Hoyes Field Elementary - A Net Zero Energy School

Integration of Sustainable Design in an Interdisciplinary Capstone Studio

Project Description

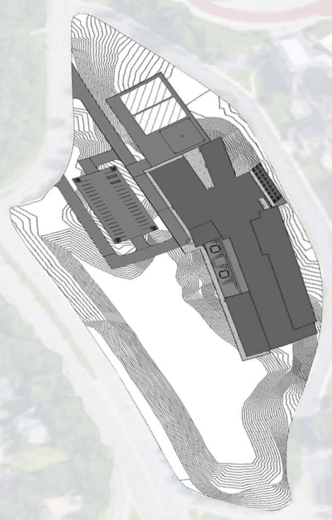
This effort utilizes the Solar Decathlon Design Challenge to create a Net-Zero Energy Elementary School as the project for a required, interdisciplinary senior capstone experience. The capstone spans one and a half semesters and includes undergraduate students across the three majors of Architectural Engineering, Civil Engineering and Construction Management who work in interdisciplinary teams to address issues of design, engineering and construction. A significant focus of the capstone for all three majors is sustainability and the Solar Decathlon charge to design buildings that ***"meet the nation's rapidly evolving demand for buildings that are innovative, cost effective, quick to build, high quality, resilient, grid-interactive, efficient, and locally responsive"*** was an ideal fit as a project for the interdisciplinary senior level experience. In addition to the challenge of designing a contemporary energy-neutral school the level of complexity of the project was increased to match the students' abilities by selecting a local site with a steep, west-facing slope adjacent to an existing high school. With the diversity of skills and expertise represented on the student teams, the project expectations included the complete design of the school's egress, fire protection, structural, mechanical, electrical, lighting, site, and alternative energy systems as well as the development of construction details, estimate, schedule, and construction logistics for the project.

School Program - 55,000 sf

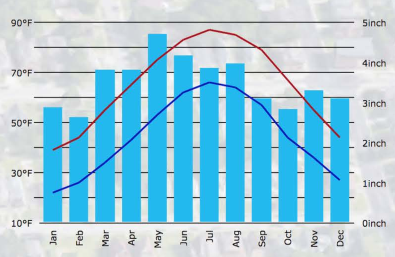
ACADEMIC SPACES
- 14 classrooms for 350 students - K-6
- Library/Media Center
- Music and Art Classrooms

ADMINISTRATION
- Office Administration
- Teacher Lounge

SHARED SPACES
- Gymnasium
- Cafeteria and Kitchen



Climate



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average high in °F:	39	44	55	65	75	83	87	85	79	67	55	44
Average low in °F:	22	26	34	43	53	62	66	64	57	44	36	27
Av. precipitation in inch:	2.87	2.64	3.82	3.82	4.72	4.17	3.86	3.98	3.11	2.83	3.31	3.11
Days with precipitation:	13	11	13	12	12	13	10	9	9	9	10	11
Hours of sunshine:	115	137	186	222	273	309	323	295	253	205	138	118

Project Design Goals

Net Zero Design
Incorporate passive and active strategies to minimize energy consumption and incorporate PVs, natural daylighting, and evacuated tube arrays for energy harvesting.

Energy Storage
Explore design implications of incorporating thermal energy storage in the form of heat captured from solar thermal arrays throughout the year to offset heating demands.

Active Learning
Design a school that engages with the site as well as the adjacent high school and provides active, direct, hands-on experience with space, nature, and technology.

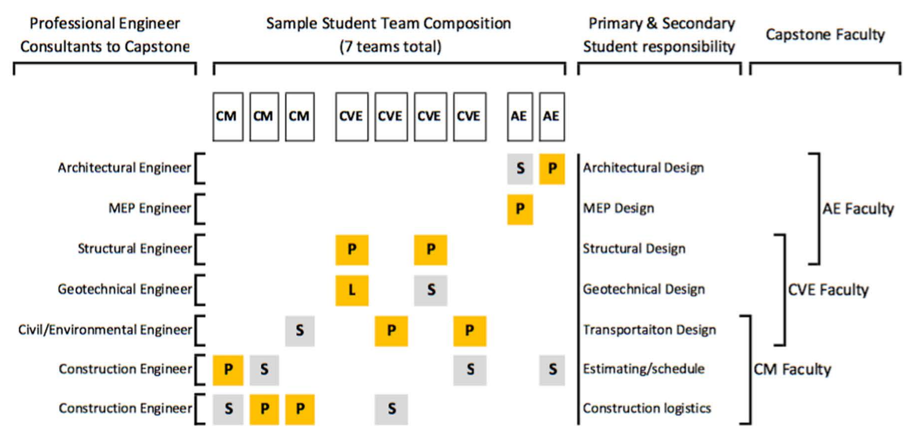
Innovation
Integrate innovative approaches in envelope design, mechanical systems, daylighting, building controls, energy storage, space utilization, and school safety.

Resilience
Develop strategies that will allow the school to function after a natural or human-made disaster using energy storage, water storage, and energy harvesting.

Project Highlights

Teams, Fundamentals, and Industry Collaborators

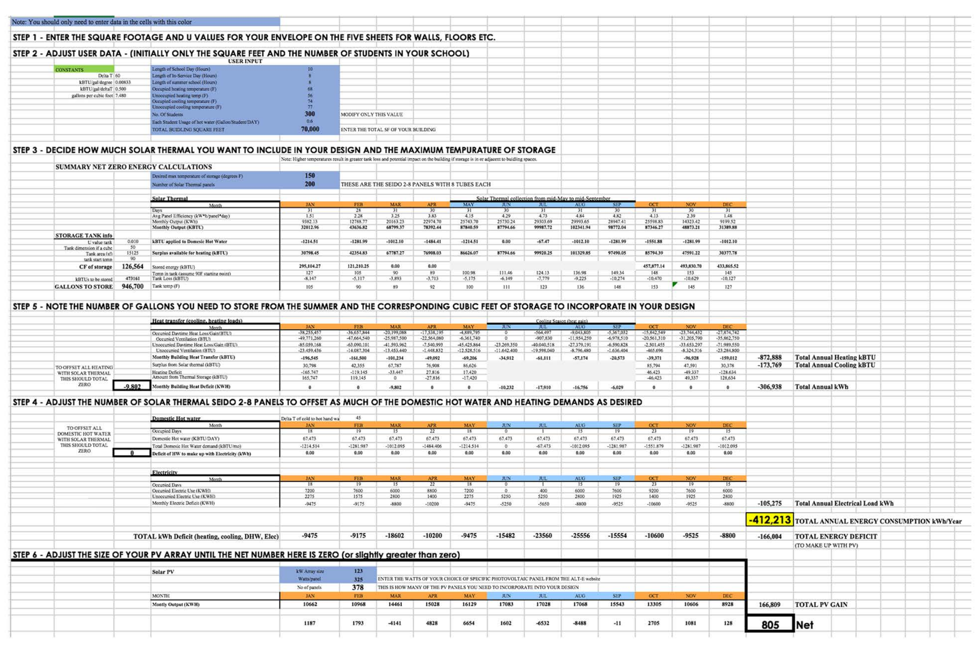
- Establish interdisicplinary teams based on student survey of expertise
- Solar Decathlon/Department of Energy - Building Science Training
- Systematic consultation with Net Zero Architects throughout
- Systematic consultation with local School Designers throughout
- Systematic consultation with Alternative Energy Engineers throughout
- Systematic consultation with MEP & Structural Engineers throughout



