
AC 2011-2609: CAPSTONE COURSE: HVAC SYSTEMS DESIGN AT UNIVERSITY OF WYOMING

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Abstract:

The architectural engineering program at the University of Wyoming offers four HVAC courses, beginning with the fundamentals of HVAC and culminating in a capstone design course. This paper describes the experiences we encountered over the past several years while developing and teaching the HVAC curricula in the Architectural Engineering program. We emphasize the importance of how such disciplines as thermodynamics, fluid mechanics, heat transfer and electricity together create a successful curriculum. In addition, we describe briefly the history of the architectural engineering curriculum at University of Wyoming, the capstone design HVAC project, and the HVAC design process.

Most importantly, project methodology will be discussed, beginning with system selection (fan coil, VAV (Variable Air Volume) terminal box, under floor air distribution system, displacement ventilation and beam system), heating and cooling load estimation, systems sizing, airflow distribution, commissioning and culminating with administrative topics. We demonstrate this methodology through the use of a comprehensive design project.

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:

The HVAC Capstone Design course consists of the mechanical systems design for a multi-story building, and utilizes the architectural drawings of an actual project under construction to develop the mechanical system design. The goals of this course are to gain an overall understanding of the mechanical design process, and to understand the mechanical building systems, their interrelations and their relationships with the architectural, structural, mechanical and electrical building systems. Mechanical systems designed by the students will include the heating and cooling systems (designed to maintain predetermined conditions) and the mechanical room, which will house the air systems and the heating and cooling equipment (including any heat recovery equipment required).

Coursework is divided into two phases: preliminary design and final design. Specific requirements for preliminary and final design submittals, as well as intermediate assignments and required submittals, are provided. The preliminary design phase concludes (approximately four weeks into the course) with formal oral presentations delivered by the students that include

their recommendation for a system, based on the evaluation of at least two different system designs. This oral presentation is delivered to fellow students, faculty and practicing engineers. The final design phase requires students to prepare a design packet comprised of a set of final calculations, drawings (including mechanical plans – with specific assignments to be determined at a later date) with selected sections and details for the mechanical systems, and a notebook detailing their project's design process.

The mechanical section of the Architectural Engineering program at the University of Wyoming (UW) includes four HVAC courses and one energy course covering design and analysis. Data obtained from the UW archive reveals the architectural engineering program at UW has been in existence as an independent program since at least 1968 (the old bulletins before 1968 are not available). At that time, a completion of the Architectural Engineering curriculum leads to a Bachelor of Science degree in Civil Engineering (Architectural Engineering option). It was mainly based on structural engineering, but students took also mechanical (heating and air conditioning) and construction management courses. Between 1974 and the present, four significant program changes were implemented at the UW.

2. The capstone design course (ARE 4740):

ARE 4740 Mechanical Systems Design Project: This course is the final course in the building mechanical systems sequence. It incorporates elements of previous design courses by executing the design of a hypothetical building with a concentration on a detailed design of the project's mechanical systems.

The ARE 4740 course exists in the Architectural Engineering program as an optional course since 2000 – 2001. Later, this course became an integrated part of Architectural Engineering curriculum (mechanical option). The objective of this course is to expand students' creativity and engineering design skills by meeting established design objectives while considering various economic, safety, reliability, aesthetic, ethical, and/or social impact factors (ABET).

During the preliminary phase the budget is estimated based on the cost of equipment and materials, shipping, and labor. Two systems are selected by the students with the guidance of the instructors, based on the building characteristics, the building functions, and the level of comfort requested and evaluated based on economy and effectiveness.

During the final design, the development of an HVAC system design can be divided into several major categories:

- HVAC Design Criteria Manual (DCM)
- Development of the HVAC Diagram
- System selection
- Heating and cooling load calculations and system analysis
- Preparation of an HVAC diagram and associated equipment list
- Preparation of HVAC arrangement, construction and detail drawings
- Pressure drop calculations
- HVAC noise calculations
- Equipment selection and preparation of specifications:

- AHU analysis
 - Heat exchanger
 - Heat and reheat analysis
 - Boiler analysis
 - Chiller analysis
 - Duct clearance
- Preparation of the HVAC system drawings

The design requirements for varying types of buildings are established using the unique HVAC Design Criteria Manual (DCM), given building specifications and any other pertinent documents. Once these design requirements are determined, the HVAC diagram is created and the heating and cooling load calculations and system analysis are performed, either manually or automatically through the use of several available software packages.

