ES 110 Engineering & Society – Fall 2012
Group Design Project

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Design of a Solar Water Heater

Background: Fossil fuels currently provide about 85% of the energy used by most of the developed world. Because of concerns over the limited supply of fossil fuels, as well as the detrimental environmental effects associated with their use, renewable energy resources such as solar, wind, hydro and geothermal energy are attracting increased attention ranging from research and development efforts to wide scale implementation. Among these renewable resources, solar energy provided about 1.4% of the total renewable energy consumed (or 0.1% of the total energy consumed) in the U.S.in 2010.[1] Solar is growing quickly in the U.S. – according to the Solar Energy Industries Association, more solar was installed in the third quarter of 2011 than in all of 2009 combined.[2]

Solar energy can be converted to electrical energy (electricity) using photovoltaic cells. Another use for solar energy is to heat water. As much as 20% to 30% of the total energy consumed by an average U.S. household is used to heat water.[3] Most commonly, that energy comes from fossil fuels – either directly from natural gas, or indirectly through electricity, which in the U.S. is produced mainly from fossil fuel combustion. A solar water heater can be an effective way to conserve fossil fuel resources and save money. There are two types of solar water heating systems: active systems, which are the most common, use a pump to circulate water; passive systemsare used less commonly and circulate the water without the aid of a pump. Household solar hot water systems have a storage tank connected to a solar collector, which is the unit where the water heating takes place. There are three types of solar collectors used for residential applications: the flat plate collector, which is basically an insulated flat box (typically black) through which the water flows; an integral collector-storage system, which is a batch system that preheats water before it enters a conventional heater; and an evacuated-tube solar collector, which uses a system of inner- and outer-tubes of glass that act as heat exchangers to transfer heat energy from warmer recycled fluid to the water being heated. Most solar systems operate as a preheater for a conventional water heater, but in warmer climates or for swimming pool applications they may operate as stand-alone systems.

Solar pool heaters essentially consist of a simple collector on its own, with no storage tank. Water is pumped from the pool by the recirculating pump, through a filter and the solar collector, and is then returned to the pool. Solar pool heaters are made out of various materials but are generally flat, flow-through structures that use simple principles of long *residence time* (the length of time the

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[1] U.S. Energy Information Administration, 2011. Annual Energy Review, October 19, 2011. Retrieved 8/3/2012 from http://www.eia.gov.
[2] Business Day: Energy & Environment. New York Times, May 17, 2012. Retrieved 8/3/12 from http://topics.nytimes.com/top/news/business/energy-environment/solar-energy/index.html.
[3] EnergyTrust of Oregon.Retrieved 8/3/2012 from http://energytrust.org/residential/incentives/solar-water-heating/solarwater/.

water is in the collector) and maximum exposure to the sun's rays to provide the most possible benefits.

Design Objective: Design and demonstrate a prototype for a solar water heater that uses heat generated by a "solar simulator" to increase the temperature of a given amount of water within a specified time period.Each design team will prepare several Progress Reports and give a summary presentation including a demonstration of the prototype (see Deliverable #5). A final design final report including peer evaluations will be submitted when the project is completed (see Deliverable #6).

Specifications/Performance Requirements: Each team is tasked to design and demonstrate a bench-scalesolar water heating system. Systems may be active or passive; teams will be supplied with a container holding 1 liter of room temperature water and a pump to use at their discretion. Simulated solar energy will be provided by two300-Watt halogen lamps, which will be located a minimum of 50 cm from the nearest point of the bench-scale solar collector.

The system should be constructed to heat a minimum of 1 liter of water in less than 5 minutes. Teams are expected to maximize the temperature gain of the water, as measured by the difference between the temperature of the influent (room temperature) and the temperature of the effluentin the collection vessel at the end of the test period (5 minutes, or possibly less for passive systems). Additional goals will be to maximize the *energy efficiency* (measured by the energy gained in the heated water divided by the total energy supplied to the system, %) as well as the *cost efficiency* of the heater (as measured by theheat gained in the water per unit cost of the system [Joules/$US]).

