**ARCHITECTURAL ENGINEERING**

Architectural engineering focuses on the design, construction and operation of buildings and the integration of their systems. The department offers Master of Science (MS) and Doctor of Philosophy (PhD) degrees in architectural engineering with a study emphasis in (1) building energy, (2) illumination, (3) materials and resources, and (4) construction engineering and management.

Graduate studies in architectural engineering are offered through the Department of Civil, Environmental and Architectural Engineering (http://www.colorado.edu/ceae/prospective-students/graduate-studies). The Graduate Record Examination (GRE), consisting of the aptitude tests and advanced test in engineering, is used to evaluate MS and PhD candidates. Candidates who submit GRE scores are more likely considered for financial assistance.

**Course code for this program is AREN.**

**Research Interests and Facilities**

The Larson HVAC Laboratory has been a staple of the University of Colorado’s building energy research activities and AREN program education. The laboratory has been the stepping stone for fundamental and applied research in building energy efficiency, energy controls, thermal comfort and indoor air quality. The newly renovated Larson HVAC Laboratory provides a unique facility that permits the evaluation of entire systems in a controlled dynamic environment, providing repeatable test conditions. The laboratory has been recently redesigned to allow maximum flexibility in conducting a wide variety of research and testing procedures. In particular, both the HVAC and control systems in the laboratory are reconfigurable in that components, subsystems or entire systems can be readily installed and tested. For instance, the performance of air handling units, displacement ventilation units, chilled beams and variable refrigerant flow units can be tested. In addition, coils, air mixers, dampers, filters and variable frequency drives can be evaluated. Moreover, the laboratory offers the possibility to test standalone HVAC and refrigeration systems such as water heaters, boilers, thermal energy storage tanks and chillers.

The Lighting Laboratory is a learning and research space for lighting students in the AREN program. The lab has a dynamic ceiling with adjustable height to allow a wide range of academic and research exploration. Although the lab has full-wall, north-facing windows, there are blackout curtains installed to eliminate any undesirable external light. In addition, this lab houses a goniophotometer used to measure the intensity of light leaving a luminaire at various vertical and horizontal angles. The measured data allow establishing photometric light distribution of the luminaire and metrics such as total lumen output, luminaire luminance and zonal lumen summary. The lab also houses a small lighting sphere, which allows testing of luminaire output of LED luminaires and LED chips. In addition, the lighting lab includes a studio sphere used primarily for lighting research. The lab has an extensive aluminum open ceiling grid that allows for quick electrical and physical connection of light sources and luminaires for research. For lighting design-oriented classes, students have access to theatrical-type and programmable color-changing luminaires to do mock-ups and study lighting effects.

The AREN laboratories offer state-of-the-art facilities to test a wide range of operational and control strategies for lighting and HVAC systems and subsystems. Indeed, several control projects have been carried out in the Larson HVAC laboratory including demand-ventilation controls, optimal chiller and thermal energy storage controls, outdoor air intake controls, and optimal operation of evaporative systems. In addition, fault diagnostic algorithms have been tested in the laboratory for specific HVAC equipment including for heating and cooling coils, chillers and outdoor air intake dampers.

**Master’s Degrees**

- Architectural Engineering - Master of Science (MS) (catalog.colorado.edu/graduate-colleges-schools/engineering-applied-science/programs-study/architectural-engineering/architectural-engineering-master-science-ms)

**Doctoral Degree**

- Architectural Engineering - Doctor of Philosophy (PhD) (catalog.colorado.edu/graduate-colleges-schools/engineering-applied-science/programs-study/architectural-engineering/architectural-engineering-doctor-philosophy-phd)

**Faculty**

While many faculty teach both undergraduate and graduate students, some instruct students at the undergraduate level only. For more information, contact the faculty member’s home department.

