

# SWEAT EQUITY

Facade System Considerations for Hot and Humid Climates

## SPEAKERS



**Andrew Blocha**

*Associate Principal Design*  
Perkins + Will



**Liz McCormick**

*Assistant Professor*  
University of North Carolina  
Charlotte



**Olivier Brouard, PE,  
LEED AP BD+C**

*Sustainability Engineering*  
Specialist Team Leader  
SOM



**Helen Sanders, PhD**

*Strategic Business*  
Development  
Technoform North America

Andrew Blocha  
Andrew.Blocha@perkinswill.com

# Dirty Secrets of Façade Design

Perkins&Will

**“How much does your building weigh?”**

**R. Buckminster Fuller to Norman Foster, 1978**

**“How much does your building wear?”**

**2019**

**Unexpected local weather.**

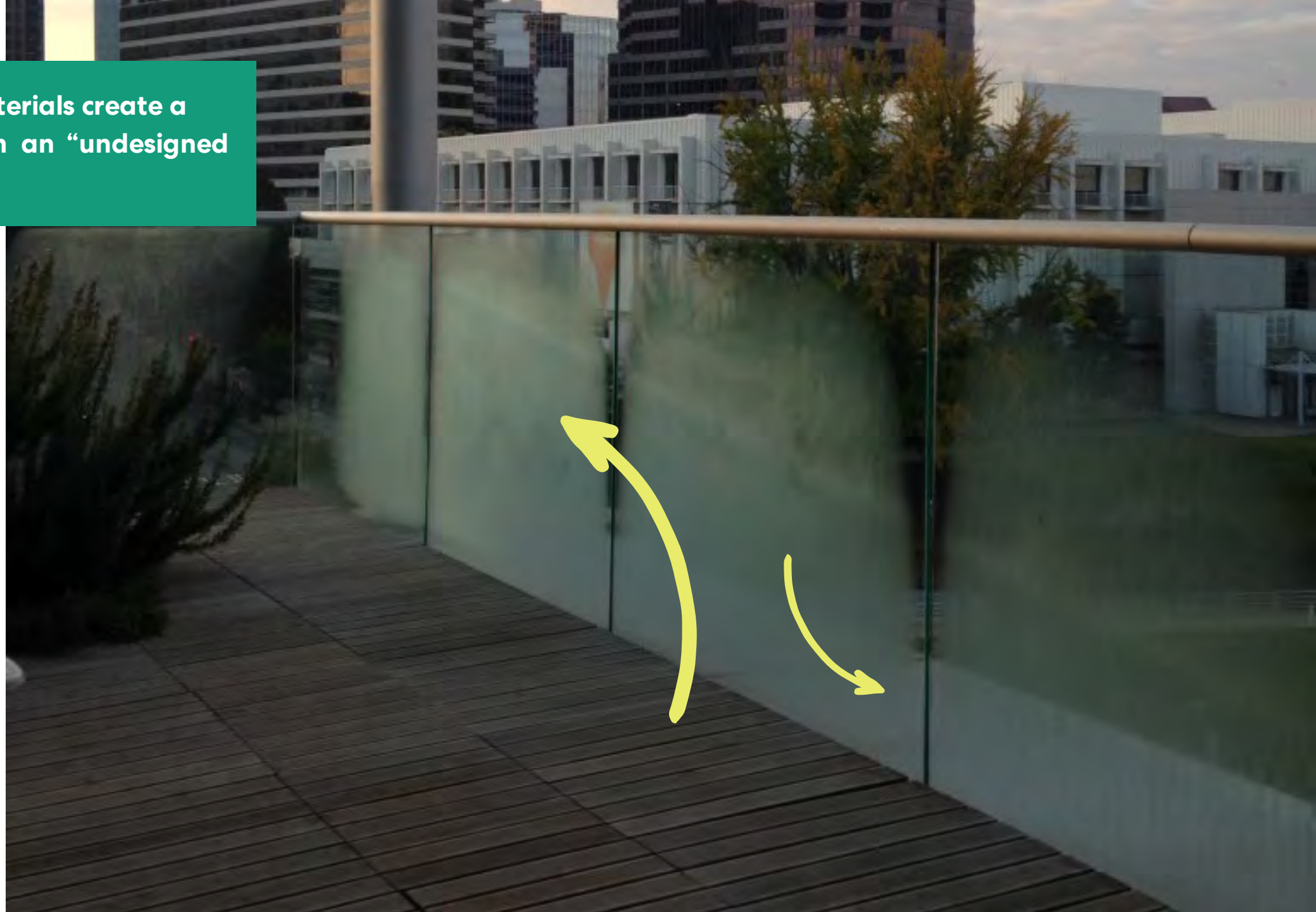
**Exterior Glass Railing**

**Atlanta, GA**





The adjacent materials create a microclimate with an “undesigned result”.



Temperature 57F

Dewpoint 52F

RH 83%.





Lobby

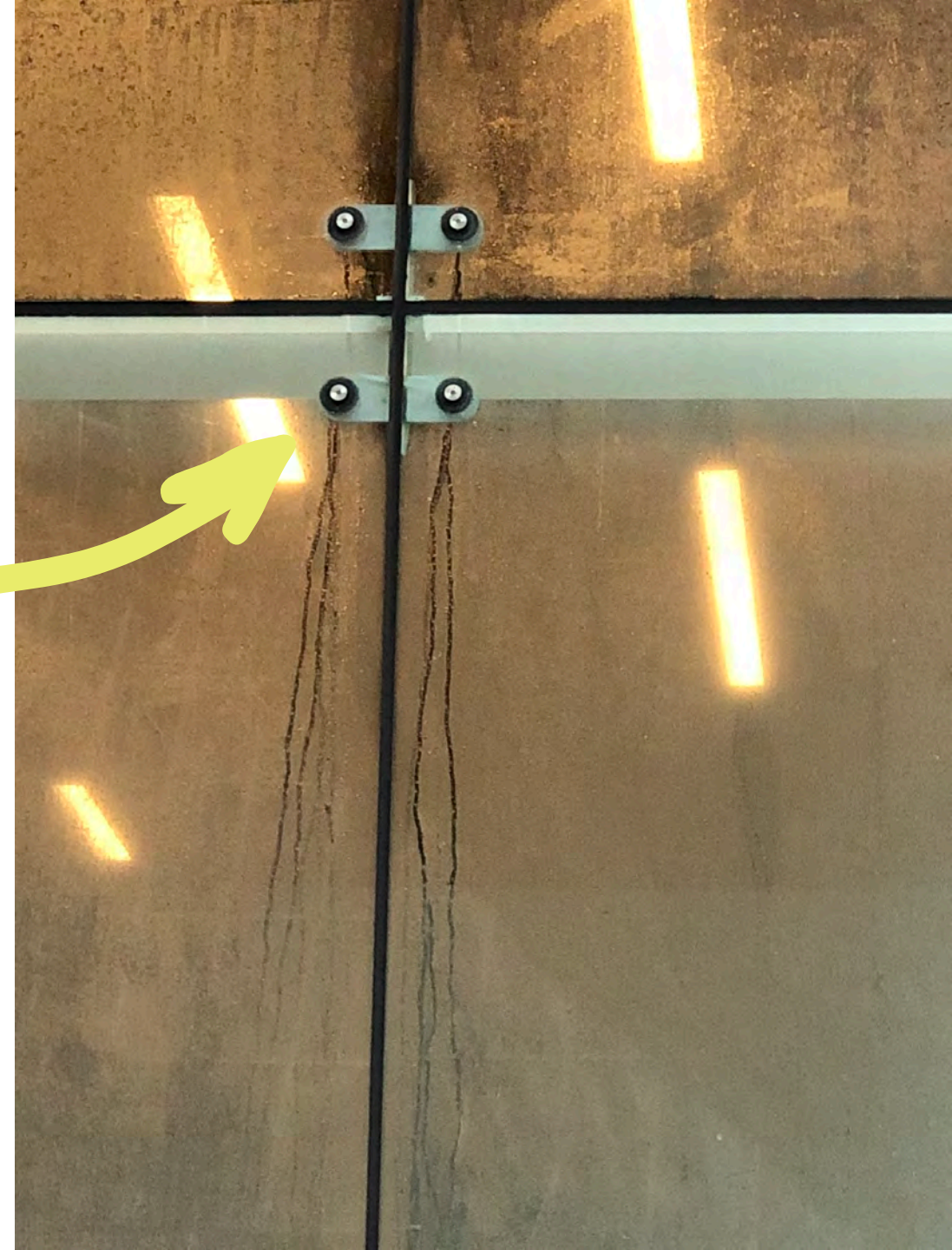
Houston, Texas

The mechanical system creates a designed result in the interior and an “undesigned” result on the exterior.

Temperature 81F

Dewpoint 73F

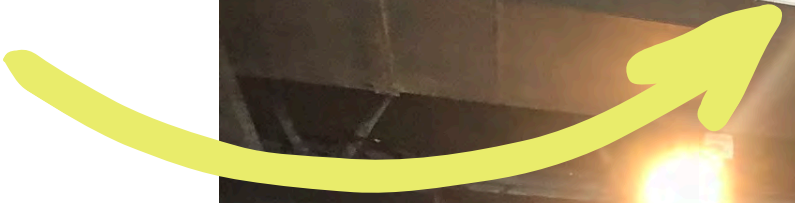
RH 77%.





**Coffee Shop**

**Houston, Texas**



Coffee Shop

Houston, Texas



**Coffee Shop**

**Houston, Texas**



**WUFI what?**

Apartment Building

Atlanta, GA



**Stud Spacing Cold Spots**



**Temperature 55F**

**Dewpoint 50F**

**RH 86%.**

## Observations of Patterns

Clearly the same issue.





Parking Deck

Houston



**Temperature had swung 30  
degrees over 2 days.**



**Temperature 66F**

**Dewpoint 63F**

**RH 89%.**



**It's Houston.  
Stuff gets wet and stays wet.**

## Dirt Buildup



Stainless steel wall support  
under cover of soffit..

Office Tower

Houston, TX

Mullion caps under cover of soffit..



Office Tower

Houston, TX



**Microclimates cause organic growth**



The tree is the culprit..



University Campus

Houston, TX

The tree is not the culprit..



University Campus

Houston, TX

Doesn't see much sunlight



University Campus

Houston, TX

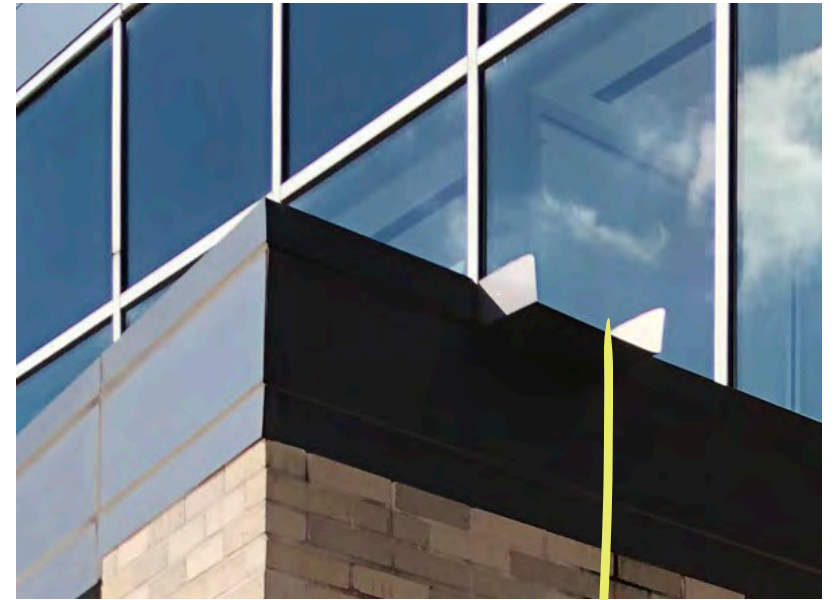


Not sure if this was a good idea.



University Campus

Houston, TX



**Surely, this pattern was not intended.**



**This detail may be headed for the same fate..**

**Clinic Building**

**Houston, TX**





**Museum Building**

**Houston, TX**

Less than a year in.



Museum Building

Houston, TX

# Research, Reference

# “Soiling and Cleaning of Facades”

Report of Technical Committee 62SCF RILEM, 1988

## **Non-biological Soiling**

Airborne Particulate Matter  
Atmospheric pollution of the façade  
Attachment of particles to the façade  
Rainfall run-off

## **Biological Soiling**

Viable Particles in the Air  
Bacteria  
Algae  
Fungi

## **Considerations**

Composition of the Air  
Climate / Prevailing Winds  
Surrounding Development  
Façade Material

# Ideas

# Example:



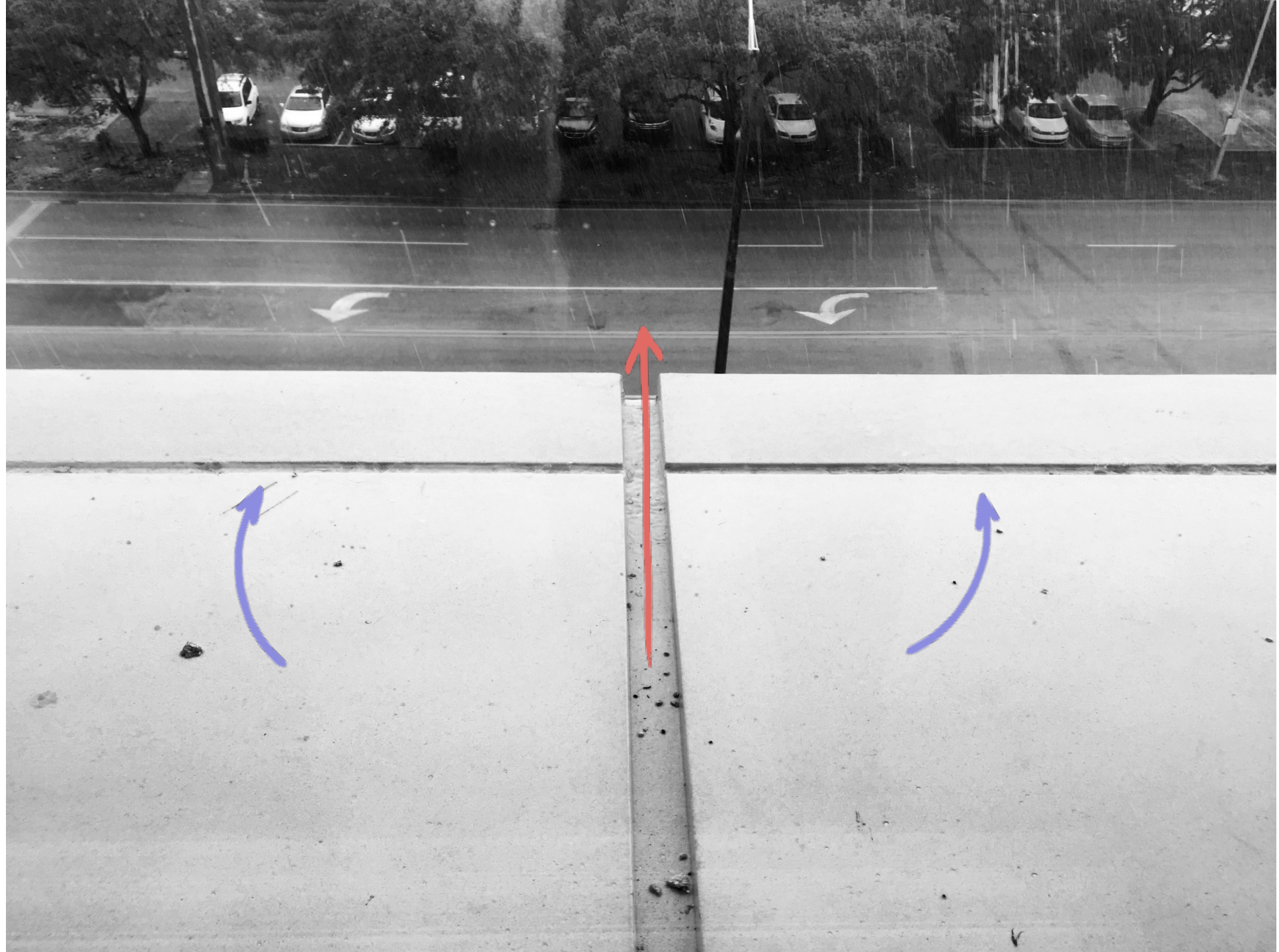
University of Miami

Coral Gables, Florida

**Simple Horizontal Concrete Shades.**



Reveals in precast cladding  
designed to direct water..

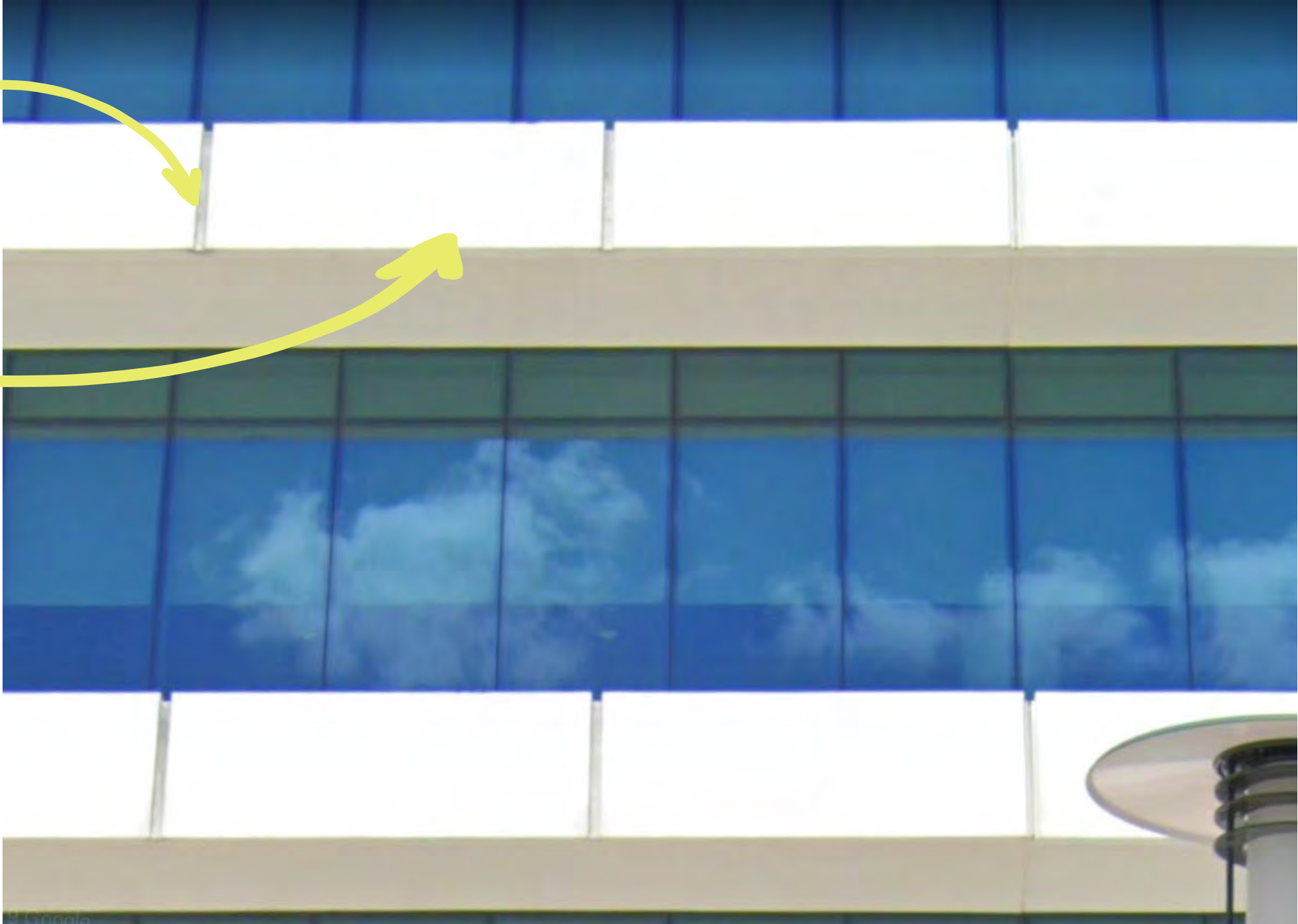




**Soiling at vertical joints as intended.**



**Face of precast remains clean.**



**Façade soiling is a sustainability issue.**

**Water usage.**

**Chemical cleaners.**

**Chemical Sealants.**

**Loss of Revenue.**



**We admire wear in  
nature.**



The Sonoma Coast

**In old world countries  
we find aged facades  
quaint.**

Sienna, Italy



**We are delighted  
occasionally by  
unexpected patterns  
in utilitarian and rural  
construction.**

Barn. Hondo Texas



**Like winemaking, we should be studying and teaching the natural aging of our buildings to create deliberate effect.**



Warehouse. Houston Texas

Andrew Blocha

# Dirty Secrets of Façade Design

H O U S T O N



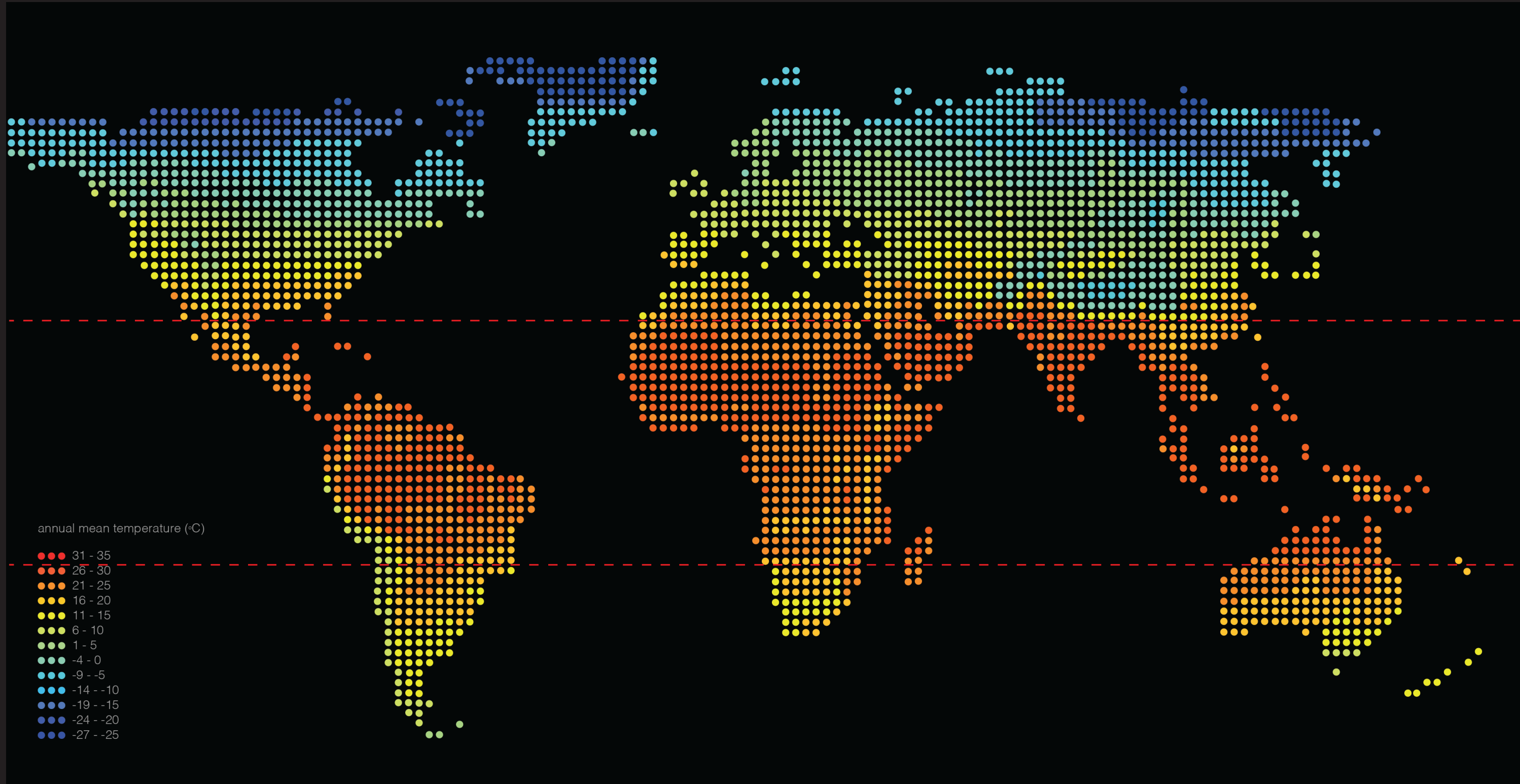
# hot humid climates access & innovation

