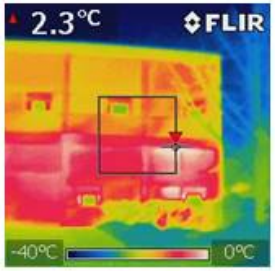
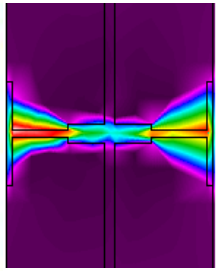
CAE 331/513 Building Science

Fall 2017





August 22, 2017

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

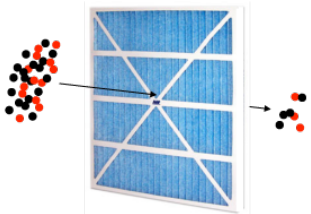
About me

- 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
- 6th year at IIT and 5th time teaching this course

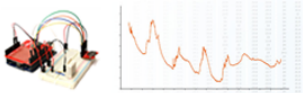
BERG: Built Environment Research Group

The **Built Environment Research Group** at IIT is dedicated to investigating problems and solutions related to energy and air quality within the built environment

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



OSBSS



Built Environment Research @ IIT

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

IIT Armour College of Engineering

ILLINOIS INSTITUTE OF TECHNOLOGY

Course information

CAE 331/513: Building Science

Course Unique Number(s)

- CAE 331 Section 01: 10405 (undergraduate)
- CAE 513 Section 01: 15258 (graduate in-class)
- CAE 513 Section 02: 17668 (graduate online)

Classroom and Meeting Time

- Stuart Building, Room 113
- Tuesdays and Thursdays 1:50 PM – 3:05 PM

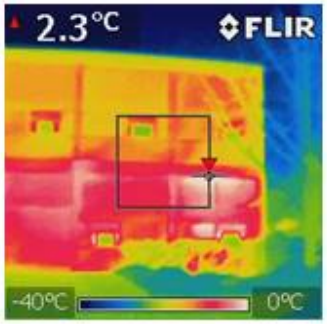
Prerequisites

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

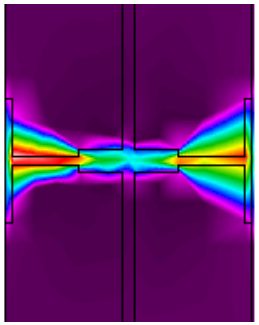
Course information

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.





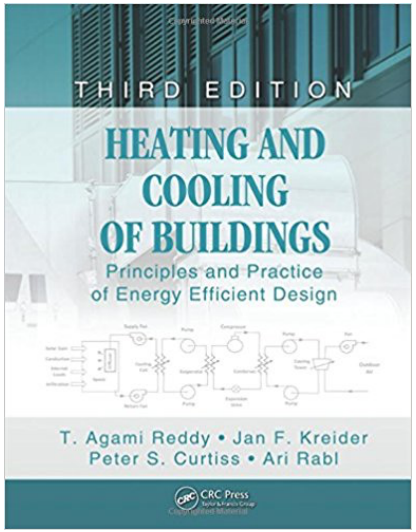


Course objectives

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, thermodynamics of refrigeration systems, fluid flows, and mass balances.
3. Calculate peak heating and cooling loads 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.

Textbook

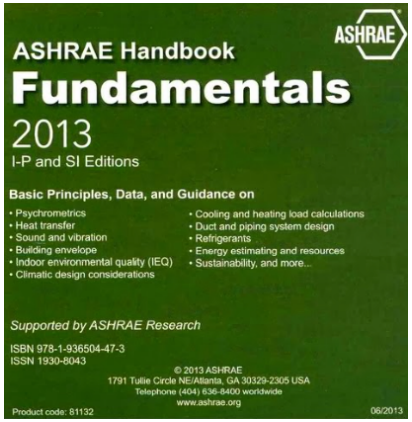


Heating and Cooling of Buildings: Principles and Practice of Energy Efficient Design (3rd Edition)
Reddy, Kreider, Curtiss, and Rabl
CRC Press, Taylor & Francis Group
ISBN: 978-1439899892

Amazon:
https://www.amazon.com/Heating-Cooling-Buildings-Principles-Engineering/dp/1439899894/ref=dp_ob_title_bk

- Should be available in the Illinois Tech bookstore as well

Another key resource



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

- Relatively cheap for ASHRAE student members
- Chapters of an older version (2013) are also available on Blackboard (BB)

Additional references

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

ASHRAE 90.1-2010. *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.

Kreider, J.F., Curtiss, P.S., and Rabl, A. 2010. *Heating and Cooling of Buildings: Design for Efficiency*. CRC Press, Taylor & Francis Group. ISBN: 978-1-4398-1151-1.

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.

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

Major course topics

- Importance of building science
- Applications of heat transfer in buildings
- Building energy balances
- Human thermal comfort
- Psychrometrics – properties and processies
- HVAC systems and thermodynamics
- Ventilation, infiltration, and indoor air quality
- Fluid flow in buildings
- Heating and cooling load calculations
- Energy efficiency and green buildings
- 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
    - 50 pts each

- **Three closed-book exams**
  - One exam scheduled for Tuesday, September 26, 2017
  - One exam scheduled for Thursday, October 26, 2017
  - 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	300	300
• Exam 1	250	250
• Exam 2	250	250
• Final exam	300	300
• Final project	n/a	300
• Total	1100	1400

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: Graduate students (CAE 513)

- There is also 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
  - Final deliverable: written technical research paper

Course website

- I will post lectures and updated syllabus on my website:
  - http://built-envi.com/courses/cae-331513-building-science-fall-2017/

- I will also post HWs, exams, lecture notes, syllabus, and other materials to **Blackboard (BB)**

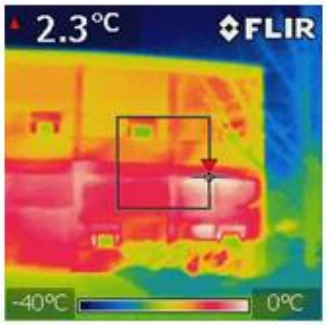
Tentative course schedule (continuously revised)