P = Primary Role S = Secondary role

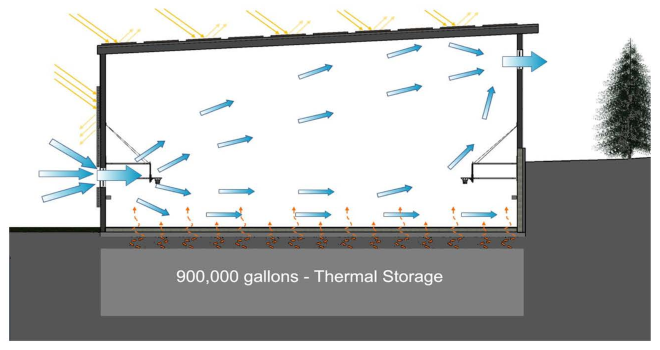
Develop class-wide Net Zero Calculator

- Spreadsheet incorporating energy analysis, PV and Solar Thermal harvesting
- Design iteration in Revit. Export of data directly to Excel for systems design



Health, Safety, and Welfare

- Structure designed for expansion of roof mounted PVs and Solar Thermal
- Consideration of sustainable materials
- Access to daylight for each space
- Accomodation for compartmentalized lockdowns for active shooter scenario
- Inclusion of massive thermal storage for use during sustained power outage



Knowledge & Skills Gained

- Interdisciplinary teamwork/collaboration
- Design of alternative energy production
- Building and site design/integration
- Structural system design/integration
- Mechanical system design/integration
- Electrical/lighting design/integration
- Water and wastewater design/integration
- Sample of software incorporated and used
  - Sefaira - energy analysis
  - Climate Consultant - energy design
  - Revit - Building Information Modeling
  - DOE Energy Plus - energy analysis
  - Visual Analysis - structural analysis
  - RAM Structural System - structural design
  - Navisworks - clash detection
  - NREL PVwatts - PV output calculator
  - BLUEBEAM - Construction Logistics

Schematic Design Iteration

- Exploration of alternatives
- Each team adopting a solution
- Initial performance EUI, & cost

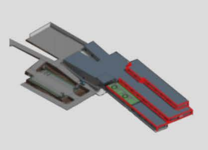
South site

Contour Integrated

1,067,129 Total kWh/yr
3,000,000 Heating
$26,555,604 Cost
52.1 EUI
$379 Cost / sf

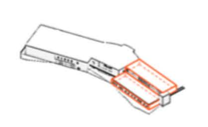
Top of hill - east side of site

Contour Integrated



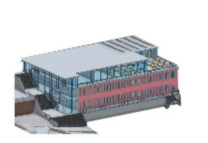
909,000 Total kWh/yr
1,107,000 Heating
$24,788,000 Cost
24.5 EUI
$349 Cost / sf

Compact Linear



625,000 Total kWh/yr
1,870,000 Heating
$18,000,000 Cost
45.4 EUI
$383 Cost / sf

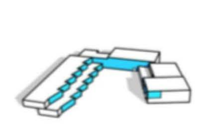
Compact Cube



531,508 Total kWh/yr
1,214,000 Heating
$25,096,000 Cost
27.9 EUI
$386 Cost / sf

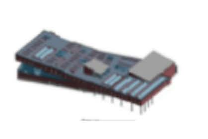
Center of site

Contour Integrated



1,491,654 Total kWh/yr
4,224,000 Heating
$31,547,378 Cost
72.8 EUI
$451 Cost / sf

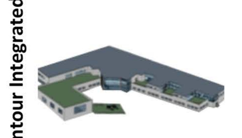
Compact Linear



1,090,190 Total kWh/yr
3,000,000 Heating
$22,500,000 Cost
43.8 EUI
$265 Cost / sf

