AC 2011-2611: ARCHITECTURAL ENGINEERING CURRICULUM AND HVAC SYSTEMS CAPSTONE DESIGN

Ahmed Cherif Megri, University of Wyoming

Dr. Ahmed Cherif Megri, associate professor of architectural engineering at the University of Wyoming (UW), teaches several HVAC and energy courses. Dr. Megri is also teaching a course titled "Comprehensive Performance of Building Envelope and HVAC Systems" for Summer School at UW, and "Smoke and Fire Dynamics" during summer session at Concordia University, Canada. His research areas include airflow modeling, zonal modeling, energy modeling, and artificial intelligence modeling using the support vector machine learning approach. Prior to his actual position at UW, he was an assistant professor and the director of Architectural Engineering Program at Illinois Institute of Technology (IIT). He was responsible for developing the current architectural engineering undergraduate and master's programs at the Illinois Institute of Technology (IIT). During his stay at IIT, he taught fundamental engineering courses, such as thermodynamics and heat transfer, as well as design courses, such as HVAC, energy, plumbing, fire protection and lighting. Also, he supervise many courses in the frame of interprofessional projects program (IPRO).

In few months, Dr. Megri will defend his "Habilitation" (HDR) degree at Pierre and Marie Curie University - Paris VI, Sorbonne Universities.

ARCHITECTURAL ENGINEERING CURRICULUM AT UNIVERSITY OF WYOMING

Ahmed Cherif Megri
Associate Professor, amegri@uwyo.edu
University of Wyoming
Civil and Architectural Engineering Department
Laramie, WY, USA

Abstract:

Architectural engineers apply engineering principles to the construction and design of buildings. They often collaborate with architects, who focus on function layout or aesthetics of building projects. Architectural Engineering often encompasses elements of other engineering disciplines, including mechanical, electrical, fire protection, and others. The architectural engineers are responsible for the different systems within a building, structure, or complex.

Architectural engineers focus several areas, including: the structural integrity of buildings; the design and analysis of heating, ventilating and air conditioning systems; efficiency and design of plumbing, safety and fire protection and electrical systems; acoustic and lighting planning, and energy conservation.

In this paper, our objective is to present the new curriculum at University of Wyoming that focuses on several disciplines: HVAC systems design, energy, plumbing, fire protection and building electricity. This multidisciplinary program focuses on the integration between architecture and engineering. It includes capstone design courses that cover the major areas. The integration aspects of different disciplines of architectural engineering will be discussed. As well as, we will discuss the integration of safety and fire protection in the curriculum. The history of the architectural engineering curriculum at University of Wyoming will be also covered. Future plans to evaluate the effectiveness of the curriculum in term of learning outcomes.

History of Architectural Engineering at University of Wyoming:

Over USA, only 18 programs of architectural engineering are accredited by ABET (Accreditation Board for Engineering and Technology). Architectural Engineering program at University of Wyoming (UW) is one of the oldest programs in the country. 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.

The first change, occurring in 1974-1975, involved adding four courses to the program, two from the mechanical engineering program and two architectural courses, namely acoustics and illumination. In 1990 – 1991, the second program change was implemented, adding building systems to the program, as well as other optional courses, such as Advanced Building Systems Design I and Advanced Building Systems Design II. The courses from mechanical department have been removed. The third significant change, in 2000-2001, involved adding several courses to the architectural engineering curriculum that were strictly elective courses. It is only later that these courses have become requested for mechanical option of architectural engineering. These courses included HVAC Systems analysis, Building Hydronic Systems, Building Air Systems, Building Thermal Systems, and Mechanical Systems Design Project (ARE 4740: the capstone design course). Until 2008, the architectural engineering program was mainly oriented toward HVAC system design. In 2009, however, the first 5000 level course in mechanical option was taught during the fall semester. The fourth major change was accomplished in 2009 and will be in application starting from 2010-2011. Three areas have been introduced to the curriculum: Energy, Fire protection, Plumbing, and Building Electrical Systems. The course prerequisite system has also been improved.

