ENGINEERING EDUCATION IN ENERGY CONSERVATION AND HVAC DESIGN

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ABSTRACT

Available information on the status of engineering education in HVAC, concervation, and solar design is reviewed and results of two new surveys on these topics are presented. It is estimated that 100,000 engineers are active in these areas - more than are active in chemical engineering, aerospace engineering, and several other educationally distinct disciplines.

Evidence suggests that many HVAC/Energy engineers receive much (if not most) of their HVAC/Energy training after college. A survey of Denver area ASHRAE members found that 60% have ME degrees, 23% have other engineering degrees, and 17% do not have an engineering degree. Those with engineering degrees have typically taken 3 or 4 courses in theoretical and applied thermal sciences - or have spent about two-thirds of a semester in studying of topics directly relevant to HVAC/Energy engineering. Those without engineering training typically had no courses directly relevant to the area.

Examination of college catalogs for 182 ME programs showed that 26% offer no courses, 48 offer one or two courses and only 26% offer more than two courses dealing with HVAC, conservation and/or solar. The nine Architectural Engineering programs offer an average of 3.6 courses in these area. Eighteen universities were identified which offer a total of five or more courses (the equivalent of one semester or more of full time study in these areas). Additional detail is provided in the paper and recommendations for a better assessment of educational needs in HVAC/Energy engineering are made.

Based on these findings, it is recommended that:

1. A comprehensive survey should be made to determine employers' perceptions of the need for increased HVAC/Energy engineering training.
2. More information should be provided to the industry about the more comprehensive existing programs.
3. Initiate steps to strengthen existing programs or establish new programs as warranted.

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Energy conservation has received a great deal of attention by the public, by practicing engineers and by the research community during the last decade. The energy use of typical new buildings has dropped substantially and the best new buildings use only a small fraction of the energy used by typical 1970's buildings. In view of this dramatic progress, it is astonishing how little is known about the needs for training HVAC/Energy engineers. There is accumulating anecdotal evidence that consulting firms find the newly graduated HVAC/Energy engineer to be rather poorly trained by comparison with structural engineers and other consulting disciplines. Bill Collins, former president of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and a prominent consultant in Oklahoma, recently stated that "We've found that two-thirds of the engineers in this profession receive 100 percent of their HVAC training after graduation" (AGA, 1984).

Engineering curricula are never able to include everything needed for the successful practice of engineering. However, American engineering education has had its greatest success where it has combined fundamental training in mathematics and the sciences with technical training which applies fundamental principles to the solution of practical problems. The evidence presented in this paper shows that the typical HVAC/Energy engineer (in the Denver area) has spent less than one semester of full-time study taking courses in both theoretical and applied thermal sciences and design. It also shows that only 10 percent of the engineering schools in the United States offer 5 courses or more (the equivalent of a full time semester or more) covering the principles and design of HVAC, Conservation and Solar systems for buildings (including undergraduate and graduate course offerings.

HVAC/ENERGY ENGINEERS

The engineers who influence the comfort and energy performance of the nation's buildings (designated HVAC/Energy Engineers in this paper) work in many different capacities for several types of employers. The classifications below span those listed by ASHRAE.

1. Engineering and/or Architectural Services
2. HVAC & R Contractor
3. User of HVAC & R Services
4. Equipment Manufacturer
5. Equipment Sales/Distribution
6. Education/Research
7. Technical/Professional/Trade Association

These categories suggest that the number of HVAC/Energy engineers is quite large, but this number is not precisely known. ASHRAE has about 41,000 non-student members and 9,000 student members. Discussion with several active professionals from different parts of the country indicates that less

than half the HVAC/Energy engineers are members of ASHRAE. Hence we estimate that 80,000 to 100,000 people currently work as HVAC/Energy engineers.

It is instructive to examine this estimate in the context of overall engineering employment. The distribution of engineers by employment sector is given in Table I which shows that about half of all engineers are employed in manufacturing, with the others split among a broad nonmanufacturing category, government and universities. The "nonmanufacturing" category shown includes construction, utilities, engineering and architectural services, and business and management consulting. Since a majority of the HVAC/Energy engineers probably fall in this category, Table I certainly seems consistent with an estimate of 100,000 HVAC/Energy engineers, but would not be consistent with 200,000.

