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Integrated Capstone Design in Architectural Engineering Curriculum

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Dr. Ahmed Cherif Megri, Associate Professor of Architectural Engineering (AE). He teaches capstone, lighting, electrical, HVAC and energy design courses. He is the ABET Coordinator for the AE Program. His research areas include airflow modeling, zonal modeling, energy modeling, and artificial intelligence modeling using the support vector machine learning approach. Dr. Megri holds a PhD degree from INSA at Lyon (France) in the area of Thermal Engineering and "Habilitation" (HDR) degree from Pierre and Marie Curie University - Paris VI, Sorbonne Universities (2011) in the area of Engineering Sciences. Prior to his actual position, he was an Associate Professor at University of Wyoming (UW) and prior to that he was an Assistant Professor and the Director of the AE Program at Illinois Institute of Technology (IIT). He participated significantly to the development of the current architectural engineering undergraduate and master's programs at IIT. During his stay at IIT, he taught thermal and fluids engineering (thermodynamics, heat transfer, and fluid mechanics), building sciences, physical performance of buildings, building enclosure, as well as design courses, such as HVAC, energy, plumbing, fire protection and lighting. Also, he supervises many courses in the frame of interprofessional projects (IPRO) program.

Areas of Interests: - Zonal modeling approach, - Integration zonal models/building energy simulation models, - Zero Net Energy (ZNE) building, - Airflow in Multizone Buildings & Smoke Control, - Thermal Comfort & Indoor Air Quality, - Predictive modeling and forecasting: Support Vector Machine (SVM) tools, - Energy, HVAC, Plumbing & Fire Protection Systems Design, - Computational Fluid Dynamic (CFD) Application in Building, - BIM & REVIT: application to Architecture and Electrical/Lighting Design systems.

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Abstract:

All Architectural Engineering students are required to complete a two capstone senior design project course (Senior Project I and Senior Project II). The students work in groups on projects covering architectural design, structural design, mechanical design, and lighting/electrical design. These projects are open-ended and get a chance to pull together the many things they've learned in classes throughout their undergraduate degree. The classes are taught by four instructors and judged by both instructors and practitioners.

The senior capstone design course 1 (Senior Project I) requires a group project involving a complete design that may contain a host of modules including architectural design, structural and foundation design, cost estimating, building mechanical and lighting/electrical system design, building occupancy and accessibility studies, elevator design, etc. The Capstone design course is a multi-disciplinary effort; and as such it may involve other disciplines in addition to those in architectural engineering. As a minimum, the project always involves an architectural design, mechanical (HVAC), electrical and lighting systems design, structural and foundation design, and at least one other module such as cost estimating, construction scheduling, green building and sustainable concept design, etc.

Within the senior capstone design course 2 (Senior Project II) students are divided into two offices or more, each office is divided into design groups, and each group is responsible of only one design component: architecture, structure, HVAC or Lighting/electrical. An office standard prepared by the department of civil, architectural and environmental engineering is distributed over the students.

This paper proposes a curricular paradigm which allows students to work in groups on a single, large, real-world problem over multiple terms. Experiences and outputs from the course can be used to provide guidance and insights into curricular changes, teaching methods, and exposure to the practice. It also helps in establishing durable connections with the industrial sector.

Most importantly, project methodology will be discussed. We discuss the capstone design program from students' point of view, and the experience earned in design, integration, and also in written and oral communication skills. Methodology used to evaluate the effectiveness of the capstone design program in term of learning outcomes is also described.

1. Introduction:

Capstone senior design experiences are both a graduation requirement for undergraduate engineering majors and for ABET accreditation of these programs. A senior design course is typically the last bridge for students between undergraduate education and the engineering profession in their respective disciplines. The course differs from other lecture and laboratory based courses in the engineering curriculum in fundamental ways.

The purpose of capstone design course, required of all seniors, is to provide a realistic experience by integrating basic material learned during the engineering undergraduate program to address real-life design problem from schematic phase into the construction design levels, including advanced engineering design aspects in certain selected focus areas of technical discipline.

There is no unique model for teaching multidisciplinary capstone design in Architectural Engineering. Capstone design courses are different from one University to another. While, few Universities focus only on one topic (mechanical or structural for example), others focus on multiple trades: architecture, structural, mechanical, and lighting/electrical. Few have one semester capstone; others have it for two consecutive semesters. This paper will highlight the multidisciplinary projects. Multidisciplinary projects where collaboration between disciplines on projects usually working on design teams, but usually is being enrolled in separate independent courses or in a one unique course.

This paper proposes a curricular paradigm which allows students to work in groups on a single, large, real-world problem over multiple terms. Experiences and outputs from the course can be used to provide guidance and insights into curricular changes, teaching methods, and exposure to the practice. It also helps in establishing durable connections with the industrial sector.

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2. Architectural Engineering Design Experience

All Architectural Engineering students are required to complete a two capstone senior design project course sequence (Fall-Senior Project I and Spring-Senior Project II). We believe that a two-course sequence is more effective for the level of design assignments that the students are required to solve. The two-semester sequence allows the students to spend more time to acquire design knowledge and to consult with practitioners and faculty. It also allows the faculty to require work that is of a higher-level of detail and engineering standards. This arrangement provides 30 weeks of contact with the professors. This set-up allows for more interactions, reporting and presentations.

The students work in groups on projects covering architectural design, structural design, mechanical design, and lighting/electrical design. These projects are open-ended and get a chance to pull together the many things they've learned in classes throughout their undergraduate degree. The classes are taught by four instructors and judged by both instructors and practitioners from the AE industry.

