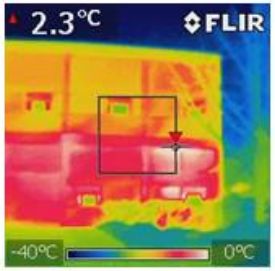
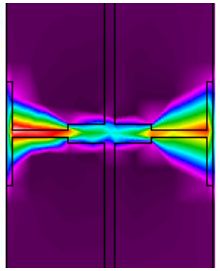
CAE 331/513 Building Science

Fall 2014





Week 1: August 26, 2014

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

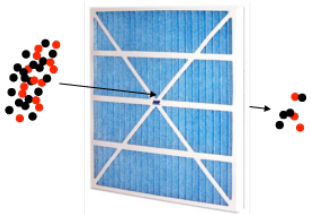
About me

- 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

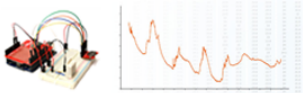
BERG: Built Environment Research Group

The **Built Environment Research Group** at IIT is dedicated to investigating problems and solutions related to energy air 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

- Wishnick Hall, Room 115
- Mondays 1:50 PM – 3:05 PM

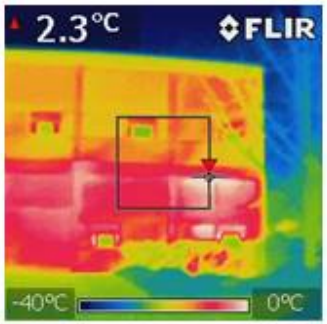
Prerequisites

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

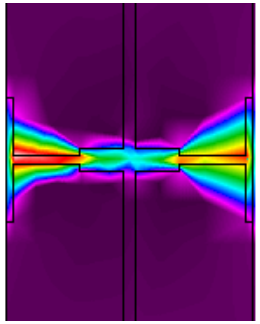
Course information

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.





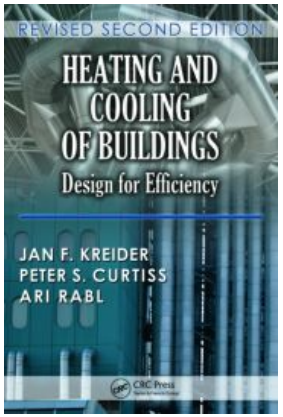


Course objectives

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 pollutants.
2. Describe the role of buildings and environmental systems in building design and construction.
3. Describe and quantify fundamental heat and mass transfer processes in buildings, including conduction, convection, radiation, thermodynamics, fluid flow, and mass balances.
4. Calculate heating and cooling loads in buildings.
5. Understand types of HVAC equipment for residential and commercial construction.
6. Understand basic ventilation and indoor air quality concepts.
7. Describe basic building diagnostic field tests (e.g., blower door tests).
8. Critically analyze claims about building components and environmental systems from product manufacturers, contractors, and building designers.

Textbook



Heating and Cooling of Buildings: Design for Efficiency
Kreider, J.F., Curtiss, P.S., and Rabl, A. 2010
CRC Press, Taylor & Francis Group.
ISBN: 978-1-4398-1151-1.
http://www.crcpress.com/product/isbn/9781439811511

- The bookstore should have some copies
- There are also new, used, and rental copies (including e-books) on Amazon

Additional references

- I will also draw on several other references in this course:
  - No need to purchase these, but I highly recommend purchasing the ASHRAE Handbook of Fundamentals
    - Relatively cheap for student members (Individual chapters are on BB)

ASHRAE 2013. *Handbook of Fundamentals.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

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.

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.

Course topics

- Importance of building science
- Elements of heat transfer in buildings
- Building energy balances
- Psychrometrics
- Thermal comfort
- HVAC systems and thermodynamics
- Mechanical, electrical, plumbing, and lighting systems
- Ventilation, infiltration, and indoor air quality
- Fluid flow in buildings
- Heating and cooling loads
- Building performance diagnostics
- Energy efficiency and green buildings

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
  - Course is mixed undergraduate/graduate
  - Graduate students have higher expectations
- Homework
  - Six HW assignments are planned throughout the semester
  - Will typically be assigned on Thursday, due following Tuesday
- Three Exams
  - One exam scheduled for Tuesday, October 14, 2014
  - One exam scheduled for Tuesday, November 18, 2014
  - Final exam (comprehensive): Thursday, December 11, 2014 2-4 PM
  - Undergraduate students will take in-class exams
  - Graduate students will take longer, more difficult take-home exams over a 2-day period (e.g., assigned Tuesday, due Thursday)

Course grading

Assignment	Max points
• HW	300
• Exam 1	250
• Exam 2	250
• Final exam	300
• Total	1100

Grading scale for both 331 and 513:

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

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 website

- I will post lectures and updated syllabus on my website:
  - http://built-envi.com/courses/cae-331513-building-science-fall-2014/

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

Tentative course schedule (continuously updated)

Course Topics and Tentative Schedule

Week	Date	Lecture Topics	Reading	Assignment Due
1	Aug 26	Introduction to building science	Kreider Ch. 1	
	Aug 28	Pre-requisite review and energy concepts		
2	Sep 2	Heat transfer in buildings	Kreider Ch. 2	HW1
	Sep 4	Heat transfer in buildings		
3	Sep 9	Heat transfer in buildings	Kreider Ch. 6	
	Sep 11	*No class – away at a conference*		
4	Sep 16	Human thermal comfort	Kreider Ch. 4	HW2
	Sep 18	Psychrometrics (chart)		
5	Sep 23	Psychrometrics (equations)	Kreider Ch. 4	
	Sep 25	Psychrometrics (processes)		
6	Sep 30	HVAC systems (introduction)	Kreider Ch. 9-10	HW3
	Oct 2	HVAC systems (mechanical properties)	Kreider Ch. 3/5	
7	Oct 7	Ventilation and indoor air quality	Kreider Ch. 4	
	Oct 9	Ventilation and indoor air quality		
8	Oct 14	**Exam 1**		
	Oct 16	*No class – away at a conference*		
9	Oct 21	Heating loads	Kreider Ch. 7	HW4
	Oct 23	Cooling loads	Kreider Ch. 7	
10	Oct 28	Cooling loads		
	Oct 30	Cooling loads		
11	Nov 4	Energy estimation	Kreider Ch. 8	HW5
	Nov 6	Energy efficiency in buildings	Kreider Ch. 14	
12	Nov 11	Electrical, lighting, and acoustics		
	Nov 13	Building performance diagnostics		
13	Nov 18	**Exam 2**		
	Nov 20	Building performance diagnostics		
14	Nov 25	Sustainability and research in building science		HW6
	Nov 27	*No class – Thanksgiving Day*		
15	Dec 2	Exam review		
	Dec 4	*Flex day*		
Final	Dec 11	**Final exam (comprehensive): 2-4 pm**		