Week	Lecture	Date	Lecture Topics	HW Due	Textbook chapter
1	1	Aug 22	Introduction to building science		HCB Ch. 1
	2	Aug 24	Pre-requisite review, energy concepts, and units		
2	3	Aug 29	Heat transfer in buildings: conduction		HCB Ch. 2
	4	Aug 31	Heat transfer in buildings: finish conduction	HW1	
3	5	Sep 5	Heat transfer in buildings: convection		
	6	Sep 7	Heat transfer in buildings: radiation		HCB Ch. 2 & 4
4	7	Sep 12	Heat transfer in buildings: combined modes		HCB Ch. 4
	8	Sep 14	Heat transfer in buildings: fenestration	HW2	HCB Ch. 5
5	9	Sep 19	Human thermal comfort		HCB Ch. 3
	-	Sep 21	Exam review: example problems		
6	-	Sep 26	**Exam 1**		
	10	Sep 28	Introduction to HVAC systems		HCB Ch. 11
7	11	Oct 3	Psychrometrics: fundamentals and chart		HCB Ch. 13 & ASHRAE Handbook Ch. 1
	12	Oct 5	Psychrometrics: equations		
8	13	Oct 10	Mechanical systems and psychrometric processes	HW3	
	14	Oct 12	Mechanical systems and psychrometric processes		
9	15	Oct 17	HVAC components and refrigeration cycles		HCB Ch. 14
	16	Oct 19	HVAC components and refrigeration cycles	HW4	
10	-	Oct 24	*Campus HVAC tour with IIT Facilities*		
	-	Oct 26	**Exam 2**		
11	17	Oct 31	Air and water distribution systems & fans		HCB Ch. 16/18/20
	18	Nov 2	Ventilation and indoor air quality		HCB Ch. 3
12	19	Nov 7	Ventilation and indoor air quality		
	20	Nov 9	Infiltration and natural ventilation	HW5	HCB Ch. 6
13	21	Nov 14	Heating load calculations		HCB Ch. 9
	22	Nov 16	Cooling load calculations		
14	23	Nov 21	Cooling load calculations	HW6	
	-	Nov 23	*No class – Thanksgiving Day*		
15	24	Nov 28	Energy estimation and design for efficiency		HCB Ch. 24
	25	Nov 30	Standards and guidelines for energy efficiency	Grad projects	
Final	n/a	TBD	**Final exam**		

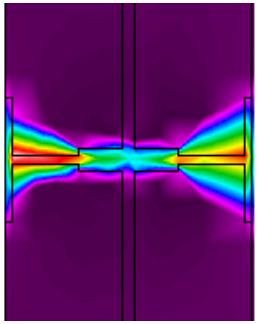
Office hours

- Office hours are by appointment
- 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?

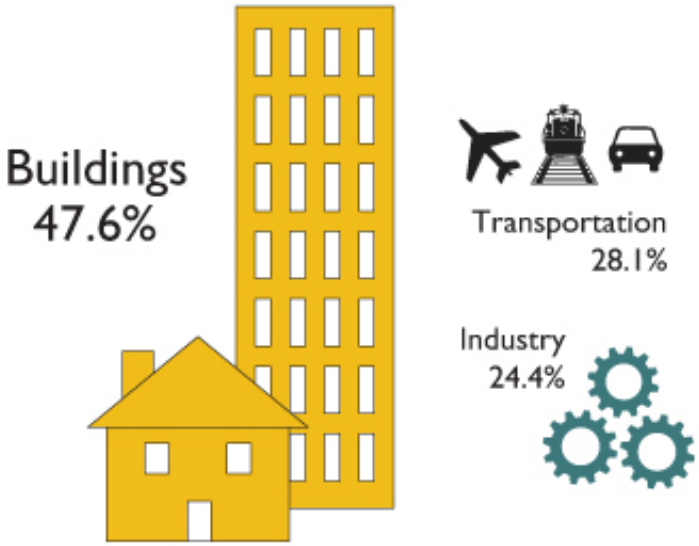
- How many of you are in a building right now?
  - Birds build nests
  - Rabbits dig holes
  - People build buildings

- 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.?

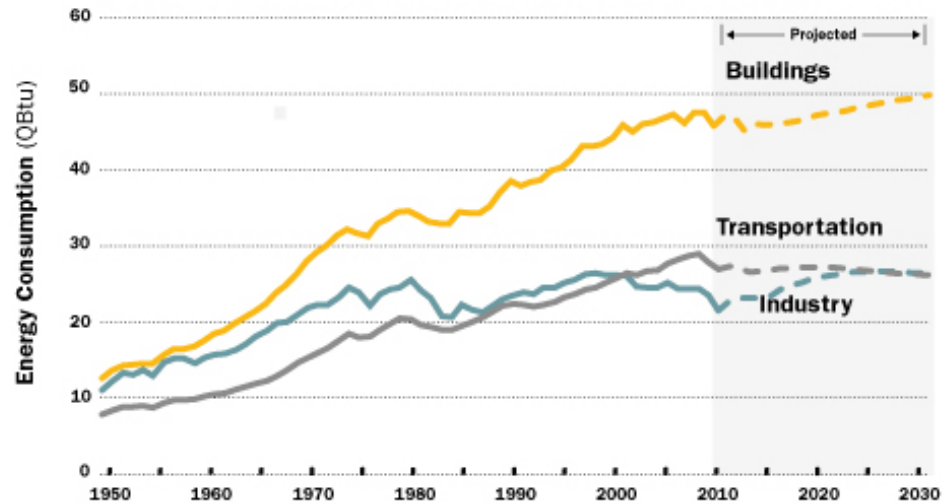
- How much time do you think people spend indoors, on average?

Buildings use *a lot* of energy



U.S. Energy Consumption by Sector

Source: ©2013 2030, Inc. / Architecture 2030. All Rights Reserved.
Data Source: U.S. Energy Information Administration (2012).