The senior capstone design course 1 (Senior Project I) is a course where students apply what they have learned in earlier courses to prepare schematic designs and design development drawings and calculations for a midsize building. This course requires a group project involving a complete design that may contain a host of modules including architectural design, structural and foundation design, cost estimating, building mechanical and lighting/electrical system design, building occupancy and accessibility studies, elevator design, etc. The Capstone design course is a multi-disciplinary effort; and as such it may involve other disciplines in addition to those in architectural engineering. As a minimum, the project always involves an architectural design, mechanical (HVAC), electrical, and lighting systems design, structural and foundation design, and at least one other module such as cost estimating, construction scheduling, green building and sustainable concept design, etc. The deliverables required for these courses include oral and poster presentation of the project and a complete set of documents including BIM drawings of all designs. The capstone design course is intended for students to use their knowledge gained in all previous courses in a realistic project that would involve a major design experience.

The senior capstone design course 2 (Senior Project II) main objective is to provide students with an opportunity to gain design experience in a simulated professional office environment. Each student prepares calculations and construction documents for one discipline, while serving on an interdisciplinary team including the following disciplines: Architecture, Structures, Heating and Air-Conditioning, and Lighting and Electrical. Within the senior capstone design course 2 students are divided into two offices or more, each office is divided into design groups, and each group is responsible of only one design component: architecture, structure, HVAC or Lighting/electrical. An office standard prepared by the department of civil and architectural engineering is distributed over the students.

This course teaches the student how to prepare a final set of discipline specific construction documents, including engineering calculations production drawings, and specifications. The student will discuss contracts, ethics, and construction administration as they relate to the project.

Autodesk Revit 2013 is pivotal in system design. This program allowed students to layout the architecture plans, sections and elevations of the architecture plans, structural, ductwork, piping, lighting fixtures, power panels, power and lighting circuits, schedules, and system components. It provided students with 3D views of everything they design so they could visualize exactly how everything fit in the building structure. It also allowed them to make numerous iterations quickly and effectively. On top of these features Revit is also capable of doing pressure loss calculations, sizing procedures, and system classifications. Annotations were placed throughout the model at the end and it indicates the size and flow of every component in the system. This was a vital tool that helped the design team provide a quality product.

The members of the advisory board represent the most common specialties of Architectural Engineering including HVAC, electrical, lighting, plumbing and fire protection, energy, construction management, and structures. This group of professional engineers has been donating their time and efforts to help in the capstone design courses and help the program in aspects such as the response to the support survey for the Program Educational Objectives. As well, this group of people serves for guidance and as evaluators for the final work.

The capstone design experience lasts a full year. The project commences with a meeting between students, practicing engineers and the instructors and a site visit. The project ends with a report and oral presentation. This provides students with a proposal writing experience and clarifies the project for the student team and the client.

Progress reports are due over the semester. These reports include different steps of the project, codes and standard research, and design alternatives. Oral reports of the project and progress report are made to the senior class by each office.

While student teams have been successful in their projects, the process has not always been without exempt of problems. It is important to have the necessary information circulating between the different groups of the same office and each group provides the necessary information needed from the others. For instance, the structural group needs to know about the weights and locations of the HVAC equipment located on the roof. In the same time, the electrical group needs to know about the rating, voltage and the power of different HVAC equipment. Activities and interactions between the groups are very primordial at the beginning of the project, so that problems can be identified and addressed early.

Design is not only project-based for public or private works, but can also involve problem solving and innovation in terms of technological applications and development of new means and methods. It is important to have a program that satisfy ABET requirements and not to use ABET as program development guide.

3. Project Methodology and case study:

The two capstone design courses are complementary. In Fall semester, all the students are divided into groups of two or three students. All the groups have to go through the design process for all trades (at least architecture, structural, mechanical and lighting/electrical), starting from schematic design and moving toward the design development. The semester is divided into two distinctive parts for schematic and design development.

The second semester, the construction documents is being accomplished. Based on the number of students, usually the students are divided into two offices or more, where each office includes 4 groups. Each group is assigned to one trade (architecture, structural, mechanical, lighting/electrical).

The integration and collaboration between the groups of each office is primordial for each office. The information moves between the groups continuously. The first meeting of the spring semester, all the students meet with the instructors and the best two projects from Fall semester are selected for the two offices.

Depending on the situation and the opportunities, usually the project is suggested by an AE firm or an MEP design company. This connection with the industry is resourceful in multiples ways. First, these companies serve as guidance for the students, provide them with resource of information and knowledge and most importantly serve as judges for the final work. The most important aspect of these two capstone courses is the coordination with other trades, architectural, structural, mechanical, lighting/electrical, plumbing, and others to minimize conflicts in the work execution.

The study starts by gathering information about the project, building AutoCAD drawings, building area and height, and rooms' dimensions. Next, the building's group occupancy identification, and decide if the building is mixed-use or separate-use. The construction type is determined depending on the construction materials and the materials combustibility.

The next step is to determine if any special use and occupancy requirements will apply, such as the case of malls, and high-rise buildings, and other special occupancy. The building zoning is designed by different groups and the occupant load is then estimated. The means of egress are established, such as the number of required exists with respect to the remoteness.

Case Study:

Mechanical Components:

Trade-offs and choices are made to achieve the proposed design/construction solutions, usually for economic reasons. For the actual project, multiple integration and/or trades-offs have been made between different disciplines:

- If possible, the HVAC units are not located on the roof, consequently the structural system is more simplified and economic, since it does not include the mechanical systems weights.
- Electrical/lighting criteria, take into account the energy code and energy saving (0.8 W/ft^2 was considered as the maximum density for lighting).
- Use of VFD system to control the HVAC fans to save energy: the integration of HVAC, electrical and controls design, and the vital role of information in managing an efficient and comfortable environment.