The number of engineers in different engineering disciplines is shown in Table II. This table shows that nearly 70 percent of all engineers have been trained in one of the traditional "big three" disciplines (electrical, mechanical or civil) with the remaining 30 percent scattered among nine other disciplines. The total number of engineers indicated in Table II is 15%-20% lower than the total shown in Table I. This may be due to a large number of practicing engineers who do not have traditional engineering training.

Educational Background of HVAC/Energy Engineers

It is often assumed that HVAC/Energy engineers are generally mechanical engineers. Table II shows that only 213,000 graduate mechanical engineers were in the labor market in 1980. It is clear that far fewer than half the new Mechanical Engineering graduates enter the HVAC/Energy field, so while many HVAC/Energy engineers are mechanical engineers, a large number apparently have other training.

Contacts with ASHRAE, ACEC (American Consulting Engineers Council) and NSPE (National Society of Professional Engineers) all indicate a concern about the level and quality of HVAC/Energy education available today, but none of these organizations seem to have a comprehensive picture of the training received by today's practicing engineers.

Anecdotal evidence shows other significant groups active as HVAC/Energy engineers. It is clear that many HVAC/Energy engineers come from other engineering disciplines such as Architectural, Civil, Chemical, Aeronautical, Electrical, etc. Others have engineering technology training, or no formal engineering training. As noted earlier, Bill Collins recently stated, "We've found that two-thirds of the engineers in this profession receive 100 percent of their HVAC training after graduation."(AGA, 1984).

Jack Warner of ACEC indicates that many employers tell him they hire people without engineering degrees and train them. Arthur Sirjord, Jr., partner in a large Seattle A/E firm, indicates that many of their HVAC engineers come from two-year technology programs and get on-the-job training.

The authors were unable to locate any quantitative information on the educational background of practicing HVAC engineers, so a short questionnaire

was sent to all 238 members of the Rocky Mountain Chapter of ASHRAE (most of whom live in the Denver area).

91 were returned of which there were 55 whose degrees were in Mechanical Engineering, 21 who had degrees in other engineering disciplines, 12 who had non-engineering degrees, and 3 who did not have college degrees.

The responses to a question which asked about formal courses in areas felt to be primary preparation for practicing engineers in building energy applications (Thermodynamics/Heat Transfer, HVAC, Energy Conservation, and Solar Utilization and Design) are shown in Table III. They may be summarized as follows:

1. 38% had no courses in HVAC, Energy Conservation or Solar, and only 19% had 3 or more such courses.
2. 15% had no Thermo/Heat Transfer courses; however 80% had taken 2 or more such courses.
3. 89% had no coursework at all in energy conservation.
4. Although 42% of the ME graduates had 5 or more courses in all the areas combined, only 16% had 3 or more courses in HVAC, Energy Conservation and Solar - a lower proportion than the whole sample.
5. The "other" course named most frequently in table III was fluid mechanics, but only 20% named one such course, 8% named two, and 8% named four or more.
6. If one considers a base of 5 courses as adequate preparation for professional practice, or in other words, about one semester's work, only 34% had achieved this level.

When this preparation is compared to the area of structural analysis and design the absence of applicable courses becomes even more distressing. Most structures programs have at least 4 courses in structural mechanics and 3 or more in design for minimal preparation. By that measure (7 courses) a bare 18% qualify as being professionally prepared for HVAC/Energy engineering by their formal education.

The response to a question which asked what courses were needed in one's work but were not available showed some expected results: 24 of the M.E.'s indicated a need for more thorough HVAC training. 11 listed some aspect of controls and 5 named computer aplications to both design and controls as needed. 4 identified energy conservation, 4 listed codes used in design, and 4 felt that writing and communication skills were needed but apparently had not been taken in college. 4 cited solar courses and 3 listed management as being necessary. One listed electrical systems in this category. Only six were satisfied that nothing was needed beyond courses they had taken.

