

# THERMAL EXPANSION SPEAKERS



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*Atelier Ten*



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*National Sustainable Design  
Director*  
HGA

**Façade Tectonics Forum**

Minneapolis

April 15, 2019

# **BUILDING ENVELOPE**

## **ENERGY + CODES + PERFORMANCE**

**Scott Murray**

Associate Professor of Architecture

University of Illinois at Urbana-Champaign

# **BUILDING ENVELOPE**

**ENERGY + CODES + PERFORMANCE**

**ENERGY + CODES + PERFORMANCE**

# **BUILDING CODES**



## Fire at the Triangle Shirtwaist Factory New York City 1911

# The New York Times.

NEW YORK, SUNDAY, MARCH 26, 1911.—90 PAGES, In Eight Parts, Including Picture Section and Review of Books.

## 141 MEN AND GIRLS DIE IN WAIST FACTORY FIRE; TRAPPED HIGH UP IN WASHINGTON PLACE BUILDING; STREET STREWN WITH BODIES; PILES OF DEAD INSIDE

The Flames Spread with Deadly Rapidity Through Flimsy Material Used in the Factory.

600 GIRLS ARE HEMMED IN

When Elevators Stop Many Jump to Certain Death and Others Perish in Fire-Filled Lofts.

STUDENTS RESCUE SOME

Help Them to Roof of New York University Building, Keeping the Panic-Stricken in Check.

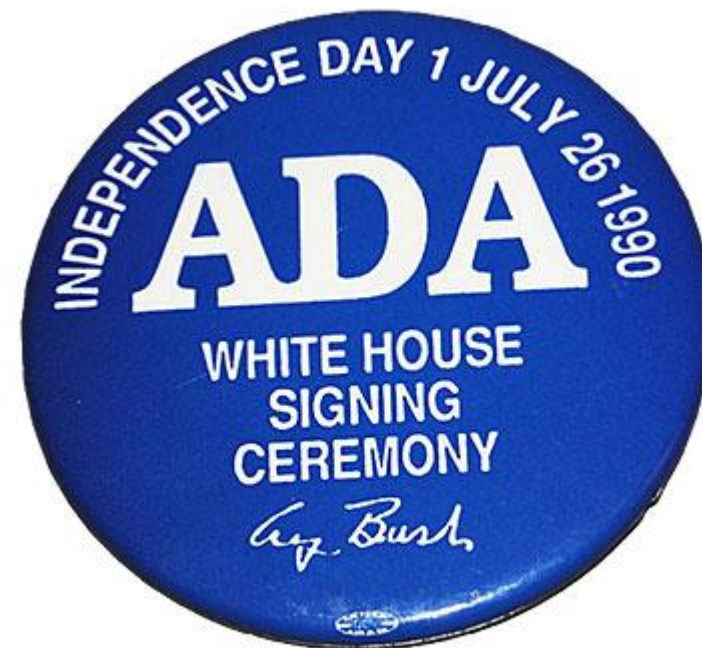
ONE MAN TAKEN OUT ALIVE

Plunged to Bottom of Elevator Shaft and Lived There Amid





Americans with Disabilities Act (ADA)  
1990



# **BUILDING CODES**

## **REFLECTING CULTURAL PRIORITIES**

**early 1900s**  
**EGRESS / LIFE SAFTEY**

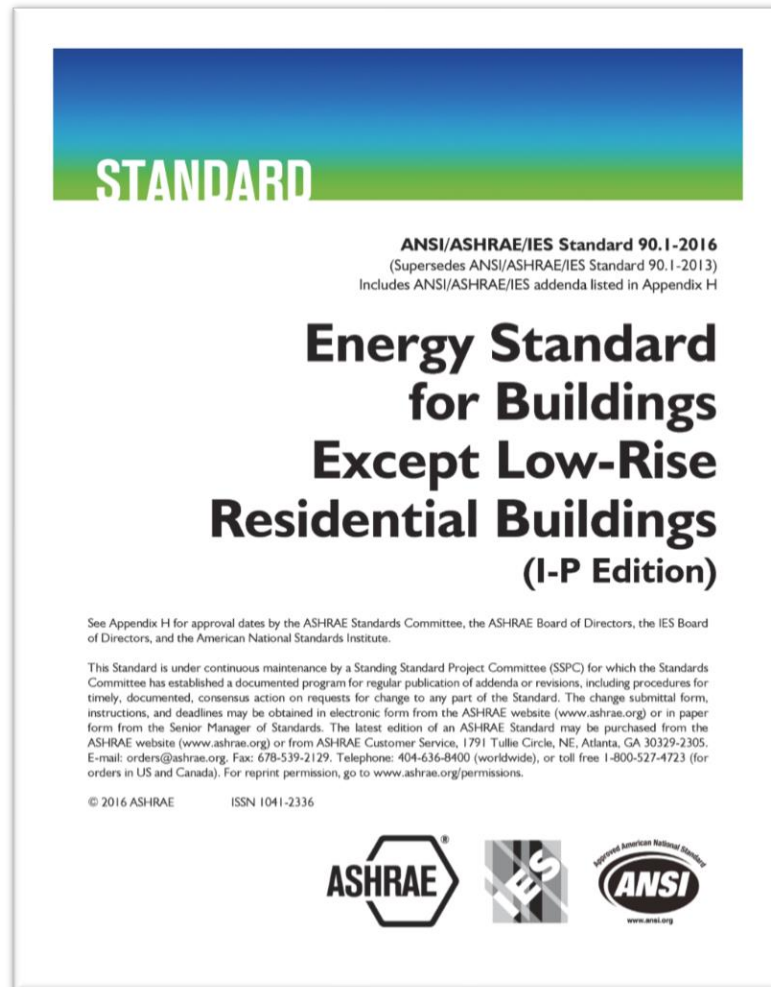


**late 1900s**  
**ACCESSIBILITY**



**early 2000s**  
**ENERGY PERFORMANCE**

## ASHRAE Standard 90.1: Energy Standard for Buildings 1975 - today



**STANDARD**




**ANSI/ASHRAE/IES Standard 90.1-2016**  
(Supersedes ANSI/ASHRAE/IES Standard 90.1-2013)  
Includes ANSI/ASHRAE/IES addenda listed in Appendix H

**Energy Standard  
for Buildings  
Except Low-Rise  
Residential Buildings  
(I-P Edition)**

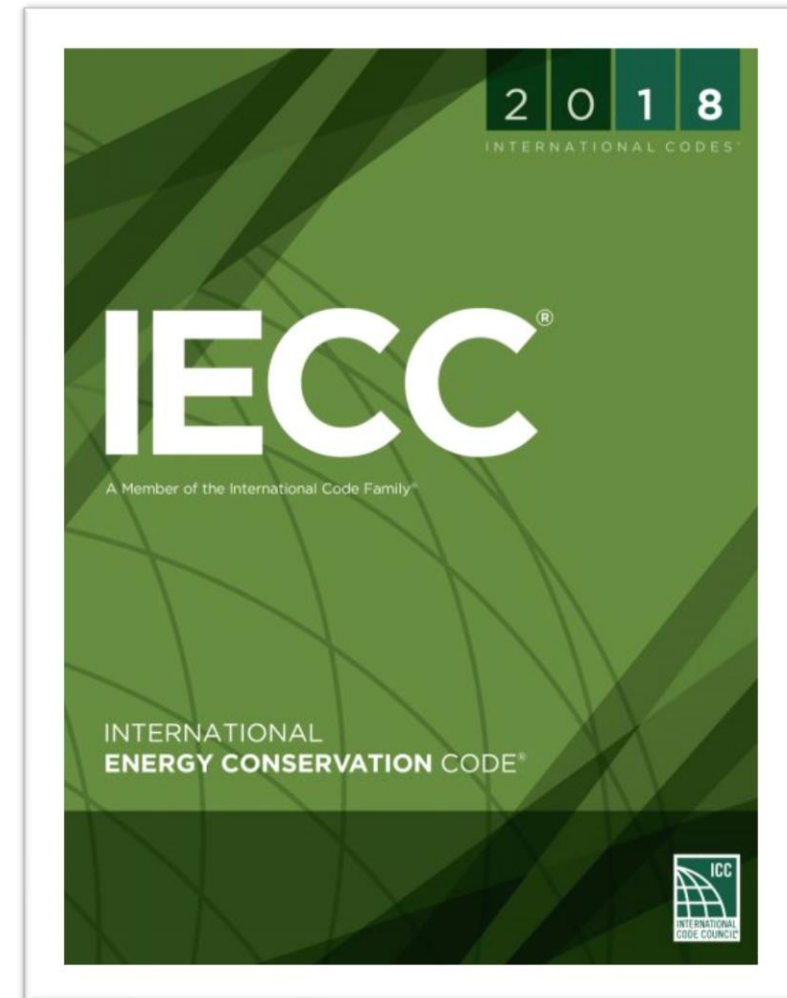
See Appendix H for approval dates by the ASHRAE Standards Committee, the ASHRAE Board of Directors, the IES Board of Directors, and the American National Standards Institute.

This Standard is under continuous maintenance by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the Standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website ([www.ashrae.org](http://www.ashrae.org)) or in paper form from the Senior Manager of Standards. The latest edition of an ASHRAE Standard may be purchased from the ASHRAE website ([www.ashrae.org](http://www.ashrae.org)) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: [orders@ashrae.org](mailto:orders@ashrae.org). Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to [www.ashrae.org/permissions](http://www.ashrae.org/permissions).

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## International Energy Conservation Code 1998 - today




**2018**  
INTERNATIONAL CODES™

**IECC®**

A Member of the International Code Family™

INTERNATIONAL  
ENERGY CONSERVATION CODE®



# Energy Code adoption by state (as of Dec. 2018)

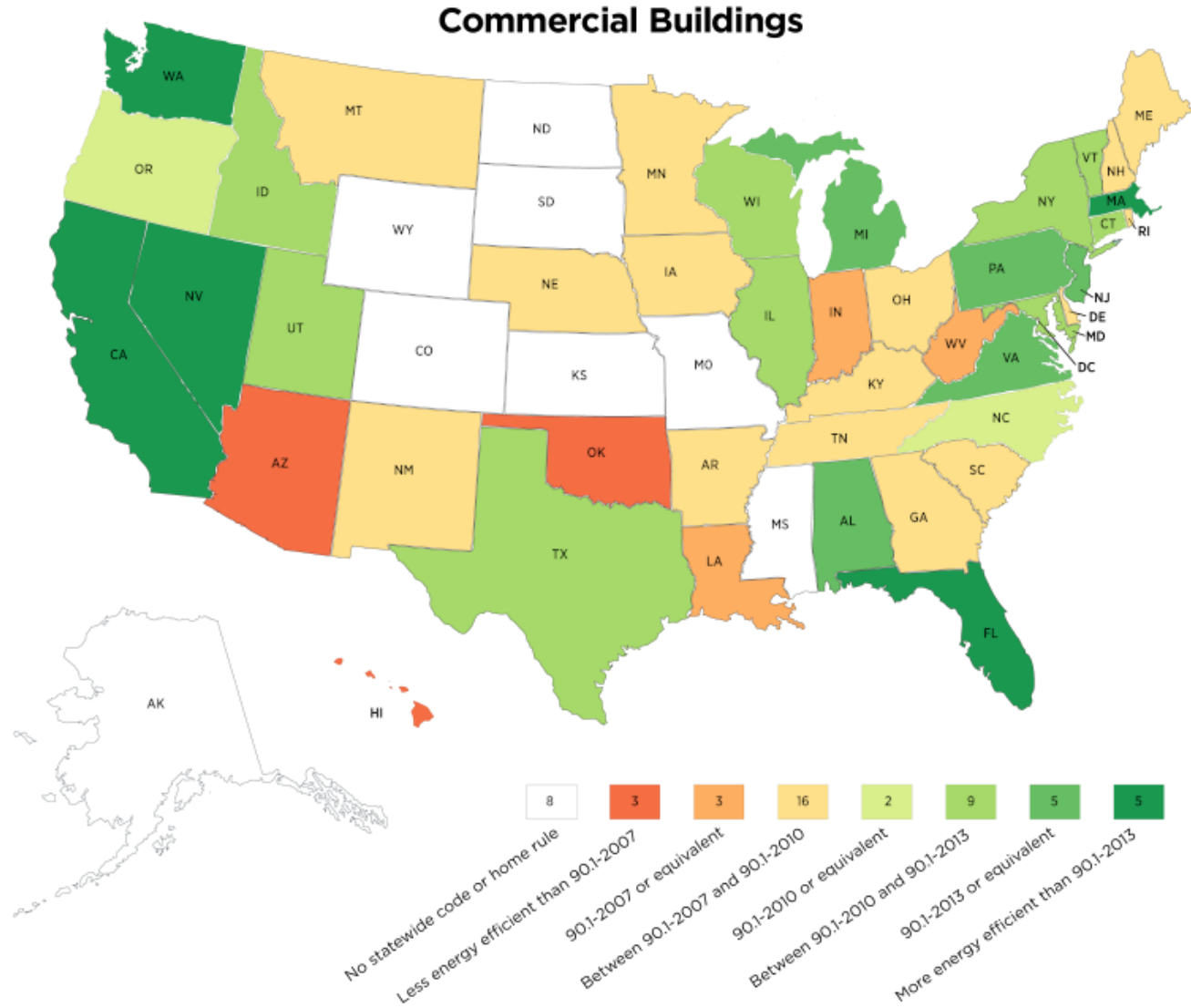
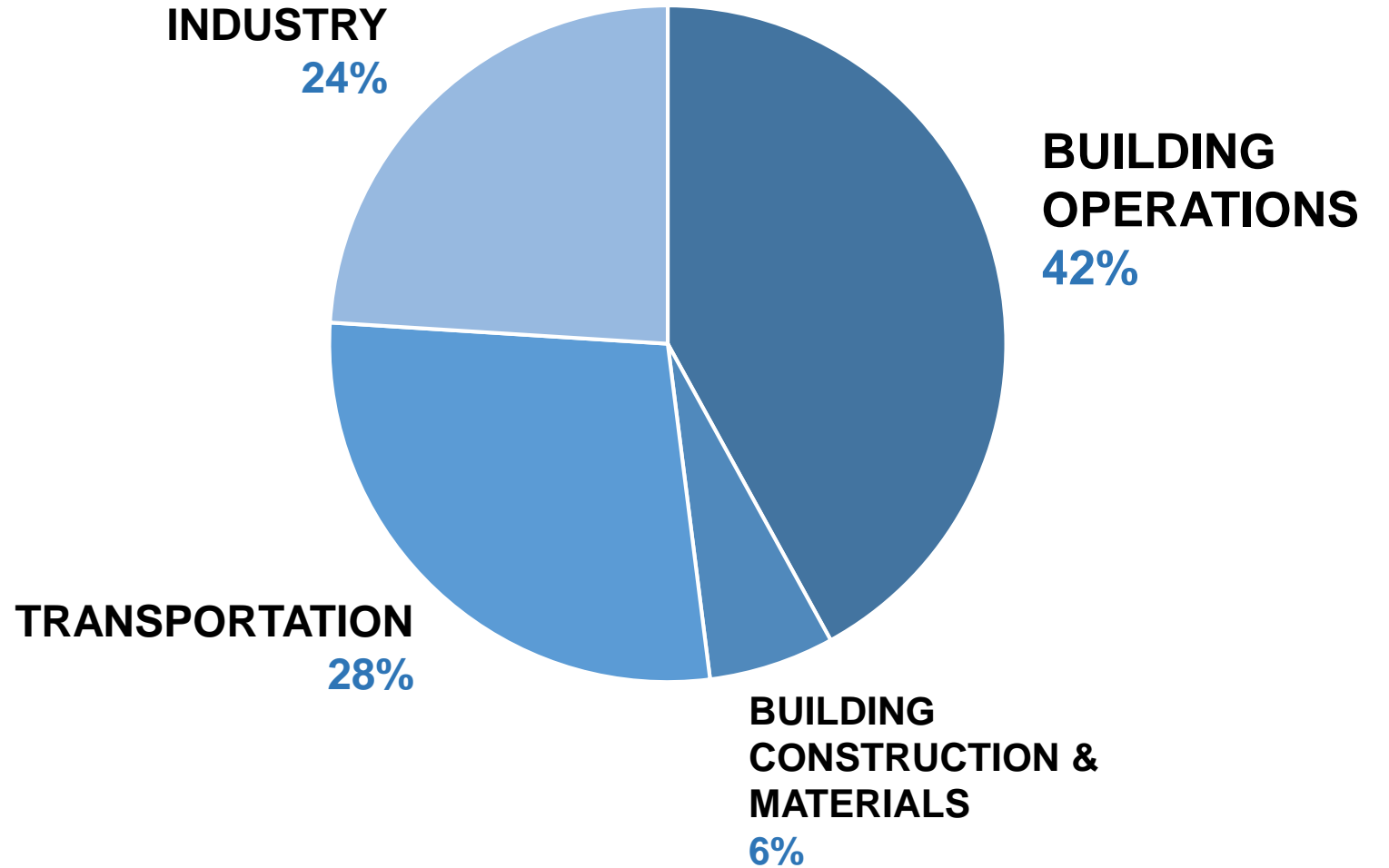