Objectives

Our objective is to design the mechanical systems for an 18,000 square foot commercial building and to utilize integration approaches to achieve minimum energy waste, as well as maximum human comfort satisfaction. This is a new building with the majority of the building being finished space, while a small portion on the second floor, the west side of the building roughly spanning 2840 square feet is to be leased or used at a future date. The building is designed for the location, Laramie, Wyoming. The owner of the building requires that the building needs to be heated to 70 degrees Fahrenheit, and cooled to 75 degrees Fahrenheit. The relative humidity can vary from 10-50%.

To satisfy the building load calculations, we determined that the best system for this building was an air-water system. A hydronic system is needed to heat the perimeter spaces of the building. The rest of the system is all air. To satisfy each zone, a VAV was sized and placed to take care of the heating and cooling conditions. On the first floor, there are 19 zones and consequently 19 VAV boxes and on the second floor, there are 16 zones and 16 VAV boxes. Design of the zones was done repeatedly and scrutinized heavily to ensure the satisfaction of every building occupant.

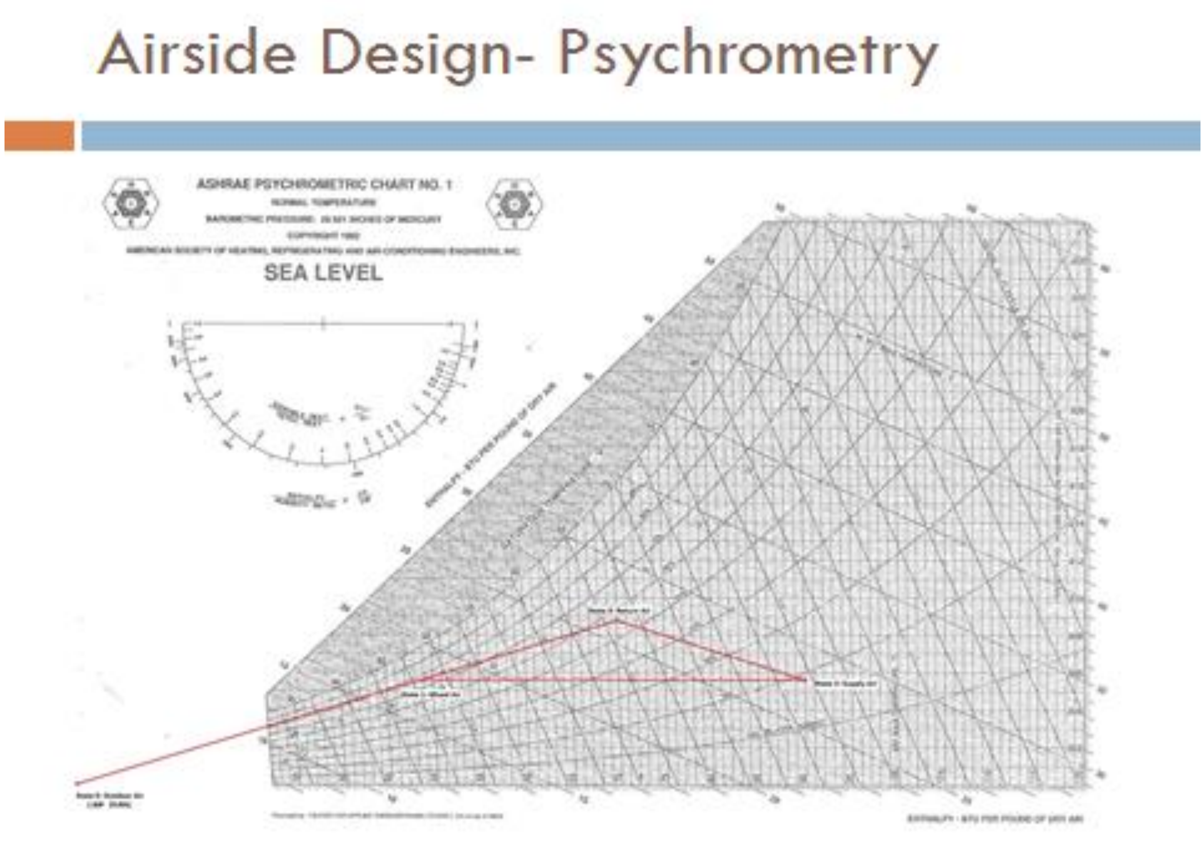
Throughout the design process there were several codes which were adhered to. The main code used throughout the design process was the 2011 International Building Code (IBC). We also used the appropriate NFPA documents, along with the NEC. For outdoor air quality, both IBC and ASHRAE 62.1 were utilized, and for all wall and window U-values the ASHRAE 90.1 Standard and ASHRAE handbook fundamentals 2009 were employed.

Psychrometrics Processes and Load Calculation

Psychrometrics

Using the psychrometric chart, the process of heating or cooling air for supply to building spaces could be determined and adjusted. The first step in determining the psychrometric processes at work in the air handling unit was to determine the outdoor conditions for heating and cooling in Laramie, WY. Design temperature for heating was found in the ASHRAE handbook fundamentals 2009 to be -30˚F. At this temperature, there is no relative humidity, humidity ratio, or wet bulb temperature. This value is not found on the psychrometric chart provided by ASHRAE, so its position was estimated in the margins of the diagram. This condition was found to be at 84˚F dry bulb, and 54˚F wet bulb.