Students create 2-D CAD HVAC diagrams that visually demonstrate the HVAC system arrangements, indicate the spaces served, identify airflow quantities and label HVAC equipment. Throughout this design phase, HVAC equipment lists are prepared to provide all necessary engineering equipment data.

Under the supervision of their instructor, students use AutoCAD to prepare their HVAC detailed design drawings, including the HVAC system component spatial arrangements, construction drawings, installation details, ductwork fabrication sheets and part lists.

Pressure drop calculations are the next step. To calculate these pressure losses within the HVAC system, computer programs are utilized as a student design tool. These programs employ the three main design methods: Equal friction, balanced capacity (balanced system by changing diameters) and static regain methods.

Careful selection and sizing of HVAC equipment can reduce initial costs, increase homeowner comfort, increase operating efficiency, and greatly reduce utility costs. In contrast, over-capacity equipment systems have higher initial costs, operating costs, and may in fact be less effective than optimally sized systems.

3. Building Design Process

Planning/pre-design phase

Every project begins with an idea or a need. The owner will then elicit the services of a registered design professional to perform or assist in the preparation of planning/ pre-design phase activities such as feasibility studies, facilities planning, site analysis, budgeting, or environmental impact analysis. The objective of this phase is to determine whether or not the idea is economically sound and whether the return on investment will satisfactorily cover the projected construction cost, operating expenses, and generate the projected level of revenue. The designer will investigate basic building code and zoning ordinances, and related items through this pre-design analysis^{1,2}. This investigation will lead to preliminary design decisions at the project level.

Design phase

The design phase consists of four sub-phases:

- conceptual design phase
- schematic design phase
- design development phase
- construction documents and specifications phase

a. Conceptual Design Phase

The designer provides the owner with alternative approaches to the design and construction of the project, adhering to the budget requirements and the owner's desires. The designer prepares various design schemes and a detailed design program listing all the spaces, functions, estimated areas, preferred adjacencies and inter-relationships.

The results will include small-scale preliminary sketches of the overall form of the building, the massing, relationship diagrams, and an outline of the building in relation to the site. A simple sketch of the key sections and elevations may also be included. The designer presents these conceptual drawings to the owner in order to obtain his/her approval of a design scheme for development during the next phase^{2,3}.

While preparing the design schemes, the designer should examine and revise the decisions made during the previous phase and extrapolate the analysis to the building code related issues at building and major space level.

b. Schematic Design Phase

The design scheme selected by the owner is detailed during this phase. The designer begins by identifying the requirements for the building materials and products, for exterior elevation finishes and for structural, mechanical and electrical systems based on the approved design criteria. During this phase, the fire-rating of materials is carefully examined and the code requirements identified and respected.

Based on the design program and overall shape and form, the designer begins to locate and dimension major spaces at an abstract level. This design development is presented to the owner in a form of plans, elevations, sections, renderings, perspectives, 3D models and basic detailing of specific areas. The owner also receives written documents, which provide preliminary project description, outline specifications and cost projections^{2,3,4}. During the schematic design phase, the building code analysis process continues in revising former building design data and checks all design decisions at floor and space level.

Now the real job of MEP (Mechanical, Electrical and Plumbing) integration begins. Decisions must be made as to the location of equipment. Although the schematic drawings are not final, they do reflect the space allowed for the MEP systems (mechanical room, electrical closet, adequate space for a fire pump, etc).

c. Design Development Phase

The design development phase immediately follows approval of the schematic design and any necessary modifications to the budget or design program. During this phase, the design is further refined, and detailed plans, sections, elevations and construction details are developed. The designer determines the type and size of equipment, and focuses on technical issues such as constructability and integration of building systems and components. The space layout is then finalized to include its physical characteristics (length, height and depth) and material properties of walls, doors, windows, floor and ceiling. The outline specifications are revised after update of all of these design elements.

In this phase, the design development drawings are performed; and they indicate all aspects of architectural and structural components of the building. They are the drawings submitted to the contractors for bidding. All MEP systems must be described in sufficient detail so that a reasonable and accurate bid can be made. Before preparing the construction documents, the design must be meticulously checked against locally adopted building code and other design criteria related to circulation, energy, lighting, as well as owner preferences^{3,4}.