The new Program Curriculum (starting from fall 2010):

The Program's aim is to meet the educational objectives and outcomes and to educate graduates that are well-rounded to enter the profession or to pursue graduate studies. This is achieved through a well-balanced set of courses to ensure the strength needed in basic science and engineering, basic architectural engineering, hands-on experience through laboratory and projects, humanities and social sciences, senior level architectural engineering professional experience and major design experience through senior-level courses and the capstone design course. The courses required are versatile. Each course has a set of objectives that focuses on learning the materials needed to ensure the level of competency required from students. The Program outcomes are listed in each course descriptions; and the specific relevance of the course to various outcomes is indicated. The instructor ensures the compliance with the course objectives and outcomes in an evaluation of students' performance in the course. This evaluation is used to improve the course, if students' performance falls short of intended learning objectives, in an effort to maintain compliance with the Program educational objectives and outcomes.

The curriculum in architectural engineering has a requirement of one hundred and thirty two (132) semester credit hours. This curriculum can be organized under five general categories: Basic Sciences (physics and chemistry) and Mathematics, Humanities and Social Sciences, Basic Engineering, Introductory Architectural Engineering, and Professional level Architectural Engineering. More specifically, the content of the curriculum takes the following form.

Our objective is to have four professional specialization areas are listed under architectural engineering. These are: (1) building mechanical and energy; (2) building electricity; (3) Plumbing, fire protection and life safety; and (4) structural engineering.

Department of Civil & Architectural Engineering, 2010-2011, Mechanical Option (132 Credit Hours)

FRESHMAN YEAR, FALL SEMESTER			
ES 1000	Orientation to Engr. Study	I,L,O	1
ES 1060	Intro. to Engr. Computing	-	3
CHEM 1020	General Chemistry I	SP	4
ENGL 1010	English Composition	WA	3
MATH 2200	Calculus I	QA/QB	4
PEAC ______	Physical Activity Elective	P	1
			16
SPRING SEMESTER			
ES 2110	Statics	-	3
MATH 2205	Calculus II	-	4
PHYS 1210	Engineering Physics I	SP	4
	[1] Univ. Studies	*	3
	U.S. and WY Constitutions	V	3
			17
SOPHOMORE YEAR, FALL SEMESTER			
ARE 2100	Architectural Engr. Graphics	-	3
ARE 2200	Building Mat'l & Contr. Meth.		3
ES 2120	Dynamics	-	3
ES 2410	Mechanics of Materials	-	3
MATH 2210	Calculus III	-	4
			16
SPRING SEMESTER			
	[4] ARE General Elective	-	3
ARE 2410	Fundamentals of Building Performance	-	3
ES 2310	Thermodynamics	-	3
MATH 2310	Applied Differential Equations I	-	3
GEOL 1100 or GEOL 1500	Physical Geology or Water, Dirt, and EarthÂ's Environment	SE	4
			16
JUNIOR YEAR, FALL SEMESTER			
ARE 3030	Architectural History	-	3
ARE 3200	Structural Analysis I	-	3
ARE 3400	HVAC of Buildings	-	3
ARE 3600	Architectural Design I	O	3

ES 2330	Fluid Dynamics	-	3
	[2] Math / Science Elective	-	3
			18
SPRING SEMESTER			
ARE 3300	Plumbing and Electrical Systems	-	3
	ARE Mechanical Course (ARE 4430 or 4490)	-	3
ARE 3360	Fund. of Transport. Phenom.	-	3
ES 2210	Electrical Circuit Analysis	-	3
CE 3900	Engineering Economics & Professional Ethics	-	3
ARE 3210	Civil Engineering Materials	WB	3
			18
SENIOR YEAR, FALL SEMESTER			
	[5] Structural Design Elective	-	3
ARE 4600	Architectural Design II	O	3
	ARE Mechanical Course (ARE 4330 or 4390)	-	3
ARE 3100	Civil and Architectural Engineering Practice	-	3
STAT 4220	Basic Engineering Statistics	-	3
			15
SPRING SEMESTER			
ARE 4740	Mech. Sys. Design Project	-	4
	ARE Mechanical Course (ARE 4430 or 4490)	-	3
	[3] Mechanical Option Elective	-	3
ENGL 4010	Scientific & Technical Writing	WC	3
	[1] Univ. Studies	*	3
			16

Footnotes:
[1] Select courses to comply with University Studies 2003 requirements
[2] Course shall be selected from the Architectural Engineering Mathematics / Science elective list.
[3] Course shall be selected from the Architectural Engineering Electives / Mechanical Option list.
[4] Course shall be selected from the Architectural Engineering Electives / General Elective List.
[5] Course shall be selected from the Architectural Engineering Electives / Structural Design Elective list.
* A minimum of 12 hours must be selected from USP 2003 requirements (including all of CH, CS, CA, O, WB, D and G). USP Courses by Category, USP Courses by Course

Note:
Students should be aware that courses taken out of sequence may result in unavoidable delays in the date of graduation. The Department of Civil and Architectural Engineering assumes no responsibility for such delays.