North site

Contour Integrated

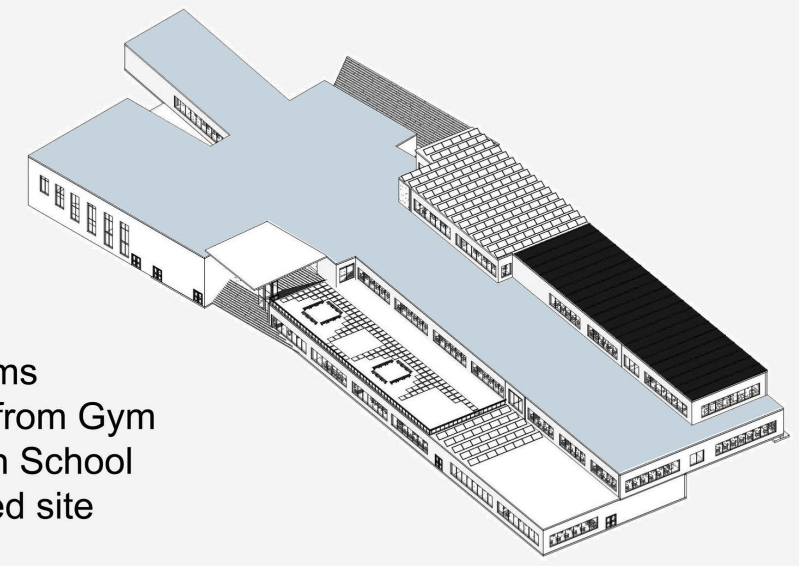


432,826 Total kWh/yr
274,000 Heating
$17,968,628 Cost
26.9 EUI
$327 Cost / sf

Design Development & Integration

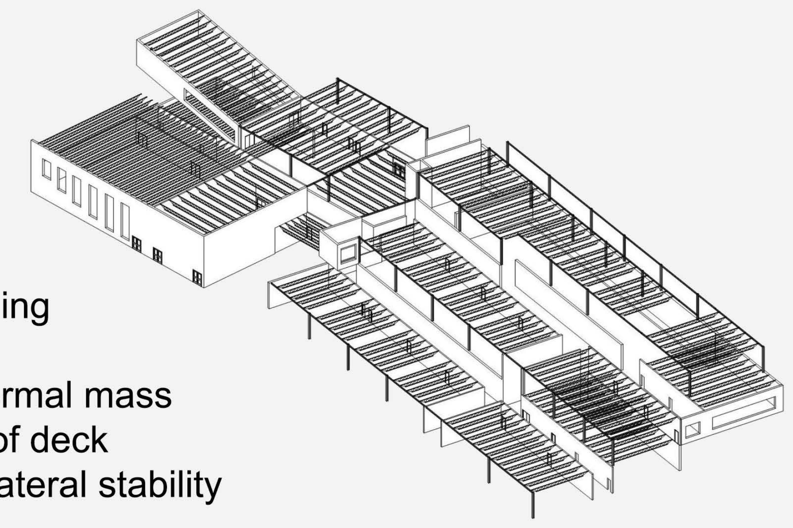
(Sample team project)

Architecture



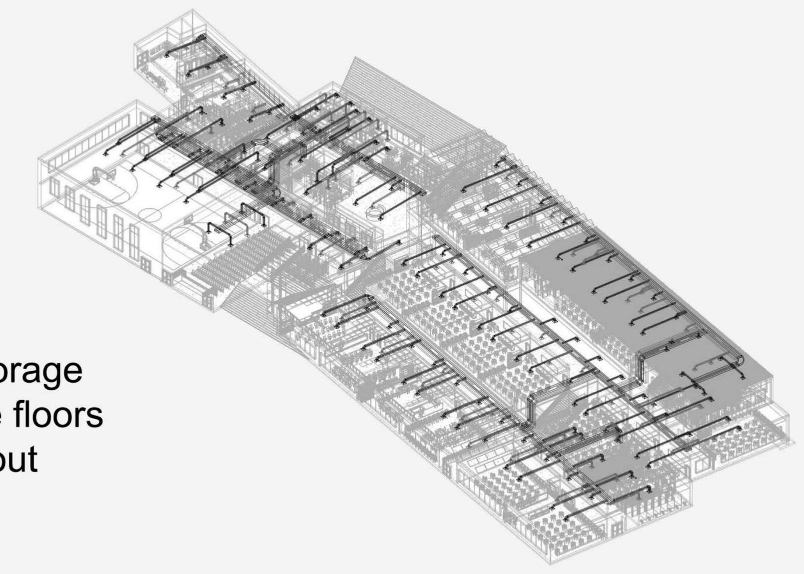
- Stepped with site
- 30% earth sheltered
- Roof terraces for classrooms
- Classroom wing separate from Gym
- Upper entry related to High School
- Lower level entry to wooded site

Structure



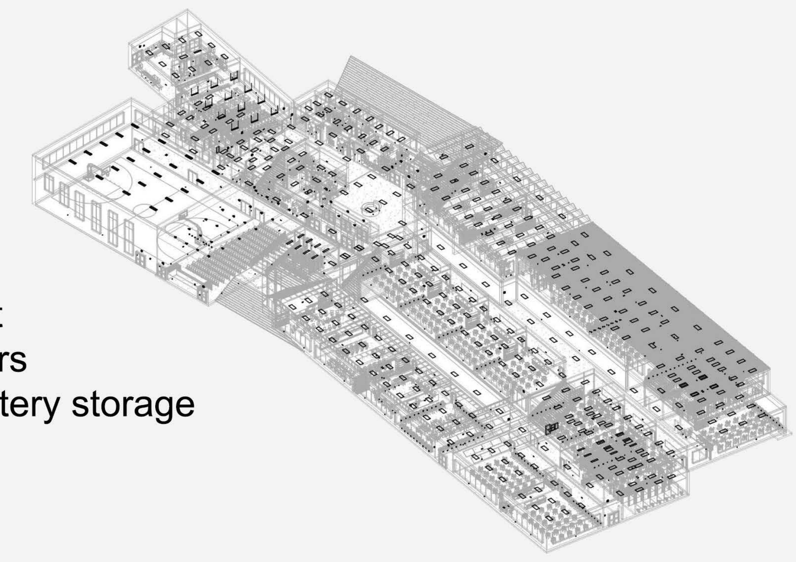
- Deep pile foundations
- Concrete foundation/retaining
- Optimized steel frame
- Concrete floor deck for thermal mass
- Cross laminated timber roof deck
- Pilasters & stair cores for lateral stability

Mechanical



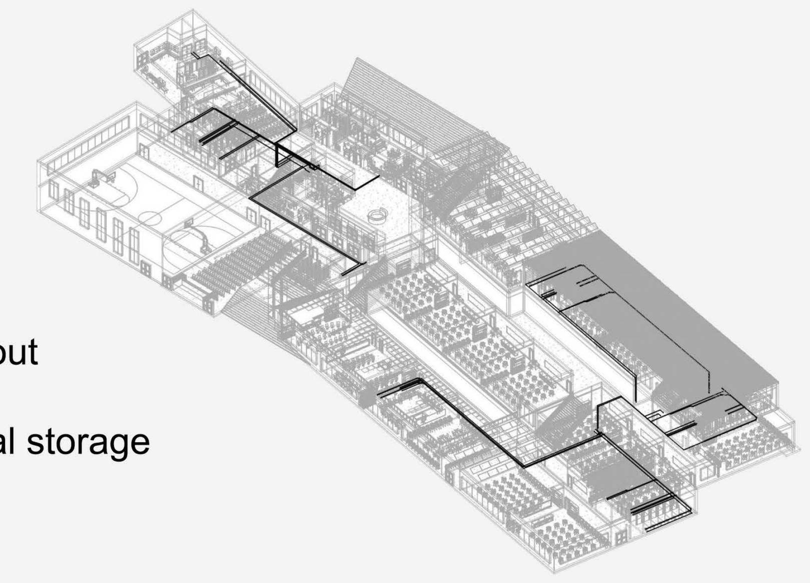
- Solar thermal heating
- DOAS ventilation system
- 900,000 gallon thermal storage
- Radiant tubing in concrete floors
- VRF heat pumps throughout

