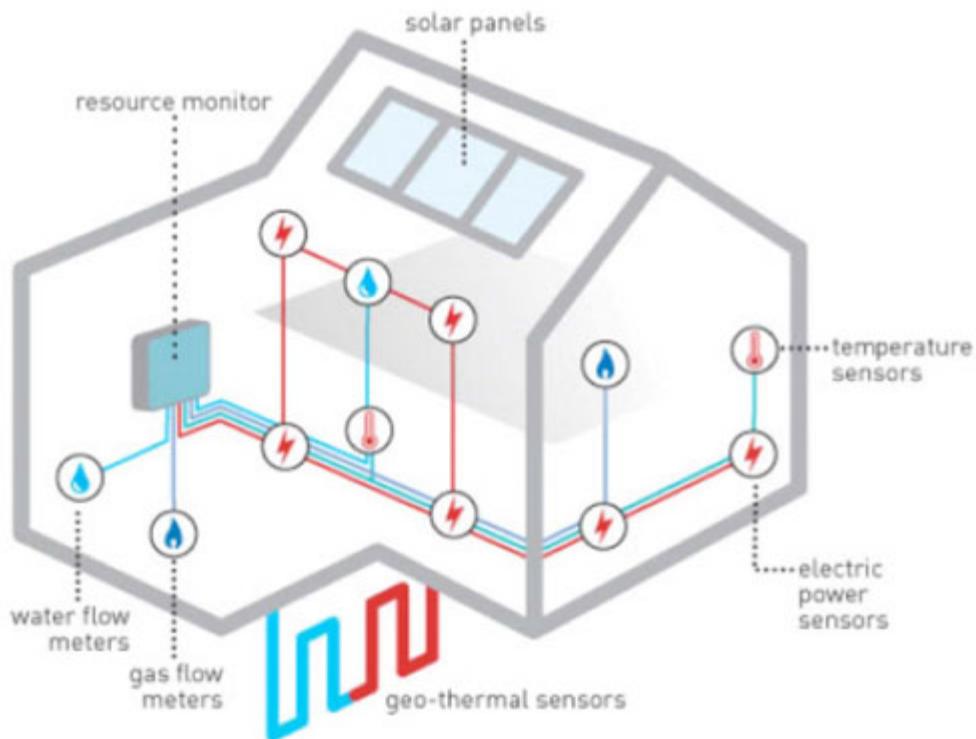




Figure 29: An illustration of various forms of monitoring allowed by Agilewaves.

Though there are subtle differences, Agilewaves and Lucid Design Group are both very comprehensive systems, keeping track of nearly everything one would need to make smart and efficient energy decisions. The main difference here is that Agilewaves “bridges the gap between monitoring and automation” as they put it. This is just a creative way of illustrating their partnership with Crestron, an automation company. Through this partnership, not is resource consumption tracked and monitored, but the information gathered can be used to control aspects of the house, everything from turning off lights automatically when no one is home to opening windows automatically to lower HVAC energy usage.

Crestron

Crestron was the first automation company that we looked into, and seems to be one of the most comprehensive. Though their system can basically control anything, it can also be highly customizable to what needs to be controlled. The problem comes from the system almost being too much; simple tasks like turning on or off electronics seem far too simplistic to make Crestron worth the cost. However, there is no doubt that Crestron transforms a normal house into something much more convenient and efficient. Whether the system will truly be of use is going to depend on the criteria with which the Solar Houses are graded. Although the automation is nice, it doesn't come particularly cheap, so if the money is spent on areas that are awarded more points, it may be one of the first aspects to be cut.

Mile High Automation

Mile High Automation is another company that offers fairly comprehensive packages, but also has options for bare-bones systems that provide us with cost savings. The most interesting system for our purposes is the Value System, which provides the automation panel, door and window security contacts, a smart thermostat, dimmer switches and a scene controller, LCD keypads, CAT 5e cable, software and support, for \$3,500. While we can probably find most of the parts separately for less, what is nice about the system is the guaranteed compatibility and support we would receive, which we agreed makes a decent plan B.

