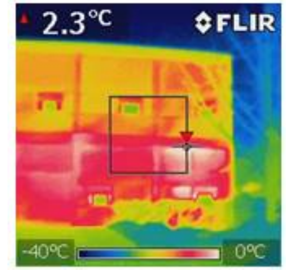
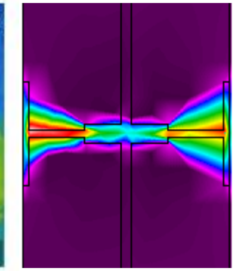
CAE 331/513
Building Science
Fall 2019





August 20, 2019
Introduction to Building Science

Built
Environment
Research
@ IIT

Advancing energy, environmental, and sustainability research within the built environment

www.built-envi.com

Twitter: @built_envi

Dr. Brent Stephens, Ph.D.
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
brent@iit.edu

Objectives for today's lecture

- Introduce myself
- Introduce course topics
- Introduce yourselves
- Discuss syllabus
  - Course information, outline, schedule, ground rules
  - Why are we all here?
- Introduce fundamentals of building science

About me

- B.S.E., Civil Engineering
  - Tennessee Tech University, 2007
- M.S.E., Environmental and Water Resources Engineering
  - The University of Texas at Austin, 2009
  - Thesis: "Energy implications of filtration in residential and light-commercial buildings"
- Ph.D., Civil Engineering
  - The University of Texas at Austin, 2012
  - Dissertation: "Characterizing the impacts of air-conditioning systems, filters, and building envelopes on exposures to indoor pollutants and energy consumption in residential and light-commercial buildings"
- Work experience relevant to this course
  - NSF IGERT Fellow in Indoor Environmental Science in Engineering
  - Energy intern at Southface Energy Institute in Atlanta, GA

The **Built Environment Research Group** in the **Department of Civil, Architectural, and Environmental Engineering at Illinois Tech** is dedicated to investigating energy and air quality within the built environment

Research areas:

Indoor pollutant dynamics

Building science measurements and methods

Air cleaning and filtration

Human exposure assessment

Building energy efficiency and energy simulation

Read more online:
http://built-envi.com

Course information

CAE 331/513: Building Science

Course Unique Number(s)

- CAE 331 Section 01: 10123 (undergraduate)
- CAE 513 Section 01: 11125 (graduate in-class)
- CAE 513 Section 02: 11500 (graduate online)

Classroom and Meeting Time

- Wishnick Hall, Room 117
- Tuesdays and Thursdays 1:50 PM – 3:05 PM

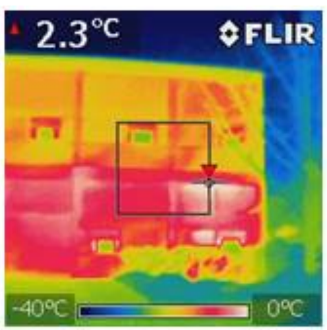
Prerequisites

- CAE 209 Thermal Fluids Engineering II, or MMAE 322 Heat and Mass Transfer, or CHE 302 Heat and Mass Transfer Operations

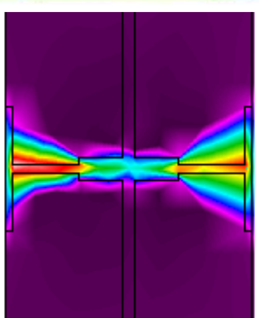
Course information

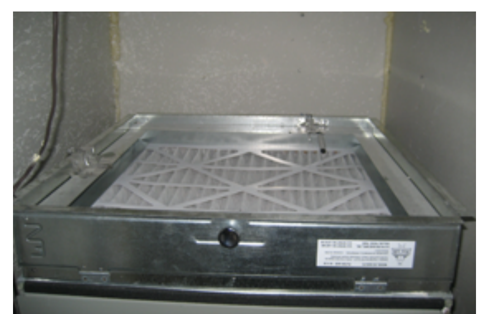
Course Catalog Description

- Study of the physical interaction of climate (humidity, temperature, wind, sun, rain, snow, etc.) and buildings. Topics include psychrometrics, indoor air quality, indoor thermal comfort, heat transfer, air infiltration, solar insolation, and heating and cooling load calculation.







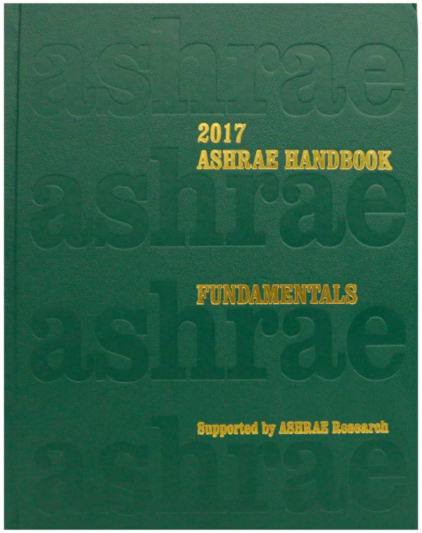


Course objectives

To introduce students to physical phenomena that affect building design and performance. By taking this course students will be able to:

1. Describe the role of building components and building environmental systems in energy consumption, peak electricity demand, thermal comfort, and human exposures to indoor airborne pollutants.
2. Describe and quantify fundamental heat and mass transfer properties and processes in buildings, including conduction, convection, radiation, psychrometrics, basic thermodynamics of refrigeration systems, and mass and energy balances.
3. Calculate peak heating and cooling loads and annual energy use for buildings using commercially available software.
4. Understand types of HVAC equipment for residential and commercial construction and how they operate.
5. Understand fundamental ventilation and indoor air quality concepts.
6. Understand strategies to improve energy efficiency in buildings.
7. Understand relevant codes and standards for energy efficiency in buildings.
8. Critically analyze claims about building components and environmental systems from product manufacturers, contractors, and building designers.

Required text



ASHRAE 2017 Handbook of Fundamentals

American Society of Heating, Refrigerating, and Air-Conditioning Engineers

https://www.ashrae.org/resources--publications/handbook/2017-ashrae-handbook-fundamentals

- $209 for non-ASHRAE members
- $49 for ASHRAE student members
- ASHRAE student membership: $25
  - **Total (membership + HoF): $74**

- You should purchase the IP unit hard copy version of this (**email me/come to my office**)
  - Comes with IP/SI CD

Additional references

- I will also draw on several other references in this course:
  - You **do not** need to purchase these

ASHRAE 90.1-2013. *Energy Standard for Buildings Except Low-Rise Residential Buildings.*

Janis, R.R. and Tao, W.K.Y. 2009. *Mechanical and Electrical Systems in Buildings*. Pearson Prentice Hall. ISBN: 978-0-13-513013-1.

Kuehn, T.H., Ramsey, J.W., and Threlkeld, J.L. 1998. *Thermal Environmental Engineering*. Prentice Hall. ISBN: 0-13-917220-3.

McQuiston, F.C., Parker, J.D., and Spitler, J.D. 2005. *Heating, ventilating, and air conditioning: analysis and design*. John Wiley & Sons, Inc. ISBN: 0-471-47015-5.

Mitchell, J.W. and Braun, J.E. 2013. *Principles of Heating, Ventilation, and Air Conditioning in Buildings*. John Wiley & Sons, Inc. ISBN: 978-0-470-62457-9.

Moss, K.J. 2007. *Heat and Mass Transfer in Buildings* (Second Edition). Taylor & Francis. ISBN: 978-0-415-40908-7.

Reddy, T.A., Kreider, J.F., Curtiss, P.S., and Rabl, A. *Heating and Cooling of Buildings: Principles and Practice of Energy Efficient Design* (3rd Edition), CRC Press, Taylor & Francis Group. ISBN: 978-1439899892.

Straube, J. and Burnett, E. 2005. *Building Science for Building Enclosures*. Building Science Press. ISBN: 0-9755127-4-9.

Wang, S.K. 2000. *Handbook of air conditioning and refrigeration* (2nd edition). McGraw-Hill. ISBN: 0-07-068167-8.

