AC 2007-801: BEING DR. EVIL: ENGAGING STUDENTS WITH HUMOROUS PROJECT PREMISES

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Being Dr. Evil: Engaging Students with Humorous Project Premises

Abstract

Design projects or open-ended problems are assigned throughout the engineering curriculum at the University of Alabama at Birmingham (UAB). In senior design courses, assigning realworld design projects is imperative to prepare the students for the job they may be performing the following year. In the basic engineering science courses, however, finding design projects that engage the students, that demonstrate the real-world applications of the basic engineering science, and that do not seem like "busy-work" to the students requires imagination. Over the past four years, humorous projects, based on the Austin Powers movie trilogy (parodies of the James Bond movie series and other action and espionage movies), have been extremely successful in keeping students engaged in basic engineering-science projects. Three examples of "Dr. Evil" projects are discussed. One of the projects was assigned in a section of ME 242 Thermodynamics II course and involved the design of Rankine-Brayton combined cycle power plant. The second project was assigned in a section of ME 321 Introduction to Fluid Mechanics and required the students to determine the thrust-reverser turn angle on the Virtucon Inc. corporate jet necessary to stop the jet when landing on the short runway at Dr. Evil's Secret-Lair Island. The final project, assigned in ME 455 Thermal Systems Design, requires the students to design a hot-water heating system for the Secret-Lair's Engineering Office Building. While being funny and engaging students, the projects have also been very useful in 1) providing a ghost audience for the students' technical documents, 2) introducing environmental and ethical concepts, 3) introducing the bidding process, 4) demonstrating the engineering-related implausibility of plots common to many "evil villain-world domination" films.

Introduction

In many ways, this paper may seem to be just another example of what happens when a class clown grows up to become a professor [1-5]. However, the benefits of using humor while teaching are well documented [6-8]. The process of learning is uncomfortable! Teaching with active learning requires asking students questions about material that has not been presented or about material that has only been partially presented. When asked a question to which a person does not know the answer, the individual naturally feels uneasy. Classroom humor relaxes the student and promotes active learning.

Current engineering pedagogy includes the use of design projects throughout the engineering curriculum. In senior-level courses, students are normally motivated and do not need a comical pretense for design projects. At the senior level, students fully understand the relationship between the projects and the work that they may be performing in a few short months.

In sophomore and junior-level engineering courses, which are primarily basic engineering sciences, students often do not understand the purpose of design projects. The level of the material presented in the sophomore and junior-level courses requires that design projects be "birds-eye view" projects. For example in an applied thermodynamics course where power cycle basics are covered, students can "design" a power system, but many of the real component engineering details cannot be addressed by the students. Because of the lack of engineering

component detail, students often find design projects in an applied thermodynamics course to be contrived, simplistic, or simply busy-work. Fictional pretenses are used by many professors to provide context for design projects in basic engineering science courses.

In senior level courses, the primary motivation for fictional pretense for the design projects is to provide a "ghost" audience for the students' report communications. In many informal conversations with colleagues, one of the most frustrating shortcomings of senior-level design projects is a report that is written to the professor. Students are commonly instructed to write for an audience that is a "trained engineer who may not be an expert in the scope of the report." However, students commonly submit reports that are written with a style and composition that only the instructor can understand. Fictional premises constructed with a company and contact name are fantastic mechanisms for providing students with an understanding of the audience for technical project reports.

Over the past four years, humorous projects have been used successfully 1) to keep students engaged in basic engineering-science projects and 2) to provide a specific audience for senior-level design reports. The design project premises have been based primarily on the Austin Powers movie trilogy (parodies of the James Bond movie series and other action and espionage movies) [9-11].

The Projects

"Dr. Evil" projects have been used in three courses that require design projects: ME 242 Thermodynamics II, ME 321 Introduction to Fluid Mechanics, and ME 455 Thermal Systems Design. The projects are described in the following sections and the complete assignments are presented as appendices.