The picture which emerges shows three large groups of individuals active in HVAC/Energy engineering. Mechanical engineers constitute the largest group. The second group was trained in any of a variety of engineering disciplines. The third group has come from engineering technology programs or from non-engineering backgrounds. It is probably fair to say that HVAC/Energy engineering as a discipline is at a stage of development comparable to that of other disciplines such as structures 30-50 years ago when many of the

practicing engineers were trained on the job. Just as the increasing complexity of the discipline necessitated a stronger educational background in other engineering disciplines, the same pattern is repeating in the HVAC/Energy area today.

HVAC, CONSERVATION AND SOLAR EDUCATION

There have been no comprehensive surveys or analyses of the current engineering curricula in the HVAC/Energy area. This section will summarize information contained in an analysis of 135 courses published by ACEC Research and Management Foundation (ACEC, 1984) and will present the results of a survey of the offerings of Mechanical Engineering and Architectural Engineering departments as indicated by current university course catalogs. This analysis is not exhaustive, but reveals major trends, and it is hoped that it will serve as a catalyst for further discussion of the need for improved curricula in the HVAC/Energy area.

ACEC Research and Management Foundation Survey

The ACEC Research and Management Foundation has been actively working to improve curricula in the HVAC/Energy area for several years. The foundation has developed a model HVAC curriculum and has conducted an Institute on Energy and Engineering Education each year for the last five years. These institutes have brought together 40-50 faculty from engineering, engineering technology and architecture programs annually. One outgrowth of this effort has been the collection of 135 course outlines dealing with at least some of the HVAC/Energy topics outlined in the ACEC "Model HVAC Curriculum." These courses are offered by 59 different schools. The ACEC curriculum includes nine major topics: psychrometics, design heating and cooling calculations, air distribution/pipe and duct systems, system controls, economic analysis, principles of comfort and health, heating and cooling systems components, and energy evaluation methods. The course outlines have been examined to determine which of these topics are included in each course and the results have been published by the Foundation (ACEC, 1984).

Over half of the schools in the ACEC survey (33 of 59) offer only one HVAC/Energy course. It should be noted that this survey did not list schools identified as offering no courses - presumably because Institute attendees were selected on the basis of participation in HVAC/Energy instruction. One fourth of the schools offer 2 (10 schools) or 3 (5 schools) HVAC/Energy courses. The remaining 11 schools offer more than three courses: 2 offer 4 courses; 3 offer 5 courses; 1 offers 6 courses; 3 offer 7 courses; 1 offers 8 courses; and 1 offers 9 courses. Table IV shows the distribution of course offerings by departments. It can be seen that a majority of the Mechanical Engineering, Engineering Science, and "Unknown" departments offer only one HVAC/Energy course. The "unknown" category refers to courses with a course number which could not be identified with a standard department. While their number is small, a majority of the Architectural Engineering, Architecture, and Engineering Technology departments offer at least two courses.

The course outlines were then examined to determine major topical content as listed in Table V. Courses with traditional HVAC topics are listed

under that heading, courses with major emphasis on energy management, audits, energy calculation procedures, etc. are listed as "Conservation" courses, and courses with major emphasis on active or passive solar systems are listed as "Solar". The major emphasis of several courses could not be determined, so they were listed as "Unknown". It can be seen that about 2/3 of the courses are HVAC courses while the remaining third is about 2/3 solar and 1/3 conservation.

Course Catalog Listings of HVAC/Energy Courses

The ACEC survey is neither complete nor random, so the course listings for Mechanical Engineering departments and for Architectural Engineering departments were examined to develop a more comprehensive picture of engineering course offerings in the HVAC/Energy area. These are the only engineering curricula which frequently contain HVAC/Energy courses.