Materials Provided and Constraints:

1. **Materials**: Each team will have access to a station that is equipped with a vessel of room temperature water and a peristaltic pump. The pump will be equipped with a short piece of inflow/outflow tubing, to which the collector may be attached with additional fittings, nozzles, etc. Two300-watt halogen lights will be provided to simulate solar energy. Teams will be responsible for procuring all materials to construct the collector, as well as materials to connect the collector to the pump if desired. A collection of fittings will be made available for use. Students wishing to design passive systems may obtain additional vessels for effluent collection. Materials for construction may include standard craft items and throwaways or recyclables, such as empty containers, tubing, hosing, plastics, string, wire, etc. Additional construction materials may be purchased, including but not limited to tubing, fittings, adhesives and fasteners (screws, bolts and nuts) as long as the total charges do not exceed the maximum allowable budget. Materials that are not available through local vendors may be purchased over the Internet with the assistance the assigned ES110 Design Project Teaching Assistants.

2. **Tools**: Construction of the prototype may employ typical hand tools used in crafting. Hand tools such as pliers, wire cutters, saw, and screwdrivers are allowed; hot glue guns are allowed. In general, power tools and machine tools *are not*to be used by students. If you need a hole drilled or a special cut made, you may request assistance from shop personnel. In addition to the tool kits, a work area will be made available to the design teams.

3. **Cost**: The cost of materials used to construct the bench-scale solar water heater should not exceed $35.00 U.S. A detailed budget must be included in Progress Report #3. The detailed budget,detailing all costs and including copies of receipts for all purchased materials, must be provided in an appendix of the Final Report.**A 10 point penalty will be assessed on the final report for any design with a cost exceeding $35.00 U.S. as demonstrated.**

4. **Assistance:** Two teaching assistants will be available on a limited basis to help with laboratory procedures and material procurement. For example, if a team does not have any means for making on-line purchases, arrangements can be made through the design project assistants. Regular lab hours will be posted, during which time design teams will find one assistant onsite and available to help. Additional assistance may be obtained by contacting a teaching assistant by email. Details will be forthcoming.

Teams: Teams will be self-selected (form your own teams) and consist of 4-5 members each. Instructors may institute special requirements for team selection.

Deliverables: **ALL REPORT DELIVERABLES MUST BE PREPARED ACCORDING TO THE ATTACHED GUIDELINES – SEE '****Team Design Project Reporting Guidelines****'**

1. **Progress Report #1: Background/Introduction, Project Description, andSpecifications (due 9/24, 10 points)**. Based on the Design Objective stated, prepare and submit a Progress Report that includes:
    a. Project background. Using the materials compiled from design-project related homework questions, if appropriate, as well as additional resources,provide background information that explains the societal context of – or societal need for – renewable resources, and the potential role that solar energy could play. At a minimum, include:
        i. information on energy consumption both globally and nationally;
        ii. energy production by various energy resources, including renewable sources; and
        iii. adiscussion of the pros and cons related to solar power installations (photovoltaic as well as hot water).

       Include references for the information you use.
    b. A brief description of the project task. Explain what you were tasked with (the *Design Objective*), and why the design of this product is important. Describe who will benefit from your design, how your design will be marketed or distributed, and how your design will impact society at large. *Include references for the information you use.*
    c. A list of specificationsthat includes:
        i. the performance requirements of the design; and
        ii. theconstraints for the project(these are provided in the problem statement).
    d. Any additional performance goals and constraints that may be identified by your team (include an explanation for these additional items).

2. **Progress Report #2: Results of Brainstorming; Identification and Evaluation of Possible Design Strategies; Description of Preferred Approach (due 9/24, 10 points)**.
   Submit a Progress Report that includes:
   a. A summary of the factors that influence the performance of a solar water heater, including a description of which factors can be controlled by engineering design. Keep in mind that “performance” includes the performance requirements for this project, described above.
   b. A description of the results from the brainstorming process completed in class. This should include both a description of the process itself and a summary of the design approaches (ideas) that were generated as a result of the process.
   c. A description of the preferred design approach (the approach your team has chosen to pursue) and why it was selected over the other approaches identified in (b) this should include an explanation of why the other approaches were eliminated. Try to put these design decisions in the context of 1) the information you provide in part (a), and 2) the feasibility of each approach.

Note: A formal brainstorming process will be conducted in class using the methods outlined in Chapter 2, Section 5 of <u>ES 110 Engineering and Society</u>(Moosbrugger, et al.) with a summary similar to that shown on p. 52 (Example 2). Deliverables 1 and 2 may be combined into one document, but must have separate authors.

