ENGINEERING A SUSTAINABLE HOUSE FOR SOLAR DECATHLON 2002

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Introduction The very first Solar Decathlon Competition, sponsored by the U.S. Department of Energy (DOE), was announced in the early part of 2001. Although DOE had anticipated twenty entries for this intra-university event, only about a dozen universities responded. As some of these universities dropped out before the summer of 2001, DOE re-issued the solicitation in July of 2001. The re-solicitation was relayed to three professors at the University of North Carolina at Charlotte (UNCC): the author who is an engineering faculty and two architectural professors. After a brief discussion they decided to take the challenge by submitting a proposal. Their proposal was accepted by DOE, which initiated a long collaboration process between the College of Engineering and the College of Architecture, culminating in the construction of a green building by a team of students in the summer and fall of 2002.

The first UNCC green building has 500 square-feet of conditioned floor-area and is powered by the sun's energy solely. This student-designed and student-constructed house was one of the fourteen entries in the 2002 Solar Decathlon Competition, held in the in Washington, D. C. mall during the last week of September and the first week of October in 2002.

The UNCC solar house project was organized as a joint-venture endeavor between the Colleges of Engineering and the College of Architecture, with one faculty from each college acting as the principal investigator, chief faculty advisor, and inter-college coordinator. They solicited for help with advising this endeavor from their colleagues, and nine professors from the two colleges volunteered. The professors re-structured the contents of their existing regular course works to incorporate studies, researches, and designs that were necessary to make the house a reality. They helped organize various student teams, and each of them was responsible for guiding students in one or more aspects of the project. The technical advice, time, and efforts they contributed led to the success of the solar house project.

The advisors announced the project in their respective classes, and together more than 50 students responded and took part in the project in one stage or another. Architectural students developed several conceptual designs, from which two were chosen. Engineering students were grouped into different teams, with each of these teams focused on one or two technical tasks.

Design information and data were freely exchanged between students of the two colleges. From the start to the end of the competition, student teams solicited funding, designed, engineered, built, and operated this solar house while it was in competition.

Because the solar house was actually constructed, rather than stopped at the end of the design stage like previous senior design projects, each student and faculty advisor who participated in the event has learned something valuable from the project.

Engineering Goals The solar house competition is called Solar Decathlon because, for scoring purposes, DOE divided it into ten different categories. The categories included design and livability, design presentation and simulation, graphics and communication, the comfort zone, refrigeration, hot water, energy balance, lighting, home business, and getting around. Details of Solar Decathlon are posted on DOE's Solar Decathlon Web-site. Some of these categories fell clearly into the architectural group's domain, some in the engineering group's domain, and some needed to be addressed by both groups. Besides addressing the engineering goals set by DOE for the solar house competition, the UNCC house was engineered to address the following specific goals and issues:

1. To build a house that can be easily taken apart, easily transported to another location, and easily assembled for use in a new location.
2. To build a house that uses only the sun's energy, and yet has enough energy to support normal living activities, such as washing, cooking, office work, entertaining, and transportation.
3. To build a house that not only requires no excavation (for conventional form of foundation), but also has enough strength to balance loads from nature and capability to provide stability to the house itself.
4. To design an energy-efficient house that not only has adequate insulation and moisture barrier, but also has enough lighting and other nice features of livability.

Curriculum Collaboration Key advisors of the UNCC solar house project named it "the Regenerative House Project." They started the project with only small seed money from DOE and the two colleges at the beginning of fall semester. Time wise, it was too late to make any change to information already published in the university catalog. Because of this, it was clear to the key advisors that the project could not follow the normal design-bid-build process used by most commercial construction projects. The process had to be unique, one that was flexible enough to incorporate the streams of cash contributions and in-kind donations, and the fluctuation of faculty and student participations. There would be no clear demarcation lines marking the different stages of the project, and the key advisors themselves would have to bear any burdens required to provide continuity between the stages.