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

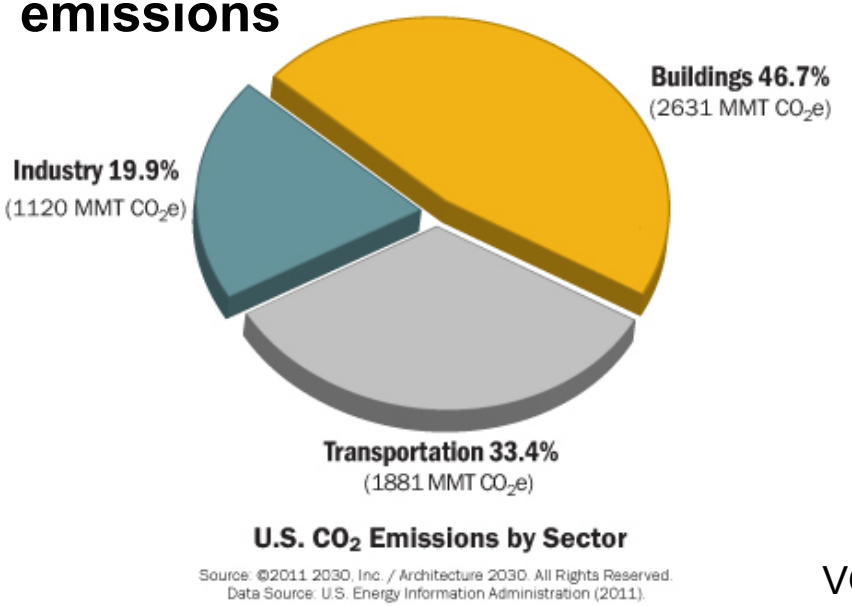
Source: ©2013 2030, Inc. / Architecture 2030. All Rights Reserved.
Data Source: U.S. Energy Information Administration (2012).

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

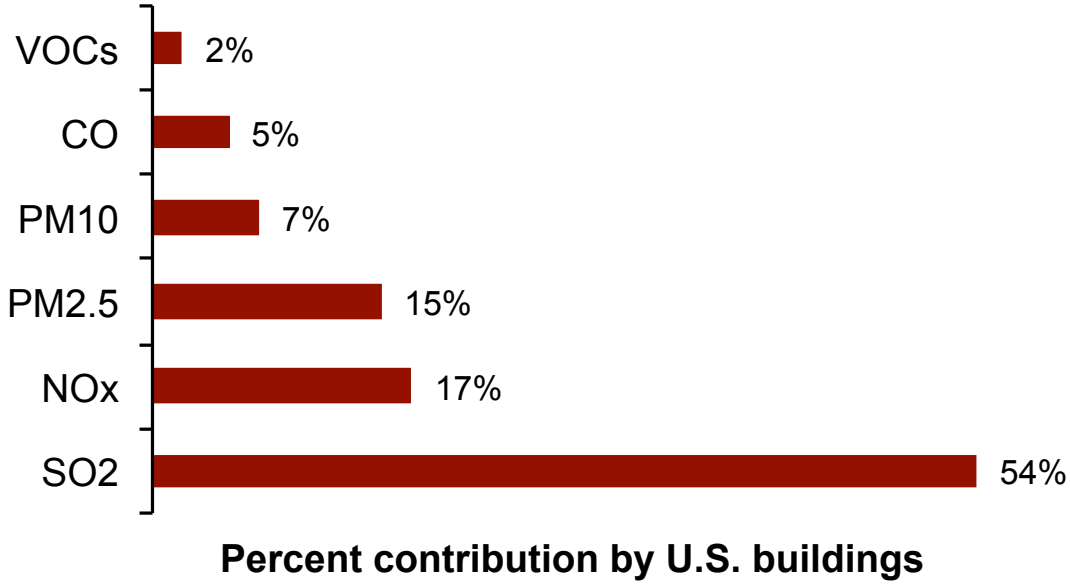
Contribution to greenhouse gas (GHG) emissions



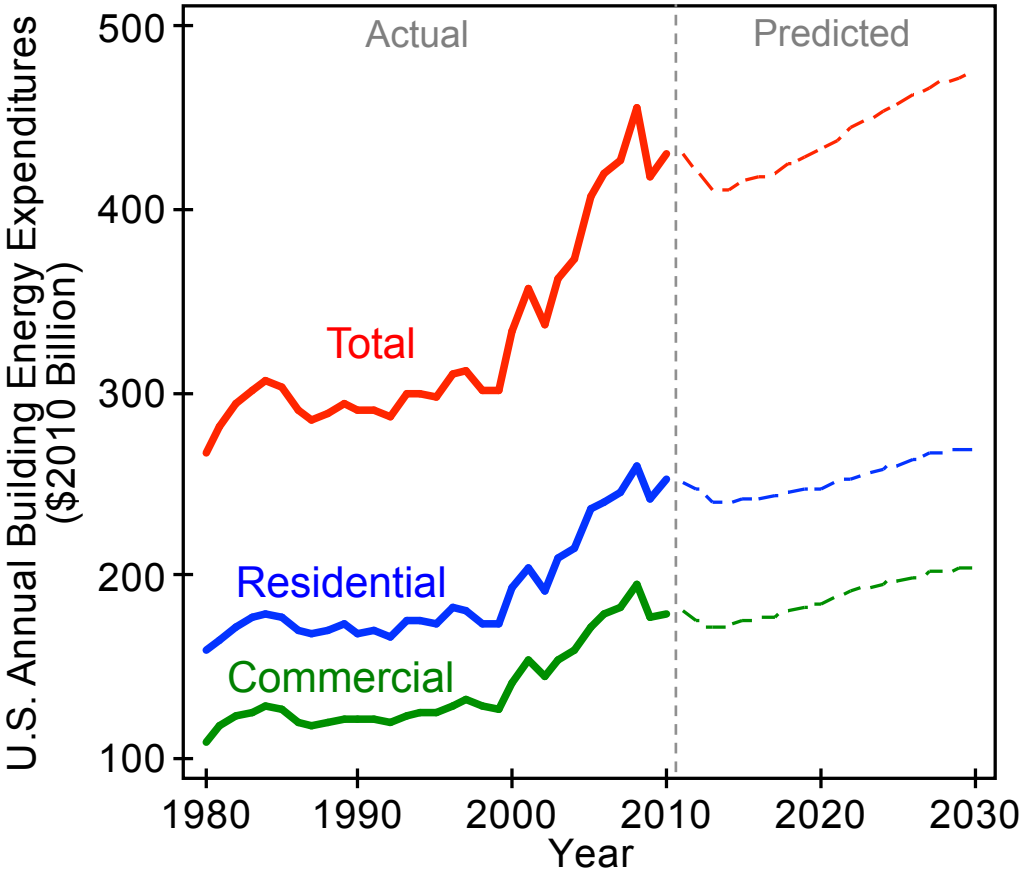
Major energy uses?