After plotting the outdoor conditions onto the psychrometric chart (Figure 1), the interior design conditions were determined. These conditions were determined from the project guidelines to be 70˚F for heating conditions and 75˚F for cooling conditions. Appropriate wet bulb temperatures were determined by design team to be at 60˚F for both conditions. These conditions were plotted onto the psychrometric chart, and a line between this "return" state and the original outdoor state was determined, known as the "mixing line". Using an equation to determine the humidity ratio of the mixing condition by knowledge of the outdoor and return conditions, the mixing condition was found by intersecting the humidity ratio and the mixing line. As a rule of thumb, it was determined that air would be supplied at 20˚F above design conditions for heating, and 20˚F below design conditions for cooling. This allowed the "supply" state to be determined by locating the respective dry bulb temperatures, and following the vertical line up until its intersection with the humidity ratio found at the mixing condition.



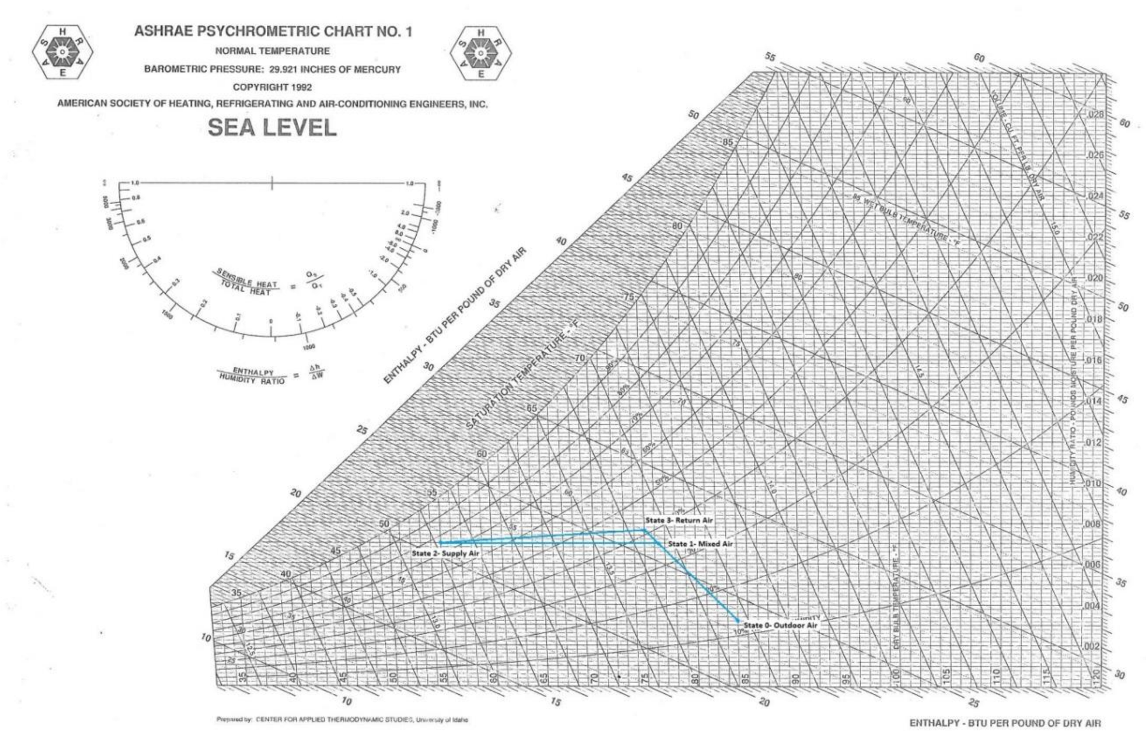


Figure 1: Psychrometric charts for heating (a) and cooling (b) seasons

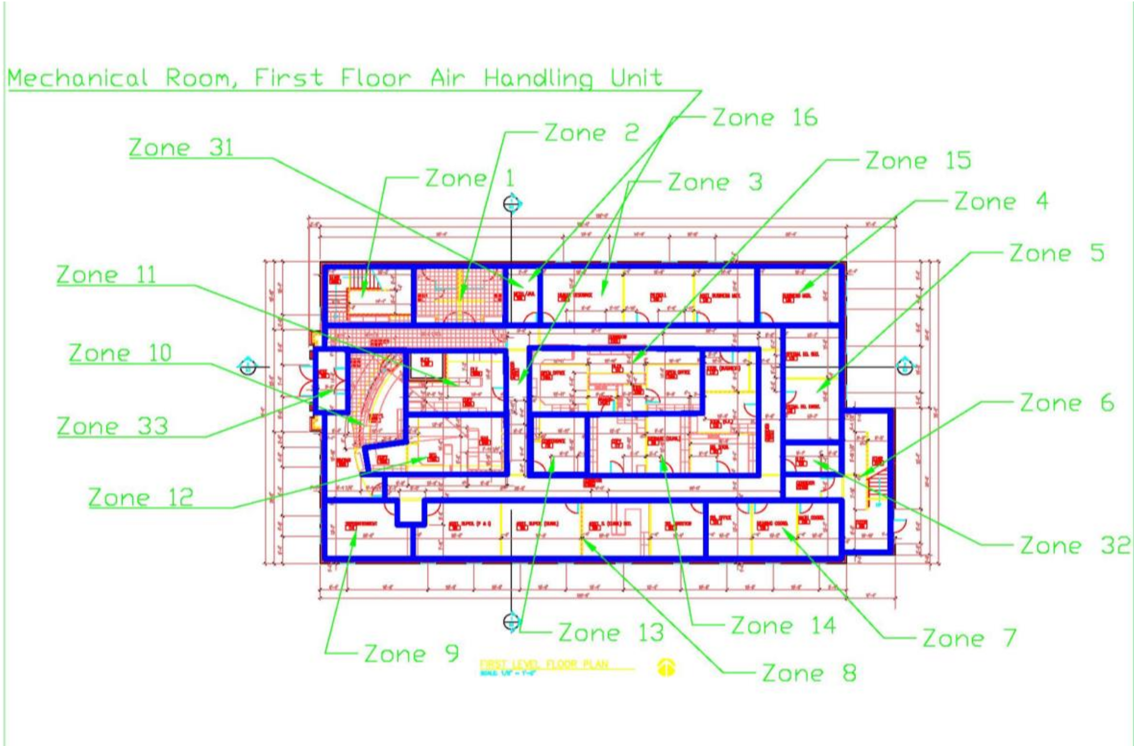
<u>Wall and Windows Input</u>: In determining our walls and windows U-Values ASHRAE Standard 90.1 and ASHRAE handbook fundamentals 2009 were utilized. We went with all of the base values stipulated by them.