Major course topics

- Importance of building science
- Applications of heat transfer in buildings
- Human thermal comfort
- HVAC systems basics
- Psychrometrics – properties and processes
- Ventilation, infiltration, and indoor air quality
- Building energy balances
- Heating and cooling load calculations
- Building energy simulation
- Introduction to energy efficient building design
- Codes and standards for building energy performance

About you

- Who are you?
  - First and last name
  - Where are you from?
- Degree info
  - Undergraduate or graduate?
  - Engineering or other?
  - If graduate, masters or PhD?

Course expectations

- Grading
  - This course is mixed undergraduate/graduate
  - No differences in HW or exams between UG/G

- Homework
  - **Six HW** assignments are planned throughout the semester
    - 100 pts each; individual assignments

- **Three closed-book exams (tentative schedule)**
  - Thursday, September 19, 2019
  - Thursday, October 24, 2019
  - Final exam (comprehensive): TBD (finals week)
    - Online students: I prefer that you be able to take the exams in class
      - Otherwise, arrange with a local testing center

Why a mixed UG/G course?

For undergraduate students:

- We are trying to help you adapt your basic physics and engineering knowledge to buildings
  - And to build a solid foundation for more advanced courses in architectural engineering

For graduate students (with a wide range of backgrounds):

- We are also trying to help you advance your physics and engineering knowledge to apply to buildings
  - And to build a foundation for advanced study, professional practice, and/or research in architectural engineering
  - Primarily reserved for graduate students without significant building science or architectural engineering background

Course grading

Assignment	Undergraduate (331) Max points	Graduate (513) Max points
• HW	600	600
• Exam 1	250	250
• Exam 2	250	250
• Final exam	300	300
• Final project	n/a	300
• Total	1400	1700

Grading scale for both CAE 331 and CAE 513:

A	B	C	D	F
90% and up	80.0-89.9%	70.0-79.9%	60.0-69.9%	<60.0%

Course grading: <u>Graduate</u> students (CAE 513)

- There is an **additional deliverable** for graduate students
  - Graduate students will be required to complete a technical research project in addition to the regular HW and exam requirements
  - The project will involve researching, writing a literature review, and conducting a technical analysis on a specific topic in building science
  - <u>Final deliverable</u>: written technical research paper

Course website

- I will post all HWs, exams, lecture notes, syllabus, and other materials to **Blackboard (BB)**
  - https://blackboard.iit.edu

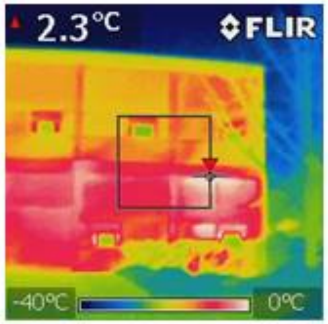
Tentative course schedule (continuously revised)

Week	Lecture	Date	Lecture Topics	HW Due	Handbook chapter
1	1	Aug 20	Introduction to building science		Chapter 34, 38
	2	Aug 22	Pre-requisite review, energy concepts, and units		
2	3	Aug 27	Heat transfer in buildings: conduction part 1		Chapter 4, 25, 26
	4	Aug 29	Heat transfer in buildings: conduction part 2	HW1	
3	5	Sep 3	Heat transfer in buildings: convection		
	6	Sep 5	Heat transfer in buildings: radiation		
4	7	Sep 10	Heat transfer in buildings: combined modes		
	8	Sep 12	Heat transfer in buildings: fenestration	HW2	Chapter 15
5	-	Sep 17	Exam review: example problems		
	-	Sep 19	**Exam 1**		
6	9	Sep 24	Human thermal comfort		Chapter 9
	10	Sep 26	Psychrometrics: fundamentals and chart		Chapter 1
7	11	Oct 1	Psychrometrics: equations		
	12	Oct 3	Introduction to HVAC systems part 1		
8	13	Oct 8	Mechanical systems and psychrometric processes	HW3	
	14	Oct 10	Mechanical systems and psychrometric processes		Chapter 1
9	15	Oct 15	Mechanical systems and psychrometric processes		
	16	Oct 17	Introduction to HVAC systems part 2	HW4	
10	-	Oct 22	Hands-on building investigation and exam review		
	-	Oct 24	**Exam 2**		
11	17	Oct 29	Ventilation and indoor air quality		Chapter 10, 11
	18	Oct 31	Ventilation and indoor air quality		
12	19	Nov 5	Infiltration and natural ventilation		Chapter 16
	20	Nov 7	Building energy balances: fundamentals	HW5	Chapter 14, 17, 1
13	21	Nov 12	Energy balances: heating load calculations		
	22	Nov 14	Energy balances: cooling load calculations		
14	23	Nov 19	Energy balances: annual energy simulations		
	24	Nov 21	Energy efficient building design	HW6	Chapter 19
15	25	Nov 26	Building codes, standards, and guidelines		Chapter 35
	-	Nov 28	*No class – Thanksgiving Day*		
Final	-	TBD	**Final exam, week of Dec 2**		
		Dec 8	**Graduate student projects due Sun@11:59 pm**	Grad projects	

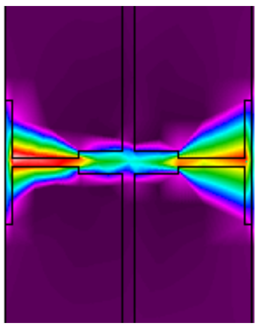
Office hours

- Office hours are primarily by appointment
- Office: Alumni Hall 228E
- Email me to schedule an appointment
  - brent@iit.edu

Questions so far?





INTRODUCTION TO BUILDING SCIENCE

What is building science?

Building science is the application of physics to buildings and the built environment

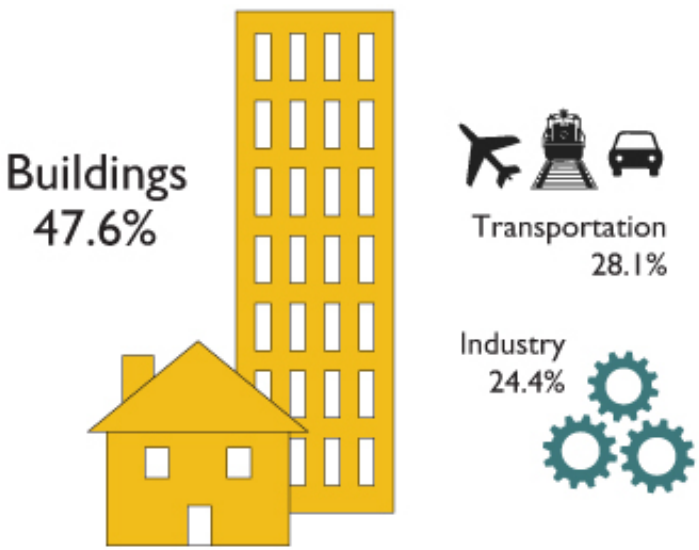
- Building science involves studying all of the physical phenomena that govern energy use, human comfort, function, and overall performance of buildings

- Building science requires complete understanding of:
  - Weather conditions, subterranean (soil) conditions, building material characteristics, physics, chemistry, biology, and human physiology
  - Each of these combines to influence energy consumption, environmental impacts, environmental control, system design, maintenance, construction, building longevity, human comfort and health, and overall sustainability

Why study building science?