Smarthouse/Insteon

This was one of the last aspects to be considered, but may actually be the best option. Instead of a system that contains monitoring and automation for every aspect in the entire house, these companies

sells components that you simply apply to a given electrical device. A central controlling device also must be purchased, and then the given devices can be controlled and monitored remotely. The advantages of this are fairly obvious; buying by components allows the flexibility to control what needs to be controlled and stay under a reasonable budget. However, there are more limitations in this system, and it can be more complicated, because there are many different formats of communication, and it must be ensured that they will be compatible. Even so, this seems like perhaps the most logical option, and will definitely be looked into more before a final decision is made.

Custom Designed System

If we were to build our own system, the following would be the elements we would be looking to control.

Temperature Control

This is the largest and most important task of the automation group. There is a potentially a lot of energy that can be saved by automating the thermostat efficiently to achieve a desired temperature and humidity. A big unknown still remains, though, and that is the windows. Depending on which windows open and close, and how they do so, we would like to be able to automate them to open and close a method of heating and cooling the house. By comparing the outside temperature and humidity with the energy cost of using the HVAC system to achieve the desired temperature and humidity, we can make a decision to turn on the HVAC based on the following inequality:

$$(P_{HVAC}t_{HVAC}) + (P_{humidifier\ or\ dehumidifier}) < 2E_{servos} + (P_{humidifier\ or\ dehumidifier}) \text{ OR } 2E_{servos} + (P_{HVAC}t_{HVAC})$$

Where P is the power consumed by a system and t is the time it would have to run to achieve the desired. The servo energy, E_{servos} , is required to move the windows and is multiplied by two to take into consideration that they will eventually be closed. It should be noted that to do this, we would want to use a custom system to avoid high costs.

Lighting

While our ability to influence energy saving through automation is diminished both by the use of compact fluorescence and our inability to dim lights based on rules, timing control of lights can avoid wasteful use of energy through. Syncing control of the lights and possibly shades with sunrise and sunset could be a nice effect and prevent unnecessary electric lighting. This should be fairly straightforward, no matter which type of system we decide to go with.

Security

While not incredibly necessary, a security system could help improve marketability. Sensors on doors and windows can be set to alert police or send texts to a cell phone, while CO and fire detectors can alert other emergency authorities. Sensors can be placed around the home as needed, in places like medicine cabinets or desks. Besides alarms, these entries can be logged into a database for later review. This system should also be fairly straightforward to produce.

Energy control

Monitoring the usage of energy on each circuit could be a big help in conscious energy conservation. Just visualizing a breakdown of what is using the most energy might help the user save money. In terms of the competition, we could automate the circuits to ensure that we are never using too much energy at a time. In a practical sense, the system could be used to help control the energy of a user with a set energy budget. However, so far we have been unable to find a system with a price low enough to justify the cost savings. A device proposed earlier, the energy detective, is unfeasible in both monetary and practical standpoints. The only situation in which it would be practical would be to track the amount of energy output from the solar panels.

Appliances

The automation of appliances is almost purely for convenience. Having the coffee maker be on before waking up is a neat trick, but if the appliances don't get used, they're a waste of energy. Some higher end appliances already have these functions, so it may be worth it to just upgrade the appliances rather than automate them. However, we should carefully examine whether or not they will actually be used before spending the extra money.

