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Instructional Laboratory Apparatuses Designed and Built by Capstone Senior Design Students

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In this article, the author describes his experience in taking advantage of capstone senior design courses to design and build instructional experimental apparatuses for the thermal laboratory of the mechanical engineering programme at Indiana University-Purdue University Fort Wayne in Fort Wayne, USA. In the last five years, a total of six experimental apparatuses were produced. Four apparatuses were produced by capstone senior design teams composed of mechanical engineering students, while the other two were produced by multidisciplinary (mechanical and electrical) capstone senior design teams. The design projects were externally supported and were accomplished with zero cost to the Department of Engineering at Indiana University-Purdue University Fort Wayne. These types of projects allow capstone senior design students to experience real world design and engineering processes.

INTRODUCTION

Thermodynamics and heat transfer are basic and very important topics that deal with energy, and have long been essential parts of mechanical engineering curricula all over the world. The principles of thermodynamics and heat transfer are based on people's everyday experiences and observations. Mechanical engineers use thermodynamics principles and heat transfer concepts as part of an engineering science to study and design a wide variety of energy systems, such as jet engines and rockets, refrigeration systems, air conditioning systems, chemical processes and power plants. It is essential for thermal engineers to understand the principles of thermodynamics and heat transfer, and be able to employ the rate equations that govern the amount of energy being transferred. However, the majority of students perceive these topics (thermodynamics and heat transfer) as difficult subjects.

Because of these facts, it was decided that experimental apparatuses designed to demonstrate the thermodynamics processes/principles and heat transfer concepts are needed [1][2]. Such apparatuses would enhance and add another dimension to the teaching/learning process of the subjects of heat transfer and thermodynamics. Students would be able to apply thermodynamics principles, such as the first and second laws, and heat transfer concepts that they learned in the classroom lectures to real life applications. This approach could make the subjects of heat transfer and thermodynamics a more pleasant experience for undergraduate mechanical engineering students.

UTILISATION OF CAPSTONE SENIOR DESIGN

Indiana University-Purdue University Fort Wayne in Fort Wayne, USA, is a state-supported institution. Thus, it makes acquiring new instructional laboratory apparatus a challenge due to typical budgetary limitations. In addition, the apparatus designed by companies specialising in education equipment may not exactly reflect the educational objective intended by the faculty. These obstacles forced different venues to be sought and searched in order to acquire experimental laboratory apparatuses for demonstrating heat transfer concepts and thermodynamics processes and principles. It was concluded that such apparatuses can be designed, developed and constructed *in house* within a manageable budget. This can be successfully accomplished by taking advantage of the capstone senior design project and external support, such as the Undergraduate Senior Project Grant Program of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE).

The capstone senior design in the engineering programmes at Indiana University-Purdue University Fort Wayne spans two semesters. In the first semester, the design teams complete their design on paper. In the second semester, they build it and test it. Whenever it is possible, multidisciplinary capstone senior design teams are formed. The multidisciplinary design teams are composed of mechanical and electrical and/or computer engineering students. Each multidisciplinary design team is advised by two engineering faculty members: mechanical and electrical/computer engineering.

These types of design projects (laboratory apparatuses) are comprehensive systems designed to demonstrate thermodynamics processes/principles or heat transfer concepts. Such design projects provide the opportunity for senior design students to experience real world design and engineering processes.

EXTERNAL SUPPORT

The cost of constructing a prototype of finished design is usually high. This is especially true when the design projects deal with practical and real life problems. For small undergraduate engineering programmes with limited resources, such as at the University, the high cost of building these projects tends to cause a problem and hampers the selection of good quality capstone senior design projects. This problem becomes more pressing when the senior design projects are multidisciplinary [3][4]. This focus is to comply with the Accreditation Board for Engineering and Technology (ABET) accreditation criteria, which require that graduates of engineering programmes possess *an ability to function on multi-disciplinary teams* [5].

The ASHRAE has a programme called the Undergraduate Senior Project Grant Program that provides funding (currently, grants up to US$7,500.00 are awarded) for undergraduate engineering senior design projects and technical school projects. These grants are made to the school for the support of the materials required for the project and not to fund school overhead costs, faculty or student salaries. These grants are provided to engineering, technical and architectural schools worldwide. Obtaining these types of grants to support the design, development and construction of instructional laboratory apparatus would greatly help the normally stressed department's equipment budget. In addition, it would provide students with quality and real life design projects to work on.