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

Contribution to outdoor air pollution

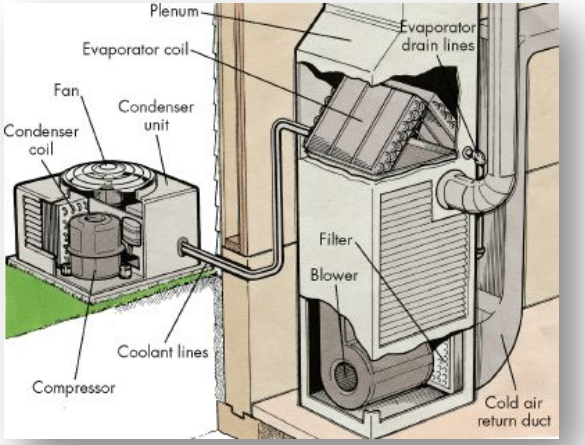


Building energy use costs *a lot* of money



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

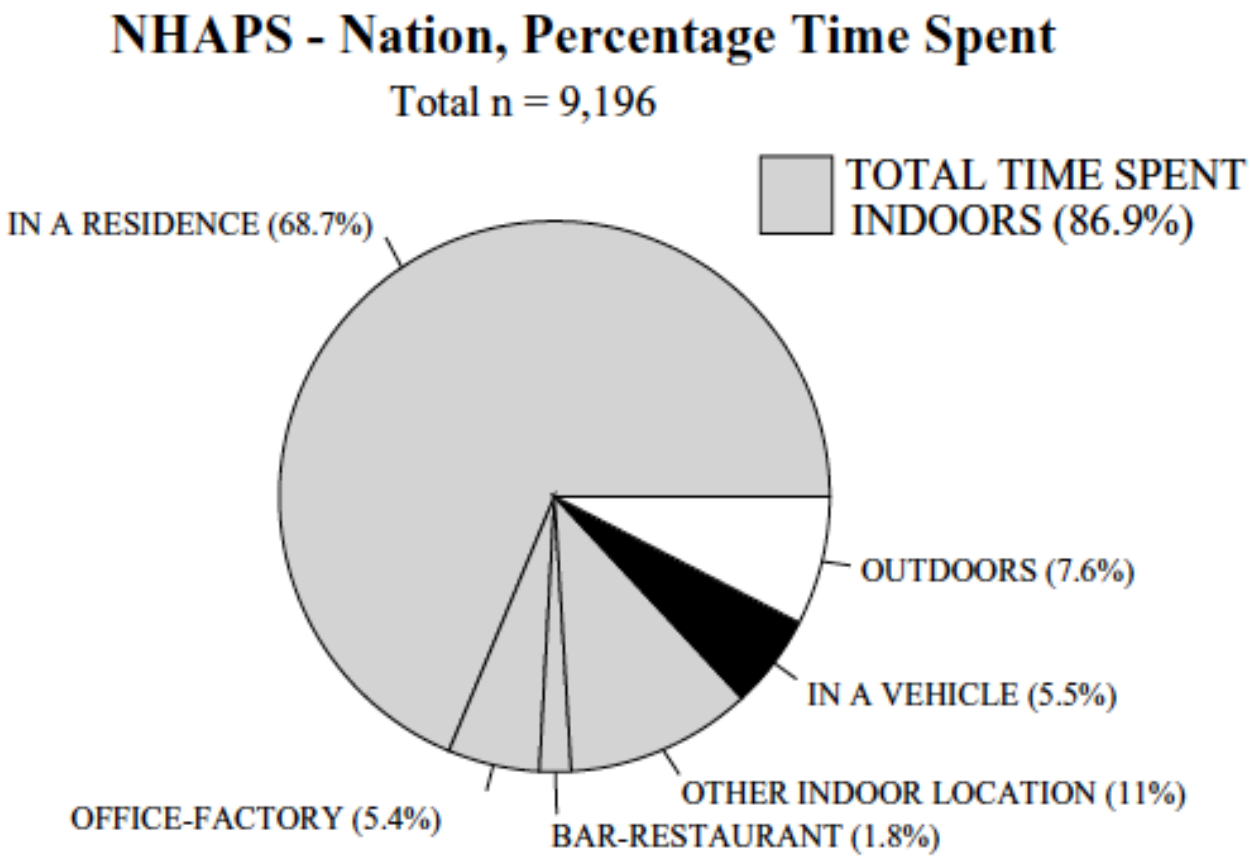
Approximately 3% of our GDP



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

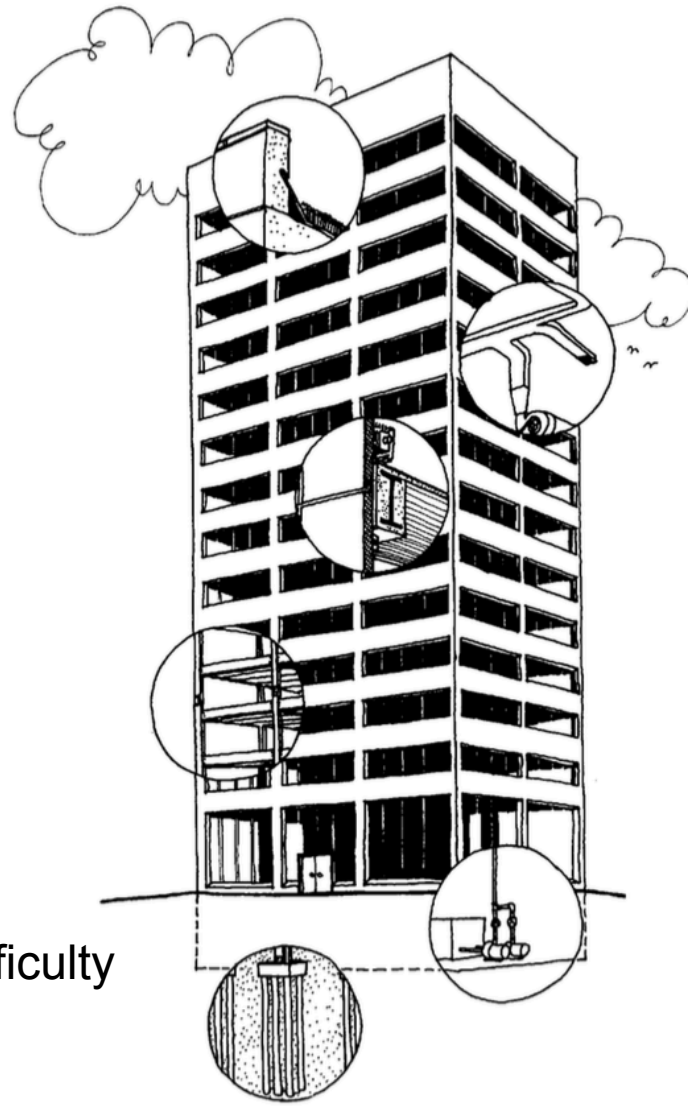
Klepeis et al., *J Exp. Anal. Environ. Epidem.* **2001**, 11, 231-252