Office hours

- By appointment only: Email me for an appointment
  - brent@iit.edu

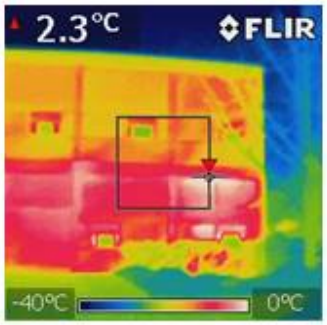
Your TA this fall

- Elizabeth “Liz” Mullin
  - emullin@hawk.iit.edu
- Email her to make an appointment
- She will also be working the following hours:
  - Sundays 6-9 PM, in the ARC (Hermann Hall)
  - Wednesdays 9 AM - 12 PM in the lobby of Alumni Hall

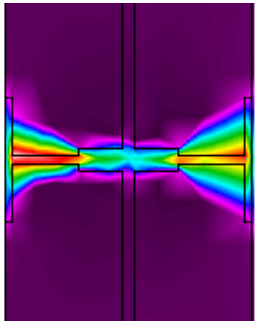
Questions thus far?

Today’s topics

- Introduction to building science







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?

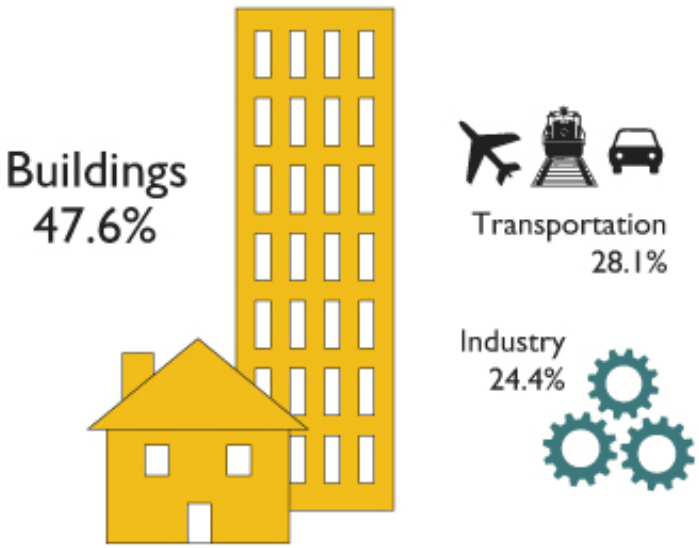
- How many of you are in a building right now?
  - Birds build nests
  - Rabbits dig holes
  - People build buildings

- 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.?

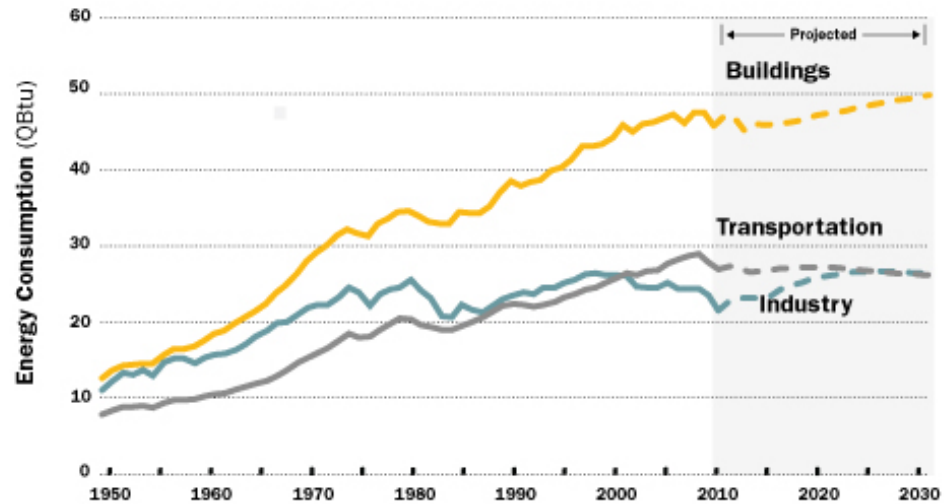
- How much time do you think people spend indoors, on average?