Research Summary

Table 6: Summary of control system research

Company Name	Pros	Cons	Conclusion
Agilewaves	<ul style="list-style-type: none"> • Comprehensive resource monitoring • Helps make intelligent energy saving decisions • Works easily with Crestron to 	<ul style="list-style-type: none"> • Cost: approx \$5,000 • Gives more information than perhaps is necessary (overkill?) • Installation must 	If we decide a comprehensive and all-inclusive monitoring system is desired, Agilewaves works very well, and combines nicely with an excellent

	automate system	be considered during construction	automation system.
Lucid Design	<ul style="list-style-type: none"> • Comprehensive resource monitoring • Helps make intelligent energy saving decisions 	<ul style="list-style-type: none"> • Cost: approx \$5,000 • Gives more information than perhaps is necessary (overkill?) • Does not integrate as well with Crestron • Installation must be considered during construction 	If we choose a comprehensive system, and Agilewaves doesn't work out, Lucid Design is a good alternative, but doesn't seem to offer much than Agilewaves does not.
Crestron	<ul style="list-style-type: none"> • Very smart and convenient automation system • Automation can be applied to nearly anything in the solar house • Works well with Agilewaves 	<ul style="list-style-type: none"> • Cost: approx \$5,000 • Again, might be more comprehensive than needed (i.e. how important is it to be able to control every aspect of house) • Installation must be considered during construction 	If we are going with a comprehensive system, Crestron can likely do anything and everything we need. The biggest question is if the additional cost is worth the benefits it gives.
Mile High Automation	<ul style="list-style-type: none"> • Moderately priced • Guaranteed support • Well reviewed software 	<ul style="list-style-type: none"> • Self installed • Some features might go unused • Would be better to install during construction 	More basic, not as professional. A good fallback plan
Smarthouse	<ul style="list-style-type: none"> • Cost: as low as \$100 per component • Installation is easy and can be changed if necessary • Can easily be customized to only include electric devices that really benefit the solar 	<ul style="list-style-type: none"> • Not comprehensive, components must be selected separately • Resource monitoring can be difficult, especially for power generated and power to/from the grid 	Almost 180 degrees from Agilewaves and Lucid Design with Crestron. If we are going with an affordable and customizable system, Smarthouse makes a lot of sense. It can easily be adapted to fit whatever the solar house needs, even

	<ul style="list-style-type: none"> house • Offers different brands and services 	<ul style="list-style-type: none"> • Must ensure all components are compatible • Require separate resources to monitor (personal computer) 	after construction.
Insteon	<ul style="list-style-type: none"> • Cost: as low as \$100 per component • Installation is easy and can be changed if necessary • Can easily be customized to only include electric devices that really benefit the solar house 	<ul style="list-style-type: none"> • Not comprehensive, components must be selected separately • Resource monitoring can be difficult, especially for power generated and power to/from the grid • Require separate resources to monitor (personal computer) 	Similar to Smarthouse, but Insteon makes a single line of products, so compatibility is not an issue. However, this sacrifices some freedom of choice, and could be slightly more expensive and/or less flexible. Still a good option though.

Software Considerations

There were many options available to choose from for our software, so narrowing down the field was our first task. We decided to use an Insteon compatible system to control lighting and outlets, so that was the first thing we looked for in our software. The systems we originally looked at included the ISY-99i from universal devices, the Home Control Assistant 8 from Advanced Quonset Technology, the Artemis V2 from South Coast Logic, mControl from Imbedded Automation, Indigo 3.0 from Perceptive Automation, and SmartLinc from Smarthome.

The Artemis V2, while initially very promising, turned out to be specifically designed for lighting controls. While it still would have been able to perform other tasks, the high price tag for lighting features that we would not be able to take advantage of ruled it out. We were able to rule out Indigo 3.0 because it was specifically designed for Macs, since we anticipated other elements of our project needing to be windows compatible. After much debate and research, the Home Control Assistant 8 and mControl we dismissed because of their interfaces and ease of use. In the end, we decided to use a

combination of the ISY-99i and the SmartLinc. The ISY-99i will be used to control systems that are on timers, and the entire behind the scenes aspect of the control system.

Specifically, the ISY-99i was chosen because it was compatible with a security system that we strongly considered purchasing. The SmartLinc on the other hand, will be the face of the system. It has a straightforward interface, allows for easy control from wireless devices such as an iPod touch, and gives us the internet capabilities that we require for remote use. Also, it should be simple to tailor the interface to include other features such as power monitoring. Once we had decided on this software package, the decision for the operating system was made simple, as Windows XP was the preferred system of both pieces of software. While we originally considered using Windows Vista as our operating system, no one on our team is very familiar with it, and we did not want to have to work around any unexpected complications from using a new operating system.