3. **Progress Report #3: Design of Prototype (due 10/12, 10 points)**: Provide a Progress Report containing:
   a. Asummary (~ one page) of the main features of the prototype design (this should be understandable by a non-technical person, much like a patent disclosure).
   b. Aprofessional-quality,scaled drawing showing the key features and dimensions of the prototype design. <u>*Either*</u>hand sketches<u>*or*</u>computer-aided drawings are acceptable, but drawings <u>*must*</u> be to scale and hand drawings must be of professional quality; rough sketches prepared without measurements or a straight edge (ruler) <u>*will not*</u> be accepted.
   c. A detailed budget, including a complete list of supplies, where they will be obtained, and with itemized costs.

Note: Your report should provide enough accurate detail to enable a person not familiar with your design to construct your prototype using the drawing and text you provide.We will conduct a peer-review of this Progress Report in class on the due date, with the final edited version due on Monday 10/15. The original version with peer comments should be attached to the final version. Details will follow.

4. **Progress Report #4: Prototype Build and Test procedures (due 11/7, 25 points): Each design team will provide a Progress Report describing the build process, the test procedures, and the test results (b-e, PR):**
   a. A description of the build process and any iterations required.

b. A description of the test procedures. As you plan your test procedures and perform the testing, keep in mind that the goal of the engineering design process is to deliver a product that meets specifications or performs as advertised.
c. A summary of the test results (both qualitative and quantitative). See note above regarding design process.
d. A brief summary and explanation of any design modifications resulting from the testing process. *Optional: Include a photo showing build and test.*

5. **In-Class Presentation and Final Product Demonstration (7 minutes): Design Iterations; Final Design and Prototype;and Prototype Demonstration (due ca. 11/28, TBA, 25 points): Prepare and present a power point presentation (~ 7 minutes or less) that includes:**
    a. Asummary of your prototype design (original design, and design iterations, and prototype design).
    b. A summary of the main features and advantages of your prototype.
    c. A summary of your test procedures and results including design modifications.
    d. A description of the final design.
    e. A demonstration of the final product showing that it meets the specifications and adheres to the design constraints.***While all team members must be present, it <u>is not</u> a requirement that <u>all</u> team members speak**.*

    10 points for performance:

    1. **Water flows successfully through the system with no leaks or spills.**
    2. **Bench-scale solar water heater is able to raise the temperature of the water by at least 1.5˚C, measured as the difference between the initial water temperature and final temperature at the end of the test period (5 minutes or less).**
    3. **Cost efficiency of system is at least 200 Joules/$US.**
    4. **Energy efficiency of system is successfully calculated using data collected during the demonstration.**

    - **0 points: (0/4 of above)**
    - **3 points: (1/4 of above)**
    - **6 points: (2/4 of above)**
    - **8 points: (3/4 of above)**
    - **10 points (4/4 of above)**

6. **Final Report* (due 12/6, 20 points):** Submit a final report that is prepared according to the attached guidelines. Deliverables submitted previously (or materials included in them)may be included as appendices and referred to in the main body of the report for details.

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Note: The self- and peer-evaluations (described below)<u>must</u> be completed <u>by each team member</u> using the attached form and submitted with the final report in order that the final design projectbe considered "complete" andproject grades computed and assigned!!

<u>Grading</u>: Each team member will receive an individual score for the project, computed according to the attached grading procedure and rubric. In most cases, each member of a team will receive the same score. Occasionally, however, someone will simply not put forth much effort or will contribute virtually nothing to the project and this will be clear from the peer evaluations. Such individuals will receive a lower score, accordingly.

******** Team Design Project Reporting Guidelines *********

These guidelines must be followed for all Progress Reports <u>and</u> the Final Report. Progress and Final Reports do not need to be extensive, but must convey the necessary information in a clear, concise manner. Ideally, one group member will be primarily responsible for writing portion of **<u>each</u>** of the 5 deliverables (the 4 written progress reports and the final report). The designated person will change for each new deliverable. This method is to provide each student with a chance to have technical writing practice in the course.*Since this is a group project with a team grade, it is strongly encouraged that all team members review all reports and pay particular attention to grading feedback before writing their own sections.*

All reports are to be typed in 11 or 12 point font, with 1-inch margins and page numbers bottom center or bottom right. Hand-written reports will be returned with a 0 grade. Calculations, where present, can be hand-written, but must follow the same guidelines for that of typed fonts. (However, use of an Equation Editor is strongly recommended.) When possible print all reports double sided.