HVAC/Energy in Mechanical Engineering Programs

A systematic examination of the course offerings in 182 Mechanical Engineering programs as indicated by the listings in current university catalogs was conducted. The results are summarized in Table VI. Listings for the other 19 accredited ME programs were not available. Forty seven (one fourth) of these departments offer no HVAC/Energy courses. Twenty four offer a single solar course and 24 offer a single HVAC course. Forty departments offer two courses, with 27 offering one HVAC and one Solar course, 8 offering two HVAC courses, 4 offering two solar courses and 1 offering one solar course and one conservation course. Twenty four ME departments offer three courses with most (15) offering two HVAC and one solar or (5) three HVAC courses. The other four schools offer courses in at least two of the three areas - HVAC, Conservation, and Solar. The 182 departments examined offer a total of 307 courses: 170 HVAC, 120 Solar and 17 Conservation. The average is about 1 HVAC/Conservation course per department and 0.7 solar courses per department.

HVAC/Energy in Architectural Engineering Programs

There are only nine accredited Architectural Engineering programs in the United States. All but one offer some form of Environmental Systems option. These options often combine an emphasis on thermal design and mechanical systems design with courses in building electrical systems and illumination. Table VII summarizes the HVAC/Energy offerings of these nine programs. The column headed "# Energy Courses" shows the number of HVAC/Energy courses offered by the Architectural Engineering department (with courses offered for non-majors excluded). The number of courses offered by the Mechanical Engineering department at each of these schools is shown in parentheses (Environmental Engineering at Cal Poly). The remaining columns show the distribution of the Arch E courses among HVAC, Conservation and Solar. The number of HVAC/Energy offerings in the Architectural Engineering programs ranges from a high of 11 at the University of Colorado, Boulder (where the graduate portion of the program is in Civil Engineering) to no offerings at Cal Poly and the University of Miami. Cal Poly offers only a structures option in its Arch

E. program, while the Arch E. program at the University of Miami utilizes courses offered by Mechanical Engineering.

A total of 32 HVAC/Energy courses are offered by the nine Arch E. programs and it is interesting to note that the HVAC/Energy offerings by the ME departments at these schools are well above average with a total of 30 courses. Some of the Arch E. and ME courses overlap, but others do not, so it appears possible to take from four to thirteen HVAC/Energy courses at these schools. It can be seen that the Arch E. courses show a somewhat greater HVAC emphasis (68%) than was the case with the ME courses (55%).

Programs with Five or More HVAC/Energy Courses

Eighteen schools with five or more HVAC/Energy courses have been identified. This corresponds to about one semester or more of full-time course work. The distribution of course offerings at these schools is shown in Table VIII. It should be noted that this table includes both graduate and undergraduate course offerings, so it will not always be possible to incorporate this much training in a student's undergraduate program. The total number of HVAC/Energy courses at these schools ranges from a low of five to a high of 13 at the University of Colorado. All but two of these schools have instruction in each of the three areas listed. Emphasis on individual areas by some schools is evident. The "average" program available at these schools is 3 HVAC courses, 2 solar courses and 1 conservation course.

In programs with this depth of coverage, there is often significant coverage of topics not evident in course titles or catalog descriptions, so it is likely that the schools without "Conservation" courses are likely to devote significant time to energy estimating methods. Likewise, solar courses often have considerable overlap with mechanical systems and conservation courses, particularly in passive or design related courses.

HOW MUCH HVAC/ENERGY INSTRUCTION IS NEEDED?

This paper has demonstrated that very little HVAC/Energy content is generally available in engineering curricula. It has not yet addressed the question, "How much is needed?"

The ACEC Research and Management Foundation as part of its effort established an HVAC Curriculum Development Committee. This committee was composed of 3 mechanical engineering professors, 2 consultants, and one engineer employed by an equipment manufacturer. They recommended a curriculum "...intended to be taught in 6-9 credit hours over two semesters. The depth of coverage can, of course, be scaled up or down and various areas emphasized depending on program objectives." (ACEC, 1984).

