AC 2008-1278: DESIGN, BUILD AND TEST: AN APPROACH FOR A CAPSTONE DESIGN COURSE IN ENGINEERING TECHNOLOGY

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Design, Build and Test: An Approach for a Capstone Design Course in Engineering Technology

Abstract

Undergraduate engineering technology students traditionally take a capstone or senior design course during their last semester which involves the design of an engineering system that has a real application. Senior design projects usually focus on specific design aspects including equipment sizing, cost analysis, and material selection; however, many senior design courses do not give students the opportunity to apply hands-on skills or produce a real physical prototype. Furthermore, few engineering technology courses provide the opportunity to approach practical design and production problems in a comprehensive and holistic manner. There is a real need to expose students to a variety of design considerations as well as production, construction, or testing activities so that they may grasp fully the importance of the design process. Students also should learn to take into consideration constraints such as time, cost, and space during the design process.

In this paper, a case study is presented in which a group of senior design students was able to design, build, and test a passive cooling system for residential, commercial, and industrial flat roofs. First, the students created a number of designs for a passive cooling system taking into consideration material properties, cost, manufacturability, and proven passive cooling concepts. The students then evaluated each of the design options and fabricated only those with the best overall design attributes. All prototypes were tested using a lab-scale experimental set up capable of measuring the thermal performance of each specimen. The students also provided a thorough discussion on the benefits and drawbacks of each prototype, and recommended a course of action for the potential commercialization of the proposed technology.

The case study illustrates that students can learn to design, build and test a simple system taking into account several objectives and attributes in a comprehensive manner. This particular experience indicates that future capstone design courses should regularly consider prototype construction and testing as essential components of the entire design process.

Introduction and Motivation

Senior design courses offer students the opportunity to manage a multidisciplinary capstone project in a relatively short period of time; however, few colleges and universities have student projects that involve design, construction, and testing of multi-component systems[1-2] in the same course. In some universities, the senior-design course is preceded by a structured course sequence[3-4] to guarantee a certain level of expertise before students take their final design course. Others[1,5] have design-build-test senior capstone projects that take an entire academic year to complete. The design, construction, and testing of a mechanical system requires a good understanding of basic principles to be able to meet the established design criteria; however, senior design projects should also give the students the opportunity to see first hand the different phases of product development in a short period of time (i.e. one semester). In addition, engineering and engineering technology students should be able to:

• Design and build mechanical systems within a limited budget
• Integrate and use multiple engineering and science disciplines in a simple and organized manner
• Understand the importance of design and see first hand the impact of each design decision
• Select materials and components taking into account physical properties, cost, durability, and manufacturing constraints
• Use and manage time effectively
• Consider manufacturing and fabrication issues during the design process
• Take into account testing and validation concerns of each designed prototype
• Assess each designed prototype by taking into account performance, cost, durability, ease of installation and operation

It is shown in this paper how a simple project gave a group of students the opportunity to design, build, and test a passive cooling system by taking into account all the considerations highlighted above. This particular experience indicates that capstone design courses should regularly consider a design-build-test approach to enhance the students' understanding about the importance of a well-organized design process.

Background

In the past few years several articles have addressed the importance of senior design courses in engineering and engineering technology curricula. Several approaches have been attempted ranging from large classes[4] to multi-semester courses[1,3,5]. Others have used senior design courses to design and build mechanical systems[1,6]. A common concern is to give students the necessary design experience so they can succeed in industry[7-11]. Recently, activities such as designing, building[12-15], and testing thermal equipment for laboratory courses[16] have been shown to promote lifelong learning.

Educators are still faced with the challenge of how to incorporate several multidisciplinary activities into a single course. Dong and Dave[1] used a design-build-test approach to help students gain additional skills including time and project management; however, their approach requires an entire academic year. Alvarado[2] used a similar approach to design, build, and test a lab-scale ground source heat pump in three semesters. Although such projects gave students the opportunity gain additional skills, both took a considerable amount of time to complete. These publications show that a design-build-test approach can be a formal and regular part of any capstone design course. In this paper, a design-build-test approach was followed as part of a single-semester senior design course. A group of four students was able to complete all the design, construction, and validation tasks successfully.