ME 242 Thermodynamics II

Several different projects have been provided in ME 242 over the past four years. Previous topics have included the design of a "50 MW Laser-Power System" and "200 MW Combined Cycle Power Plant." The design project assignment for the Spring 2006 offering of ME 242 is presented in Appendix A.

The Spring 2006 ME 242 project required the design of a 250 MW Combined Cycle Power Plant for the Global "Hot Pocket" factory in the southwestern region of "Kerblockestan." Most of the previous project assignments in ME 242 focused on maximizing cycle efficiency. However, the design criterion for the Spring 2006 project was net power per cost of fuel.

The students, in groups of three, were asked to design a combined Rankine-Brayton power cycle to produce 250 MW. The students were provided a cost of fuel-oil to run the Brayton cycle. The students were also provided a cost of coal available in the southwest "Kerblockestan" area to be used for superheating the steam in the Rankine cycle. Device efficiencies and heat rejection options were also provided to the students. The students were then asked to maximize the specific power, *SP*, defined as the net combined cycle power per unit cost of all fuels used, in

kW·hr/\$. While not stated in the project assignment, the students were limited to a maximum of two reheat processes for either Rankine or Brayton component cycle.

Appendix A also indicates another recent change in project metrics to engage and challenge the students. Previous project metrics were split into an oral report portion (30%), a design portion (35%), and a written report portion (35%). Recently, the scores on the design portion have been made competitive across the groups. That is, individual groups receive a base design score that is dependent on the accuracy of their calculations, the achievement of the design parameters, and the feasibility of the design. To arrive at the group's final design score, the base design score is then multiplied by the ratio of the group's specific power, *SP*, to the maximum *SP* achieved by any group in the class. This change in scoring has increased student participation, brought more realism to the group interactions, limited cross-group information exchanges, and invigorated project presentation day. The students also claim that the competitive scoring system has added a bit more "*evil*" to the projects.

Over the past four years, student performance on the ME 242 projects has far surpassed instructor expectations. The students are required to create their designs using Mathcad and steam and air thermodynamic property functions created for the class [12]. Using Mathcad, many groups have identified good strategies for cycle optimization based on perturbation or "hunt-and-peck" methods. Other groups have used more of a brute-force technique using many pre-selected variations to find an optimum cycle. Figure 1 presents the results from one student group using a brute-force technique to identify the fact that, for the fuel costs provided in the Spring 2006 ME 242 design project, any operation of the Brayton cycle increases the cost of power opposed to using the coal-based Rankine cycle alone.

Most surprisingly for the Spring 2006 project, two groups attempted to use the "Given-Maximize" or "Given-Minimize" structures in Mathcad with the thermodynamic property functions to optimize their cycle specific power. Using the two structures in Mathcad, users generate functions of multiple variables and then create a set of restrictions on the parameter. Mathcad then uses a modified Newton-Raphson technique to find the set of variable values that maximizes or minimizes the function. Unfortunately for the two groups, the nature of the combined-cycle optimization caused Mathcad to find local-maximums for specific power based on the groups' initial guesses that were less than the class maximum specific power. However, consideration was given to the groups for ingenuity and resolve.

ME 321 Introduction to Fluid Mechanics

Appendix B presents the project assigned during the Fall 2003 offering of ME 321 Introduction to Fluid Mechanics. The project required designing a thrust reverser to retrofit the Gulfstream II business jet owned by Virtucon Inc., the cover company for Dr. Evil's empire. The thrust reversers were needed to safely land the Gulfstream II on the 0.5-mile landing strip on Dr. Evil's Island. The specifics of the Gulfstream II's engines and landing drag characteristics of the Gulfstream II were provided to the students. Three different worst-case scenarios were provided, and each group of three students was instructed to select the required turn angle of the flow to allow the jet to stop on the short landing strip.