Power Monitoring

Monitoring the usage of energy on each circuit could be a big help in conscious energy conservation. Just visualizing a breakdown of what is using the most energy might help the user save money. In terms of the competition, we could automate the circuits to ensure that we are never using too much energy at a time. In a practical sense, the system could be used to help control the energy of a user with a set energy budget. Many off the shelf options were available for the purpose of monitoring energy use. For instance, Sunpower has a monitor designed for the specific inverters we chose. Also, P3 International's kill-a-watt is a full line of individual monitoring devices. However, both of these solutions are not enough for our needs. Our goal is to monitor each individual outlet and have many *variables* on screen. For example, to monitor each outlet we could use multiple KAW's. However, using KAW's would be expensive, given the number of items we wanted (32) to monitor. In addition, this solution would just allow us to see the energy/power use on individual basis, and not the system as a whole. On the other hand, Sunpower's inverter monitor does present the energy monitoring of the whole house but it cannot do it for individual items of the house. Trying to merge both solutions would be difficult and expensive. Furthermore, it would be difficult to add features we may need in the future. Therefore, we decided to create our own solution. This will allow us to accomplish the aforementioned objectives, and to have an easily expandable system.

The Solution

Our design allows us to monitor the power and energy use in real-time. It is also flexible enough to allow for easy updates such as internet streaming of the power used. In order to accommodate for these needs our solution must be robust and precise. Below is a breakdown of each component to be used.

Current

- A split ring current transformer will be placed around each circuit in the main panel and the lines coming from each inverter
- A resistor will be placed across the leads of each current transformer to produce the desired +/- 5V output per the

Datasheet

- CR Magnetics CR3110-3000
- Digi-key Product Page
- UL Listed, XODW2.E235509
- 30 units should be purchased to accommodate extra circuits. At a per-unit cost of \$11.83, the total cost sums to
\$354.90

Voltage

- A circuit from each of the mains will be fed into the control group's box from which both 120V legs can be monitored while the 240V created by combining both 120V legs can also be monitored
- Inside the box, a monitor will be created that can be plugged directly into a standard wall socket. From this connection, a power transformer will be used to step down the voltage to a level readable by the DAQ
- Power transformer: Hammond 166F5, Datasheet
- Mouser Product Page
- UL Listed
- 5 units should be purchased to allow for replacement parts. At a per-unit cost of \$17.87, the total cost sums to
\$89.35

Data Acquisition



- Data from the above-described current and voltage monitoring methods will be acquired using a 32-input DAQ

supplied from NI

- DAQ will communicate with the computer via a USB connection

- NI USB-6218, Datasheet

- NI Product Page

- UL Listed, 61010-1

- Data will be analyzed to determine real power, power factor, etc. using LabView from which it will be exported to a

medium that can be easily read other softwares such as a web page, likely export formats are MySQL database or TXT file

- Retail cost is \$1249, however we are currently in contact with National Instruments to arrange for sponsorship

Software

-Labview

Future Features

The following features are potentially to be added in the future:

- Stream live view of power and energy usage. This view may be embedded on 491sd uiuc website, to allow visitors to see our performance.
- Automated control of individual outlets based on profiles. i.e. power saving, vacation, out for work.
- Energy/power usage based on kw-h price.

Lighting Control

While lighting is explained in some detail elsewhere in the project manual, we touch on it here with respect to control. Due to the high efficiency provided by the LED, the lighting group has decided to use LEDs to provide light to the interior of the house. Controlling the LED light fixture is essential

since it allows an efficient placement of luminous power throughout the house, therefore reducing the overall power consumption used in lighting the house. However, the amount of control we have on these light fixtures is limited considering diming is not possible with LED light fixtures. As a result, our control is limited to the switching of the LEDs between the on and off states.