<u>Outside Supply Air</u>: To determine the amount of required outside supply air we used a spreadsheet which utilized both IBC and ASHRAE standard 62.1. In this spreadsheet room occupancy classifications were given along with their areas and the normal number of occupants. Based on these simple variables the program then calculated the optimum required amount of outdoor air needed to satisfy ASHRAE Standard 62.1. These values were then used in our project to ensure our complete compliance with the IBC and ASHRAE standards.

<u>Zoning</u>: Zoning the building was a process done in iterations with the load calculations. One of the parameters that can be adjusted with the software used for load calculations is the grouping of spaces, or zoning. Part of adjusting the load was adjusting zones, to ensure that a given space was not demanding too much of the air handling unit. Many rounds of trial and error were completed before arriving at the final zoning design. The zonings of these two floors are shown below (Figure 2).

<u>Load Calculations</u>: Before design work could begin, an understanding of the building load requirements was needed. Load analysis was run using CHVAC Elite software. The software required a variety of inputs to determine the load that the building would be subjected to. Information about the location of the building was needed to determine climate conditions. Dimensions of each space in the building were needed, along with placement of windows, area of glass, and U values for all windows, walls, ceilings, and floors. Information about air changes, infiltration rates, and air handling equipment were input.

Many of these values were based on educated assumptions made by the design team, as well as values recommended by the program. Load calculations were run, and adjustments were made as needed in order to put the loads into a reasonable range.



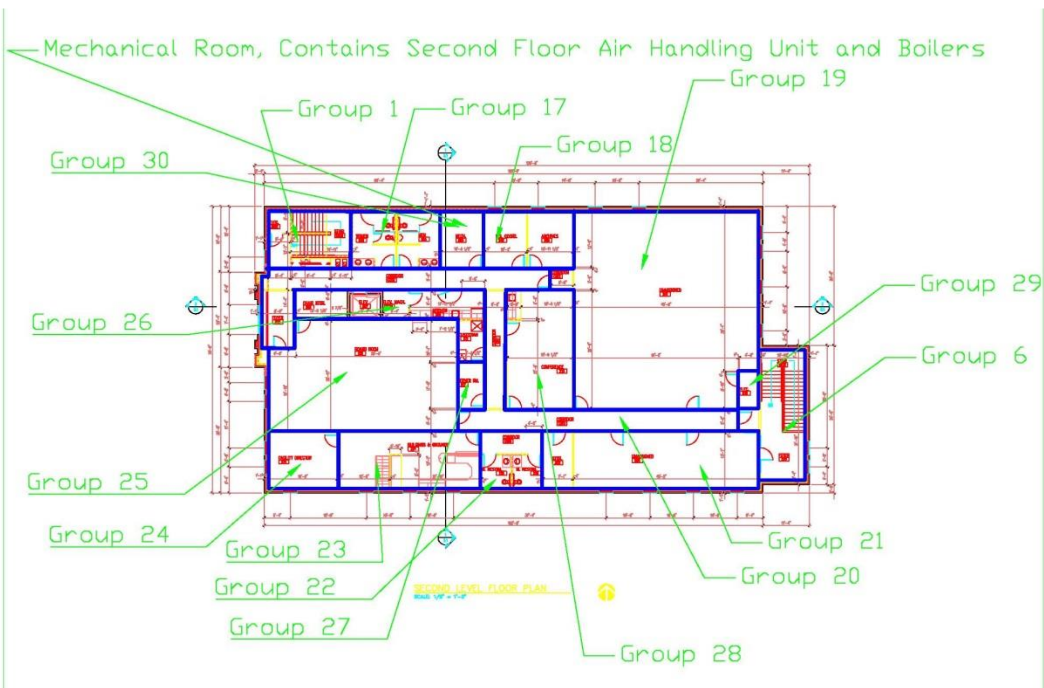


Figure 2: Zoning for both first and second floors

System selection

Heating system: The heating of the central zones is assured partially by the air handling unit and by the VAV boxes where the air is heated to 90 degrees Fahrenheit. For the perimeter zones, the load is additionally handled by baseboard heaters.

Baseboard Heating Procedure: To design the baseboard heating system the program "HVAC solutions" was utilized. The load calculations from the Elite software were plugged into the program and the system selection and sizing was completed. The results were two main pumps running at 26.1 GPM. Also the glycol feeder was accordingly sized at 26.1 GPM. There is also a small pump before each individual VAV box. The two main pumps and the glycol feeder are located in the second floor mechanical room. The small VAV pumps are located in the piping system right before each VAV.