This will offer more choices for students to select their desired path and result in more flexibility in terms of course scheduling and course management. This action has also been effective in reducing the need for course substitutions.

New Methodology for teaching Architectural Engineering Program at UW:

Our objective is to teach design courses, such as HVAC systems and fire protection, oriented specifically to Architectural Engineering students, in which we place emphasis on the theory and fundamentals with applied information to design and integration between systems, integration between systems and architectural design.

Usually, in each course, students have to perform an independent project with the help of a mentor. This technique was applied for 6 years in another institution Illinois Institute of Technology (IIT) by the author of this paper and has been encouraged by ABET visitors. Recently, Timothy M. Scruby, PE, Senior Project Manager with 28 years of experience in the area of HVAC said "I firmly believe that the process of mentoring is the best way to grow better HVAC engineers and people." (http://www.csemag.com/article/178132-Mentoring_HVAC_engineers.php)

Our teaching is not only oriented toward residential houses, but also toward commercial buildings (including high-rise buildings). For example within HVAC courses, a particular emphasis is made on technology and systems, such as fan coil system, chilled beam, underfloor air distribution system and VAV using terminal boxes. Our methodology is based on:

- Focus on the fundamentals and keep the applications for the project
- Discuss the new technology (not existing in the textbooks)
- Mentors from industry
- Use real case study for projects (actual drawings and actual buildings)
- Integration aspects
- Use software of each aspect of the course
- Use videos to demonstrate technologies
- Use flow charts to illustrate design methods after theory and numerical applications (Figure 1 shows an example of a large number of flow charts developed for architectural engineering courses).

a. Integration between Architecture and Architectural Engineering:

The Architects are responsible for turning the owner's program and requirements into a model. They are responsible on designing the spaces and give function to each space of the building. In particular, they are responsible on developing the initial architecture plans that represents the shape of the building and the function of the spaces. The architectural engineer needs to have enough knowledge about architecture, to be able to understand the plans, extract the necessary information, discuss them with the architects and add the systems into these drawings.

The design of a commercial office building is a complex process, in which various designers from different perspectives involving the architects, mechanical and structural engineers, lighting designers and specialist simulation modelers contribute to an integrated approach. The integrated approach may involve the use of local weather conditions, such as wind-driven ventilation and daylighting, as well as the characteristics of the building materials and space planning needs.