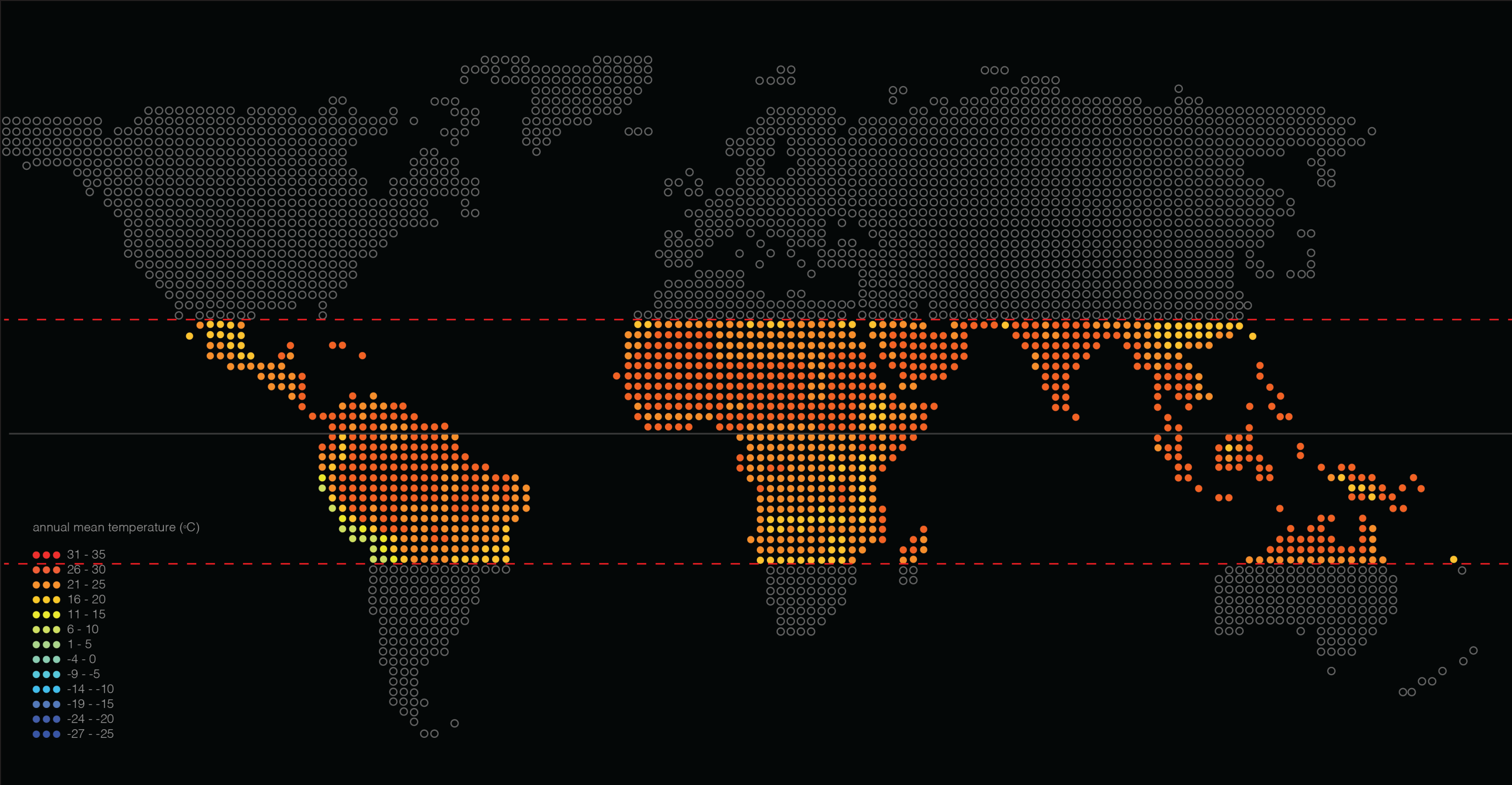
**liz mccormick**

RA | LEED AP | CPHC

Assistant Professor  
University of North Carolina Charlotte

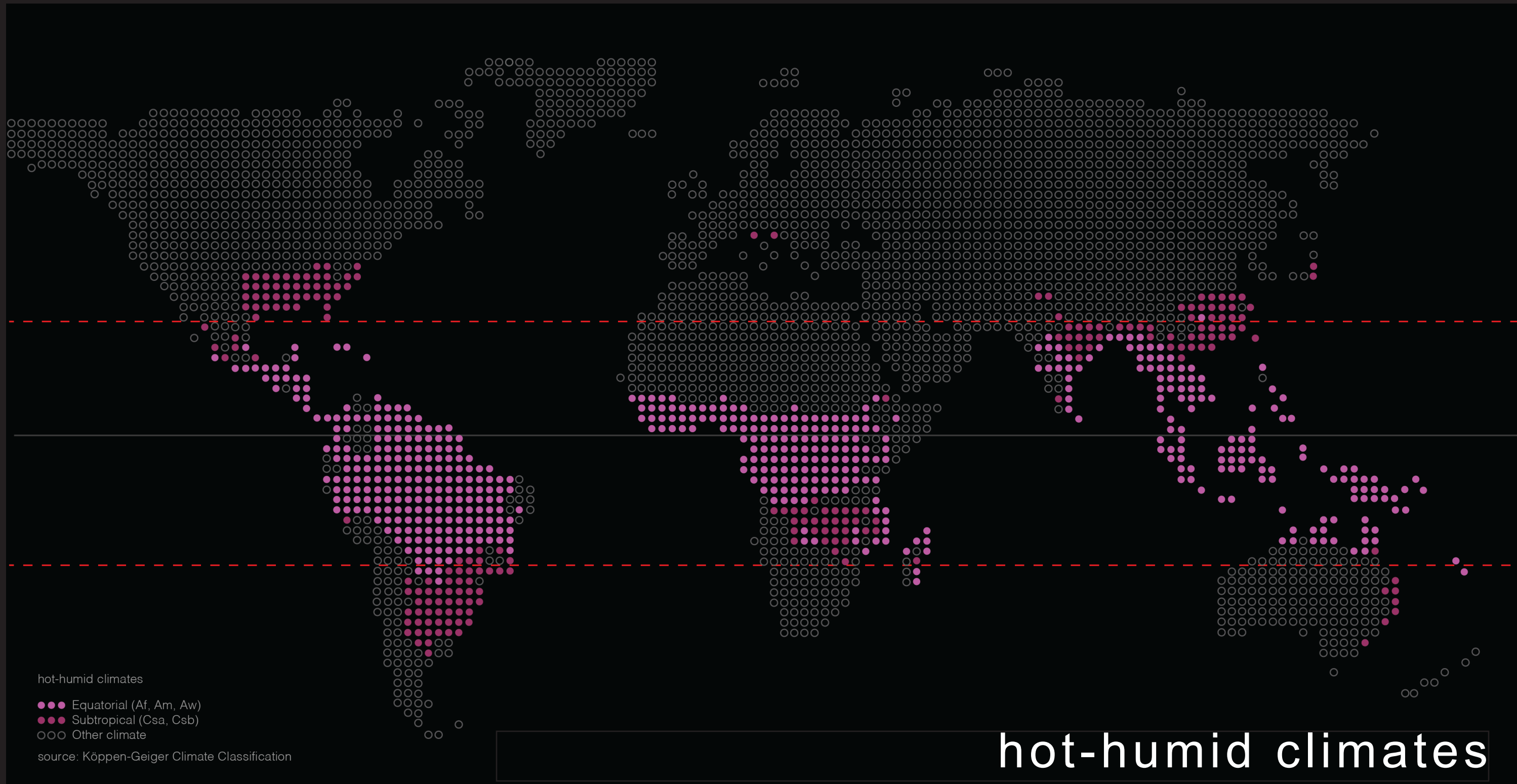
Façade Tectonics Institute Forum, Houston, 2019





annual mean temperature (°C)

- ● 31 - 35
- ● 26 - 30
- ● 21 - 25
- ● 16 - 20
- ● 11 - 15
- ● 6 - 10
- ● 1 - 5
- ● -4 - 0
- ● -9 - -5
- ● -14 - -10
- ● -19 - -15
- ● -24 - -20
- ● -27 - -25



hot-humid climates

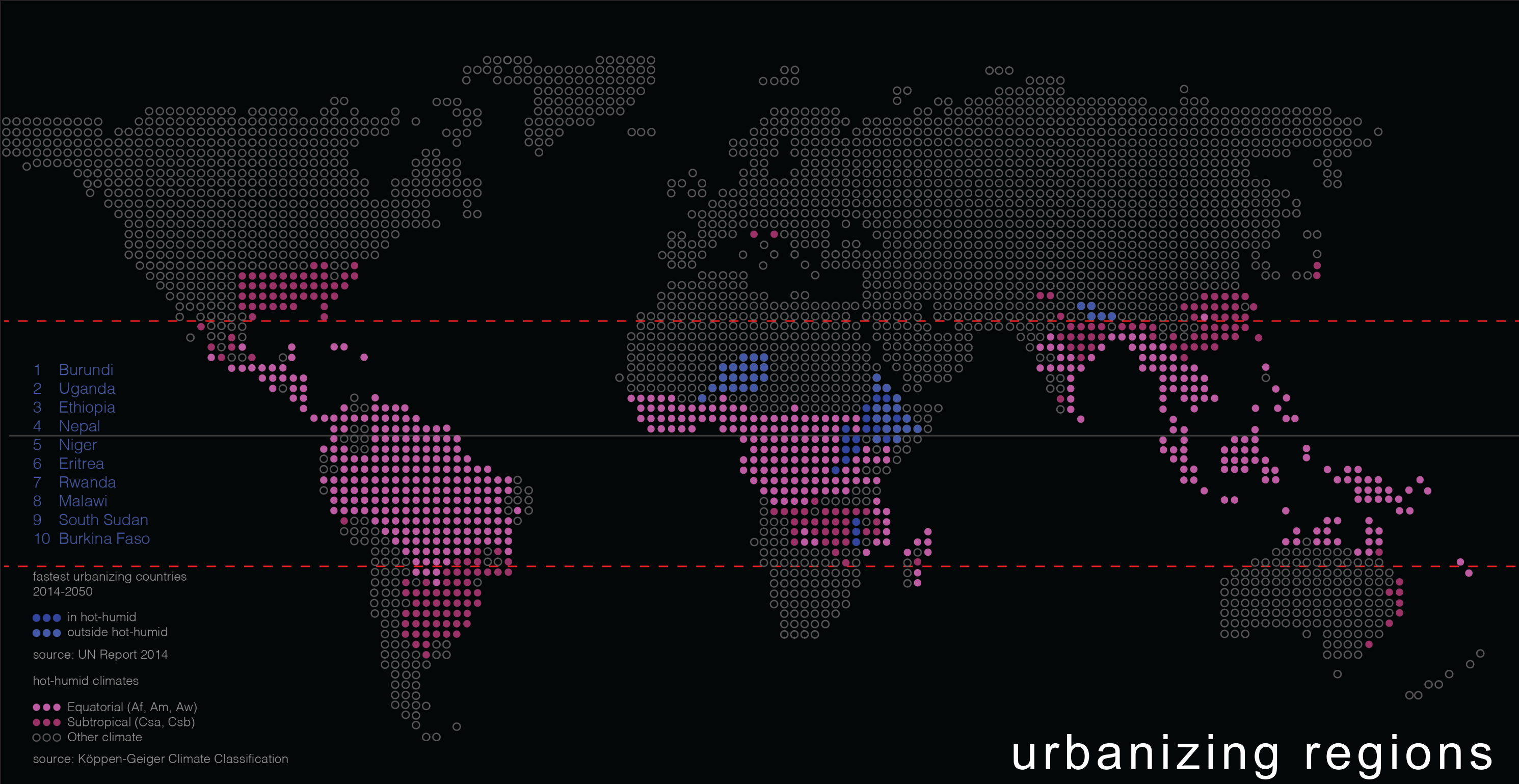
●●● Equatorial (Af, Am, Aw)

●● Subtropical (Csa, Csb)

○○○ Other climate

source: Köppen-Geiger Climate Classification

hot-humid climates



- 1 Burundi
- 2 Uganda
- 3 Ethiopia
- 4 Nepal
- 5 Niger
- 6 Eritrea
- 7 Rwanda
- 8 Malawi
- 9 South Sudan
- 10 Burkina Faso

fastest urbanizing countries  
2014-2050

- in hot-humid
- outside hot-humid

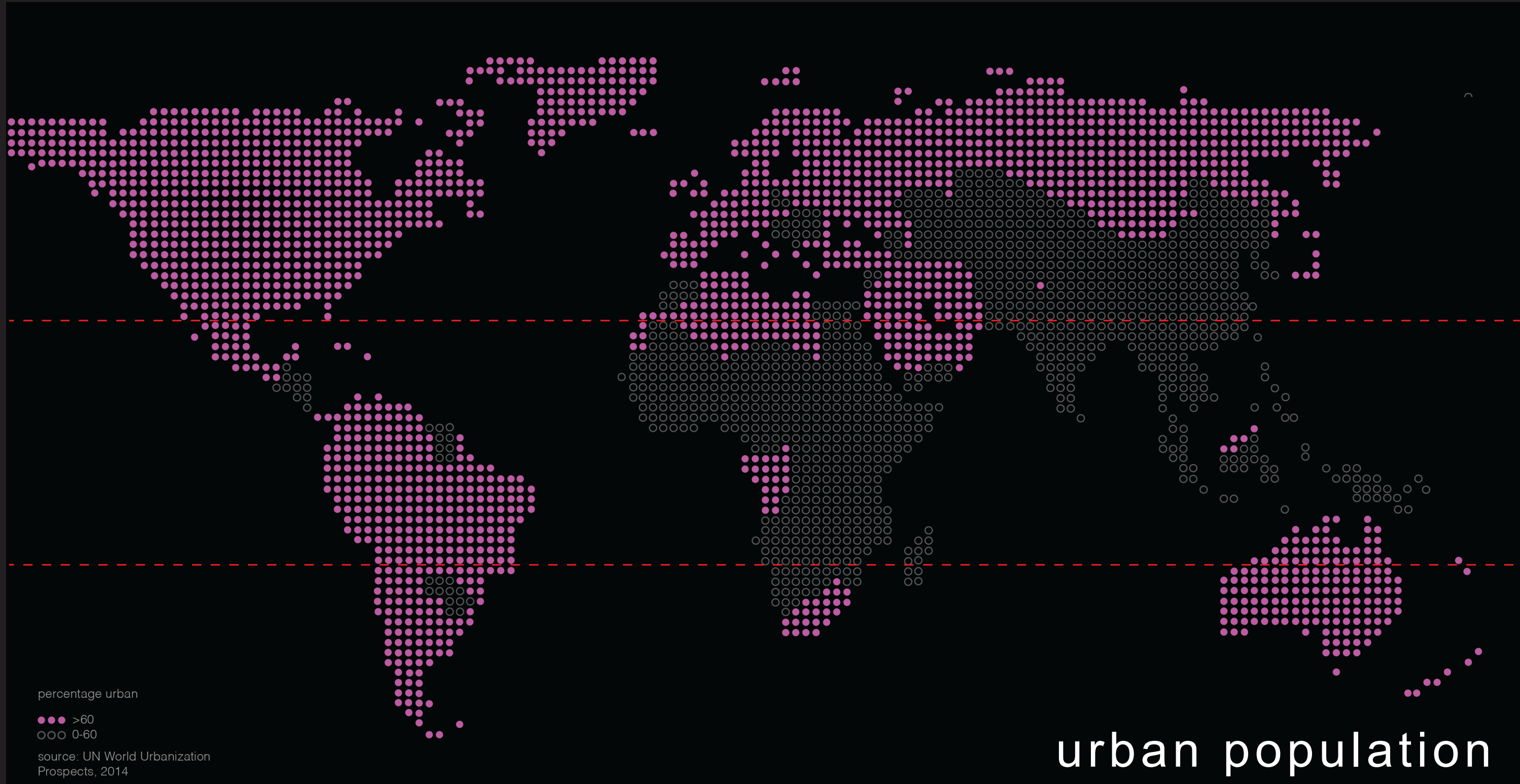
source: UN Report 2014

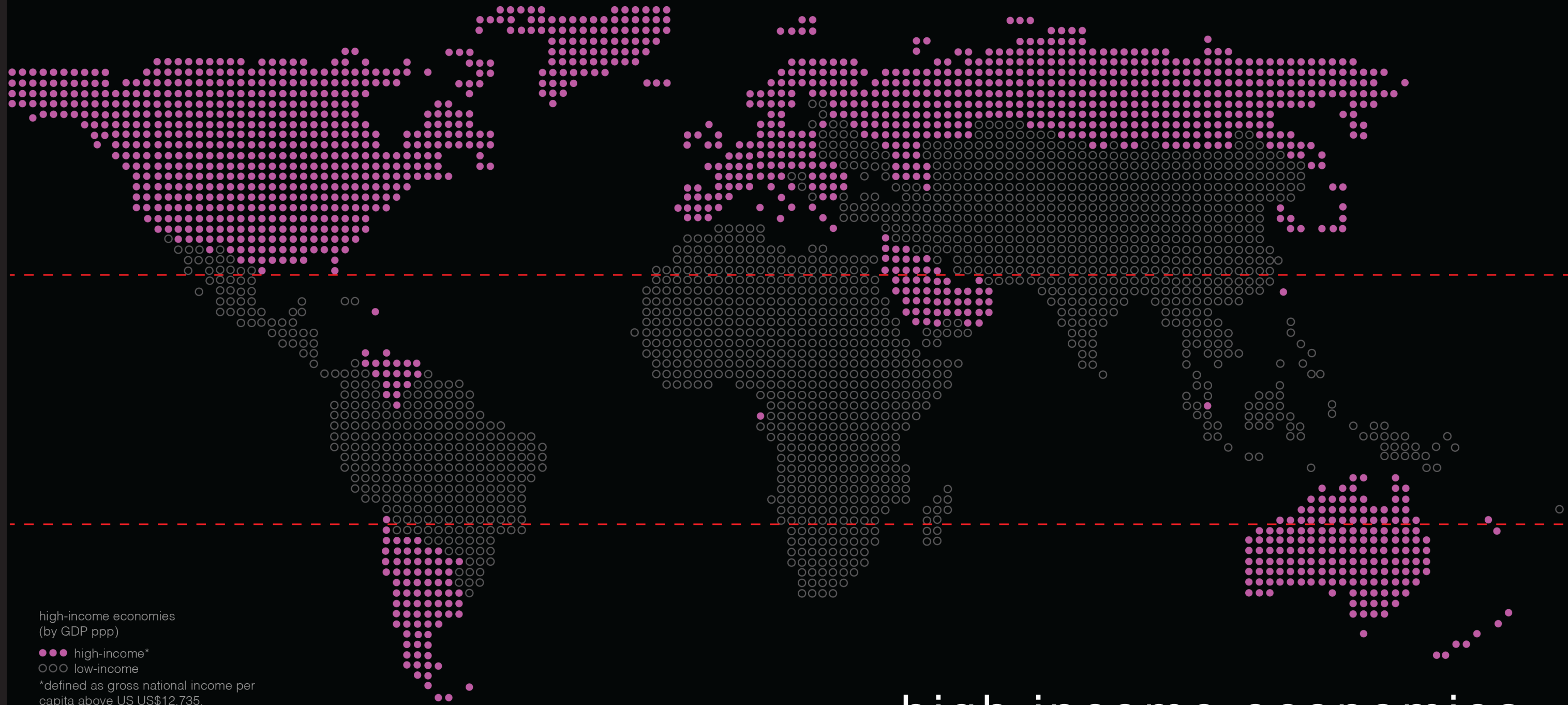
hot-humid climates

- Equatorial (Af, Am, Aw)
- Subtropical (Csa, Csb)
- Other climate

source: Köppen-Geiger Climate Classification

# urbanizing regions





high-income economies  
(by GDP ppp)

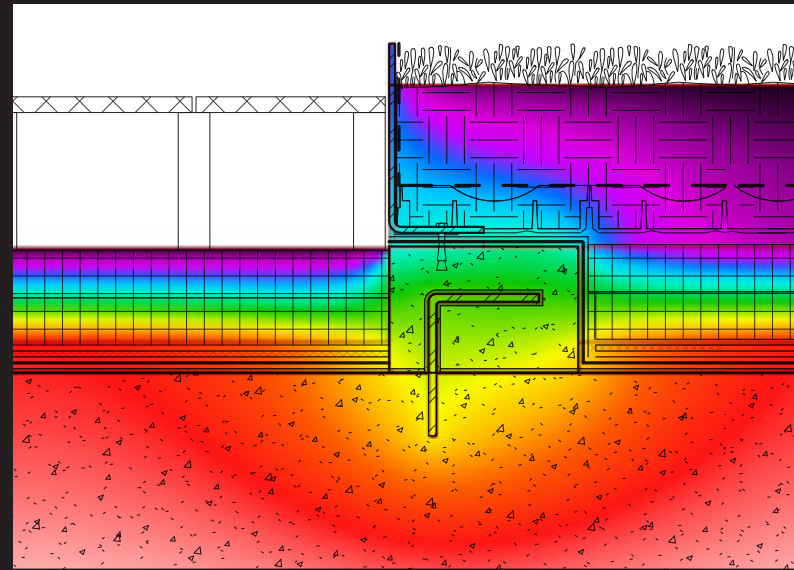
●●● high-income\*  
○○○ low-income

\*defined as gross national income per  
capita above US US\$12,735.