This depth of coverage is far too shallow in the view of the authors of this paper. Perhaps it is based on the perception that this level of coverage is as much as could generally be implemented in a large number of departments. Louis Bacon, the president of NSPE (and a structural engineering who hires HVAC engineers for his firm) recently stated:

> "For some time I have been concerned about the shortage of engineers educated and interested in HVAC and Electrical Engineering for the Building Science Field ... Unfortunately, even the A-E students in environmental options (at least the ones I've had experience with) are spread too thin in their program to provide them with an adequate education in any one part of that program. Thus, they do not become good strong HVAC Engineers until many years after graduation; whereas, the structural option people are ready to assume heavy design and project management responsibilities much sooner than Structural Engineers graduating from Civil Engineering programs." (Bacon, 1984).

This statement implicitly suggests that the 3-4 HVAC/Energy courses found in the average Arch E program are inadequate preparation.

Experience at the University of Colorado certainly emphasizes the need for more than two or three courses in the HVAC/Energy area. Most undergraduates in the Building Energy Engineering program now take six to nine such courses. Once these courses are properly sequenced to eliminate overlaps and include all of the needed content, the authors believe that the curriculum will have close to the proper HVAC/Energy content. Many program graduates find the additional content of the Building Energy M.S. program to be valuable, just as many graduates of comprehensive structures programs continue to the Master's level.

SUMMARY AND CONCLUSIONS

The evidence presented suggests that today's HVAC/Energy engineers often receive very limted formal training in these topics. A large group comes from mechanical engineering programs, another large group from other engineering disciplines, and the third group comes from engineering technology or non-engineering programs. Even those who come from mechanical engineering programs generally have access to very limited HVAC/Energy training; 1/4 of the ME programs have no HVAC/Energy courses, 1/2 offer 1 or 2 courses, and only 1/4 offer 3 or more courses. It appears that only a dozen offer anything approaching a comprehensive HVAC/Energy curriculum. Several of the Architectural Engineering programs offer HVAC/Energy training which appears to compare favorably with the better ME programs.

It can be estimated that the industry is hiring 5,000 new HVAC/Energy engineers per year. It might be inferred from the summary above that a massive program to strengthen HVAC/Energy curricula is needed. However, it is believed that the first priority should be to determine with greater care where the industry is now hiring its engineers. How general is Mr. Bacon's perception of the time required for HVAC engineers to become productive relative to other disciplines?

The eighteen universities with "comprehensive" HVAC/Energy programs as identified in this paper currently educate about 16 percent of the engineering undergraduates in the United States. It is possible that the next dozen programs with three or four courses educate another 10-15 percent of the engineers in the country. If comprehensive programs were available at schools

educating 25 percent of the engineers, it is entirely possible that this would be adequate to meet the needs of the industry.

Hence we recommend:

1. A comprehensive survey should be made to determine employers' perceptions of the need for increased HVAC/Energy engineering training.
2. More information should be provided to the industry about the more comprehensive existing programs.
3. Initiate steps to strengthen existing programs or establish new programs as warranted.

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Table I. 1980 engineering employment by sector.

Nonmanufacturing	400,000
Manufacturing	600,000
Federal, State & Local Governments	160,000
Colleges and Universities	40,000
	1,200,000

Source: BLS, 1982.

Table II

Table II. distribution of engineers by discipline.

Aerospace	68,000
Agricultural	15,000
Biomedical	4,000
Ceramic	15,000
Chemical	55,000
Civil	165,000
Electrical	325,000
Industrial	115,000
Mechanical	213,000
Metallurgical	15,000
Mining	6,000
Petroleum	18,000
Total	1,014,000

Source: BLS, 1982.

Table III. Number of survey respondents who have taken the indicated number of courses in basic and applied thermal sciences topics.