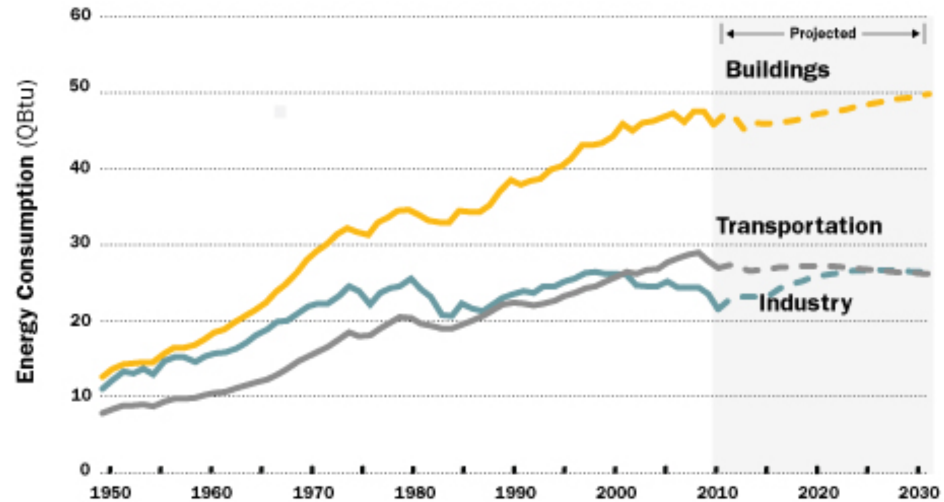
- How many of you are in a building right now?
  - Birds build nests
  - Rabbits dig holes
  - People build buildings
- How much energy do buildings use in the U.S.?
- How much money do we spend on energy use in buildings in the U.S.?
- How much time do you think people spend indoors, on average?

Buildings use *a lot* of energy



U.S. Energy Consumption by Sector

Data Source: U.S. Energy Information Administration (2012).



U.S. Energy Consumption by Sector (Historic / Projected)

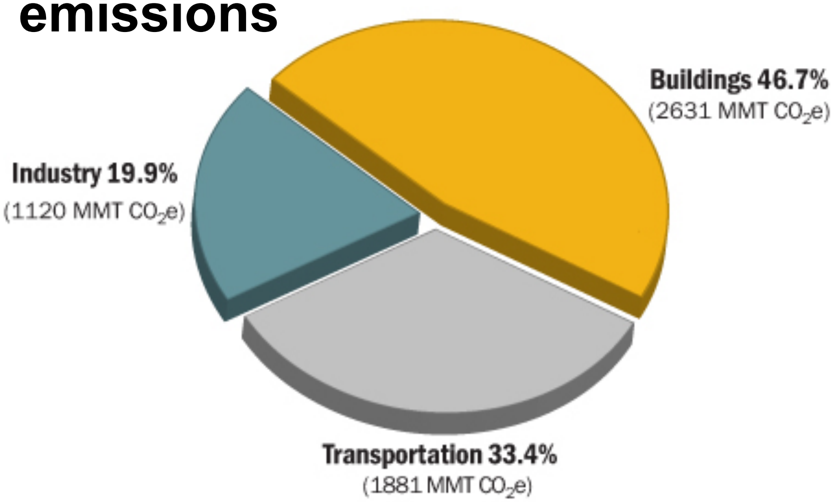
Data Source: U.S. Energy Information Administration (2012).

Buildings account for ~47% of energy in the U.S.
(Operations: ~41% | Construction and materials: ~6%)

Buildings in the U.S. account for ~7% of the total amount of energy used in the world

Buildings account for *a lot* of GHG and pollutant emissions

Contribution to greenhouse gas (GHG) emissions



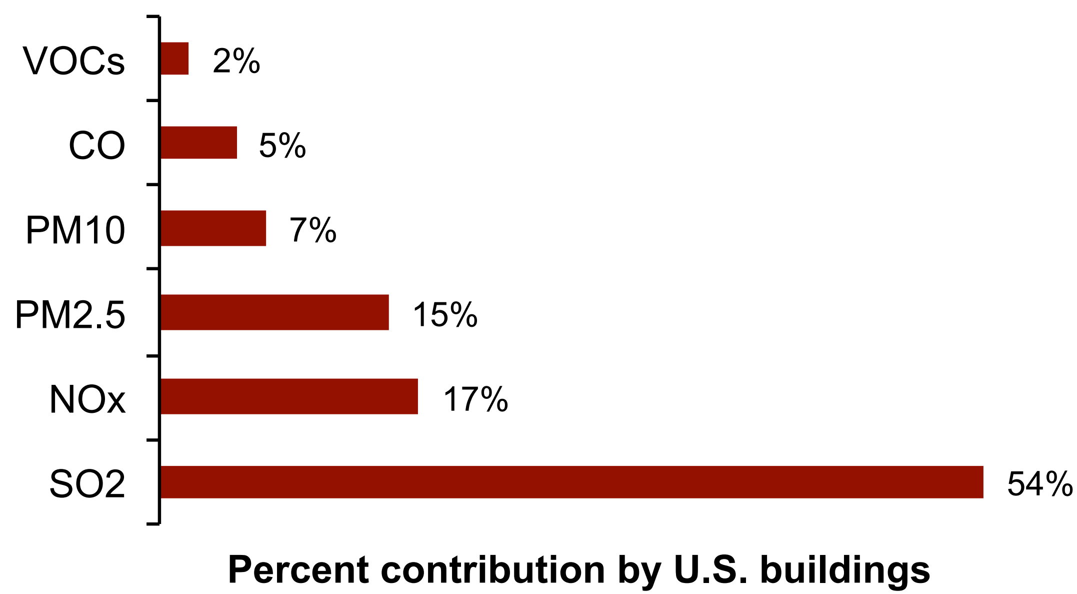
U.S. CO_2 Emissions by Sector

Source: ©2011 2030, Inc. / Architecture 2030. All Rights Reserved.
Data Source: U.S. Energy Information Administration (2011).

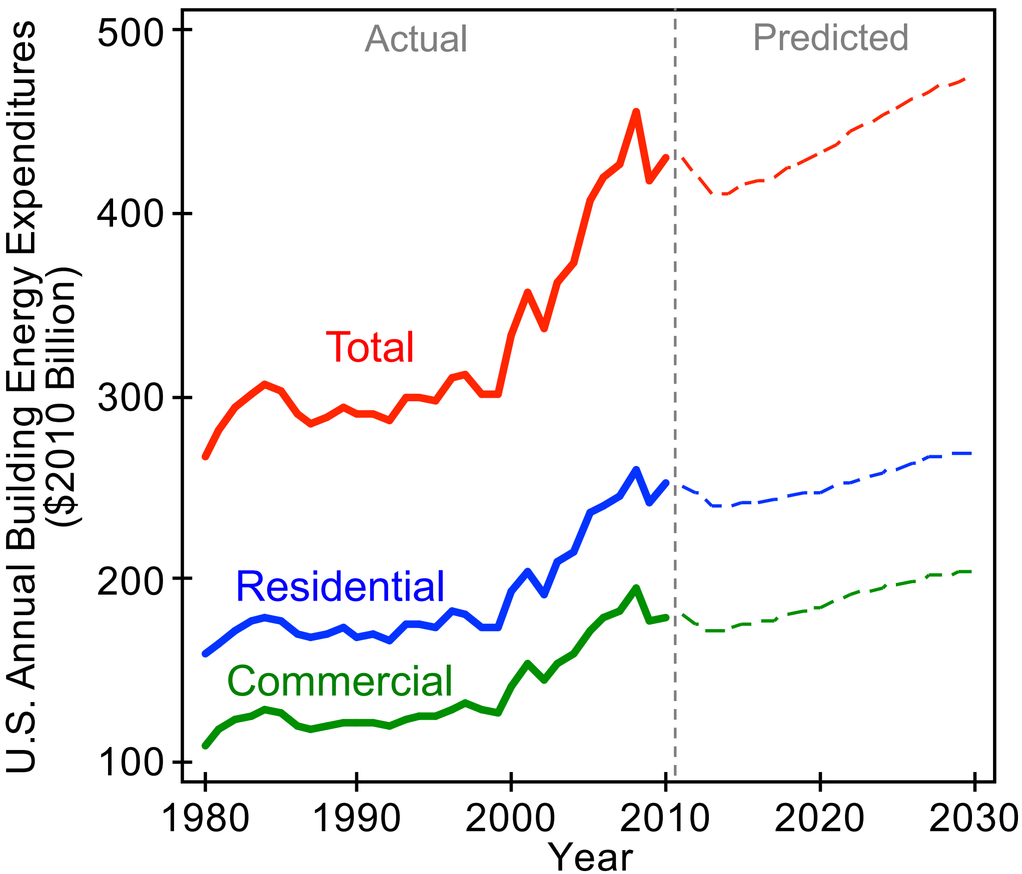
Major energy uses?