Case Study: Design, Build and Test a Lab-Scale Passive Cooling System

Brief introduction of Passive Cooling System
Passive cooling systems are used in commercial, industrial, and residential applications to minimize the amount of heat being transferred across walls and roofs without making use of an active mechanical (vapor-compression) system. Several systems have been designed and used in the past including green roofs, reflective paints, and those based on evaporative cooling[17].

Recently, Alvarado and Martinez[18] designed, built, and tested a passive cooling system that consisted of a combination of materials that minimized heat transfer through a cement-based roof. Passive cooling systems offer several advantages including low maintenance and virtually no energy consumption. They are used in places where energy availability may be a concern, and in locations with sufficient solar irradiation. Design, construction, and testing of a passive cooling system was chosen as senior design (capstone) project due to its simplicity and multidisciplinary nature.

Project scope and objectives

The scope and objectives of the project were to research, design, build, and test a lab-scale passive cooling system in a single semester. The project objectives were broken down into three main categories: research and design of several passive cooling systems, select the optimal materials, and build and test each prototype. One group of undergraduate students taking the senior design course in the department was responsible for achieving the project's objectives. As a first step, the students were asked to review several papers in the area of passive cooling so they could become familiar with key theoretical concepts including the effect of material properties (e.g. thermal conductivity, reflectivity, etc.) on thermal performance.

Research and Material Selection for Passive Cooling System

The first task that the students undertook was to propose a basic passive cooling system design from where multiple variations could be contemplated. The basic design took into account two main desirable characteristics: low overall thermal conductivity and high surface reflectivity. Figure 1 shows the basic design where insulating and reflective materials can provide low thermal conductivity and high reflectivity, respectively.

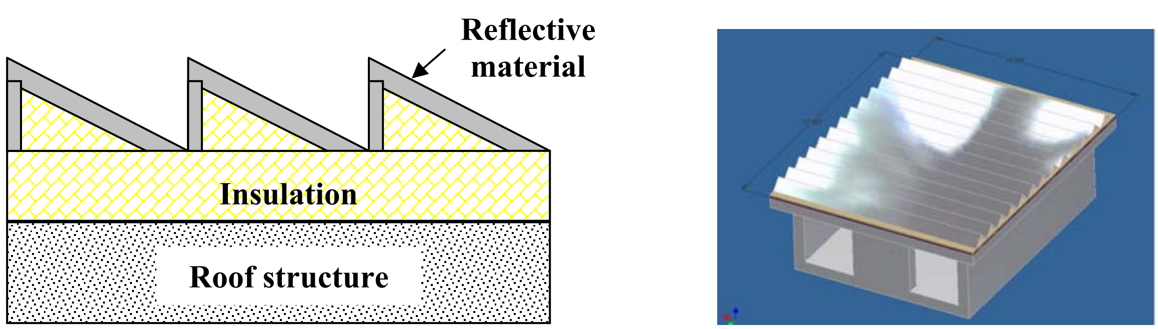

Figure 1. Basic passive cooling system design[19]

The second main task was to consider several materials for each system. The students conducted a materials search using the internet and library resources. They compiled a materials database which included attributes such as thermal conductivity, density, cost, ease of installation, and durability. Fiberglass, polyurethane, and polystyrene were selected as insulating materials because of their low thermal conductivity, low density, and relatively low cost. Aluminum 1100-H14 and galvanized steel were selected as reflective materials.

In addition to selecting several materials for each component, the students also proposed and modeled (using computer-aided design) three surface configurations including flat, semi-circular (Figure 2), and triangular (Figure 3) configurations.