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

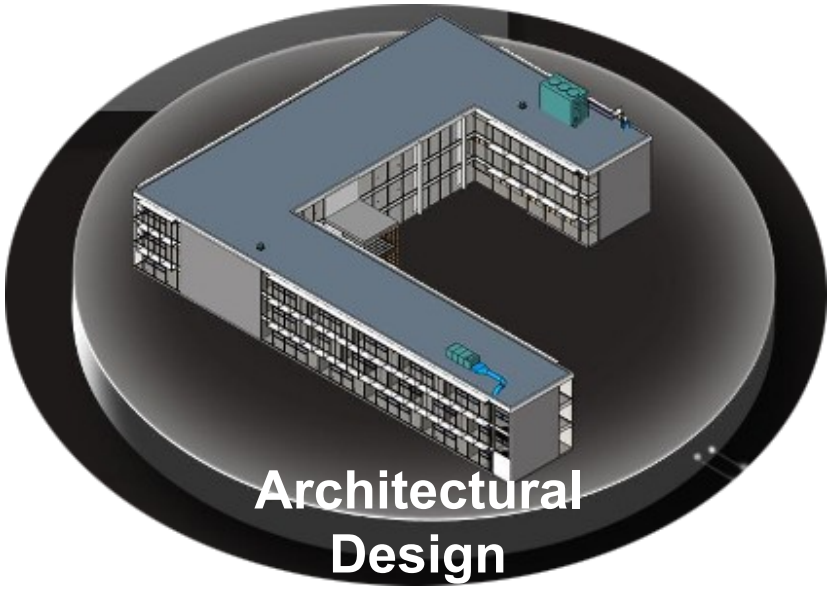
What do we expect of buildings?

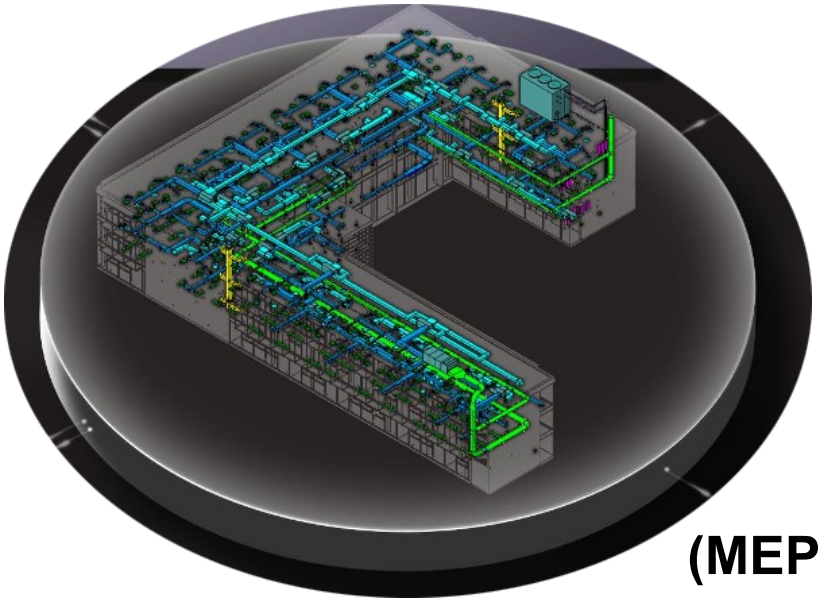
We expect buildings to:
Provide clean air for breathing
Provide clean water for drinking, food preparation, etc.
Removal and recycling of waste
Control the indoor environment for thermal comfort
Control air circulation
Satisfy sensory comfort (acoustics, visual, etc.)
Control the entry and exit of living 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



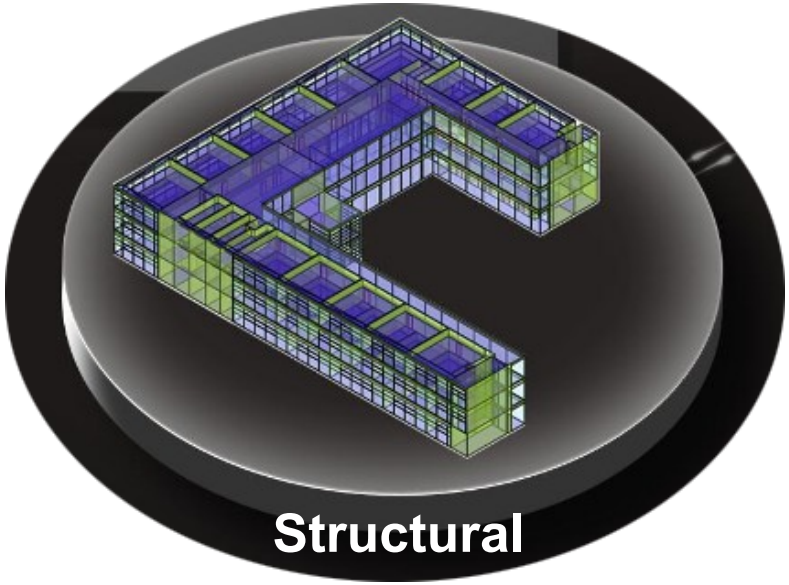
Allen, *How Buildings Work: The Natural Order of Architecture*, 3rd Edition