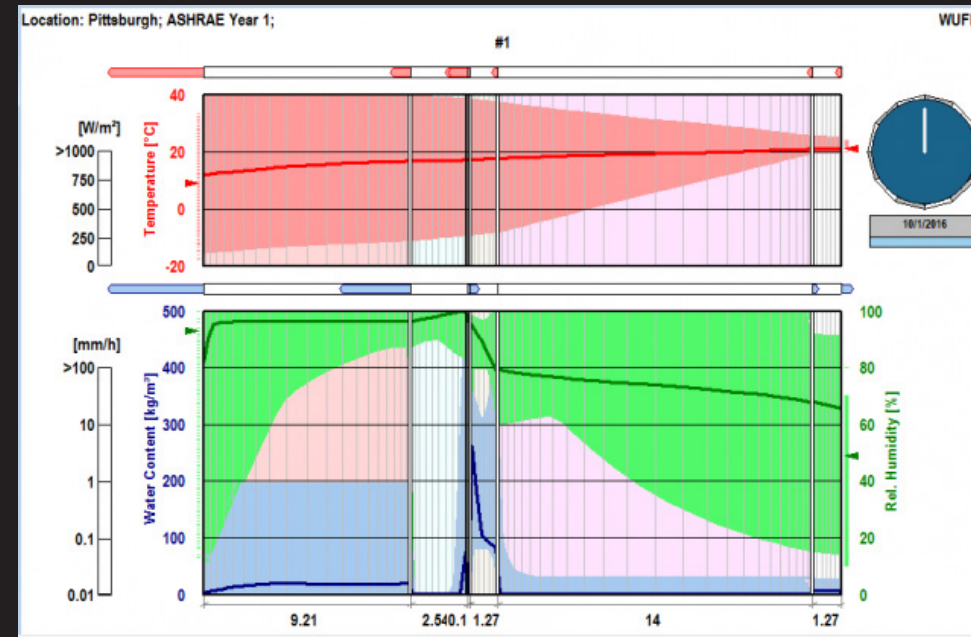
source: The World Bank, Country and  
Lending Groups, 2013

# high income economies

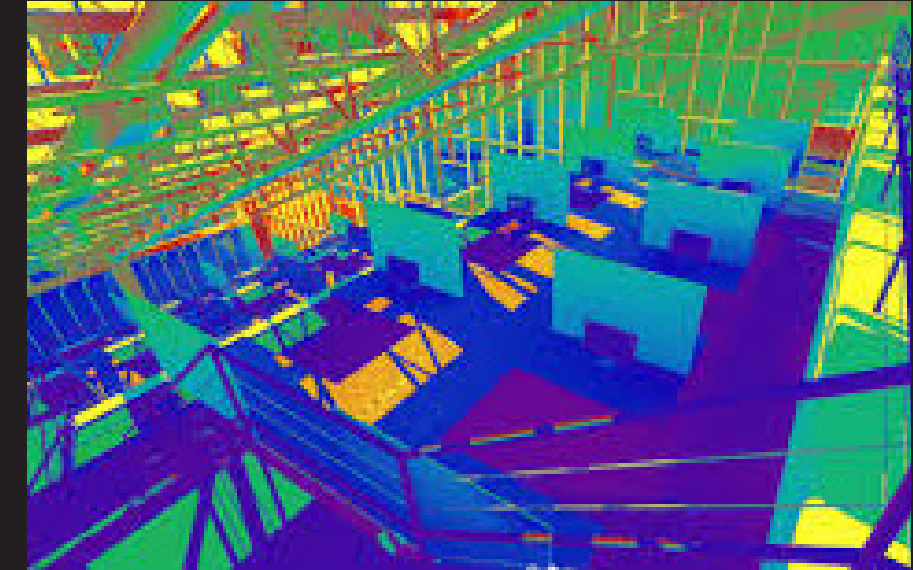
# computational approach



**THERM**  
(thermal gradients)



**WUFI**  
(moisture)



**Energy Plus**  
(energy)

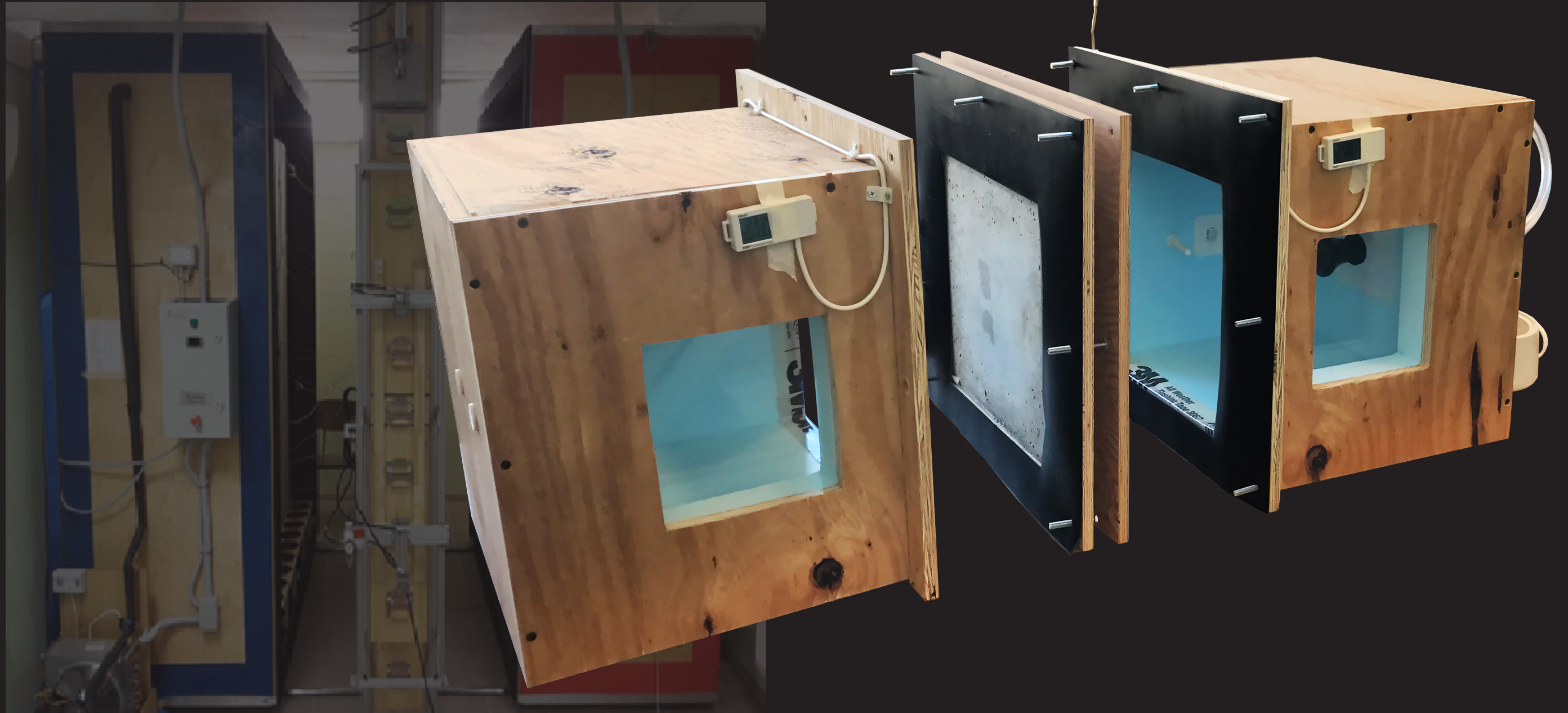
# testing procedures



**build:**  
*commercial hotbox apparatus*  
*~\$800K - 1.2M*

**test:**  
*~\$20,000 per sample*  
*may take several months*

# testing procedures



# testing procedures

materials			
2"DOW XPS foam 2' x 8' x 2"	2	\$ 26.00	\$ 52.00
5/8" CDX plywood 4' x 8' x 5/8"	1	\$ 48.00	\$ 48.00
1/8" Sheet Neoprene 24" x 24" x 1/8"	2	\$ 14.86	\$ 29.72
5/16" Clear Acrylic 22" x 18" x 5/16"	1	\$ 28.00	\$ 28.00

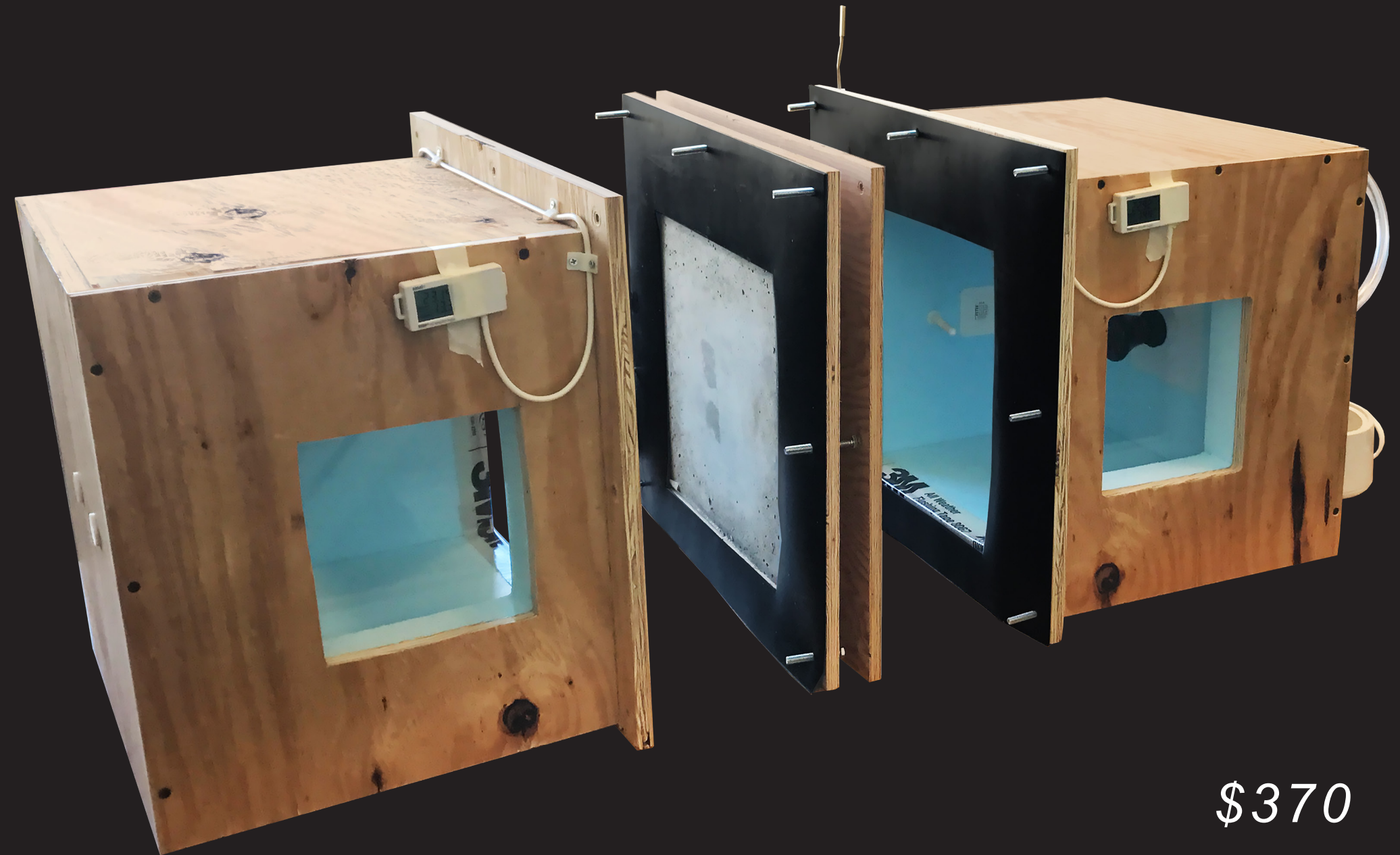
hardware			
box of wood screws	1	\$ 8.47	\$ 8.47
1/4"-20 x 2 coarse hex bolts	20	\$ .62	\$ 12.40
1/4" Hex Screws	20	\$ .18	\$ 3.60

accessories			
gorilla tape	1	\$ 4.88	\$ 4.88
3M building tape	1	\$ 12.50	\$ 12.50
vinyl tubing	1	\$ 4.93	\$ 4.93
USB cable	1	\$ 5.49	\$ 5.49
power adapter	1	\$ 5.99	\$ 5.99
heat shrink	1	\$ 3.30	\$ 3.30
jumper cables	1	\$ 7.99	\$ 7.99

electronics			
Arduino Uno	1	\$ 21.99	\$ 21.99
breadboard	1	\$ 8.99	\$ 8.99
2-channel relay	1	\$ 6.79	\$ 6.79
DHT22 sensors	2	\$ 9.95	\$ 19.90
LCD screen	1	\$ 18.99	\$ 18.99
weatherproof lampholder	1	\$ 3.98	\$ 3.98
extension cord	1	\$ -	\$ -

appliances			
humidifier	1	\$ 35.99	\$ 35.99
heat lamp	1	\$ 9.99	\$ 9.99
power strip	1	\$ 16.99	\$ 16.99

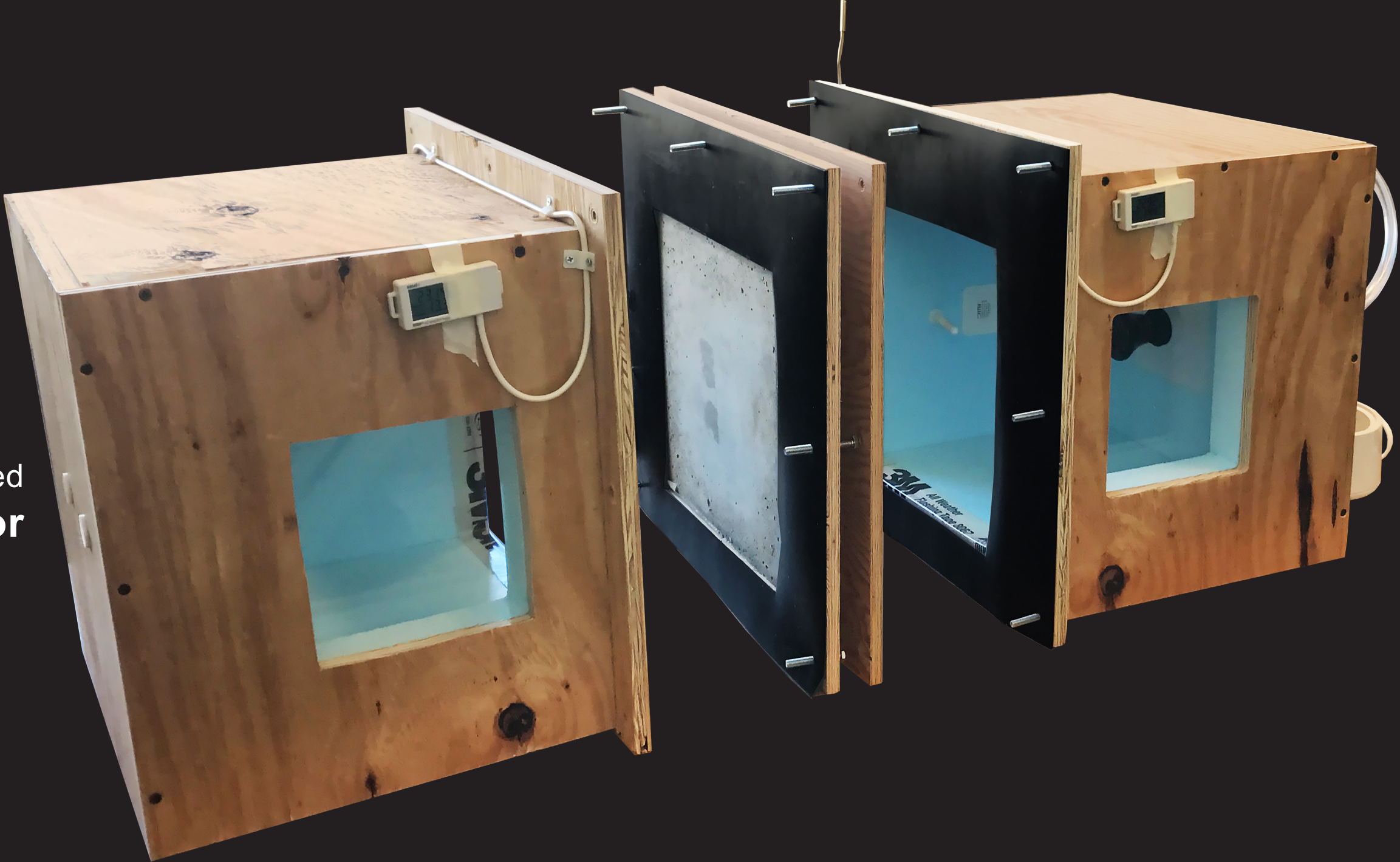
commercial sensors			
4-Channel External Data Logger	1	\$ 249.00	\$ 249.00
Hobo - temp/RH with probe	2	\$ 189.00	\$ 378.00



**\$370**

*(not including sensors)*

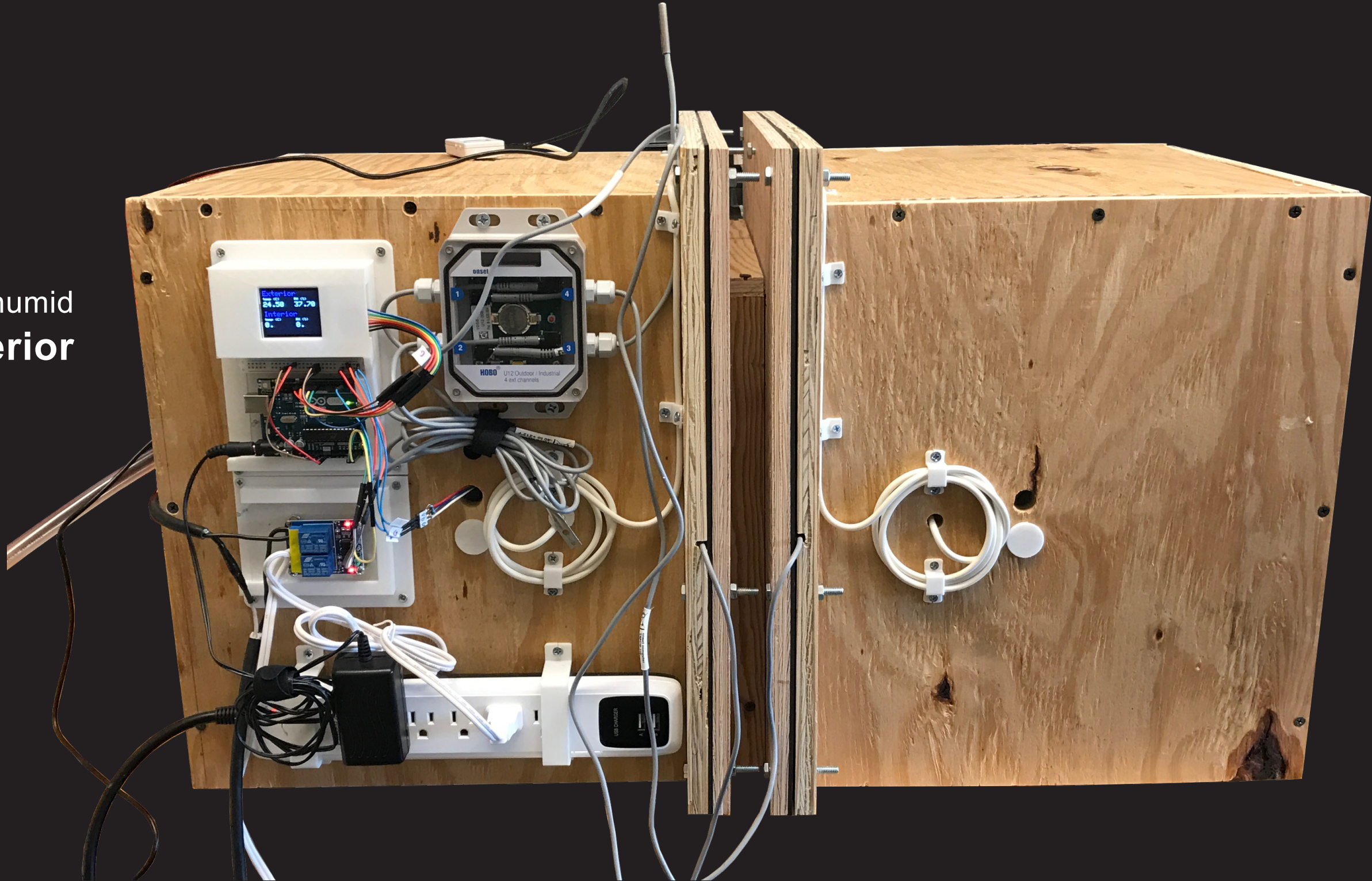
environment box



unconditioned  
**interior**

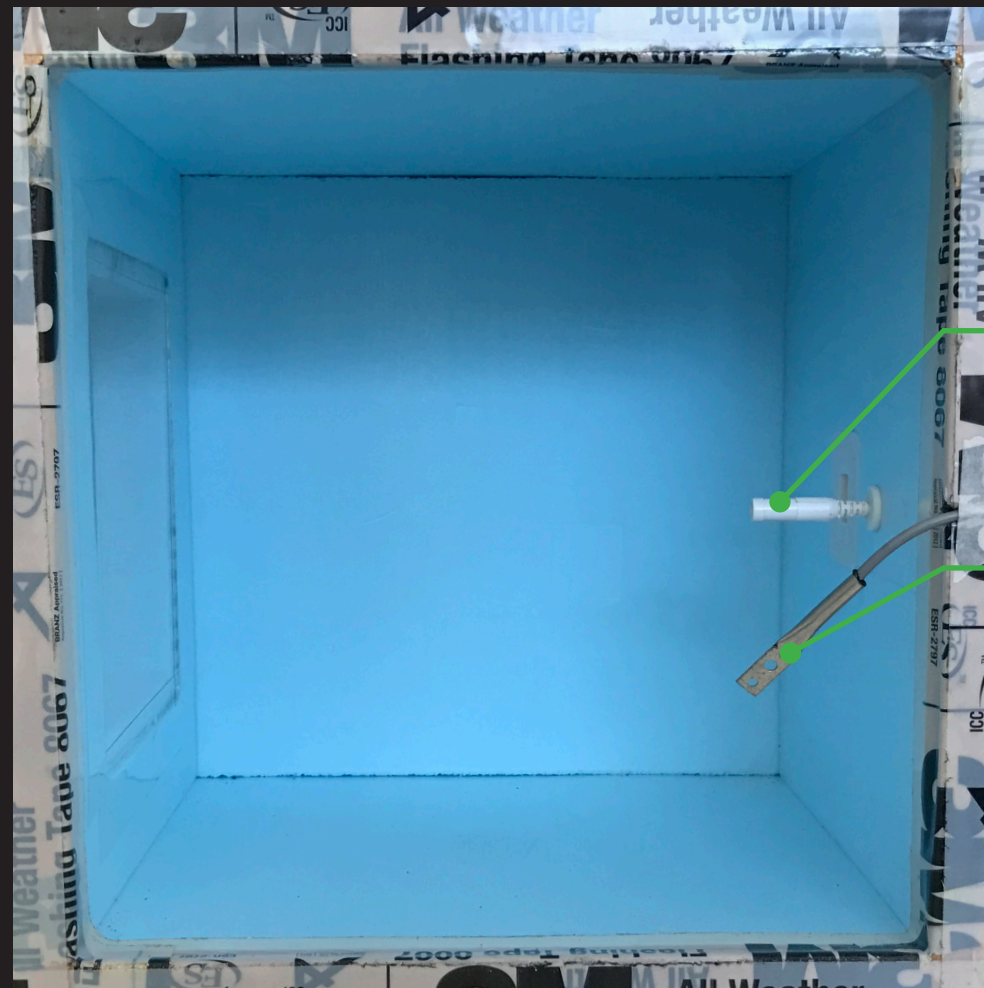
hot/humid  
**exterior**

hot/humid  
exterior



unconditioned  
interior

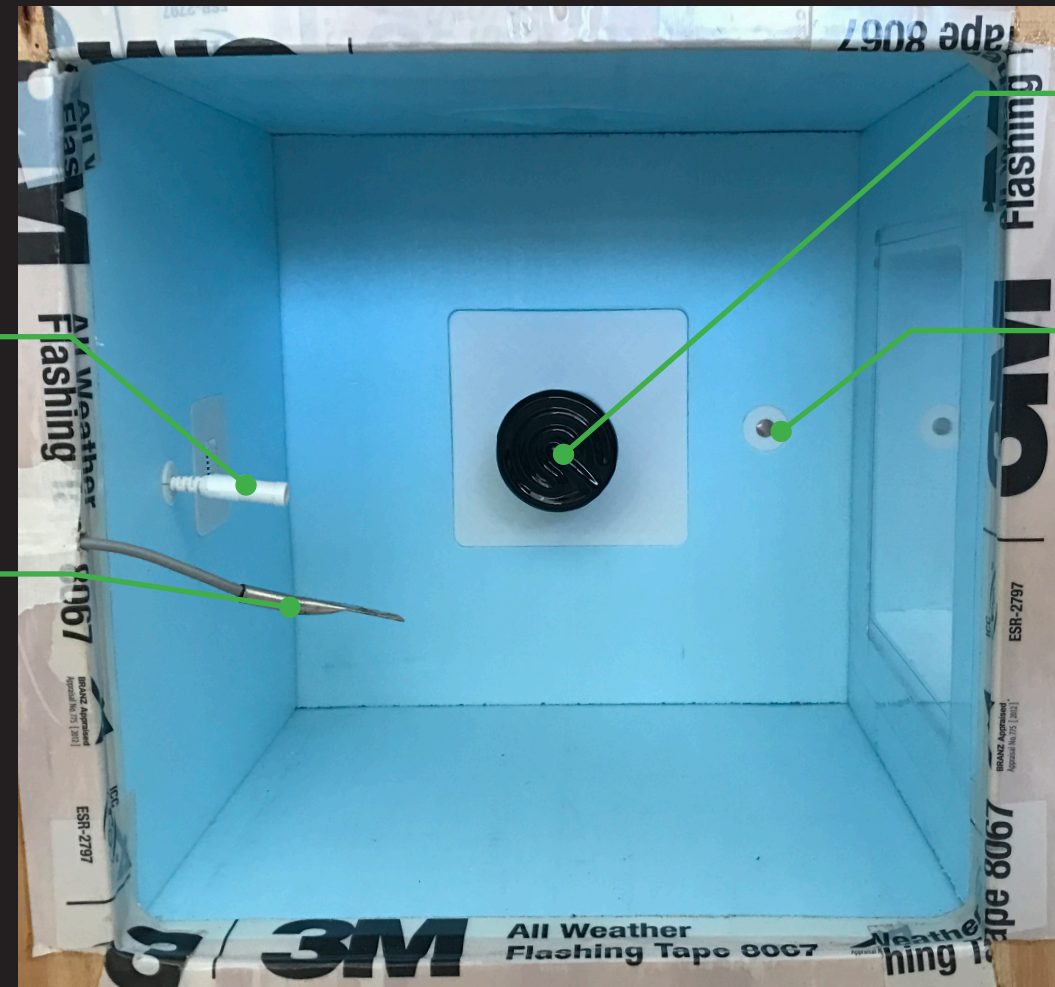
# sensors & controls



*unconditioned*

*ambient  
temp / RH*

*surface  
temp*



*heater*

*humidifier*

*hotbox (exterior)*



# Build Test Iterate Repeat

[www.buildtestbuildtest.com](http://www.buildtestbuildtest.com)