With these understandings, the advisors orchestrated a curriculum collaboration that was unprecedented between the two colleges. On the engineering side, the contents of four upper-division technical courses were re-structured to incorporate various information gatherings, studies, researches, and designs that were necessary to engineering the solar house. Courses altered included senior design project, electrical and mechanical building systems, construction management technology, and individual research. These engineering courses were conducted in close coordination with studio design classes on the architectural side.

For example, student teams enrolled in the 2002 senior design project were not allowed to have the same freedom to choose their own design topic as the students of previous years. They were mandated to design the structural and transportation aspects of the solar house. Every week during the regular semester, the last hour of this class was held together with the architectural studio in their design studio. They visited a local manufactured-house factory with the architectural studio students. Such arrangements greatly enhanced the interaction between the architectural and engineering design teams.

The Building Envelop While the architectural students were busy conceiving concepts for the solar house, students in a civil-engineering-technology class, ETCE 3293 Electrical and Mechanical Building Systems, were quietly engaged in the engineering of the building envelop of that future house. As the cooling load calculation for a building contains many components and is, therefore, much more complicated than the associated heating load calculation, it was decided by the author that the basic design of the building envelop would be independent from the energy simulation, to be perform by a mechanical engineering student team later and as a fulfillment of one of the DOE requirements. It would be based on the heating load requirement alone.

In the electrical and mechanical building system class, a routine individual, take-home assignment on heating load calculation was thus altered to facilitate that process. Each student was required to estimate the heating loads, gather information on doors, windows and other building materials, and design the building envelop. Using a very sketchy floor plan submitted by one of the architectural design teams, each student was required to solicit the cost associated with the building materials he or she used in the building envelop, as shown in Figure 1. In order to give the building-systems students enough time to prepare better reports, another routine assignment on cooling load calculation that normally followed the heating load calculation was purposely scrapped. Students were also encouraged to use the building materials, including building insulation panels, sky-lights, and Kal-wall, of those companies that showed interests to donate in-kinds or provide engineering assistance to the project.

A collection of information was gathered, and two types of building envelop were selected from the reports and the summary sheets the building-systems-class students submitted. The information and designs were passed on to the engineering students who took part in an individual-study class, ETGR 3000, Solar Decathlon, and a civil-engineering-technology capstone class, ETCE 3642, Senior Design Project. The capstone class was a Spring/2002 class. It immediately followed the Fall/2001 building-systems class. The individual-study was held continuously until the end of 2nd Summer Session/2002. The summer engineering participants of the solar house project had all taken the building-system class and/or the individual study class previously. This provided certain valuable continuity to the project.

Building Systems The frame work provided by the DOE for the solar competition encouraged the participant teams to be as innovative as possible in their design of the building and systems to be used inside the solar hose. Architectural and engineering students cooperated on the design of most electrical and mechanical building systems. On the engineering side, sessions of individual-study class, ETGR 3000, were held by civil, electrical, mechanical, and manufacturing professors. One or more student teams were organized inside each of these sessions, and initially each of these teams focused on the design or simulation of only one important building system without considering any system integration needs. During the actual design of the building systems performed later in the summer, the final design team tried to reduce the size of the originally conceptualized building systems by establishing a link between some of the units. For instance, a link was made between water heating and space heating and cooling. In this way, some of the excess heat exhausted from the house by the HVAC-unit was captured and used to heat water in parallel with a small solar hot water panel on the roof of the solar house.

Certain key power-supply decisions needed to be made in the early stage of the project. This includes the amount of solar power to be provided by the solar panels, the use of direct current only or a combination of direct current and alternative current, and at what voltages? After fair amount of study, participating electrical-engineering-technology students decided to use a roof-mounted solar photovoltaic (PV) power system that could provide 4.5 kilowatts. They estimated it could provide enough power for lighting, appliances, and charging the electrical vehicle during the competition. Ordinary appliances use 220-Volt and/or 110-Volt alternating current; while the PV panels produce direct current at different voltages. A conversion between direct current and alternative current is, therefore, usually required. The students wanted to stay away from using 220-Volt system and tried to minimize the conversion need. They contacted EQUATOR, a marine supplier, to provide a compact dishwasher, a dryer, and a cloth washer to be used in the project---all require only 120-Volt direct current. A small 120-Volt stove was later installed and it fitted nicely into the space designed. SEAWARD, another marine manufacturer provided a 120-Volt convection oven.