The switching is controlled by a series of INSTEON relay switches, which function only as on/off switches. More specifically, twelve 2476S Insteon light switches are to be installed to control the lights placed in the interior edges of the house. The on and off switching will be controlled by the user via a computer (see software/computer annex. These switches were chosen over other brands based on the following criteria:

- The INSTEON relay switches have a quieter built in relay, which allows control of the lighting without disturbing the ambient noise.
- Other switches use semiconductors which absorb a considerable amount of power. The design of this switch uses a relay, which runs cooler and allows the full voltage to dissipate through the load. This points to an increase in the amount of energy saved.
- This switch is fully INSTEON compatible, allowing us to control the switches from a central INSTEON controller.
- The settings for the SwitchLinc Relay are stored in non-volatile memory and are not lost during power failures. In the event of a power outage, the SwitchLinc Relay will return to its last on/off state when the power is restored.

Figure 30 shows a flowchart of the lighting control.

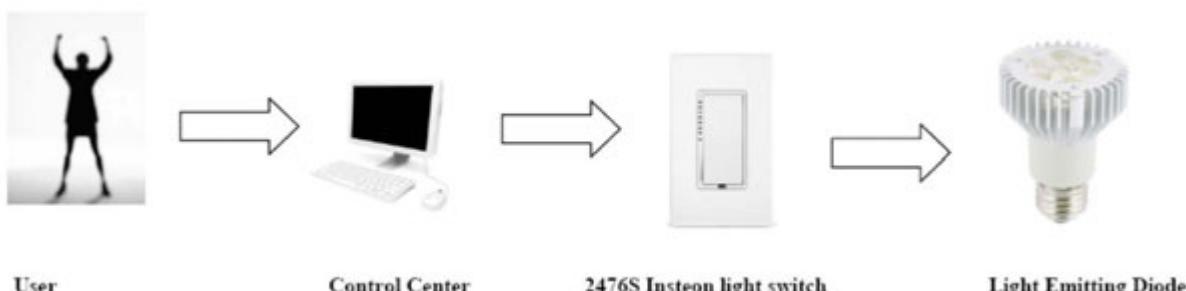


Figure 30 Flowchart of lighting control.

HVAC Control

The following is a list of inputs/outputs that needed to be controlled by the HVAC team.

- 7 inputs
- 0-5v out
- 0-10v out
- 120 or 240v on/off
- 240v on/off
- 120v on/off
- 3-24v on/off
- Reversing valve
- Maybe 2 expansion valves

Because of the complexity of this system, including at least 6 different output voltages, our options for controlling the HVAC system were expensive and somewhat complicated. The following parts would work, but barring some donations or discounts, appears to be slightly more expensive than would be preferred.

Again, the reason the parts are so expensive is because of the variation in outputs that need to be available.

Table 7: Data acquisition boards for building control.

	Vendor	Item	Item Number	Price per Unit	#	Total Cost	Link
	National Instruments	Analog Current Output Module	777318-200	\$629.00	1	\$629.00	http://sine.ni.com/nips/cds/view/p/lang/en/nid/11592
	National Instruments	Controller Interface	777317-2200	\$1449.00	1	\$1449.00	http://sine.ni.com/nips/cds/view/p/lang/en/nid/11570
	National Instruments	Backplane	778617-04	\$429.00	1	\$429.00	http://sine.ni.com/nips/cds/view/p/lang/en/nid/11609

The Analog Current Output Module features eight 4 mA to 20 mA or 0 mA to 20 mA current outputs, so one can control the 6 or so different output voltages that were required. The wiring diagram of the

device is pictured below. As it is necessary to be fairly complex, the item does not come cheap, but there are few other options to control as many different outputs as we were given.