Image source: U.S. Department of Energy

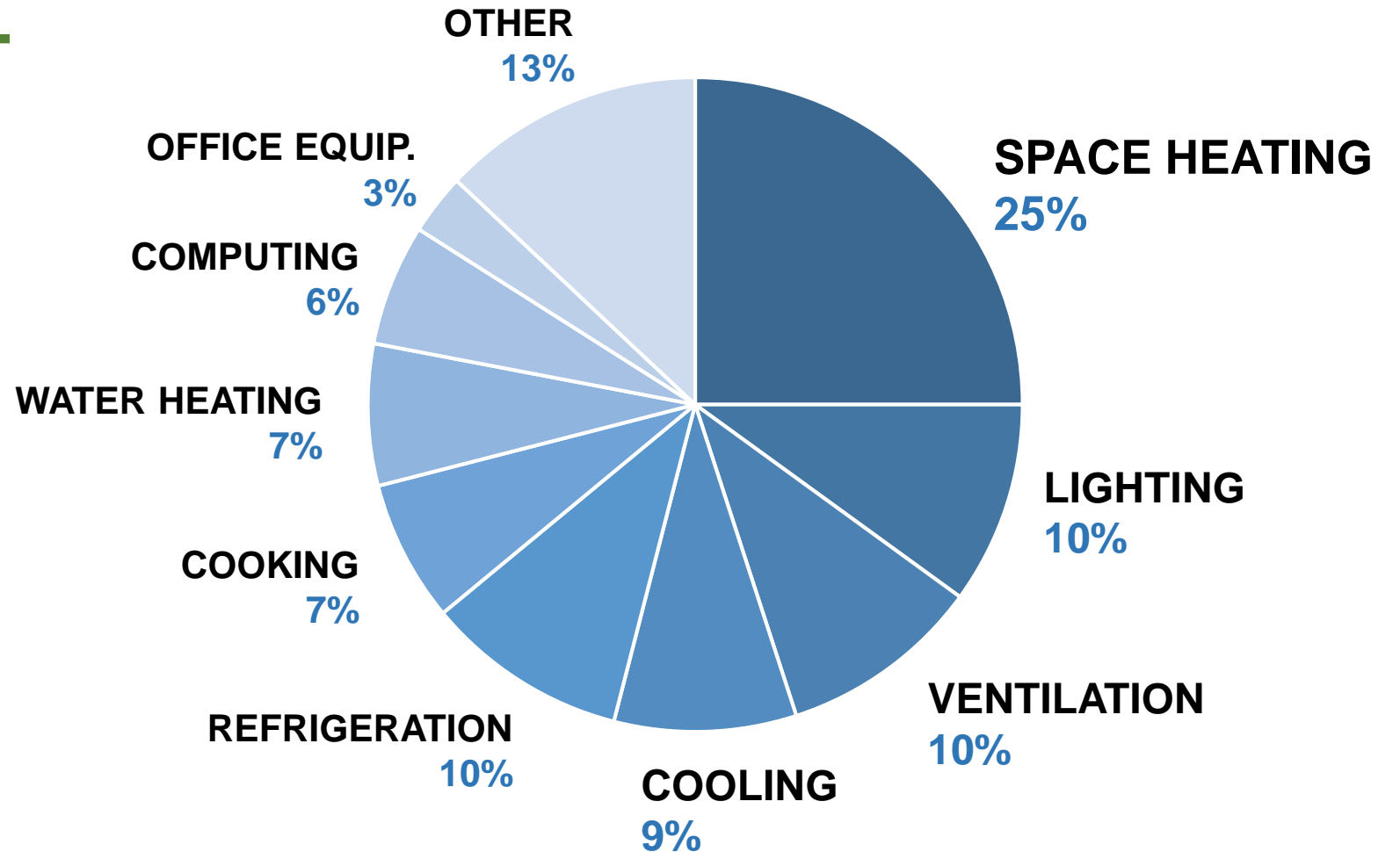
# ENERGY PERFORMANCE

# ENERGY CONSUMPTION BY SECTOR (U.S.)



Data source: U.S. Energy Information Administration, 2012

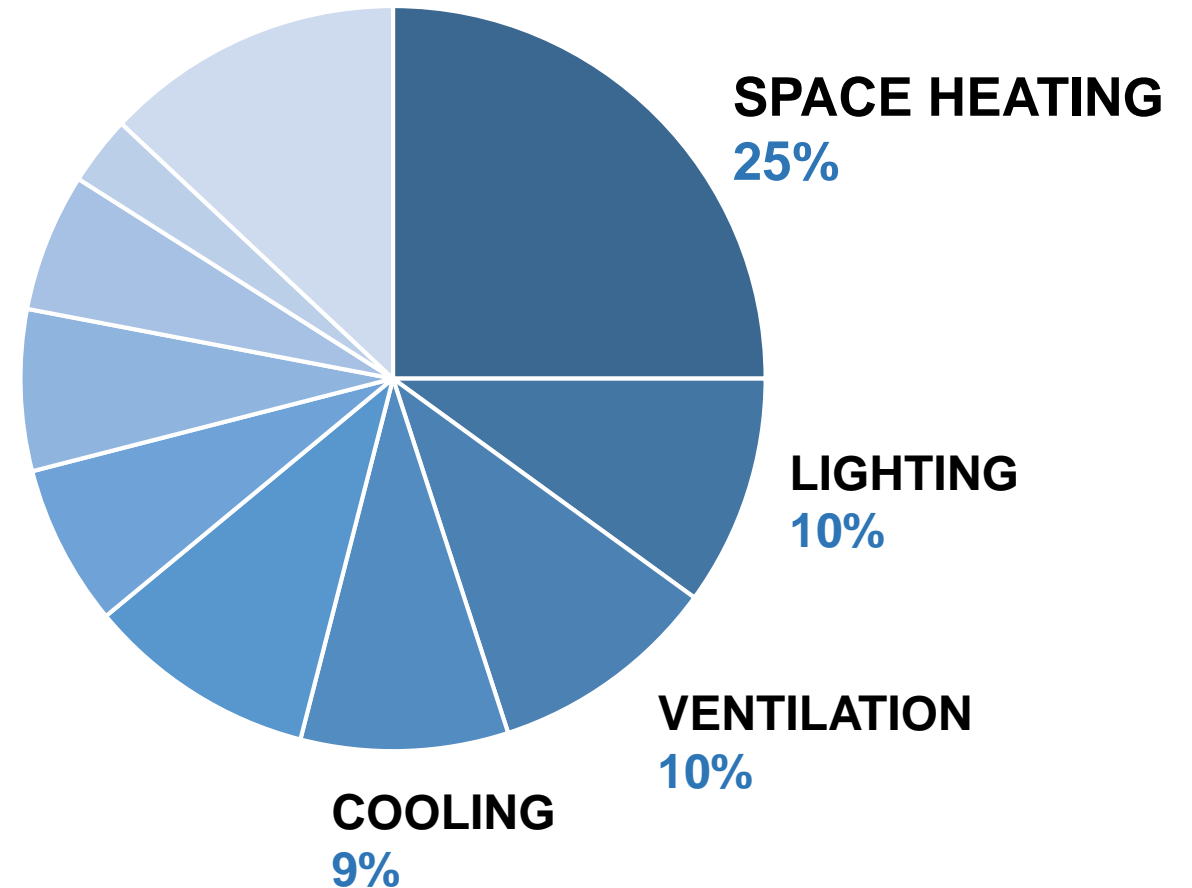
# ENERGY USE IN U.S. COMMERCIAL BUILDINGS



Data source: U.S. Energy Information Administration, 2012

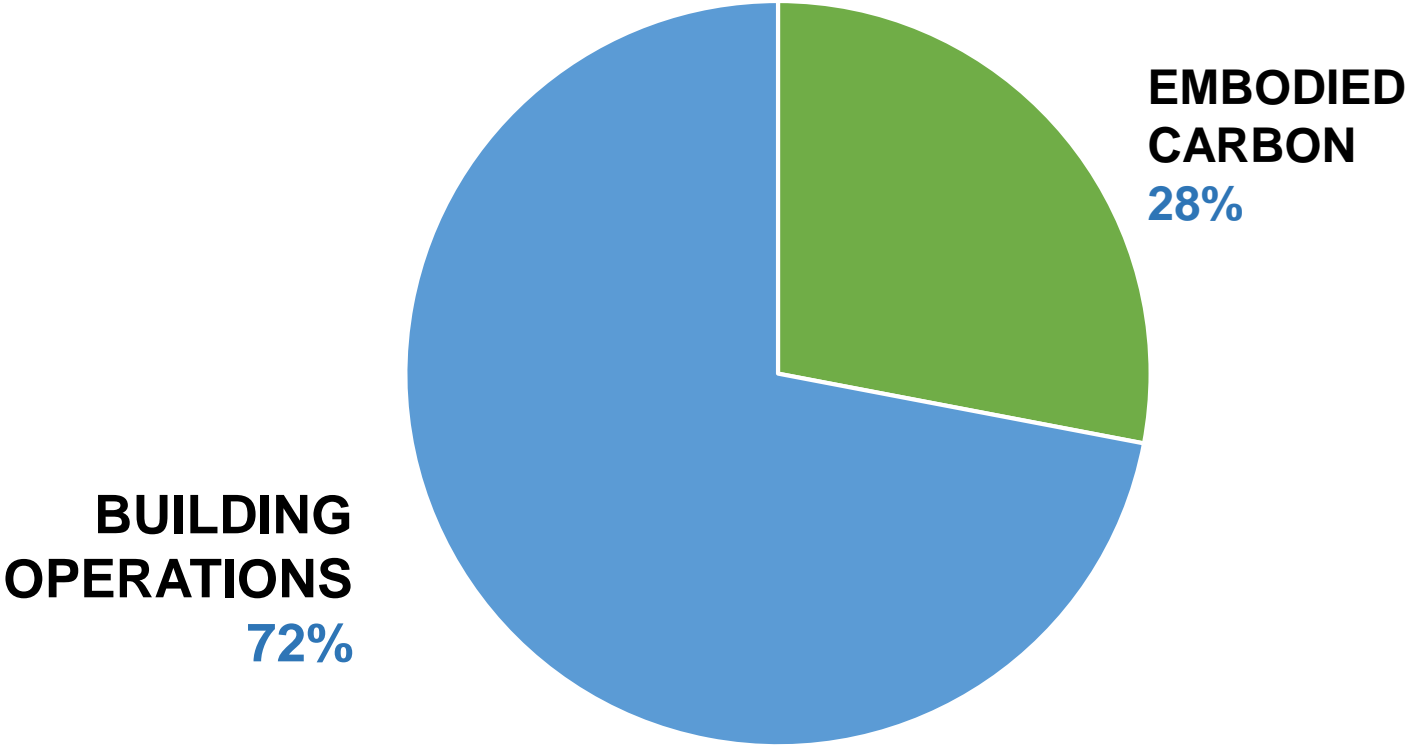
# ENERGY USE IN U.S. COMMERCIAL BUILDINGS

HEATING  
+  
COOLING  
+  
LIGHTING  
+  
VENTILATION  
=  
**54%**

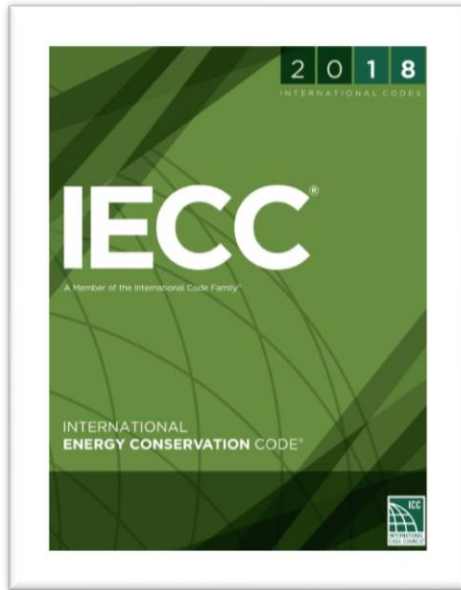


Data source: U.S. Energy Information Administration, 2012

# ANNUAL GLOBAL BUILDING SECTOR CO<sub>2</sub> EMISSIONS



Data source: Architecture 2030

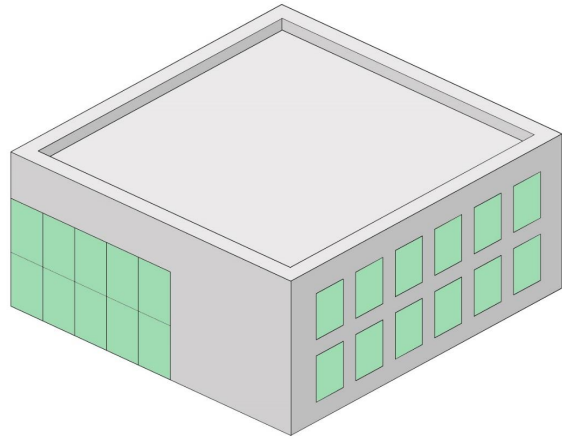


# INTERNATIONAL ENERGY CONSERVATION CODE

- Updated every 3 years, 2000 - 2018
- Energy efficiency for Commercial and Residential building types
- Section C402: BUILDING ENVELOPE REQUIREMENTS



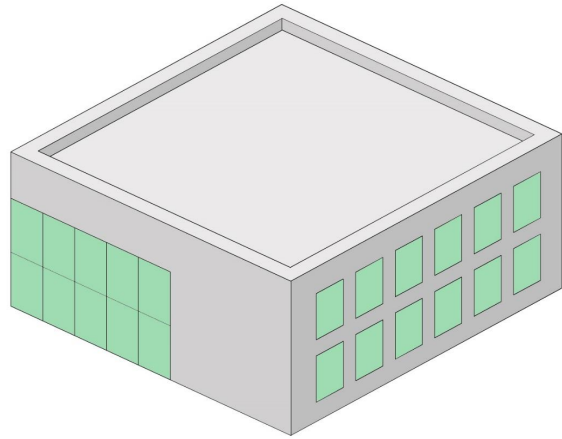
# THERMAL PERFORMANCE OF COMPONENTS



**Two categories of envelope components:**

1. opaque walls/roofs
2. fenestration

# THERMAL PERFORMANCE OF COMPONENTS

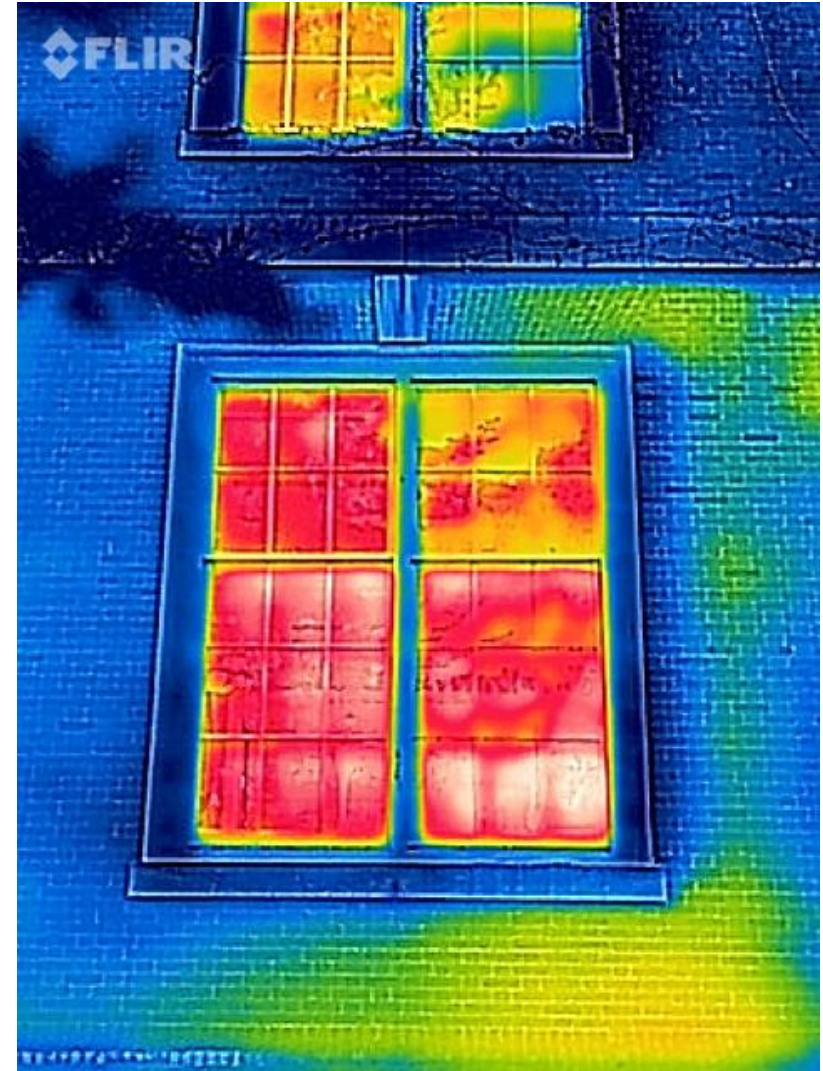
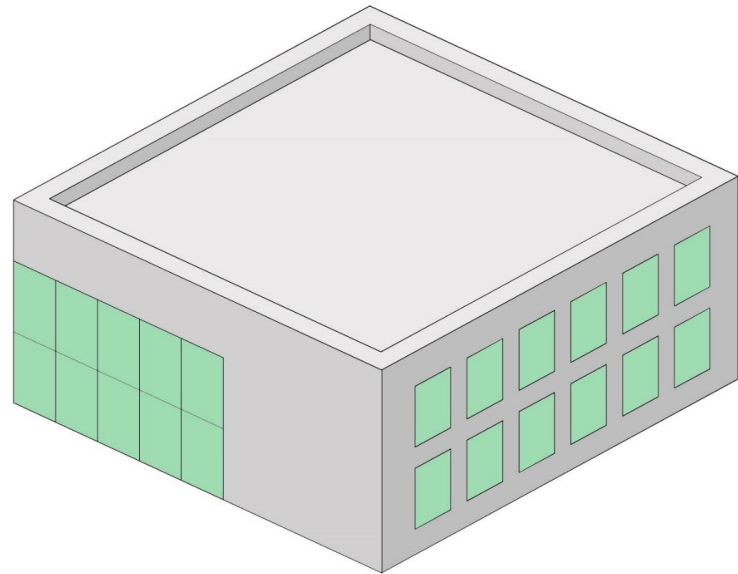


## Two categories of envelope components:

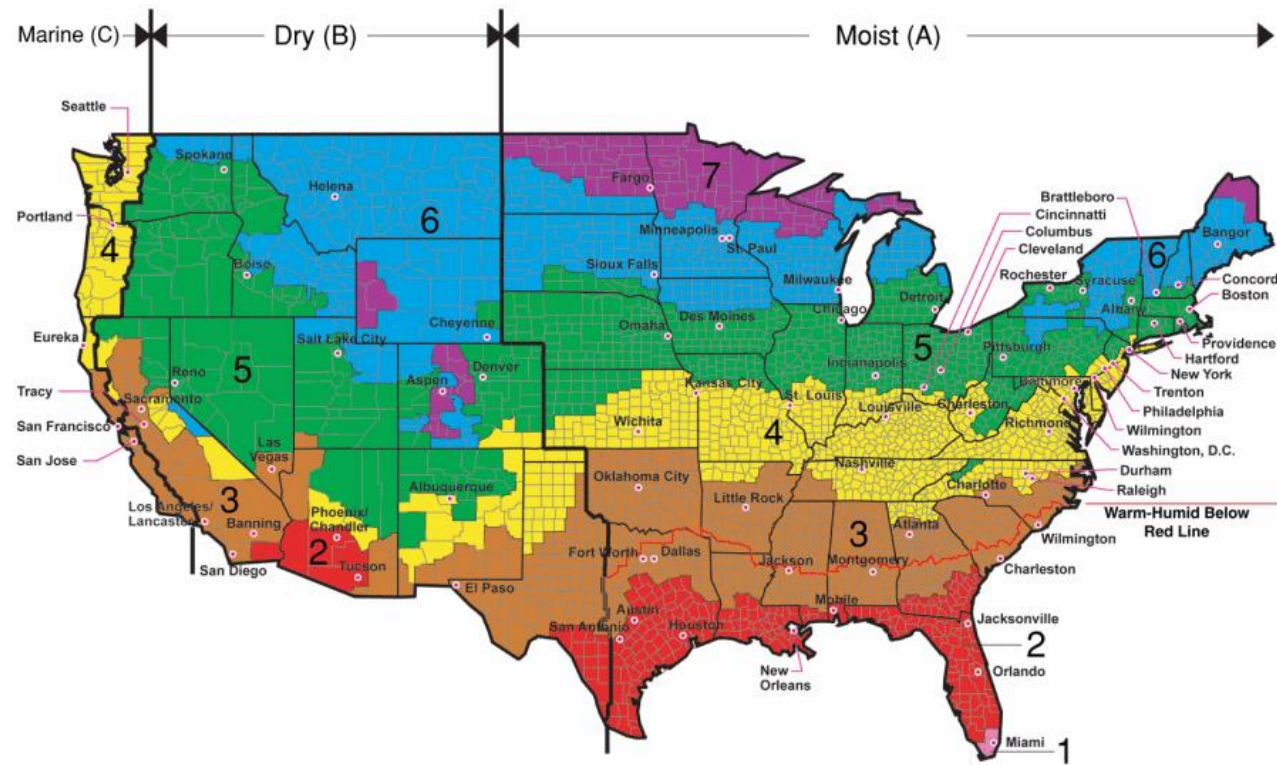
1. opaque walls/roofs ➡ minimum R-values
2. fenestration ➡ maximum U-values and SHGC

# WINDOW / WALL RATIO

The code restricts the amount of fenestration as % of the total envelope (walls and roofs)



# example: Minneapolis, Zone 6

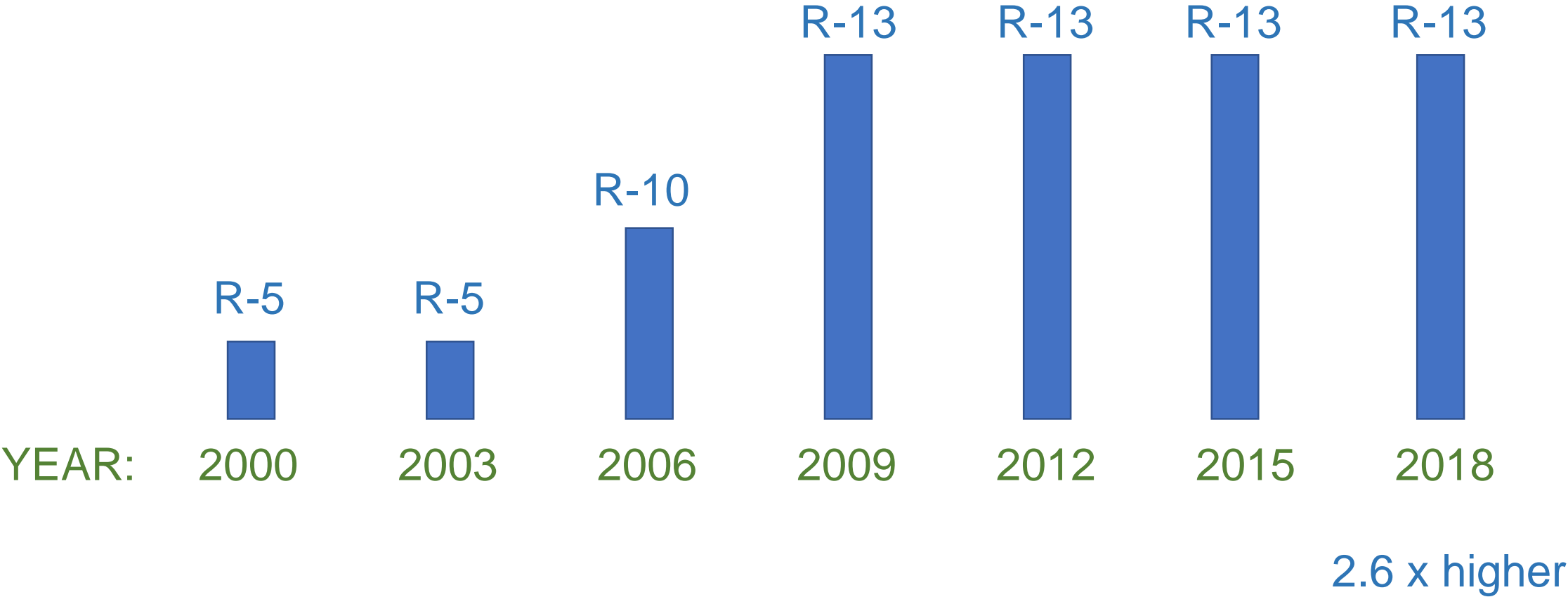


All of Alaska in Zone 7 except for the following Boroughs in Zone 8: Bethel, Dellingham, Fairbanks, N. Star, Nome North Slope, Northwest Arctic, Southeast Fairbanks, Wade Hampton, and Yukon-Koyukuk