Electrical



- LED lighting throughout
- Large windows for daylight
- Occupancy/daylight sensors
- Grid tied PV with small battery storage

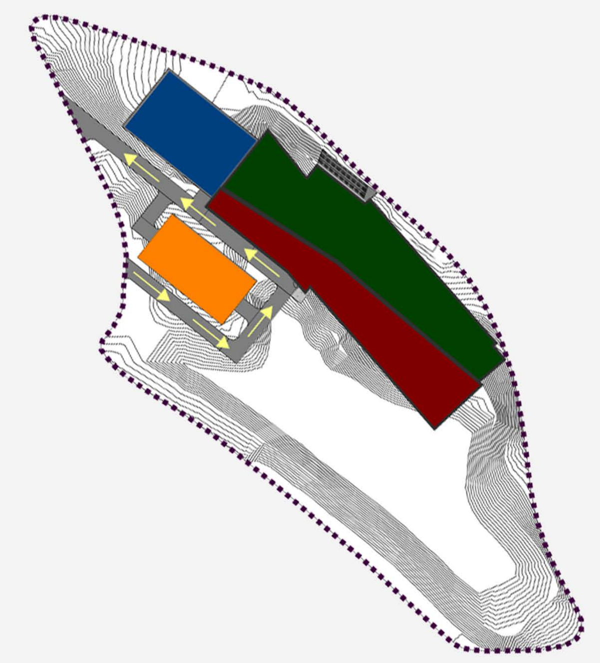
Plumbing



- Runoff detention in pond
- Rainwater collection
- Low flow fixtures throughout
- Grey water for irrigation
- Water heated from thermal storage

Construction

SITE LOGISTICS KEY
- Site Border
- Trailer & Material Storage
- Construction Parking
- Truck Deliver Route
- Cut: 42,000 CY
- Fill: 20,000 CY



- TOTAL Construction Estimate:

$ 24,788,000

2018

September **October** **November** **December**

2019

January **February**

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This effort utilizes the Solar Decathlon Design Challenge to create a Net-Zero Energy Elementary School as the project for a required, interdisciplinary senior capstone experience. The capstone spans one and a half semesters and includes undergraduate students across the three majors of Architectural Engineering, Civil Engineering and Construction Management who work in interdisciplinary teams to address issues of design, engineering and construction. A significant focus of the capstone for all three majors is sustainability and the Solar Decathlon charge to design buildings that ***"meet the nation's rapidly evolving demand for buildings that are innovative, cost effective, quick to build, high quality, resilient, grid-interactive, efficient, and locally responsive"*** was an ideal fit as a project for the interdisciplinary senior level experience. In addition to the challenge of designing a contemporary energy-neutral school the level of complexity of the project was increased to match the students' abilities by selecting a local site with a steep, west-facing slope adjacent to an existing high school. With the diversity of skills and expertise represented on the student teams, the project expectations included the complete design of the school's egress, fire protection, structural, mechanical, electrical, lighting, site, and alternative energy systems as well as the development of construction details, estimate, schedule, and construction logistics for the project.

A unique aspect of the required capstone year is creation of teams incorporating students from all three majors that work collaboratively, in a studio environment, to solve a complex design problem. Teams are formed in a "blind" process according to student responses to a survey in which they identify their area of focus and expertise and every effort is made to balance each team so that primary and secondary levels of interest and expertise yields at least one and ideally two individuals on each team who have sufficient depth of knowledge in their sub-discipline. Areas of student expertise include; building design, building systems engineering (MEP,) structural engineering, geotechnical engineering, transportation engineering, construction engineering and construction management.

Local consulting engineers and architects were identified early on in the Fall term matching their expertise with the project chosen for the capstone and then were invited on a regular basis to provide individual feedback to teams as the projects progressed, as well as feedback during formal presentations at midterm and final design stages. Several individuals from the firms participated as well, enriching the feedback by bringing alternative perspectives for the teams to consider. The focus on holistic building design and integration of the various systems, including alternative energy production, resulted in the innovative proposal to include massive thermal energy storage in the designs by incorporating evacuated tube solar thermal collectors and harvesting the heat all summer long when school is not in session and storing it for the winter months.

By default, the students on each team from the different disciplines experienced significant cross-over of knowledge and skills on a routine basis. For example, structural engineering students learned about HVAC design from the AE students and the AE students learned about construction scheduling from the Construction Engineering students. Furthermore, since alternative energy production and net-zero design is not currently a part of the curriculum leading up to the capstone studio for any of the three majors in the department, the knowledge learned and skills gained in design, engineering and the use of software, such as Enscape, Navisworks, Revit, Sefaira, RAM structural, Energy Plus, Bluebeam, etc. were profound across all disciplines.

1 - Project Description

1.1 Academic Context

The Academic context of this project is the senior capstone with the Department of Civil and Architectural Engineering and Construction Management (CAECM) at the university All three programs are five-year programs that include 8 academic semesters of study and a required sequence of cooperative education/experiential learning terms.

The capstone experience in the department spans one and a half semesters and comes after the final cooperative education semester. Students in each major enter the capstone year with work experience directly related to their interest in Civil Engineering (CVE,) Architectural Engineering (AE,) and/or Construction Management (CM.) Like all other Engineering and Design curricula, CAECM attempts to incorporate issues of sustainability throughout the course of study in each major but the department faculty have agreed that the capstone experience is the logical place to integrate sustainability in a significant way through a shared, comprehensive design experience.

1.2 The Challenge of Integrating the Design Challenge into the Capstone

While several units on campus allow students to choose their own capstone project and assemble their own teams, the capstone instructors in CAECM chose to create a single, senior capstone experience in which Civil Engineering, Architectural Engineering and Construction Management students are placed on interdisciplinary teams to solve a complex architectural, engineering and construction design problem. Since the university does not allow faculty to create "select" teams for a required capstone, we began the capstone by assessing student expertise and interest by distributing a survey to the junior class prior to the start of the semester. The expertise between the disciplines varies and the number of students who specialize in each area varies as well.

The survey responses are used to assemble teams randomly using a "blind" process in which skills, area of expertise and work experience are distributed evenly across all teams. This distribution ensures that there is sufficient depth across all aspects of the building design, engineering, and construction processes on each team to solve the design problem. Furthermore, this random distribution mimics what might happen in practice where members of various consulting firms are thrust together on a building project, resulting in a capstone experience that might be more realistic.