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)

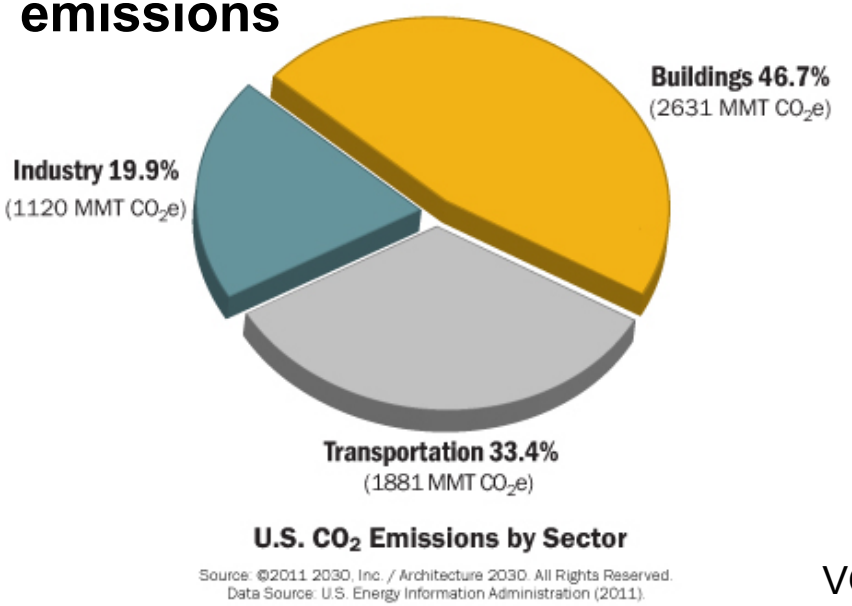
Source: ©2013 2030, Inc. / Architecture 2030. All Rights Reserved.
Data Source: U.S. Energy Information Administration (2012).

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

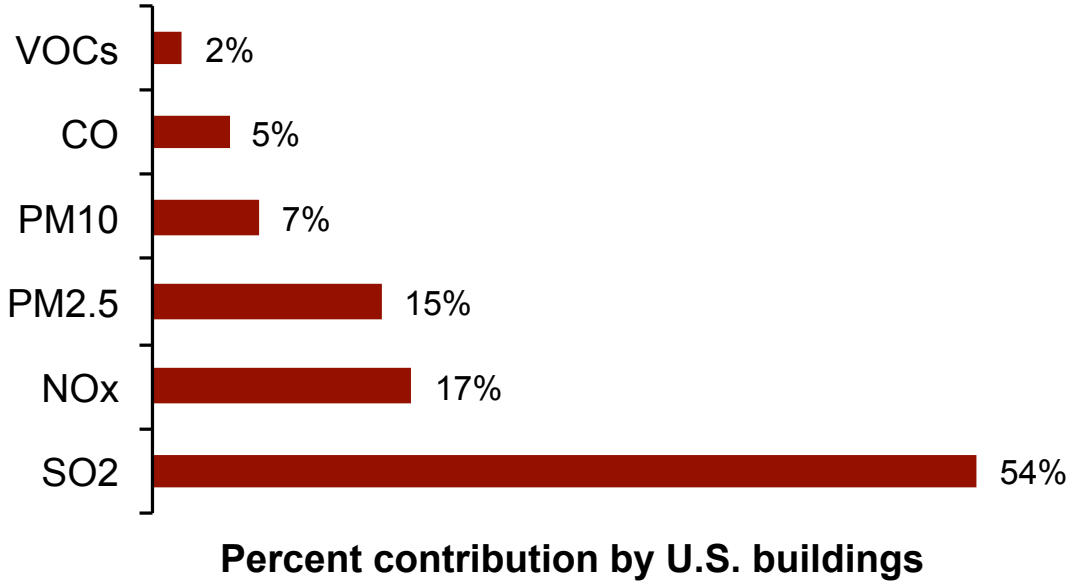
Contribution to greenhouse gas (GHG) emissions