Hydronic System: Our hydronic system has several main components. It consists of a boiler, two main pumps, an expansion tank, VAV pumps, air separator, strainer, piping, and the numerous baseboard heating units. The boiler heats the fluid which brings energy to the system for space heat. The main pumps move the fluid throughout the system. An expansion tank relieves excessive pressure or generates pressure when needed for the system. The VAV pumps provide heated fluid to each VAV. The glycol feeder feeds glycol into the system just as a pump would. When the pressure in the loop falls below a set point glycol is added to make up for losses due to leakage. The air separator removes air from the system to ensure the efficiency of the system. The strainer removes any impurities in the liquid to again optimize the system. Piping simply carriers the fluid throughout the building to the various baseboard heaters, and the baseboard heaters deliver thermal energy to the space.

Cooling System: The cooling is assured using a DX Unitary Systems, where the evaporator is in direct contact with the air stream, so the cooling coil of the airside loop is also the evaporator of the refrigeration loop. Factors affecting the decision to select DX Unitary or Chiller-Based Applied systems include:

- Installed Cost
- Energy consumption
- Space requirements
- Freeze prevention
- Precision
- Building height, size, shape
- System cooling and heating capacity
- Centralized maintenance
- Stability of control
- Individual tenant billing

This system is composed in our air handling unit and our condensing unit, both of which are located on the roof. Our air handling unit has two of the DX Unitary cooling coils to ensure that for the worst Laramie weather conditions we can supply cooled air at 55 degrees Fahrenheit.

Air Handling Unit: To size the air handling unit the information from out load calculations along with Carrier AHU Builder software was utilized. The result was one two phase air handling unit, which indicates the method in which. This air handling unit has a capacity of 1,500 to 60,500 nominal CFM. From our Elite load calculations we determined that we would operate our air handling unit at 28,800 CFM. Because of the high mixed air temperature, 65 degrees Fahrenheit we did not need heating coils, but we did need two DX coils for cooling. The heating was done by the VAV's and complimented by our baseboard heating system. Our air handling unit also contains variable frequency drives to help with efficiency. On top of that we did not need louvers in our air handling unit because we decided to place the unit on the roof. It was simply too large at 15' 4"x 19' 11"x 8' 8" to place in either of our mechanical rooms. This unit also weighs 7,338 pounds.

Air System: Our air system has several main components. The system contains an air handling unit, various VAV's of varying size, the duct work, the plenums and the return grilles. The air handling unit treats the air for cooling conditions and distributes air throughout the system. The VAV's heat the air for each of the zones they are responsible for. The ductwork carries all of the air throughout the building. All of the main trunks of the ductwork are rectangular. The ductwork heading into each VAV needed to be circular, and all of the small trunks of the main lines consisted of circular ductwork which transitioned into flexible ductwork as it attached to the plenums. The plenums distribute the air to the varying spaces and the return grilles return the used air to the air handling unit. These components work together to ensure the indoor quality.

Fans: Fans are a major component of the air handling system. Fans move air through the ductwork system and within spaces. In VAV air distribution systems, fans must operate at capacities varying from as low as 20% to 100% capacity. Because of this fluctuation in demand, selecting an appropriate fan is one of the most important parts of air distribution design.

Pumps: Pumps drive the fluid flow in HVAC systems. For our project, pumps were required for VAV units and the boiler. Selection of both pumps was done using the WebCAPS selection tool available through the Grundfos website at http://www.grundfos.com. The boiler pump selected was a NB 32-125.1/140 A-F-A-BAQE which is a non-self-priming, single stage centrifugal pump. The VAV pump selected was an ALPHA 15-55 LCF 165 which uses a permanent magnet motor design to circulate water.

Boiler: Boilers provide heat to air-handing unit's heating coil for space heating, baseboard, and heater units used to heat the stairs. A Mach all aluminum condensing boiler was selected that provides 96% efficiency with a capacity of 1,500,000 BTU/hour, and uses untreated glycol.

Lighting/Electrical Component:

A building electrical system is composed of different components, designed and assembled into a safe, functional power-delivery system, according to the NEC code. The building's electrical system is connected to the utility system. A pad-mounted transformer or a bank of transformers mounted overhead on a utility pole. The underground service connects the utility system to building's main distribution panel (MDP). Located within the MDP is the main building over-current device, or main disconnect, as well as individual over-current devices for the system components connected to the MDP. The MDP may also contain provisions for utility metering, as well as instrumentation for the measurement of system voltage and current.

The main disconnect device can be either a circuit breaker or a fused switch. The Electrical load estimation is based on considering all the systems, such as estimated general illumination load, heating/cooling electrical load, power load, and any other electrical loads, such as elevators and kitchens. An estimated load of 0.1 kilowatt per square meter of habitable area may be used to countercheck the estimated load.

The exact electrical rating of all equipment, HVAC, plumbing are provided by the HVAC design group. Other loads, such as elevators and escalators, kitchen and others are provided by specialized companies. Consultation of the local company as regards the point of service entrance, service voltage, metering equipment and other requirements for power connections; the same should be done for the telephone system.

The feeder is the wire feeding the panelboard. The branches are the branches coming off of the panelboard. For example one spreadsheet can be used for the Main Distribution Panel of a buildings electrical service with a limited number of larger circuit breakers feeding risers, elevators, air conditioning equipment etc. Other schedules may be developed for lighting panels, power panels, heating and air conditioning equipment panels and elevators panels and the loads from each of these other panels can then be used as the loads for each branch of the MDP.