*part* building science  
*part* fabrication  
*part* representation

goal: democratize building  
science research and facade  
innovation through low-cost,  
low-tech testing methods

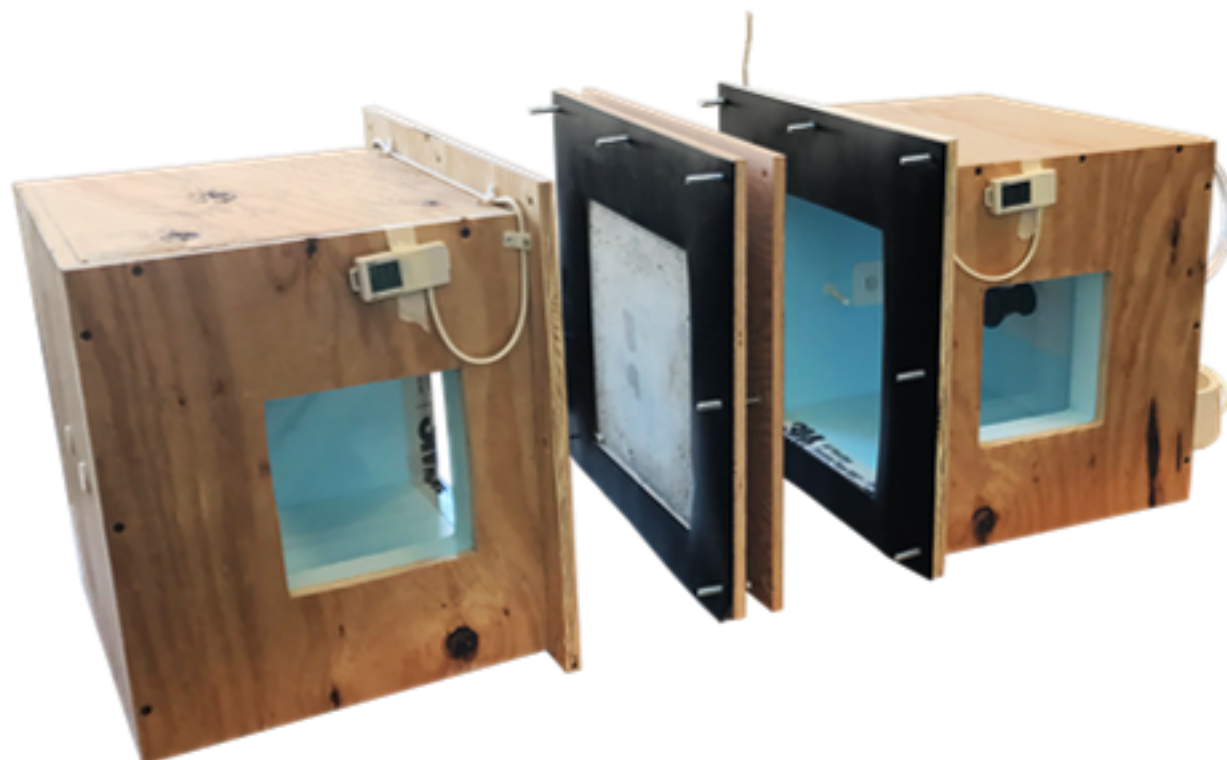
# BUILD, TEST, ITERATE, REPEAT

## Course Announcement

ARCH 4050/6306, Spring 2020

**Instructor:** Liz McCormick  
**Contact:** lizmccormick@uncc.edu  
Storrs 243, 704-687-0111  
[buildtestbuildtest.com](http://buildtestbuildtest.com)

**Prerequisite:** ARCH 4302 or Equivalent

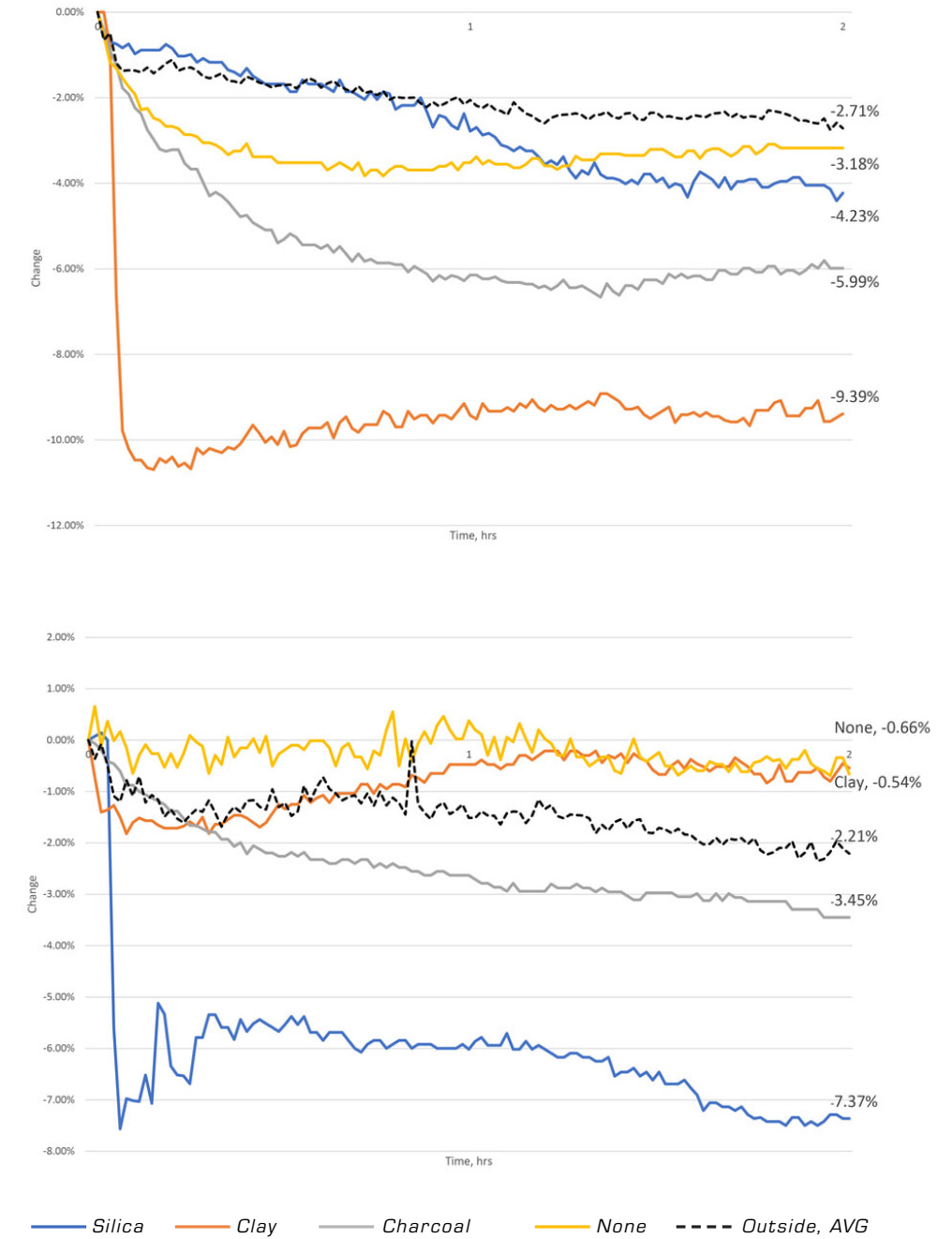
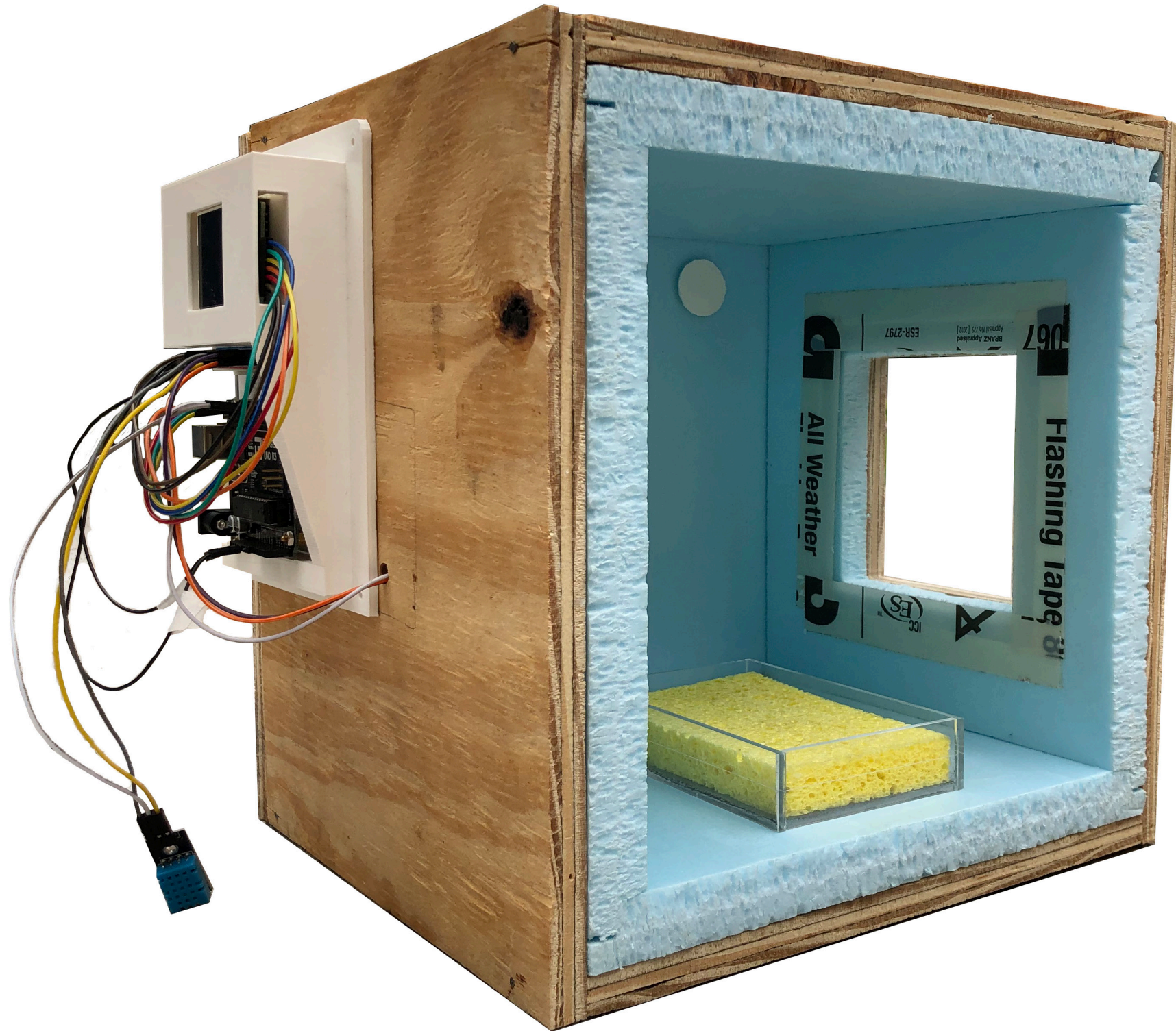


## Course Description:

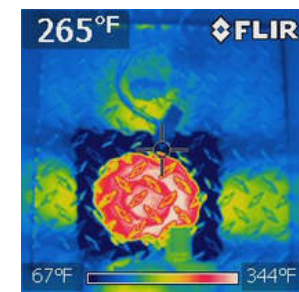
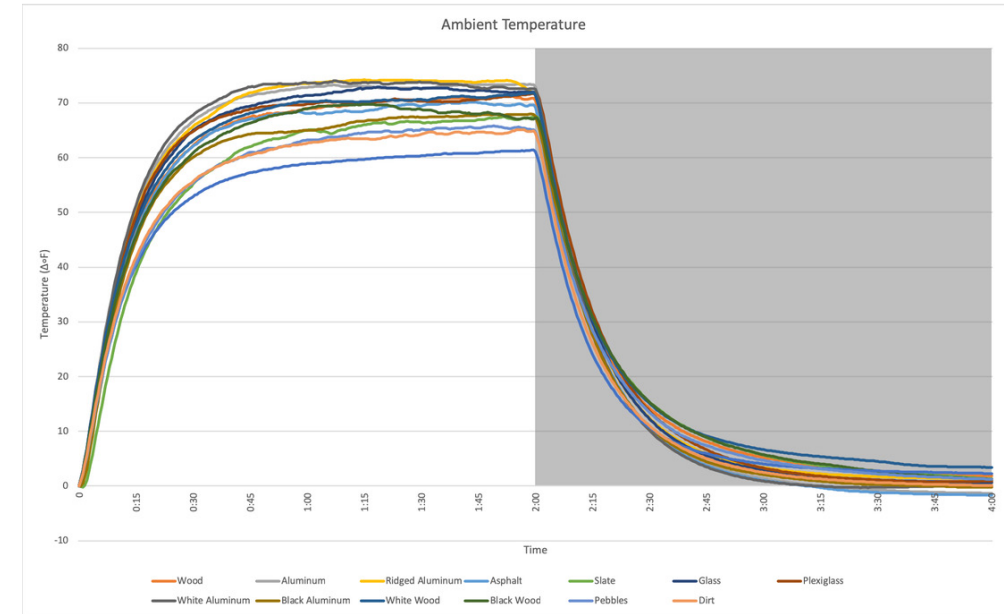
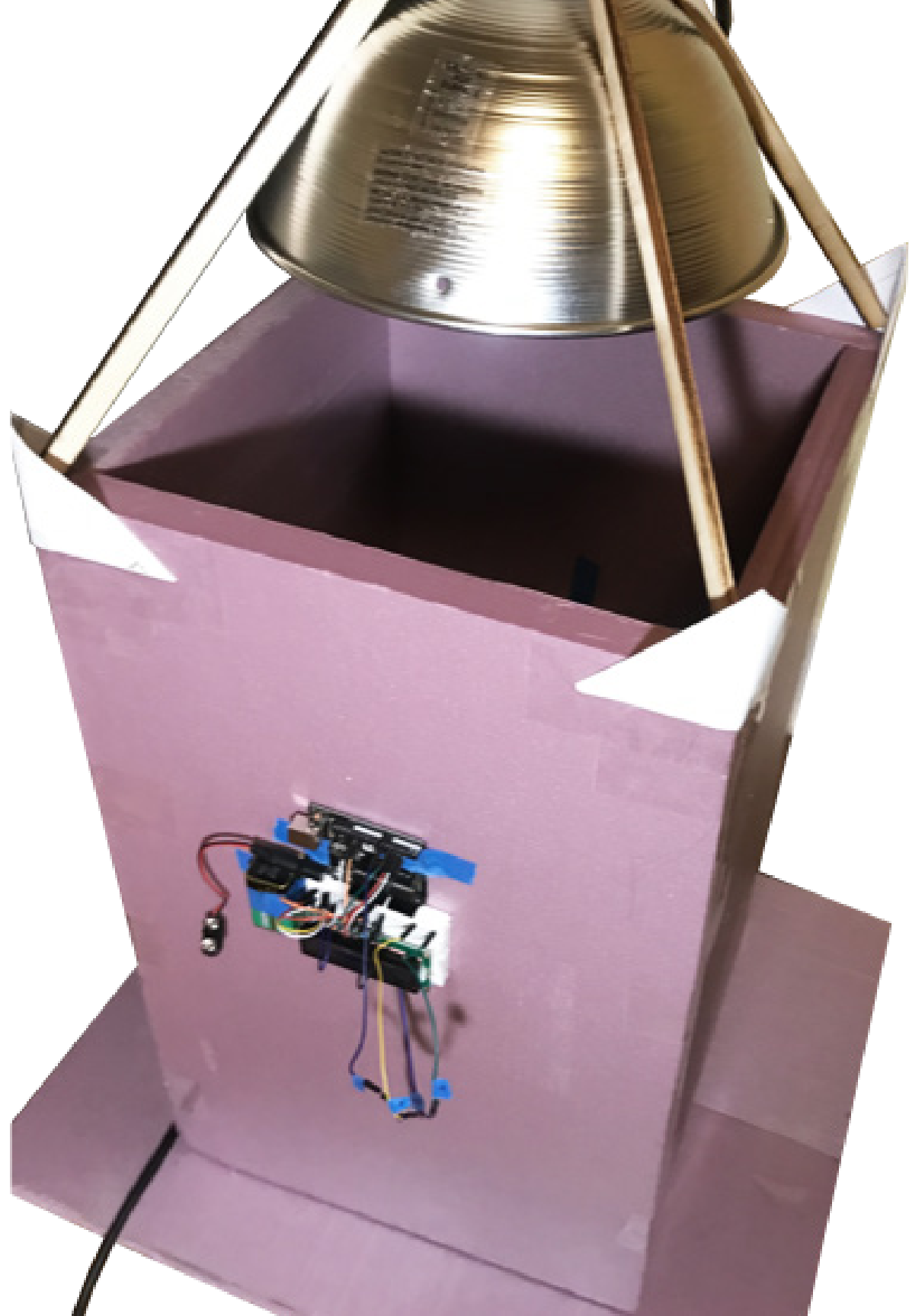
Often *design* and *building science* are considered separate fields with entirely different languages. Designers explore ideas through sketches, models, and renderings yet principles of building science are communicated through complicated models and equations. By combining students from across the UNCC campus, this interdisciplinary course strives to bridge the gap between design and hard science. Students will explore ways to understand, visualize and *communicate* basic thermodynamic phenomena in physical and tangible ways.

# Ana Sandoval & Michelle Barrett

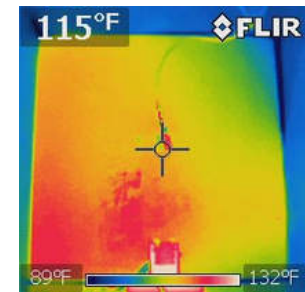
## "low-fab dehumidification"



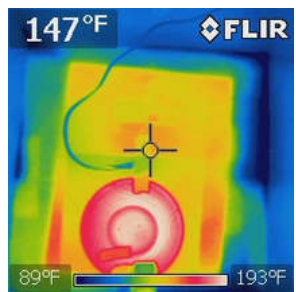
# Hanna Li "cooling materials"



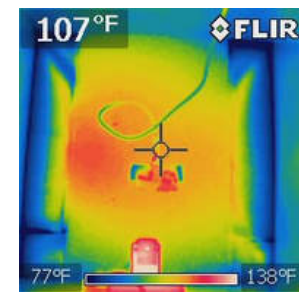
ridged steel



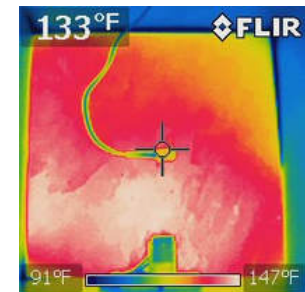
white metal



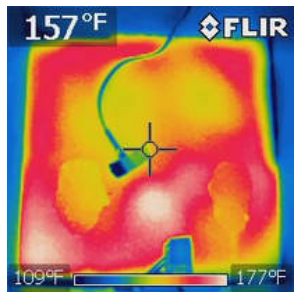
glass



concrete

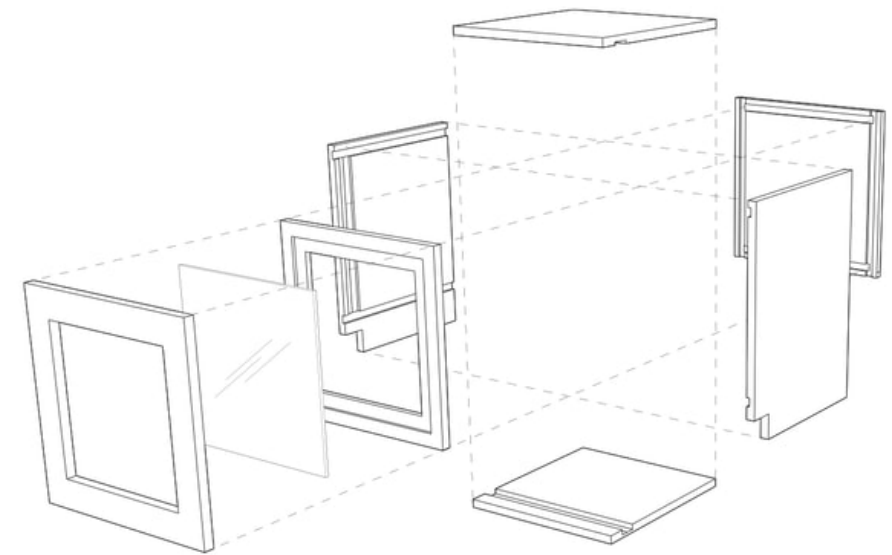
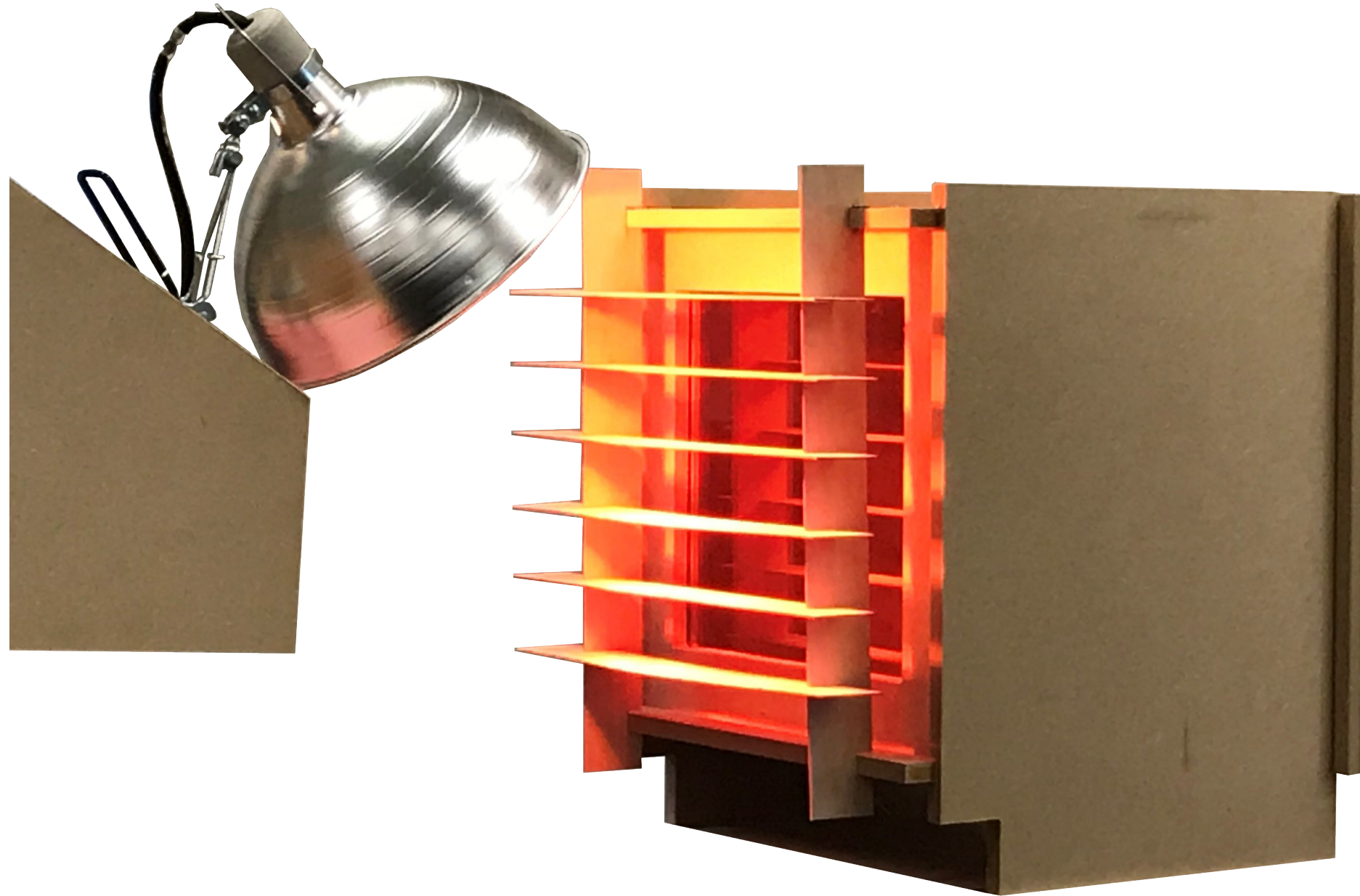


slate



asphalt

*Chewys Parra Paulino*  
*"passive shading"*





**thank you.**

**liz mccormick**

RA | LEED AP | CPHC

Assistant Professor  
University of North Carolina Charlotte  
lizmccormick@uncc.edu