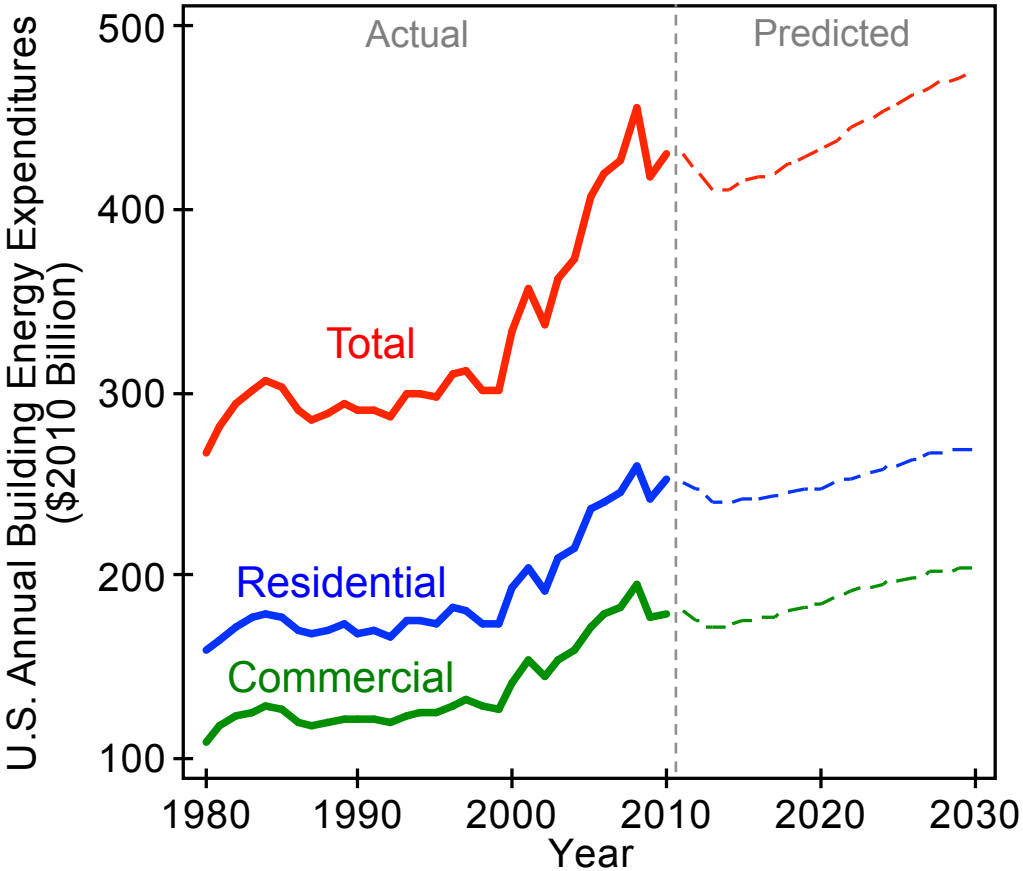
Major uses

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

Contribution to outdoor air pollution

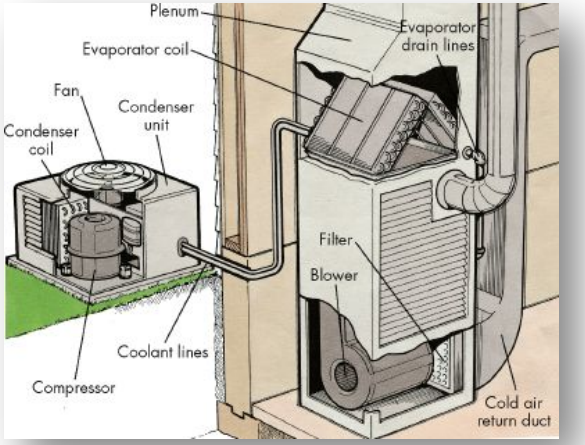


Building energy use costs *a lot* of money



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

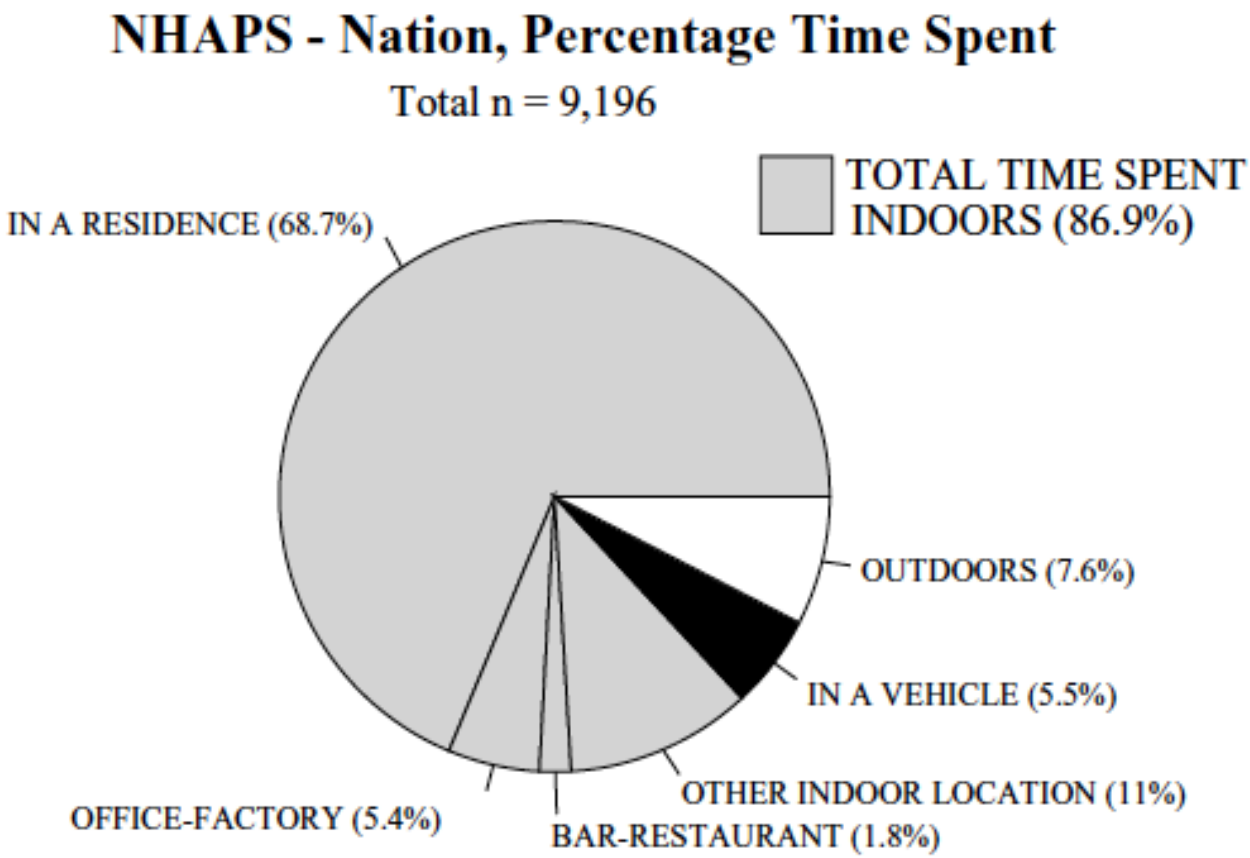
Approximately 3% of our GDP



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



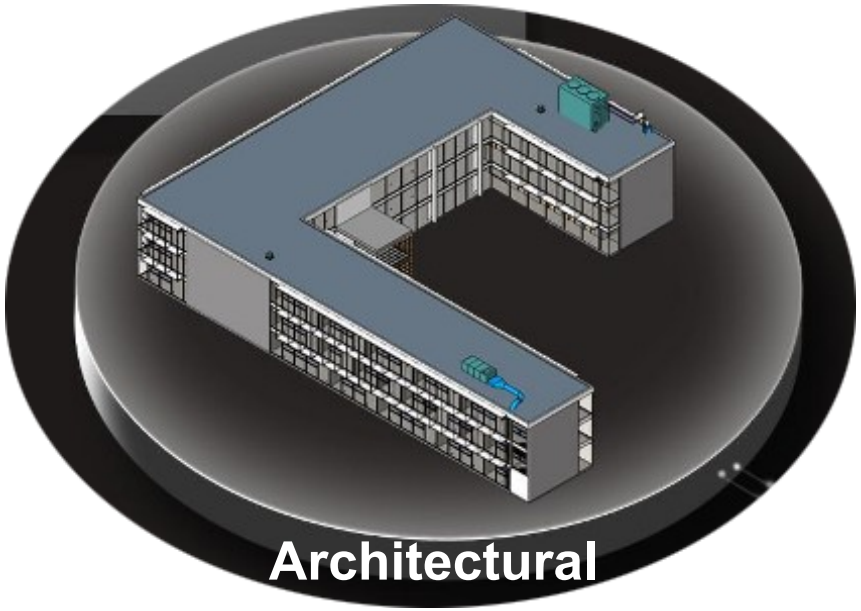
- Americans spend almost 90% of their time indoors
  - 75% at home or in an office