The preparation of the riser and/or one-line diagrams to include the main distribution panels, load centers, switchboards or switchgears, and other service equipment. The feeder, sub-feeder sizes and all protective equipment ratings are computed.

4. Survey and Project Evaluation:

The design course instructors are having discussion regarding the selection between two-semesters integrated capstone design course versus two independents capstone design courses, where the first one will be prepared by the students to participate to national competitions, such as ASHRAE and AIE design competitions and the second semester will be oriented toward an integrated design performed in collaboration with the industry. Another important aspect of this course is how the students see this course toward their preparation to their future. The importance of integration in also surveyed.

The survey questions are:

<u>Question 1</u>: The importance of having two semesters capstone integrated design course vs. two independent design courses? (Not at all Important, Very Unimportant, Neither Important or Unimportant, Very Important, Extremely Important)

<u>Question 2</u>: How you see the importance of integration between the four design trades (architecture, structure, mechanical, lighting/electrical)? (Not at all Important, Very Unimportant, Neither Important or Unimportant, Very Important, Extremely Important)

<u>Question 3</u>: The importance of this course to help you to be prepared for the industry? (Not at all Important, Very Unimportant, Neither Important or Unimportant, Very Important, Extremely Important)

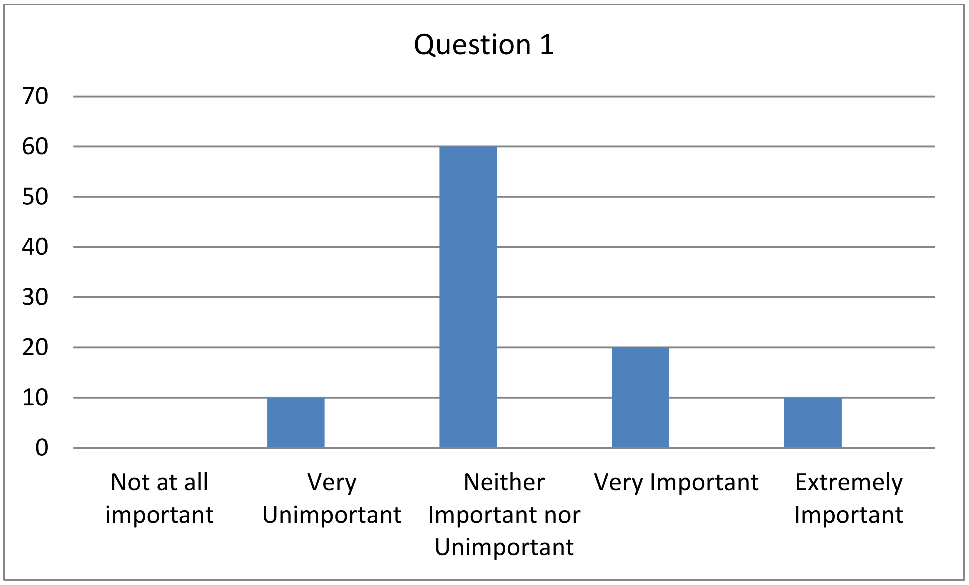


Figure 3: The importance of having two semesters capstone integrated design course vs. two independent design courses?

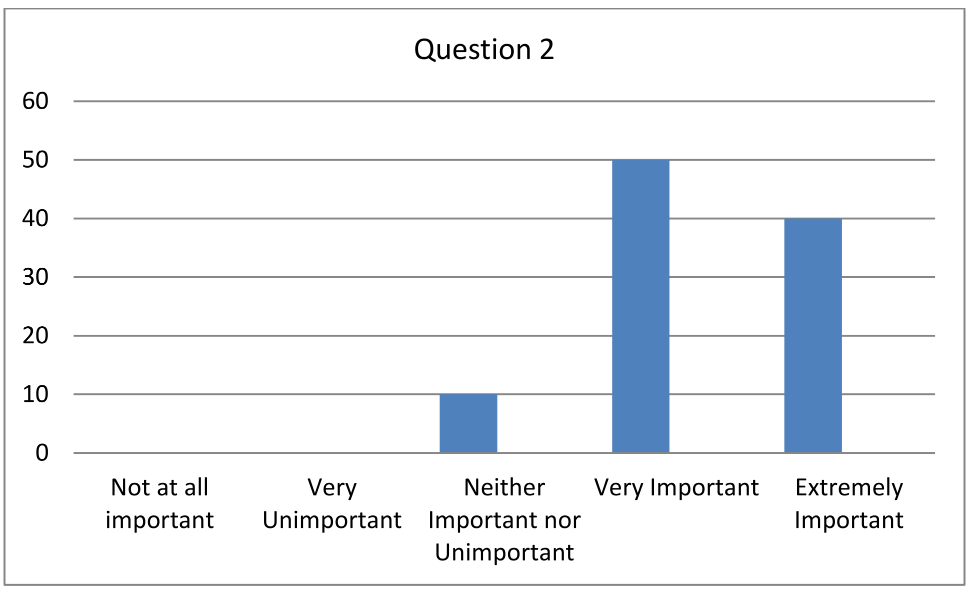


Figure 4: How you see the importance of integration between the four design trades (architecture, structure, mechanical, lighting/electrical)?