1.3 Capstone Project Selection

In order to create a meaningful capstone experience for the diverse skill sets and sub-disciplines represented on each team, the faculty developed a rubric for the selection of a project and site that would require members of each team to work collaboratively on the development of the design solution. Any project selected, therefore, needed to include architectural, transportation, site, and structural engineering problems to solve as well as construction logistics, sequencing and estimating opportunities that allowed all Architectural Engineering, Civil Engineering and Construction Management seniors to bring their individual expertise and participate equally in the project. The rubric for the selection of the capstone project and site follows;

1. Provide a project that ensures issues of sustainability are considered across all sub-disciplines.
2. Provide a program with sufficient size and complexity to allow for meaningful design exploration.
3. Provide a site that poses sufficient geotechnical design challenges.
4. Provide a program and site that poses significant traffic and transportation issues to address.
5. Provide a program with long span and lateral structural design issues to address.
6. Provide a program and site that requires the design & integration of complex MEP systems.
7. Provide an opportunity to incorporate construction estimating and project estimating during design.
8. Provide an opportunity to solve a unique construction logistics and scheduling problem.

To address each of the items in the rubric, the capstone instructors selected the Solar Decathlon Design Challenge to design a net-zero energy elementary school as a reasonably complex project for the seniors in all three majors. By default, the Solar Decathlon raises the question of sustainability to the foreground so all seniors are forced to address the questions of carbon, waste, and energy in their respective disciplines. To increase the complexity for each sub-discipline, the site chosen for the new K-5 school is a steep, West-facing slope that sits directly in front of an existing high school. Figure 1 illustrates the site with contours and the relationship to the existing high school. Figure 2 illustrates the existing high school adjacent to the site on its east side.

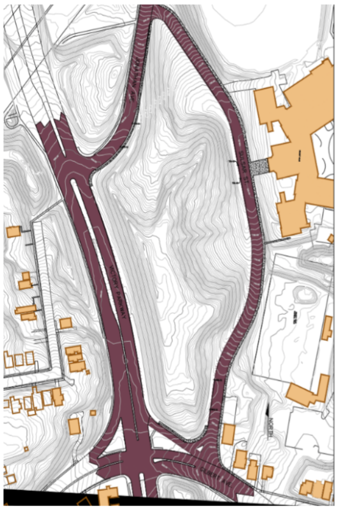


Figure 1: Site with contours

Figure 2: Existing high school at East side of site

2 - Collaboration of faculty, students, and licensed professional engineers

2.1 Interdisciplinary Capstone Teams and Studio Format

Our capstone student design teams consist of a mix of AE, CVE, and CM majors with expertise across the building design, building systems engineering, structural engineering, geotechnical engineering, transportation engineering, construction engineering/management fields. The capstone is delivered in a studio format with teams assigned to a workspace equipped with a large table and large screen for collaborating. The space, shown in Figure 3, is available to them 24/7 allowing them to work outside of class time on the design and engineering of their project.

Figure 3: Collaborative studio space for capstone

On average, each student design team has 2 to 3 AE students, 3 to 4 Civil Engineering students and 3 to 4 CM students. This mix varies year-to-year based on enrollment and distribution of expertise. Every effort is made to balance each team so that primary and secondary levels of interest and expertise identified by the survey provides at least two individuals on each team who have sufficient depth of knowledge in their sub-discipline. Once teams were formed, students in each team developed a responsibility matrix identifying both primary and secondary roles as shown in Figure 4.

2.2 Capstone Faculty and Professional Engineers

Three primary instructors are assigned to the capstone studio, one from Architectural Engineering, one from Civil Engineering and one from Construction Management. Between the three faculty there is significant overlap in expertise and knowledge about building design, engineering and construction. Furthermore, the disciplinary depth represented by the faculty allowed each faculty member to bring their local contacts within the profession to the table (figuratively and literally) to help the capstone teams with their emerging designs. In addition to the primary capstone faculty, several other faculty in the Department of Civil and Architectural Engineering and Construction Management served as consultants during the process and participated in the review of the teams at midterm and end of semester formal presentations.

The local consulting engineers and architects were identified early on in the term matching their expertise with the project chosen for the capstone and then were invited on a regular basis to provide individual feedback to teams as the projects progressed as well as feedback during formal presentations and midterm and final design stages. Several individuals from the firms participated as well, enriching the feedback by bringing alternative perspectives for the teams to consider. A brief description of the firms who consulted with the student teams on a regular basis follows.

- (XXX) Design is a local architectural engineering firm whose specialty is innovative educational space and K-12 school design. The firm has designed approximately 50 elementary, middle and high schools in the metropolitan area and are regional experts in the design of educational environments. Architects and engineers from this firm were instrumental in helping teams understand the complexity of issues related to programming, school operations, energy patterns, school safety, etc.

- (XXX) Design is architectural firm whose expertise is in sustainability and net zero energy design. The firm has designed and engineered several zero energy buildings in the city and helped student teams integrate both passive and active solar design techniques into their buildings.

- (XXX) is a Mechanical Engineer with expertise in thermodynamics, fluid mechanics, and heat transfer who has participated in the 2007 Solar Decathlon and brought that experience and expertise in solar thermal energy harvesting and thermal energy storage concepts to the project team.

- (XXX) is a large structural engineering firm with offices in multiple states. Their firm has considerable expertise in structural steel design and they have developed expertise in heavy timber and cross laminated design as well and encouraged students to consider the use of timber as an alternative structural material. This firm also provided significant geotechnical insights to the teams.

- (XXX) Consulting Engineers provided insight into transportation issues, utility integration and site design and layout as well as additional geotechnical assistance, runoff and detention pond design advice.

- (XXX) Construction is a large local construction firm with considerable expertise in BIM and Virtual Design and Construction. The construction engineers from this firm helped student teams develop an appreciation for the use of BIM throughout the design process as well as using BIM as a virtual model for estimating, scheduling and construction efforts.

The overall relationship between capstone students, primary capstone faculty and local licensed professionals is shown in diagram form in Figure 4.