Figure 1. Example Chart and Combined Cycle From ME 242 Student Project Report

The primary aspects of the design and analysis were 1) the determination of the jet exhaust velocity and thrust through the engine cycle analysis and 2) the integration of the nonlinear differential equation describing the deceleration of the jet during landing. Each group used Mathcad including the thermodynamic property functions for the cycle analysis and incorporating the "rkfixed" function for integration of the nonlinear differential equation. The combination of the thermodynamic property functions and the "rkfixed" function in Mathcad enabled the students to, when possible, easily select the flow turn angle required stop the jet. One of the worst-case scenarios did not enable the jet to stop on the 0.5-mile landing strip. To circumvent this problem, each of the two groups assigned that scenario, separately asked to and was allowed to select a reasonable thrust-reverser turn angle and identify the minimum braking force required to stop the jet. Neither group was willing to accept "it is not possible," and both groups independently searched for alternative stopping methods.

ME 455 Thermal Systems Design

The design project assigned for the Fall 2006 offering of ME 455 Thermal Systems Design is presented in Appendix C. The project requires the design of a hot-water heating system for a building to house the engineering support offices associated with Dr. Evil's Secret Lair Facility. The students, in groups of three, were asked to design the boiler, one air-handling unit, and the piping system; select an appropriate pump; and perform a Hardy-Cross system simulation to verify system operation.

The project assignment for ME 455 is different from the project assignments in the basic engineering science courses in that it is divided into a letter from a fictional company and a design packet. This division reflects the fact that most senior-level engineering students understand the importance of their design classes and their relationship to their future practice. Most senior-level students do not require fictional pretenses to engage them with their design projects. The letter with fictional pretense is provided solely for formal written and oral report audience identification.

Discussion

Student response to the projects in each of the three courses has been excellent. Whether the student groups have been assigned or at the students' choice, most groups have developed a sense of ownership for their work on the projects and many groups added twists or extra effort beyond the minimum requirements of the project. While evidence is only anecdotal, complaints regarding lack of group member participation have also decreased.

In all of the courses, the "Dr. Evil" projects have been extremely successful in providing the students with a proper audience for their technical communications. While a few students or groups still write report sections in a style and format that are directed towards the instructor, the presence of the ghost audience allows for more constructive and fruitful criticism of student work.

The projects have been a huge success in introducing the bidding process for engineering jobs. Assignments reflecting the true bidding process are difficult to create within the context of most engineering courses. For the projects presented in the appendices, the requested result is a design; however in the real world, a letter from a client would more likely be a request for proposals for design and possibly construction management. Only after a competitive bidding process would a contract be awarded and substantial design work be initiated. To emphasize this point and initiate discussions about the real bid and commercial work process, the sentence, "Because of time and secrecy constraints, the normal bidding process will not be observed," has been included on all "Dr. Evil" projects since 2004.

While a specific survey form has not been created to evaluate the effectiveness of the projects in improving student learning, indirect evidence is provided through student evaluations of instruction. At UAB, students are provided twenty statements to which they can strongly agree (4 points), agree (3 points), disagree (2 points), or strongly disagree (1 point). Table 1 presents a summary of the course evaluation results for statements most directly related to the use of humor in the classroom and in the assignments. The results are presented only for the last offerings of the courses discussed with available student evaluation results. Table 1 demonstrates that the average student response for the statements most related to the use of humor in assignments is more than one-quarter point above the UAB, School of Engineering average student response for the statements.

Students in courses with "Dr. Evil" projects have also provided some excellent feedback in response to the question "What did you like most about the class/the instructor?" on the UAB Student Evaluation of Teaching form. Examples of student responses related to the above question from courses using "Dr. Evil" projects and related to the projects and to the use of humor in the course are:

ME 321, Fluid Mechanics, Fall 2003

"Personality, attitude, civil engineering jokes."