1. Heating
2. Cooling
3. Lighting
4. Water heating

Contribution to outdoor air pollution

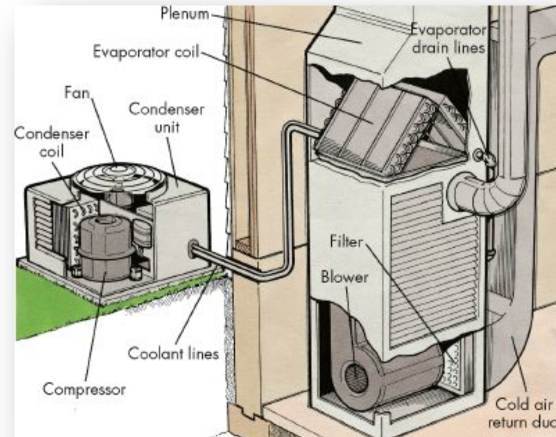


Building energy use costs ***a lot*** of money



U.S. building energy expenditures totaled ~$430 billion in 2010

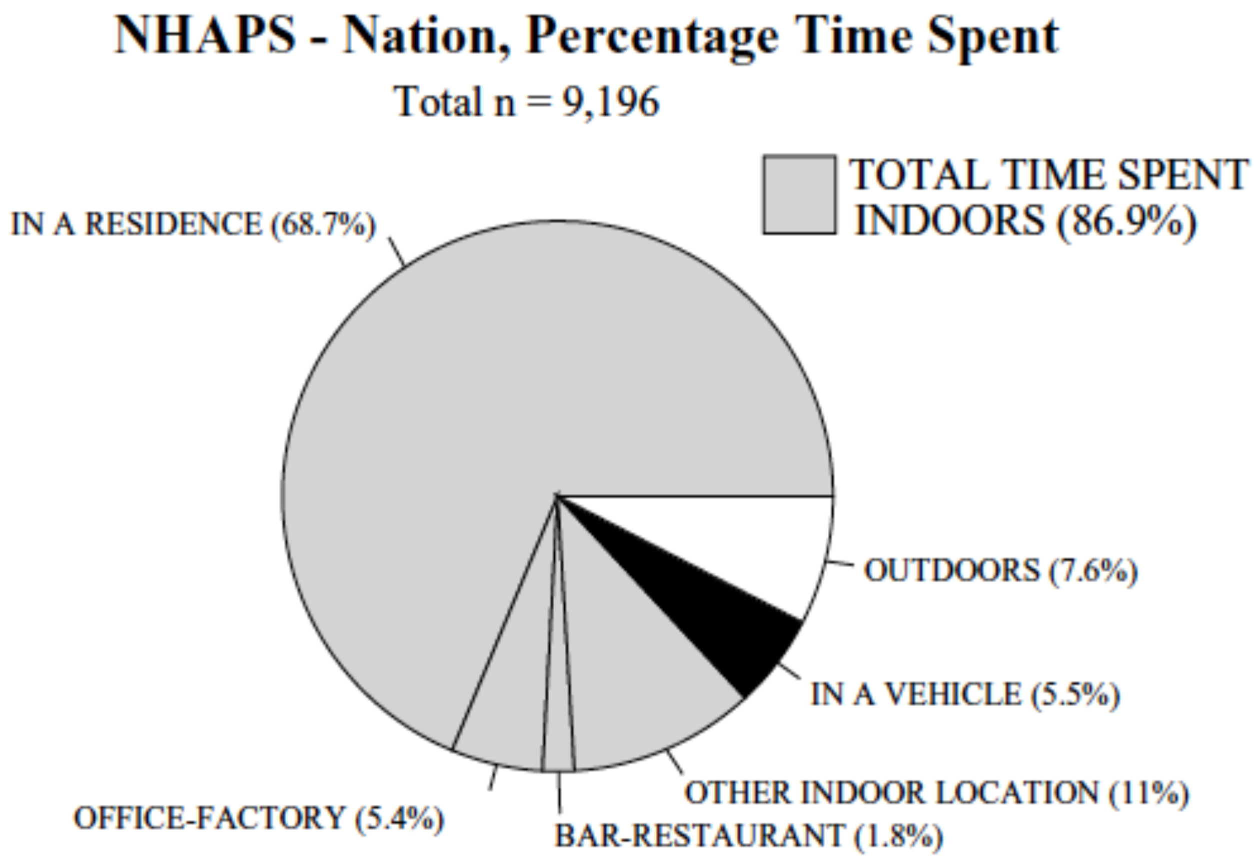
Approximately 3% of our GDP



Approximately 1/3 of building energy use is for space conditioning

~1% of our GDP is spent on heating and cooling buildings

We spend *a lot* of time in buildings



- Americans spend almost 90% of their time indoors
  - 75% at home or in an office

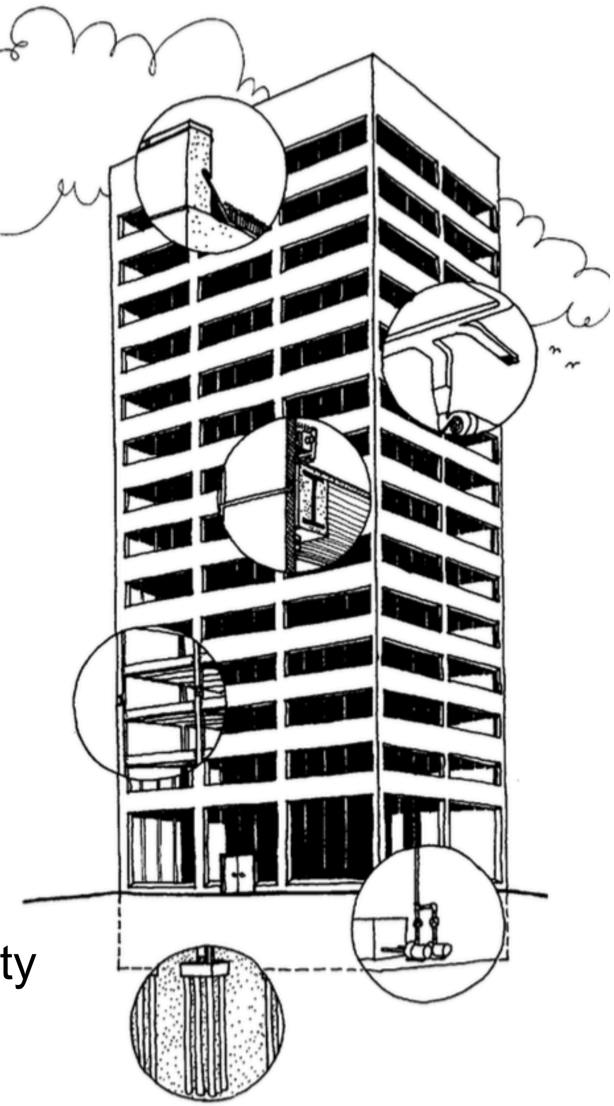
Klepeis et al., *J Exp. Anal. Environ. Epidem.* **2001**, 11, 231-252

Buildings impact people, energy, and the environment

The design, construction, and operation of buildings greatly affect their contribution to energy use, greenhouse gas emissions, financial expenditures, and human exposures to airborne pollutants in the indoor environment

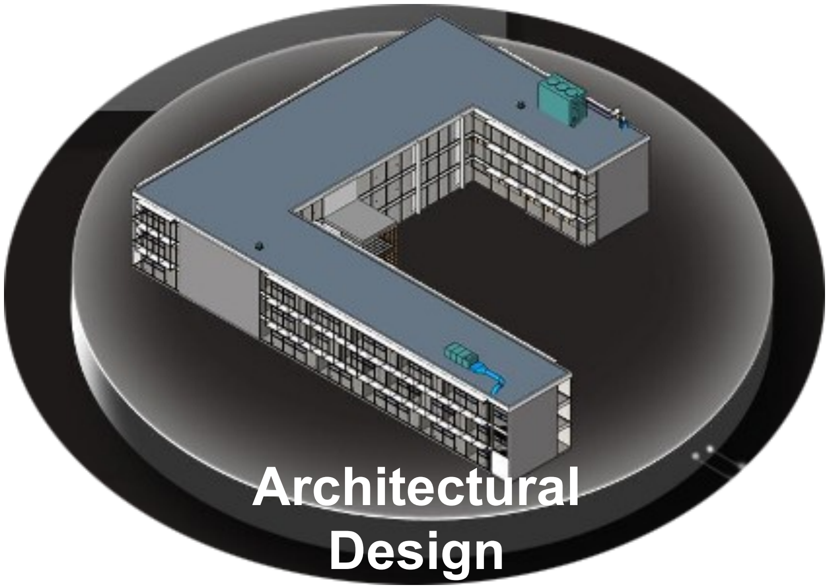
What do we expect of buildings?