- Amadei, Bernard (https://experts.colorado.edu/display/fisid_105978)
  Distinguished Professor; PhD, University of California, Berkeley

- Amy, Gary L.
  Professor Emeritus

- Balaji, Rajagopalan (https://experts.colorado.edu/display/fisid_118480)
  Professor, Chair; PhD, Utah State University

- Bielefeldt, Angela R. (https://experts.colorado.edu/display/fisid_110322)
  Professor; PhD, University of Washington

- Brandemuehl, Michael J.
  Professor Emeritus

- Chinowsky, Paul (https://experts.colorado.edu/display/fisid_125496)
  Professor; PhD, Stanford University

- Cook, Sherri M. (https://experts.colorado.edu/display/fisid_154773)
  Assistant Professor; PhD, University of Michigan Ann Arbor

- Corotis, Ross B. (https://experts.colorado.edu/display/fisid_100942)
  Professor; PhD, Massachusetts Institute of Technology

- Crimaldi, John P. (https://experts.colorado.edu/display/fisid_115733)
  Professor, Associate Chair; PhD, Stanford University

- Dashti, Shideh (https://experts.colorado.edu/display/fisid_148493)
  Associate Professor, Faculty Director; PhD, University of California, Berkeley

- Diekmann, James E.
  Professor Emeritus

- DiLaura, David L.
  Professor Emeritus
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<tr>
<th>Name</th>
<th>Title</th>
<th>University/Institution</th>
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<tr>
<td>Dow, John O.</td>
<td>Associate Professor Emeritus</td>
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<td>Evan, Thomas</td>
<td>Associate Professor; PhD, University of Colorado Boulder</td>
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<td>Frangopol, Dan M.</td>
<td>Professor Emeritus</td>
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<td>Goodrum, Paul M.</td>
<td>Professor; PhD, University of Texas at Austin</td>
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<td>Gooseff, Michael N.</td>
<td>Professor; PhD, University of Colorado Boulder</td>
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<td>Gupta, Vijay</td>
<td>Professor Emeritus</td>
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<td>Halek, Milan F.</td>
<td>Senior Instructor Emeritus</td>
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<td>Hallowell, Matthew Ryan</td>
<td>Associate Professor; PhD, Oregon State University</td>
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<td>Hearn, George</td>
<td>Associate Professor; PhD, Columbia University</td>
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<td>Henze, Gregor P.</td>
<td>Professor; PhD, University of Colorado Boulder</td>
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<td>Hernandez, Mark T.</td>
<td>Professor; University of California, Berkeley</td>
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<td>Hubler, Mija H.</td>
<td>Assistant Professor, Faculty Director; PhD, Northwestern University</td>
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<td>Javernick-Will, Amy N.</td>
<td>Associate Professor, Associate Faculty Director; PhD, Stanford University</td>
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<td>Kasprzyk, Joseph R.</td>
<td>Assistant Professor; PhD, Pennsylvania State University</td>
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<td>Klees, Rita C.</td>
<td>Associate Faculty Director, Scholar in Residence; PhD, University of Colorado</td>
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<td>Ko, Hon-Yim</td>
<td>Professor Emeritus</td>
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<td>Korak, Julie A.</td>
<td>Assistant Professor; PhD, University of Colorado Boulder</td>
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<td>Kuchenrither, Richard D.</td>
<td>Scholar in Residence; PhD, University of Colorado Boulder</td>
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<td>Liel, Abbie B.</td>
<td>Associate Professor, Faculty Director; PhD, Stanford University</td>
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<td>Linden, Karl G.</td>
<td>Professor; PhD, University of California, Davis</td>
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<td>Livneh, Ben</td>
<td>Assistant Professor; PhD, University of Washington</td>
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<td>Mansfeldt, Cresten</td>
<td>Assistant Professor; PhD, Cornell University</td>
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<td>McKnight, Diane M.</td>
<td>Professor; PhD, Massachusetts Institute of Technology</td>
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<td>Molenaar, Keith Robert</td>
<td>Professor; PhD, University of Colorado Boulder</td>
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<td>Morris, Matthew R.</td>
<td>Senior Instructor, MS, University of Colorado Boulder</td>
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<td>Neupauer, Roseanna M.</td>
<td>Professor, Associate Chair; PhD, New Mexico Institute of Mining and Technology</td>
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<td>Pak, Ronald Y.S.</td>
<td>Professor; PhD, California Institute of Technology</td>
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<td>Pfeffer, Tad</td>
<td>Professor; PhD, University of Washington</td>
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<td>Porter, Keith Alan</td>
<td>Research Professor; PhD, Stanford University</td>
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<td>Pourahmadian, Fatemeh</td>
<td>Assistant Professor; PhD, University of Minnesota</td>
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<td>Regueiro, Richard A.</td>
<td>Associate Professor; PhD, Stanford University</td>
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<td>Rosario-Ortiz, Fernando L.</td>
<td>Director; Professor; DEnv, University of California, Los Angeles</td>
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<td>Ryan, Joseph N.</td>
<td>Professor; PhD, Massachusetts Institute of Technology</td>
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<td>Salvinelli, Carlo</td>
<td>Instructor; PhD, Missouri University of Science and Technology</td>
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<td>Saouma, Victor E.</td>
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<td>Scheib, Jennifer G.</td>
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<td>Song, Jeong-Hoon</td>
<td>Assistant Professor; PhD, Northwestern University</td>
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<td>Srubar, Wil V. III</td>
<td>Assistant Professor, Faculty Director; PhD, Stanford University</td>
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Courses