"Enthusiastic about the subject."

| Student Evaluation of Teaching Statement | Fa 03, ME 321 | Fa 05, ME 455 | Sp 06, ME 242 | Average | SoE Running Average | Difference |
|--|---------------|---------------|---------------|---------|------------------------|------------|
| Instructor was enthusiastic about teaching the subject | 3.813 | 3.800 | 3.857 | 3.823 | 3.570 | 0.254 |
| Improved understanding of concepts and principles | 3.813 | 3.867 | 3.786 | 3.822 | 3.433 | 0.389 |
| Course has challenged me to think | 3.625 | 3.667 | 3.857 | 3.716 | 3.465 | 0.251 |
| Instructor motivated me to do my best work | 3.563 | 3.667 | 3.679 | 3.636 | 3.362 | 0.275 |
| Assignments contributed to my learning experience | 3.438 | 3.533 | 3.667 | 3.546 | 3.421 | 0.126 |
| Mean Value | | | | 3.709 | 3.450 | 0.259 |
| Students Participating | 16 | 15 | 28 | | | |
| Students Enrolled | 21 | 16 | 29 | | | |

Table 1. Student Evaluation Results Related to the Use of Humor in Assignments

ME 455, Thermal Systems Design, Fall 2005

"His presentation."

"...Dr. McClain does a great job teaching one of the most valuable ME courses."

ME 242, Thermodynamics II, Spring 2006

"This is a very knowledgeable, insightful instructor. It is a joy to learn from him. He forces you to think and challenges you as a student..."

"The projects and how they applied to real engineering problems."

"I enjoyed the instructor's knowledge and enthusiasm of the subject matter. He really enjoys teaching this class."

The direct effects of using humorous project premises cannot be isolated with the teaching evaluations and the student comments. However, the evaluations and comments combined with the extraordinary efforts of selected groups, which were discussed earlier, definitely indicate that the students have responded to the teaching style and project assignments.

Unintended Consequences

The projects have also resulted in several unexpected consequences. For example, many of the student groups have become quite creative with their team names and fictional design firms responding to the request for designs. Many students use their imaginations and create documents that are certainly interesting reads for the professor! Because of the relationship to the Austin Power's movies, however, many student groups create designs where everything costs "One-*million* dollars."

The projects have presented excellent opportunities to discuss ethics and global and societal impact related to EAC of ABET criteria 3(f) and 3(h) [13]. Especially in ME 242 when many of the students see the Dr. Evil projects for the first time, the pretenses usually raise questions such as "Should we consider construction labor costs?" or "Would Dr. Evil pay for labor costs?" and other questions related to ethics. The competing costs of energy from different types of fuels and their related pollution issues is certainly a primary and contemporary concern of power companies. In the ABET current culture and use of "direct assessments," projects based on fictional and comical pretenses provide many opportunities for the students to demonstrate understanding of ethical and contemporary societal issues.

The projects have also been useful in demonstrating the implausibility of many "world domination" movie plots. Most "world domination" schemes would require significant effort requiring far more engineers that one independent leader and a few henchmen. Not only would a money trail be present, but outside of a rogue government's help and shelter, significant engineering and construction trails would also be present and identifiable by an astute intelligence agency.

Caveats

While the fictional or comical pretenses for design projects in engineering courses are successful in engaging students, instructors must take precautions and choose the pretenses well. The situations cannot portray the instructor as a "crack-pot" and subvert the authority of the instructor. One of the most important ways to avoid this is to make sure the students understand how seriously the instructor considers the education of the students and why the comical pretenses are being used.

Finally, the premises cannot be too dated or too obscure. Because of the popularity of the Austin Powers trilogy, the "Dr. Evil" projects have been excellent in engaging the students. However, the original Austin Powers movie is now a decade old, so a new comical pretense may be needed in the near future.

In anticipation of the retirement of the "Dr. Evil" projects, several new topics and premises are being considered. In ME 242 Thermodynamics II, possible future topics are:

- 1) Related to the movie *Zoolander*: The design of a co-generation power system supplying steam for a textile factory making fabrics for Mugatu Inc.'s "Derelicte Campaign" and producing 50 MW of power [14].
- 2) Related to Cartoon Network's animated *Squidbillies*: The design of a 100 MW power plant to provide power for Dan Halen Inc.'s future "Glug: Pine-Cone Liquor" distillery to be located in northwest Georgia [15].