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

Building science and other detailed courses in ARCE

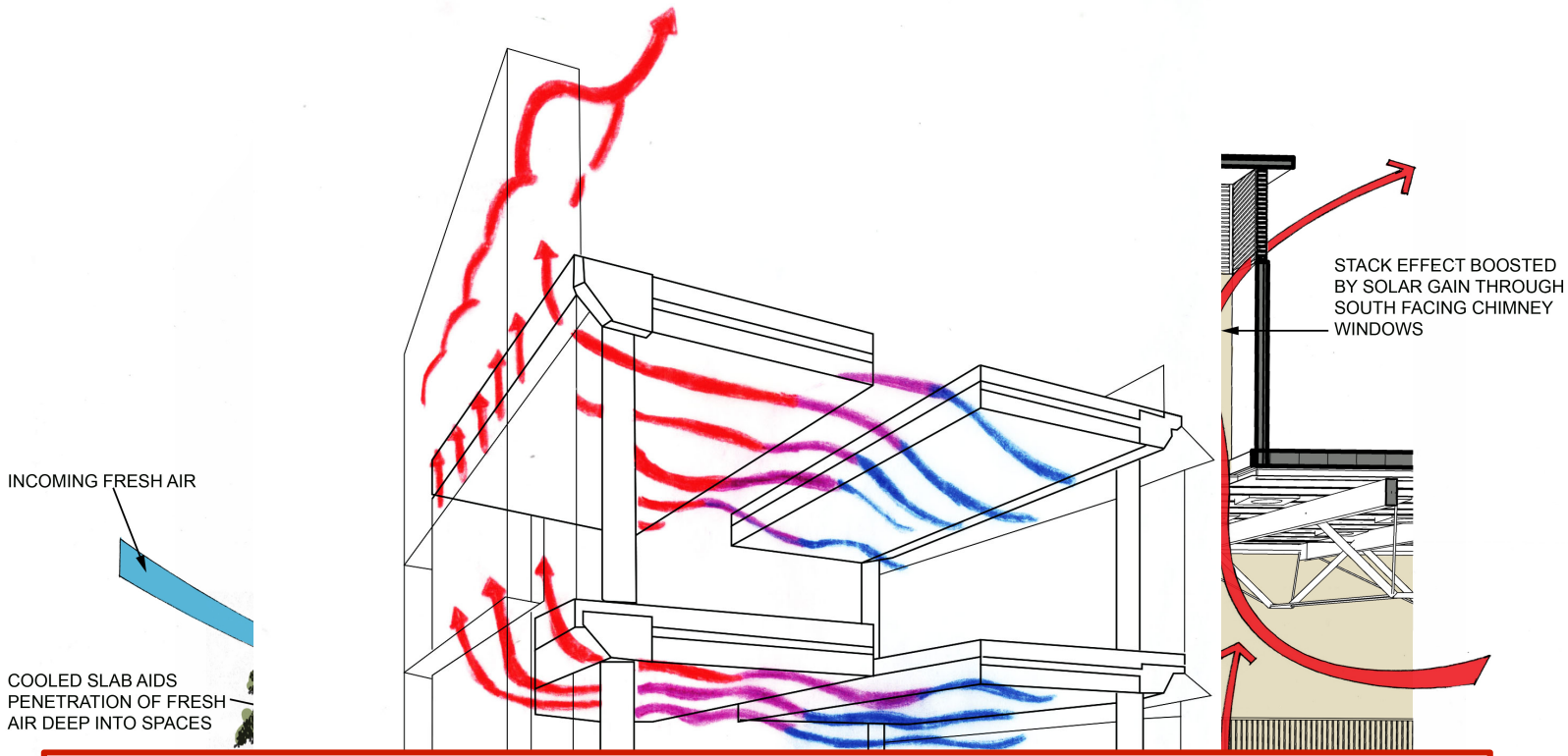
- Enclosure/architectural/energy
  - CAE 463/524 Building Enclosure Design
  - CAE 515 Building Energy Modeling
  - CAE 556 and 557 Net Zero Energy Home Design Competition I and II
  - CAE 550 Applied Building Energy Modeling

- Mechanical
  - CAE 464 HVAC Design
  - CAE 465/526 Energy Conservation Design in Buildings
  - ENVE 576 Indoor Air Pollution (partial coverage)

- Electrical and Lighting
  - CAE 466 Building Electrical Systems Design
  - CAE 467 Lighting Systems Design

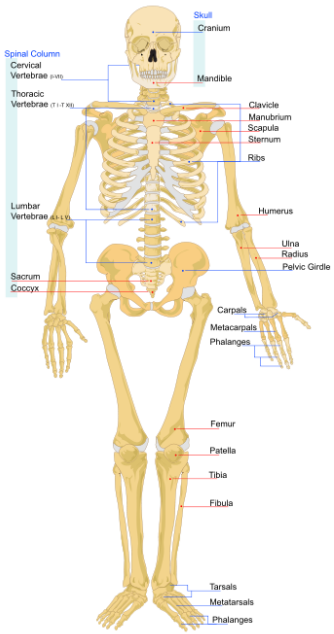
- Plumbing and Fire Protection
  - CAE 422 Sprinklers, Standpipes, Fire Pumps, Special Suppression, and Detection
  - CAE 424 Introduction to Fire Dynamics
  - CAE 425 Fire Protection and Life Safety in Building Design
  - CAE 461 Plumbing and Fire Protection Design

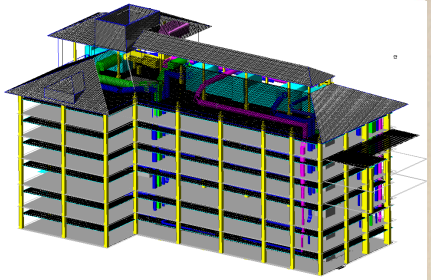
Why do we need building science?