The intensive building code checking process covers every building code related item and detail. The design data at this phase is considered almost final. The data includes, but is not limited to: occupancy and construction type of all spaces, construction details that reflect the relation and connection between building materials and components, and layout and height of the building.

d. Construction Documents and Specifications Phase

The construction document and specification phase is considered the final design phase, and it is based on the approved design development documents. The objective of this phase is to provide graphic and written information necessary for bidding, construction and future building management. All the documents produced during this phase, in the form of drawings and specifications, are considered as legal documents and should clearly illustrate the work, rights, duties and responsibilities of all parties involved in the construction process^{2,3,4}.

The designer is obligated to explicitly prove project compliance with various adopted building codes by graphic presentation and written affirmation of the description of every building component or detail related to issues addressed by the building code.

4. Design Considerations:

a. Systems selection

Proper heating and cooling system selection takes into consideration fuel sources (e.g., natural gas and electricity), distribution mechanisms (e.g., air and hydronic), equipment options (e.g., furnace and heat pump), and equipment efficiency.

A life-cycle analysis of various, properly sized HVAC options must be performed in order to select a cost-effective system. Cost considerations include equipment and installation prices,

annual heating and cooling expenses, and maintenance costs. Although more difficult to evaluate, equipment reliability, longevity, warranty coverage, and safety are also important.

For example, heating fuel sources directly impact system operating costs. Also, high-efficiency heating equipment often costs more than standard-efficiency models, however they cost less to operate. Therefore, life-cycle cost rather than initial purchase price may make high-efficiency equipment and fuel selection an important economic selection criterion.

HVAC system component options include:

- VAV with terminal boxes
- Fan coils system
- Chilled Beam
- Underfloor Air Distribution Systems
- Hydronic in floor system
- Hydronic baseboard
- Electric resistance baseboard
- Evaporative cooling
- Forced air heating and cooling
- Constant volume forced air w/ evaporation cooling or air washer
- Heat pump
- Geothermal system
- Gas-fired fan coil

b. Mechanical room

The mechanical rooms contain many types of equipment, including boilers, chillers, air handling unit (AHU) systems, ductwork and piping, valves, security devices, expansion tanks, pumps and fans. Typically these rooms are located within or outside the building, or are split between inside and outside of the building. When located inside, they are typically situated either in the basement or on the roof. A design penthouse can be used as a screen for the mechanical room to improve the overall aesthetics of the building while maintaining functionality and providing protection from the effects of both wind and weather. Details included in this type of building design include openings and framing for both louvers and doors. For high-rise buildings, a mechanical floor, mechanical penthouse, or mechanical level is a story of a high-rise building dedicated to mechanical and electronic equipment. They are present in all tall buildings, including the world's tallest skyscrapers which possess significant structural, mechanical and aesthetics concerns. As a rule of thumb, skyscrapers require a mechanical floor for every ten tenant floors (10%), although this percentage can vary widely. In some buildings, they are clustered into groups dividing the building into blocks, whereas in others they can be spread evenly throughout the structure or concentrated at the top.

Mechanical floors are generally counted in the building's floor numbering, as required by building codes, but are accessible only through service elevators. However, in some circles they are excluded from the maximum floor area calculations, leading to significant increases in overall building sizes. In some cases, the building's designer arranges for the mechanical floor to be located on the thirteenth floor, to avoid problems in renting the space due to superstitions about the number thirteen.

c. Equipment selection

Trane Official Product Selection System (TOPSS) is a flexible and powerful software package that helps designers determine what Trane equipment best serves their HVAC needs. TOPSS guides the designer through various steps in order to generate a list of product selections that meet or exceed the determined specifications by using fundamental models to establish equipment performance. Many of these models are rated and certified. For example, ARI 410 establishes a single set of testing and rating requirements for determining capacities on air cooling/heating coils and product performance. If the designer enters a set of conditions and desired performances into TOPSS, the program decides on product configurations that are appropriate for the specified parameters. After performing these calculations, TOPSS provides an online location to review, print, graph, select, export schedules to Microsoft Excel™, and e-mail the designer's equipment selections to the Trane sales engineer.

d. Other considerations:

i. Altitude considerations in HVAC equipment selection

To ensure that properly sized equipment is installed, the designer must take into account the effects of altitude on equipment performance. One of these considerations is how to adjust the HVAC equipment performance for varying altitudes. Of course, there are some pieces of HVAC equipment that do not need to have their performance derated for altitude: refrigeration compressors, water-cooled condensing units, evaporative condensers, pumps, and water-cooled chillers. However, the performance of much of the equipment selected for HVAC systems is affected by altitude changes such as boilers.

ii. Codes and Standards

The project must comply with all relevant ICC (International Code Council) codes, in particular the International Building code, International Mechanical code, International Fire code, as well as NFPA (National Fire Protection Association) and ASHREA (American Society of Heating, Refrigeration and Air-Conditioning Engineers) standards: standard for outside air ventilation is ASHRAE Standard 62.1-200, Ventilation for Acceptable Indoor Air Quality and its published Addendum. This standard is often incorporated into state and local building codes, and specifies the amount of outside air that must be provided by natural or mechanical ventilation systems to various areas of the school, including classrooms, gymnasiums, kitchens and other special use areas.