Zone 1 includes: Hawaii, Guam, Puerto Rico, and the Virgin Islands

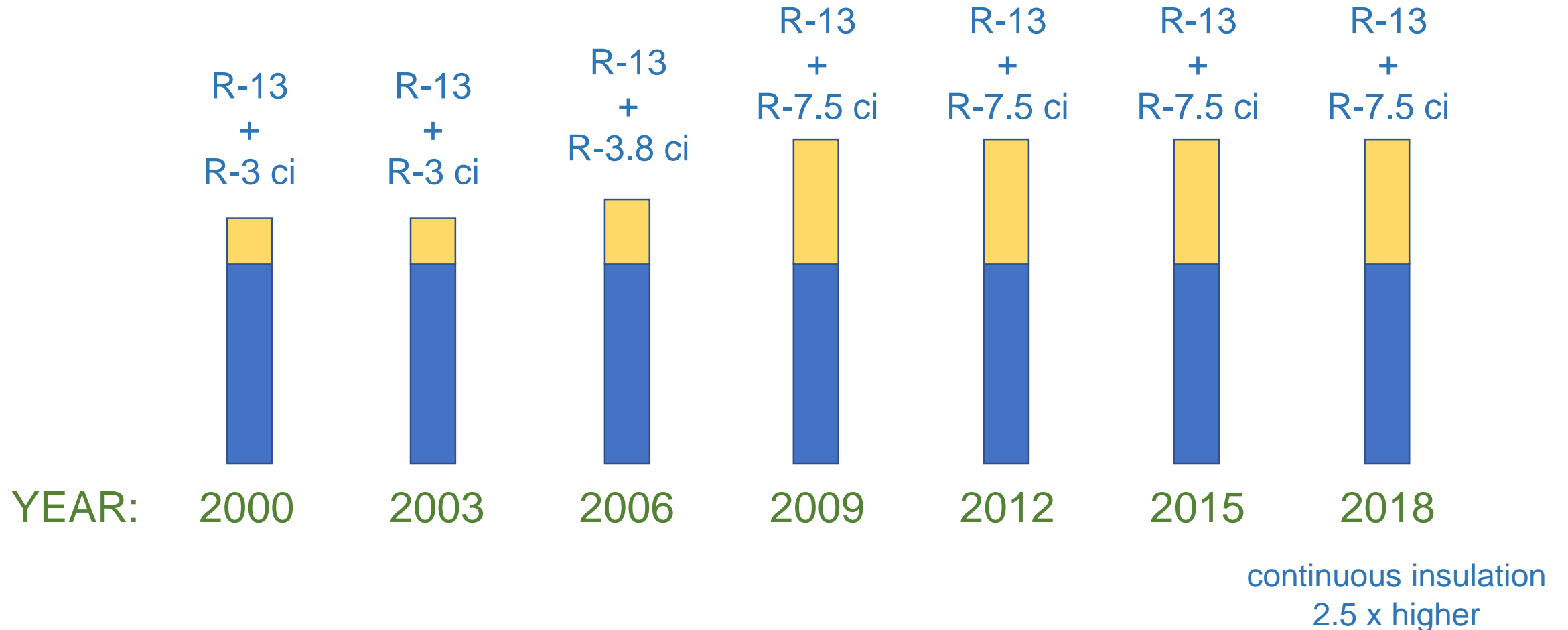
# Minimum R-values for opaque components

## ABOVE-GRADE MASS WALLS



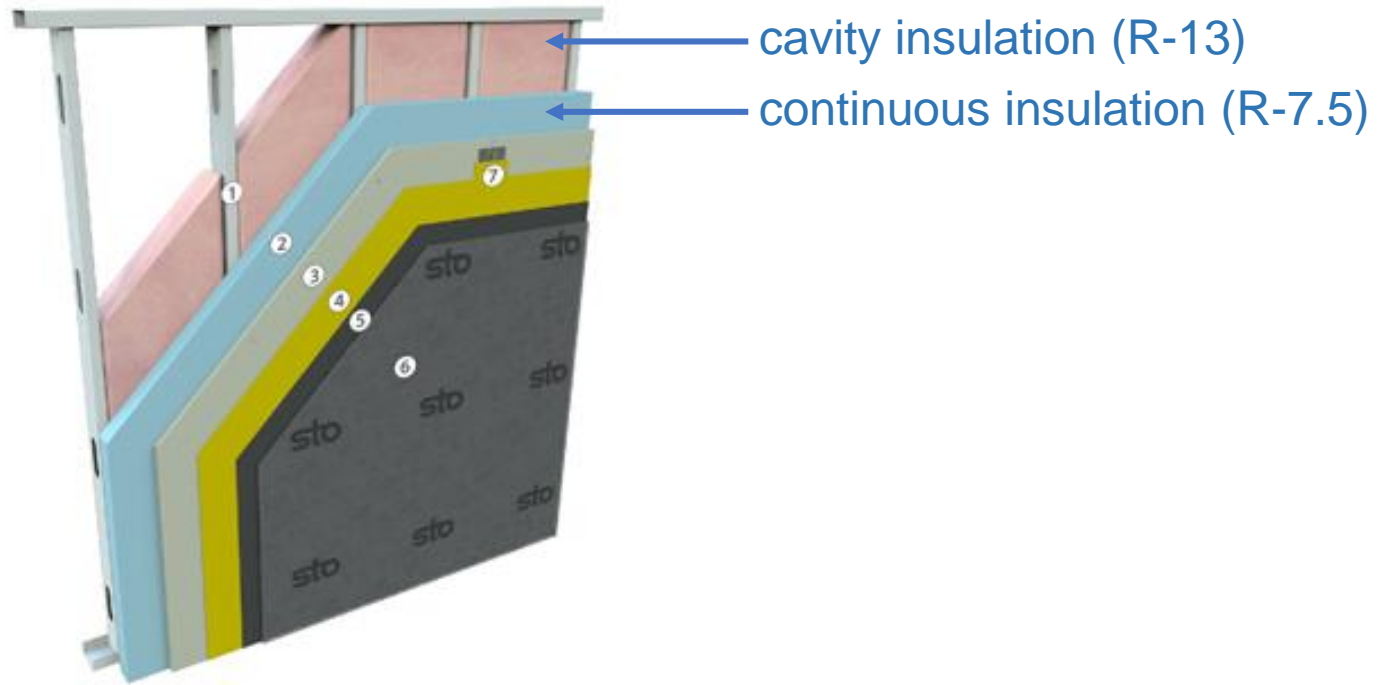
# Minimum R-values for opaque components

## ABOVE-GRADE METAL-FRAMED WALLS



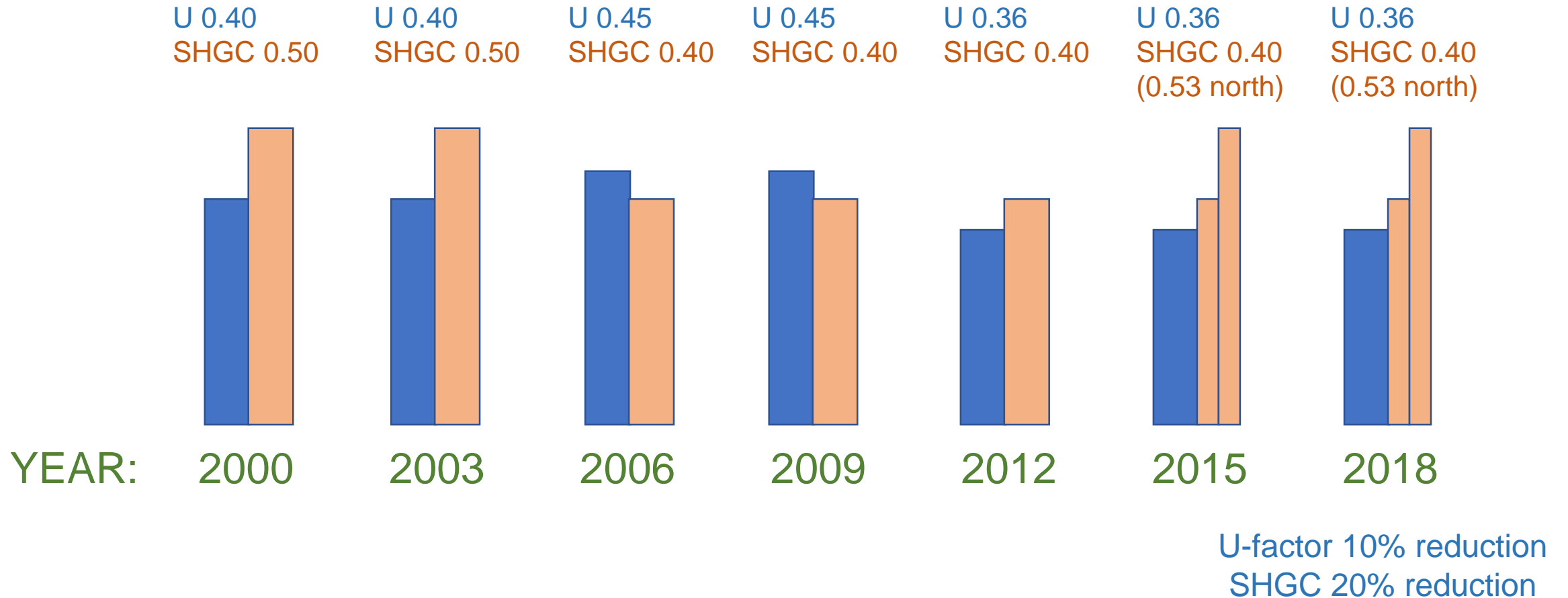
# Minimum R-values for opaque components

## ABOVE-GRADE METAL-FRAMED WALLS



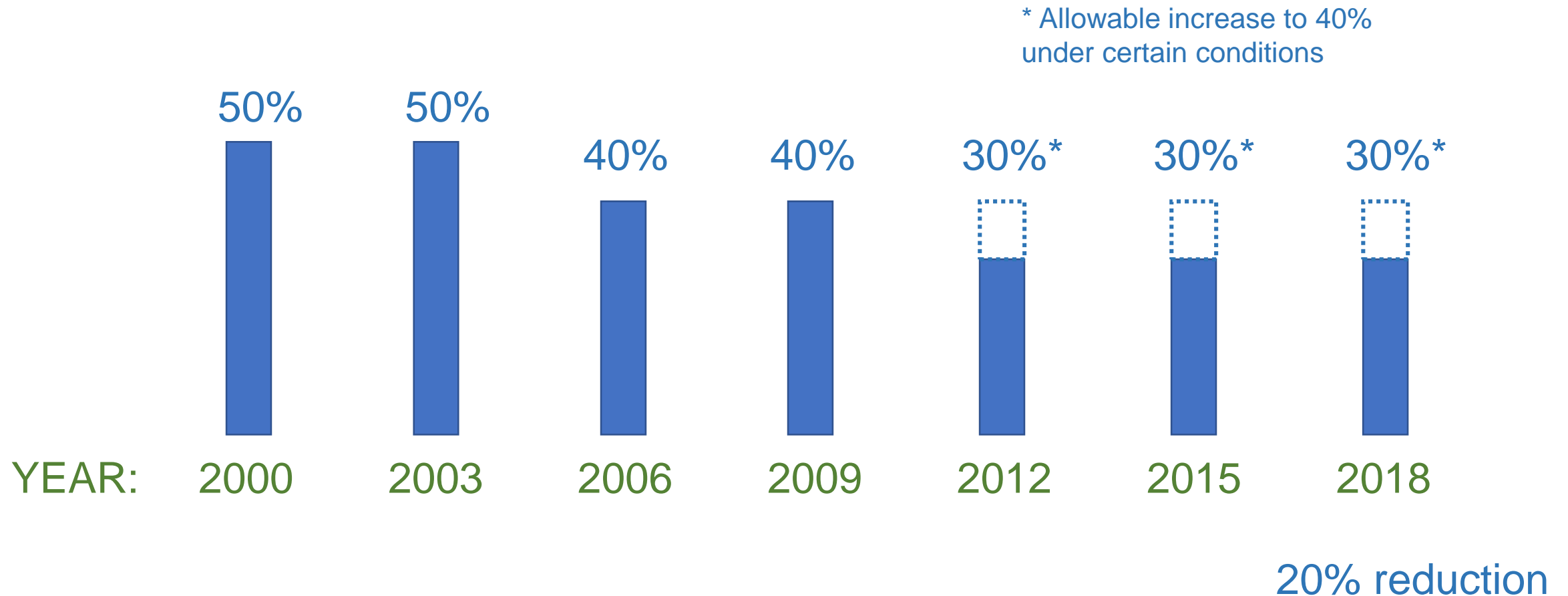
# Maximum U-factors & SHGC for fenestration

## VERTICAL GLAZING (FIXED)



# Maximum area (as % of total wall area)

## VERTICAL FENESTRATION



# THERMAL PERFORMANCE COMPARISON

OPAQUE MASS WALL: R-13 (min.)

FENESTRATION: U-0.36 (max.)

# THERMAL PERFORMANCE COMPARISON

OPAQUE MASS WALL: R-13 (min.)

U-factor equivalent = U-0.08 (max.)

FENESTRATION: U-0.36 (max.)

# IMPACTS OF ENERGY CODE ADOPTION IN U.S.

# IMPACTS OF ENERGY CODE ADOPTION IN U.S.

Between 2010 and 2016:

- Energy cost savings: \$5 billion
- CO<sub>2</sub> reduction: 30 million metric tons  
(equivalent to emissions from 6.3 million passenger vehicles driven for one year)

Data source: Pacific Northwest National Laboratory, "Impacts of Model Building Energy Codes," October 2016.

# IMPACTS OF ENERGY CODE ADOPTION IN U.S.

Between 2010 and 2040 (projected):

- Energy cost savings: \$126 billion
- CO<sub>2</sub> reduction: 840 million metric tons  
(equivalent to emissions from 177 million passenger vehicles driven for one year)

Data source: Pacific Northwest National Laboratory, "Impacts of Model Building Energy Codes," October 2016.

## ENERGY CODE

- window / wall ratios
- minimum levels of thermal performance

## ENERGY CODE →

- window / wall ratios
- minimum levels of thermal performance

## DESIGN →

- building massing / orientation
- passive-solar principles
- innovation in new materials
- innovation in new assemblies
- advanced simulation software

# ENERGY CODE COMPLIANCE

PRESCRIPTIVE  
APPROACH



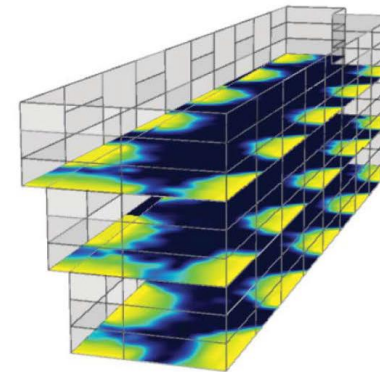
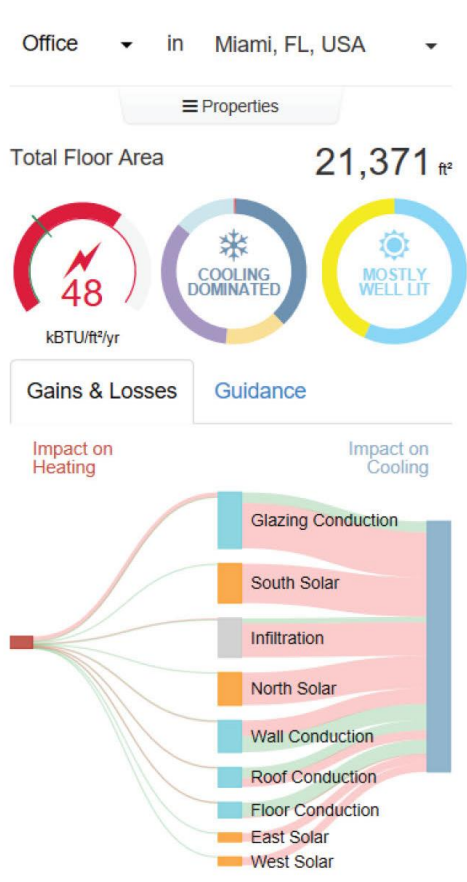
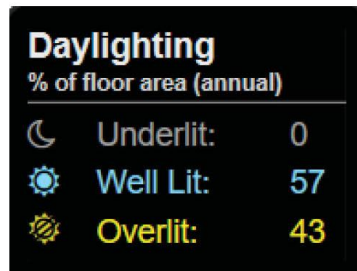
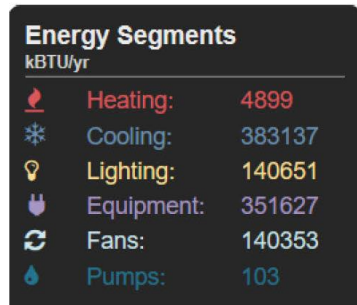
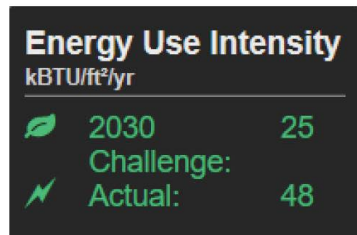
TRADE-OFF  
APPROACH



PERFORMANCE  
APPROACH

# ENERGY-ANALYSIS SOFTWARE

Formerly a “final check” ... now integrated into design process from beginning.



Percentage of occupied hours where illuminance is at least 28 footcandles, measured at 2.79 feet above the floor plate.

0% 25% 50% 75%

Annual Daylighting Visualization



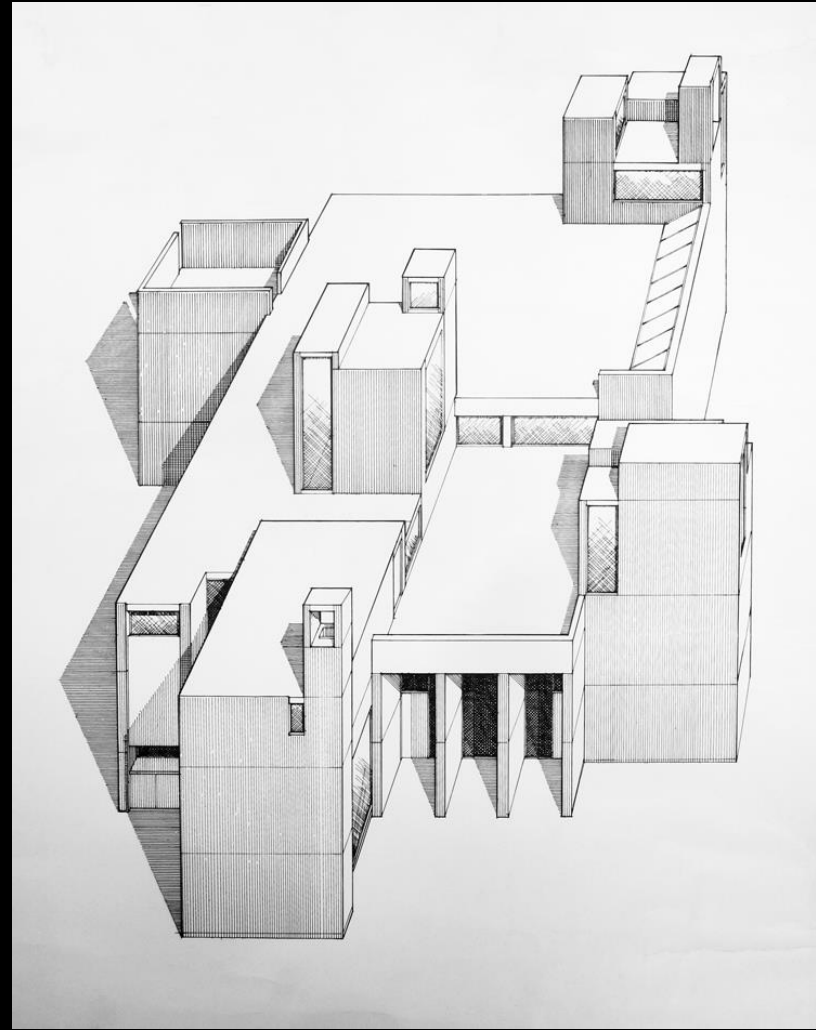
**Christian Science Building, Champaign, Illinois**  
Paul Rudolph, Architect  
built 1965, demolished 1986

Photo sources: Chicago History Museum (left), Myra Kaha (right)



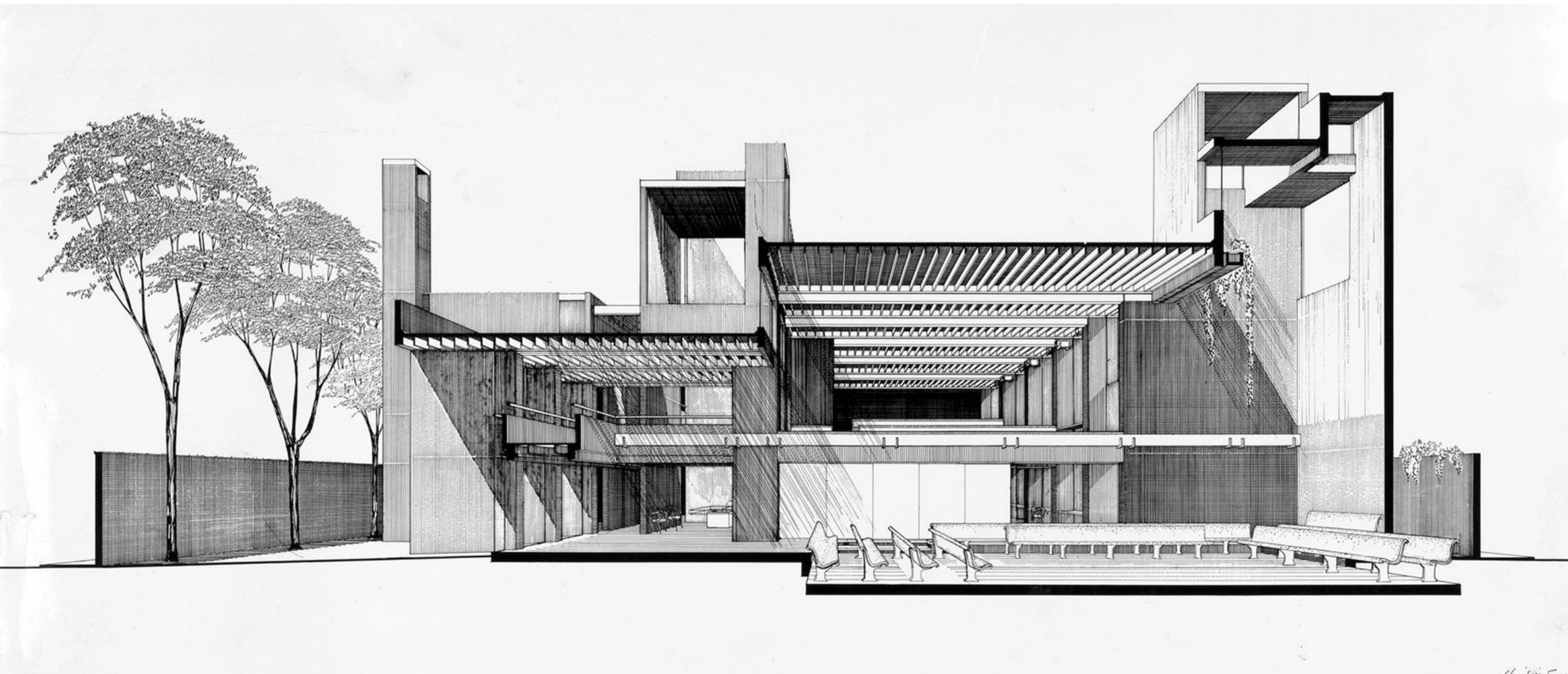
**Christian Science Building, Champaign, Illinois**  
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Photo source: Chicago History Museum



**Christian Science Building**  
Champaign, Illinois, 1965

Photo source: Chicago History Museum.  
Drawing from Paul Rudolph Archive, Library of Congress.