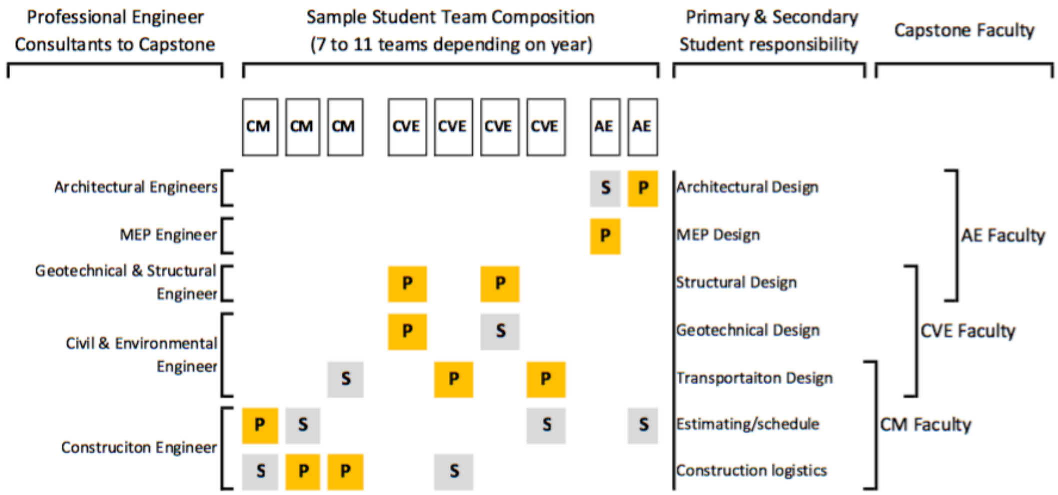


Figure 4: Matrix illustrating relationship and integration of licensed professionals, student design teams and faculty around the design of a net zero elementary school senior capstone project. Primary and secondary student roles identified in orange and gray respectively.

3 – Protection of health, safety, and/or welfare of the public.

The protection of public health, safety and welfare was a primary focus of the studio in several respects. During the design process, students considered each design decision with respect to these issues. The elementary school project raised the level of engagement with health, safety, and welfare issues to the foreground throughout the design process.

3.1 Health

An aspect of sustainable design is to minimize impacts on the environment by incorporating materials that have low or no VOCs, have high recycled content or can be easily recycled, and minimize the use of carbon in their manufacturing, delivery and installation processes. This led most teams to consider the use of heavy timber and cross laminated timber as a viable alternative for portions of their buildings as the wood was both a natural material with no volatile organic compounds and could also sequester carbon within the building at the same time. Maximizing natural daylight in all spaces also has direct benefits to the health of faculty, staff and students.

3.2 Safety

At early stages, safety of the children during drop-off and pick-up forced students to consider several iterations that avoided dangerous interactions between school bus access and vehicular access by parents. These transportation and site issues had profound impacts on every team's design. Once designs began to emerge, local architects and fire protection professionals provided feedback about emergency egress and fire protection. These issues also impacted designs in terms of circulation within the building and exiting from the building during a fire that were complicated by the steep, sloped site. One consideration brought up by the school design expert, that students were wholly unprepared to cope with, was to divide the school into "lockdown compartments" to minimize access by an active shooter. This safety issue left an indelible mark on both the students and their designs.

3.3 Welfare

Since taxpayer money is used to fund operations and utilities in public schools, by default, a net-zero energy building addresses the issue of public welfare by reducing the on-going tax burden associated with utility bills. Typically, total cost of building construction and operating costs are calculated over a twenty-year period in order to justify the initial investment of higher quality materials and alternative energy installations. However, with many of the warrantees and life expectancies expiring at 20 years, our students calculated the life cycle cost for a 30-year period when pumps, PV panels, roofing etc. expire or need to be replaced. This extended life cycle analysis provided further verification that investment in higher quality construction and net-zero energy production would actually make economic sense. Depending on the specific team design, this analysis revealed overwhelming support for the initial and ongoing investments while in other designs, it was more difficult to justify.

The student in the Construction Engineering and Management area of focus provided constructability reviews during the process as well as value engineering reviews at major stages of design. These efforts helped the teams make informed and wise choices about form, site integration, materials, etc. For example, during initial architectural design, the designers chose to step the foundations on the sloping site, the value engineering review suggested that one larger excavation would reduce cost significantly. This suggestion resulted in several thousand square feet of unneeded space buried deep within the building that then was put to good use by serving as the large volume required for the storage of thermal energy collected during the summer months.

4 – Multidiscipline and allied profession participation

Alternative energy production is not currently a part of the curriculum for any of the three majors in the department. Consequently, the capstone faculty and students relied on expertise from local architects and faculty who specialize in net-zero building design. The focus on holistic building design and integration of the various systems, including alternative energy production, resulted in an innovative proposal to include massive thermal energy storage in the designs by incorporating evacuated tube solar thermal collectors and harvesting the heat all summer long, when school is not in session, and storing it for the winter months. Solar thermal harvesting and storage was suggested by one of the local consulting mechanical engineers who specializes in solar thermal installations and was embraced by most teams as a design and engineering challenge to incorporate into their designs. Figure 5 illustrates the building occupancy vs solar thermal output and an evacuated tube array.

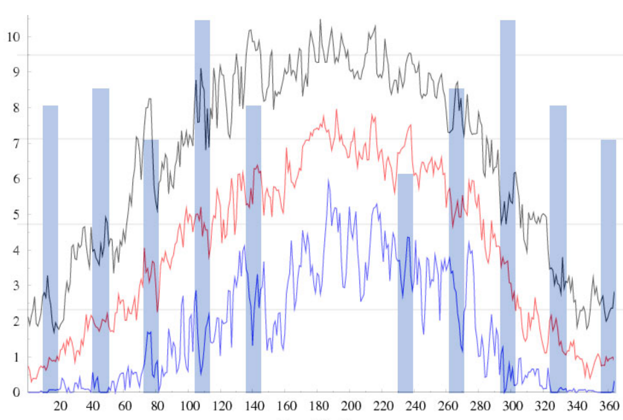


Figure 5 – Overlay of school occupancy in days per month to energy output (high, average and low) of solar thermal collectors (left.) Evacuated tube solar thermal collector array (right.)

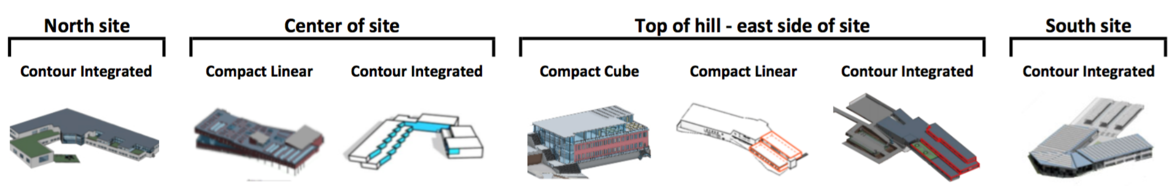
While general building design is part of the AE curriculum, no students or faculty in the department have experience in the design of an elementary school. Consequently, the capstone relied on local architecture and AE firms with that expertise to participate in the schematic design and design development phases in both informal individual team reviews and during formal presentations. Additionally, a local expert who was on the development team for Sefaira, a design and analysis tool for building energy, offered training for the student teams on the use of the software as a design tool.