Many state codes also specify minimum energy efficiency requirements, ventilation controls, pipe and duct insulation and sealing, and system sizing, among other factors. In addition, some states and localities have established ventilation and/or other indoor air quality related requirements that must also be adhered to.

5. Case study of a new HVAC system of an existing building:

Following is an example of analysis, design and conclusions of a study performed by capstone students.

The building designed is about 95,000 square feet and has two floors. The building is a casino that includes a large playing floor on the first floor and a large concert area on the second floor. The first floor is about 40,000 square feet. The casino floor is on the first floor of the building, and holds all the gambling tables and slot machines. The remaining spaces on the first floor are the offices. One office on the first floor is the security room. This room holds a significant amount of electrical equipment used for casino surveillance and security. The 26' high entertainment room dominates the second floor. The main kitchen of the casino is also located on the second floor.

a. Underfloor Air Distribution HVAC System

Underfloor air distribution (UFAD) system is selected to air condition this casino, among other suggestions, for environmental, aesthetic, and economical reasons. Underfloor air distribution provides a more comfortable climate than traditional ceiling duct systems. With the air coming directly from the floor, it mixes directly with the occupied space better and more efficiently. Underfloor air distribution provides cleaner air comparatively to the traditional ceiling duct systems. Another reason to select UFAD system is that it lifts cigarette smoke from the occupied space and out of the room, where a traditional overhead duct system mixes the smoke back into the occupied space.

Economically, UFAD is more efficient than overhead duct systems. Specifically, during the cooling season, the hot air in the room is allowed to rise as it would naturally and is replaced by the cooler supplied air. Supply air in an UFAD system can be supplied at temperatures closer to the target temperature of the occupied space. This means warmer air in the summer and cooler air in the winter, which leads directly to energy savings. UFAD is interesting from architecture point of view, since it allows for much more flexibility in the design of the ceiling area.

However, there are several drawbacks to underfloor air distribution systems. For example, the diffuser placement must be chosen carefully. Diffusers should not be under desks, tables or any other place where it may be in close contact with people and cause discomfort. Another drawback for underfloor systems is that they must be installed correctly. Only low leak or infiltration in the area under the floor is tolerated. If holes exist, the area under the floor will lose its pressure and air will not be forced into the occupied zone.

b. Mechanical room

The HVAC equipment is designed to be built onto second floor mezzanine, instead of on the roof for aesthetic, maintenance and functionality reasons. The height and the volume of the mezzanine are limited, so we decided to locate the mechanical equipments in four relatively small mechanical rooms in the building. The three indoor air handling units and the kitchen make-up air unit are located in one mezzanine area. The chilled water pumps and VFDs (Variable-frequency drive), glycol feeder, air separator, and expansion tank are located in a smaller adjacent room. In another room at the other end of the building are 2 large air handling units, heating water pumps and VFDs, glycol feeder, expansion tank, etc. The two large AHU (Air Handling Unit) in this mechanical room must supply air to the entertainment level. All 5 AHU are connected directly to outdoor air louvers. The function of the 5 AHU's are as follows:

- AHU-1: VAV (Variable Air Volume) Areas on the North of the Building

- AHU-2: South End of the Entertainment Level.
- AHU-3: South End of the Entertainment Level.
- AHU-4: Underfloor Air of Casino Level
- AHU-5: VAV Areas on the South End of the Building

The glycol feeder works by pumping a set amount of glycol into a closed loop at a set pressure. The feeder includes a tank, pump, and control panel. The glycol is needed in the system to protect pipes from bursting from frozen water.