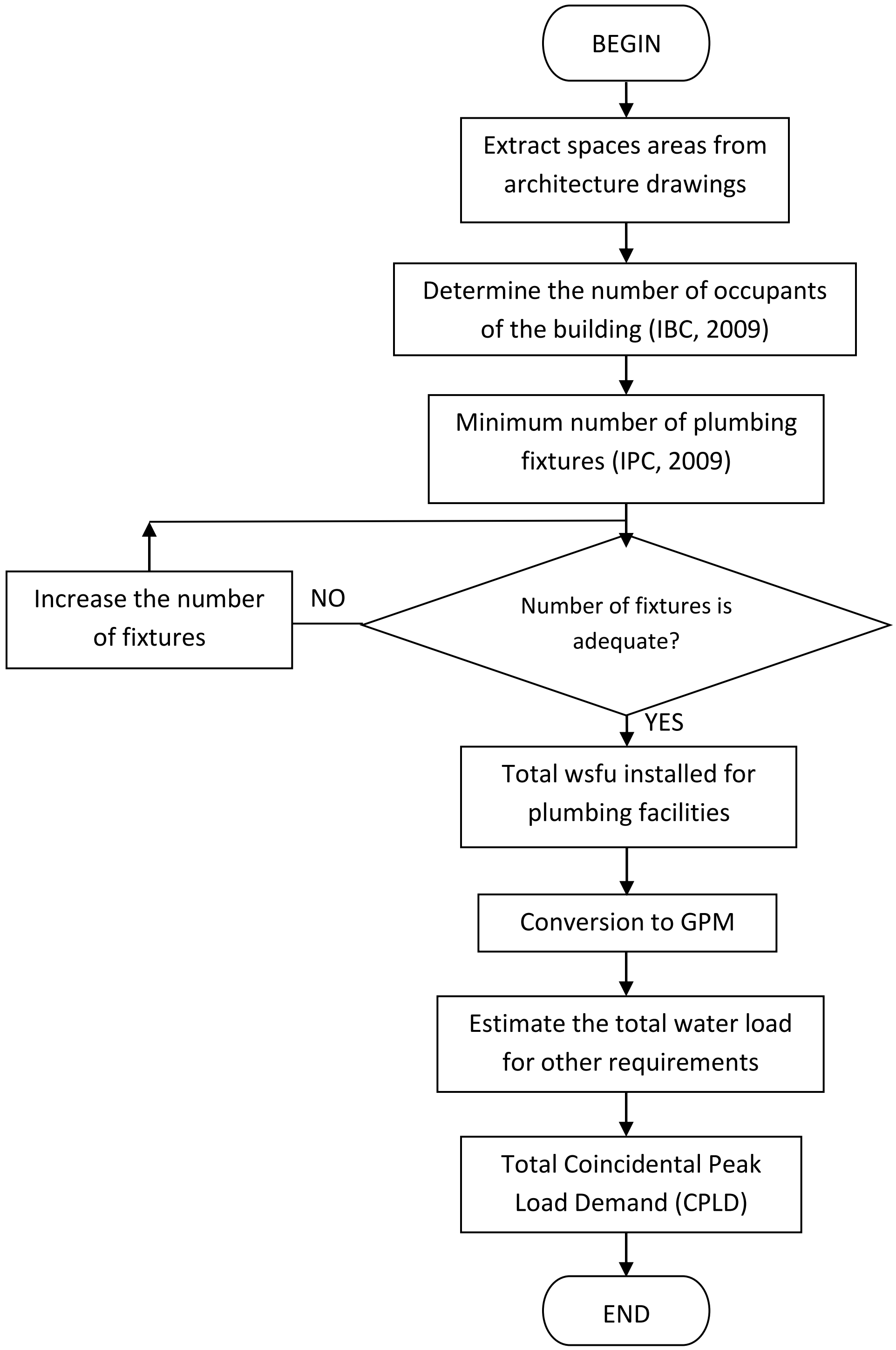

Figure 1: An example of flow chart developed in plumbing class (estimation of CPLD).

The integration of architecture and sustainable engineering principles has many benefits, including improving energy efficiency of the building while maintaining a reasonable level of thermal comfort. The creation of office environments that influence the productivity and health of the working population through natural ventilation, operable windows, and daylight interiors is of concern as well.

However, a number of issues arise because of the interdependence and interaction between various disciplines. For instance, one decision about glazing that allows more light into the building might also simultaneously increase the solar gain to the point where the cooling from natural ventilation alone will not be sufficient to maintain acceptable indoor conditions in terms of temperature and relative humidity. The solar gain may serve to diminish the cooling effect of the thermal mass during the earliest hours of the day because of long-wave radiative exchange between the warmed low level surfaces exposed to the sun and the night-cooled thermal mass above. This would cause the necessity of the introduction of an air-conditioning system, which would then add electrical load to the building. Consequently, the decision of using clearer glazing should be accompanied by other considerations, such as the placement of exterior shade not only to provide solar protection but also to allow for a form-based visible architecture with a standard repeatable floor plan (Allard, 2005). Also, fins have to be introduced on appropriate façades to intercept direct solar radiation during the afternoon hours when the sun would otherwise fall on the glazing at the same time outdoor air temperatures peak.

b. Architectural Engineering Laboratory:

The following laboratories have been suggested to be incorporated into the architectural engineering curriculum (Figures 1, 2 and 3):

- Study of thermal comfort (experimentation + simulation)
- Blower door (the study of the airtightness of the building)
- Duct blaster (the study of the airtightness of the duct system)
- Infrared thermography
- Combustion analysis
- Energy simulation: Energy performance comparison of Heating/Cooling Systems
- HVAC system Analysis
- Airflow study in multizone Buildings
- CFD applications
- Wall conduction: application to ground heat transfer

Architectural engineering at UW prior 2008:

a. <u>Strong Architecture Component:</u>

Our Architectural Engineering program includes a strong architecture component (namely, ARE 3600 & ARE 4600) in which students perform a comprehensive project. Many technical solutions, such as the use of heat recovery and energy conservation measures are included in the projects, without any specific calculation. This is very interesting, since it engages students to the integration process of techniques and technology that will be addressed in detail in future ARE courses, such as ARE 4430, ARE 4490, ARE 4480 and ARE 4740. Collaboration between these architecture courses and technical courses is very suitable.

