AC 2011-1793: EDUCATIONAL NEEDS OF THE FUTURE HVAC DESIGN ENGINEER

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Educational Needs of the Future HVAC Design Engineer

I. Introduction

Buildings are a major consumer of energy in the United States. A large percentage of this consumption is accounted for by the heating, ventilation, and air-conditioning (HVAC) needs of the building. Students and entry level engineers in this field need to have a firm understanding of energy mechanisms and processes specific to building systems. This includes new renewable energy and energy efficiency technologies. They also need to be familiar with a constantly changing and growing list of subsidiary knowledge; such as construction principles, advanced control systems, state and federal energy standards, and new professional certifications.

Over the last several years the author has worked with entry level and experienced HVAC engineers as a Student Branch Advisor for ASHRAE, as manager of a series of continuing education classes on energy in buildings, and as an instructor of an undergraduate HVAC course. Combining this experience with literature research and several personal interviews with industry personnel a list of educational needs for future HVAC engineers will be created. This will then be discussed with regard to what is achievable in the engineering curriculum and what other options for attainment (workshops, continuing education, on the job experience, etc.) are possible. The combination of options that are being pursued by Minnesota State University, Mankato will then be described.

II. Putting it into Perspective

While fuel efficiency in automobiles is often in the news, it has only been recently when large scale public discussion of energy use in buildings has emerged. However, energy use in buildings is quite large. For 2009, a total of 41% of total energy consumption in the U.S. went to residences and commercial sectors whereas only 29% went to transportation.[1]

> "On an annual basis, buildings in the United States consume 39% of America's energy and 68% of its electricity. Furthermore, buildings emit 38% of the carbon dioxide (the primary greenhouse gas associated with climate change), 49% of the sulfur dioxide, and 25% of the nitrogen oxides found in the air."[2]

According to a study by the U.S. Department of Energy, "the total cooling energy use in commercial building HVAC systems, including the refrigerant compressors and chillers, accounts for about 1.4 quads of primary energy use annually, while the total heating energy use in commercial building HVAC systems, including furnaces and boilers, accounts for about 1.7 quads of primary energy".[3] Looking just at cooling, this is roughly equivalent to 50 million tons of coal annually. On the residential side, the Energy Information Administration reports that in 2001 as much as 31% of electricity use by residences was for HVAC purposes.[4]

As the public and business owners have come to recognize the impact of the HVAC design, engineers have responded with new design approaches, new technologies, and some not-so-new technologies. The new technologies might include things such as new building materials, new refrigerants, and new control systems which were not in existence when many existing buildings and homes were manufactured. However, there has also been a new embracing and updating of technologies that have been around for many years. The increased use of renewable energy sources, particularly solar, is helping to reframe many areas of the HVAC market. Nowhere is this better demonstrated than in the DOE Solar Decathlon competition. Started in 2002, this competition challenges student teams to design, build, and operate a small solar powered house that is "cost-effective, energy-efficient, and attractive".[5]

The obvious impact of HVAC technologies also places new responsibilities and requirements on those who design, construct, and maintain these systems. The engineering practices of previous decades are increasingly unable to satisfy the stringent demands of the present, and future, buildings.[6] This has seen the accompanying growth of new organizations and standards to promote efficient use of energy is buildings. In 1993 the U.S. Green Building Council (USGBC) was started. One of the group's first tasks was to develop metrics for sustainability in buildings and to indentify "green buildings". This resulted in the release of the Leadership in Energy and Environmental Design (LEED) version 1.0 in 1998. Subsequently version 2.0 was released in 2000 and 3.0 in 2009. In the LEED system points are awarded for difference sustainable aspects of a building's design and operation. While many of these points do not relate to the HVAC system the integrated nature of a building's design mandates the HVAC engineer's involvement. In addition, the most recent updates to the LEED specification (version 3.0) have shifted more of the possible points to the Energy and Atmosphere categories, which directly address many HVAC issues.[7]

Taking into consideration all of these aspects, an entry level engineer entering the HVAC workplace today is faced with greater challenges and responsibilities than ever before. The amount of knowledge and the number of different fields it comes from is larger than ever – and growing every day. In many ways this makes the HVAC engineer's ability to learn and accept new ideas their most valuable skill.