Design Challenges The engineering team that provided the final design works required for system integration during the summer of 2002 consisted of three undergraduate students, one each from civil, mechanical, and electrical engineering-technology discipline. The engineering team worked alongside the architectural and construction teams. They faced and overcame many challenges, and handled new task distributions, change orders, scheduled changes, and material deliveries. They worked on a fast-track project, meaning the design, fund raising, and construction of the solar-house project were being carried out at the same time, because of the budget needs. Up till the last minutes of construction, the team was shopping around for alternative solutions to fit the limited budget of the project.

The biggest challenge for the engineering team was due to the need to make structural changes at the final moment. The chassis and base plate of the house was delivered by R-anell in early summer, and the next big delivery was for structural woods, including timber, joists, and rafters. From the start of the project, the solar house was designed based on using types of insulated walls and roofs panels produced by ThermaSteel Corporation, and a beam-and-post timber system by a local timber company. In early summer, the local timber company backed out. Well into the summer/2002, the company that promised to deliver the insulated wall and roof panels also withdrew their delivery. Nevertheless, faculty advisors and students responded to both situations quickly. Modifications to the structural and building-envelop designs were made to adapt to the new situations. Different and cheaper insulation panels, made by Insulspan, were used. Wood beams and other structural elements were re-structured and re-sized to pick up new loads. The new design was based on the design manual by Southern Pine Council, entitled "Maximum Span---Southern Pine Joists and Rafters."

The changes from ThermaSteel to Insulspan panels necessitated a design verification of the chassis, which was already delivered. Since only wall and roof panels were changed, the solution was to compare the unit weights of the two panels. The comparison revealed that ThermaSteel panel was heavier than Insulspan panel. Consequently, it was safely concluded that the chassis, being able to support the heavier ThermaSteel panels, would easily support the Insulspan panels.

Transportation and Foundation The solar house was designed for multi-relocation, as it needed to be constructed in Charlotte North Carolina first, then moved to Washington D. C. for the competition, and then moved back to one or more locations in Charlotte. From the transportation's viewpoint, one of the easiest ways out was to design the house as a mobile home. Considering the geometry of most mobile homes, designing the house as a regular mobile home, however, would limit the possibilities for students' creativity to bloom, if not doom the project from the beginning. After consulting with manufacturing-home on several weight- and transportation-related issues, the key advisors decided on a compromise solution. Their solution was to design the house as an irregular mobile home. It is irregular in the sense that the chassis of the house would be longer and have more axles than that of most mobile homes. This would allow more weight to be carried. It is irregular also because the chassis would be made of three connected sections, instead of one single section. This would allow the tail two sections of the chassis to be un-coupled from the main section, allowing flexibility to re-configure the house when it arrives at a new location. The student team followed this basic design concept. In the final design and actual construction, the chassis was made of three sections. The front section carried the main portion of the solar house, and the two tail sections the front porch and back sun room.

At a permanent location, the solar house was to be anchored in a manner similar to that of most mobile homes. The permanent anchoring system was patterned after the licensed design of a Florida company. The system has the capability to withstand the force of a design tornado for this type of mobile home. The temporarily anchoring system used in the competition site in Washington D. C. was designed by the student team, and was manufactured by a local steel manufacturing company. The temporarily anchoring system allowed the house to be leveled properly at the site.

Construction The Solar Decathlon project provided a unique opportunity for students to practice working in a multi-disciplinary environment similar to that of the real world. This statement was particularly true during the construction phase of the project, which spanned from the beginning of the start of the 1st Summer Session/2002 up to the competition time in the end of October, 2002. The tasks of the construction phase required the participating students to constantly exchange knowledge and information across the disciplinary boundaries. They were forced to use languages other than those of their own for communication, to work together with students of different training and background, and to deal with real materials, construction techniques and procedures, a tight schedule, a very tight budget, and an ever-changing environment. For most of the students who participated in this phase, the project was their first such exposure and experience.