Each of the topics has great potential. While the movie *Zoolander* (2001) is already six years old, the co-generation system for Mugatu's "Derelicte" campaign has excellent opportunities for cycle design assignments. The *Zoolander* premise would also allow the use of excellent adapted

quotes from the movie such as "You will *learn*" power cycle design and "Obey my dog!" in the project assignments.

The *Squidbillies* distillery power plant also provides interesting cycle design opportunities. Since distilleries are dependent on fluid and thermal processes, and the premise could also be used for heat exchanger design premises and piping network design premises for the ME 455 Thermal Systems Design course. Since not all students have cable TV or watch Cartoon Network's Adult Swim late on Sunday nights, however, the premise may be too obscure. Since the premise also deals with "pine-cone liquor," the topic might not be appropriate for ME 242 where many of the students are second semester sophomores and may be under the legal drinking age. While the premise may be controversial or obscure, the students who know the show (and admittedly the professor) would find the premise absolutely hilarious. Because of the premise's potential, a little effort may be expended to refine the premise and make it more suitable for assignment.

Conclusions

For the past four years, design project premises based on the *Austin Powers* movie trilogy have been used to engage students. The projects have been very successful and have also been very useful in 1) providing a ghost audience for the students' technical documents, 2) introducing environmental and ethical concepts, 3) introducing the bidding process, 4) demonstrating the engineering-related implausibility of plots common to many "evil villain-world domination" films. While care must be taken in selecting of the right premise, using the comical pretenses for the right purposes, and ensuring the students understand the seriousness of their engineering education, fictional and comical pretenses can be extremely motivational and beneficial for students in basic engineering science courses and also for students in senior-level design courses.

Acknowledgements

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Virtucon Inc. Engineering Division 416 Secret Lair Blvd. Dr. Evil's Island, EI 99999-0999

March 15, 2006

Director of Engineering Generic Engineering Consulting, Inc. 1150 10th Ave. S., BEC 257 Birmingham, AL 35294-4461

SUBJECT: RFD for 250 MW Combined Cycle Power Plant

Dear Director of Engineering:

As part of "Preparation J," designs are requested for a Brayton-Rankine combined cycle power plant capable of producing 250 MW in the Soviet break-away republic of Kerblockestan. The new power plant is required to meet the demands of a growing population and rising standard-of-living and to provide power for corporations constructing new manufacturing facilities, including the proposed "Hot Pocket" factory, in the southwestern region of Kerblockestan.

Because of limitations in materials from the "black market," the gas-turbine systems are limited to maximum pressures and temperatures of 3 MPa and 2200 K. The Rankine cycle components are limited to maximum pressures and temperatures of 14 MPa and 1000 °C. The combined cycle may either reject heat to the atmosphere at 310 K or to ocean water at 300 K. All compressors should be assumed to operate with 92% efficiency and all turbines (air and steam) will operate with a 95% efficiency. The air-to-steam boiler will operate with an effectiveness of 90%, and the steam cycle condenser must be designed with at least a 10 K temperature difference to the heat sink.

Recent "crack downs" by OPEC and the U.N. have limited our ability to "divert" fuel oil from suboceanic pipelines for power production. Fuel oil ($Q_{HV,oil} = 43,000 \text{ kJ/kg}$) for the gas-turbine combustor must be purchased at the government subsidized cost of \$0.70/gal (U.S.). While as much heat rejected from the gas-turbine (Brayton cycle) as possible may be used to heat steam for the Rankine cycle, a coal burning boiler/superheater may also be used. However, the quality of coal found in the southwest-Kerblockestan area is poor with a low heating value ($Q_{HV,coal} = 29,000 \text{ kJ/kg}$) and high ash and sulfur contents. Because of the coal transportation costs and flue-gas cleaning costs, the overall cost of the coal will be \$60/ton (U.S.).