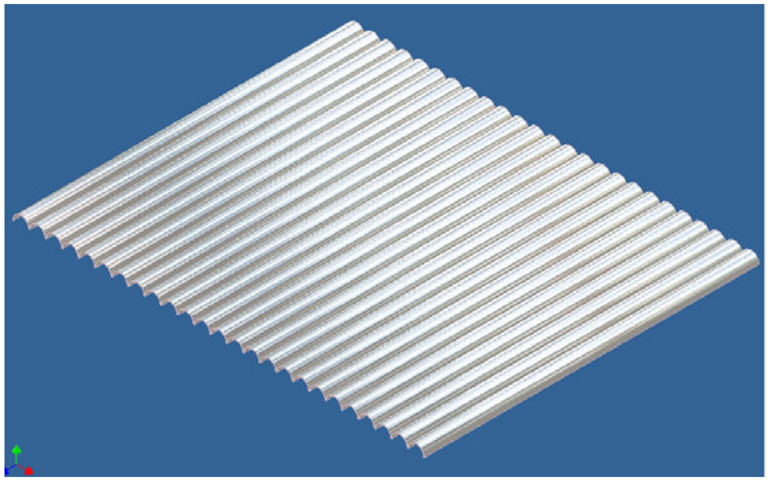

Figure 2. Semi-circular configuration[19]

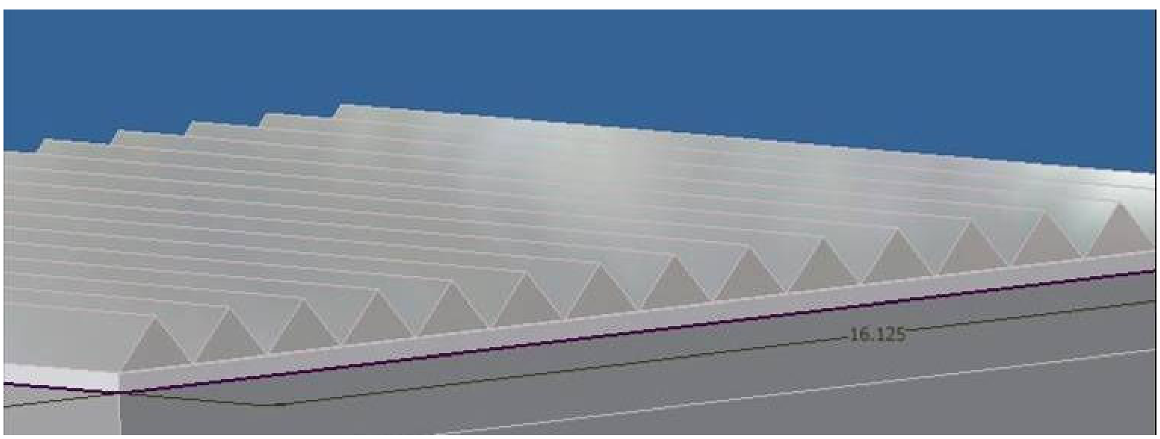

Figure 3. Triangular configuration[19]

Each configuration shape was based on previous experimental results[18] which suggest that corrugated shapes promote better natural convection. Selection of all materials was based on their immediate availability and cost. For instance, sheets of aluminum 1100-H14 and galvanized steel were purchased at a local hardware store at relatively low cost. Each designed prototype consisted of a layer of insulating material and a sheet of corrugated aluminum or galvanized steel as shown in Figure 4.