In both air handling rooms the ducting network has an extremely complicated configuration to get the outside air ducted in, relief air ducted out for full outside air economizers on all units, and the typical supply/return ducts, because of the limited space of the existing building. There is also a boiler and domestic water heater room.

c. Sizing the HVAC System and Load Calculation

Several methods exist to size the duct system. Designers usually use a ductulator for basic sizing at the preliminary stage of the design process. A ductulator is a basic tool that allows users to match either airflow and velocity or airflow and head loss per unit length and read an equivalent round or square duct diameter. The airflow to the room can be reduced, though, due to the fact that a certain percentage of the heat from people, slots, and electronics is not mixed within the occupied zone. Part of the challenge of designing a good UFAD system is determining what percentage the room airflow can be reduced. Software for duct and pipe sizing and load estimation exist from different HVAC companies, such as CARRIER and TRANE and others are developed and sold by ASHRAE, ELITE and other software development companies.

d. HVAC systems for first floor

The casino floor's main heating and cooling comes from an underfloor air distribution system. On the back wall there is a single drop duct from the mechanical systems that feeds the underfloor air system. This duct is connected to AHU-4.

The unit serving the casino floor is a retrofitted constant volume air handling unit with a variable frequency drive (VFD) fan. There is a pressure differential sensor that modulates the VFD. The sensor will ramp the fan up or down depending on how far the underfloor plenum pressure is above or below the set point. In the area of the casino floor where there are cards tables, the load is dominated by people. In this area floor diffusers have motorized dampers incorporated in them (shown in Figure 1), which regulate the airflow to the occupied space. In the area where there are slot machines, the slots dominate the load and motorized diffusers are not needed.

To ensure comfort at the tables near the windows, baseboard electric floor heaters are placed under the windows. There are several proposed diffuser layouts for the casino floor. The flexibility required in casinos is another reason for selecting underfloor air distribution system.

The remaining rooms on the first floor are supplied by overhead air systems with multiple VAV boxes. The security room holds a significant amount of electrical equipment used for casino surveillance and security. This room requires a significant cooling load to keep the equipment cool, and the functionality of this equipment is vital to the casino. Therefore, over sizing the

cooling system is requested. The load is generally calculated based on the heat rejection of the equipment.

e. HVAC systems for second floor

The entertainment room may be packed full of people for concerts and other events. To meet this load and avoid noise propagation to other rooms through the duct work, an independent system is proposed.

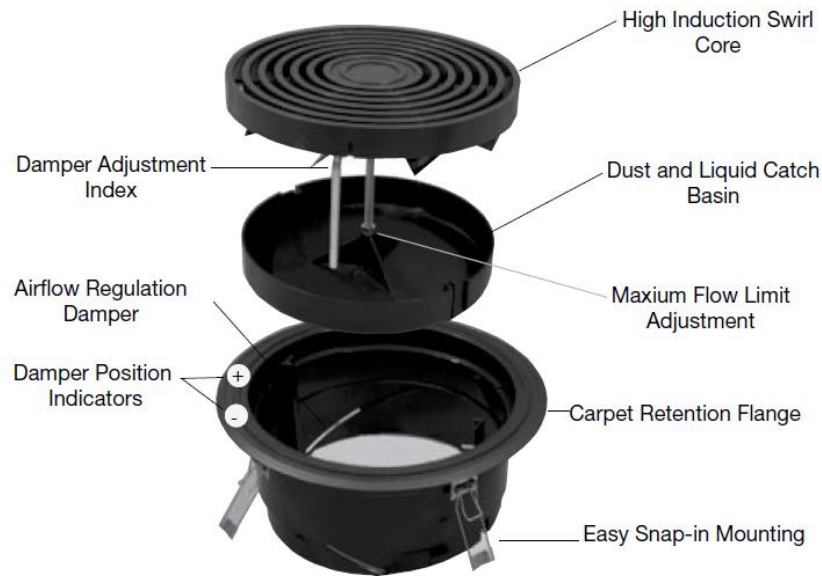


Figure 1: UFAD diffuser to be installed in the casino.

Usually the exhaust from a kitchen exits the kitchen exhaust fan (KEF). Since any roof mounted KEF might alter the historic nature of the building. Therefore, the kitchen exhaust left the building through a sidewall discharge fan. In order to do this, a pollution control unit had to be installed in the exhaust line to meet codes. This unit would not be necessary if the exhaust fan was on the roof. The UV light installed in the kitchen exhaust emits UV light into the air exiting the kitchen. This process oxidizes the grease in the air and makes the exhaust cleaner.

A figure of the pollution control unit installed in line with the duct work (directly after the kitchen exhaust) as it is designed in the project is shown in Figure 2. The pollution control unit works by forcing the kitchen exhaust air through a series of filters which remove smoke and grease from the air.