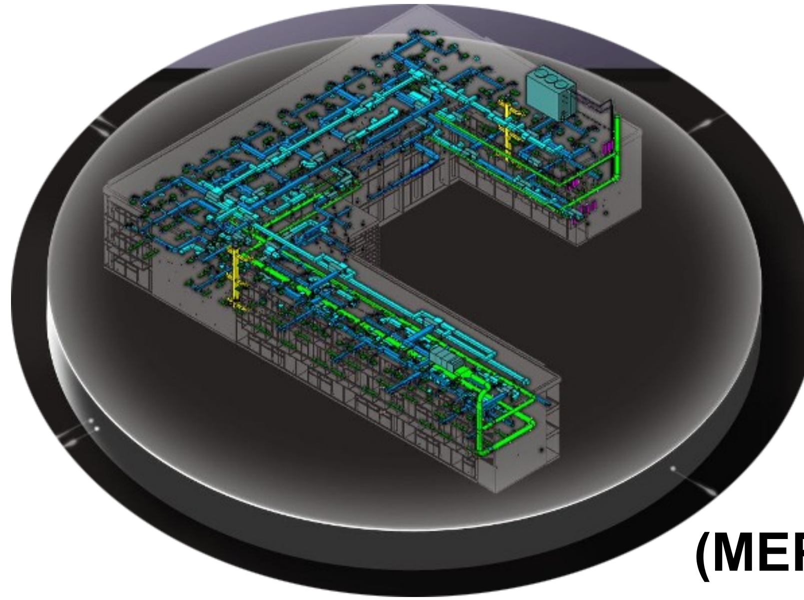
We expect buildings to:
Provide clean air for breathing
Provide clean water for drinking, food preparation, etc.
Removal and recycling of waste
Control the indoor environment for thermal comfort
Control air circulation
Satisfy sensory comfort (acoustics, visual, etc.)
Control the entry and exit of living creatures
Distribute useful energy to convenient points
Provide channels of connection and communication
Provide stable supports for people and belongings
Protect its own systems
Provide reasonable protection against fire
Adjust to its own normal movements without damage
Be built and operated without excessive expense or difficulty



Allen, *How Buildings Work: The Natural Order of Architecture*, 3rd Edition

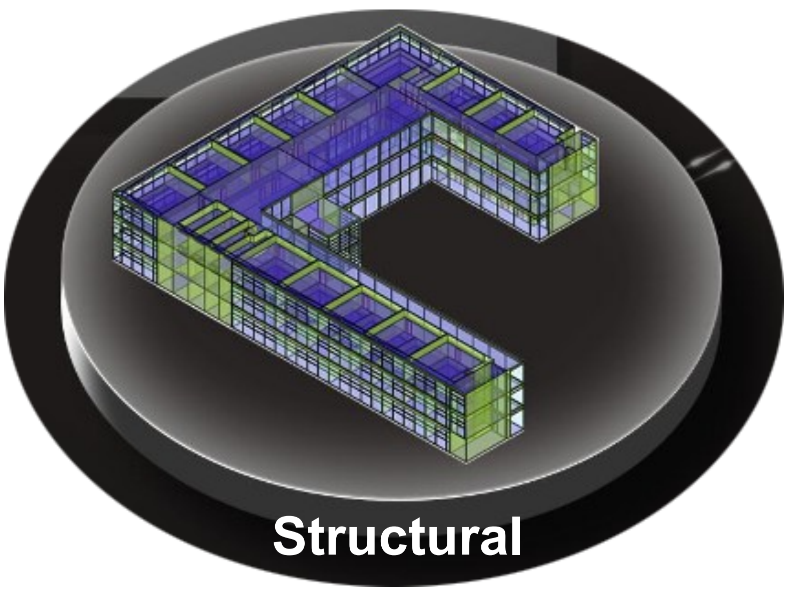
Building science in the context of Architectural Engineering





(MEP)

Mechanical, Electrical, Plumbing
"Building Systems"



Building science in the context of Architectural Engineering

- Structural engineering
- Mechanical engineering
- Electrical engineering
- Plumbing design
- Construction
- Architectural design

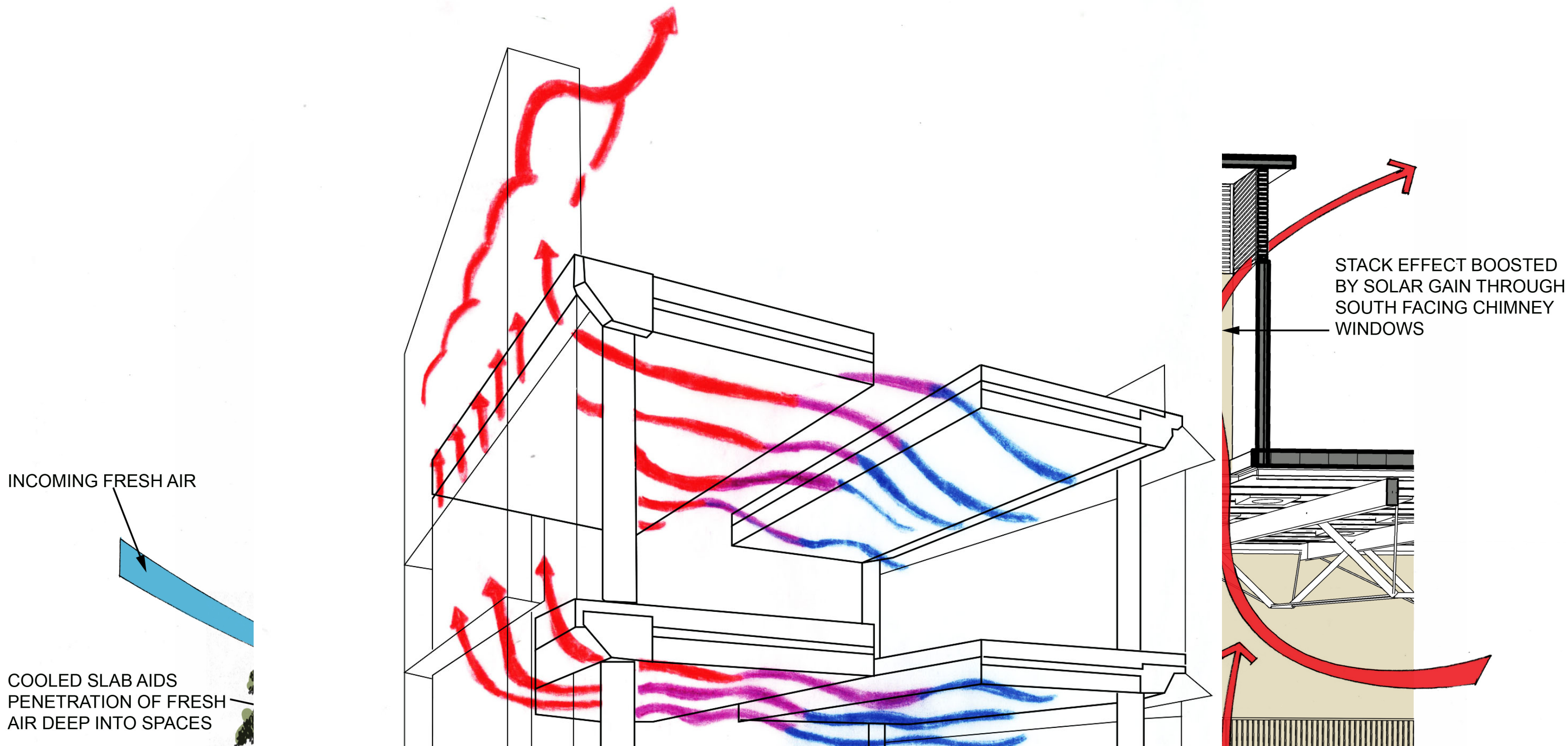
All of these disciplines must all work together to design, build, and operate a building successfully and efficiently