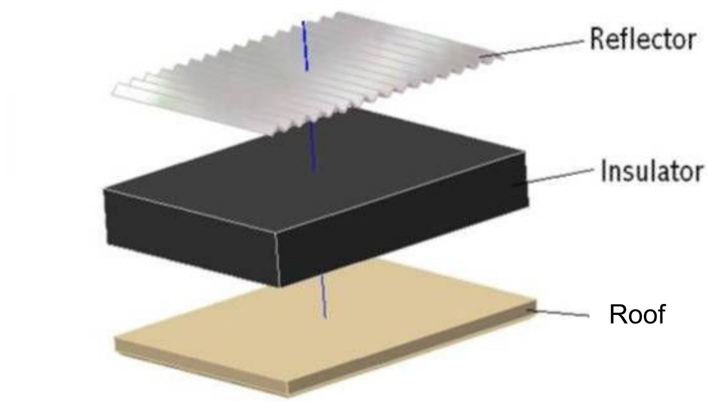

Figure 4. Passive cooling system prototype[19]

Construction and Assembly of Passive Cooling System
Once all the materials and configurations were selected, designed and sized properly, the students proceeded to assemble each prototype. The insulating materials were purchased in sheet form except for polyurethane which was applied as foam. The metallic configuration (corrugated surface) was fabricated in the department's facilities using a mechanical press as shown in Figure 5.

Figure 5. Fabrication of corrugated surface[19]

The corrugated surface then was attached to each insulating material including fiberglass, polyurethane and polystyrene as shown in Figure 6. The thickness of each material was between 3 and 19 mm since thicker insulation did not yield better overall performance from the point of view of cost and energy conservation.

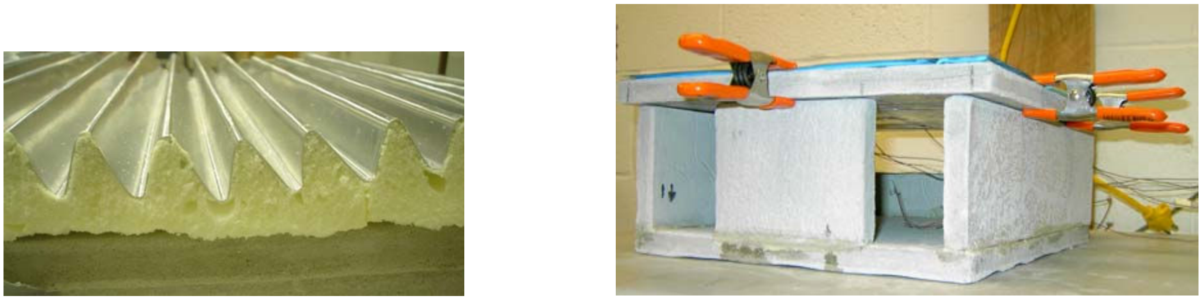

Figure 6. Assembled passive cooling system[19]

Each prototype was placed on lab-scale concrete houses which were built for a related-project. In the next section a full description of the testing protocol and experimental results are presented.

Testing and Evaluation of Passive Cooling System

All the lab-scale passive cooling systems were tested using the lab-scale concrete houses. Two houses (1 control and 1 experimental) had all the required instrumentation including surface-mount thermocouples, heat flux sensors, and a computerized data acquisition system. Each house was positioned identically underneath a 600-W lamp capable of raising the concrete surface temperature to over 45 °C. Figure 7 shows each house, lamps, and a centralized data acquisition system in operation.

Figure 7. Control and experimental houses under 600-W lamps[19]

Figure 8 shows interior surface temperatures for both houses with flat and corrugate aluminum-polyurethane, and corrugated galvanized steel-polyurethane passive cooling systems which the students determined performed better than others material-configuration combinations.