**Christian Science Building**  
Champaign, Illinois, 1965

Drawing from Paul Rudolph Archive, Library of Congress.

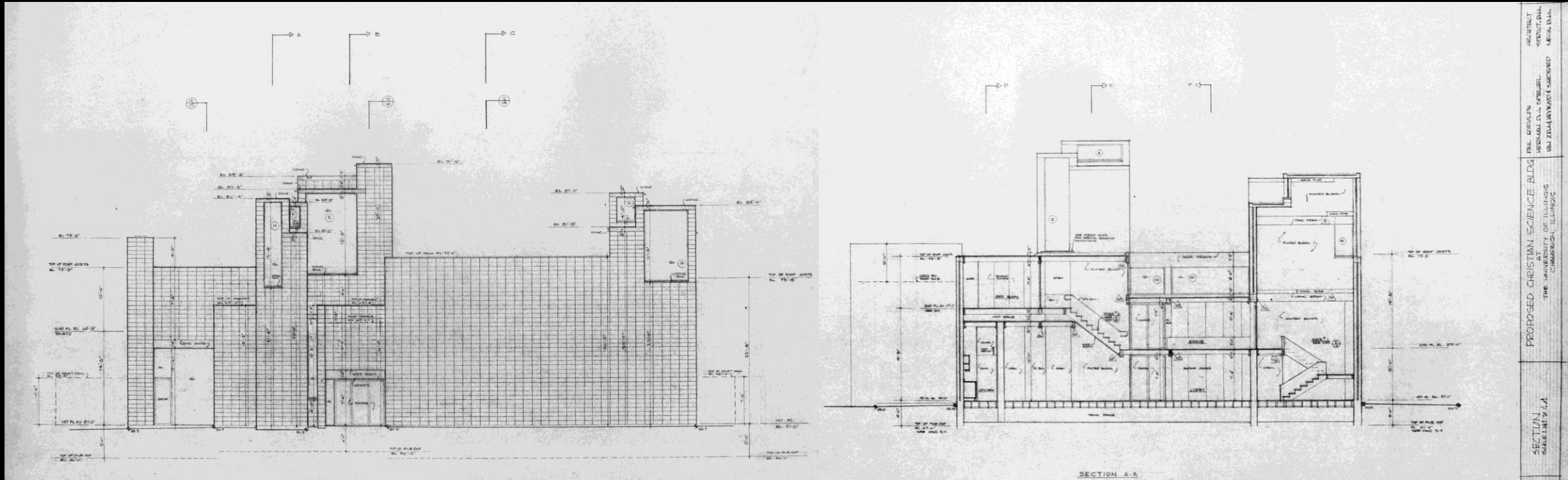


**Christian Science Building**  
Champaign, Illinois, 1965

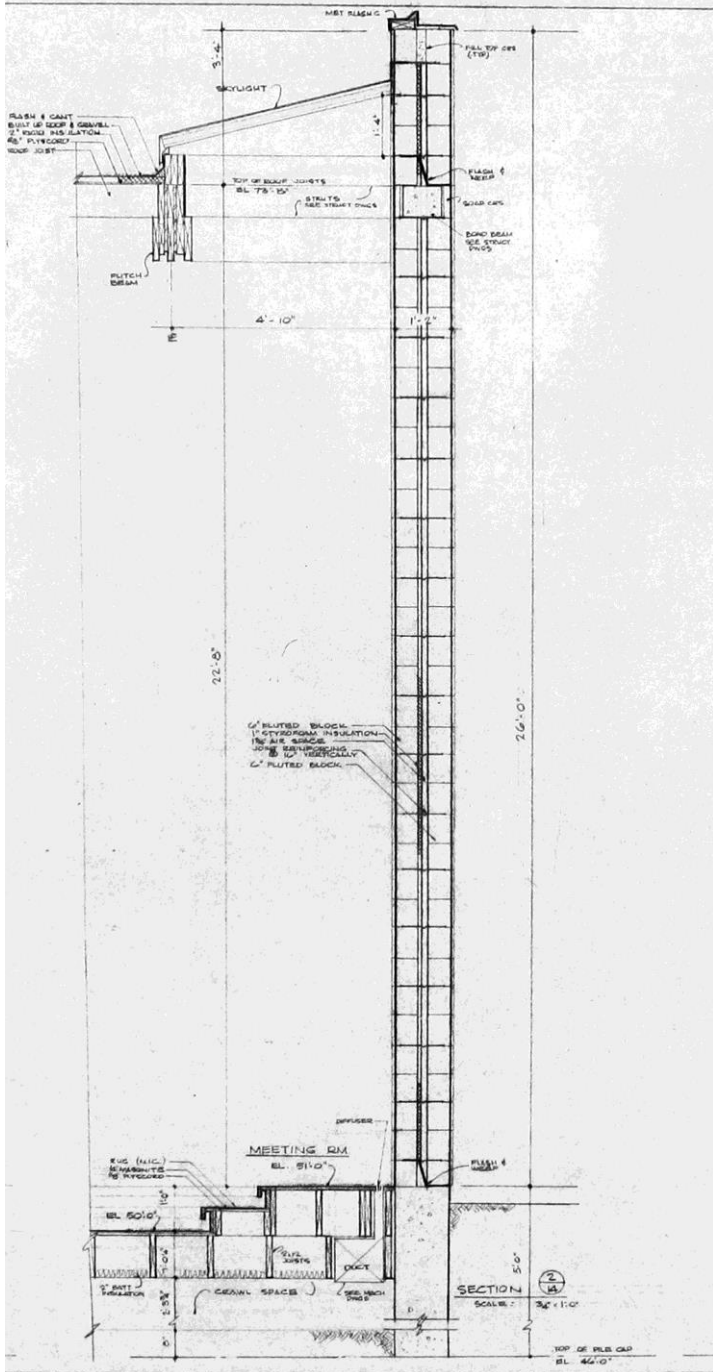


**Demolition, 1986**





Construction Drawing Sets at the Paul Rudolph Archive, Library of Congress.

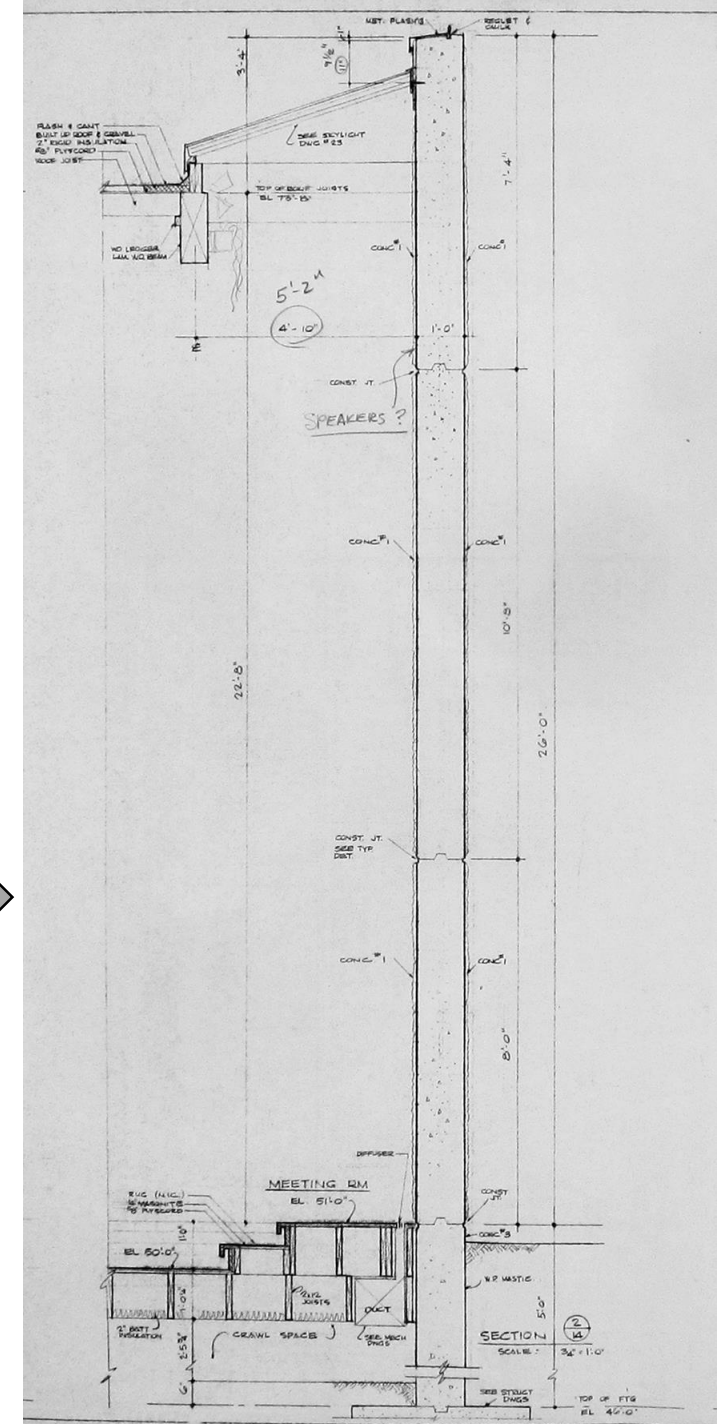


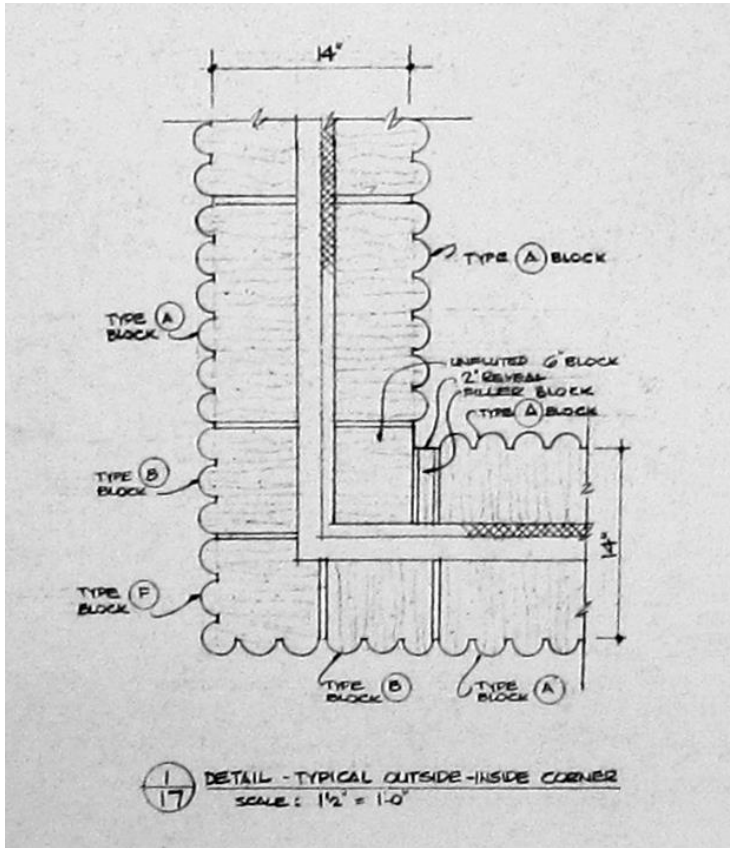
## WALL SECTION DRAWINGS

← **original design:** cavity wall with custom fluted CMU and insulation. Dated June 5, 1964.

**revised design:** monolithic CIP reinforced concrete without insulation. → Dated Nov. 11, 1964.

Drawings from Paul Rudolph Archive, Library of Congress.



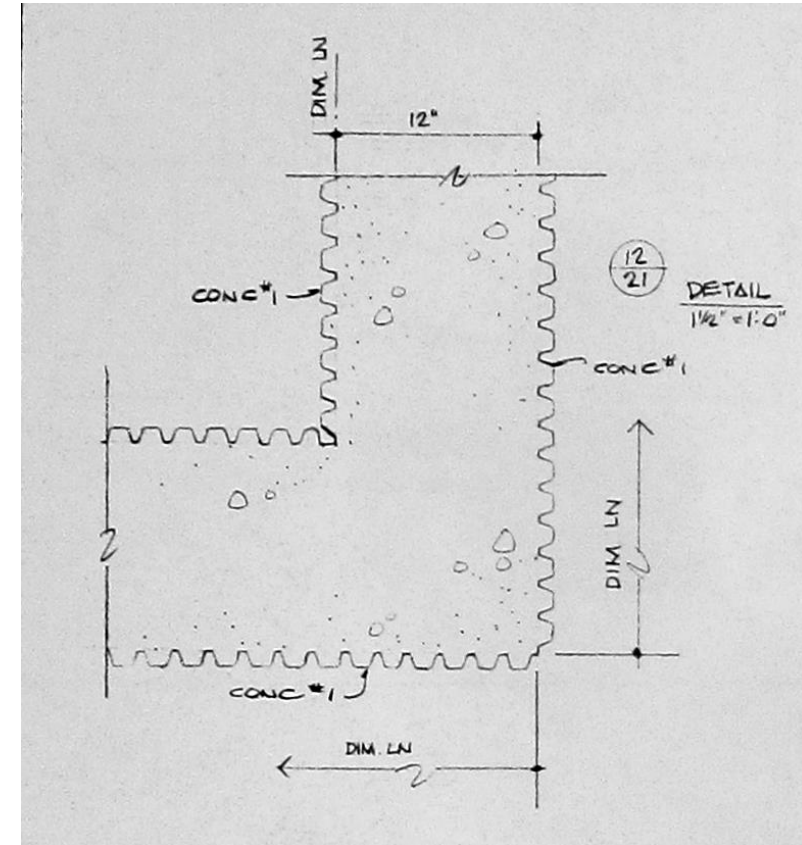


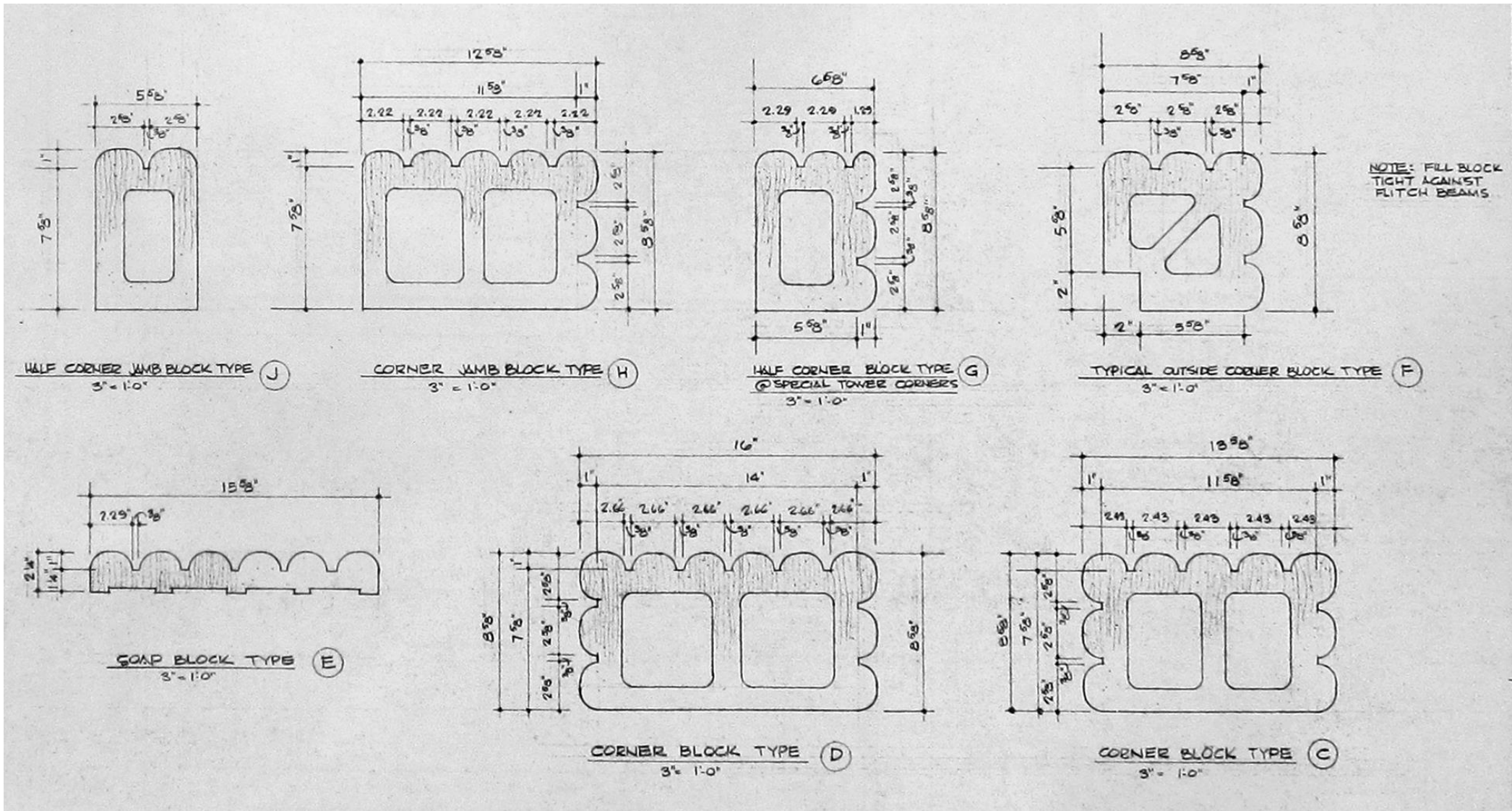
## CORNER PLAN DETAILS

← original design: cavity wall with custom fluted CMU and insulation

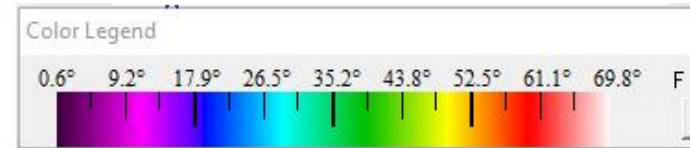
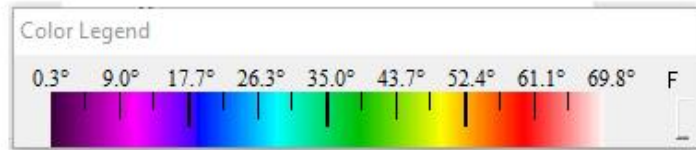
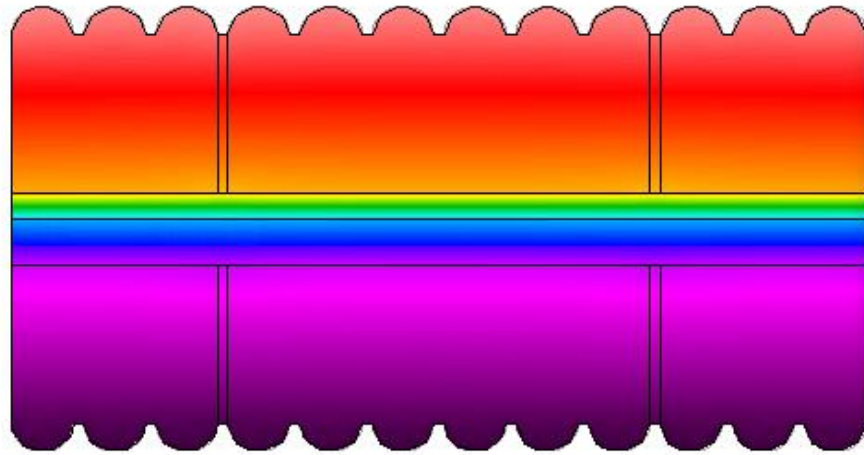
revised design: monolithic CIP reinforced concrete without insulation →

Drawings from Paul Rudolph Archive, Library of Congress.