- Architectural engineering requires knowledge of all of these disciplines

Focused building science courses in ARCE @ IIT

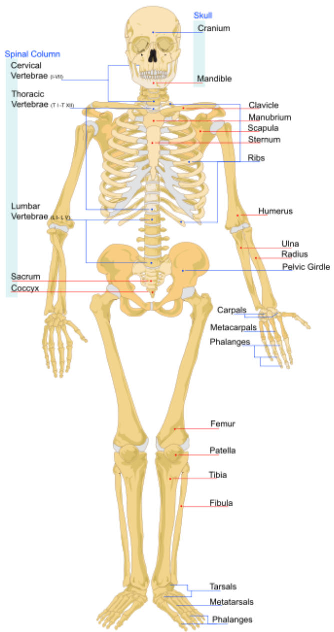
- Mechanical Systems and Energy Efficient Design
  - CAE 464 HVAC Design
  - CAE 463/524 Building Enclosure Design
  - CAE 465/526 Energy Conservation Design in Buildings
  - CAE 515 Building Information Modeling Applications for Building Performance
  - CAE 556 and 557 Net Zero Energy Home Design Competition I and II
  - CAE 550 Applied Building Energy Modeling
  - CAE 553 Measurements and Instrumentation in Architectural Engineering
  - ENVE 576 Indoor Air Pollution
- Electrical and Lighting Systems Design
  - CAE 466 Building Electrical Systems Design
  - CAE 467 Lighting Systems Design
- Plumbing and Fire Protection Systems Design
  - CAE 461 Plumbing and Fire Protection Design
  - CAE 422 Sprinklers, Standpipes, Fire Pumps, Special Suppression, and Detection
  - CAE 424 Introduction to Fire Dynamics
  - CAE 425 Fire Protection and Life Safety in Building Design

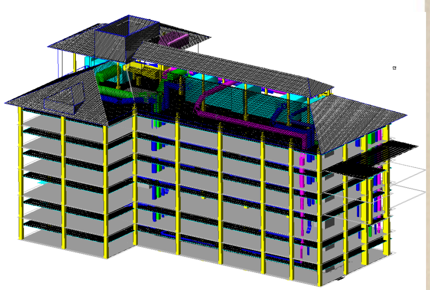
Why do we need building science?



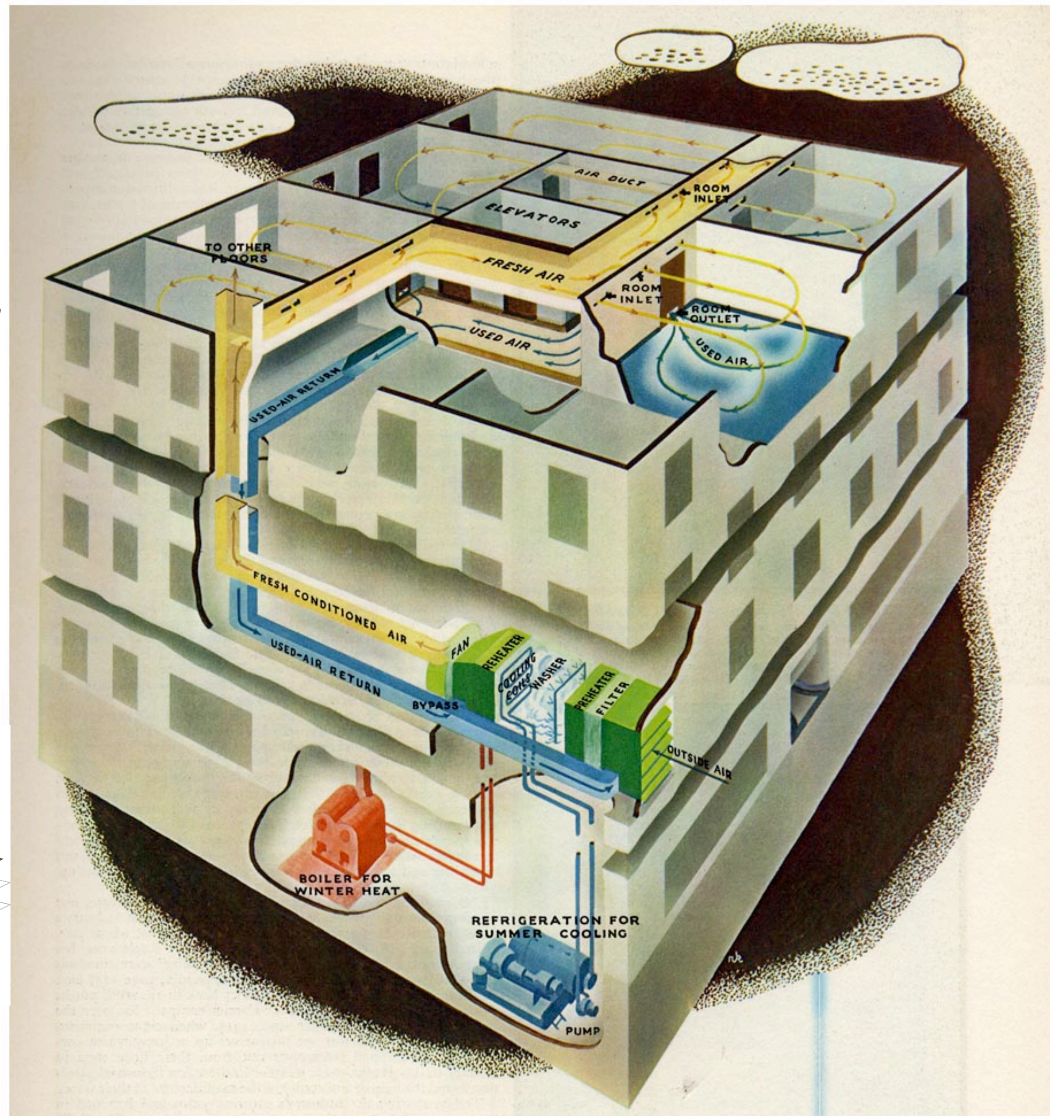
We need to understand basics of energy, heat transfer, fluid flow, and electrical power to understand how buildings work and how design and operational decisions influence their performance