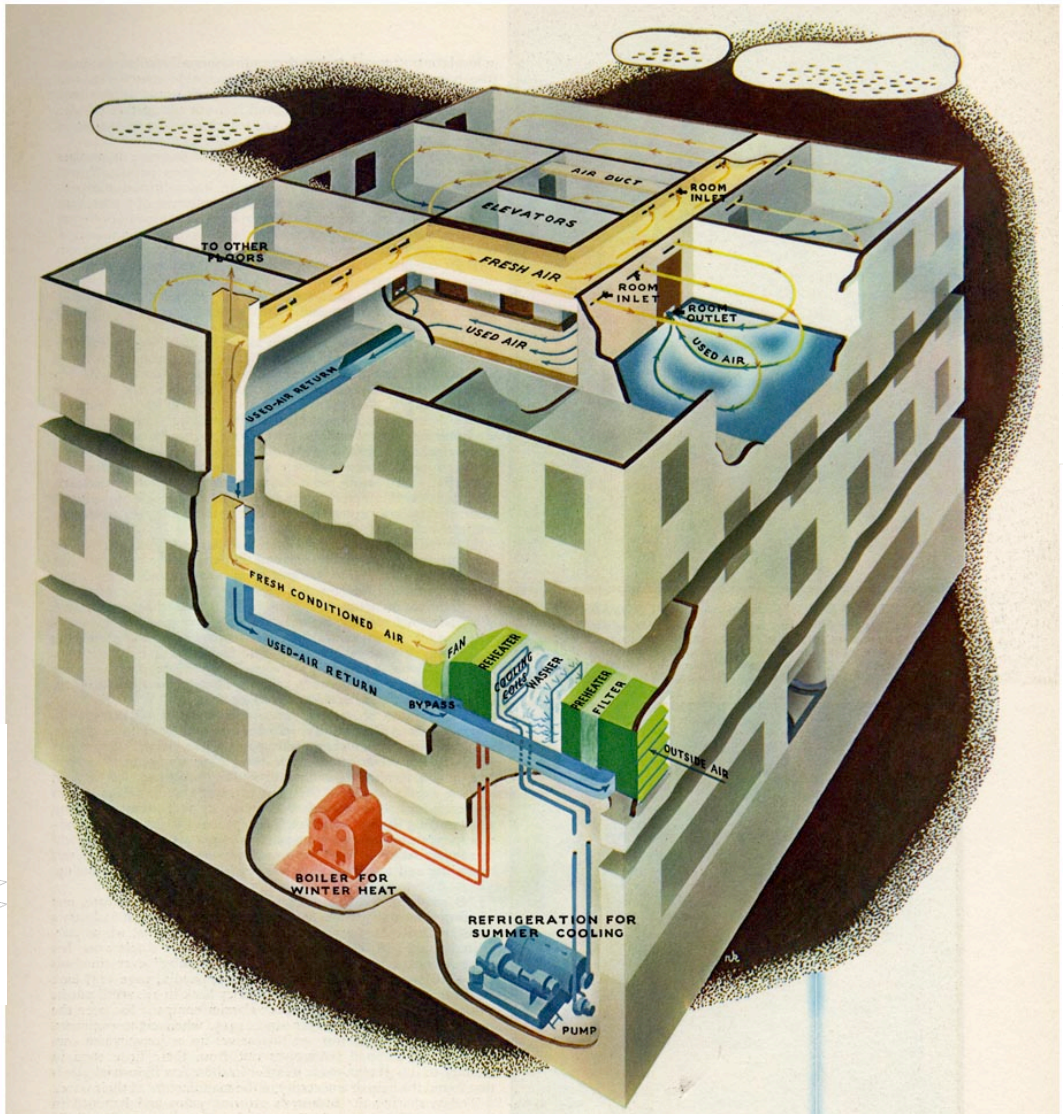
We need to understand basics of energy, heat transfer, fluid flow, and electrical power to understand how buildings work and how design and operational decisions influence their performance

When architectural engineers look inside a building





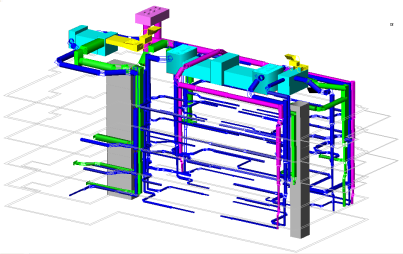
Structural



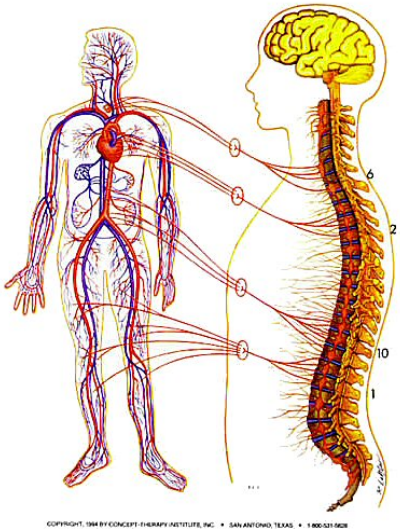
AN X-RAY VIEW OF AN AIR-CONDITIONED OFFICE BUILDING WOULD NOT LOOK SO SIMPLE AS THIS