THE DESIGN PROCESS

The design process that the engineering students follow in the capstone senior design projects is the one outlined by Bejan et al and Jaluria [6][7]. The first essential and basic feature of this process is the formulation of the problem statement.

The formulation of the design problem statement involves determining the requirements of the system, the given parameters, the design variables, any limitations or constraints, and any additional considerations arising from safety, financial, environmental or other concerns.

The second step in the design process is the generation of conceptual designs employing the well-known brainstorming technique. In this step, the configuration and main features of the system are given in general terms to indicate how the requirements and constraints of the given parameters will be achieved. The conceptual design may range from a new idea to available concepts applied to similar problems and modifications in existing systems.

The selected conceptual design leads to an initial design that is specified in terms of the configuration of the system, the given quantities from the problem statement, and an appropriate selection of the design variables. Next comes modelling and the simulation of the system. Modelling involves simplifying and approximating the given system to allow a mathematical or numerical solution to be obtained. Material property data, experimental results and information on the characteristics of various devices are also incorporated in the overall model to obtain realistic results from the simulation. The results from the simulation are used to determine if the design satisfies the requirements and constraints of the given problem. All of these activities are accomplished in the first semester.

In the second semester, the designed teams construct what they have designed on paper in the first semester. Once the construction is complete, they test and evaluate the performance of the system. In this phase, they compare the testing results with the requirements that were specified in the problem statement.

To ensure a successful outcome and to avoid unnecessary delays (students tend to leave things to the last minute), a strict timetable is enforced. The design process is divided into several milestones (tasks) that must be completed by specified deadlines. In the first semester, there are five milestones, namely:

- Problem statement (2 ½ weeks);
- Conceptual designs generation (2 ½ weeks);
- Evaluation of conceptual designs (2 ½ weeks);
- Detailed design of the selected design (6 weeks);
- Final written report and oral presentation (2 weeks).

In the second semester, there are three milestones, specifically:

- Construction of the design (10 weeks);
- Testing and evaluation of the design (4 weeks);
- Final written report and oral presentation (2 weeks).

In addition, in both semesters, the design team meets with the faculty advisor(s) on a weekly basis. Each team member is required to submit a progress report every week. This weekly progress report enables the faculty advisor to gauge the level of time and effort of each team member, thus ensuring the participation of *all* design team members.

INSTRUCTIONAL LABORATORY APPARATUSES ACQUIRED

In the last five years, a total of six instructional laboratory apparatuses were designed, developed and built by capstone senior design students. All six were externally supported through the ASHRAE's Undergraduate Senior Project Grant Program. Two of them were designed and built by multidisciplinary (mechanical and electrical) capstone senior design teams, while the other four were designed and built by senior design teams composed of mechanical engineering students only. Each apparatus is bench-like, portable and fully instrumented. It also should be noted that each apparatus has an instructional (user) manual. These user manuals were developed and prepared by the individual capstone senior design teams. Brief descriptions of the six instructional laboratory apparatuses that were acquired through the capstone senior design courses are given below.

Multidisciplinary Capstone Senior Design Projects

Bench-Top Air-to-Water Heat Pump

A bench-top air-to-water heat pump, shown in Figure 1, was designed, developed and constructed by a multidisciplinary (mechanical and electrical) capstone senior design team. The heat pump was designed to operate on a vapour-compression cycle. It was built

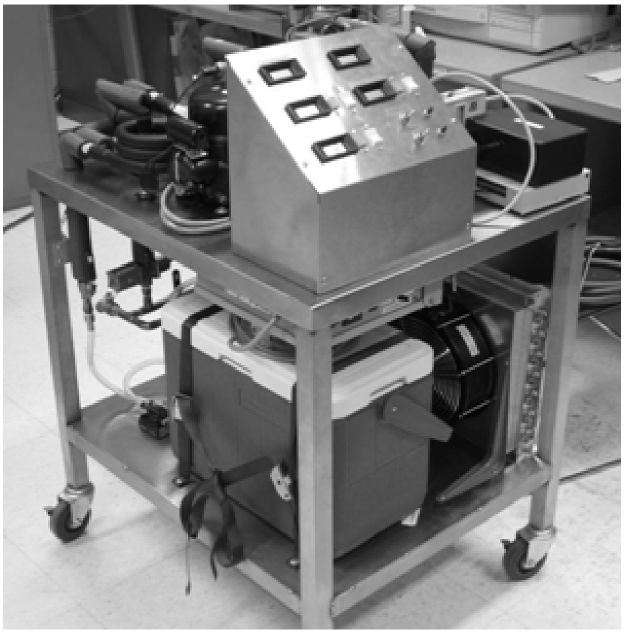

Figure 1: Bench-top air-to-water heat pump.

to allow multiple mechanical set-ups with both closed and open water loops. The electrical system also allows for multiple set-ups with the control of on/off operation of all major components.