Because of time and secrecy constraints, the normal bidding process will not be observed. Your company must submit a design; insolence will not be tolerated. Preliminary designs are due April 10, 2006, and final design reports must be submitted by April 20, 2006. Oral presentations must be made on April 20, 2006 to the Virtucon management. The engineering firm submitting the design with the lowest cost per MW·hr will receive the construction contract. All other engineering firms will be "liquidated," beaten in a burlap sack, and/or ritualistically shaven.

Sincerely yours,

Moustafa

Moustafa V.P. of Engineering and Senior Henchman

Group Assignments

| (Names removed to protect the innocent!) | |
|--|--|
| | |
| | |

Project Grade Distribution

| Oral Presentation (30%) | Every group member must speak, MS PowerPoint based, Must be professional quality (will be graded for organization, aesthetics, graphics) |
|----------------------------|---|
| Design (35%) | Accuracy of calculations, Achievement of design parameters Feasibility of design System performance relative to performance achieved by other groups (Design score will be multiplied by SP/SP _{max} where SP is the groups power per \$US. SP will have the units of kW·hr/\$.) |
| Written Presentation (35%) | Must have a letter of submission (cover letter) Executive summary that briefly describes your final design Formal section with thorough discussion of design and analysis technique (discussion of optimization process) Schematic of system and cycle T-s diagram Created in MS Word, using equation editor. (Equations created in Mathcad and pasted into Word are NOT acceptable.) |



Virtucon Inc. Engineering Division 416 Secret Lair Blvd. Dr. Evil's Island, EI 99999-0999

November 4, 2003

Director of Engineering Generic Engineering Consulting, Inc. 1150 10th Ave. S., BEC 257 Birmingham, AL 35294-4461

SUBJECT: Thrust Reverser for Gulfstream II

Director of Engineering:

Virtucon Inc. requests proposals for retrofitting the company's Gulfstream II business jet with thrust reversers. The thrust reversers are needed to safely land the Gulfstream II on the 0.5 mile landing strip on Dr. Evil's Island. The major design result is the required turn angle of the flow. The Gulfstream II is powered by two Rolls–Royce MK511-8 turbojet engines, each with a pressure ratio of 20, an intake diameter of 30 in., and a maximum temperature of 2200 F. At landing conditions, the Gulfsteam II has a drag coefficient of 0.20 and a frontal area of 48.7 ft².

For one of the three options below, determine the minimum flow turning angle for the thrust reversers:

- 1) Landing speed of 150 mph, landing weight of 62000 lbf, and no brakes
- 2) Landing speed of 140 mph, 61000 lbf weight, with partial brakes ($F_b = 1000$ lbf)
- 3) Landing speed of 155 mph, 58500 lbf weight, and partial brakes ($F_b = 1200$ lbf)

Your final design submission must include:

- 1) Cover letter
- 2) Executive Summary that briefly describes your final design
- 3) Detailed thermodynamic, fluids, and dynamic analysis in a formal report justifying your design and demonstrating that the plane can land within the specified length
- 4) System Drawing and a Free Body Diagram detailing the forces on the aircraft

Preliminary designs are due on November 25, 2003. Paper and electronic copies of your final reports must be received by December 4, 2003. Insolence will not be tolerated.

Sincerely,

Moustafa

Mustafa, Henchman and Senior Engineer

Group Assignments:

| Group 1 (Names removed to protect the innocent.) | Group 2 | Option 1 |
|---|---------|----------|
| Group 3 | Group 4 | Option 2 |
| Group 5 | Group 6 | Option 3 |

Drawings:



Figure 1. Sketch of Virtucon Inc. Business Jet



Figure 2. Image of Actual Thrust Reverser on Cargo Jet [16]



Virtucon Inc. Engineering Division 416 Secret Lair Blvd. Dr. Evil's Island, EI 99999-0999