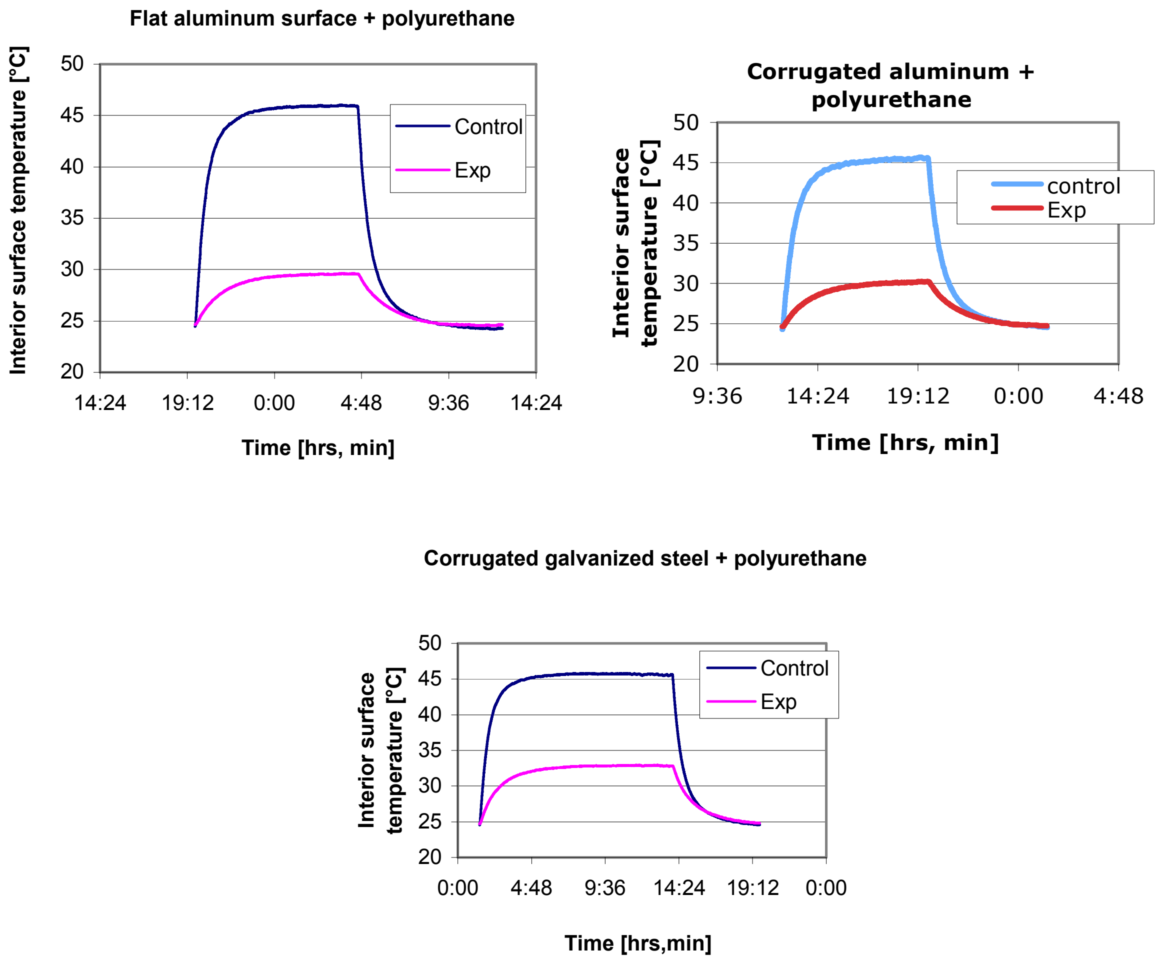

Figure 8. Interior surface temperatures of houses for three passive cooling system prototypes[19]