CMU block types from initial drawing set by Paul Rudolph Architect;  
 Drawings from Paul Rudolph Archive, Library of Congress.



## THERMAL ANALYSIS

Thermal analysis demonstrates temperature gradients based on 70° F interior and 0° F exterior conditions in winter for the original design of cavity wall with custom fluted CMU and insulation (left) vs. revised design of monolithic cast-in-place reinforced concrete (right).



**Christian Science Building, Champaign, Illinois**  
Paul Rudolph, Architect  
built 1965, demolished 1986

Photo sources: Chicago History Museum (left), Myra Kaha (right)







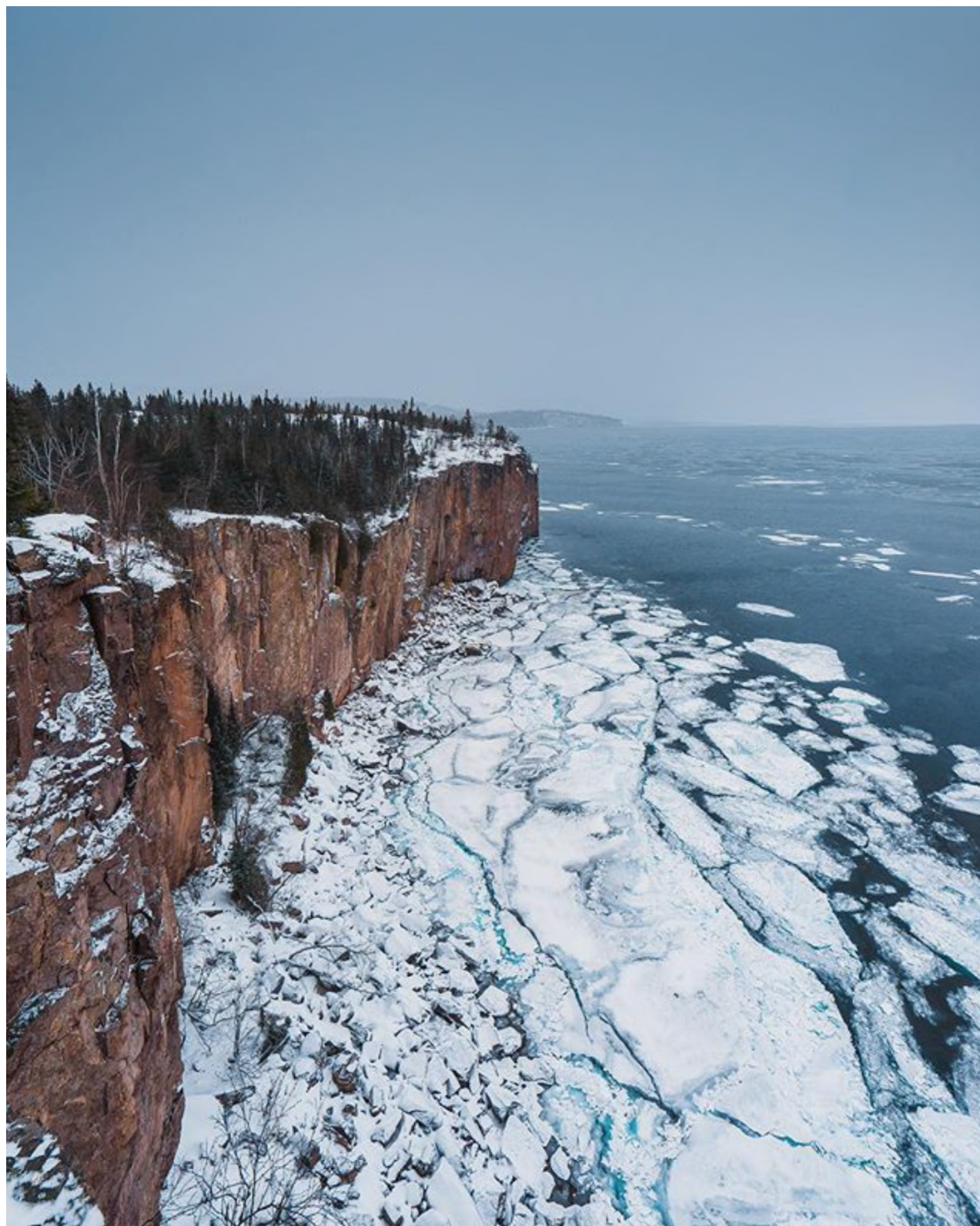






INVISIBLE

**SUSTAINABILITY**



“ HOW MUCH DOES YOUR BUILDING WEIGH ? ”

- *R. Buckminster Fuller*

94%

pEUI AIA 2030 Signatory



[www.coulson.co](http://www.coulson.co)

**Carly Coulson**, AIA, LEED AP, CPHD



**CONSERVATION-FIRST**

# CONSERVATION-FIRST



reduce exterior surface area

winter passive solar

summer shading

super-insulation

air tight enclosure

heat recovery ventilation

# CONSERVATION-FIRST



**NO  
HEAT  
COOL**

**reduce exterior surface area**

**winter passive solar**

**summer shading**

**super-insulation**

**air tight enclosure**

**heat recovery ventilation**

**80 - 100 %**

**heating**

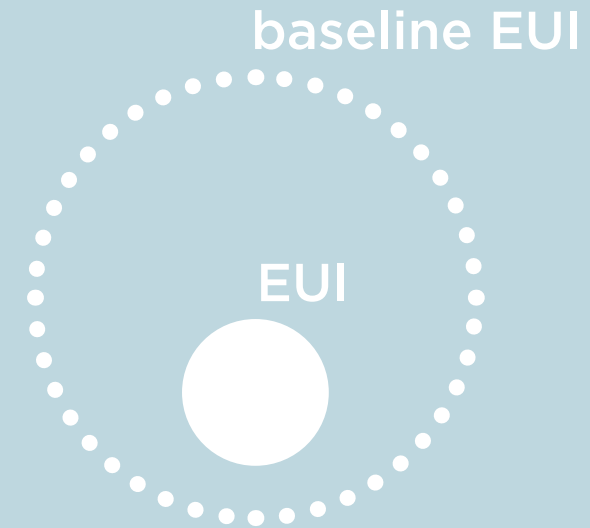
**cooling**

**reduction**

# CONSERVATION-FIRST



**NO  
HEAT  
COOL**



**reduce exterior surface area**

**winter passive solar**

**summer shading**

**super-insulation**

**air tight enclosure**

**heat recovery ventilation**

**80 - 100 %**

**heating**

**cooling**

**reduction**

**70 - 80 %**

**primary**

**energy**

**reduction**

**before any renewables**

# CONSERVATION-FIRST



**NO  
HEAT  
COOL**



**2030**

reduce exterior surface area

winter passive solar

summer shading

super-insulation

air tight enclosure

heat recovery ventilation

**80 - 100 %**

heating

cooling

reduction

**70 - 80 %**

primary

energy

reduction

before any renewables





90%

pEUI  
No PV

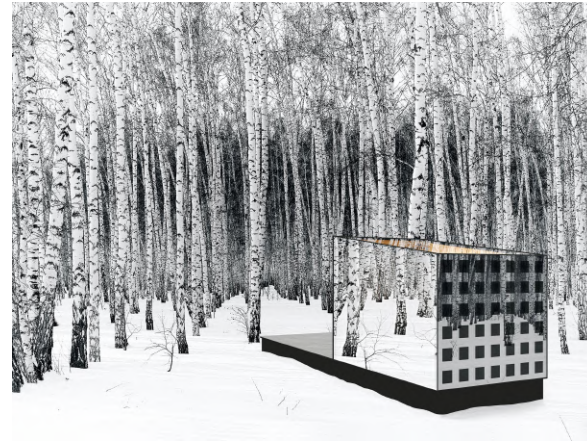
# MH HOUSE

Duluth, MN

2430 sf

2000 watt peak  
heat load





86%  
pEUI  
Before  
PV



DISAPPEAR  
RETREAT  
Grand Marais, MN



83 sf  
100 watt peak  
heat load





81%  
pEUI  
Before  
PV



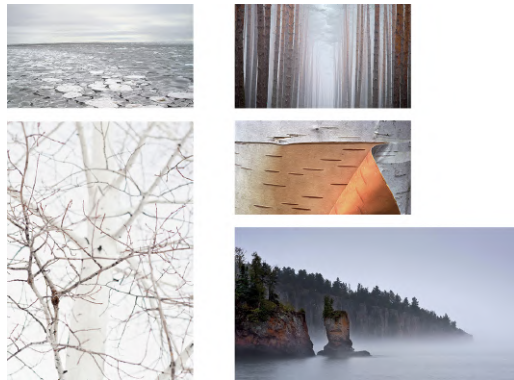
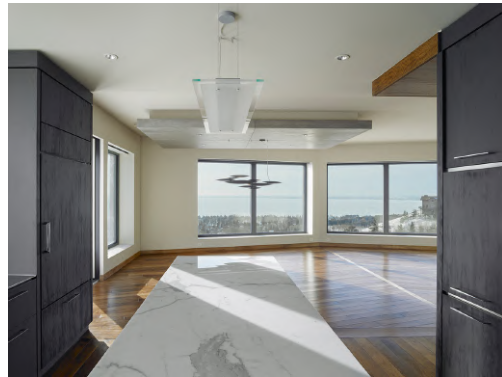
BAGLEY  
CLASSROOM  
Duluth, MN



1550 sf

3000 watt peak  
heat load





82%

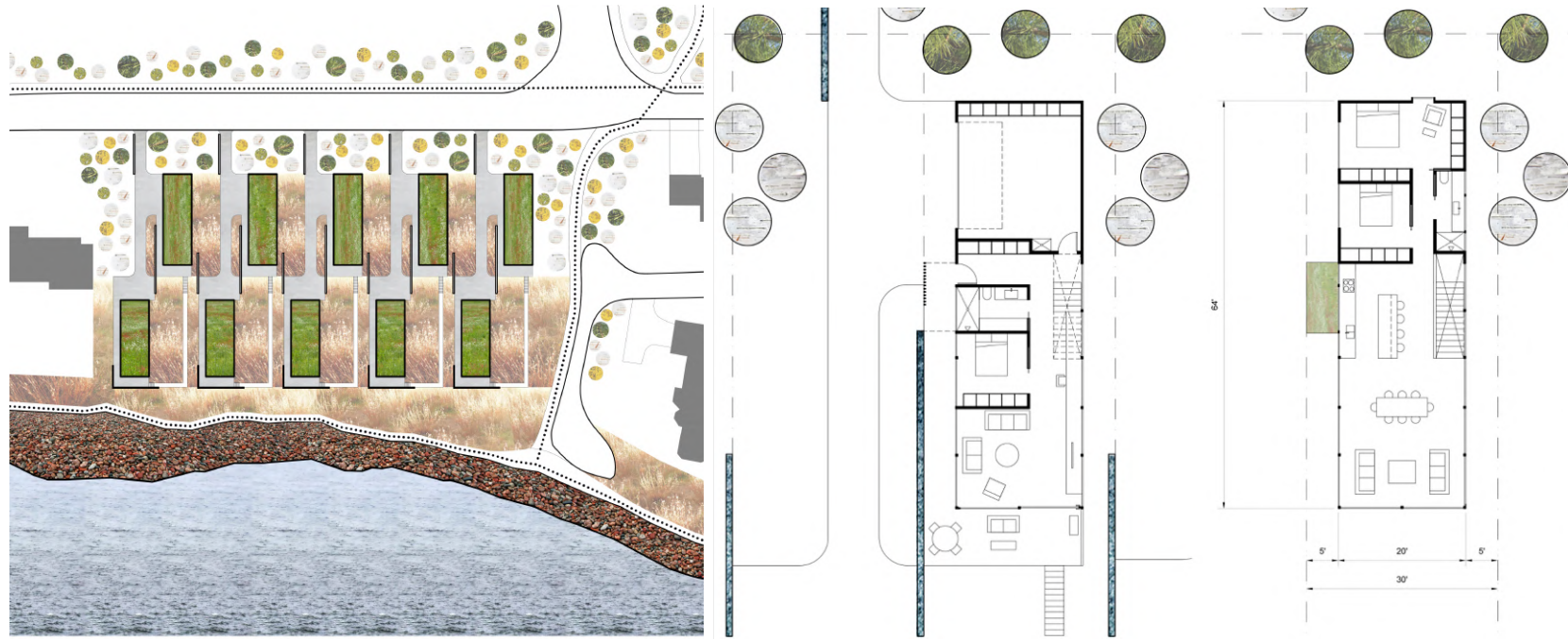
pEUI  
No PV

PAYS D'EN HAUT  
RENOVATION  
Duluth, MN

2500 sf

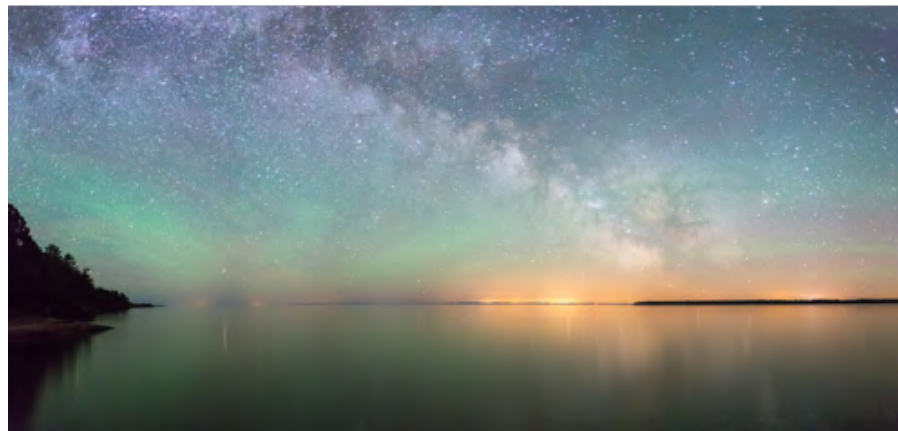
4300 watt peak  
heat load





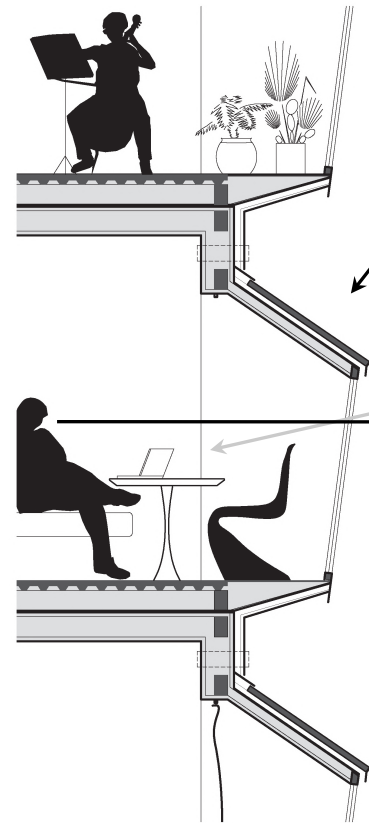
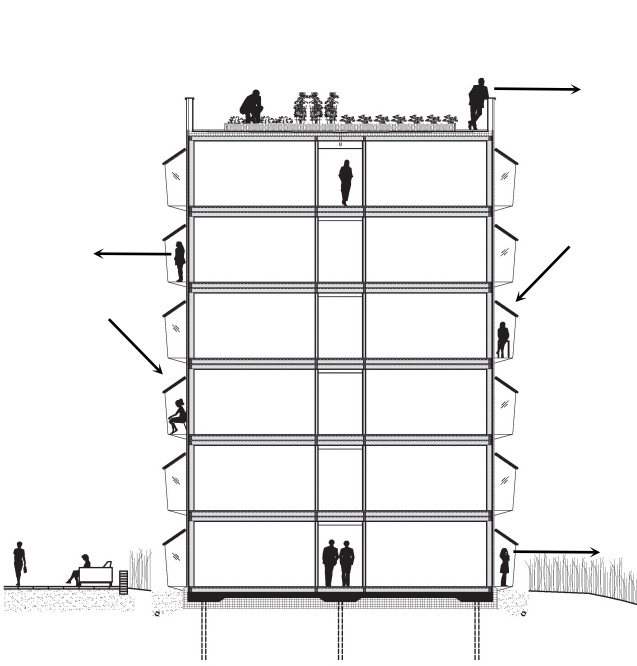
79%  
pEUI  
No PV

WATER  
RESIDENCES  
Duluth, MN



2130 sf home  
1400 watt peak  
heat load





active solar photovoltaic panel

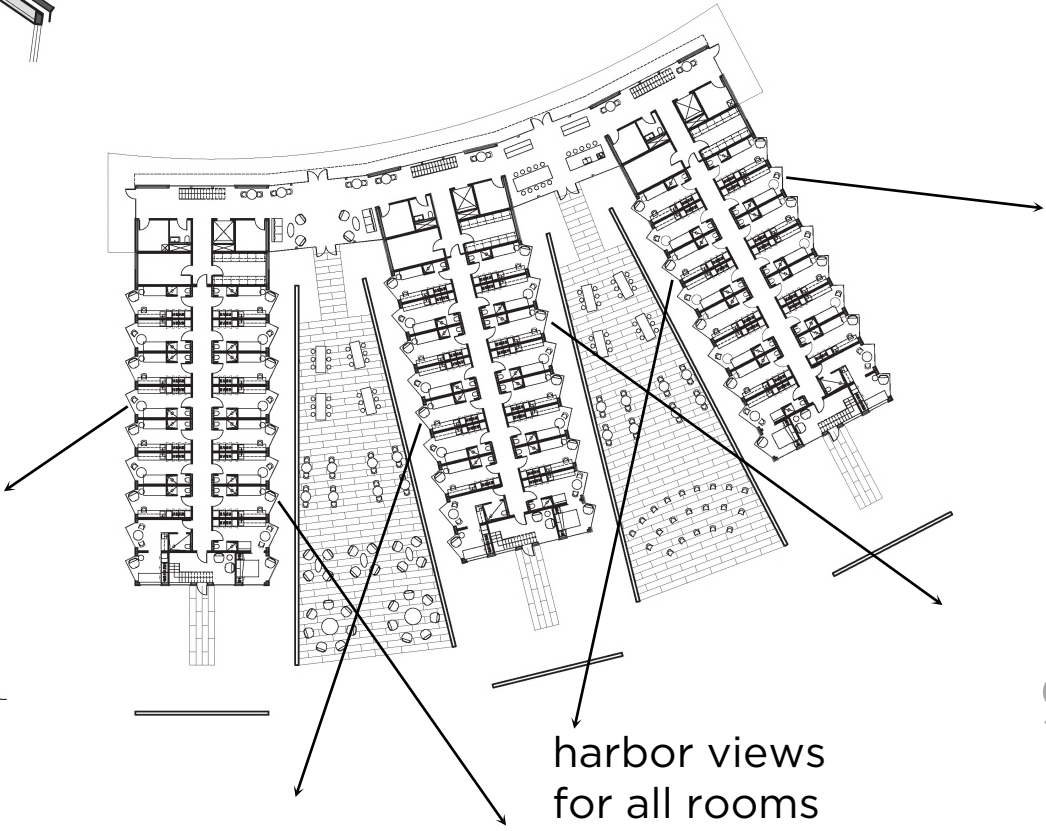
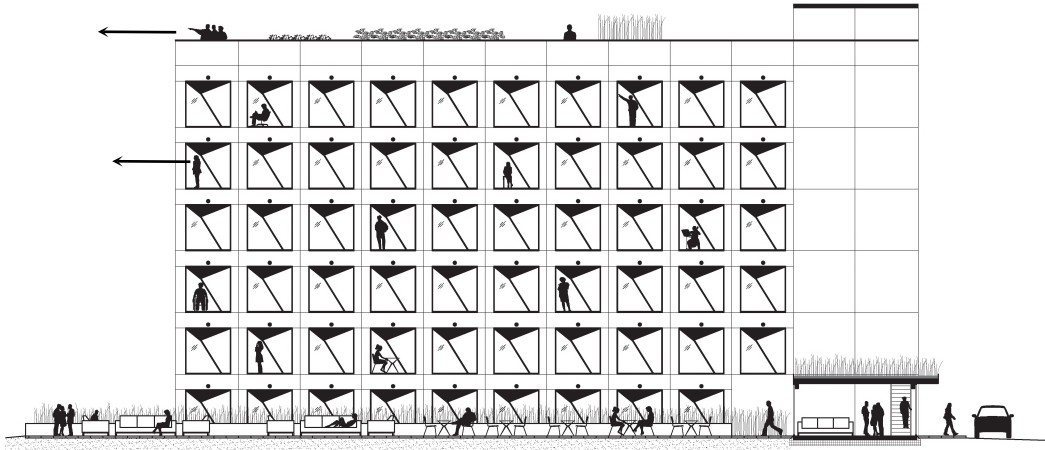
winter passive solar