When architectural engineers look inside a building





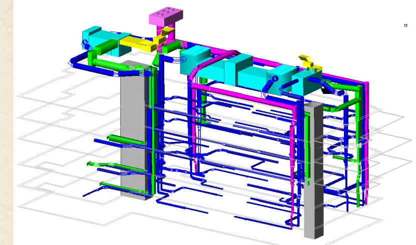
Structural

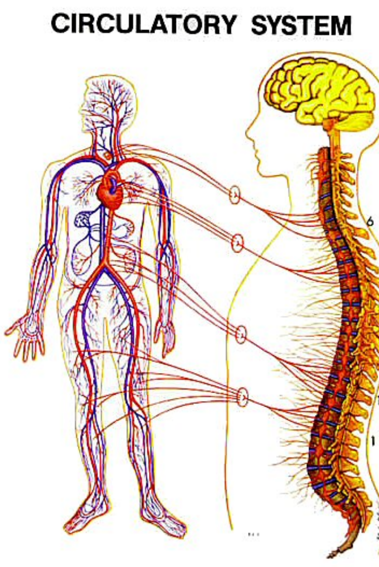


AN X-RAY VIEW OF AN AIR-CONDITIONED OFFICE BUILDING WOULD NOT LOOK SO SIMPLE AS THIS

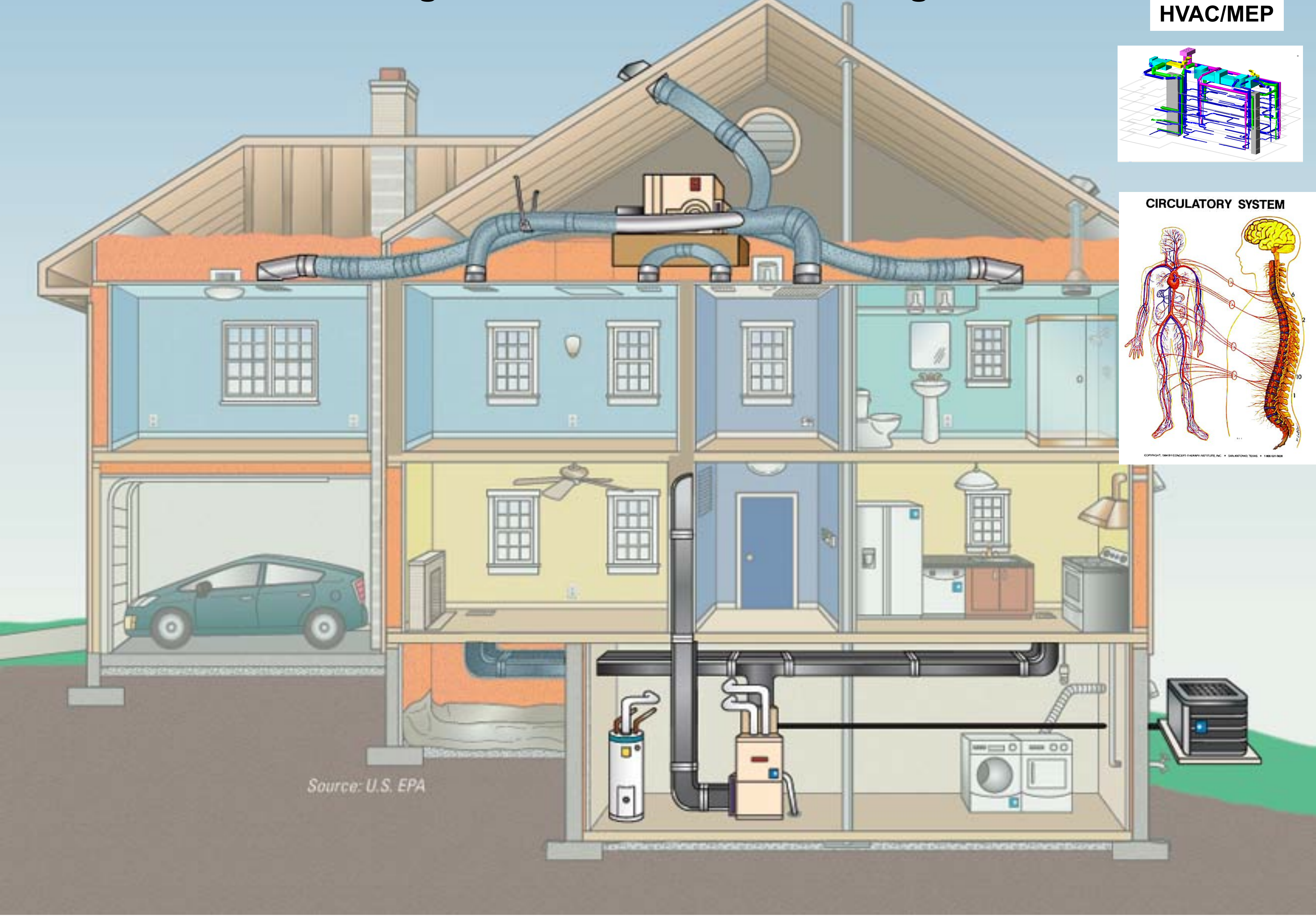
. . . but the diagram gives a good idea of the way a big year-round installation works. In winter, the boiler sends steam up through the red pipe to coils in the conditioning apparatus; in summer, the refrigerating unit sends cold water up through the blue pipe. Air drawn from the building mixed with outside air is filtered, washed, heated and humidified (in winter), cooled and dehumidified (in summer), and then led into each office.

HVAC/MEP





When architectural engineers look inside a building



HVAC/MEP

CIRCULATORY SYSTEM

What happens when you don't understand building science?

http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/55801/Fail-Ignorance-of-Building-Science-Is-No-Excuse

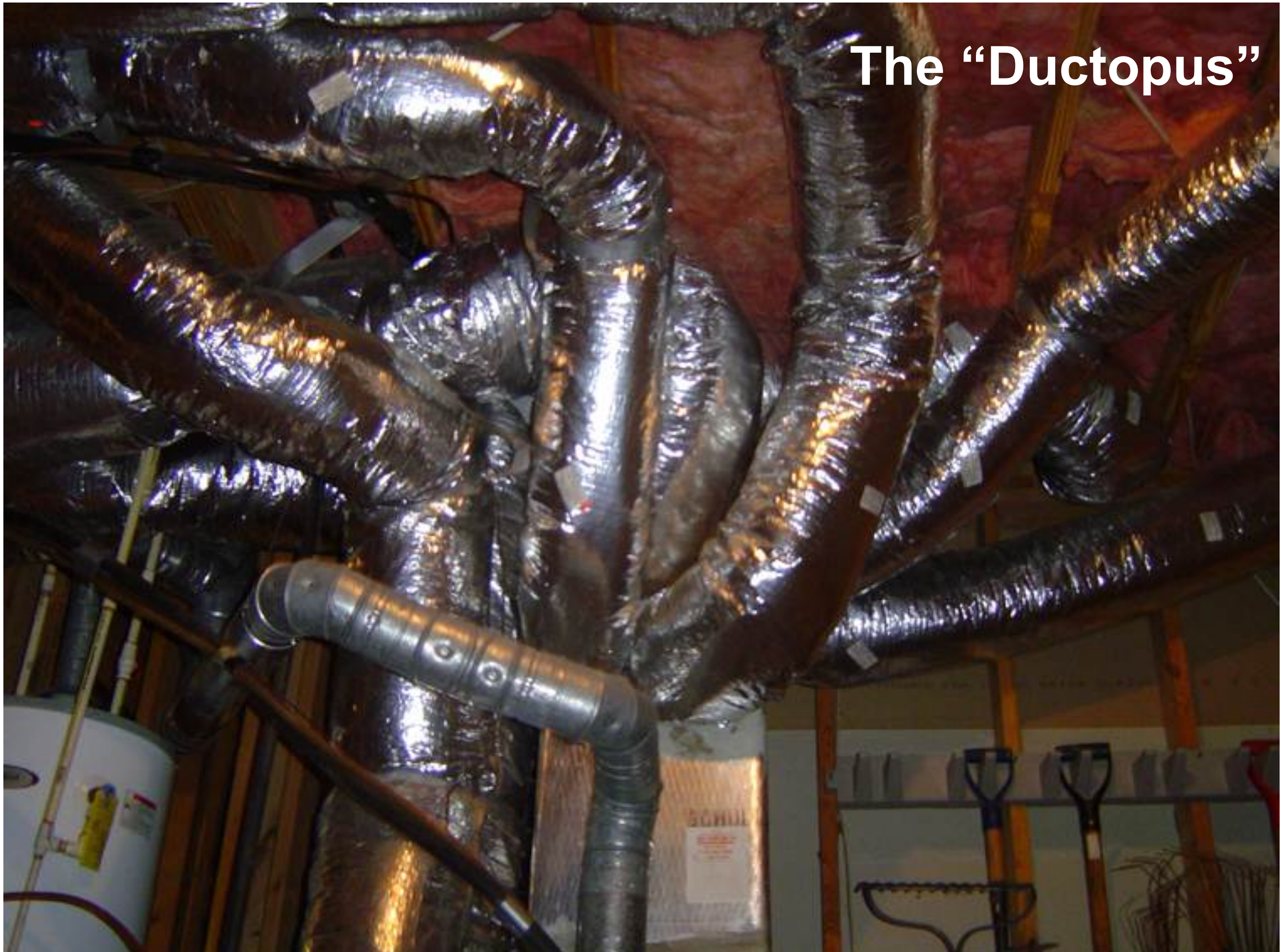
What happens when you don't understand building science?

http://www.greenbuildingadvisor.com/blogs/dept/building-science/should-flex-duct-be-banned

What happens when you don’t understand building science?

http://www.hvacfun.com/hall-shame-59.htm

What happens when you don't understand building science?



http://www.greenbuildingadvisor.com/blogs/dept/building-science/should-flex-duct-be-banned

What happens when you don't understand building science?