. . . 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

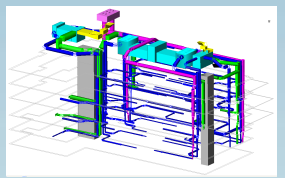


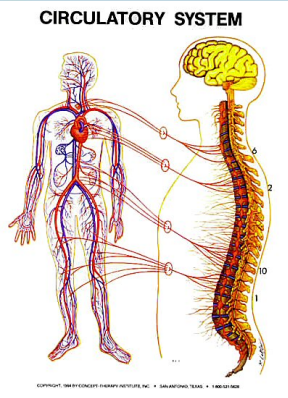
CIRCULATORY SYSTEM



When architectural engineers look inside a building

HVAC/MEP





Source: U.S. EPA

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

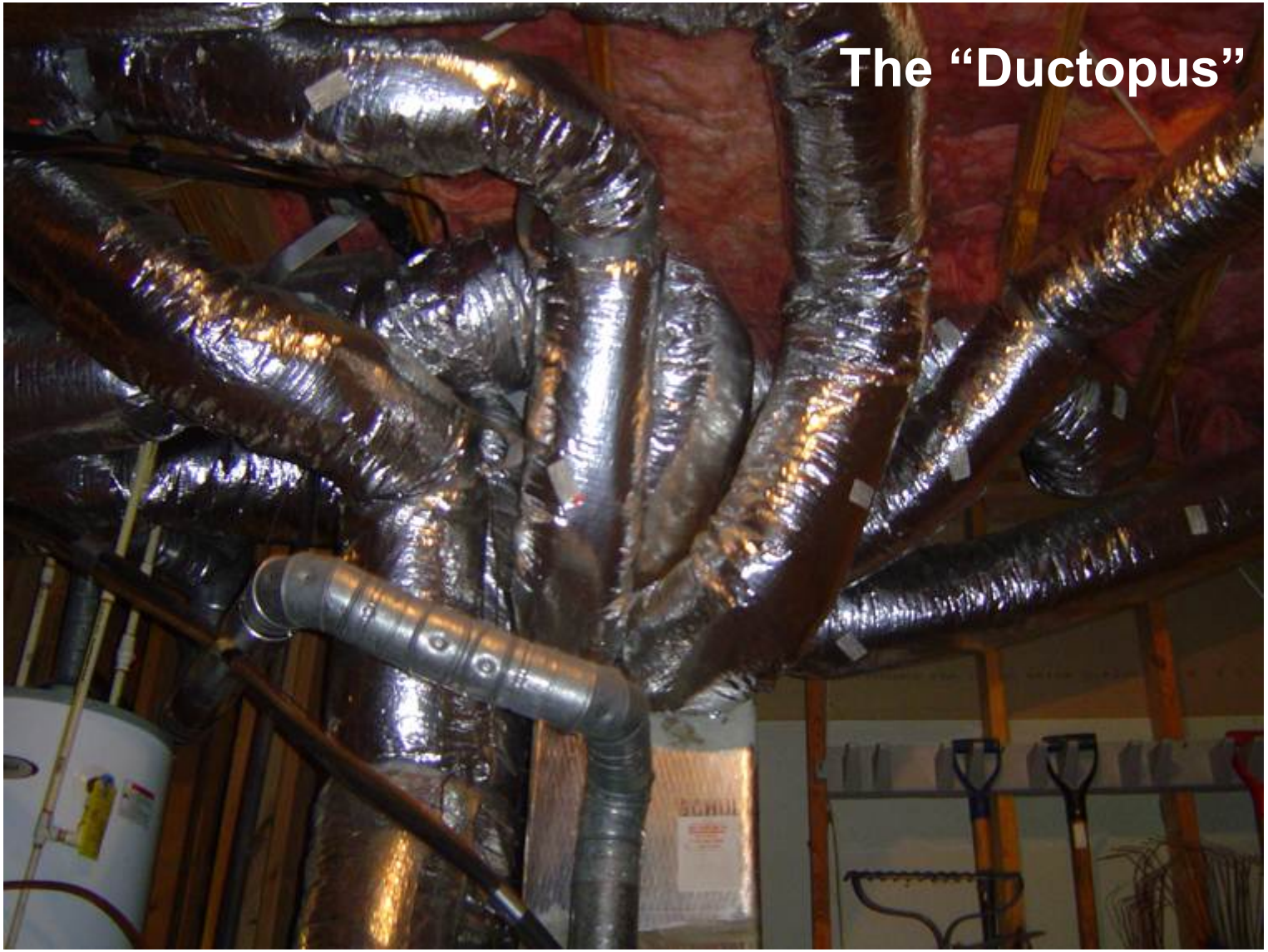
What happens when you don't understand building science?

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

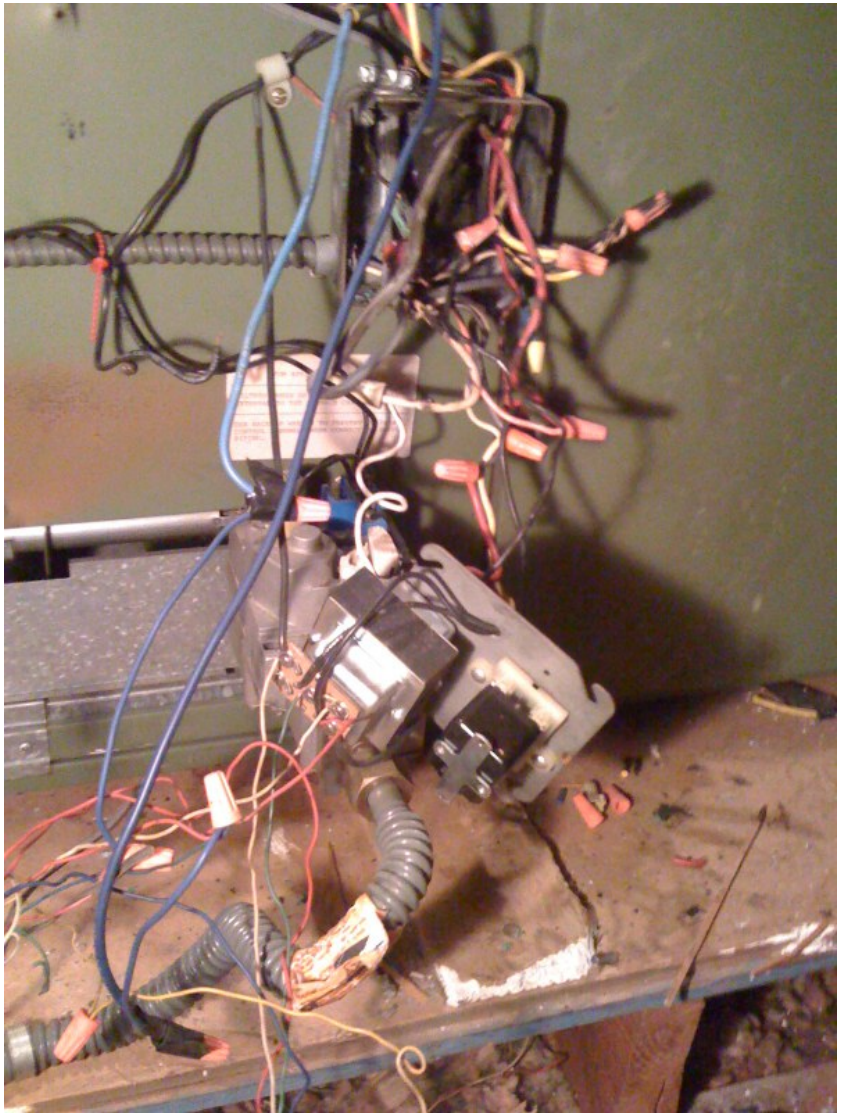
What happens when you don't understand building science?

http://www.hvacfun.com/hall-shame-22.htm

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

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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

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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/

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Next time

- Review of pre-requisite topics
  - Energy concepts and unit conversions