Architectural and engineering students who enrolled in the summer sessions formed the core of the construction crews. The core crews planned, scheduled, and controlled some procurements, most material deliveries, and constructions. Many building elements were donated to the project by outside companies. Other large-item procurements went through regular university procurement channels, as mandated by university rules. They were aided by volunteer students, who did not take credits from the project in the summer. As the competition drew closer, weekend work was initiated and more volunteer workers were called to join the construction. Volunteer students were allowed to work at their own paces.

The construction undertaken by the student team started with the leveling of the steel chassis and floor plate of the solar house, delivered by R-ANELL HOMES. The insulated panels, provided by Panel Wrights Group and Jefferson Homes, were the first elements to be installed on the chassis. As soon as these wall and roof panels were erected, the generative house began to show its form, and that attracted much more attention. The VELUX skylights were installed next. Thereafter, students started to work on the placement of roof materials. After the roof was secured, the interior was framed, and more clearly defined spaces for appliances, HVAC, and other building-systems components were emerging. Some of these building systems were installed at the construction site in the UNCC campus. The balance, including the PV panels and water supply and circulation system, was later installed at the competition site in the Washington D. C. mall.

Budgetary Matters Before its start the solar-house project received a seeding fund of $5,000 from DOE. The project also received limited supports from the university administration, which came in the form of matching funds from the deans of the two colleges and financial aids from the Office of Academic Affair. The rest of the cash and in-kind contributions needed for the project came from sources outside the university. For two major reasons, raising funds turned out to be the biggest challenge for the project and involved all faculty advisors.

The first major reason had to do with the then on-going UNC-Charlotte university-wide fund-raising campaign. An ambitious five-year funding campaign was in progress, and its duration overlapped the duration of the solar-house project. This made project-level fund-raising extremely difficult.

In order to prevent any interference with the university funding campaign, cash donations and gift-in-kind contributions to projects not initiated by the university administration were subjected to the regulations of university's development office. Permits for soliciting from both companies and individual that were on the university target list needed to be obtained beforehand. The university list included almost all well-known national companies that have a strong Charlotte-area presence, for example, Duke Energy, Charlotte Motor Speedway, and Bank of America. The list also included most of the large firms that have relations with the faculty advisors of the Solar Decathlon project. If a non-administration-initiated project was allowed to approach a company on the list, a limited time-duration would then be assigned for doing the solicitation.

The second major reason had to do with the then poor economic atmosphere in Charlotte area. The economic conditions in 2001 for a lot of the medium- and small-sized architectural, engineering, and construction firms in the area were poor.

The university fund-raising campaign and the then poor economic condition in the Charlotte area made solicitation of supports from local firms on energy-efficient projects very hard, if not impossible. They presented the project team with the biggest challenges. A lot of doors, both inside and outside the university, were knocked on by students and faculty advisors on the project team, but most of them yielded no or limited results. Although the project had enough money at the competition time, the amount of money available for the project was minimal when that was compared to those of our competitors. Some university teams were rumored to have spent up to quarter or even half of a million dollars. The presence of large-sized and well-welded steel beams, professional workmanship, and elaborate interior finishes and materials in some of the other houses sufficiently bore these rumors out. However, the UNCC students met the budget challenges by taking most of the construction tasks up on their own shoulders. Some students were trained interns and technicians. They guided the other students. Minimum professional help, such as lifting of insulation panels and installation of PV panels, were provided only when they were absolutely necessary.

Different Views Because the solar project was a collaboration between two colleges, it had an embedded and persistant gulf between the participating faculty and students. An engineering professor, for example, tends to give more clearly defined guidelines for solving problems in a senior project design class, while it seems to be a taboo for an architectural professor to do the same in a studio design class. At the beginning, engineering professors mostly saw the solar-house competition as a techincal competition; while architectural professors mostly saw it as a architecural-design competition.