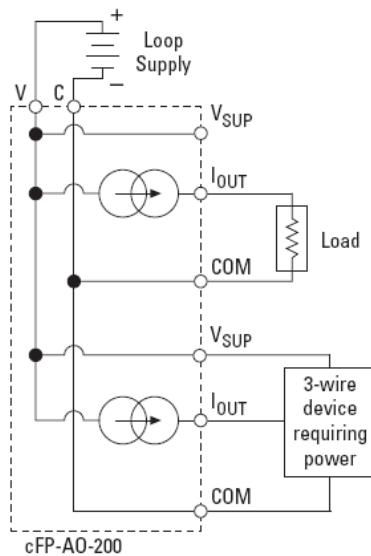


Figure 31: Wiring diagram for analog current output module.

The controller interface is similarly complex, and thus expensive, and is required to be able to read and log the data that we are obtaining regarding the HVAC system. This controller has the benefit of using LabView for the data gathering process, which is the same software we are using to monitor power and resource usage. LabView makes it very simple to take inputs and use algorithms to manipulative them into useful data to either be displayed or used in some type of system control. The following is just a small sample of the simplistic graphical interfaces that can be created.

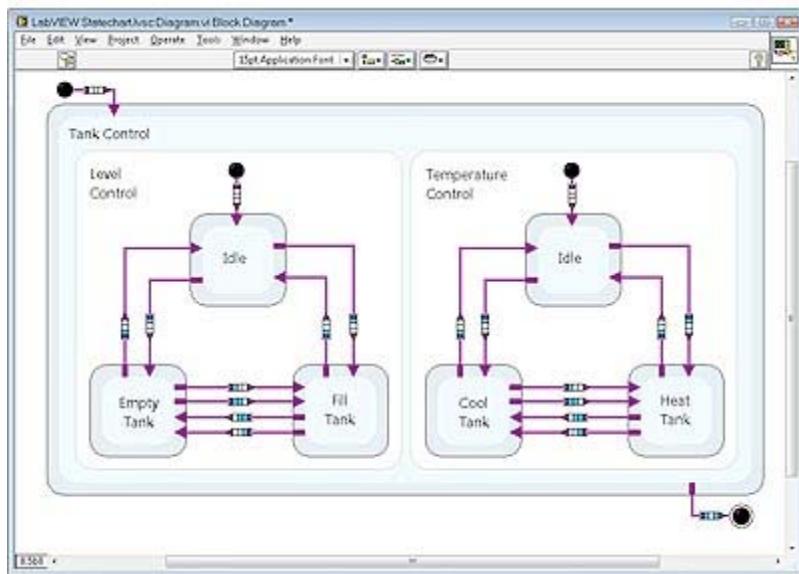


Figure 32: An example of LabView graphical interface.

Lastly the backplane is required in order to properly mount the I/O and control modules that we will use. Since saving space is an obvious concern for our house this is absolutely essential despite the cost.

The system totals over \$2500.00, which seems too expensive for one aspect of the control system. However, for our own budget purposes, National Instruments has already agreed to donate a DAQ for the power monitoring aspect of our system. If there were to donate or reduce the price on any of these parts, the system would become a much more viable option.

If this is not the case, another option we have considered for controlling the HVAC system would be the use of a programmable logic controller, or PLC. These devices are essentially single input/output controllers that are used very similarly to the control module we were looking at. The biggest downfall of using PLCs is the programming can be considerably more complex than the programming using LabView, and the system would essentially be completely in our hands. Nevertheless, this is an important option to consider if the cost of our intended system is too high.

Control Computer and Touch Screen Monitor

Control Computer



To control the resources at the SD house, we decided to have a separate control computer than the home computer. The system that we had chosen is the Dell Mini 9. It is a power efficient laptop with compact size and great usability which fits our purpose. The following the specification of the laptop:

- OPERATING SYSTEM: Genuine Windows® XP Home Edition
- MEMORY: 1GB DDR2 at 533MHz
- HARD DRIVE: 8GB Solid State Drive
- BLUETOOTH OPTION: Built-in Bluetooth 2.1 capability

We decided on using Windows XP due to its compatibility with INSTEON software that we've chosen.