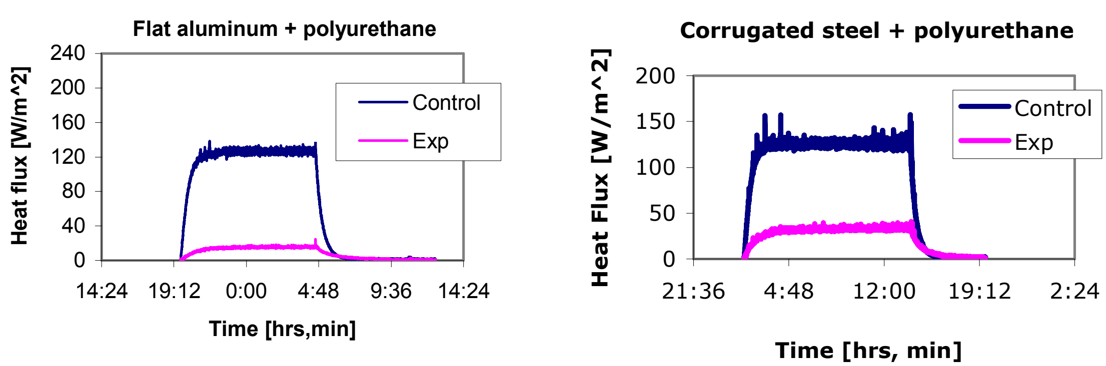

Figure 9. Heat flux measurements of optimal passive cooling systems[19]

The experimental results (Figures 8 and 9) demonstrate that a flat aluminum configuration with polyurethane as insulator minimizes heat conduction through the lab-scale roof the most; however, the students also took into account the cost of aluminum and galvanized steel sheets, and found out that the former costs about four times more than the latter per unit area. As a result, the students came to the conclusion that the corrugated galvanized steel-polyurethane system offers the best trade-off between total material cost and thermal performance, and they selected it as the best overall prototype.

Case Study Assessment
The group of students was evaluated based on the project objectives and stated goals including their ability to design and build mechanical systems within a limited budget. They were evaluated also on how they chose materials, managed time, considered manufacturing and fabrication issues, ran each test, and assessed each designed prototype with little supervision.

Table 1 shows how the technical advisor (faculty member) evaluated the design group. The legend below shows and explains the meaning of each designated letter.

Table 1. Evaluation of design, construction, testing, and assessment activities

Met Design Objectives	Cost Control	Material Selection	Timely Execution	Consideration for manufacturing concerns	Management of experiments	Assessment of prototypes	Overall Score
E	E	E	S	E	G	E	G

Legend:
- **E-**Excellent
- **G-**Good
- **S-**Satisfactory
- **NI-**Needs improvement
- **U-**Unacceptable

Based on the qualitative assessment of the design group, it is clear that the students met the stated objectives satisfactorily. From the students' point of view, they valued each activity and gained a considerable amount of self-confidence during the entire project. The students also appreciated the opportunity to design, build, and test all the prototypes, and being involved in a ground-breaking research project. Other observations worth noting include the students' ability to manage the project and conduct research independently.

Recommendations for future projects

In future projects, the course director and technical advisors should assess prospective projects carefully to determine which ones fit the methodology presented and discussed in the case study. One of the main objectives is to make sure that each project provides students the opportunity to design, build and test a prototype in a single semester. The level of complexity and the estimated time required to complete each project will be used to select and propose an appropriate scope of work. The numbers of students assigned to each project will also depend on the scope of work. Better coordination between the course director and technical advisor(s) is needed to make sure students exceed expectations in all aspect of the senior design course. Currently, several new course management mechanisms are being contemplated including holding bi-weekly meetings with the students, course director, and technical advisors to make sure the students manage their time and resources properly. Future projects should also be evaluated using the criteria used in Table 1 to identify possible areas of concerns and improvement opportunities.

Conclusion

In this paper, a case study is presented which shows how a group of students taking a capstone design course was able to design, build, and test several lab-scale passive cooling systems successfully. The group successfully designed and selected the right materials to achieve the stated goals. The students were able to build and test several prototypes, and concluded that a corrugated galvanized steel-polyurethane passive cooling system is the best option if cost concerns are taken into consideration.

The case study shows that engineering and engineering technology students can undertake a senior design or capstone project that has the main phases of product development in one semester. The case study shows that a design-build-test approach helps students to make the best use of several disciplines including economics, computer-aided design, heat transfer, and manufacturing processes.

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