TECHNOFORM

# U-Factor Matters In Hot Climates

Helen Sanders  
Technoform North America

Façade Tectonics Institute Forum, Houston, 2019



## U-factor matters in hot as well as cold climates

## TECHNOFORM



© Minneapolis Happening Magazine



© Marriott

# Energy Saving Potential of Thermally Broken Aluminum Frames in Tropical Climates

**TECHNOFORM**

Research Project Conducted by:



SERIS

Solar Energy Research  
Institute of Singapore

For

**TECHNOFORM**

Supported by



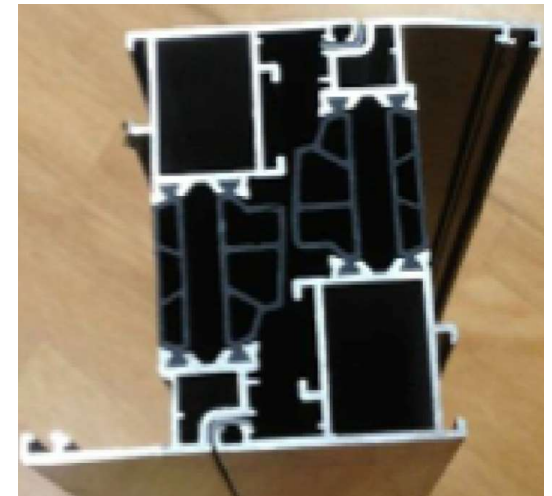
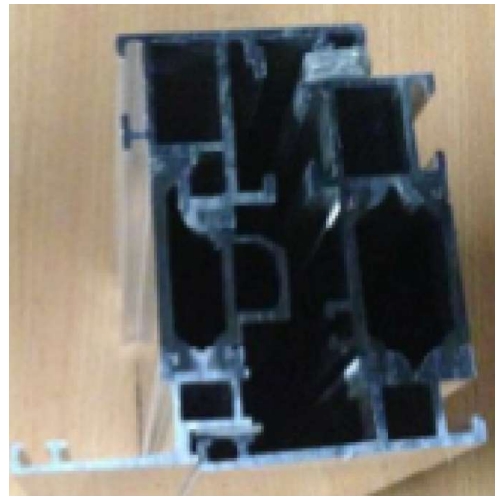
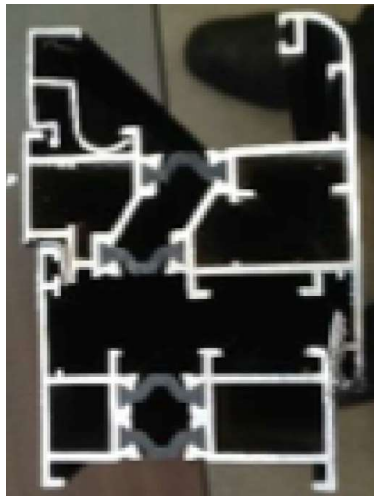
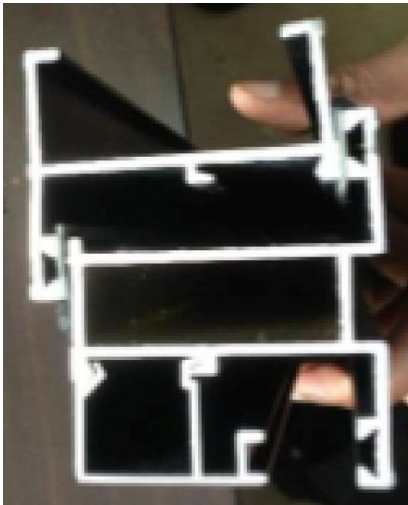
**MEIN-HARDT**



# Frames Tested

# TECHNOFORM

Increasing metal separation



Non-thermally broken

Low Performance thermally broken

Moderate Performance thermally broken

High Performance thermally broken

## Interior frame temperatures: Singapore

TECHNOFORM



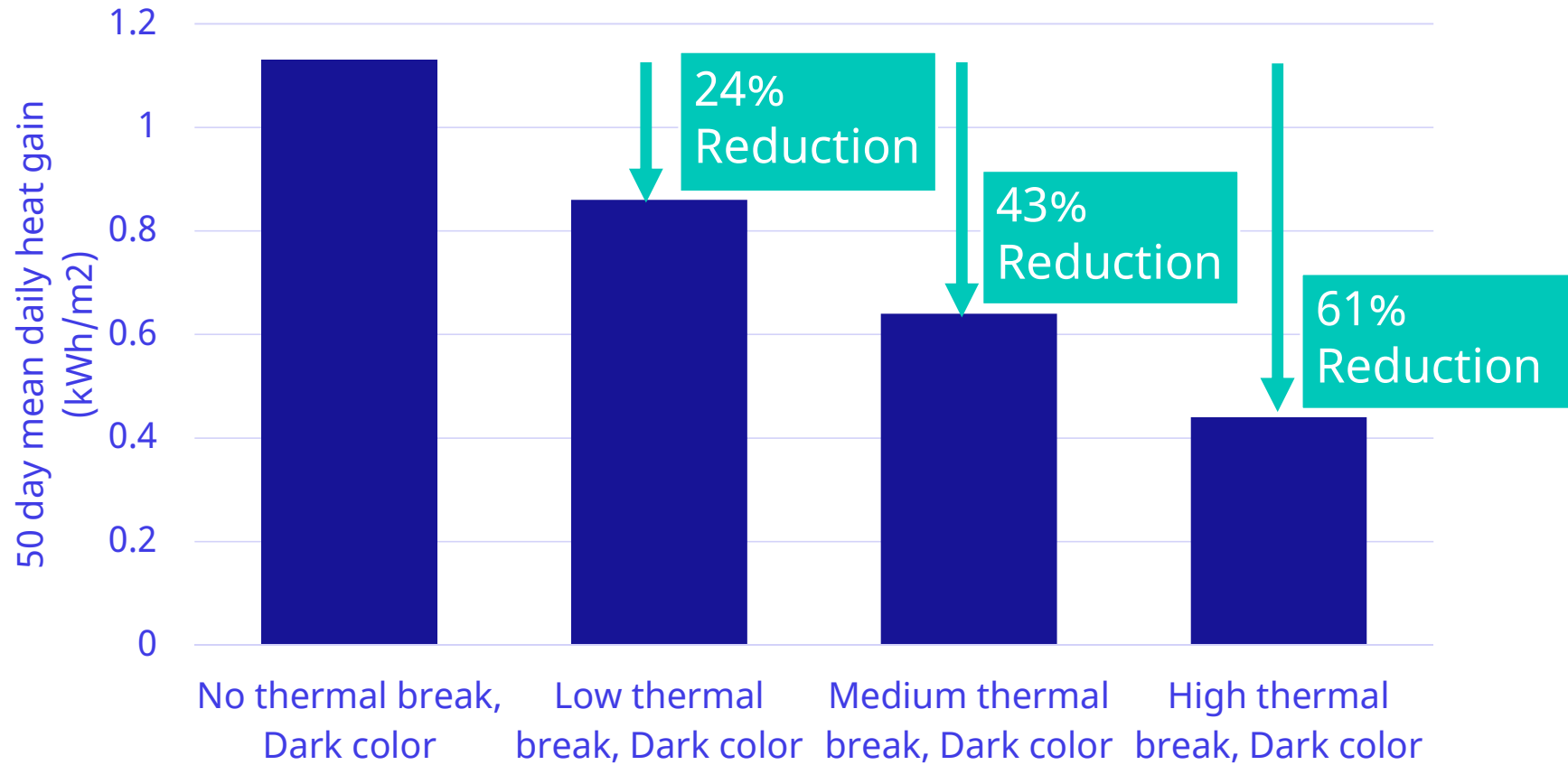
Dark and light colored frames



Solar Energy Research Institute of Singapore (SERIS) 2014, Pilot Study on Energy Saving Potential of Thermally Broken Aluminium Frames in the Tropical Climate.

# Mean Daily Heat Gain Through Frame: Singapore

TECHNOFORM

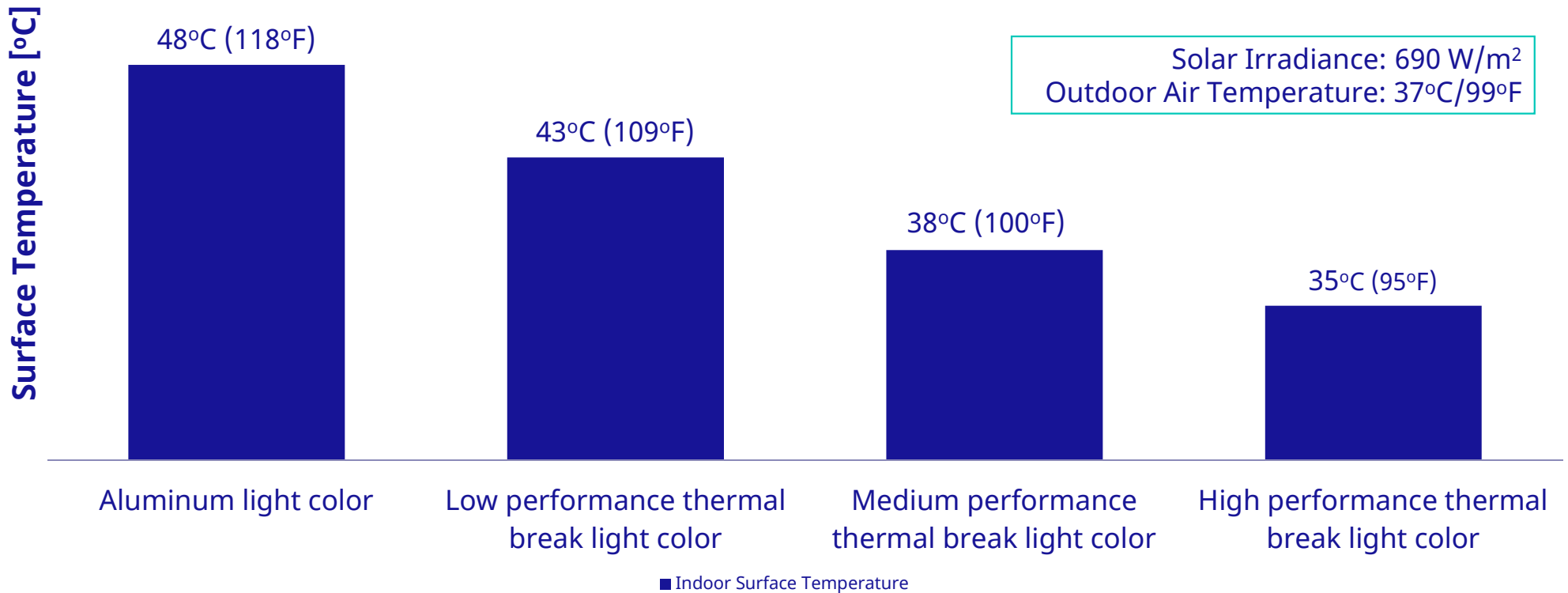


## Interior frame temperature: Singapore

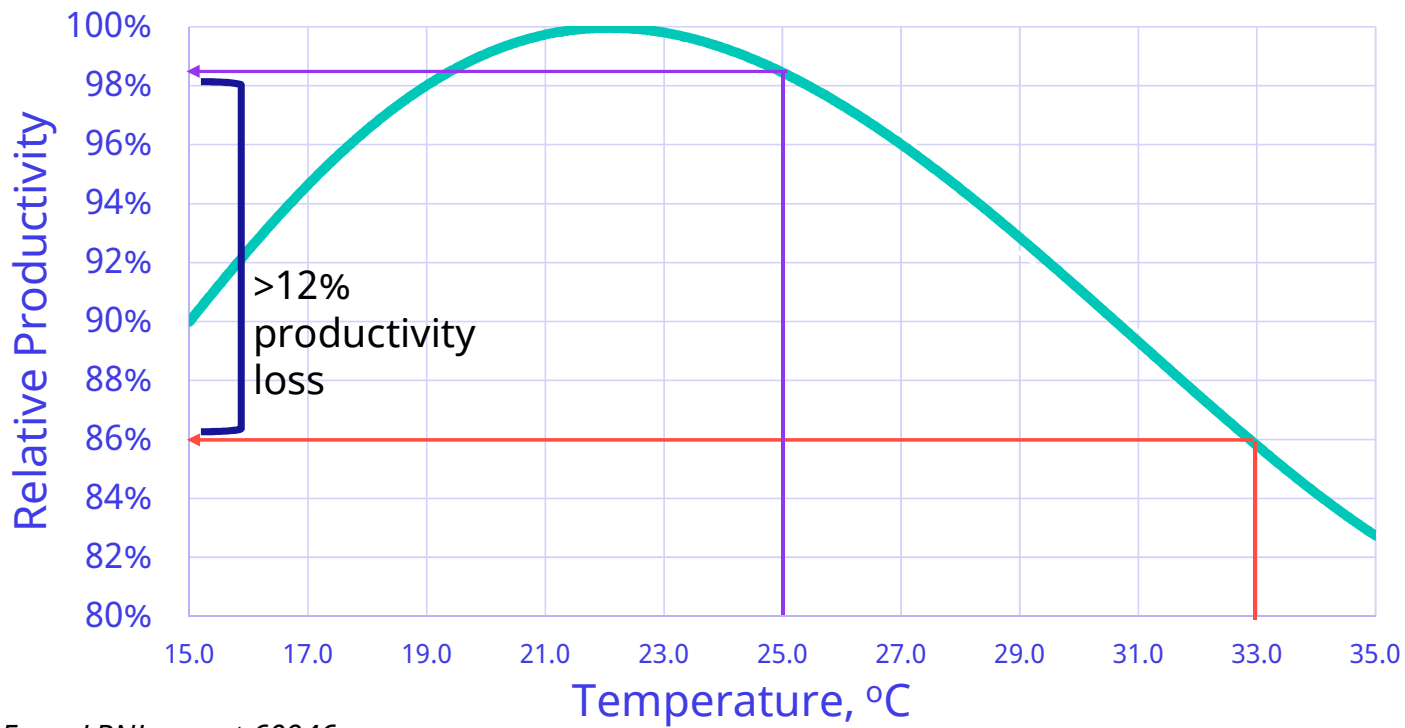
TECHNOFORM

High performance frame = better energy efficiency and comfort

**27%** difference in terms of frame indoor surface temperature!



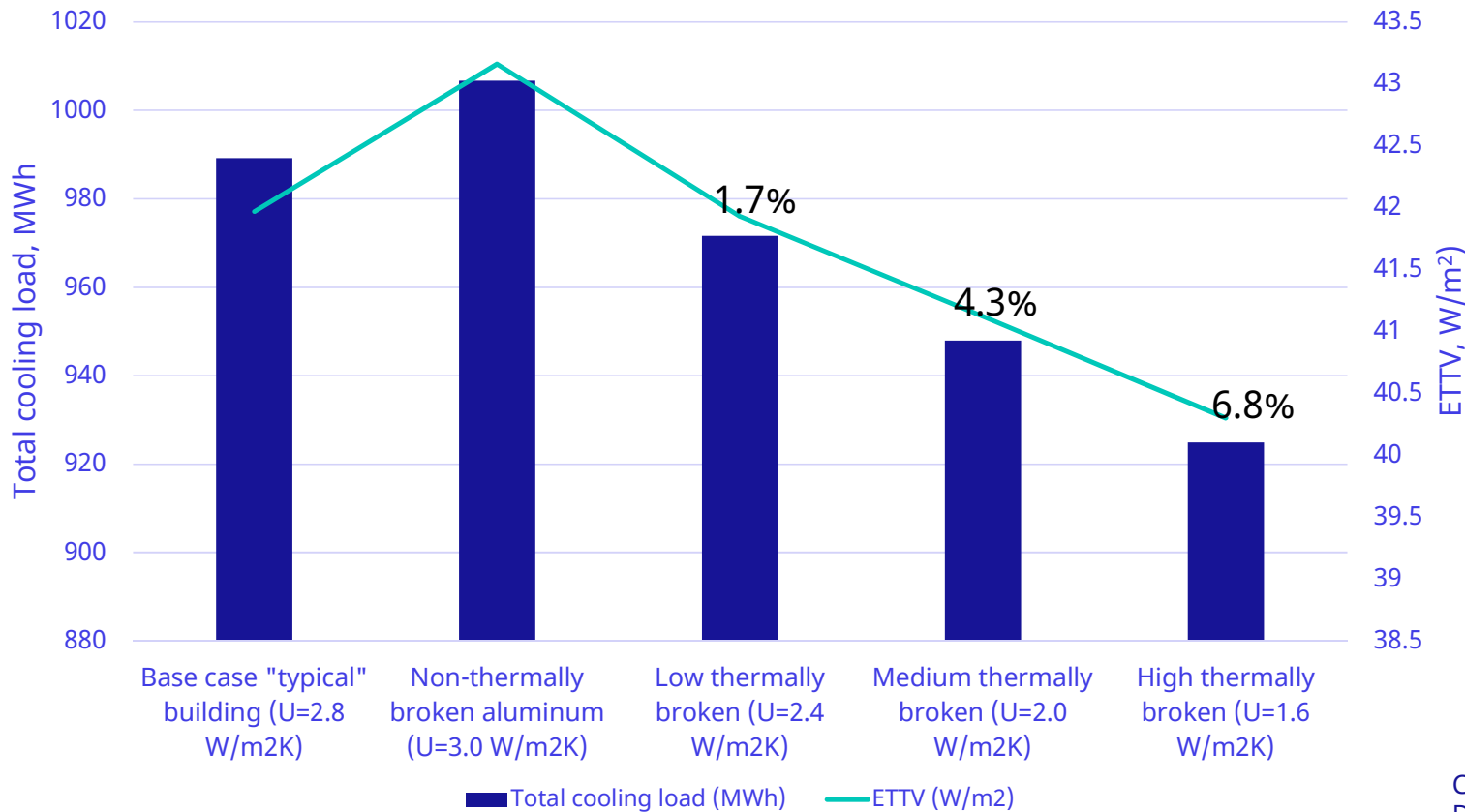
## Impact of Temperature on Productivity



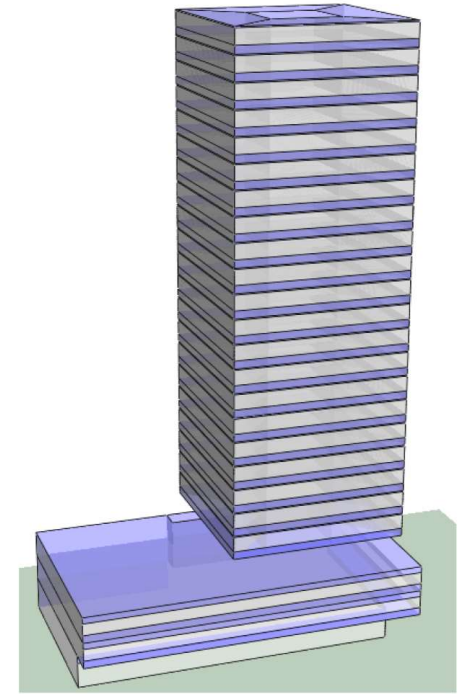
From LBNL report 60946

# U-Factor impact on Building Energy Performance: Hot humid climate (Singapore)

Impact of U-factor on building cooling load and ETTV



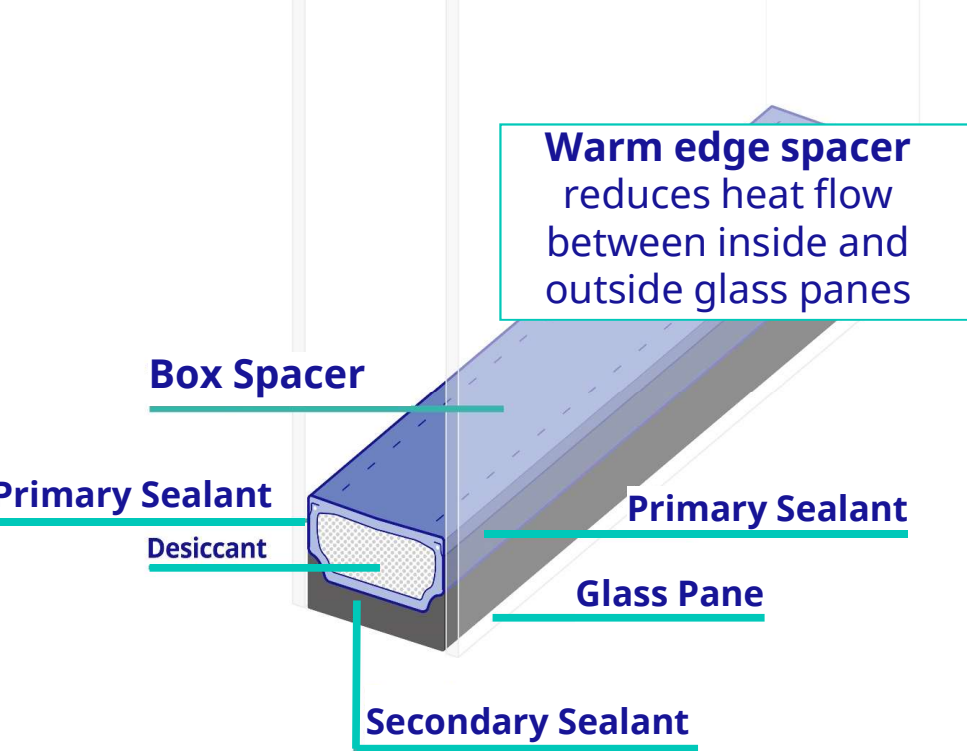
## TECHNOFORM



Indoor temp: 24°C  
 Floor area: 8,290 m<sup>2</sup>  
 WWR: 44%

Calculations by Building System & Diagnostics (BSD) for Technoform

# The Edge of Glass U-factor Matters Too



## Case Study: The Space Needle Renovation

Thermal + structural



## TECHNOFORM

**Olson Kundig** -  
Architects

**Front Inc** - Façade  
Engineers

**Arup** - Energy analysis

**Herzog Glass** - Glazier  
Pulp Studio - Insulating  
Glass (IG)

**Technoform** - IG Warm  
Edge Spacer

## Case Study: The Space Needle Renovation

## TECHNOFORM



Plastic hybrid stainless steel **warm edge** spacer key to

- Hitting thermal targets
- Chiller sizing
- Meeting structural needs

## Case Study: The Space Needle Renovation

## TECHNOFORM



Plastic hybrid stainless steel  
**warm edge** spacer key to

- Hitting thermal targets
- Meeting structural needs

Butt joints thermal weak link  
**Unsupported** edge condition  
required rigid warm-edge spacer

## Conclusions

## TECHNOFORM

- Non-thermally broken frames admit a significant amount of heat
  - By solar absorptance and uncontrolled conduction from outside to inside
  - Frame SHGC strongly correlated with its U-factor and solar absorptance
- Frame and edge of glass U-factor strongly influence energy performance and thermal comfort in hot climates and in summer
- Recommendation:
  - Use high performance thermal breaks and warm-edge spacer in all climate zones