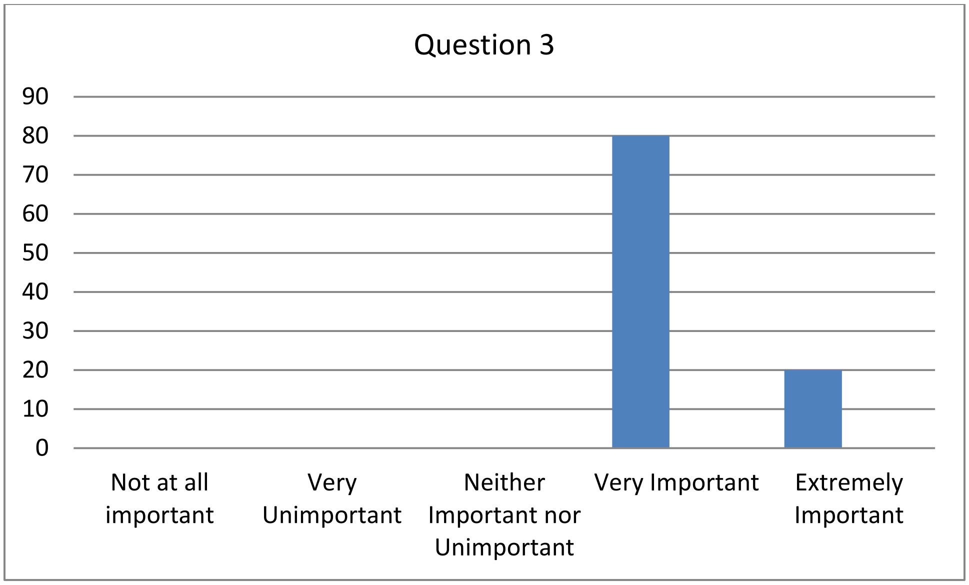


Figure 5: The importance of this course to help you to be prepared for the industry?

Here, responses of design students to Questions 1, 2, and 3 are summarized. The survey focuses only on global questions regarding the course. A detailed questions need to be surveyed in the future to recognize the importance and also how to improve different aspects of this course.

As a second step, the instructors' point view need to be surveyed regarding these aspects, since the students' answers are conditioned by other considerations, such as those who are concerned by graduation in December, where two independent capstone courses are more suitable for them. Also, the aspect of participating to national competition affects the result of the survey.

In parallel with the self-evaluation of each course by the instructor, we also conduct a course evaluation by students. This topic is a part of the HVAC laboratory course. The course objectives introduced earlier in the course are again provided to the students at the end of the semester. The students' input on whether the materials offered have met the objectives is then complied and used in the program outcome assessment process. Results of instructor course evaluations (conducted by students) are reviewed by the Department Chair and the Dean and shared with the faculty.

Each faculty member also conducts an evaluation of performance of students in his/her courses as part of the Program objectives and outcome assessment process. A summary report on the performance of students (to meet the Program objectives) and compliance with the Program outcomes is prepared and submitted to the Department Chair for the assessment purposes.

Future plans to evaluate the effectiveness of the capstone in term of learning outcomes: Actions that will be implemented to improve the effectiveness of the curriculum in term of learning outcomes:

- We expanded on the instructors' self-evaluation such that more direct assessment of students' learning outcomes is obtained. A set of standards for instructor's self-evaluation will be prepared by the faculty and the Board of Advisors and will be implemented with the annual assessment cycle. The main point of these standards is that the evaluation of students' performance will based on samples of work in three categories of students: those in the upper 75 percentile, those in the 50 – 75 percentile and those below the 50 percentile populations. Thus the assessment results compiled are based on course performances and grades, exams, projects, presentations of students, and writings as required in some courses. Furthermore, each course specifically addresses the learning outcomes and relation between the course and the Program outcomes, the methods used for the evaluation of students' performance and the relevance of the course materials to the Program outcomes following the standards adopted for the assessment process.

- Students will be provided with the course descriptions including learning objectives and outcomes. Students also will provide their input on the Program outcomes. The results from this instrument are used along with those from the instructors' self-assessment of courses as a means to ensuring compatibility in results obtained.
- A more rigorous process in assessing the learning outcomes of this lab course will be implemented, which are in parallel with the Program outcomes. The following outlines process will be used for this capstone course assessment.
    - Individual instructor evaluation of the degree of learning achievement of individual students on a capstone team, which includes consideration of the collective achievements of the team.
    - Peer evaluation (optional by instructor).
    - Grading of deliverables by the instructors.
    - Teamwork survey.
    - Self-assessment.

5. Conclusions:

Capstone design are courses where students have the freedom to make their design of the architecture design, structural, mechanical systems, and lighting/electrical on a real building, under the supervision of four instructors and the guidance of multiple designers from the industry. Student progress is discussed twice a week and during the office hours. Participation in the capstone course provides another opportunity for students to apply knowledge they learned during several other courses. In the first course, the trades are conducted in sequence. However, in spring, the trades are conducted in parallel. All students collaborate to achieve a final project. For example, the weight of HVAC systems is transmitted from mechanical students to structural students to be considered for mechanical loads and later the structural students transmit the structural design to mechanical students to be considered for duct layout.

The capstone design is conducted in two phases: preliminary and final design. Within the preliminary design an estimated budget is calculated based on simplified assumptions. The final design is based on actual data regarding weather data and the building information collected from different sources.

The capstone design program has been positively accepted by the students, and has provided them with a comprehensive experience in both design and systems integration. Students are required to use multiple software programs that are commonly used within the industry, and learn the fundamentals of architecture, structural, mechanical, lighting/electrical design process through an actual project, from its architectural drawings through its construction. Finally, it provides the students an opportunity to improve their skills in both written and oral communication.

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