

Indoor Environmental Science and Engineering: An Integrated Academic Program

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ABSTRACT

The indoor environmental science and engineering discipline in North America lags far behind other environmental and public health areas in terms of academic programs to educate the next generation of leaders in the field. We have developed a unique academic program that blends the fields of architectural and environmental engineering and that takes an integrated educational approach to solving indoor environmental problems. Six new courses have been added to the curriculum: *Indoor Air Quality (Transport and Control)*, *Indoor Air Quality (Physics and Chemistry)*, *HVAC Design*, *Building Energy Simulation*, *Design of Energy Efficient and Healthy Buildings*, and *Human Exposure Analysis*. These courses are designed to share several common approaches, including the use of an IEQ toolkit of field and laboratory instruments, and project-based learning; a rigorous semester-long project is required in each course. The final outcome of student projects includes a peer-reviewed paper and presentations at an annual *Indoor Air Quality Symposium* sponsored by local professional organizations. Several student term projects have been published in archival journals and presented at international conferences, even by undergraduate students. Additionally, we were recently awarded an Integrated Graduate Education Research and Training (IGERT) award from the National Science Foundation (NSF). This award is being used to initiate an interdisciplinary program for graduate students who will become leaders in indoor environmental science and engineering. In this paper, we present our indoor environmental science and engineering program and suggest the need and strategies for integrating indoor environmental issues into science and engineering curricula across North America.

INTRODUCTION

Americans are indoor creatures, spending on average 18 hours indoors for every hour spent outdoors¹. This statistic is disturbing given that recent studies indicate that indoor environments are generally more contaminated than outdoor environments, and human exposure to toxic chemicals is dominated by activities that take place in the home². Ironically, for the past three decades a myriad of federal and state legislation has led to a complex regulatory framework aimed at protecting the outdoor environment. Academic research motivated by and supporting these acts plays a major role in directing important policy decisions, and entire graduate programs have evolved to educate scientists, engineers, and policy makers in these fields. While there is no doubt that the health of Americans benefits as a result of regulations such as the Clean Water Act and the Clean Air Act, the environmental quality inside of buildings receives no regulatory attention and little research funding. Academic programs are lacking to train engineers and scientists in indoor environmental quality, even as it is emerging as a critical environmental issue in the United States and elsewhere in the world. As a result, many problems

go unresolved, and a plethora of new issues continue to emerge without sufficient intellectual or financial resources to solve them, or in many cases even to understand their root causes.

The importance of indoor air is well recognized in other nations. Scandinavian nations have several excellent educational programs that focus on the indoor environment and several Asian countries, including China and Singapore, are emerging as regional leaders in this discipline. Despite the fact that there are many problems that are unique to American buildings, there are very few opportunities for domestic graduate and undergraduate students to study the indoor environment. Although there are a handful of internationally-recognized indoor environmental science and engineering academicians and researchers at American universities and national laboratories, our nation lacks an interdisciplinary academic program in the area. At the University of Texas at Austin, we are developing such a program that will train future leaders in indoor environmental science and engineering. The program consists of a robust curriculum, state-of-the-art research facilities, a toolbox of equipment for student exploration and semester projects, and internet-based teaching resources. Additionally, we were recently awarded a National Science Foundation (NSF) Integrated Graduate Education and Research Traineeship Program (IGERT) award that will create an interdisciplinary five-year graduate program that integrates faculty and resources across several departments. The purpose of this paper is to describe the goals and features of our program.

GOALS

The goals of our undergraduate program are to train students who are broad experts in their chosen field (Civil/Environmental Engineering or Architectural Engineering) with an understanding of and enthusiasm for issues associated with indoor environmental engineering. Undergraduate students are able to take several of our graduate courses (described below) and are also well prepared in the specific area of indoor engineering in several of their core classes. The objectives of our graduate program are exemplified by the specific goals of the IGERT program: (1) facilitate interdisciplinary interactions amongst students and faculty in disciplines related to indoor environmental science and engineering, (2) promote in-depth knowledge relevant to the field, (3) provide students with skills necessary to create innovative solutions to indoor environmental problems, (4) develop personal, professional, and mentoring skills in future leaders of the field, (5) produce leaders in research and education who have a global focus and are creative agents for change, and (6) recruit, mentor, and retain students from historically underrepresented groups. The educational program described below is designed to achieve these goals.

CURRICULUM AND EDUCATIONAL FEATURES

The heart of our academic program is in our curriculum of graduate courses. Three core faculty members (Richard Corsi, Atila Novoselac, Jeffrey Siegel) currently offer seven courses related explicitly to the indoor environment: *Indoor Air Quality (Transport and Control)*, *Indoor Air Quality (Physics and Chemistry)*, *HVAC Design*, *Building Energy Simulation*, *Building Air Flow Simulation*, *Design of Energy Efficient and Healthy Buildings*, and *Human Exposure Analysis*. Each of these classes is project-based with 50% or more of the project grade derived from semester-long projects. Examples of recent projects include: shelter in place in motor vehicles

during catastrophic events, the net effect of ion generators on indoor fine particulate matter, near head chemistry driven by scented personal care products, and the effects of candle composition on fine particle emission rates. The projects are often presented at professional society sponsored symposiums at the end of each semester. Several papers resulting from final projects have been published in refereed journals³ and presented by students and faculty at international and national conferences⁴.