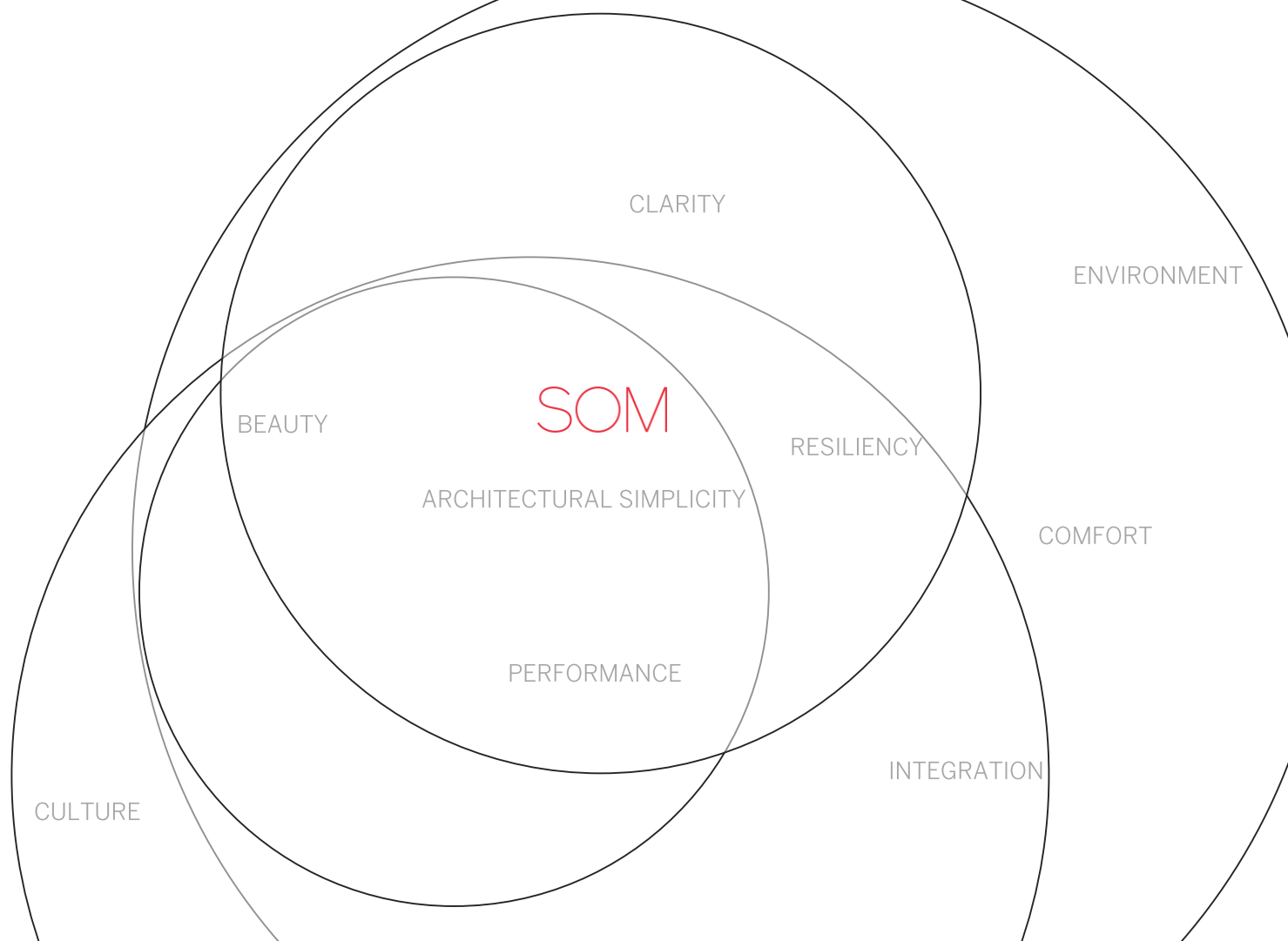
FAÇADE TECTONICS  
FAÇADE SYSTEM CONSIDERATIONS FOR HOT AND HUMID CLIMATE  
HOUSTON, OCTOBER 10TH, 2019

BANGKOK THAILAND MIXED USE PROJECT

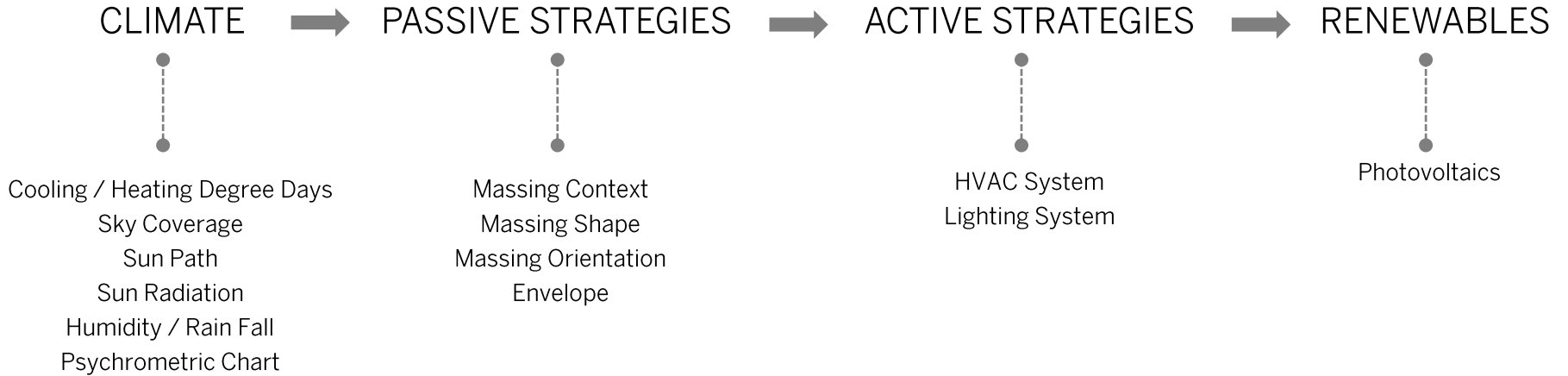
OLIVIER BROUARD  
SUSTAINABILITY ENGINEERING TEAM LEADER  
ASSOCIATE, PE, LEED AP BD+C

SOM

# DESIGN ETHOS



# HOLISTIC INTEGRATED APPROACH



# BANGKOK OFFICE

## Team members:

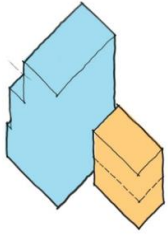
- Client: Confidential
- SOM:
  - PM: Steve Sobel
  - LD: Sean Ragasa
  - TD: Alex Welsh
  - HPD: Olivier Brouard
- WSP Built Ecology

## Project data:

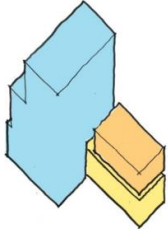
- Area: 518,000ft<sup>2</sup>
- Number of stories: 17
- Building height: 222ft
- Window-to-Wall Ratio: 47%
- Market: Office & Commercial
- ASHRAE Climate Zone: 1A



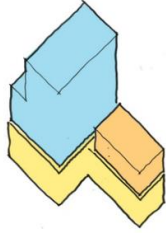
# DESIGN CONCEPT



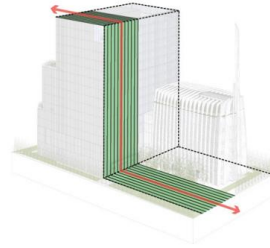
Office + Ecclesiastical



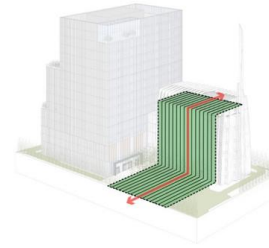
Office + Meeting House +  
Temple



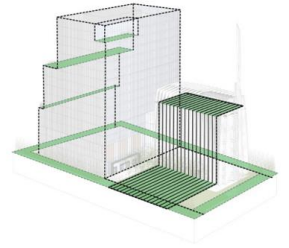
Podium +  
Tower/Temple



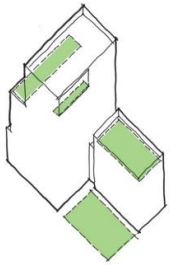
Office Identity



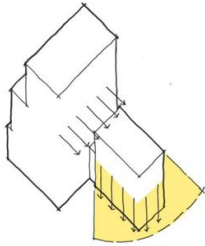
Temple Identity



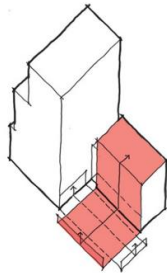
Project Gardens



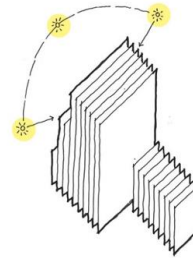
Gardens



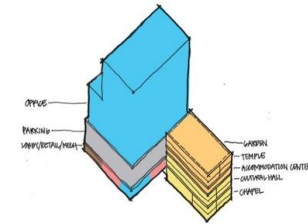
Views



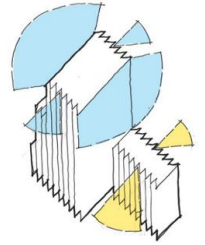
Extended Identity:  
From Roof Garden to Façade,  
Façade to Front Garden



Sun Shading



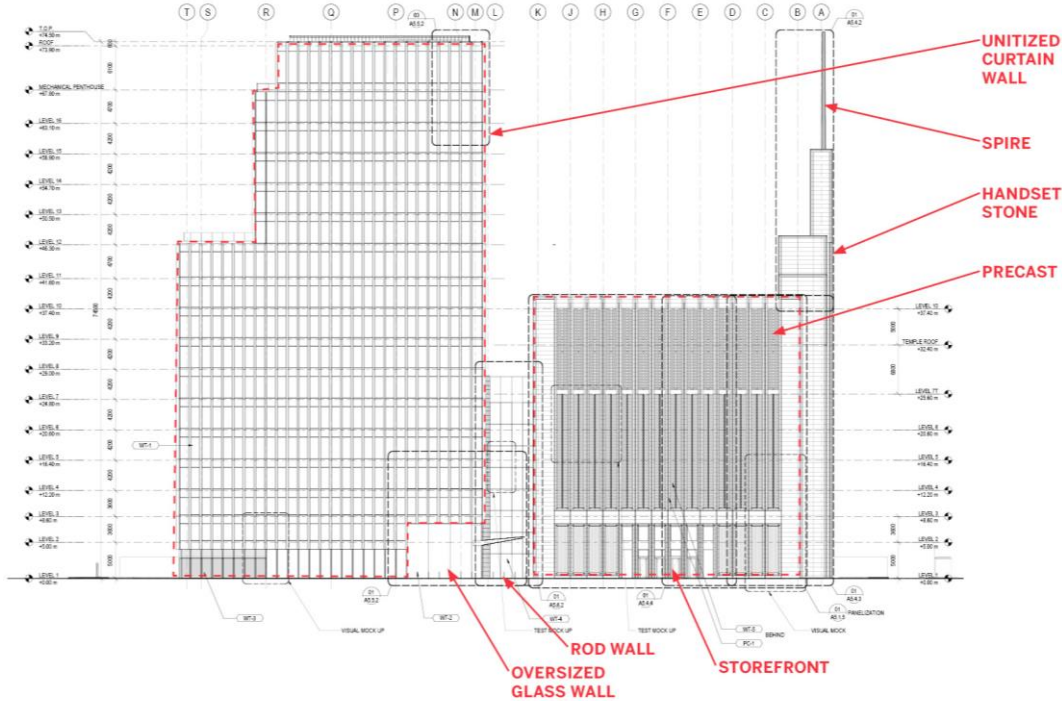
Program Stacking



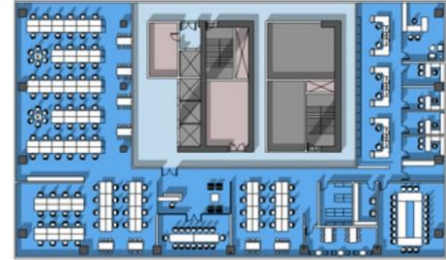
Optimized Views



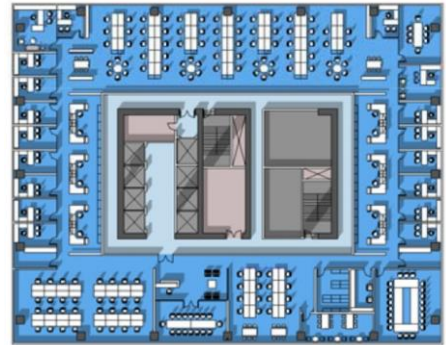
# BUILDING LAYOUT



Levels 12-16



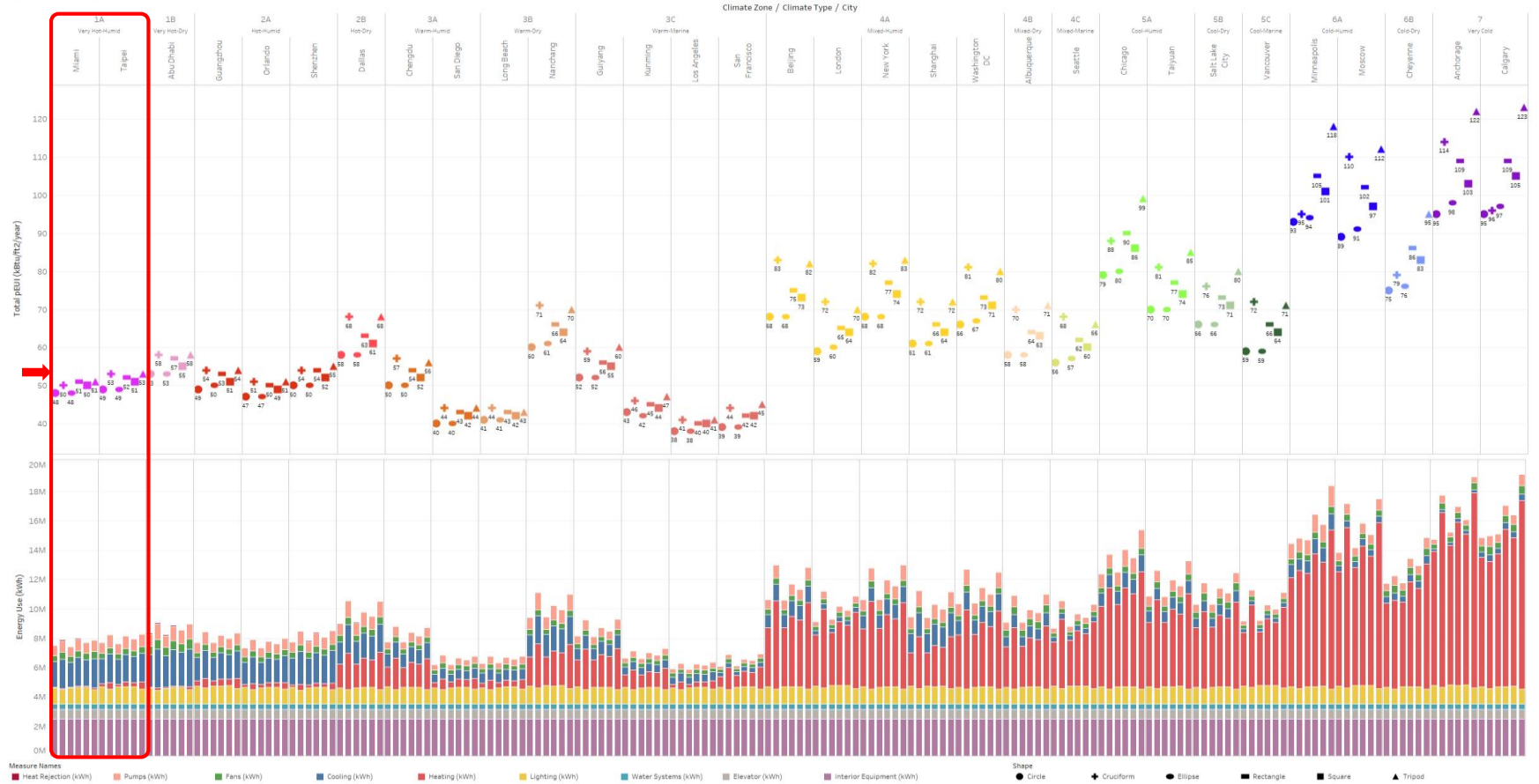
Levels 8-11





# MASSING EFFICIENCY RESEARCH

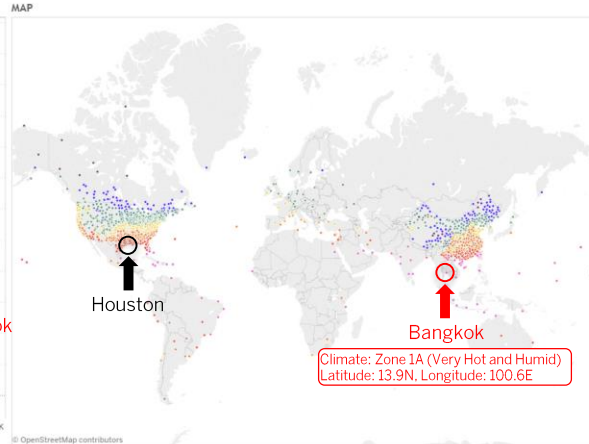
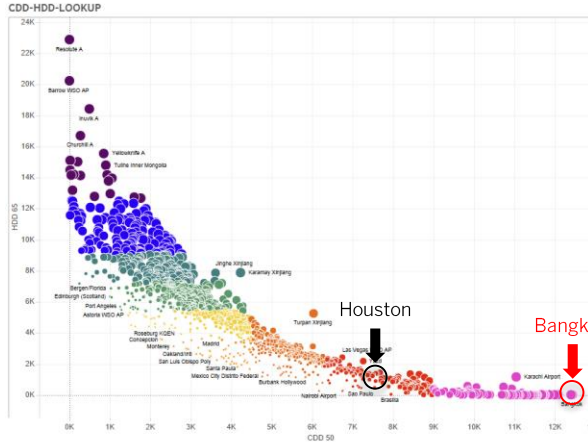
**SOM** Office Building Massing Shape Comparison - Annual predicted Energy Use Intensity (pEUI in kBtu/ft<sup>2</sup>) (500,000 GSF - 70%WWR - ASHRAE 90.1.2010)



# BANGKOK CLIMATE PROFILE

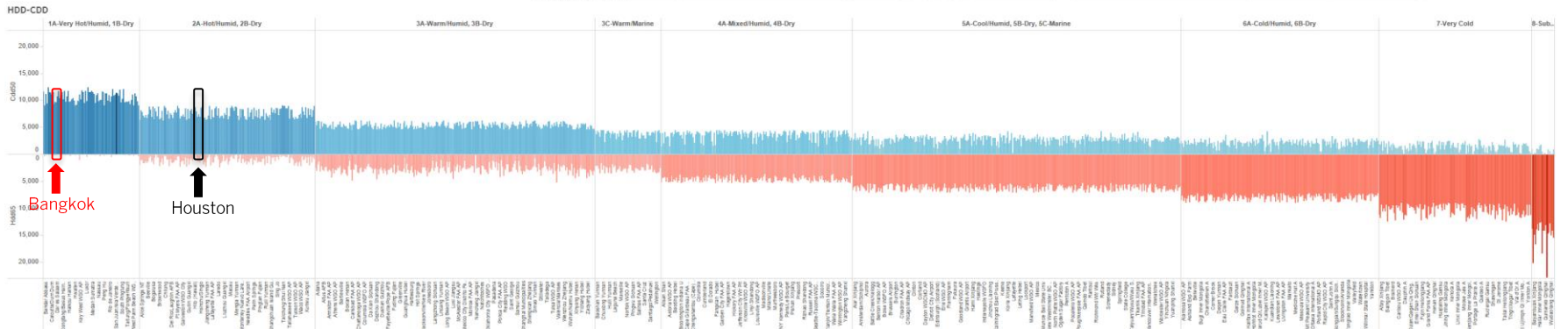
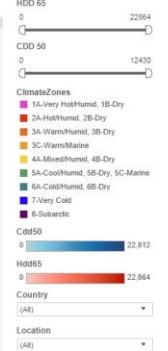
Source: ANSI/ASHRAE Standard 169-2006, Climatic Data

**SOM** WORLDWIDE CLIMATE ZONES COMPARISON TOOL (MAJOR CITIES INDEX MATCH)  
REFERENCE: ASHRAE CLIMATE DEFINITION

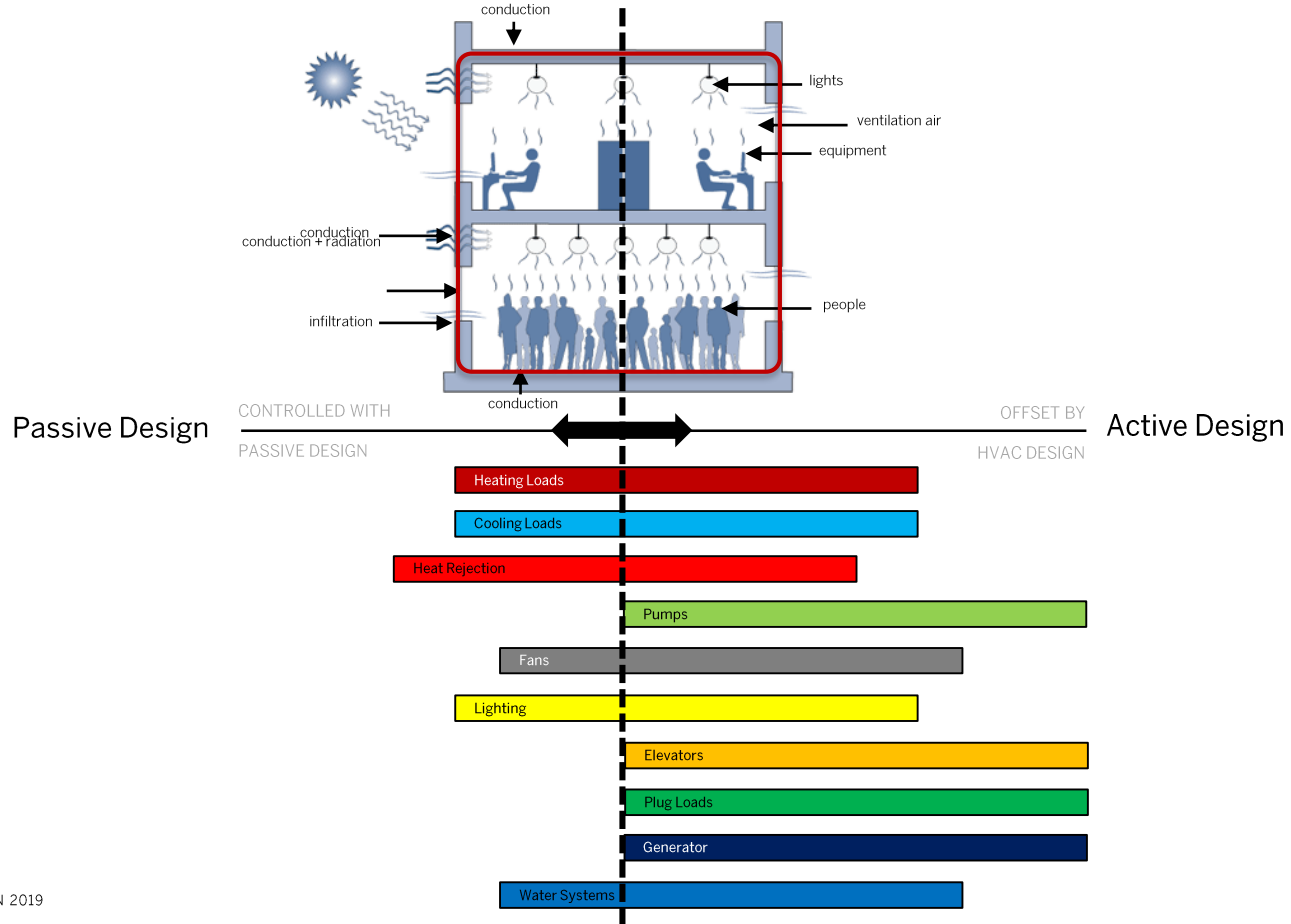


LOOKUP CITY LIST

Ahmedabad	31	11648	
Asuncion/Stressner	409	9005	
Bandar Abbas	133	11194	
Bangalore	2	9499	
Bangkok	0	12430	
Belem	9	11552	
Bombay/Santa Cruz	2	11372	
Calcutta/Dum Dum	26	11064	
Caracas/Maqueta	9	11501	
Chennai	275	8288	
Dakar/Yoff	6	9750	
Damian/Nada Hainan	245	9696	
Dar es Salaam	4	10755	
Damen Airport NT	0	11736	
Davao	24	10355	
Dhahran	381	10936	
Djakarta/Halimendra Java	9	11477	
Dongfang/Bassou Hainan	107	10169	
Fortaleza	1	11748	
FL Lauderdale	171	9735	
Guam (Gili)-Anderson AFB	9	10689	
Guantanamo Bay NAS Cte	9	11719	
Halkou Hainan	211	9659	
Hanoi/Giam	330	8668	
Hengchun	23	10407	
Hengchun/Wu Lu Tien	21	10407	
Honolulu WSFO AP (Oahu)	0	9949	
Houston	221	9043	
Jinghong Yunnan	82	9106	
Kao Hsiang	70	9940	
Kao Hsiang Int. Aipt	111	9702	