	HVAC + Consv + Solar				Thermo/Ht + HVAC + Consv + Solar				
# Courses	0	1or2	3or4	5or more	0	1or2	3or4	5or6	7or more
ME	12	34	5	4	0	4	28	11	12
Other Engr	11	5	2	3	2	8	5	3	3
Non-Engr	9	0	1	2	9	1	0	1	1
Non-Deg.	3	0	0	0	3	0	0	0	0
Total	35	39	8	9	14	13	33	15	16

	Thermo/Heat Tr.					HVAC					Energy Consv.			
# Courses	0	1	2	3	4+	0	1	2	3	4+	0	1	2	3
ME	0	0	17	15	23	16	23	12	3	1	48	3	3	1
Other Engr	2	3	11	3	2	13	5	1	0	2	19	0	1	1
Non-Engr	9	1	1	1	0	9	1	1	0	1	11	1	0	0
Non-Deg.	3	0	0	0	0	3	0	0	0	0	3	0	0	0
TOTAL	14	4	29	19	25	41	29	14	3	4	81	4	4	2

	Solar					Other				Total
# Courses	0	1	2	3	4+	1	2	3	4+	Respondents
ME	45	6	2	2	0	15	4	0	3	55
Other Engr	16	2	1	1	1	3	3	0	4	21
Non-Engr	11	1	0	0	0	0	0	0	0	12
Non-Deg.	3	0	0	0	0	0	0	0	0	3
Total	75	9	3	3	1	18	7	0	7	91

Table IV. Departments in the ACEC survey which offer the listed number of HVAC/energy courses.

Number of Courses Offered	1	2	3	4	5	6	7	8
Department								
Mechanical Engineering	20	6	3	1	2	1	1	
Architectural Engineering	1				2			
Architecture		2	2					
Engineering Technology	3	5					1	1
Engineering Science	4	1						
Unknown	5	2	1					

Table V. Number of HVAC, conservation, and solar courses listed in ACEC survey.

Course Topic	HVAC	Conservation	Solar	Unknown
Engineering	59	11	21	2
Engineering Tech/Architecture	25	2	5	1
Unknown	3			4

Table VI. Distribution of HVAC/energy course offerings in 182 mechanical engineering departments.

# of Courses Offered	# of Departments	Course Distribution
0	47	
1	48	1 HVAC - 24 depts., 1 Solar - 24 depts.
2	40	2 HVAC - 8 depts., 1 HVAC/1 Solar -27 depts. 2 Solar - 4 depts., 1 Solar/1 Cons - 1 dept.
3	24	2 HVAC/1 Solar - 15 depts., 3 HVAC - 5 depts.
4	12	
5	7	
6	2	
7	2	

Table VII. HVAC/Energy Course Offerings by Architectural Engineering Programs.

University	#HVAC/Energy Courses	HVAC	Conservation	Solar
U. Colorado	11(2)	3	5	3
U. Kansas	5(4)	3	2	
Penn State	6	4	1.5	5
N.C. A&T	4(2)	3	1	
Kansas State	2(4)	2		
U. Texas-Austin	2(2)	2		
Tennessee State	2(3)	2		
U. Miami	0(4)			
Cal Poly SLO	0(9)			
Totals	32(30)	19	9.5	3.5

Table VIII. Course Offerings of Nine Architectural Engineering and Mechanical Engineering Department with Five or More HVAC/Energy Courses.

University	#HVAC/Energy Courses	HVAC	Conservation	Solar
U. Colorado - Arch E/CE/ME	13	5	5	3
Cal Poly SLO - Env. E.	9	6	3	
U. Kansas - Arch E/ME	9	5	3	1
U. Florida - ME	8	5	2	1
Iowa State - ME	7	4	2	1
U. Lowell - Nuc. E/ME	7	5	1	1
Washington U. - ME	7	1	6	0
Georgia Tech - ME	6	4	2	1
Catholic U. - ME	6	3	1.5	1.5
Penn State - Arch E	6	4	1.5	.5
Purdue - ME	6	3	3	
Texas A & M U. - ME	6	1	1	4
Cal Poly, Pomona - ME	5	2	2	1
George Wash. U. - ME	5	1	2	2
Mississippi State - ME	5	3	1	1
U. Cent. Fla. - ME	5	1	2	2
U. Nevada - ME	5	3.5	1	0.5
Virginia Polytech U. - ME	5	2	3	
Totals	120	58.5	52	19.5