harbor views

# 100%

pEUI  
With PV

LSC  
STUDENT  
HOUSING  
Duluth, MN



harbor views for all rooms

320 units

98000 sf

90 watts peak  
heat load/rm

# ADVANCED ENERGY MODELING





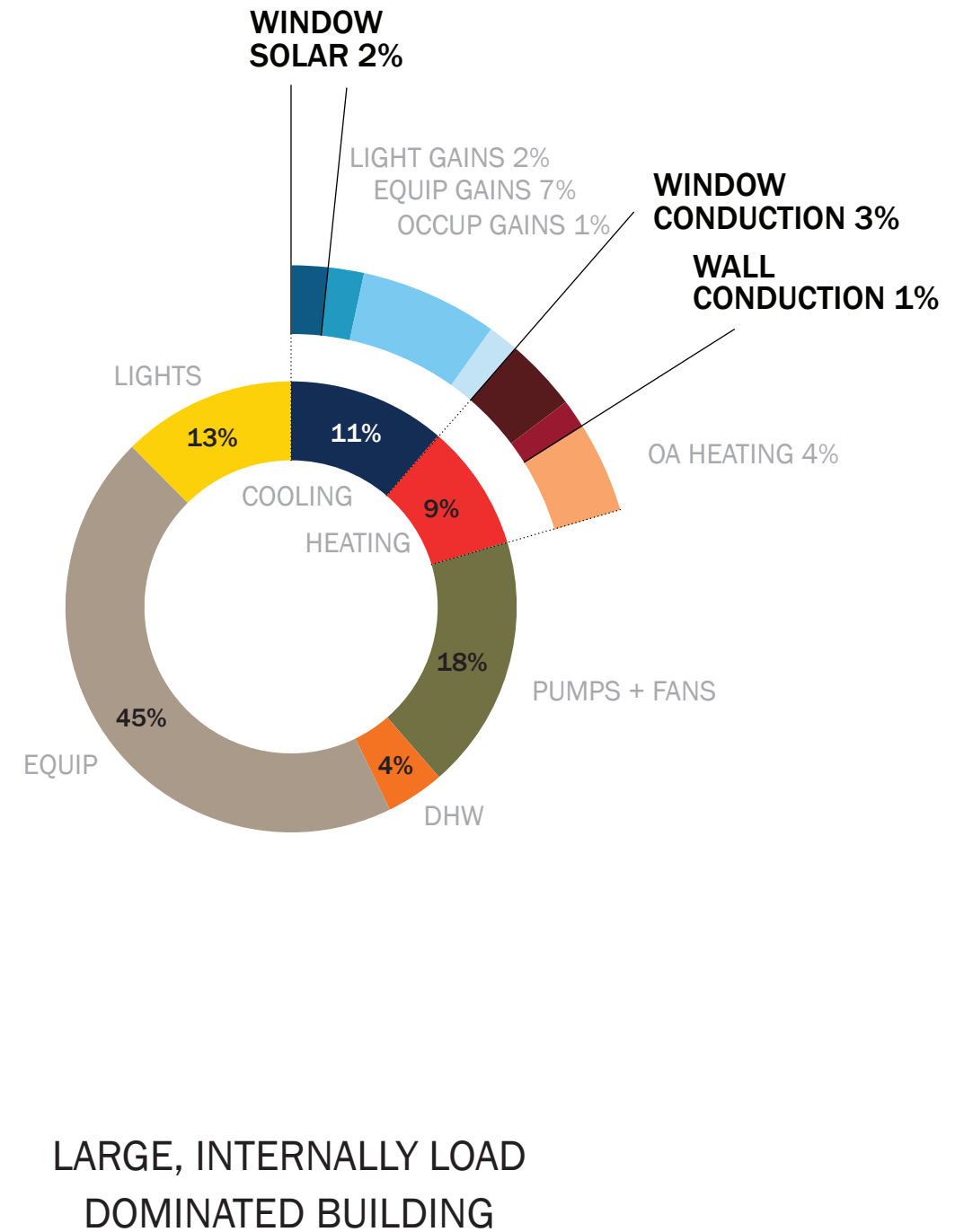
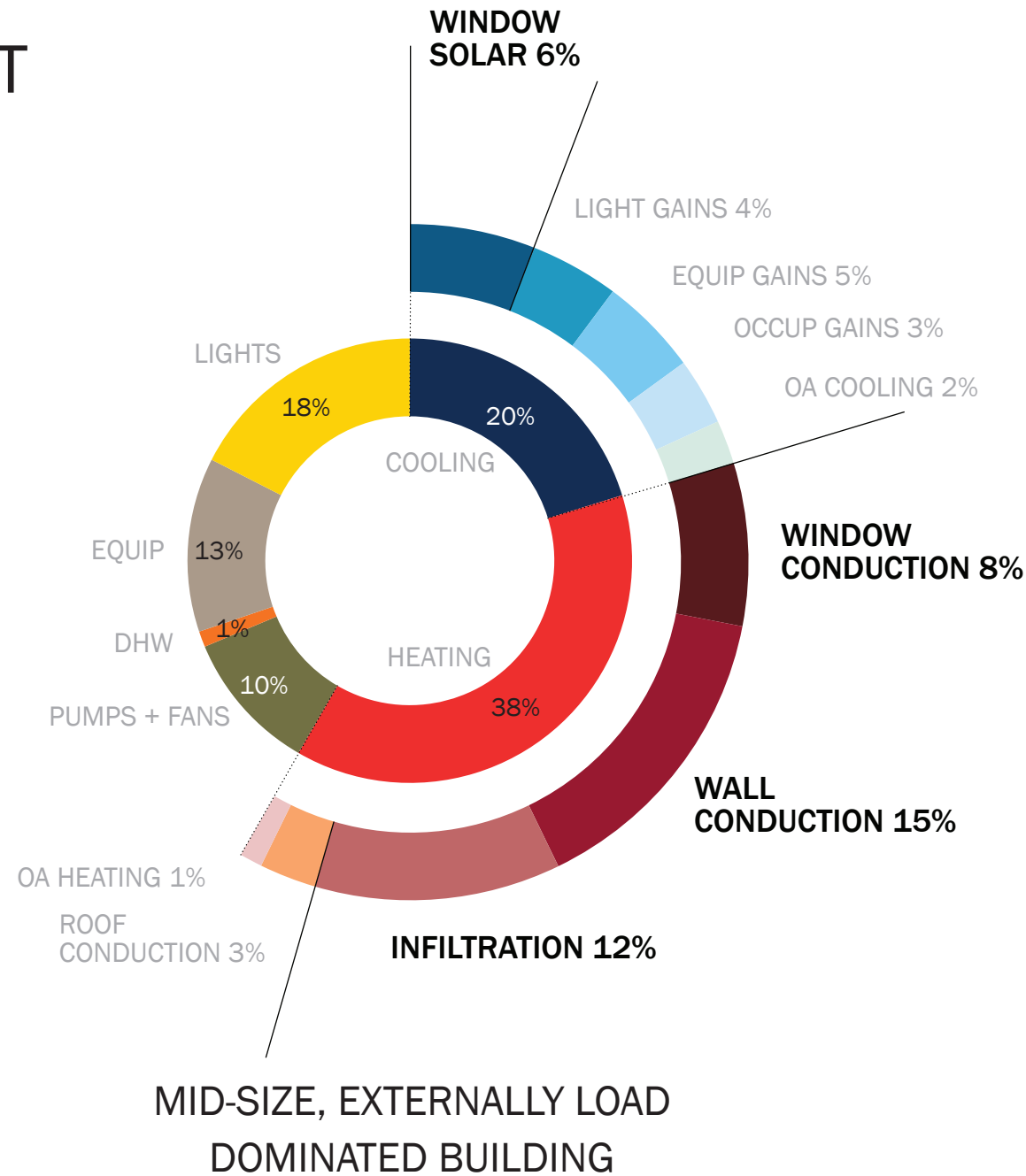


# DEFINING THE ROLE OF THE FACADE

FACADE TECTONICS, MINNEAPOLIS 2019

# PUTTING THE FACADE IN CONTEXT

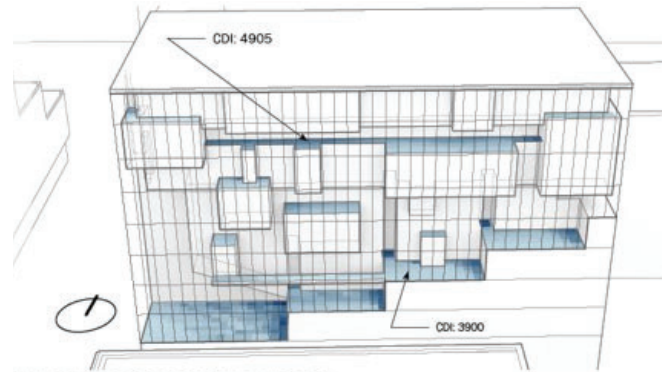
THE IMPACT OF FACADE PERFORMANCE ON OVERALL ENERGY CONSUMPTION VARIES BY BUILDING TYPE.



# WHAT ROLES CAN THE FACADE PLAY?

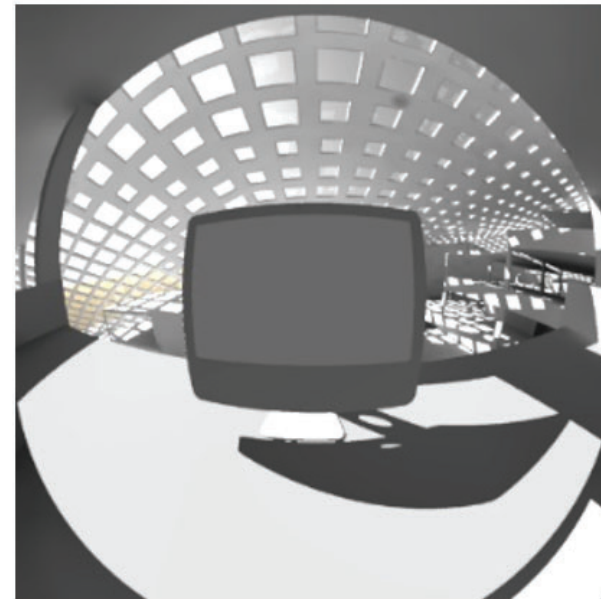


HEAT DISCOMFORT

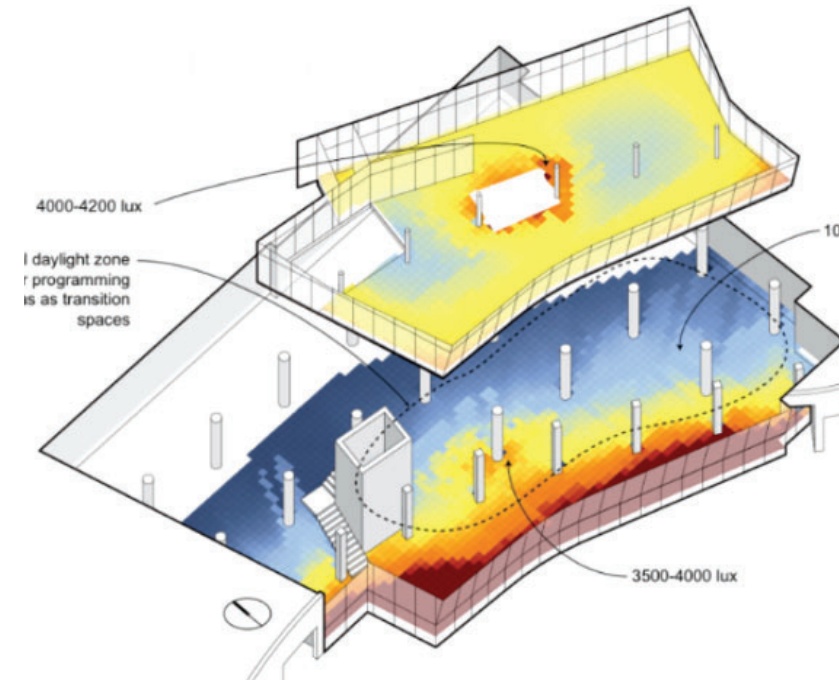


COLD DISCOMFORT

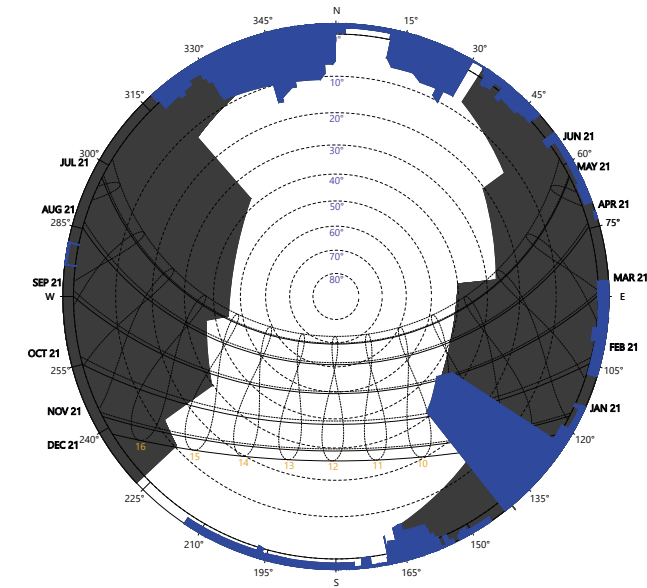
THERMAL COMFORT



VISUAL COMFORT



OCCUPANT WELL-BEING:  
DAYLIGHT + VIEWS



RESPONSE TO CONTEXT

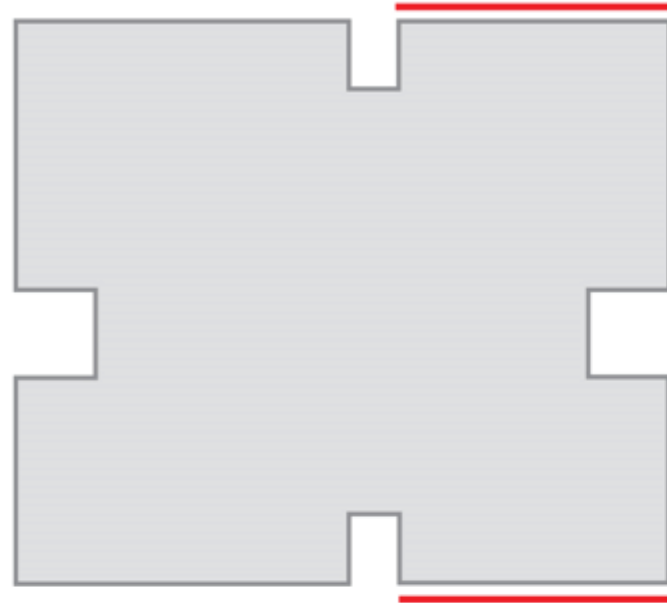
# COLUMBIA MANHATTANVILLE JEROME L. GREENE SCIENCE CENTER

ARCHITECT: RENZO PIANO BUILDING WORKSHOP  
MEP ENGINEER: JAROS, BAUM, & BOLLES  
FACADE: IBA, ENCLOS  
SUSTAINABILITY: ATELIER TEN

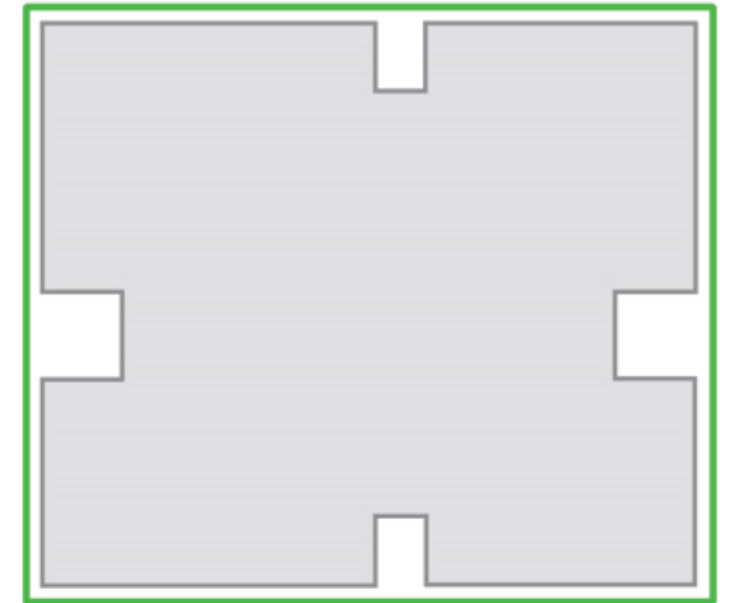
PROJECT TYPE: HIGHER EDUCATION / LAB  
SIZE: 450,000 SF