III. Skill and Knowledge Requirements of the HVAC Engineer

The best way to start identifying the knowledge needed by an HVAC engineer is to look at the requirements for certification and licensure in this field. Whereas some areas of mechanical engineering do not focus on professional engineer (PE) licensure, this is a very important aspect of the HVAC field. Partially this is due to the fact that HVAC design engineers will be specifying product designs for clients that may require the signature and stamp of a licensed engineer. However, another justification of the PE's worth is the fact that HVAC engineers work closely with civil engineers and architects, fields which have high regard for professional licensure. Applicants for the PE are required to pass an 8-hour examination covering topics from their field. For HVAC engineers coming from the mechanical engineering side this will involve a 4-hour general portion, covering all aspects of mechanical engineering, and a 4-hour portion specific to the applicant's field of specialty. HVAC and Refrigeration is one of three choices for this portion of the exam consisting of 40 multiple choice questions. Table 1 shows an itemized list of topics that can be expected on this portion of the exam. While many of the topics under Principles can be covered at the undergraduate level, those in the Application section generally require real world experience and/or continued training.

Engineers in the HVAC generally pursue certifications in addition to the PE. Currently the most popular is the aforementioned LEED certification. With the release of version 3.0 applicants can receive certification in several different areas, depending on their work function and experience. The most relevant for many engineers is the LEED-NC certification, where NC signifies new construction. However, with 3.0 a new first step in the certification process was added; the Green Associate (GA). While an applicant does not have to have on-the-job experience to satisfy the LEED-GA requirements they do have to pass a certification exam which covers a number of topics relevant to the LEED process (Table 2).

While the PE and LEED requirements make for a lengthy list of topics to know, in actuality they are the tip of the iceberg. There are a host of real-world, applied, skills that come into play when an engineer enters the HVAC workplace. Through discussions with several working HVAC professionals, and working with them on developing continuing education courses, some trends have been identified. Putting it succinctly; they need real world experience before they start. This includes things like being able to recognize actual pieces of equipment, knowing how a building is constructed, even being able to recognize what the acronyms and abbreviations mean. Items which have arisen consistently are presented in Table 3 (i.e. this is an edited and reduced list). However, all sources are in agreement that new hires have to hit the ground running.

The one item from the list that can be singled out due to its importance, and the fact that it can be easily addressed, is the use of the Revit© software package and Building Information Management (BIM).[10] BIM allows buildings to be modeled in three dimensions in a dynamic manner. The model incorporates all associated properties. This includes not only the spatial sizes and architectural properties, but the thermal properties associated with load and energy calculations. Revit© is a building design software packaged the implements BIM. It is produced by Autodesk© and is one of the leading packages in this field.

The HVAC field is, however, dynamic and the topics it encompasses are constantly changing. A recent report from the Department of Energy looked at opportunities for energy savings in commercial building HVAC system. The report narrowed the list down to a mere fifty-five options (Table 4), from which fifteen were eventually selected as most favorable.[11] It should be noted that a number of the fifteen items are topics which are not covered in a typical undergraduate engineering program, and are not listed on either the PE or GA exam requirements. Several of the topics are in fact technologies that are so new that until recently they would have only been found in research laboratories or graduate programs (e.g. microchannel heat exchangers).

IV. Training Possibilities for the HVAC Engineer

For most engineers, a bachelor's degree in some field of engineering is the starting point for their HVAC education. Students who choose to pursue a technology related career in HVAC have a number of two and four year options across the country. However, for those students destined for the design side and future professional licensure as an engineer, there are few specialty degree options. Most will pursue a degree in mechanical engineering, often taking elective courses related to HVAC and/or the other thermal-fluid sciences. In fact, an ABET accredited engineering degree is one of the initial requirements for PE licensure. Not surprisingly, the best source of additional knowledge is actual industry work experience through internship and coop opportunities. However, even an internship experience cannot fill in all the blanks. One option is to restructure the traditional engineering undergraduate curriculum so that it relies more on applied examples. Structuring learning around mock buildings rather than generic problems will allow students to be more comfortable going straight from the classroom to the design room, or building site.