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

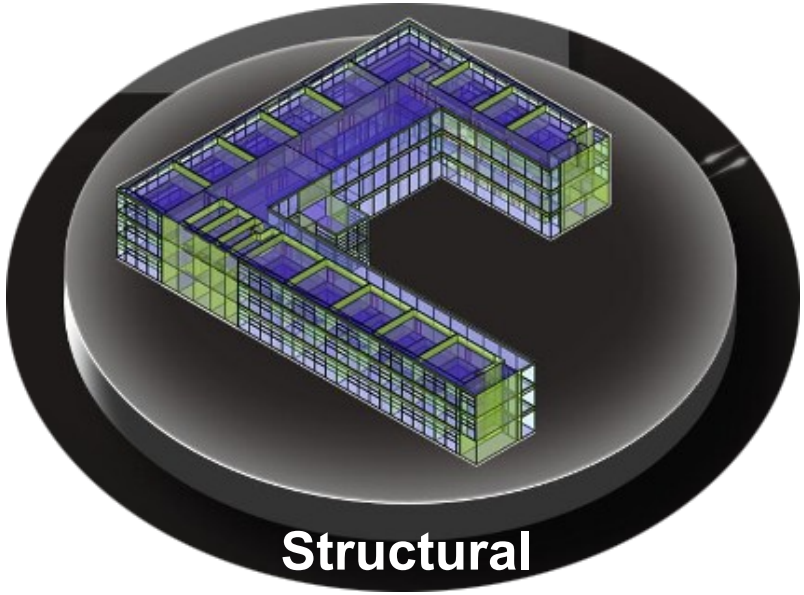
Buildings impact people, energy, and the environment

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

Building science in context

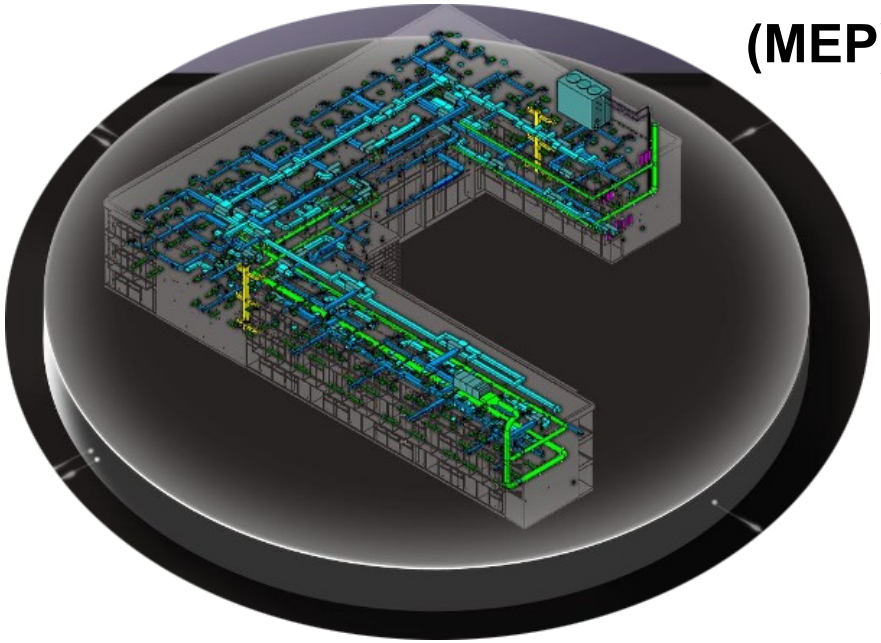


Architectural



Structural

Mechanical, Electrical, Plumbing (MEP)



Building science in context

- Structural
- Mechanical
- Construction
- Electrical
- Plumbing
- Architectural

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

- Architectural engineering has become a catch-all for many of these disciplines

Building science and other detailed courses in ARCE

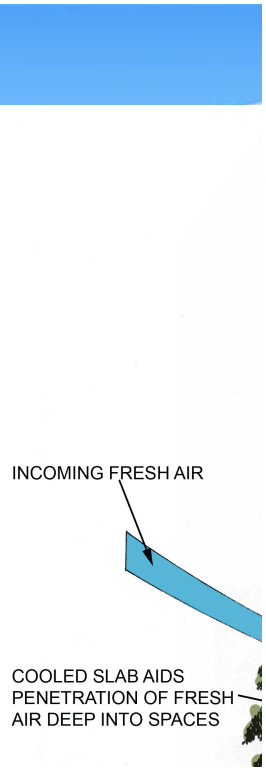
- Enclosure/architectural/energy
  - CAE 463/524 Building Enclosure Design