AREN 5001 (3) Building Energy Systems: Thermal, Electrical & Lighting Sys
Prepares graduate students with general knowledge and skills that are required by advanced AREN technical courses. Covers three parts of materials: 1) building thermal systems, 2) building lighting systems, 3) building electrical systems.
**Requisites:** Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.
**Grading Basis:** Letter Grade
**Additional Information:** Departmental Category: Building Systems Engineering

AREN 5010 (3) Energy System Modeling and Control
Engineering course devoted to building automation and control systems. Topics include HVAC control technology and strategies, measurement and device technologies, analysis and modeling of dynamic systems, simulation of conventional and advanced control approaches, assessment of control loop performance and hands-on direct digital control (DDC) programming exercises as used in current building control practice.
**Equivalent - Duplicate Degree Credit Not Granted:** AREN 4010
**Requisites:** Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.
**Recommended:** Prerequisite AREN 4140.
**Additional Information:** Departmental Category: Building Systems Engineering

AREN 5020 (3) Building Energy Audits
Analyzes and measures performance of HVAC systems, envelopes, lighting and hot water systems, and modifications to reduce energy use. Emphasizes existing buildings.
**Requisites:** Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.
**Recommended:** Prerequisite AREN 3010.
**Additional Information:** Departmental Category: Building Systems Engineering

AREN 5050 (3) Advanced Solar Design
Predicts performance and analyzes economics of low-temperature, high-temperature, photovoltaic, and other innovative solar systems. Also includes performance prediction methods for solar processes. Taught intermittently.
**Requisites:** Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.
**Additional Information:** Departmental Category: Building Systems Engineering

AREN 5060 (3) Distributed Electricity Generation
Introduces basic distributed generation (DG) technologies including fuel-based systems and renewable energy technologies and overview approaches to conduct energy, economical, and environmental analysis of selected DG technologies using state-of-the-art analysis tools to evaluate optimal hybrid distributed generation systems to meet required electrical loads specific to urban centers, campuses, and residential communities.
**Requisites:** Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.
**Grading Basis:** Letter Grade
**Additional Information:** Departmental Category: Building Systems Engineering

AREN 5070 (3) Thermal Analysis of Buildings
Examines response factors, conduction transfer functions and weighting factors for dynamic analysis of building envelopes. Also studies radiative and convective exchange in buildings, internal gains and infiltration analysis as modeled in hourly simulations. Taught intermittently.
**Requisites:** Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-ARENCVEN, or C-EVENCVEN) only.
**Additional Information:** Departmental Category: Building Systems Engineering
AREN 5080 (3) Computer Simulation of Building Energy Systems
Introduces major simulation programs for analysis of building energy loads and system performance. Focuses on one hourly simulation program to develop capability for analysis of multizone structure.
Requisites: Requires prerequisite course of AREN 4110 or AREN 5110 (minimum grade C-). Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-AREN/CEVEN, or C-EVENCVEN) only.
Additional Information: Departmental Category: Building Systems Engineering