Also, it is suitable to include safety and fire protection aspects into architecture courses, such as means of egress, systems and interior finish. These aspects are extremely related to architecture.

b. Students are limited to one specialization (HVAC Systems Design):

The mechanical program is based solely on HVAC systems design. The HVAC program is divided into a series of five HVAC courses. Many HVAC engineering aspects are excluded, such as the study of smoke management, control systems and the study of airflow in the buildings.

c. Absence of building safety and building code related courses:

Life safety and building codes are essential for every architectural engineering project (HVAC, plumbing, fire protection or energy). From past experience, I have come to realize that UW students consistently lack appropriate knowledge regarding building use groups and types of construction, height and floor area calculations, means of egress, fire protection systems and the special requirements for covered mall buildings, high rise buildings, atriums, open parking structures, private & public garages, fire resistance rated construction, application of flammable finishes, and accessibility/handicapped requirements.

With a course that includes fire protection, the student gains valuable skills and insight for plan review and code application during the design process. This course provides comprehensive instruction and illustration on the use, application, intent and rationale of the building codes.

d. Absence of integration between teaching and research:

From my previous experience, I have found that a number of excellent students have the capacity to perform high-level projects, such as research on specific topics. We believe that the styles previously existent at UW do not encourage students to perform high-level works.

a. Absence of national and international components:

Green build conference is relatively interesting for professors but has limited impact on students. The majority of the presentations are out of reach for our students. We believe that more exposure to design and technology can be accomplished by inviting expert designers from various areas of architectural engineering to speak to our students (this is what we are doing through ASHRAE chapter).

International collaboration will be established between UW and other universities through “students exchange programs”, conferences and International Energy Agency Annexes.

Figure 2: In-situ measurements (air, surface and globe temperatures).

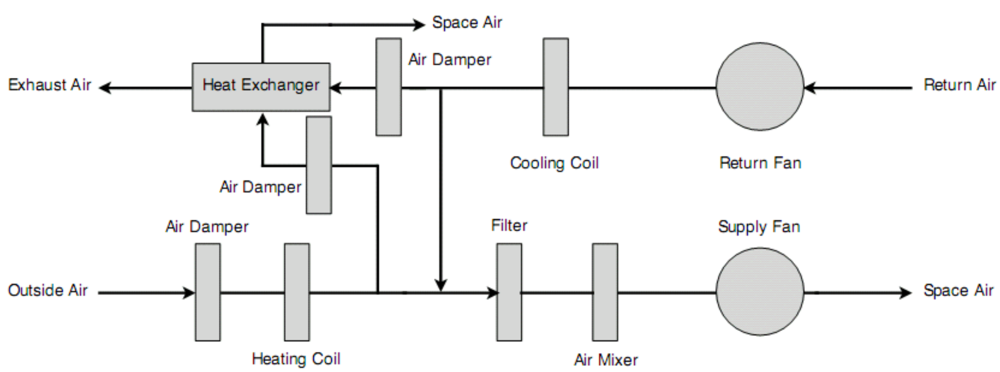

Figure 3a: HVAC existing Lab (Room L60)