The heat pump apparatus is fully instrumented with autonomous gauges so that it could demonstrate the principles without requiring an outside computer. The unit is also outfitted with a data acquisition (DAQ) bus that can be connected to an external DAQ board or software system. This bus is capable of supplying to the external DAQ system the measurements that are shown on the onboard instrumentation.

This experimental apparatus is currently being used to demonstrate to undergraduate students some thermodynamics and heat transfer concepts and principles. A PC-based control system, which consists of *LabVIEW* and a data acquisition unit, is employed to monitor and control this experimental laboratory apparatus.

Air-Conditioning Bench Experimental Apparatus

A bench-top air-conditioning experimental apparatus, shown in Figure 2, was designed, developed and constructed by a multidisciplinary (mechanical and electrical) capstone senior design team.

The air-conditioning apparatus is fully instrumented with autonomous gauges so that it could demonstrate the fundamentals of the refrigeration cycle and psychrometric properties of air, as well as fundamental heat transfer and thermodynamics concepts and principles without requiring an outside computer. The

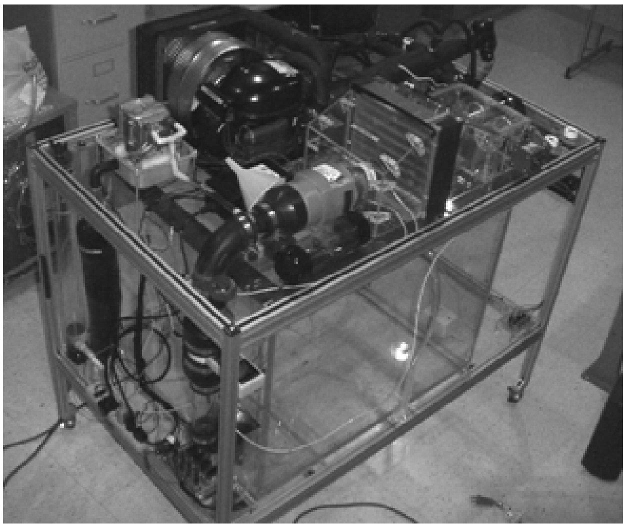

Figure 2: Air-conditioner bench experimental apparatus.

unit can also be connected to an external DAQ board or software system.

This experimental apparatus is currently used to demonstrate to undergraduate students air-conditioning processes such as cooling, heating and humidification, as well as the fundamentals of the refrigeration cycle. The level of cooling, heating or humidification is monitored and controlled using a PC-based control system that consists of *LabVIEW* and a data acquisition unit.

Mechanical Engineering Capstone Senior Design Projects

Solar Water Heating System

An experimental apparatus for demonstrating solar water heating, shown in Figure 3, was designed and constructed by a mechanical engineering capstone senior design team. The system operates using the thermosiphon principle, in which flow through the system is created by density differences in the fluid. The solar water heating system consists of two major components: a storage tank and a solar collector.

The solar collector has the capability to rotate throughout the day to maintain the face of the solar collector directly facing the sun's rays. This is accomplished by the mean of a motor that will be instigated by a Programmable Logic Controller (PLC) with the aid of two light-sensing devices (silicon semiconducting solar cells). This allows students to compare the performance of a regular (fixed) solar collector and a rotating solar collector.

A second glass cover for the solar collector was designed and built. It can be added to the solar collector. This makes it a double glass collector. Students examine the difference in performance between the single and double glass solar collector arrangements.