Although primarily designed for graduate students, several undergraduate students have taken each of the graduate courses described above. However, our primary challenge with most Architectural and Environmental Engineering undergraduate students is making them aware of the field and career options in the indoor environmental area. Consequently, we have integrated indoor environmental topics into several core courses including Building Environmental Systems, Environmental Engineering, Air Pollution Engineering, and Fluid Mechanics. We also employ novel teaching techniques including websites and a toolbox of indoor environmental monitoring equipment, both described below.

In order to enhance student learning and motivate interest in the indoor environmental area, we have worked with the University of Texas College of Engineering Faculty Innovation Center (FIC) to develop and maintain two websites: Energy Conservation Myths (<http://utwired.engr.utexas.edu/conservationMyths>) and Building Mass and Energy Balances (<http://ficip.engr.utexas.edu/bmeb/index.cfm>). The objectives of the energy conservation myths website are to train students to 1) Critically analyze claims about energy and resource conservation, 2) Apply engineering principles to myth evaluation, and 3) apply building environmental systems knowledge to new problems in real buildings. The website analyzes common claims about energy conservation such as “Even an uninsulated drape can trap up to one third of the heat lost through an ordinary window pane. An insulated drape can trap 50%.” There are currently five myths evaluated on the website and students in the Building Environmental Systems class evaluate new myths each year using a framework developed for the myths on the page. An additional benefit has been the attention of media and the general public who contribute suggestions for myths.

A more ambitious multi-level web-based learning tool is the Building Mass and Energy Balances (BMEB) website. The objectives of this site are to 1) reinforce course lectures and homework assignments related to mass and energy balances with applications to buildings, 2) explore the implications of numerous parameter variations on building mass and energy balances, and 3) use simulation tools appropriate for self-paced and visual learners. Students learning about ventilation and pollutant sources can change parameters such as the number of smokers in a bar or the ventilation level for a classroom and examine the resulting steady state concentrations of pollutants of interest. Results are presented in both a numeric and a graphical format (i.e. transparency of a smoke cloud). Students who are learning to calculate heating and cooling loads for HVAC sizing can vary parameters such as glazing area and attic insulation. More advanced students who are learning mass balances and reactor models can vary any input parameter (i.e. emission source strength, deposition loss to surfaces, ventilation rate) and track either the steady state or transient pollutant concentration. Each term of a general governing equation is given and described as well as reasonable input values for several pollutants. Additionally, we are developing a resources section that provides information on additional pollutants as well as more

advanced software, such as CONTAMW for transient multizone air flow and pollutant transport and ENERGY10 and ENERGY PLUS for transient energy balance problems.

To complement classroom lectures, discussions, assignments, and the web-based learning tools above, we have also developed a library of tools for measuring parameters of interest in the indoor environment. The equipment ranges from inexpensive multifunction devices that measure temperature, relative humidity, air velocity, and illumination to a research-grade photo ionization detector for measuring TVOCs. The toolbox includes equipment for measuring particulate matter (ultrafine number concentration, $PM_1 - PM_{10}$ mass concentration), CO_2 , CO, TVOCs, temperature (air, water, surface), relative humidity, airflow, building air exchange (SF_6 decay), building and duct system tightness (fan pressurization), air velocity, air flow, wet-bulb temperature, diffuse illumination, air pressure, electrical power (energy use, power demand, current, voltage, frequency, power factor) and several other variables. Most of this equipment is equipped with portable dataloggers. Students use this equipment for homework assignments (i.e. Find and measure the dry-bulb temperature, wet-bulb temperature, surface temperature, and relative humidity of a condensing indoor microenvironment and confirm your results with the psychrometric chart.) and for semester-long projects.

To motivate undergraduate student interest in indoor environments, the Department of Civil, Architectural, and Environmental Engineering purchased the House of Pressure (HOP) in 2003. The HOP (Figure 1) is a bench scale Plexiglas house with functioning doors, windows, HVAC system, plumbing vent stacks, exhaust fans, and controllable building envelope leaks. Together with a datalogger, desktop computer, calibrated fan (a Duct Blaster™), and tracer smoke to visualize flows, students use the HOP to relate classroom concepts to a physical manifestation and as a bridge to conducting field investigations in real buildings.