Touch Screen Monitor

We also decided to have a touch screen monitor which will be the main control interface for the SD Home residents. It will show the condition of the house from time to time to see its performance and allows the residents to control the appliances and power usage of the SD Home. Since the main interface for control is the touch screen, the setting done on the laptop will not be easily accessed by public users and can be limited to admin only for security reasons.

The touch screen monitor model that we have chosen is a 19-inch GVISION P19BH-AB-459G Black.

- Touchscreen Type : 5-wire Resistive
- Panel: Active Matrix, TFT LCD
- Screen Size: 19"
- Display Type: SXGA
- Maximum Resolution: 1280 x 1024
- Recommended Resolution: 1280 x 1024

The monitor will be recessed in the depth of the wall because we are tight on width for ADA requirements. The center of the monitor will be placed 4'6" off the floor.



Summary and the Way Forward

This narrative has described the most important subjects of the engineering effort. The Gable House is nearly ready for delivery to the UI campus and most of the engineering equipment has been ordered or has already arrived. This will enable the summer to be used for installation, testing, and refinement of the subsystems, as well as the system as a whole. This work will enable us to develop a competition strategy based on different weather scenarios. In addition, this summer we will focus on getting our work 100% right in preparation for the competition.

LIGHTING DESIGN NARRATIVE

The lighting design for the Gable Home follows Midwestern vernacular building methods as does the home design. Both artificial lighting and daylighting systems have been evaluated and optimized for energy efficiency, practicality, and aesthetics.

Daylighting Design

The north windows were designed for heating loads using Passive House software and optimized for daylighting and energy losses. By placing windows only in locations where north light would be utilized, energy losses could be minimized. Based on this placement, southern windows could be designed, using the same Passive House software, to offset the energy losses from the north windows and provide desired daylight to the interior of the house. It is important to note that the exterior shading devices can be manipulated by the home user to regulate, not only the lighting level, but also the amount of solar heat gain absorbed by the house. Using energy modeling software, the University of Illinois team has developed a design that balances daylighting and heating loads for the overall benefit of the home.

Artificial Lighting Design

The artificial lighting design was based primarily on functional requirements, and developed to provide the needed amount of light while minimizing the amount of energy usage. Two lighting groups, each having different lighting requirements, were assigned to appropriate spaces in the house. The first lighting group was the general ambient lighting and the second lighting group was work surface lighting. Track lighting with adjustable gimble fixtures installed in the center of the ceiling was used to provide the required ambient lighting for each space. This lighting was designed to wash the ceiling, diffusing an even ambient light throughout the spaces. Track lighting was used for its versatility and integration as an exposed duct also runs along the center of the ceiling. PAR30 LED's were chosen as the bulbs by the engineering team for their high performance and compatibility with the fixtures.

The work surface lighting was accomplished through the design of closer and more focused light sources. This allowed for the minimization of the number of fixtures needed by optimizing the use of produced light. For this, the team selected pendent lighting in the spaces identified as requiring work space lighting, such as the kitchen prep work surface, the dining table, and the bedroom desk.

Exterior lighting was selected to identify the home entrances, as well as to articulate the spacing of the barn siding. Sufficiently lighting the porch entry was a major concern for the team as this area is a transition between the outdoors and the safety of the indoors. As such, it is vital that occupants of the



home regard this area as a safe and comfortable transition of space. The team has accomplished this through substantial lighting of the space, providing three 10" fixtures, chosen to match artificial lighting often used in barns. Articulation of the exterior surface of the home supplements this idea by identifying the home as an expression in the landscape.

LED's were developed by University of Illinois Professor Dr. Nick Holonyak and have been used not only to maximize the efficiency of our lights, but also to recognize sustainable efforts being made by faculty and students at the University of Illinois. The development of warmer LED's allows our team to efficiently satisfy lighting requirements, while maintaining the welcoming spirit so typical of Midwestern vernacular houses.