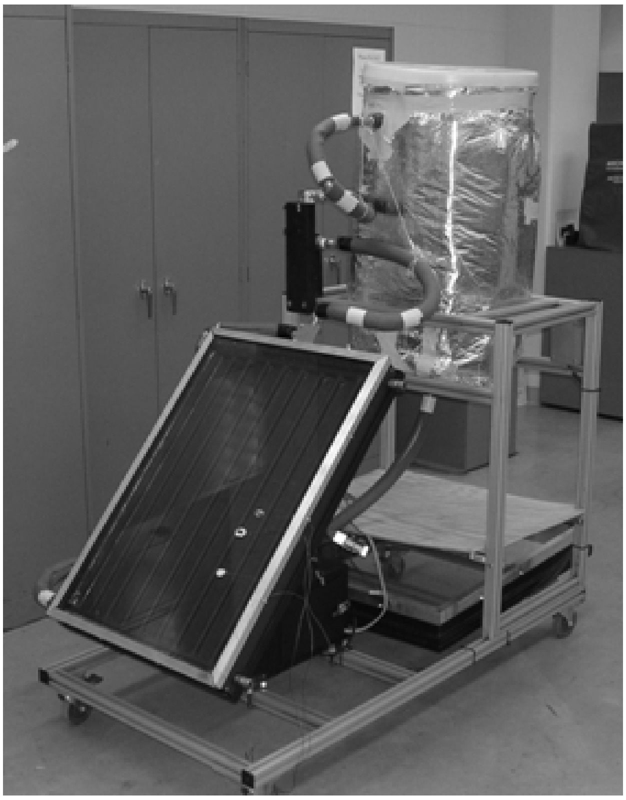

Figure 3: Solar water heating system.

Thermosiphon Heat Recovery System

A portable experimental apparatus for demonstrating the thermosiphon heat recovery concept, shown in Figure 4, was designed and constructed by a mechanical engineering capstone senior design team. Details of this instructional apparatus are reported in ref. [8].

The purpose of this experimental apparatus is to demonstrate heat transfer principles and the concept

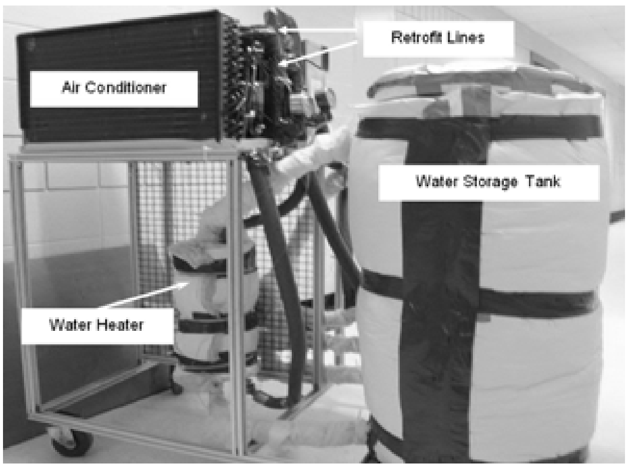

Figure 4: Thermosiphon heat recovery system.

of the thermosiphon heat recovery system. This kind of heat recovery system helps undergraduate mechanical engineering students in understanding the basic heat transfer processes by utilising real life applications, such as using waste heat from a window type air conditioner to heat water for residential and commercial use. Heat recovery from an air conditioner by thermosiphon is attractive because it eliminates the need for a circulating pump.

This apparatus incorporates two types of heat exchangers (water heaters), namely a concentric heat exchanger and a coiled heat exchanger.

Heat Recovery System

A wastewater heat recovery system experimental apparatus, shown in Figure 5, was designed, developed and constructed by a mechanical engineering capstone senior design team. Details of this instructional apparatus are reported in ref. [2].

The purpose of this experimental apparatus is to demonstrate heat transfer principles and heat recovery concepts. This heat recovery system helps undergraduate mechanical engineering students in understanding the basic heat transfer processes by utilising real life applications, such as a wastewater heat recovery system. This kind of heat recovery system is a preheating unit for the incoming cold water of residential and commercial (such as restaurants and hotels) hot water systems. It is designed to recover some of the heat of the wastewater flowing into the sewage system.

This apparatus incorporates two types of heat exchangers, specifically a plate-and-frame heat exchanger and a shell-and-tube heat exchanger. Plate-and-frame heat exchangers are typically used for exchanging heat between two liquid streams and are very effective for water-to-water applications. Shell-and-tube heat exchangers are also commonly used in heat exchange between two liquid streams.