Figure 1: The House of Pressure

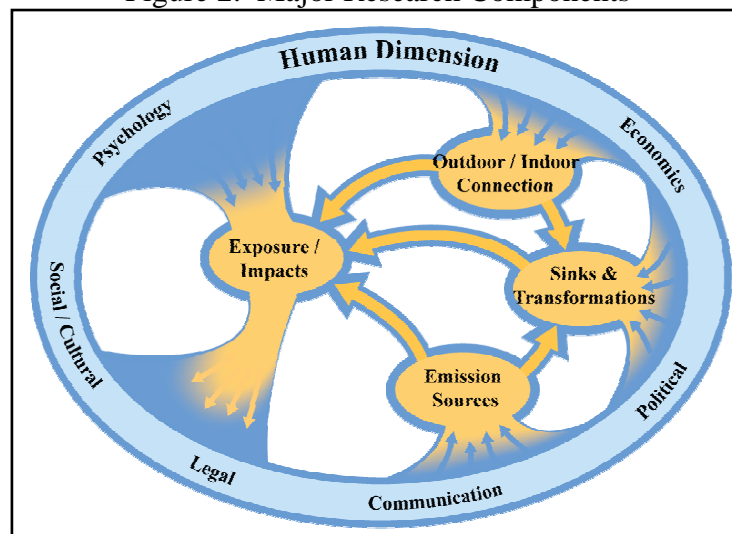


NSF IGERT PROGRAM

In 2006, we inaugurated an interdisciplinary indoor environmental science and engineering graduate program. Funded by the National Science Foundation, this program aims to educate a new generation of leaders in the field. Figure 2 depicts the major inter-connected components

that define the thematic research areas of the proposed IGERT program. These components include (1) outdoor-to-indoor transport of pollutants, moisture, and energy, (2) indoor sources of pollution, (3) sinks, including engineered control systems, and transformations that alter pollutant concentrations and also lead to the generation of secondary pollutants, and (4) exposure of building occupants and sensitive materials to indoor pollutants, and the adverse impacts that result from such exposures. The interconnectedness among components depicted in Figure 2 emphasizes the importance of considering each component within the context of the greater integrated system. Further, the outer ring in Figure 2 depicts the human dimension that influences all components, and thus the system as a whole. The connectedness of the integrated system and importance of the human dimension are themes of this IGERT program. The components shown in Figure 2 will serve as a roadmap for interdisciplinary research amongst IGERT students in a wide range of disciplines: architecture, biology, economics, engineering (architectural, chemical, environmental, mechanical), human ecology, pharmacy and toxicology, and psychology. Further, the integrated system of components will be studied by IGERT students in a new test house facility at The University of Texas.

Figure 2. Major Research Components

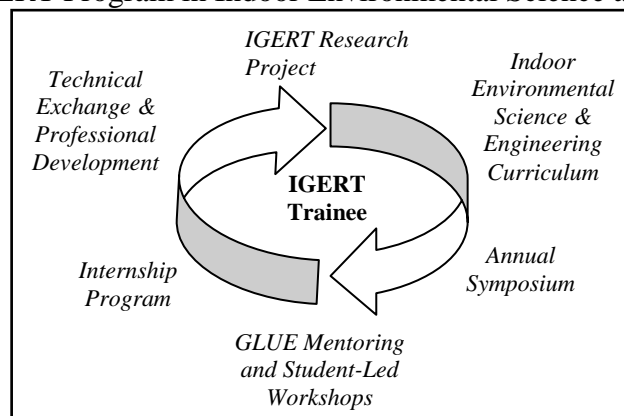


The objective of the IGERT program is to develop leaders who can not only build the technical foundation necessary to improve the indoor environment but also address the broader human dimension of this emerging field. The key elements of the proposed IGERT program are depicted in Figure 3. This comprehensive IGERT program is designed to develop trainees who will thrive within an interdisciplinary framework and establish the directions for the field of indoor environmental science and engineering. The main elements of the education and training program are as follows:

- A research project that incorporates at least two of the thematic areas in Figure 2;
- Internships at internationally recognized institutions in the field of indoor environmental science and engineering, including the Lawrence Berkeley National Laboratory, National Institute of Standards and Technology, and The USEPA's National Exposure Research Laboratory;

- A curriculum that includes core courses supplemented with elective courses from 10 departments across campus;
- A Technical Exchange and Professional Development course that integrates technical presentations and debates on ethical issues with professional development workshops and research team rotations;
- Mentoring and outreach efforts that include student-run workshops as well as mentoring of undergraduate students through an extension of the GLUE program (Graduates Linking to Undergraduates in Engineering); and
- An annual IGERT research symposium to showcase the work of IGERT trainees and promote the exchange of ideas among researchers, the public, and policy makers.

Figure 3. IGERT Program in Indoor Environmental Science and Engineering



The program is centered on each IGERT trainee, so as to simultaneously achieve the educational and research objectives of the IGERT program and meet the individual needs of each graduate student. The first cohort of IGERT trainees will begin the program in Fall 2006.

SUMMARY

We have developed a unique academic program in indoor environmental engineering that blends the fields of architectural and environmental engineering and that takes an integrated educational approach to solving indoor environmental problems. By introducing undergraduate students to indoor environmental engineering with innovative digital tools and laboratory and field equipment, we hope to increase the number of students who pursue this discipline in their careers and in graduate school. By providing a robust curriculum of graduate courses and research opportunities, we hope to train engineering students who can raise the state-of-the-art and the US profile in this field. Through our NSF-funded interdisciplinary IGERT program, we hope to train Ph.D. students to be the next generation of leaders in this emerging and important field.

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