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## **AC 2011-2742: ARCHITECTURAL ENGINEERING CURRICULUM: INTEGRATION OF ARCHITECTURE AND ARCHITECTURAL ENGINEERING**

### **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: INTEGRATION OF ARCHITECTURE AND ARCHITECTURAL ENGINEERING

**Ahmed Cherif Megri**

Associate Professor, [amegri@uwyo.edu](mailto: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 introduce 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, a methodology presented to our students in the framework of this course is discussed through case studies. This methodology is based on using actual buildings, where local weather conditions as well as engineering considerations and architecture are used in an integrated approach to achieve a successful design.

## **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.

### **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](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

### **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.

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.

### **Case Studies:**

The objective of this paper is to address some issues regarding the integration between the building's systems and the architecture through actual project design. A methodology presented to our students in the framework of this course is presented. This methodology is based on using actual buildings, where local weather conditions as well as engineering considerations and architecture are used in an integrated approach to achieve a successful design.

#### ***Design of Argonne National Laboratories:***

As an example, the Argonne National Laboratories, designed by OWP/P (architecture and MEP design and consulting company), includes a passive ventilation system created by using wind towers all along the building to the top. The wind tower works by creating a pressure differential. The wind blowing over the top of the tower creates a lower pressure than the atmospheric pressure inside the building. This difference in pressure causes the air to flow naturally up and out of the top of the building. Stack effects created with wind towers is an old concept that has improved over the years with better technology and electronic controls. Modeling systems have further enhanced the usefulness of natural ventilation through the use of a wind tower.

In addition to this, an open atrium area is used in the center of the building mass to create an area for air to flow freely. By using this design, the objective is a building which is architecturally interesting with an energy conscious ventilation system, and which includes day-lighting.

Incorporating an open atrium in a building allows greater flexibility in planning. While not used in the design of this building, a closed atrium can act as a buffer zone between the interior climate and the outside climate. More control over the temperature of the used space is gained when using a closed atrium and the cost is lower.

Another system used to create natural ventilation is the hollow flooring used on the second, third and fourth floors. These flooring systems allow additional natural airflow through the mass of the building. Also used in buildings are materials that absorb energy when the temperature exceeds human comfort levels and expels energy when the temperature drops. This building uses concrete to absorb and expel the heat. Concrete is used because of its ability to collect and hold energy more efficiently than other materials such as metals. This is another way that the HVAC system may be integrated into the architectural design of the building.

This building also uses the same system that is used to allow for passive ventilation to allow for natural lighting to enter and reflect in the building and atrium. The dual use of the system allows for savings in initial cost and ongoing costs through energy conservation. Visual comfort is also increased by the implementation of this system by allowing the people inside the building to use more natural lighting than electric fluorescent lighting.

### ***Design of Foxconn Building:***

These concepts are also followed in the design of the Foxconn building project in China (OWP/P), in which a similar passive ventilation system was implemented, used in conjunction with a forced air system. However, the passive ventilation was drawn upward through hollow walls and flooring alone rather than by means of an open atrium. The architectural design of the building allowed for the mass to be wider at the base and taper toward the top. This design permitted pressure difference to be used more effectively at the bottom where it is greater and as the building goes up, the pressure difference decreases, diminishing the supply of natural air changes. Again, this shows the integration of the mechanical aspect of the HVAC system and the physical side of the architectural design. As in the Argonne building, relative humidity is controlled by using hybrid ventilation. The ventilation is not controlled entirely by passive or forced ventilation thus allowing humidity to be controlled in the building.

Choices in integrated design are based on many factors. The first of the factors is based on the owner's needs, wants and support. The owner determines the budget, massing, orientation and operating costs of the building among many other features. Another factor is the systems that were used in the past. An owner may be more inclined to use what has been chosen in the past, rather than selection a more innovative building.

The designs presented depend upon the climate concerned. The buildings would not perform the same way in different local weather conditions with different temperature, relative humidity, and wind velocity and direction. The buildings are also oriented according to the availability of natural airflow as well as natural lighting. The physical setting of the building may also influence the size and shape of the building as in the Foxconn building in China. Each building has to be designed to be lower than the building behind it in relation to the river at the center of the city. This constraint creates a challenge for the architect.

***Additional considerations:***

**Glazing:** The glazing used can differ based on the needs of the building. General glazing can be a simple double pane window with a low-e coating. Factors that change what glazing is used can be the aesthetics needed or the light and heating that needs to be allowed or reflected from the building. Heat gain versus heat loss can change the coating options or insulating gap of the glazing.

**Control of Climate:** Integration can be controlled automatically, manually or a hybrid of the two. If it is controlled automatically, the system is monitored by a computerized detection system. This system monitors a building according to zones and can open and close vents and windows according to ventilation needs. A manually controlled system allows freedom of those inside to open and close windows freely. A hybrid system can have controls such as a display showing when the windows can be opened and closed yet still allows for the inhabitants to override the suggestions made by the computer.

**Control of Humidity:** Relative humidity can be controlled by these computerized systems. By monitoring the humidity in the building, the system can control natural ventilation somewhat while controlling the forced ventilation HVAC system. These systems are also designed with climate considerations. Hot and humid climates would be treated differently than cold and dry areas.

**Cultural Factors:** Cultural differences also lead to different designs. In American culture, a majority of the public is used to closed buildings and controlled climates. Other countries around the world have varying preferences according to the way building have been historically designed.

**Pollution as a Factor:** Other factors included with the design of naturally ventilated buildings include pollution and dust. In an area where pollution is higher, the use of natural ventilation would be detrimental to the well-being of the occupants. Noise pollution can also be a factor in deciding whether or not natural ventilation is beneficial in designing an HVAC system.

**Sustainability in Design:** Natural ventilation and day-lighting, as well as high performance HVAC systems and the use of renewable energy can be part of a sustainable design. Owners choose to use this feature as part of their building for a number of reasons. One of the reasons

can be a decrease in cost. This decrease in cost can be in the initial cost or in the long term operating costs. While one system may be more expensive in the beginning, by using more natural ventilation and lighting it may save costs for the owner over time.

These variables can be used to find the balance between energy consumption and performance. In other cases, the owner is concerned about other issues such as pollution and the protection of the environment.

### **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).

### **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.

Integrated design refers to the use of multiple building systems working together. In our case the integrated design refers to the functionality of the engineering aspect working in conjunction with the architectural appeal and usefulness of the building. Both of the examples showed the use of the architectural design as a passive ventilation system. This appears to be a forerunner in designing new and desirable structures while helping to create sustainable designs. The designs presented are reliant on the climate they were designed for. The buildings would not work as well in a different temperature, humidity, etc. The buildings are also oriented according to the availability of natural airflow as well as natural lighting.

The architectural engineering firms use many different software systems to analyze the designs used in creating a building. Usually DOE2, eQuest, EnergyPlus as well as TRNSYS/COMIS, TRNSYS/CONTAM are used to determine energy use and cost along with AGI for daylight analysis. Other CFD models are also used, such as FLUENT. These software programs allow architects and engineers to determine what the impact of each of their designs would have on the overall effect of the HVAC system.

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