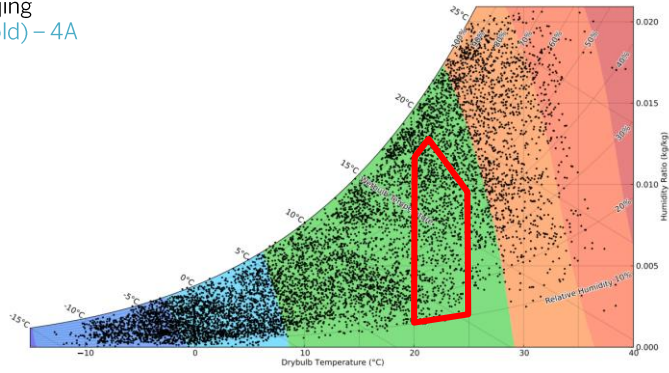


# THERMAL LOADS

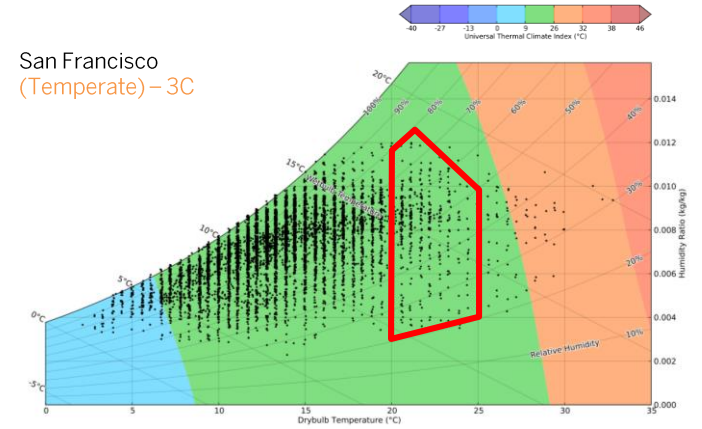


# CLIMATE PROFILES

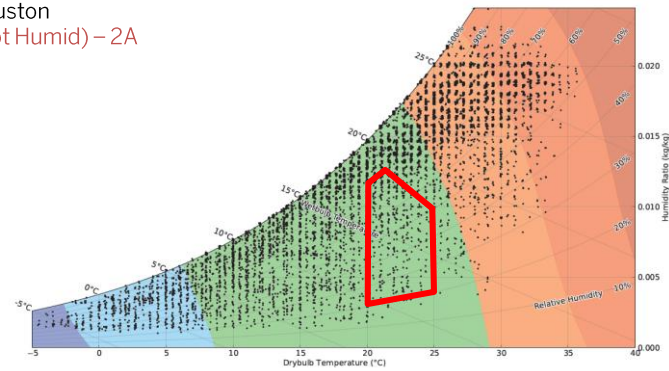
Beijing  
(Cold) – 4A



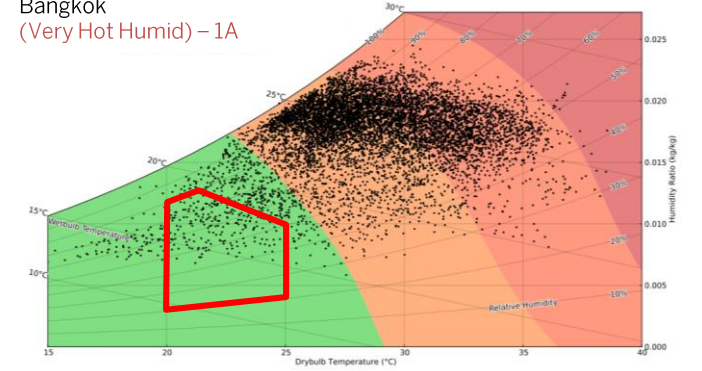
San Francisco  
(Temperate) – 3C



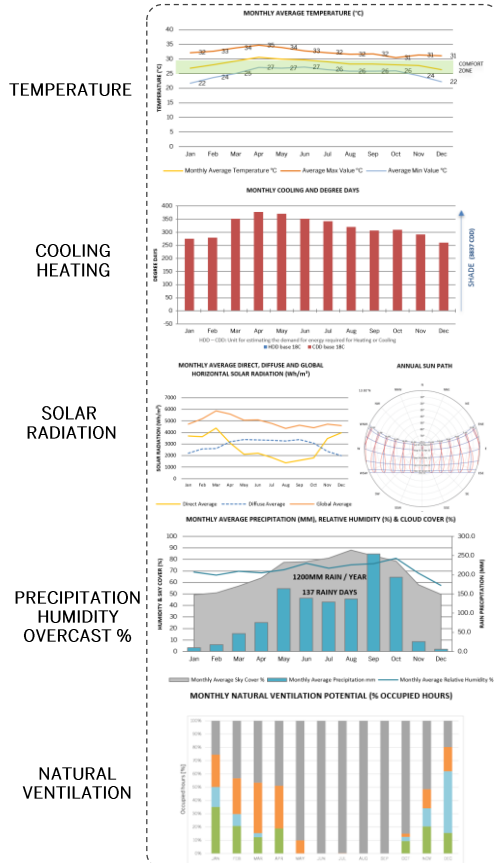
Houston  
(Hot Humid) – 2A



Bangkok  
(Very Hot Humid) – 1A



# BANGKOK CLIMATE



## PROGRAM

## DRIVERS

## RESPONSE

## DESIGN VARIABLE

OFFICE

SOLAR RADIATION + INTERNAL LOADS

MOSTLY COOLING ALL YEAR ROUND  
AVOID NATURAL VENTILATION POTENTIAL ONLY 10% OF THE YEARLY HOURS

REDUCE WINDOW TO WALL RATIO AND INCREASE SHGC COEFFICIENT PERFORMANCE TO REDUCE SOLAR TRANSMISSION  
PROVIDE SHADING DEVICES TO PREVENT GLARING ISSUES  
DEHUMIDIFY EFFICIENTLY

RETAIL

SOLAR RADIATION  
INTERNAL LOADS (LIGHTING /COOLING)

MOSTLY COOLING ALL YEAR ROUND  
DOMESTIC HOT WATER HEATING NEEDS ALL YEAR ROUND

PRECIPITATION  
HUMIDITY  
OVERCAST %

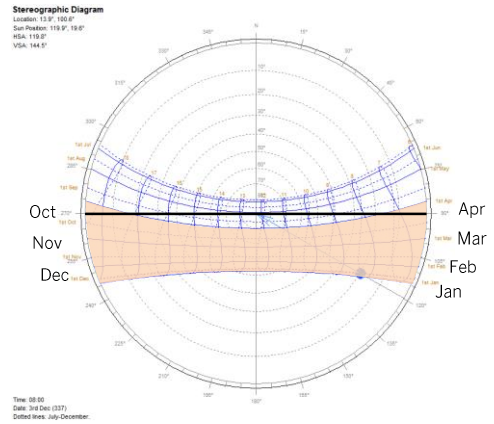
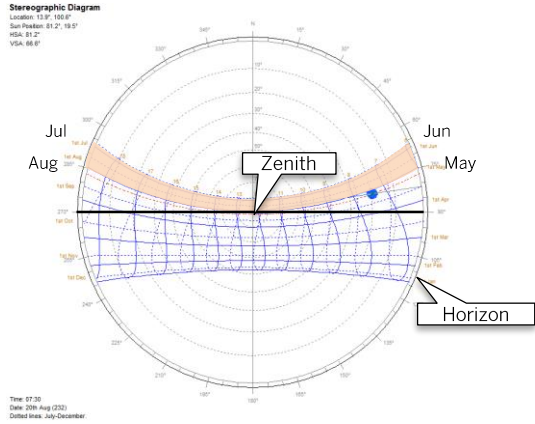
PUBLIC SPACE

SOLAR RADIATION  
MOSTLY HOT TEMP. AND HIGH RELATIVE HUMIDITY ALL YEAR ROUND  
HIGH PRECIPITATION

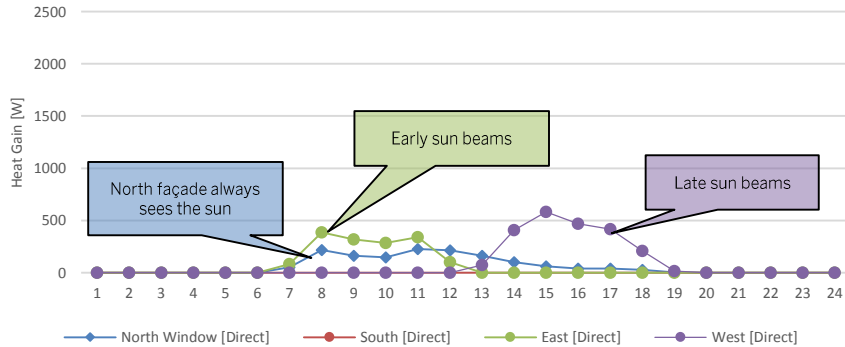
PROVIDE SHADING (SUN)  
PROVIDE SHELTER (RAIN)  
PROVIDE RAIN HARVESTING TANKS  
INCREASE OPEN SPACE RATIO WITH VEGETATION TO FILTER AND COOL AIR

PROVIDE SHADING (SUN)  
PROVIDE SHELTER (RAIN)  
PROVIDE RAIN HARVESTING TANKS TO COLLECT RAINWATER  
INCREASE OPEN SPACE RATIO WITH VEGETATION TO FILTER AND COOL SOUTH AND NORTH PREVAILING WIND / AIR

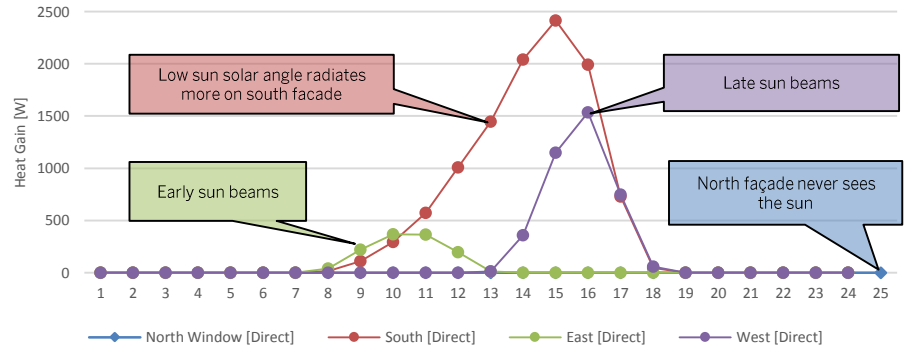
# SUN AZIMUTH AND ALTITUDE



Surface Window Transmitted Beam Solar Radiation [W/m2] - June 21th

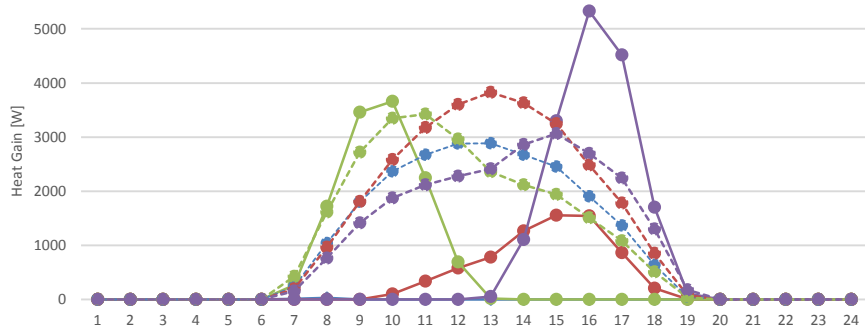


Surface Window Transmitted Beam Solar Radiation [W] - December 21th

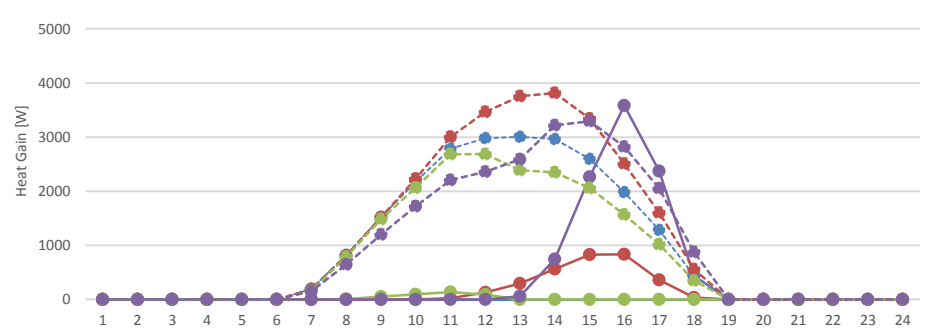


# WINDOW DIRECT TRANSMITTED BEAM AND DIFFUSE RADIATIONS

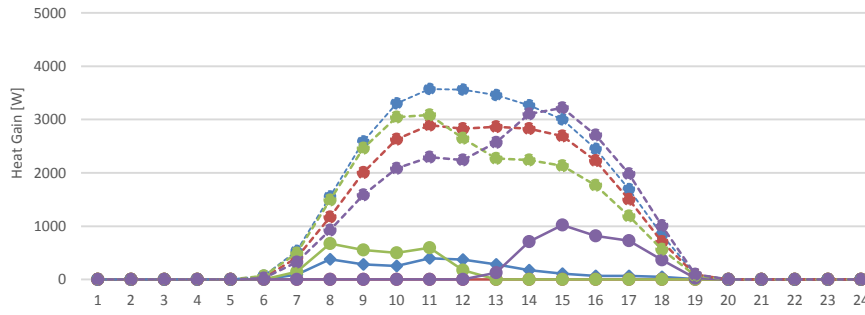
March 21th



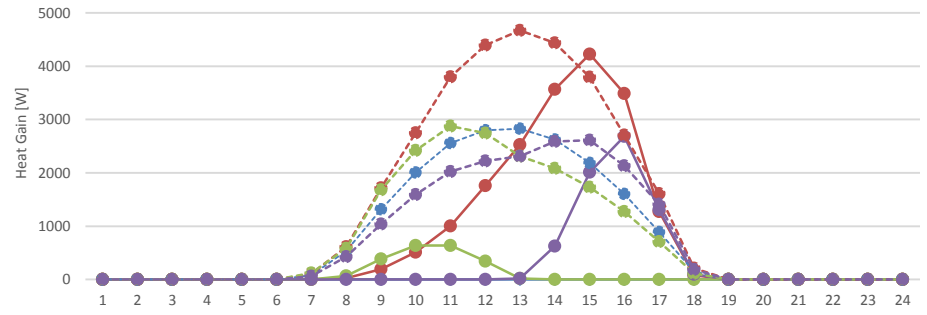
September 21th



June 21th



December 21th



- North Window [Direct]
- South [Direct]
- East [Direct]
- West [Direct]
- - -●- - North Window [Diffuse]
- - -●- - South [Diffuse]
- - -●- - East [Diffuse]
- - -●- - West [Diffuse]

# FAÇADE DESIGN



# DESIGN SOLUTIONS

To each design problem, there is a design solution



Tom Bongaerts/Facebook

# OVERALL THERMAL TRANSFER VALUE (OTTV)

Due to increasing demand of Air Conditioning in South Asia, energy governments have enforced through local code regulations that the heat gain shall be reduced to a specific limit.

The Overall Thermal Transfer Value (OTTV) is:

- a local code prescriptive requirements
- a measure of the average heat gain through the building envelope measured in  $W/m^2$ .

The Local Bangkok Ministerial Regulation regulates the rate of combined heat of external wall of the office, shouldn't exceed  $50W/m^2$  for the façade and  $15W/m^2$  for the roof.

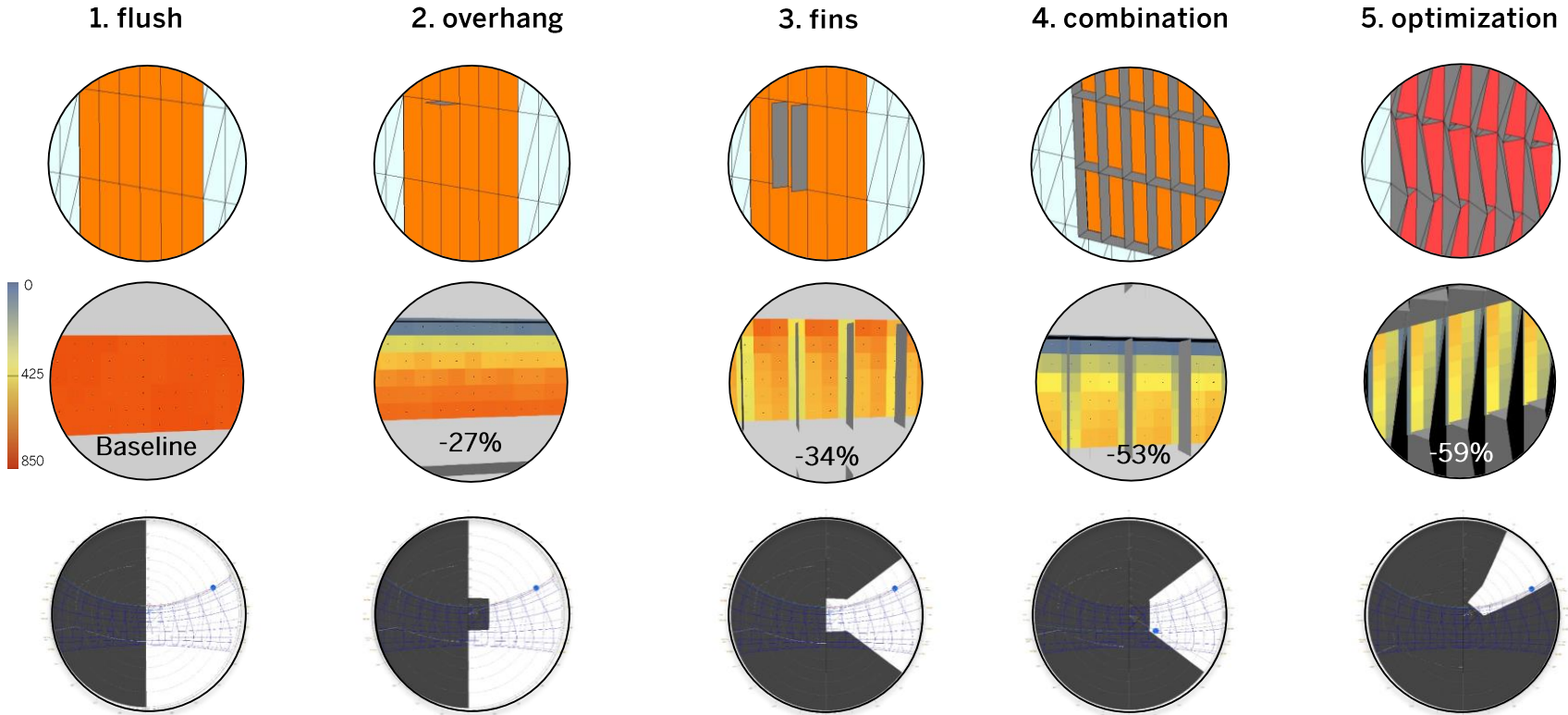
**Ministerial Regulation**  
**Prescribing Type or Size of Building and**  
**Standard, Criteria and Procedure in**  
**Designing Building for Energy**  
**Conservation**  
**B.E. 2552**



Department of Alternative  
Energy Development and Efficiency  
**MINISTRY OF ENERGY**

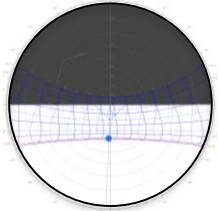
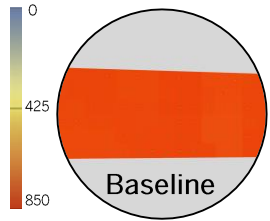
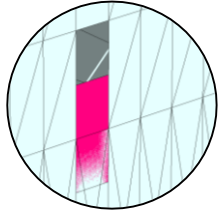


# SOLAR REDUCTION – EAST/WEST FACADE

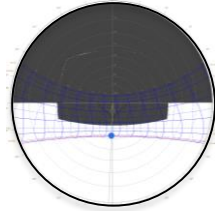
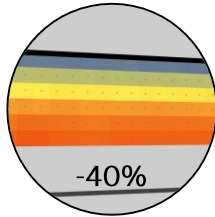
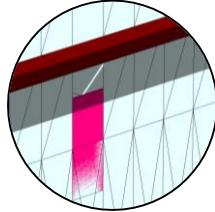


# SOLAR REDUCTION – SOUTH FACADE

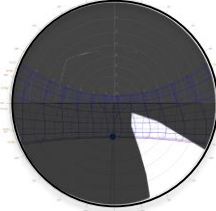
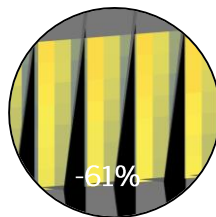
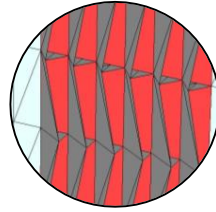
## 1. flush



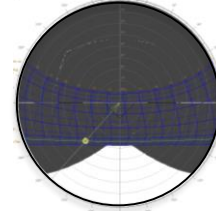
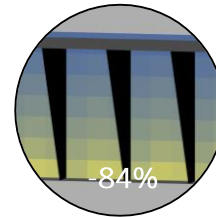
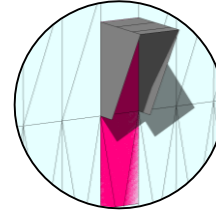
## 2. overhang



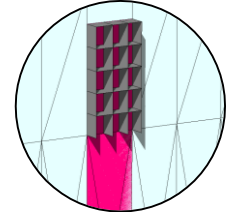
## 3. Uniformization



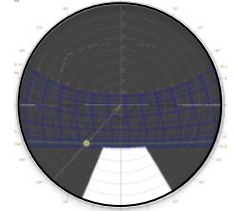
## 4. Optimization



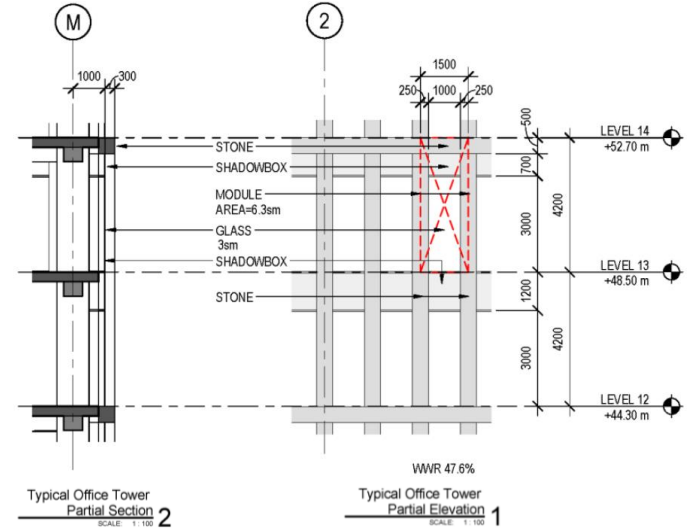
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# FAÇADE PERFORMANCE EVALUATION