There is currently no faculty in the Civil Engineering Program with expertise in heavy timber and cross laminated timber design, engineering and construction. Consequently, for the several teams choosing to incorporate wood as a sustainable and carbon sequestering material, a local engineering firm with expertise in heavy timber and cross laminated timber served as a consultant to the teams, helping them with their calculations and detailing efforts.

5 – Knowledge or skills gained

5.1 Student gains

As mentioned previously, the capstone students in Civil Engineering and Construction Management had little to no experience in holistic design and building systems integration pushing them even further to the edge of their comfort zone. To address this, the capstone faculty developed a systematic methodology for the generation and evaluation of alternatives as a way to accelerate the schematic design and site integration process. This was a new concept for all students and added a powerful approach to their arsenal of engineering and design strategies. A summary of the schematic designs explored (one by each team) follows in Figure 6.



	Contour Integrated	Compact Linear	Contour Integrated	Compact Cube	Compact Linear	Contour Integrated	Contour Integrated
Total kWh/yr	432,826	1,090,190	1,491,654	431,508	625,000	409,000	1,067,129
Heating	274,000	3,000,000	4,224,000	1,214,000	1,870,000	1,107,000	3,000,000
Cost	$17,968,628	$22,500,000	$31,547,378	$25,096,000	$13,000,000	$24,788,000	$26,555,604

Figure 6 – Schematic exploration of various site strategies.

The capstone effort also represents the first time most of the students actively worked on a multidisciplinary team to solve a comprehensive and complex design problem. The students quickly resolved to use Revit to create a single model for collaboration and integration of structural, mechanical, electrical, plumbing, and alternative energy systems. To help facilitate the collaboration of the team members, Autodesk donated licenses of BIM 360 to the capstone teams exposing the students to this powerful collaboration tool as well. For many of the Civil Engineering and CM students, this was the first significant effort in the use of Revit and for students in all three majors, this was the first time using BIM 360 as a collaboration tool. Introduction to other new software such as Enscape, Navisworks and Bluebeam provided additional opportunities for students to exercise or gain new experience with advanced tools. The lessons learned about collaboration, communication, presentation, compromise, integration and design throughout the process was invaluable.

Since none of the capstone students had experience in the design and integration of alternative energy strategies, the learning curve here was equally steep and intense. Students were exposed to new concepts and tools for designing and integrating Photovoltaic systems and Solar thermal collection into their buildings. All students in all three majors on the Solar Decathlon design teams were required to complete 10 hours of on-line training in building science offered by the National Renewable Energy Laboratory (NREL.) Students also developed new skills and knowledge in this area by learning and using software such as NREL's PVwatts calculator, Solar Thermal Output calculator developed by XXX Mechanical Engineer, Trimble-Sefaira for early stage analysis of building design performance and lighting simulation and other energy modeling and simulation tools. From these various tools and the building science training, students (one from each team) collaboratively developed a single spreadsheet tool to help them determine net zero demands for their emerging designs. The spreadsheet incorporates and links data exported from Revit, HVAC, lighting and electric loads, and output from PVs and Solar thermal to calculate the number of PV panels, the number of Evacuated tube arrays, and the gallons of thermal storage required for an iteration of their design to reach net-zero.

Note: You should only need to enter data in the cells with this color

STEP 1 - ENTER THE SQUARE FOOTAGE AND U VALUES FOR YOUR ENVELOPE ON THE FIVE SHEETS FOR WALLS, FLOORS ETC.

STEP 2 - ADJUST USER DATA - (INITIALLY ONLY THE SQUARE FEET AND THE NUMBER OF STUDENTS IN YOUR SCHOOL)

CONSTANTS	
Delta T	60
kBTU/gal/degree	0.00833
kBTU/gal/deltaT	0.500
gallons per cubic foot	7.480

USER INPUT		
Length of School Day (Hours)	10	
Length of In-Service Day (Hours)	8	
Length of summer school (Hours)	8	
Occupied heating temperature (F)	68	
Unoccupied heating temp (F)	56	
Occupied cooling temperature (F)	74	
Unoccupied cooling temperature (F)	77	
No. Of Students	300	MODIFY ONLY THIS VALUE
Each Student Usage of hot water (Gallon/Student/DAY)	0.6	
TOTAL BUIDLING SQUARE FEET	70,000	ENTER THE TOTAL SF OF YOUR BUILDING

STEP 3 - DECIDE HOW MUCH SOLAR THERMAL YOU WANT TO INCLUDE IN YOUR DESIGN AND THE MAXIMUM TEMPURATURE OF STORAGE

Note: Higher temperatures result in greater tank loss and potential impact on the building if storage is in or adjacent to buidling spaces.

SUMMARY NET ZERO ENERGY CALCULATIONS

Desired max temperature of storage (degrees F)	150	
Number of Solar Thermal panels	200	THESE ARE THE SEIDO 2-8 PANELS WITH 8 TUBES EACH

Solar Thermal (Solar Thermal collection from mid-May to mid-September)

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Days	31	28	31	30	31	30	31	31	30	31	30	31
Avg Panel Efficiency (kW*h/panel*day)	1.51	2.28	3.25	3.83	4.15	4.29	4.73	4.84	4.82	4.13	2.39	1.48
Monthly Output (KWh)	9382.13	12788.77	20163.23	22974.70	25743.70	25730.24	29303.69	29993.65	28947.41	25598.83	14323.42	9199.52
Monthly Output (KBTU)	32012.96	43636.82	68799.37	78392.44	87840.59	87754.66	99987.72	102341.94	98772.04	87346.27	48873.21	31389.88
kBTU applied to Domesic Hot Water	-1214.51	-1281.99	-1012.10	-1484.41	-1214.51	0.00	-67.47	-1012.10	-1281.99	-1551.88	-1281.99	-1012.10
Surplus available for heating (kBTU)	30798.45	42354.83	67787.27	76908.03	86626.07	87794.66	99920.25	101329.85	97490.05	85794.39	47591.22	30377.78
Stored energy (kBTU)	295,104.27	121,210.25	0.00	0.00						457,877.14	493,830.70	433,865.52
Temp in tank (assume 90F starting point)	127	105	90	89	100.98	111.46	124.13	136.98	149.34	148	153	145
Tank Loss (kBTU)	-8,147	-5,117	-3,893	-3,713	-5,175	-6,149	-7,779	-9,225	-10,274	-10,470	-10,629	-10,127
Tank temp (F)	105	90	89	92	100	111	123	136	148	153	145	127