A very important consideration in the kitchen is the pressure. The pressure in the kitchen should be slightly negative so air is not leaving the kitchen and carrying smells out into the dining area. However, if the kitchen pressure magnitude is too large, air will flow heavily into the kitchen and may even cool the food. Adding complication, kitchens will have many exhaust hoods. The return hoods often have to have individual returns but they may be grouped if the pressure

difference is similar. Also, the exhaust of the hoods must be accessible so the grease can be cleaned out.

Choosing the control system depends on the size of the system and the equipment in that system. For example, a typical office will have local controls at the thermostat. Hydronic systems, however, always have a direct digital control (DDC) system because of the equipment involved.

The plumbing system of the casino building consists of 7 subsystems, which are: Overflow, roof drains; Gas; Sanitary; Grease Sanitary; Domestic Hot and Cold Water; Hot water and Soft Water.

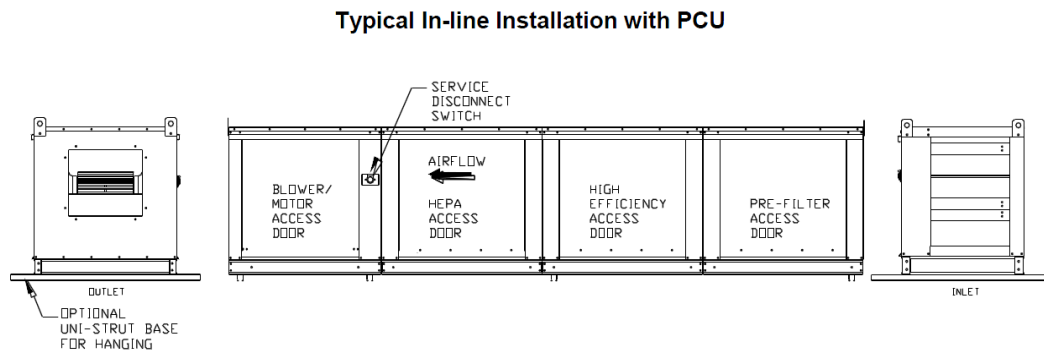


Figure 2: Pollution control unit installed in line (www.captiveaire.com).

f. Plumbing Design

The codes require that at a minimum, soft water should be supplied to the kitchen. As well, a hot water circulator should be included in larger systems to ensure hot water is available. This circulator moves water through the boiler, even if water is not being used, to ensure that hot water is available quickly. Hot water is used for heating where domestic hot water runs to sinks, showers, etc. for use by people.

The systems of the casino must be integrated into the city utilities systems. That is, the sewage must tie into the existing plumbing line. The city water pressure is tested to see whether there is enough pressure to supply the building. This pressure test is typically done by the civil engineers. If there is not enough pressure, pumps must be installed. The engineers designing the plumbing system are responsible for the system up to 5 feet from the building, at which point the civil engineers are responsible for the system.

Code dictates much of how the plumbing systems are designed. The grease sanitary line is sized to code and a grease trap is placed in the line, which separates grease from the water.

Roof drains are placed to run water off the building and into the city system. An overflow system is also designed to remove water from the building if roof drains become clogged. The drainage system is based on rainfall amounts listed in the code books.

When designing the gas system, the minimum and maximum pressure of each piece of equipment must be known. Equipment can include boilers, kitchen appliances, the rooftop unit,

etc. Based on the pressure requirements, and the pressure provided by the city, the gas system can then be sized and designed.

6. Course evaluation:

In parallel with the self-evaluation of each course by the instructor, we also conduct a course evaluation by students. 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 compiled 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 be 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 capstone 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 (project plan, mid-term review, final report, exhibit (and abstract), oral presentation, team minutes, web site if applicable).
- Teamwork survey.
- Self-assessment.
- Senior Design Symposium judging (with evaluation criteria explicitly indexed to the learning objectives and articulated via rubrics for all measures).

7. Conclusions:

Capstone design is one of UW HVAC classes in which students have the freedom to make their design of the mechanical systems on a real building, under the supervision of an instructor. Student progress is discussed twice a week and during the office hours (UW requires a minimum of 5 office hours a week). Participation in the capstone course provides another opportunity for students to apply knowledge they learned during several other courses. The capstone design course is conducted in parallel with capstone structural design. Both structural and mechanical 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.

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 HVAC industry, and learn the fundamentals of HVAC 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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