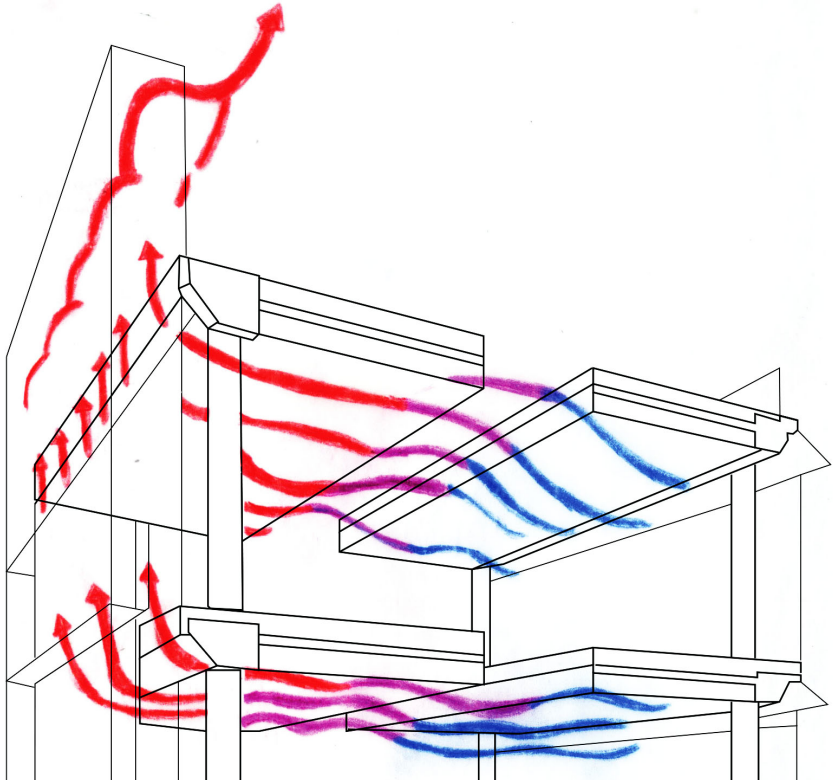
- Mechanical
  - CAE 464 HVAC Design
  - CAE 465/526 Energy Conservation Design in Buildings
  - ENVE 576 Indoor Air Pollution (partial coverage)

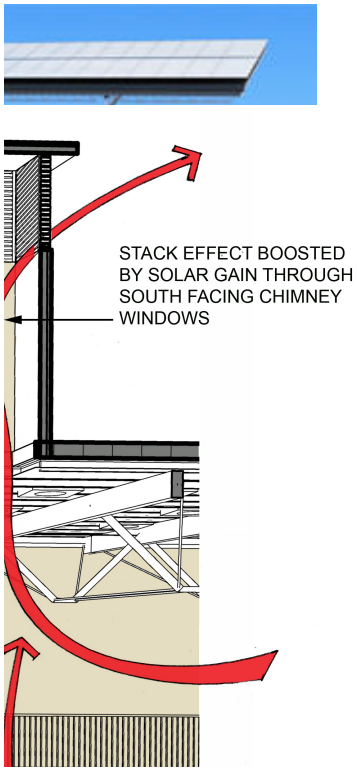
- Electrical
  - CAE 334/502 Acoustics and Lighting
  - CAE 466/528 Building Electrical Systems Design
  - CAE 467/521 Lighting Systems Design

- Plumbing and fire protection
  - CAE 424/510 Fire Dynamics
  - CAE 425/511 Fire Protection and Life Safety in Building Design
  - CAE 461 Plumbing and Fire Protection Design

Why do we need building science?

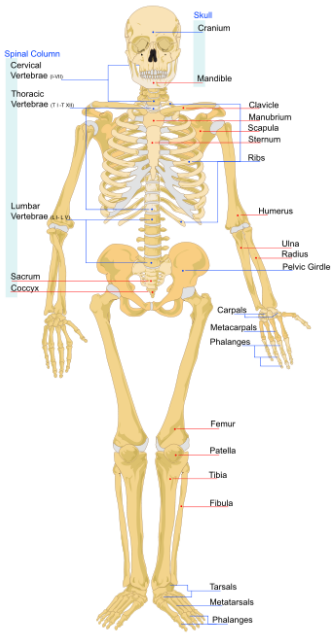


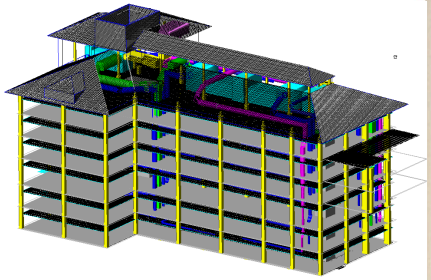




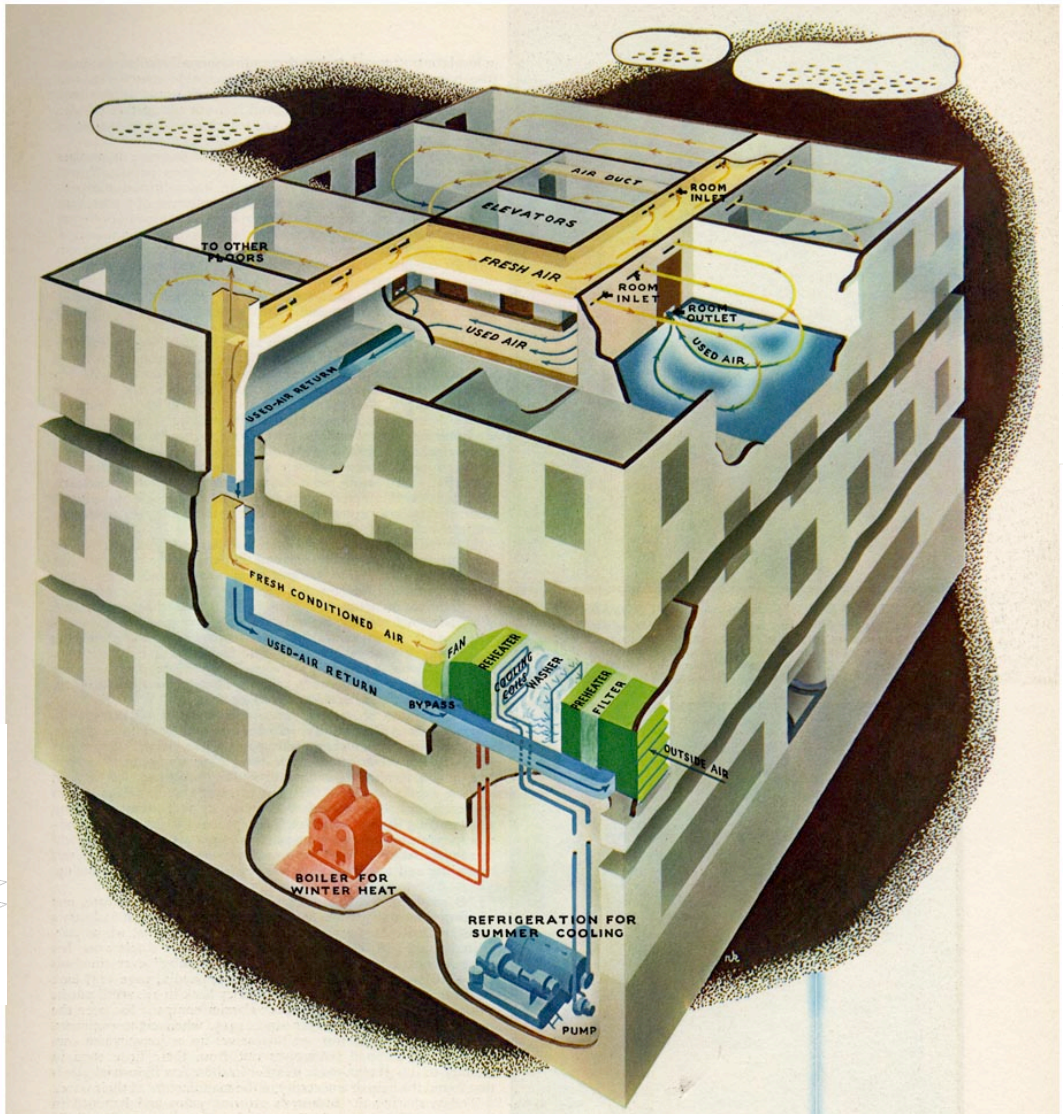
We need to understand basics of energy, heat transfer, fluid flow, and electrical power to understand how buildings work and how design and operational decisions influence their performance