AREN 5110 (3-4) HVAC System Design
Applies engineering principles to the design of heating, ventilating and air conditioning (HVAC) systems for buildings. Covers HVAC systems description, load estimation, psychometrics, coils and heat exchangers, air and water distribution systems and primary equipment and controls.
Equivalent - Duplicate Degree Credit Not Granted: AREN 4110
Recommended: Prerequisite AREN 3010.
Additional Information: Departmental Category: Building Systems Engineering

AREN 5130 (3) Optical Design for Illumination and Solid State Lighting
Covers the optical design process for illumination-based optics, emphasis on applications in architectural lighting. In-depth coverage of luminaire photometry, lamps, materials, manufacturing methods, product performance requirements. Projects utilize optical design software and include a variety of lamp types including LEDs using both reflector/lens optics.
Equivalent - Duplicate Degree Credit Not Granted: AREN 4130
Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-AREN/CEVEN, or C-EVENCVEN) only.
Recommended: Prerequisite AREN 3540.
Additional Information: Departmental Category: Building Systems Engineering

AREN 5540 (3) Exterior Lighting Systems
Engages students in exploring and solving lighting problems for exterior environments. Provides an understanding of the design criteria and lighting equipment used in three primary exterior applications: parking lots and roadways, floodlighting of buildings, and sports facilities. Taught intermittently.
Equivalent - Duplicate Degree Credit Not Granted: AREN 4540
Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-AREN/CEVEN, or C-EVENCVEN) only.
Recommended: Prerequisites AREN 3540 and AREN 4550.
Additional Information: Departmental Category: Building Systems Engineering

AREN 5650 (3) Forensic Engineering
Identify and explore the physical, chemical, mechanical, and biological deterioration mechanisms in the most common construction materials; concrete, masonry, metals, wood, polymers, and fiber-reinforced composites. Course topics include an introduction to failure analysis; materials science; ion diffusion; electrochemistry (corrosion); fracture, fatigue, and creep; and diagnostic, retrofit, and rehabilitation strategies for extended service life.
Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-AREN/CEVEN, or C-EVENCVEN) only.

AREN 5890 (3) Sustainable Building Design
Introduces green building design procedure/approach and provides insight into evolving design principles; explores aspects of building thermal/energy performance, indoor/outdoor environmental quality, occupant comfort and climate relevant to building design (structures not covered); emphasizes both comprehensive understanding and practical applications of sustainable building design strategies; applies prevailing simulation tools to assist green building design.
Equivalent - Duplicate Degree Credit Not Granted: AREN 4890
Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-AREN/CEVEN, or C-EVENCVEN) only.
Recommended: Prerequisite AREN 3010.
Additional Information: Departmental Category: Building Systems Engineering

AREN 5990 (3) Compu Fluid Dynamics (CFD) Analysis for Built/Natural Environments
Explores the fundamentals of simulating/analyzing civil and architectural environments with Computational Fluid Dynamics (CFD) method. Run with two parallel sessions: fundamentals and applications, with fundamental lectures presenting the principles of CFD technologies, and application sessions demonstrating the application of CFD for resolving building and environmental engineering problems (different than MCEN/ASEN) with hands-on exercises.
Equivalent - Duplicate Degree Credit Not Granted: AREN 4990
Requisites: Restricted to graduate students or concurrent degree sub plans (C-AREN, C-CVEN, C-AREN/CEVEN, or C-EVENCVEN) only.
Recommended: Prerequisites AREN 2120 and APPM 2360.
Additional Information: Departmental Category: Building Systems Engineering

AREN 6940 (1) Master's Candidate for Degree
Grading Basis: Pass/Fail
Additional Information: Departmental Category: Building Systems Engineering

AREN 6950 (1-6) Master's Thesis
Additional Information: Departmental Category: Building Systems Engineering

AREN 6960 (1-3) Master's Report
Repeatable: Repeatable for up to 3.00 total credit hours.
Additional Information: Departmental Category: Building Systems Engineering

AREN 8890 (1-10) Doctoral Thesis
A minimum of 30 credit hours is required.
Additional Information: Departmental Category: Building Systems Engineering