The difficulty comes in trying to fit all the knowledge and skills required into the time allowed. It is in evitable that some things will be left out. It may be time to rethink what has traditionally been thought of as "continuing education". Where workshops and training courses were once looked at as things engineers did after getting a job, it may be time to fully embrace these activities before graduation. While some topics such as LEED and Revit cannot be easily fit into an engineering curriculum, they can be pursued outside the traditional curriculum classroom. Continuing education after graduation and hire should also be expected and actively planned for. There are many resources available to new engineers; from ASHRAE publications and handbooks, workshops, to equipment catalogs and code books. However, for young engineers the requirement of time and motivation to continually study and keep up to date can be a problem.[12]

V. Description of One Approach

At Minnesota State University, Mankato (MSU) a combination of approaches has evolved which address many of the issues and topics in Tables 1-4. In a well structured mechanical engineering program, many of the topics in Table 1 can be addressed at the undergraduate level. This is particularly true for programs, like MSU's, that have a focus on application and industry preparedness. Whereas many programs have reduced thermodynamics content to one 3-4 credit course, MSU requires two 3 credit courses in thermodynamics. This allows more in-depth study of the Principles topics and some time to address the Applications topics. Given this background knowledge elective courses in Thermal Systems Design and HVAC can go into more detail with a focus on design projects.

Acknowledging the importance of LEED certification to local industry, MSU has pursued options for supporting training in this area. While students are exposed to general LEED concepts through course and capstone design projects, as well as the annual ASHRAE Student Design Competition, all of the topics in Table 2 do not fit into the engineering curriculum. MSU has partnered with local industry through grants from the State of Minnesota to develop continuing education courses addressing HVAC, green buildings, and LEED. We have found that at the Green Associate level these courses are applicable to both current students and working professionals. Excellent instructional resources exist through USGBC and in many cases a trained USGBC instructor can be obtained. Note that one requirement to qualify to take the Green Associate examination is professional experience OR taking a course related educational program (such as an HVAC elective course).

The topics in Table 3 are a little more difficult to address outside of internship or professional experience. Several approaches have been taken to incorporate them into the curriculum. In the

HVAC course traditional textbooks have been replaced with the ASHRAE Fundamentals Handbook and instructor prepared notes. The course has been structured around several smaller design projects leading up to a larger semester project based on the annual ASHRAE Student Design Competition. Through this project the students will work with actual plans for an actual building. They are exposed to actual industry practices through the mentorship of alumni and industry contacts. The final design project forces them to abandon generic or hypothetical problems and address real world constraints and processes.

A new approach to address topics in Tables 3 and 4 is also being pursued. Through funding from the State of Minnesota an “HVAC Boot Camp” continuing education course is being developed and will be offered during the next year. Tailored for entry level engineers or those switching fields, the course will address the real world side of HVAC design with a heavy emphasis on working with actual systems and components. The intent is to help take the student from the level of fundamental knowledge only to having the ability to step into a project on day one. Essentially it is intended to shortcut some aspects of the on-the-job training that all new engineers experience.

Naturally a course such as this cannot cover all of the topics in Table 4. Several of these involve leading edge research and/or industry applications that are in their infancy. Professionals are exposed to these topics through continuing education, professional publications, and seminars. Engineering programs, even ones that are not research based, still have a role to play here. Fundamental research and study of existing applications offers the opportunity for publications and presentations, both at the local and national level. As we have seen at MSU there are also a host of opportunities to partner with industry in the development of short courses or continuing education offerings.

VI. Concluding Thoughts

The future of HVAC design is exciting and more important to the future of the U.S., and the world, than at any point in the past. However, this places great educational demands on the current systems in place to produce qualified HVAC entry level engineers. The needs of industry are growing and are not likely to stop any time soon. Students must be prepared to study more topics and material during school and after hire. Educators must be prepared to update existing curriculums to reflect changes in the industry. They must also be willing to embrace new teaching approaches, specifically ones focused on applied examples, and to work with industry to offer more opportunities for education outside of the classroom. As we have seen at MSU there must be a paradigm shift from purely theory based instruction and an acknowledgement that the investment in the student does not end at graduation.