November 22, 2006

Director of Engineering Generic Engineering Consulting, Inc. 1150 10th Ave. S., BEC 257 Birmingham, AL 35294-4461

SUBJECT: RFD for Secret Lair Boiler System

In support of Operation "Bananarama," Virtucon Inc. requests a design for a boiler system for the new Secret Lair Engineering/Office Facility. Despite the proximity of the office building to the volcano lair, the local climate requires the building be created with boiler system. The design must specify all piping, pumps, fittings, chillers, and air-handling units. The initial equipment cost, the annual cost of operation, and installation costs must be specified in the design. More details regarding the proposed system are enclosed with this letter in a design packet.

Because of time and secrecy constraints, the normal bidding process will not be observed. Your company must submit a design; insolence will not be tolerated. Oral presentations must be made on December 13, 2006 to the Virtucon management. The company submitting the design with the lowest annual amortized cost will receive the construction contract. All other companies will be "liquidated," beaten in a burlap sack, and/or ritualistically shaven.

Sincerely yours,

Moustafa

Moustafa V.P. of Engineering and Senior Henchman

Enc: Proposal packet

ME 455/555 Thermal Systems Design

Design Project 3: Boiler System Design and Simulation Due: December 6, 2006

An architect has designed an office building with seven thermal zones. Figure 1 presents the general layout of the building. A boiler/hot water system is to be designed to heat the office building.

Water enters the boiler at 120 °F and must be heated to140 °F. Refrigerant R-134a enters the boiler as a saturated vapor at 155 °F and leaves as saturated liquid. The boiler should be designed as a shell-and-tube heat exchanger with the R-134a flowing through the tubes with $h_i = 3500$ BTU/(hr·ft²·°R).

The boiler is to be used to heat seven thermal zones. In each zone, an airhandling unit must be designed to heat air using the hot water from the boiler. Table 1 presents the heating requirements for each zone. The air-handling units are to be tubeand-fin, cross-flow heat exchangers with the water flowing through the tubes. Water enters each air-handling unit at 137 °F and leaves at 122 °F. After being mixed with outside air, return air enters the air-handling unit at 65 °F and exits at 85 °F.

To complete the design of the hot-water heating system, you must:

- 1) Design the boiler and one air-handling unit,
- 2) Using schedule 40 wrought iron pipe, design a piping system for the office building heating system (requires a layout drawing!),
- 3) Determine the power required by the pump and the valve settings needed to achieve the minimum flow rates required for each zone,
- 4) Select a pump from the Goulds website and locate/specify an expansion tank required to avoid system over pressurization and pump cavitation,
- 5) Specify an estimate the cost of the piping, the fittings, and the cost of the pump, the boiler, and air-handling units,
- 6) Calculate the annual operating costs,
- 7) Perform a Hardy-Cross system simulation to demonstrate that the system will perform as required.

A formal report is required, but the narrative may be integrated into a MathCAD document. Drawings of the system are required. The final document must also contain a letter of transmittal; a one-page executive summary summarizing the design method, the results, and the final cost of the system; the narrative; a bibliography; appendices of all manufacturer information.

The **executive** summary should be written for a manager or someone with a business degree. The body (narrative) **should fully document each step in the design process** and be written for an engineer who may not be an expert in heat exchanger design, piping system design, or pump design and selection.



Figure 1. Building Layout and Relative AHU Placement

| Zone | Description | Expected Heating Load | | |
|------|--|------------------------|--|--|
| | | (ft ² /ton) | | |
| 1 | Office Space, First Floor, East Wing | 650 | | |
| 2 | Office Space, Second Floor, East Wing | 650 | | |
| 3 | Office Space, Third Floor, East Wing | 500 | | |
| 4 | Office Space, First Floor, South Wing | 750 | | |
| 5 | Office Space, Second Floor, South Wing | 750 | | |
| 6 | Office Space, Third Floor, South Wing | 550 | | |
| 7 | Lobby, Viewing Deck, Exec. Offices (Glass Walls) | 500 | | |