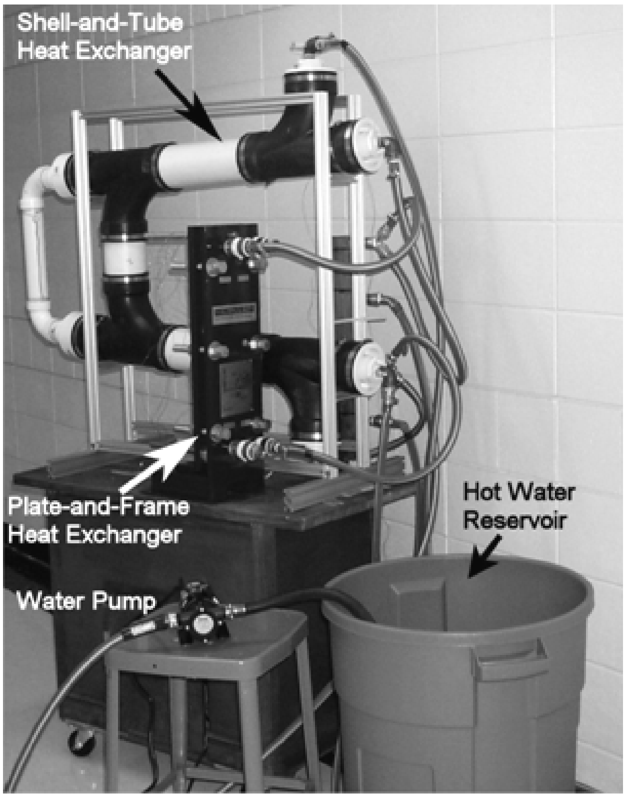

Figure 5: Heat recovery system.

Apparatus for Demonstrating Thermodynamics Principles

A refrigeration system experimental apparatus, shown in Figure 6, was designed, developed and constructed by a mechanical engineering capstone senior design team. Details of this instructional apparatus are reported in ref. [1].

The purpose of this experimental apparatus is to demonstrate thermodynamics processes and systems that are fundamental to understanding the basic concepts of thermodynamics, such as the first and second laws of thermodynamics. In addition, this apparatus demonstrates a vapour compression refrigeration cycle. A set of thermodynamics experiments can be carried out using this apparatus in which the first and second laws of thermodynamics are employed to determine the heat gained by the refrigerant in the evaporator, the heat rejected from the refrigerant in the condenser and the isentropic efficiency of the compressor. The objective of these experiments is to assist undergraduate mechanical engineering students in understanding the basic thermodynamics processes by utilising real life applications.

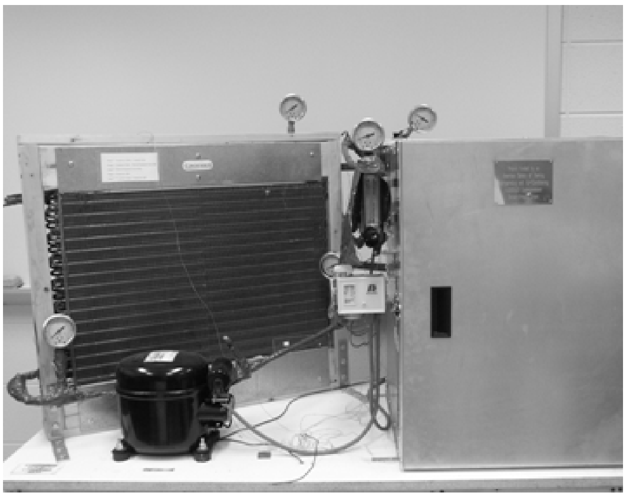

Figure 6: Apparatus for demonstrating thermodynamics principles.

CONCLUSION

This article outlined how an engineering programme can utilise a capstone senior design course to acquire valuable instructional laboratory apparatuses. This has been accomplished with zero cost to the engineering department at Indiana University-Purdue University Fort Wayne. This was made possible for two main reasons: the financial support from the ASHRAE and the effort of a capstone senior design team.

Brief descriptions of six instructional apparatuses that have been acquired through capstone senior design are also presented. These apparatuses are used in several undergraduate thermal science courses to demonstrate the principles of thermodynamics and heat transfer concepts.

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BIOGRAPHY

Hosni I. Abu-Mulaweh received his BS, MS and PhD in mechanical engineering from the University of Missouri-Rolla (UMR) in 1984, 1987 and 1992, respectively. Currently, he is a professor of mechanical engineering and Associate Chair of the Department of Engineering at Indiana University-Purdue University Fort Wayne (IPFW). He is also the overall coordinator of the capstone senior design for the Department of Engineering at the IPFW.

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