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Table 1: Topics for the Professional Engineering Afternoon HVAC Subject Portion[8]

MECHANICAL–HVAC and REFRIGERATION DEPTH Exam Specifications

	Approximate Percentage of PM Exam
I. Principles	**55%**
A. Thermodynamics 1. Cycles 2. Properties 3. Compression processes	7%
B. Psychrometrics 1. Heating/cooling cycles 2. Humidification/dehumidification 3. Heating/cooling loads	15%
C. Heat Transfer	13%
D. Fluid Mechanics	7%
E. Compressible Flow	3%
F. Energy Balances	10%
II. Applications	**45%**
A. Equipment and Components 1. Cooling towers and fluid coolers (e.g., configurations, conditions, flow rates) 2. Boilers and furnaces (e.g., configurations, efficiencies, fuel types) 3. Condensers (e.g., configurations, conditions, flow rates) 4. Pumps/compressors/fans (e.g., laws, efficiency, selection) 5. Evaporators/chillers (e.g., configurations, conditions, flow rates) 6. Cooling/heating coils (e.g., configurations, conditions, flow rates) 7. Control systems components (e.g., valves, dampers) 8. Refrigerants (e.g., properties, types) 9. Refrigeration components (e.g., expansion valves, accumulators)	20%
B. Systems 1. Air distribution (e.g., duct design, system type, terminal devices) 2. Fluid distribution (e.g., hydronic, oil and/or gas distribution design, system type, steam distribution) 3. Refrigeration (e.g., food storage, cooling and freezing) 4. Energy recovery (e.g., enthalpy wheels, heat pipes, run-around systems)	18%
C. Supportive Knowledges 1. Codes and standards (e.g., ASHRAE, NFPA) 2. Air quality and ventilation (e.g., filtration, dilution) 3. Vibration control (e.g., transmission effect, isolation) 4. Acoustics (e.g., sound control, absorption, attenuators, noise level criteria) 5. Economic analysis 6. Electrical concepts (e.g., power consumption, motor ratings, heat output, amperage)	7%

Table 2: Topics for the LEED Green Associate Examination[9]

I. Synergistic Opportunities and LEED Application Process

A. Project Requirements (e.g., site; program; budget; schedule)
B. Costs (e.g., hard costs; soft costs; life-cycle)
C. Green Resources (e.g., USGBC; Environmental Building News)
D. Standards that support LEED Credit (e.g., American Society of Heating, Refrigeration and Air-conditioning Engineers [ASHRAE]; Sheet Metal and Air Conditioning Contractors National Association [SMACNA] guidelines; Green Seal)
E. Credit Interactions (e.g., energy and IEQ; waste management)
F. Credit Interpretation Rulings/Requests and precedents that lead to exemplary performance credits
G. Components of LEED Online and Project Registration
H. Components of LEED Score Card
I. Components of Letter Templates (e.g., project calculations; supplementary documentation)
J. Strategies to Achieve Credit
K. Project Boundary; LEED Boundary; Property Boundary
L. Prerequisites and/or Minimum Program Requirements for LEED Certification
M. Preliminary Rating (target certification level)
N. Multiple Certifications for Same Building (e.g., Operations & Maintenance for certified building new construction; core and shell and commercial interior; certified building in neighborhood development)
O. Occupancy Requirements (e.g., existing building--building must be fully occupied for 12 continuous months as described in minimum program requirements)
P. USGBC Policies (e.g., trademark usage; logo usage)
Q. Requirements to Earn LEED AP Credit

II. Project Site Factors

A. Community Connectivity
1. Transportation (e.g., public transportation; bike storage; fuel efficient vehicle parking; parking capacity; car pool parking; car share membership [e.g. Zipcar™]; shuttles; carts)
2. Pedestrian Access (e.g., circulation and accessibility such as cross walks; ramps; and trails)
B. Zoning Requirements (e.g., density components such as calculations -site area and floor area ratio; construction limits; open space; building footprint; development footprint; specific landscaping restrictions)
C. Development
1. Heat Islands (e.g., non-roof; roof; Solar Reflectance Index [SRI]; emissivity; albedo; heat island effect; green roofs)

III. Water Management

A. Types and Quality of Water (e.g., potable; graywater; blackwater; stormwater)
B. Water Management (e.g., water use reduction through fixtures such as water closets; urinals; sinks; lavatory faucets; showers; harvesting; baseline water demand; calculations of Full Time Equivalent; irrigation)