Each Report must contain a <u>Title Page</u> with the following information:

- Title (e.g., Progress Report #3: Design of Prototype)
- Date
- Team Members (names *with signatures*)
- Group member responsible for writing the report

The **Final Report** should be roughly 5 to 6 pages long *excluding* sketches, drawings, appendices, figures, tables, etc.). Deliverables submitted previously (or materials included in them) may be included as appendices and referred to in the main body of the report for details. A word of caution: if a progress report was poorly graded, do not include this as an appendix – rather, correct your mistakes as you re-write these sections in the final report document.

In addition to the Title Page, the **Final Report** must contain the following sections:

1. Introduction (introduce the design problem at hand; provide background information similar to what you prepared for Progress Report #1)
2. Design Criteria and Performance Standards (briefly summarize; include technical, societal and economic constraints)

3. Prototype Design Summary (summarize the process used to design prototype and the results of that process)
4. Build and Test (describe the building and testing procedures; include results and modifications)
5. Prototype Demonstration (summarize results of the in-class demonstration; present and discuss the results that your team achieved and briefly discuss your observations of the other demonstrations; specifically note any observations/conclusions that you can make regarding design choices and their effects on performance). Remember to include and discuss the results from the in-class demonstration including **the energy efficiency of the system that you calculated using data collected during the demonstration.**
6. Recommendations (present recommendations for improving the design for "commercial development;" specifically, based on (5), what design changes do you recommend based on your demonstration and your observation of the other demonstrations?)
7. Appendices (include detailed budget, receipts for purchases, recalculations, sketches and drawings, progress reports, figures and tables that are not embedded in the text)

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Team Design Project Final Report Grading Rubric

		Weight	Points (1-10)
Introduction	Design problem clearly defined	0.1	
Completeness	All required report sections are included; materials submitted as earlier progress reports that are included as appendices are briefly described in text and clearly located in appendix; incomplete or weak progress report information is sufficiently improved in the appropriate sections of the final report	0.5	
Demonstration	Process and results of in-class demonstration are clearly described	0.2	
Recommendations	Brief; potential improvements are discussed that would enable wide scale production and implementation	0.1	
Appendices	Extra materials well organized, appropriate, and easy to interpret	0.2	
Professional presentation and communication, Mechanics	Text, graphics, drawings and tables neat and generated with appropriate computer tools; Tables, figures, drawings, calculations are used appropriately and effectively	.3	
Organization, Focus	Logical flow of material between sections that aligns with basic design process; Purpose of report overall, and each section, clearly defined; Reasonable number of section headers to guide reader	.3	
Grammar, paragraphs, spelling	Sentence structure concise and appropriate for technical communication No spelling, tense or plural/singular agreement errors	0.3	

Total points: (max 20)

Team Design Project Overall Grading Procedure
(descriptions apply to max positive or negative points)

A. Group Assessment: The product of 0.75 and the sum of point allocations for deliverables 1 through 6 ______(maximum 75 points)

B. Individual Assessment (25 points; points assigned based on peer evaluation and at the discretion of the instructor)

Team member contributed at or above average for the group _______ (maximum 25 points);

orTeam member did not do anything _______ (minimum of $-1\times$total of A. Group Assessment, so that project grade = 0);

or somewhere in between the above __________ (between -75 and 25).

C. Project Grade = Score for A + Score for B

______________________ (maximum 100 points)

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Team Design Project Self-Evaluation and Peer Evaluation Form

This form must be completed in confidence at the completion of the project by each team member on the project team, and submitted with the project in individually signed and sealed envelopes.

Please rate the contribution toward the team project of each team member in your group **including your own**. Provide a score between 0 and 10 for each member and then elaborate on what particular each member contributed. Feel free to write additional comments at the bottom of the form.

Estimated Time Required To Complete Project (hours): ___________

Time You Actually Spent on Project Tasks (hours): ____________

Group: ____________

Name	**Score (0 – 10)**	**Contribution to the Project**

Comments on team contributions/performance:

____

____

____

____

Signature and Date: ____

Name (print): ____