It was the intention of the author to mitigate this gulf through out the life of this project. Participating ngineering students were repeatedly advised that in the real world professional engineers and architects are forced to work together to achieve desirable results. With a few exceptions, engineering professors and students, nevertheless, tended to follow their traditional ways of function in a school project. The same could be said about the architectural professors and students. However, for those engineering students who could follow the advice, working alongside the architectural students was an eye-opening experience. They had the opportunity to see how architectural students do their work: coming up with preliminary design concepts, making models, presenting their own ideas, critique the ideas of their competitors, and lobbying for the votes of their fellow engineering students. They also had the first hand opprtunity to learn to communicate and work with the architectural students and engineering students from other engineering fields.

Conclusions Despite the challenges discussed in the above, a devoted sudents team was able to accomplish both the design and construction phases of the Solar Decathlon 2002. The house is now moved back to a temporary location on the university campus, and may serve as a laboratory for future students. Because the solar house was successfully built and competed in Washington, rather than stopping at the design stage, all UNCC students and faculty advisors who participated in the event seem to have learned something valuable out of this participation.

This paper documents some of the challenges that the participating engineering faculty and students have overcome in the process of achieving the goal of building the house. It presents the knowledge and experience gained from involvement in the solar house competition. Steps taken to address these engineering issues could be useful in defining the principles of green engineering. They also may indirectly address some of the political, social, economic, environmental issues that are related to the housing problem of the world.

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AISC (1994). *Manual of Steel Construction: Load & Resistance Factor Design*, *Volume I, Structural members, Specifications & Codes,* Second Edition, American Institute of Steel Construction, Chicago, Illinois.

BOCA (1999). "Section 1609.9, Wind Loads," *The BOCA National Building Code/1999*, 174-183.

Figure 1 Summary Sheet for Building Envelop and Heating Loads

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ETCE 3293 **NAME**____

Quiz #2: Building Envelop and Heating Loads for a future UNCC Solar house

A. Objective and Floor Plan: For the solar house shown in the attachment,

(1) Design a functional building envelop for the house,
(2) Estimate the individual room heating loads in BH and in tons, and
(3) Estimate the total building heating loads in BH and in tons.

The house should be considered as a real house, and have a total heated space of more than 500 square ft. The results are to be used for the purpose of sizing the heating equipment and, later, duct system.

B. Basic Requirements: This house is to be designed following modern accepted practice. Design of the house needs to meet the following "minimum" conditions:

- Location: Pick from Climate Table, distributed in class, a location in a state whose name starts with the first alphabet of your last name. (For example, Jane Dole may pick Wilmington, Delaware)
- Walls: R20 or above, and must be suitable for the location
- Window: double-hung, wood sash, single glass
- Roof: R25 or above and must be suitable for the location
- Door: 1 _ in. wood, 7 ft high.
- Ceiling height: 9 ft.
- No basement.
- Foundation: The main floor of the house must be about 2 ft. (elevated) from the ground.
- Doors, windows, and other major components used must be those that can be purchased with a reasonable price from a local building material supplier.

C. Documentation: The following supporting data should be included in the report:

- Design conditions,
- Floor plan,
- Typical wall sections used,
- Typical roof sections used,
- Design assumptions,
- A temperature profile through the typical wall section, and
- Supporting calculations (use formats in the textbook for final calculations).
- A list that summarizes the specifications, manufacturer's literature, prices, and other information on which the design is based.

D. The “Summary of Building-Envelop and Heating-Load Calculations,” given at the end of this project statement, must be submitted with the project report.

E. Project is due the Thursday immediately after spring break.

F. Useful Information:

- D.O.E. recommended R-values for your state, and envelop insulation materials
  http://www.owenscorning.com/around/insulation/

- Solar panel
  http://www.bp_solar.com

- Door
  http://www.premdor.com/DoorSearch/

- Roof material
  http://www.owenscorning.com/around/roofing/

- Laminated flooring
  Shaw Laminates SimpleLock glueless installation, 1-800-441-7249

- Instruction for wood-frame and lap-siding installation
  James Hardie, 1-800-9HARDIE

- Attic ventilation channels
  Durovent, ADO Products, Rogers, MN 55374-0236, 612-428-7802