STORAGE TANK info	
U value tank	0.010
Tank dimension if a cube	50
Tank area (sf)	15125
tank start temp	90
CF of storage	126,564
kBTUs to be stored	473161
GALLONS TO STORE	946,700

STEP 5 - NOTE THE NUMBER OF GALLONS YOU NEED TO STORE FROM THE SUMMER AND THE CORRESPONDING CUBIC FEET OF STORAGE TO INCORPORATE IN YOUR DESIGN

Heat transfer (cooling, heating loads) (Cooling Season (heat gain): JUN–SEP)

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
Occupied Daytime Heat Loss/Gain(BTU)	-38,255,457	-36,657,844	-20,199,088	-17,538,195	-4,889,795	0	-564,497	-9,043,805	-5,367,032	-15,842,549	-23,744,432	-27,874,742		
Occupied Ventilation (BTU)	-49,771,260	-47,664,540	-25,987,500	-22,564,080	-6,361,740	0	-907,830	-11,954,250	-6,978,510	-20,561,310	-31,205,790	-35,862,750		
Unoccupied Daytime Heat Loss/Gain (BTU)	-85,059,168	-63,090,101	-41,593,962	-7,540,993	-45,425,864	-23,269,350	-40,040,518	-27,379,191	-6,590,828	-2,501,455	-33,653,297	-71,989,550		
Unoccupied Ventilation (BTU)	-23,459,436	-14,087,304	-13,453,440	-1,448,832	-12,528,516	-11,642,400	-19,598,040	-8,796,480	-1,636,404	-465,696	-8,324,316	-23,284,800		
Monthly Building Heat Transfer (kBTU)	-196,545	-161,500	-101,234	-49,092	-69,206	-34,912	-61,111	-57,174	-20,573	-39,371	-96,928	-159,012	-872,888	Total Annual Heating kBTU
Surplus from Solar thermal (kBTU)	30,798	42,355	67,787	76,908	86,626					85,794	47,591	30,378	-173,769	Total Annual Cooling kBTU
Heating Deficit	-165,747	-119,145	-33,447	27,816	17,420					46,423	-49,337	-128,634		
Amount from Thermal Storage (kBTU)	165,747	119,145	0	-27,816	-17,420					-46,423	49,337	128,634		
Monthly Building Heat Deficit (KWH)	0	0	-9,802	0	0	-10,232	-17,910	-16,756	-6,029	0	0	0	-306,938	Total Annual kWh

TO OFFSET ALL HEATING WITH SOLAR THERMAL THIS SHOULD TOTAL ZERO: -9,802

STEP 4 - ADJUST THE NUMBER OF SOLAR THERMAL SEIDO 2-8 PANELS TO OFFSET AS MUCH OF THE DOMESTIC HOT WATER AND HEATING DEMANDS AS DESIRED

Domestic Hot water (Delta T of cold to hot hand w: 45)

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Occupied Days	18	19	15	22	18	0	1	15	19	23	19	15
Domestic Hot water (KBTU/DAY)	67.473	67.473	67.473	67.473	67.473	67.473	67.473	67.473	67.473	67.473	67.473	67.473
Total Domesic Hot Water demand (kBTU/mo)	-1214.514	-1281.987	-1012.095	-1484.406	-1214.514	0	-67.473	-1012.095	-1281.987	-1551.879	-1281.987	-1012.095
Deficit of HW to make up with Electricity (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TO OFFSET ALL DOMESTIC HOT WATER WITH SOLAR THERMAL THIS SHOULD TOTAL ZERO: 0

Electricity

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
Occupied Days	18	19	15	22	18	0	1	15	19	23	19	15		
Occupied Electric Use (KWH)	7200	7600	6000	8800	7200	0	400	6000	7600	9200	7600	6000		
Unoccupied Electric Use (KWH)	2275	1575	2800	1400	2275	5250	5250	2800	1925	1400	1925	2800		
Monthly Electric Deficit (KWH)	-9475	-9175	-8800	-10200	-9475	-5250	-5650	-8800	-9525	-10600	-9525	-8800	-105,275	Total Annual Electrical Load kWh
													-412,213	TOTAL ANNUAL ENERGY CONSUMPTION kWh/Year
TOTAL kWh Deficit (heating, cooling, DHW, Elec)	-9475	-9175	-18602	-10200	-9475	-15482	-23560	-25556	-15554	-10600	-9525	-8800	-166,004	TOTAL ENERGY DEFICIT (TO MAKE UP WITH PV)

STEP 6 - ADJUST THE SIZE OF YOUR PV ARRAY UNTIL THE NET NUMBER HERE IS ZERO (or slightly greater than zero)

Solar PV

kW Array size	123	
Watts/panel	325	ENTER THE WATTS OF YOUR CHOICE OF SPECIFIC PHOTOVOLTAIC PANEL FROM THE ALT-E website
No of panels	378	THIS IS HOW MANY OF THE PV PANELS YOU NEED TO INCORPORATE INTO YOUR DESIGN

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
Montly Output (KWH)	10662	10968	14461	15028	16129	17083	17028	17068	15543	13305	10606	8928	166,809	TOTAL PV GAIN
	1187	1793	-4141	4828	6654	1602	-6532	-8488	-11	2705	1081	128	805	Net

Figure 7 – Net Zero Calculator incorporating Revit and loads data, Solar Thermal and PV Watts output

5.2 Faculty gains

The lessons learned by the three faculty mimics what the students learned, since none of three are necessarily "experts" in alternative energy design, BIM collaboration, or in the use of the software introduced. Of greater importance, the lessons learned that we will carry to the delivery of the capstone next year can be summarized in the following bullet points.

- To combat "senioritis," institute more deadlines throughout the process. Students work better if there is a specific deadline to respond to.
- To minimize the time "floundering" during schematic design, begin the senior year with the building science training in parallel with a series of specific lectures on alternative and energy training sessions in the use of new software.
- To help with communication and to accelerate the schematic design phase, expand the teams to include one to two architecture majors.
- To increase direct communication with and input from consulting engineers, create a mechanism that allows our partners to collaborate with teams on a much more regular and intimate basis.