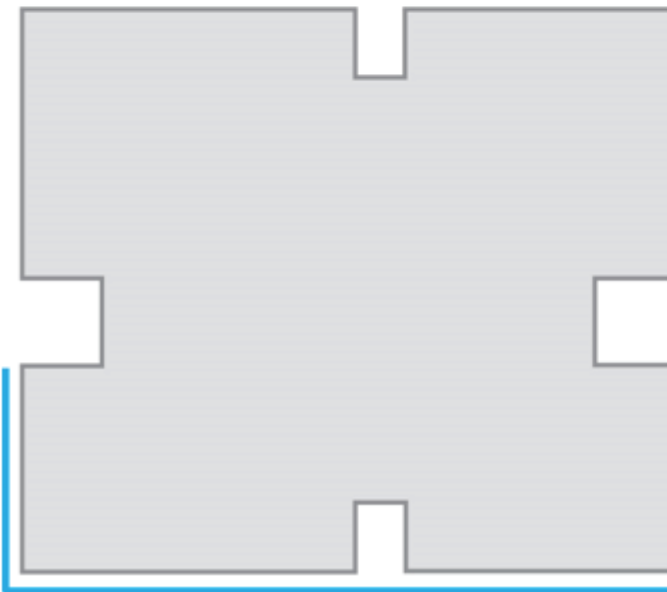
noise & context



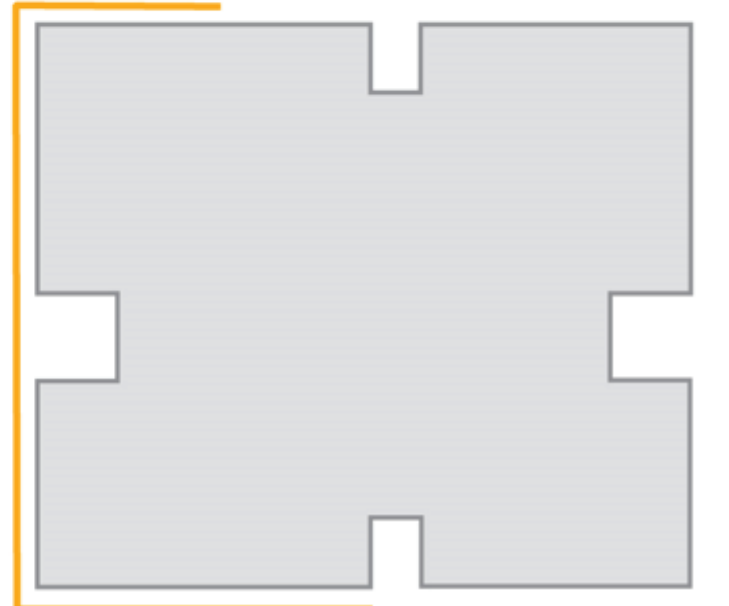
daylight & heat loss



solar gains



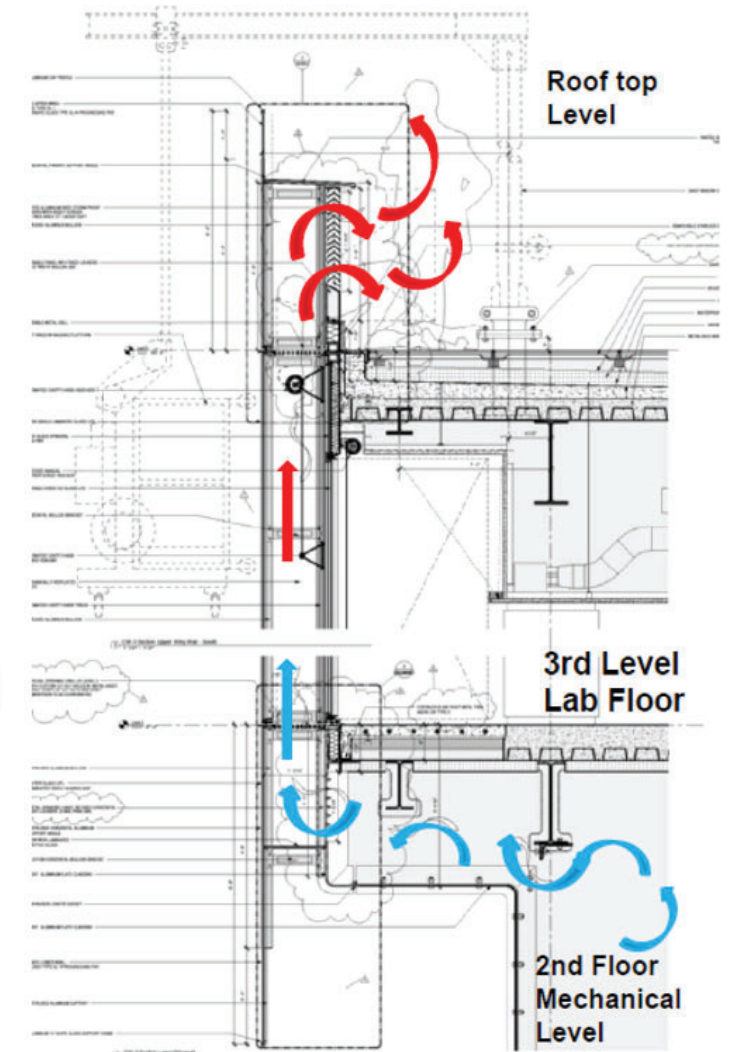
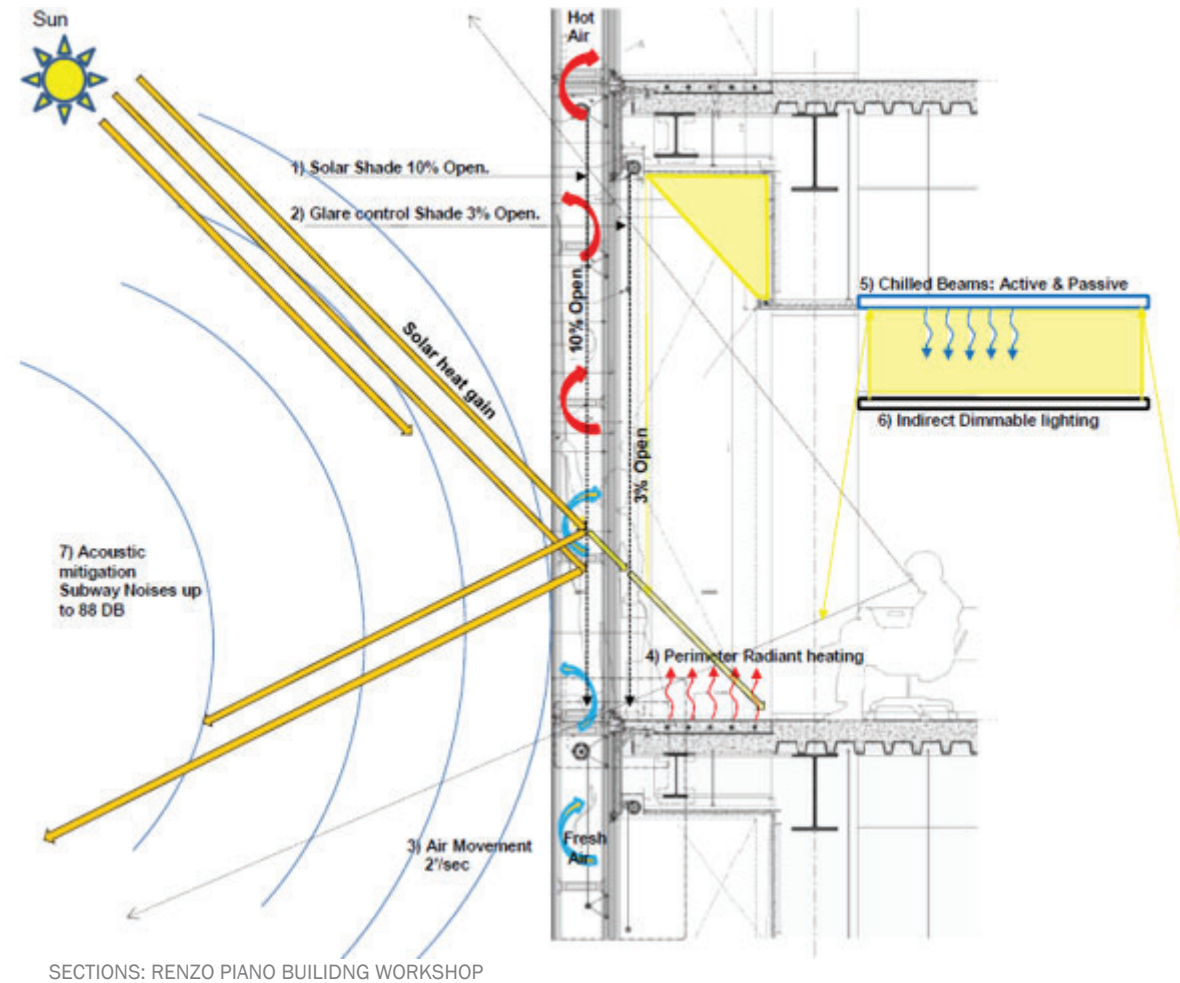
views to garden



# ENERGY OPTIMIZATION

COLUMBIA MANHATTANVILLE JEROME L. GREENE

- MECHANICAL VENTILATION EXHAUST FEEDS INTO A DOUBLE-SKIN FAÇADE TO CONDITION THE SURFACE AND SHED EXCESS HEAT THROUGH AIRFLOW
- SOLAR GAINS ARE MINIMIZED THROUGH SHADES IN THE DOUBLE SKIN FAÇADE

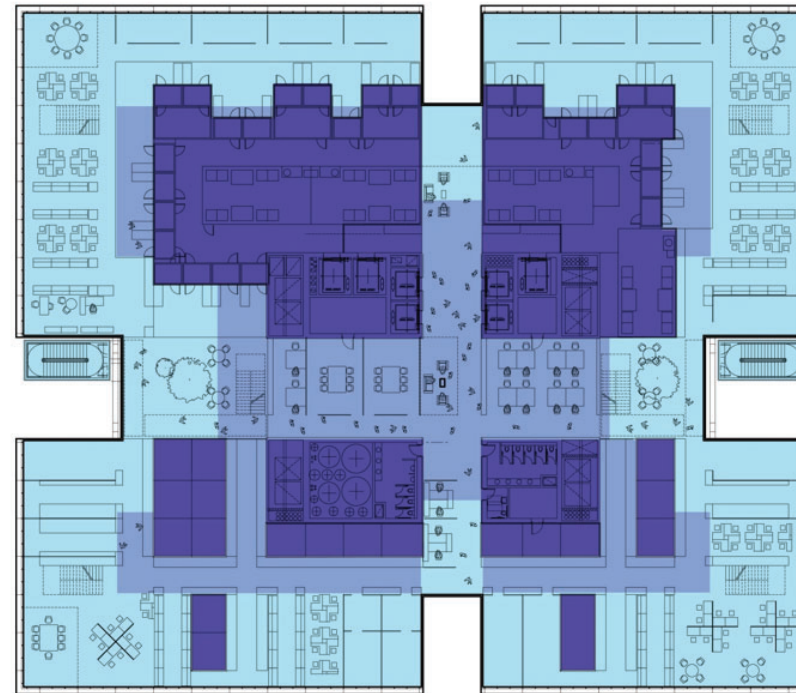


# HUMAN WELL-BEING

COLUMBIA MANHATTANVILLE JEROME L. GREENE



NOISE REDUCTION



DAYLIT SPACE



PROGRAM BENEFITS FROM DAYLIGHT, BUT SPACE WILL NOT BE DAYLIT



PROGRAM DOES NOT REQUIRE DAYLIGHT

DAYLIGHT



VIEWS

# PRINCETON UNIVERSITY RESIDENTIAL COLLEGES

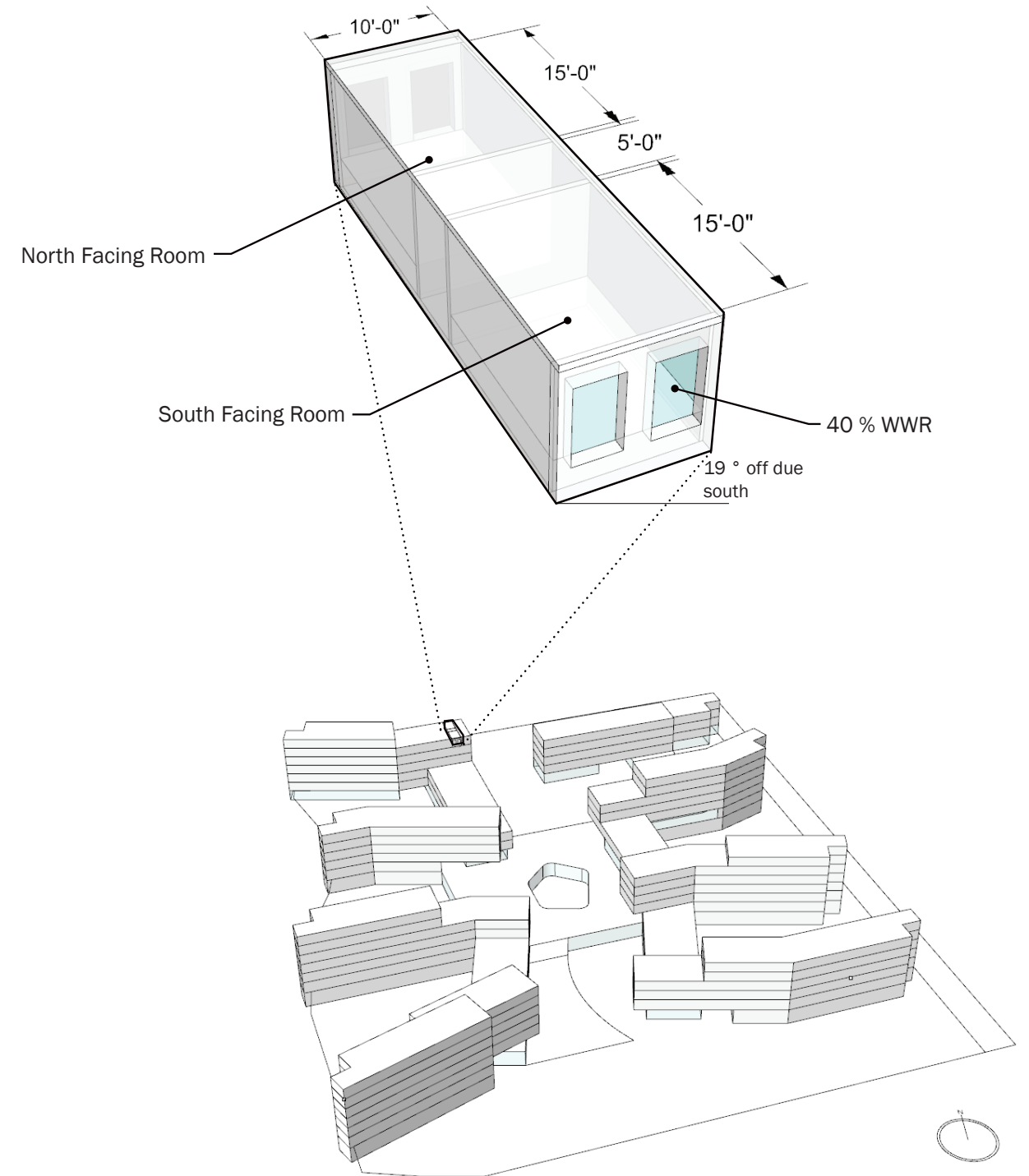
ARCHITECT: DEBORAH BERKE PARTNERS  
MEP ENGINEER: ADS ENGINEERS  
SUSTAINABILITY: ATELIER TEN

PROJECT TYPE: RESIDENTIAL / ACADEMIC  
SIZE: 550,000 SF

- 01 ORIENTATION
- 02 WINDOW-TO-WALL RATIO
- 03 DAYLIGHT
- 04 SHADING/CUTOFF ANGLE
- 05 AIRFLOW



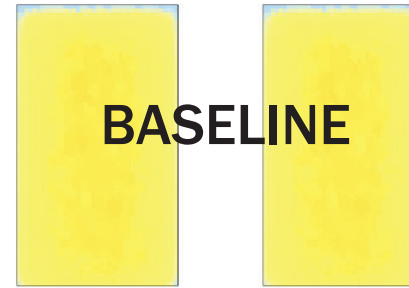
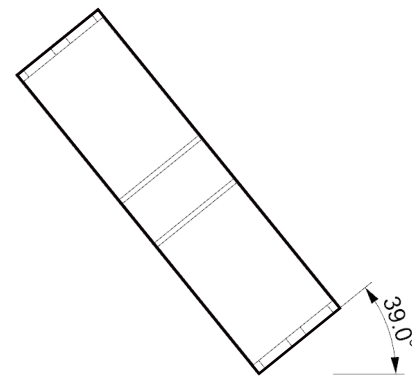
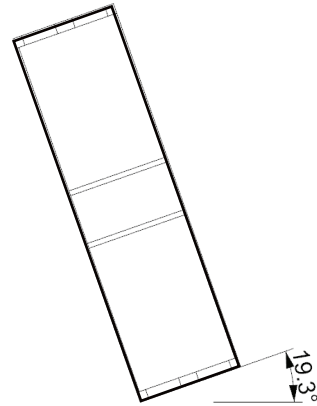
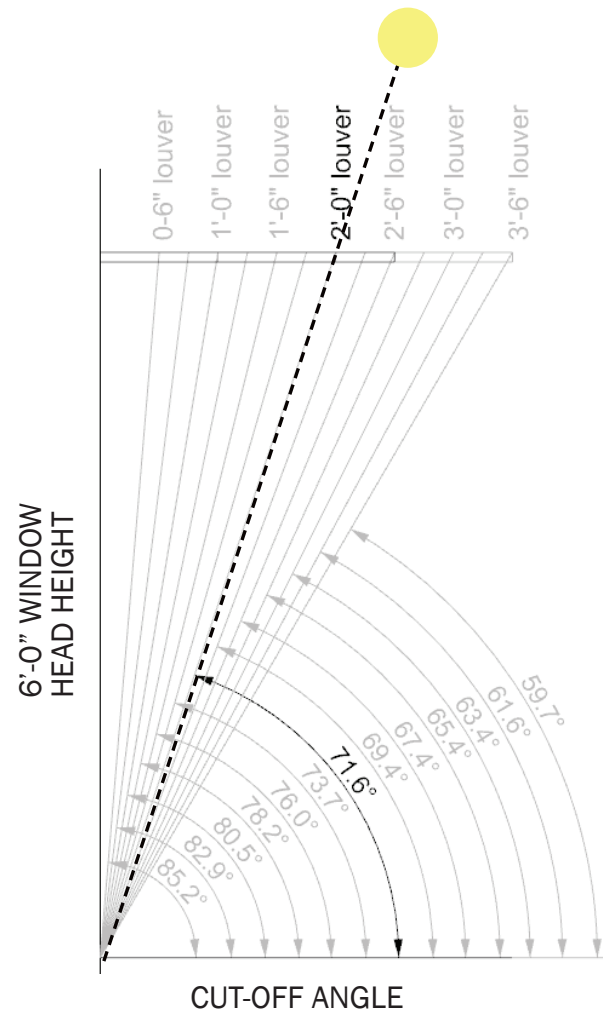
RENDERING: DEBORAH BERKE PARTNERS



# ORIENTATION / CUT-OFF ANGLE

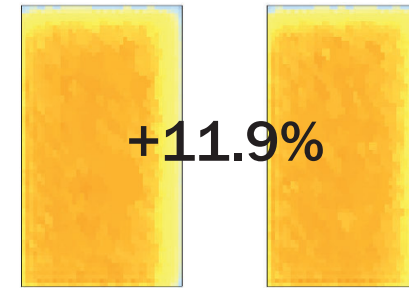
PRINCETON UNIVERSITY RESIDENTIAL COLLEGES

CUT-OFF ANGLES EXPLAINED:



**BASELINE**

NORTH FACADE - 0°  
775,163 KWH



**+11.9%**

NORTH FACADE - 19°  
867,140 KWH



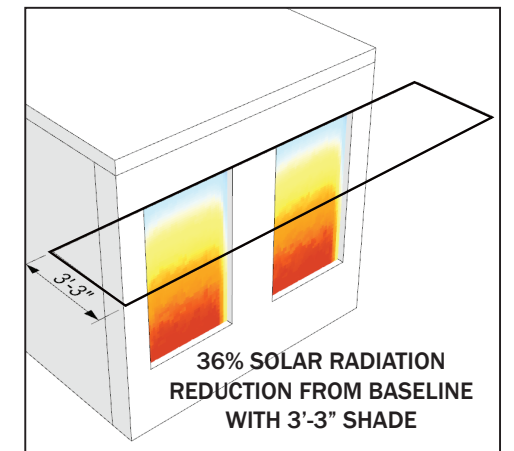
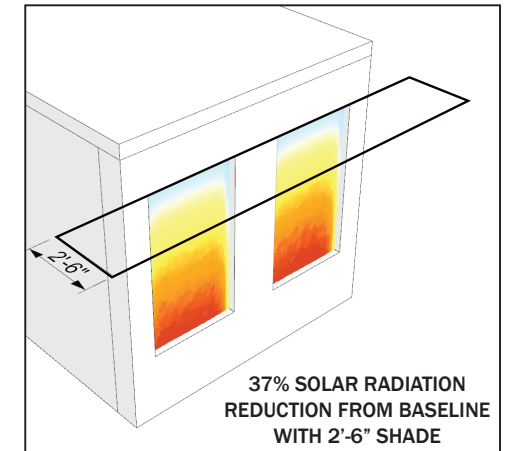
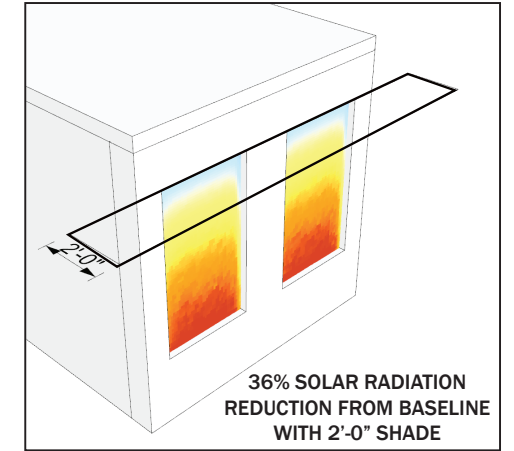
**+35.9%**

NORTH FACADE - 39°  
1,053,600 KWH

**0° FACADE  
71.6 DEGREE  
CUTOFF NEEDED**

**19° FACADE  
67.4 DEGREE  
CUTOFF NEEDED**

**39° FACADE  
61.6 DEGREE  
CUTOFF NEEDED**



# EXPLORING SHADING OPTIONS

PRINCETON UNIVERSITY RESIDENTIAL COLLEGES



**2-1/2" LOUVERS  
SPACED EVERY 6"**



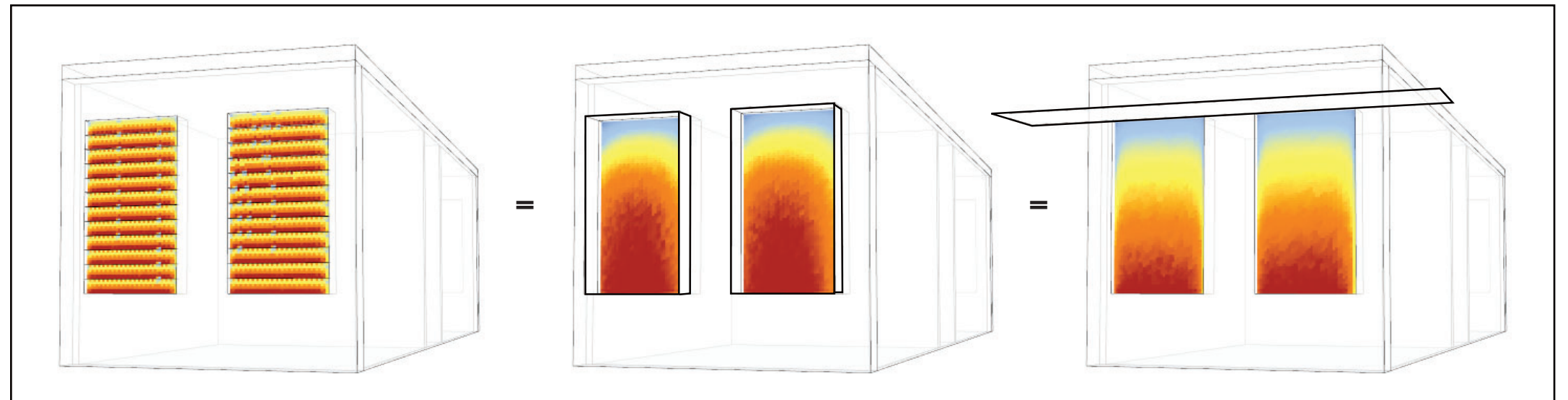
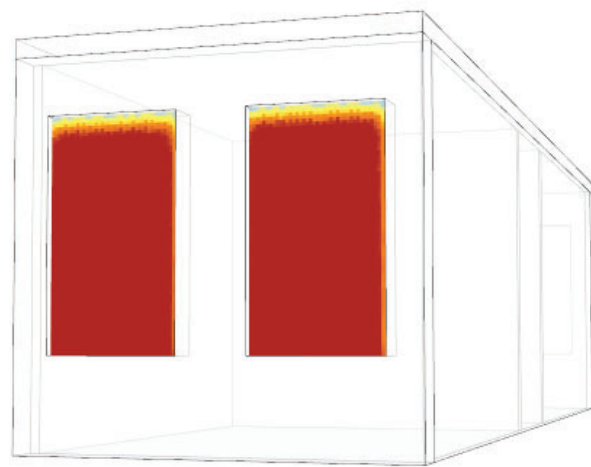
**1' BOX EXTRUSION  
(VERTICAL AND HORIZONTAL)**