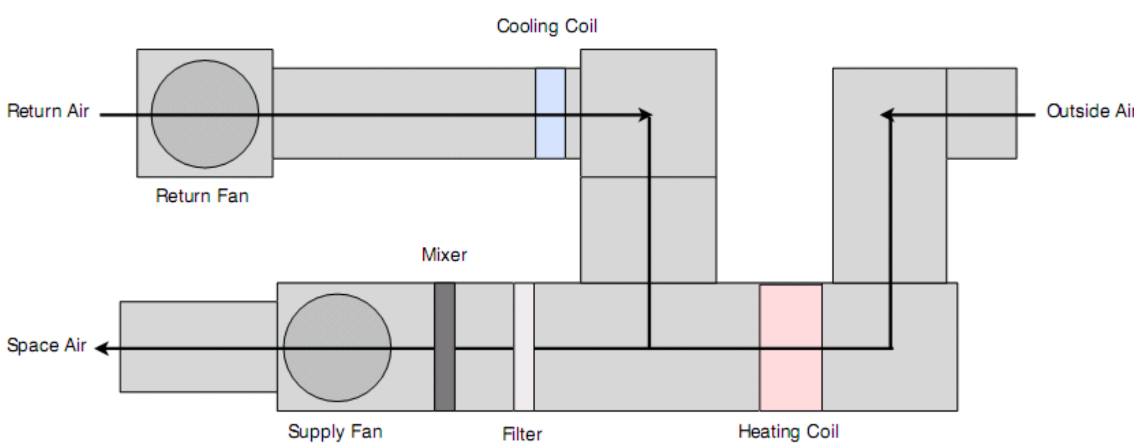

Figure 3b: HVAC Existing Lab (Room L60)

Evaluating Student Performance

Student performance in each course is evaluated, and their progress is monitored, by the instructor, who will assign a grade for the course. Although varied to a limited extent, the assignment of the grade is generally based on (a) homework problems, (b) quizzes and mid-tem exams, (c) final exam, (d) project and laboratory reports (if any), and (e) other assignments including presentation of projects, which may be required in some courses.

The senior capstone design course (ARE 4740 and CE 4740) requires a group project involving a complete design that may contain a host of modules including architectural design, structural and foundation design, cost estimating and bid document preparation, construction scheduling, building mechanical and electrical system design, lighting and acoustic systems, vibration control and serviceability design, building occupancy and accessibility studies, elevator design, etc. The Capstone design course is a multi-disciplinary effort; and as such our objective is to make involve students from other disciplines in addition to those in architectural engineering. As a minimum, the CE 4740 project always involves an architectural design, structural and foundation design, green building and sustainable design concepts, and at least one other module such as cost estimating, construction scheduling, etc. The ARE 4740 includes building envelope system, building mechanical, electrical and lighting system design. The student performance in the Capstone course is evaluated through weekly progress reports by students, mid-term presentation of project progress, final presentation of the project (power point presentation and poster presentation), examination on the learning objectives of capstone courses, results of ethics study (including preparation of a code of ethics by students), and preparation of a complete project report that contains all design drawings and calculations. The capstone courses also involve leadership and oral and writing components as part of their learning objectives.

The student performance in courses involving laboratory also includes evaluation of laboratory reports required from students. Grading of laboratory reports is rigorous and involves evaluation of technical contents, clarity and coherence of presented materials, and writing skills.

Most of the architectural engineering senior level courses also involve projects. In addition to homework problems, exams, etc. the student evaluation in these courses is also achieved through review of their final project reports and in some cases the oral presentation of their work.

Future plans to evaluate the effectiveness of the curriculum 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.
- An alumni survey will be implemented. A coherent and straightforward survey will be proposed and administered in compiling data on the perception of graduates in meeting the Program outcomes. The complete results will be included in the Program Objectives and Outcomes Assessment report.
- A more rigorous process in assessing the learning outcomes of the capstone courses will be implemented, which are in parallel with the Program outcomes. The following outlines process will be used for the 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).

- Our employer survey will be conducted with the assistance from the Board of Advisors and members of the Board who have had the graduates of the program working under their supervisions. Thus, the employers selected are those with long standing in hiring our graduates. And as such they are able to provide a very objective measurement of the

Conclusions:

The architectural Engineering Program curriculum at University of Wyoming has been improved. This paper describe how students are prepared for a professional career and further study in the discipline through the curriculum and indicate how the curriculum is consistent with the Program Educational Objectives and Program Outcomes.

We summarized the process by which student performance will be evaluated and student progress is monitored. Our objective is to expose students to organized teaching and complementary professors. The first style is oriented toward mechanical engineering students, where emphasis is placed on the theory and fundamentals of thermodynamics with an exposure to "design", with emphasis on real projects, architectural and mechanical drawings, and real systems such as fan coils, chilled beam, underfloor air distribution systems and displacement ventilation mainly because these projects and systems are not addressed enough in the textbooks.