IV. Project Systems and Energy Impacts

A. Environmental Concerns (e.g., chlorofluorocarbon [CFC] reduction, no refrigerant option, ozone depletion, fire suppressions without halons or CFC's, phase-out plan, Hydrochlorofluorocarbons [HCFC])
B. Green Power (e.g., off-site generated, renewable energy certificates, Green-e providers)

V. Acquisition, Installation, and Management of Project Materials

A. Recycled Materials (e.g., pre-consumer, post-consumer, collection requirements, commingled)
B. Locally (regionally) Harvested and Manufactured Materials
C. Construction Waste Management (e.g., written plan; accounted by weight or volume; reduction strategies; polychlorinated biphenyl (PCB) removal and Asbestos-containing materials (ACM) management)

VI. Stakeholder Involvement in Innovation

A. Integrated Project Team Criteria (architect, heating-ventilation-air-conditioning [HVAC] engineer, landscape architect, civil engineer, contractor, Facility Manager)
B. Durability Planning and Management (e.g., material lifecycle, building re-use)
C. Innovative and Regional Design (regional green design and construction measures as appropriate and established requirements)

VII. Project Surroundings and Public Outreach

A. Codes (e.g., building, plumbing, electrical, mechanical, fire protection)

Table 3: Additional knowledge topics as provided by HVAC working professionals.

AutoCAD
Revit and Building Information Management (BIM)
Construction terminology and documentation
ASHRAE, LEED, and other energy standards
Energy load calculations and software
LEED Green Associate certification (but not necessarily NC)
Geothermal heat pumps
Organizational skills
Equipment schedules
Rules of thumb

Table 4: Technology options selected for further study by DOE, with the final fifteen indicated in bold.[11]

Component (24):	*Equipment (10):*
❑ Advanced Compressors ❑ Advanced Desiccant Material ❑ Backward-Curved/Airfoil Blower ❑ Copper Rotor Motor ❑ Direct-Contact Heat Exchanger ❑ Electrodynamic Heat Transfer ❑ **Electronically Commutated Permanent Magnet Motor (ECPM)** ❑ Electrostatic Filter ❑ Heat Pipe ❑ High-Efficiency (Custom) Fan Blades ❑ High-Temperature Superconducting Motor ❑ Hydrocarbon Refrigerant ❑ **Improved Duct Sealing** ❑ Larger Fan Blade ❑ Low-Pressure Refrigerant ❑ **Microchannel Heat Exchanger** ❑ Refrigerant Additive (to Enhance Heat Transfer) ❑ **Smaller Centrifugal Compressors** ❑ Twin-Single Compressor ❑ Two-Speed Motor ❑ Unconventional (Microscale) Heat Pipe ❑ Variable-Pitch Fans ❑ Variable-Speed Drive ❑ Zeotropic Refrigerant	❑ Dual-Compressor Chiller ❑ Dual-Source Heat Pump ❑ Economizer ❑ **Enthalpy/Energy Recovery Heat Exchangers for Ventilation** ❑ Engine-Driven Heat Pump ❑ Ground-Source Heat Pump ❑ **Heat Pump for Cold Climates** ❑ **Liquid Desiccant Air Conditioner** ❑ Modulating Boiler/Furnace ❑ Phase Change Insulation
Systems (14): ❑ All-Water (versus All-Air) Systems ❑ Alternative Air Treatment (to reduce OA) ❑ Apply Energy Model to Properly Size HVAC equipment ❑ Chemical Heat/Cooling Generation ❑ Demand-Control Ventilation ❑ **Dedicated Outdoor Air Systems** ❑ **Displacement Ventilation** ❑ Ductless Split System ❑ Mass Customization of HVAC Equipment ❑ **Microenvironment (Task-ambient Conditioning)** ❑ **Novel Cool Storage** ❑ Natural Refrigerants ❑ **Radiant Ceiling Cooling/Chilled Beam** ❑ **Variable Refrigerant Volume/Flow**	*Controls / Operations (7):* ❑ **Adaptive/Fuzzy Logic HVAC Control** ❑ Building Automation System ❑ Complete/Retro Commissioning ❑ Finite State Machine Control ❑ Personal Thermostat (e.g. Ring Thermostat) ❑ Regular Maintenance ❑ **System/Component Performance Diagnostics**