**EXTENDED 2'-3"  
HORIZONTAL**

**BASELINE  
(3" GLAZING SETBACK)**

EXAMPLES OF 67 DEGREE CUTOFF ANGLE - all scenarios result in the same level of solar radiation

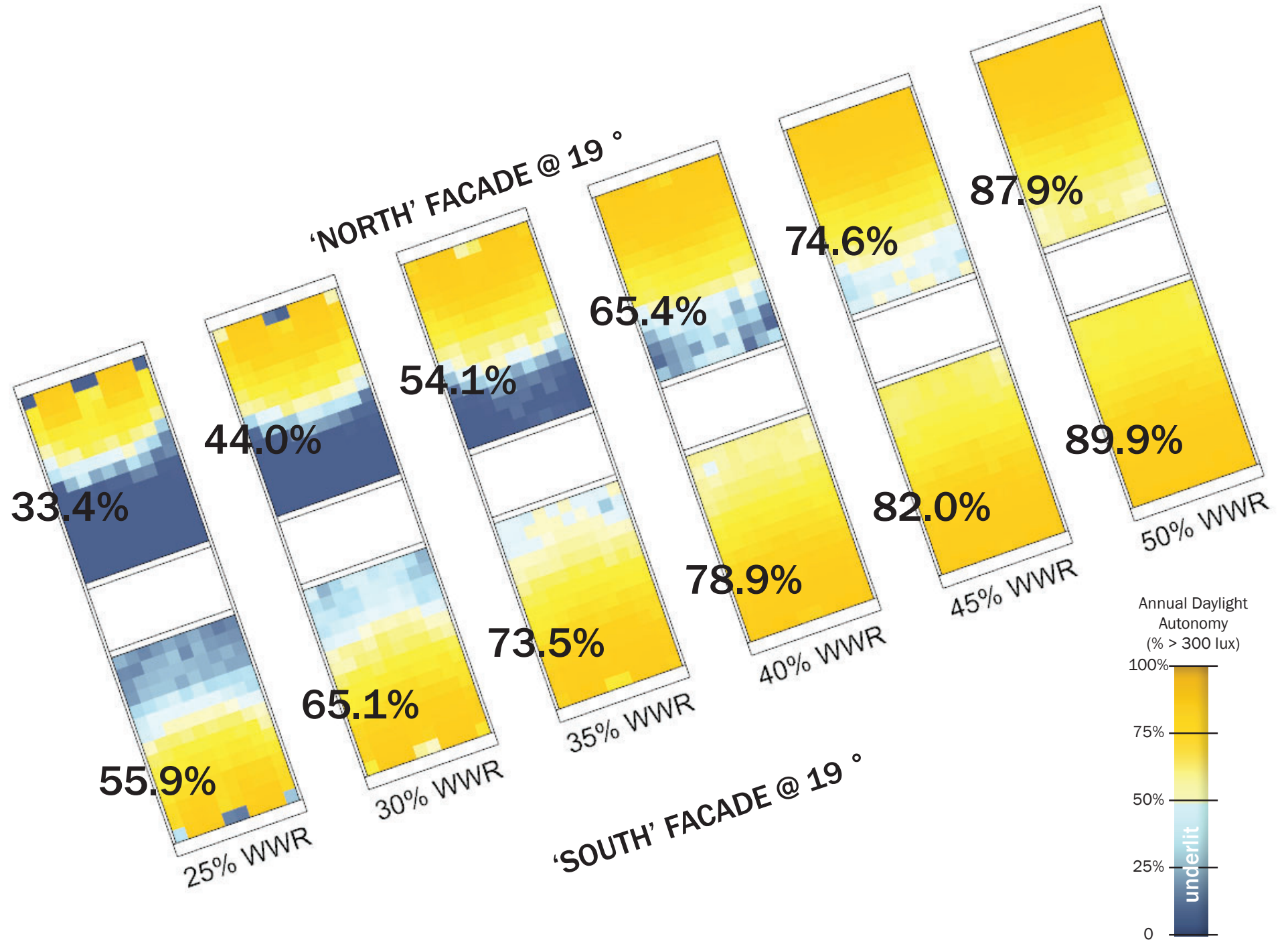
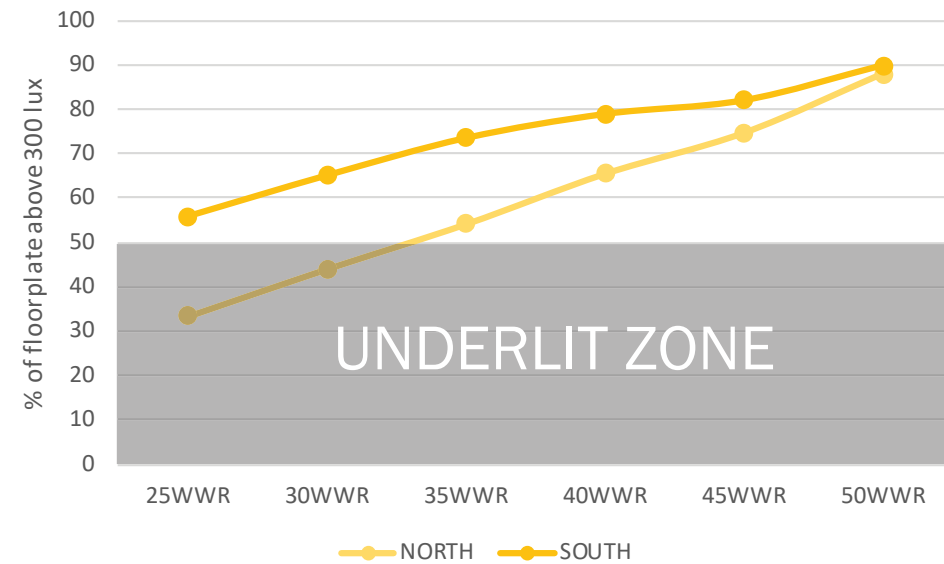


# DAYLIGHT + WINDOW-TO-WALL RATIO

PRINCETON UNIVERSITY RESIDENTIAL COLLEGES

DAYLIGHT AUTONOMY (DA):

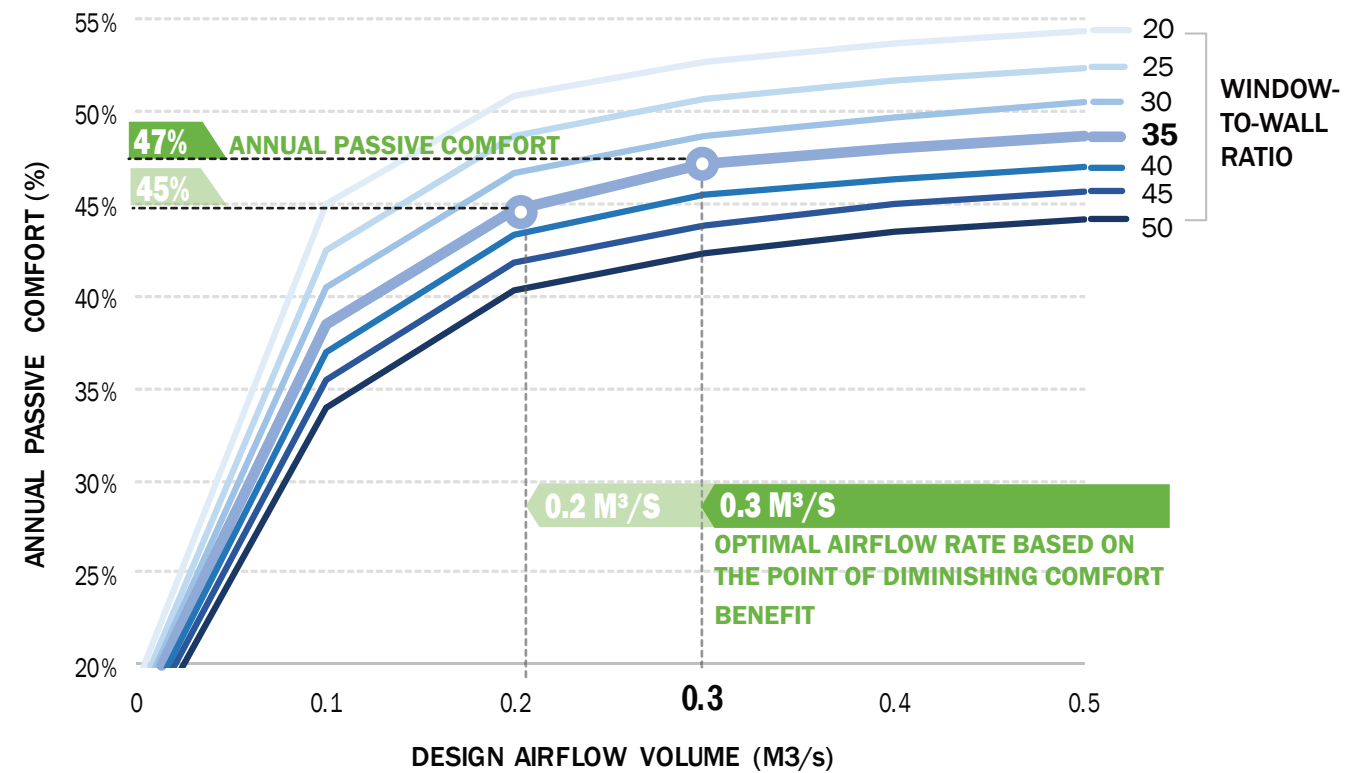
% OF THE FLOORPLATE THAT IS SUFFICIENTLY DAYLIGHT THROUGHOUT THE YEAR (ABOVE 300 LUX).



# AIRFLOW / NATURAL VENTILATION

PRINCETON UNIVERSITY RESIDENTIAL COLLEGES

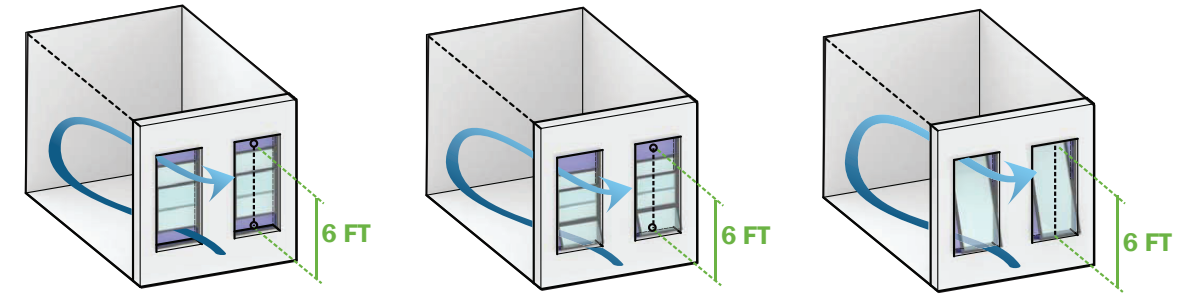
STUDY OF NATURAL VENTILATION  
FEASIBILITY FOR VARIOUS  
WINDOW TYPES.



## Recommended Window Open Area (BASED ON AIRFLOW SENSITIVITY ANALYSIS)

**SINGLE-SIDED, DUAL OPENING** DISCHARGE COEFFICIENT: **0.45**

TARGET OPEN AREA FOR 0.2-0.3 M<sup>3</sup>/S AIRFLOW RATE: **6-9 FT<sup>2</sup> (6-9% OF FACADE)**



**DOUBLE-HUNG WINDOW**

**AWNING WINDOW  
+ SINGLE-HUNG**

**HORIZONTAL PIVOT WINDOW**

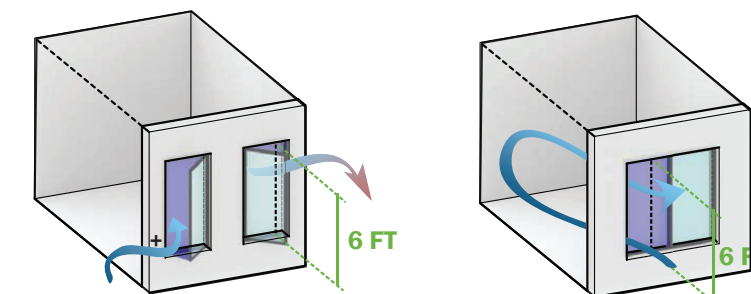
**= 9 FT<sup>2</sup> open area**

**= 9 FT<sup>2</sup> open area**

**= 9 FT<sup>2</sup> open area**

**SINGLE-SIDED, SINGLE OPENING (FULL HEIGHT OPERABLE)** DISCHARGE COEFFICIENT: **0.17**

TARGET EFFECTIVE OPEN AREA FOR 0.2-0.3 M<sup>3</sup>/S AIRFLOW RATE: **15-22 FT<sup>2</sup> (15-22% OF FACADE)**



**CASEMENT WINDOWS**

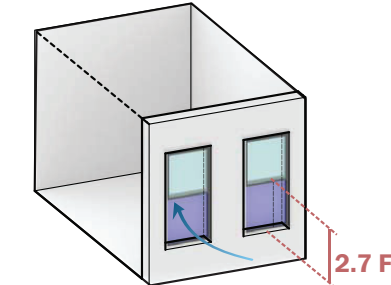
**SLIDING WINDOWS**

**= 22 FT<sup>2</sup> open area (or more)**

**= 16 FT<sup>2</sup> open area**

**SINGLE-SIDED, SINGLE OPENING (PARTIAL HEIGHT OPERABLE)** DISCHARGE COEFFICIENT: **0.17**

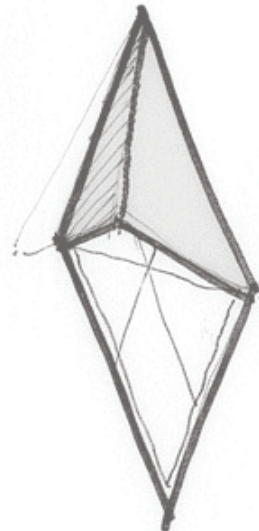
TARGET OPEN AREA FOR 0.2-0.3 M<sup>3</sup>/S AIRFLOW RATE: **21-32 FT<sup>2</sup> (21-32% OF FACADE)**



**= 16 FT<sup>2</sup> open area**

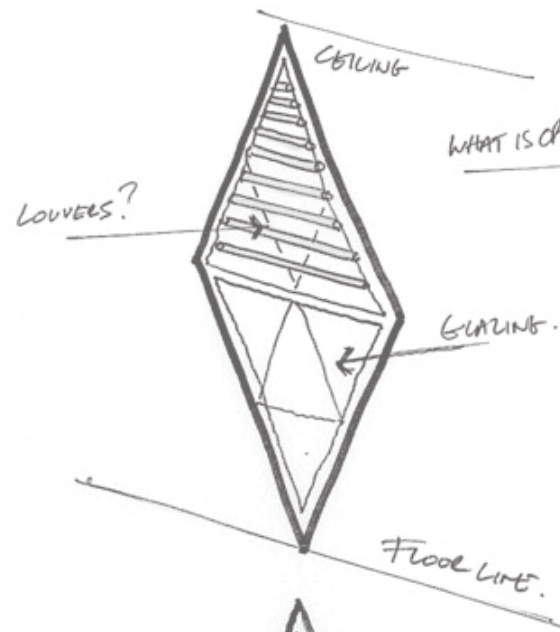
**(21-32 FT<sup>2</sup> OPEN AREA REQUIRED TO ACHIEVE DESIRED NATURAL VENTILATION AIRFLOW RATE BETWEEN 0.2-0.3m<sup>3</sup> /s)**

\* DEPTH?  
\* ANGLE?  
\* MATERIAL?



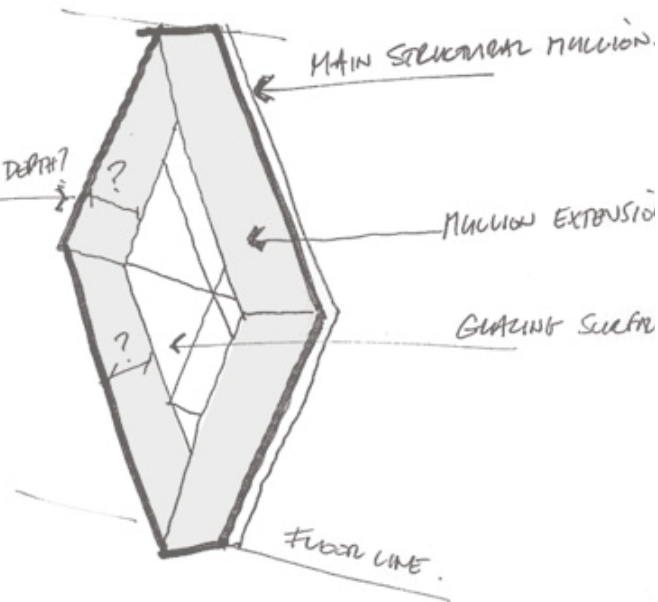
① HOODS

\* DEPTH?  
\* ANGLE?  
\* MATERIAL?

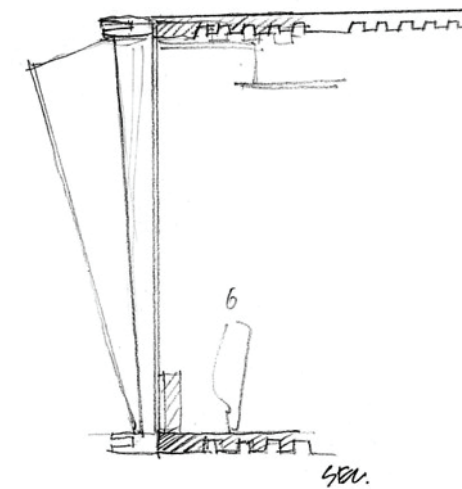
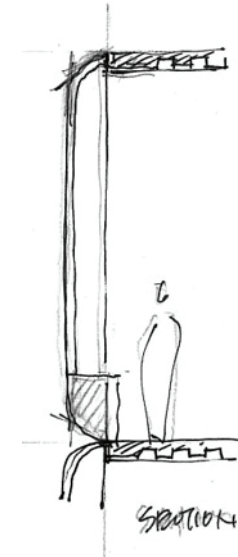
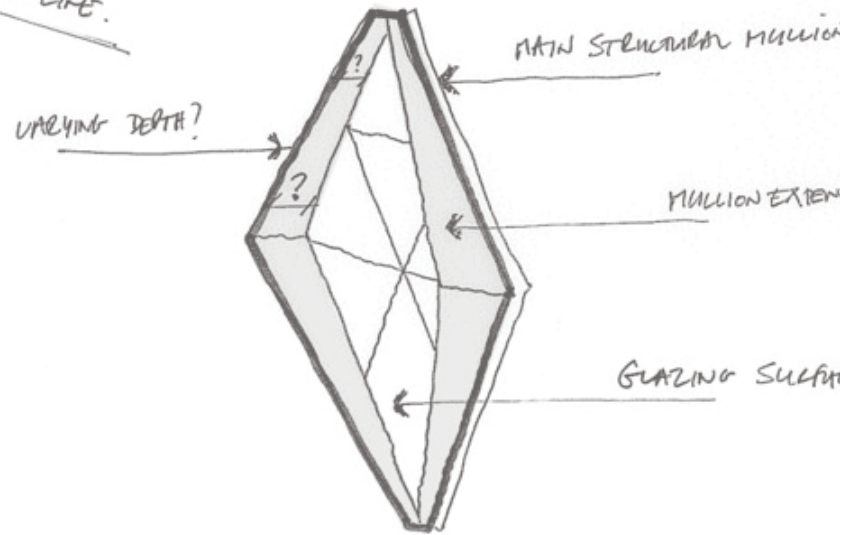
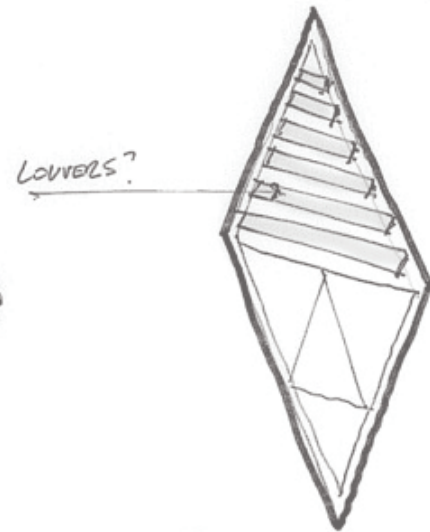


② LOUVERS.

\* DEPTH?  
\* ANGLE?  
\* MATERIAL?



③ MULLION EXTENSION



# THERMAL EXPANSION SPEAKERS



**SCOTT MURRAY**  
*Associate Professor*  
University of Illinois  
Urbana-Champaign



**CARLY COULSON, AIA,  
LEED AP, CPHD**  
*Owner & Architect*  
COULSON



**MOLLY EAGEN, AIA, LEED  
AP BD+C**  
*Atelier Ten*



**LISA MATTHIESSEN,  
FAIA, LEED FELLOW**  
*National Sustainable Design  
Director*  
HGA