When we peak inside a building





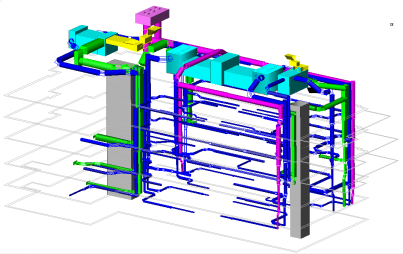
Structural



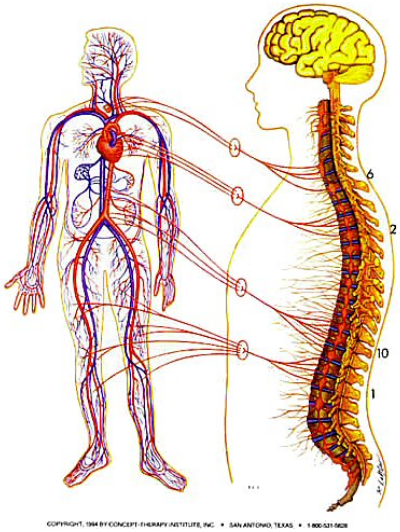
AN X-RAY VIEW OF AN AIR-CONDITIONED OFFICE BUILDING WOULD NOT LOOK SO SIMPLE AS THIS

. . . 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.

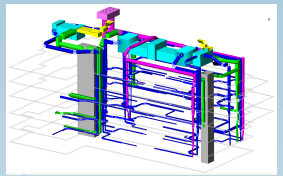
HVAC/MEP

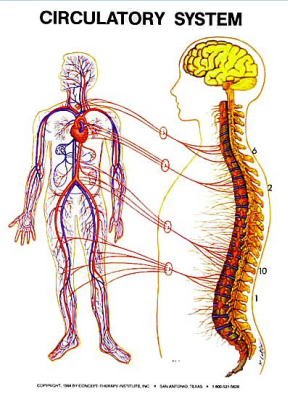


CIRCULATORY SYSTEM



HVAC/MEP





Source: U.S. EPA

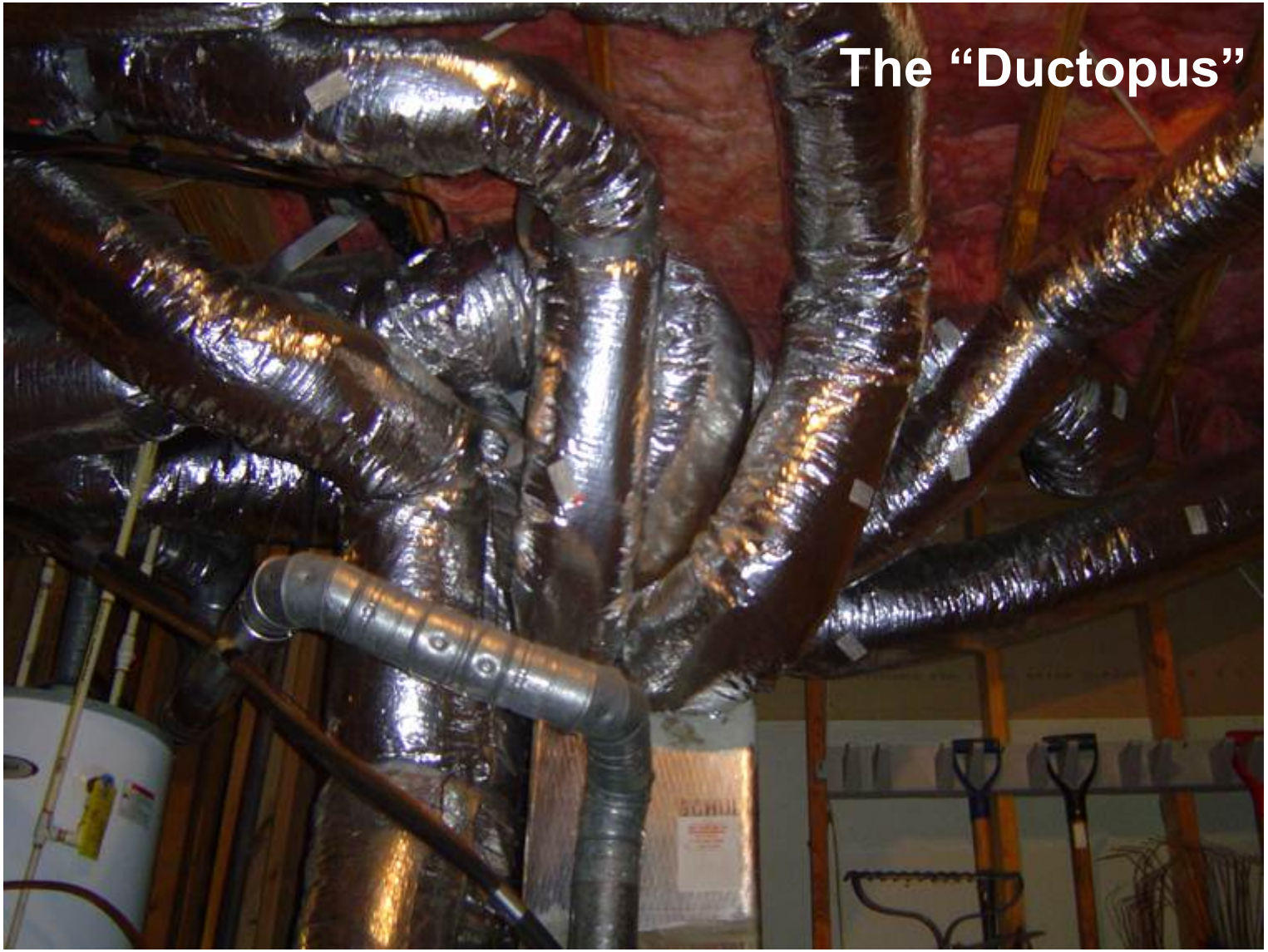
What happens when you don't understand building science?