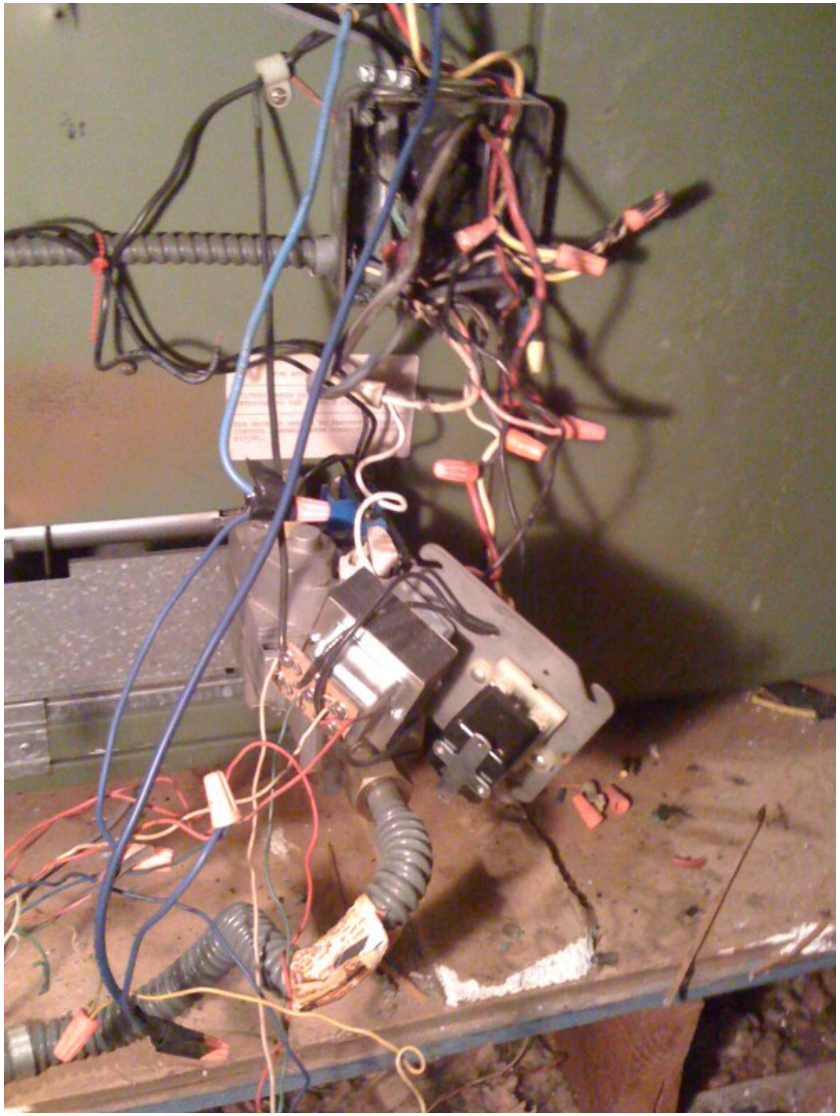
http://www.hvacfun.com/hall-shame-24.htm

What happens when you don’t understand building science?

What happens when you don't understand building science?

http://www.hvacfun.com/hall-shame-43.htm

What happens when you don't understand building science?



http://www.hvacfun.com/hall-shame-27.htm

http://www.hvacfun.com/hall-shame-35.htm

What happens when you don't understand building science?

http://www.hvacfun.com/hall-shame-82.htm

What happens when you don't understand building science?

What happens when you don’t understand building science?

Warm weather causes water on floor

1/26/2010 - NBA, BOSTON CELTICS +1 more

Share with Facebook Share with Twitter

1 Share

Chris Forsberg, ESPN Staff Writer

BOSTON -- Monday's game took Boston Celtics coach Doc Rivers back to his playing days for all the wrong reasons.

Unseasonably warm temperatures caused condensation to form on the floor of the TD Garden during Boston's 95-89 win over the Los Angeles Clippers Monday, leading to a brief delay as workers mopped the court to keep it dry late in the first quarter.

http://sports.espn.go.com/nba/news/story?id=4858097

What happens when you don’t understand building science?

When you don’t understand building science, and you are in charge of engineering, design, construction, or maintenance of a building...

… you adversely affect building energy use, energy costs, greenhouse gas and other pollutant emissions, thermal comfort, productivity, and indoor air quality

BUILDING SCIENCE RESOURCES

Important organizations to know

- American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)
  - Handbook of Fundamentals
  - Standards and design guidelines
- Department of Energy https://energy.gov/eere/buildings/building-science-education
- Lawrence Berkeley National Laboratory (LBNL)
- Oak Ridge National Laboratory (ORNL)
- Building Science Corporation https://buildingscience.com
- RESNET
- EPA Energy Star
- National Institute of Building Sciences
- National Resources Canada
- ASTM
- Passive House Institute (US)
- Pacific Northwest National Lab (PNNL)
- American Council for an Energy Efficient Economy (ACEEE)
- Energy Vanguard http://www.energyvanguard.com/blog
- Green Building Advisor http://www.greenbuildingadvisor.com

Important publications to know

- Publications*
  - *Building and Environment*
  - *Energy and Buildings*
  - *Building Simulation*
  - *Science and Technology of the Built Environment*
  - *ASHRAE Journal*
  - *ASHRAE Transactions*
  - *ASCE Journal of Architectural Engineering*

*Most of these are all available through the Galvin Library

- Online access: http://library.iit.edu/

- For instructions for accessing articles through the library off-campus: http://built-envi.com/student-info/

ASHRAE Handbook of Fundamentals

ASHRAE **Fundamentals** 2013
(SI Edition)

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U.S. DEPARTMENT OF ENERGY

SOLAR DISTRICT CUP

COLLEGIATE DESIGN COMPETITION

Goal

The goal for each team is to design a solar-plus-storage system for a campus or district that maximizes energy offset and financial savings over 20 years. Competition teams analyze electric distribution grid interactions and assume the role of renewable energy systems developers to produce a power purchase agreement (PPA) proposal for their division's district.

The Solar District Cup 2020 is a two-semester (or three-academic-quarter) project, starting in fall 2019 and culminating in spring 2020.

- April 1, 2019—Competition announced and team registration opened.
- July 31, 2019—Rules published.
- September 12, 2019, 5:00 p.m. ET—Deadline for registration of participating teams.
- September 19, 2019—Participating teams announced.
- September 23–24, 2019—Competition introduction and networking workshop at the Solar Power International conference in Salt Lake City, Utah. Attendance is optional but recommended. Information presented will also be available to teams that cannot attend.
- November 21, 2019, 5:00 p.m. ET—Deadline for receipt of Progress Deliverable Package from all participating teams.
- December 12, 2019—Finalist teams announced.
- April 11, 2020, 5:00 p.m. ET—Deadline for receipt of Final Deliverable Package from finalist teams.
- April 19–20, 2020—Finalists present projects at the Solar Power Southeast conference in Atlanta, Georgia; winners announced. In-person attendance and presentation by at least one student team member from each finalist team is required.

Next time

- Review of pre-requisite topics
  - Energy concepts and unit conversions
- Assign HW 1