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.hvacfun.com/hall-shame-22.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.greenbuildingadvisor.com/blogs/dept/building-science/should-flex-duct-be-banned

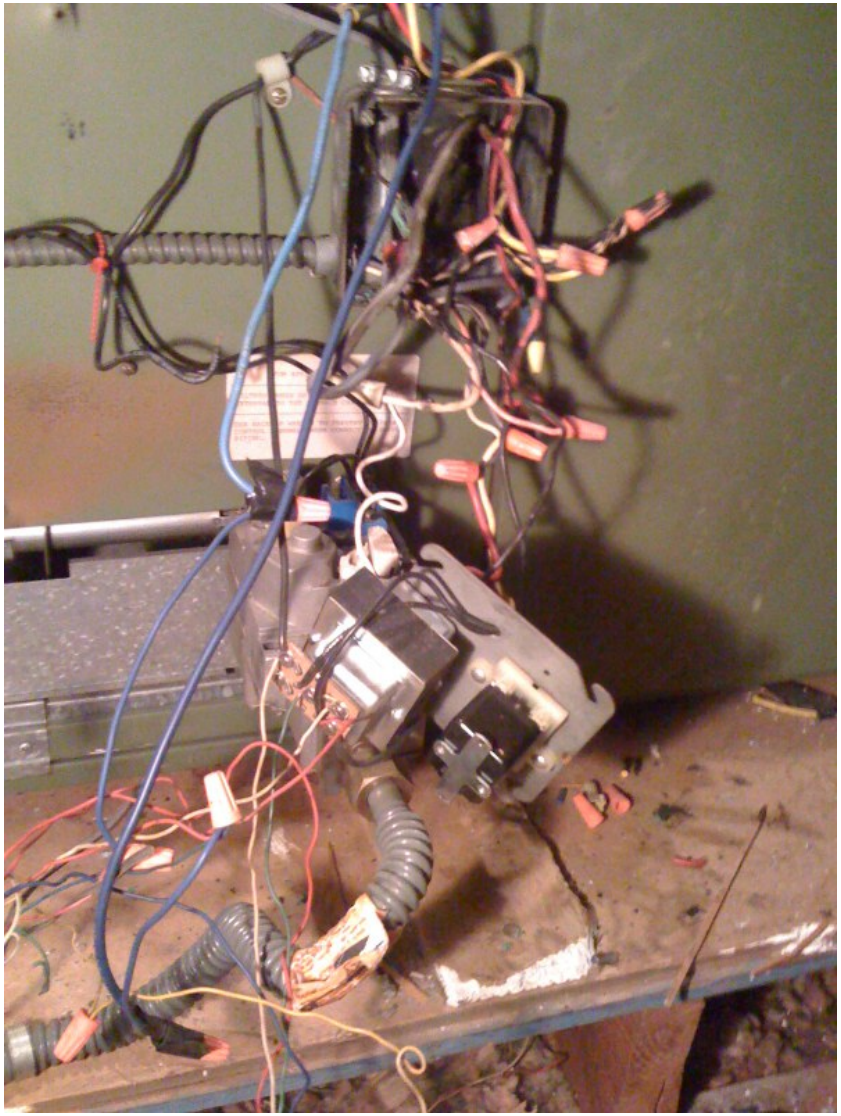
What happens when you don't understand building science?

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

What happens when you don't understand building science?

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

What happens when you don't understand building science?



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

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

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
- Lawrence Berkeley National Laboratory (LBNL)
- Oak Ridge National Laboratory (ORNL)
- Building Science Corporation
- 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)

Important publications to know

- Publications*
  - *ASHRAE Journal*
  - *HVAC&R Research*
  - *ASHRAE Transactions*
  - *Building and Environment*
  - *Energy and Buildings*
  - *ASCE Journal of Architectural Engineering*

*I believe 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)

Commercial Resources
ASHRAE Bookstore

COMMENT HELP MAIN MENU

More . . .

*Each chapter is available in the **Files** section on Blackboard*

Next time

- Review of pre-requisite topics