MODULE 1	OTTV	NORTH	EAST	SOUTH	WEST
Area of opaque wall @ Fins/Overhangs	Awall	2.6	2.6	2.6	2.6
Area of opaque wall @ Spandrel	Asp	0.7	0.7	0.7	0.7
ASHRAE 90.1 2007 - Min Requirements - CZ 1A	Uwall	0.705	0.705	0.705	0.705
Granite @ Fins/Overhangs	$\alpha$	0.55	0.55	0.55	0.55
based on Density of wall construction - (23-199 kg/m <sup>3</sup> )	$\Delta T$	3.38	6.68	5.01	5.79
Aluminum back panel @ Spandrel in Air cavity	$\alpha$	0.18	0.18	0.18	0.18
Sub Total Watts (W)	Sub Total	3.71	7.33	5.50	6.35
Area of Glass	Awindow	3	3	3	3
Shading Coefficient of Center of Glass (=SHGC/0.87)	SC	0.264	0.264	0.264	0.264
lowest number between OPF and SPF	ESM	0.751	0.852	0.79	0.85
Solar Factor (W/m <sup>2</sup> )	SF	104	168	191	175
Sub Total Watts (W)	Sub Total	61.9	113.4	119.5	117.8
Total Watts (W) per module	Heat gain	65.57	120.69	125.00	124.16
Total module Area (m <sup>2</sup> )	Atotal	6.30	6.30	6.30	6.30
<b>Total OTTV (W/m<sup>2</sup>)</b>	<b>OTTV-avg</b>	<b>10.41</b>	<b>19.16</b>	<b>19.84</b>	<b>19.71</b>
ALL ORIENTATIONS		<b>17.28</b>			
		<b>&lt;50 W/m<sup>2</sup></b>			

ROOF - OFFICE	RTTV	ROOF
Area of Roof (m <sup>2</sup> )	Aroof	1450
ASHRAE 90.1 2007 - Min Requirements - CZ 1A	Uroof	0.369
Gravel absorptivity	$\alpha$	0.29
based on Density of roof construction - (>570 kg/m <sup>3</sup> )	$\Delta T$	7.9
Sub Total Watts (W)	Sub Total	1225.80
Area of Glass (m <sup>2</sup> )	Awindow	0
Shading Coefficient of Center of Glass (=SHGC/0.87)	SC	0.264
Solar Factor (W/m <sup>2</sup> )	SF	264
Sub Total Watts (W)	Sub Total	0.0
Total Watts (W) per unit area	OTTV-avg	1225.80
Total area (m <sup>2</sup> )	Atotal	1450.00
<b>Total OTTV (W/m<sup>2</sup>)</b>	<b>OTTV-avg</b>	<b>0.85</b>
		<b>&lt;15 W/m<sup>2</sup></b>

$$OTTV_w = \frac{(A_w \times U \times \alpha \times T_{DEQw}) + (A_{f_w} \times SC \times ESM \times SF)}{A_{o_w}} < 50W/m^2$$

CONDUCTION HEAT TRANSFER THROUGH OPAQUE WALL

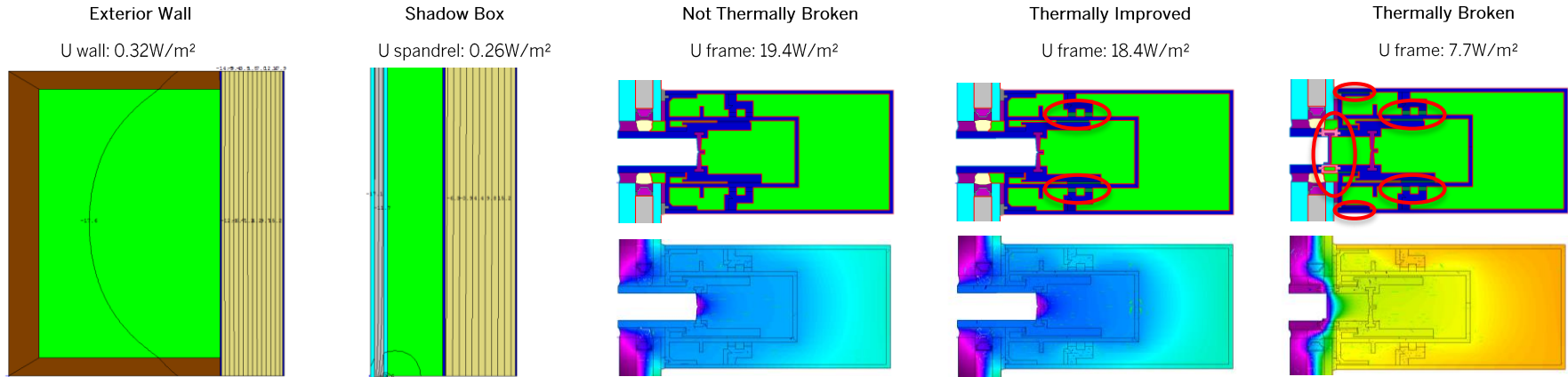
RADIATION HEAT TRANSFER THROUGH GLAZING

$$OTTV_r = \frac{(A_r \times U \times \alpha \times T_{DEQr}) + (A_{f_r} \times SC \times SF)}{A_{o_r}} < 15W/m^2$$

CONDUCTION HEAT TRANSFER THROUGH OPAQUE ROOF

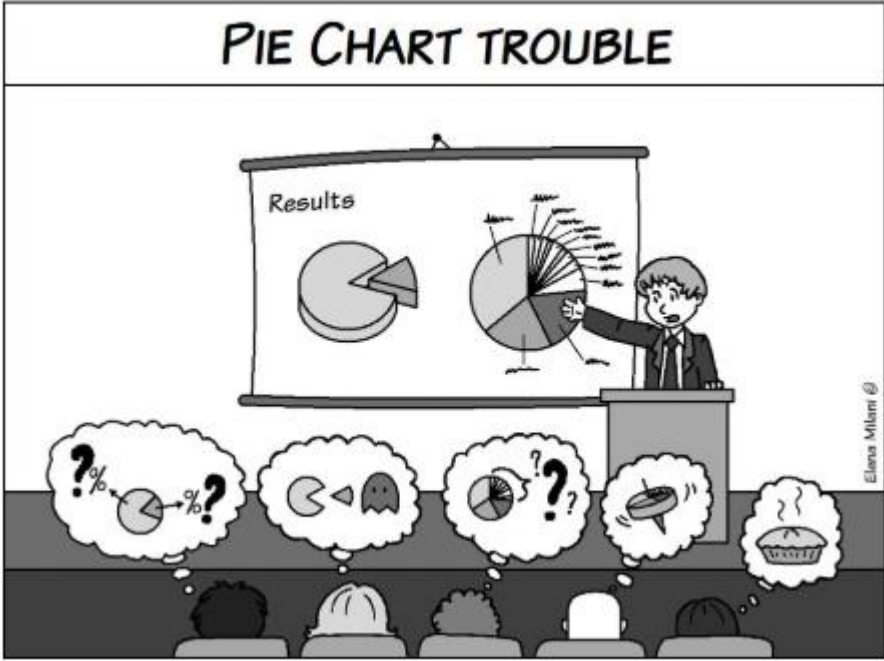
RADIATION HEAT TRANSFER THROUGH GLAZING

# FENESTRATION THERMAL TRANSMITTANCE

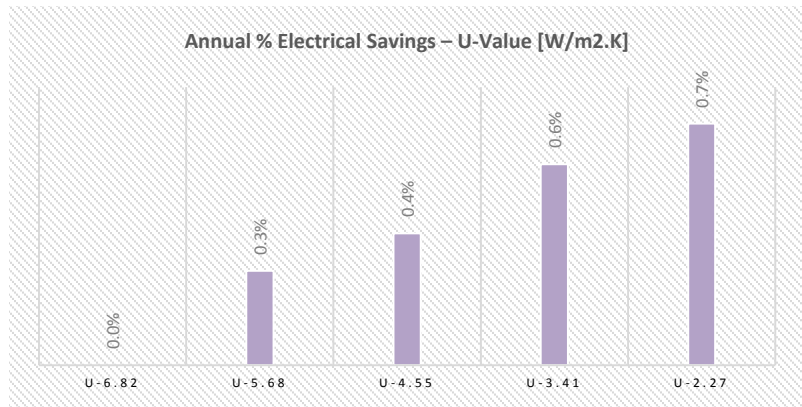
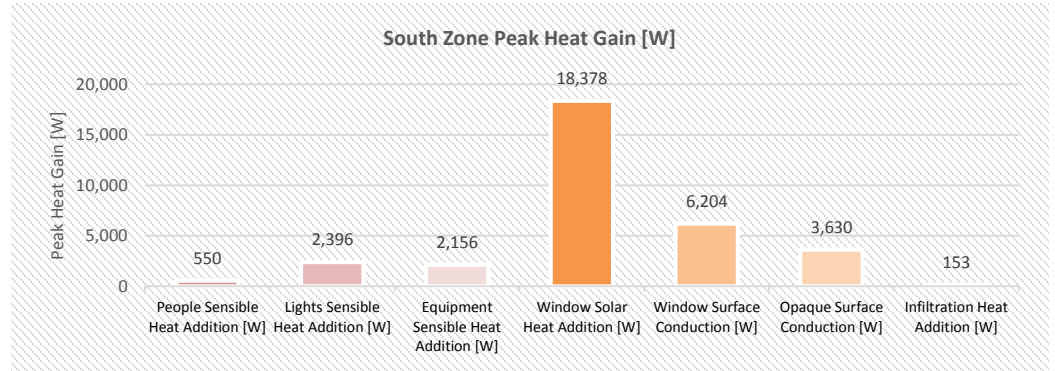
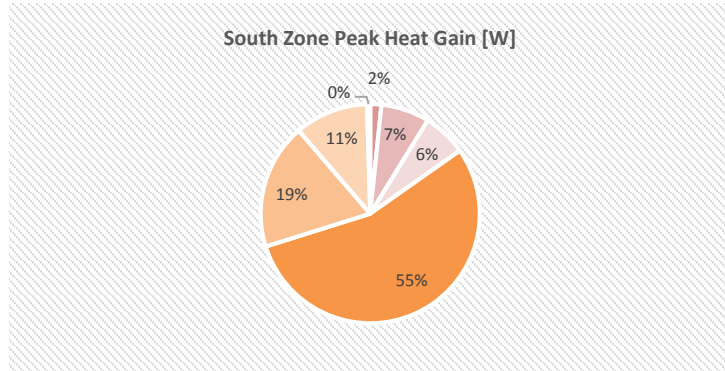


- ASHRAE 90.1 2007 minimum performance:
- Façade - U-Wall (Steel-Framed): 0.705 W/m<sup>2</sup>.K
  - Roof - U-Roof (Metal Building): 0.369 W/m<sup>2</sup>.K

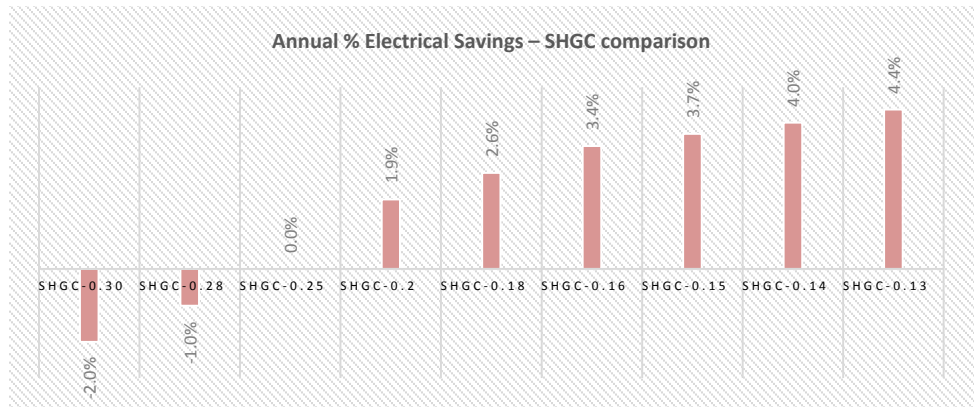
# DATA ANALYTICS



# FENESTRATION PERFORMANCE COMPARISON

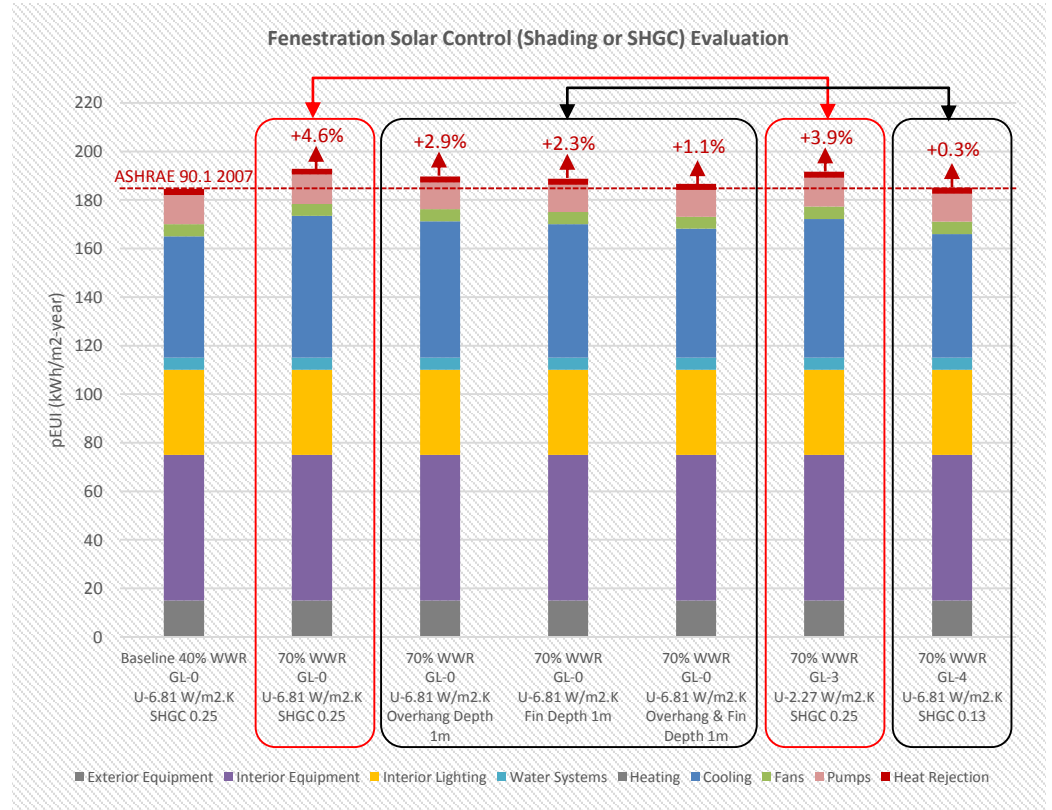
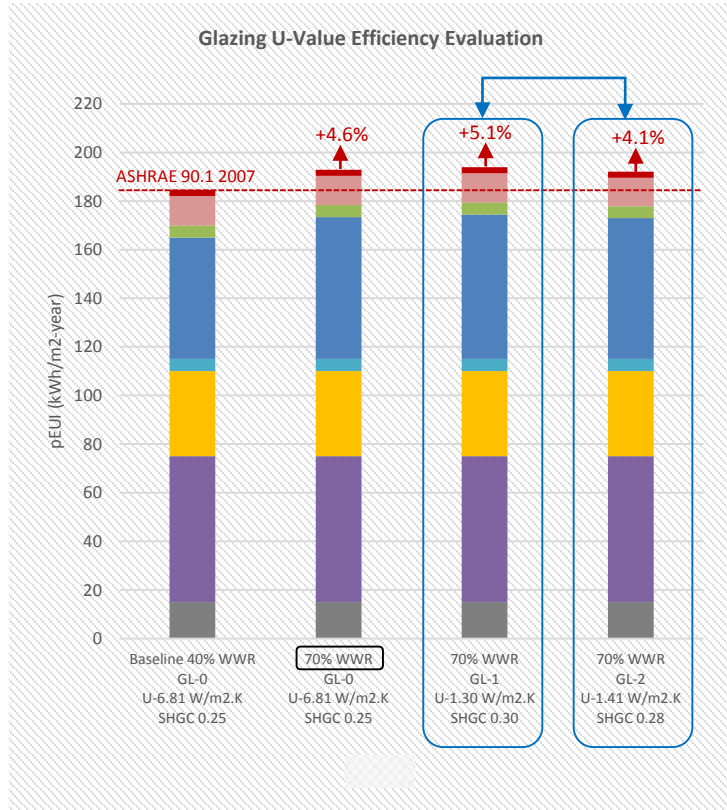


(U-value 6.81 W/m<sup>2</sup>.K, WWR 70% across all runs)

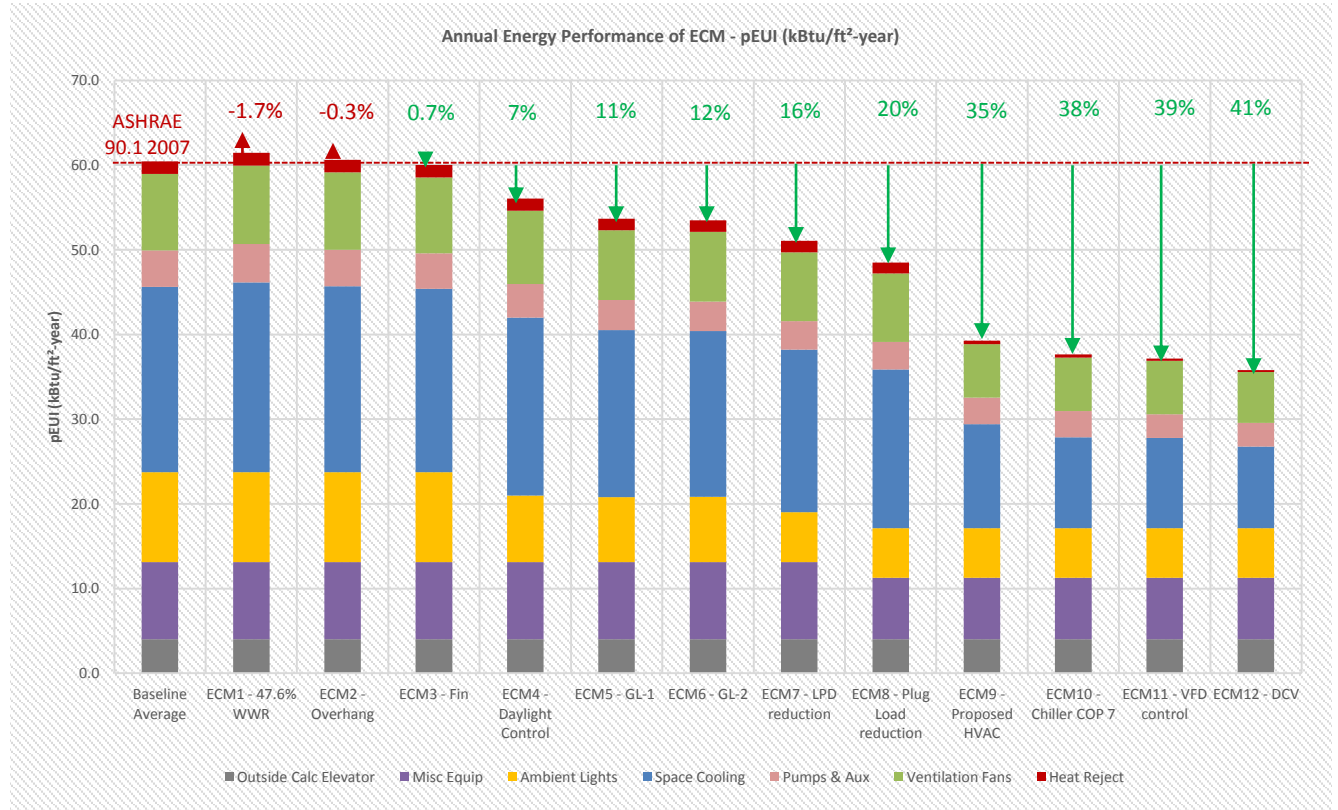
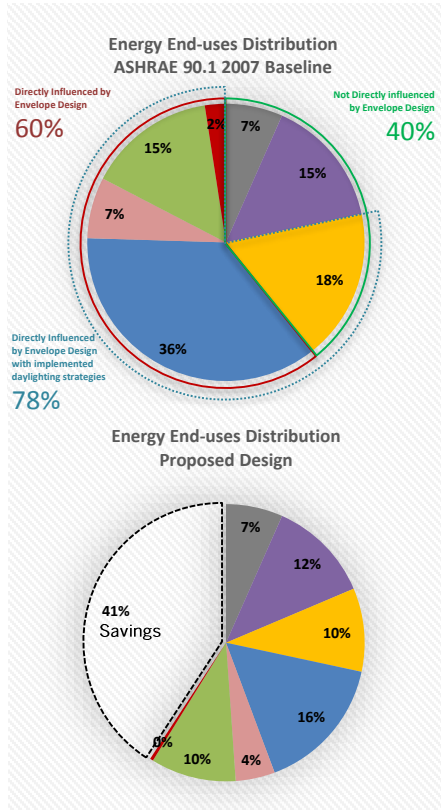


(SHGC 0.25, WWR 70% across all runs)

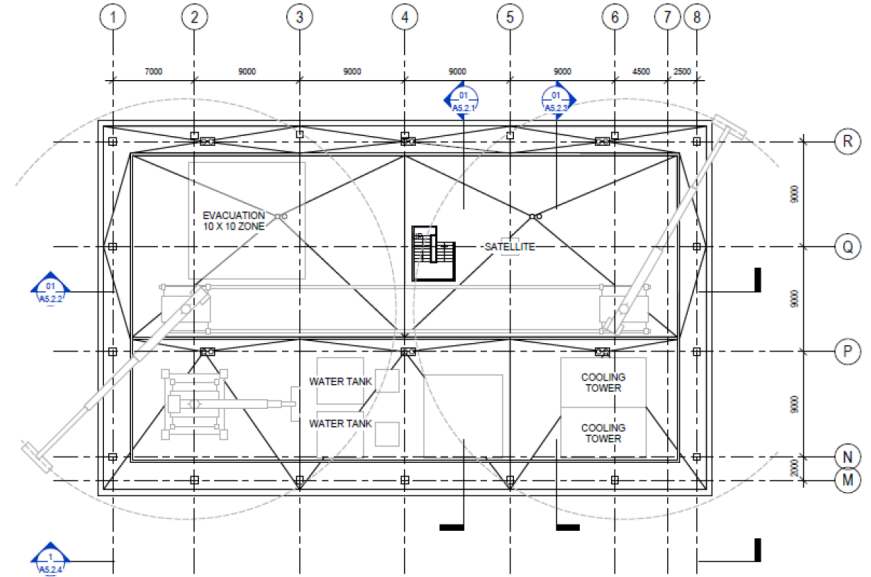
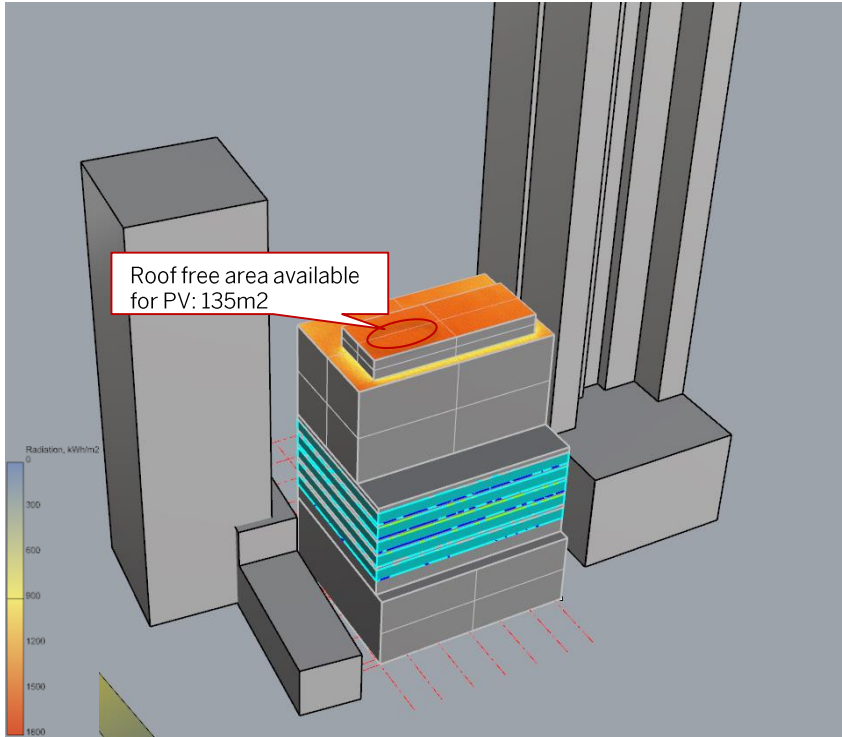
# PASSIVE DESIGN EXPLORATION



# ENERGY CONSERVATIVE MEASURES

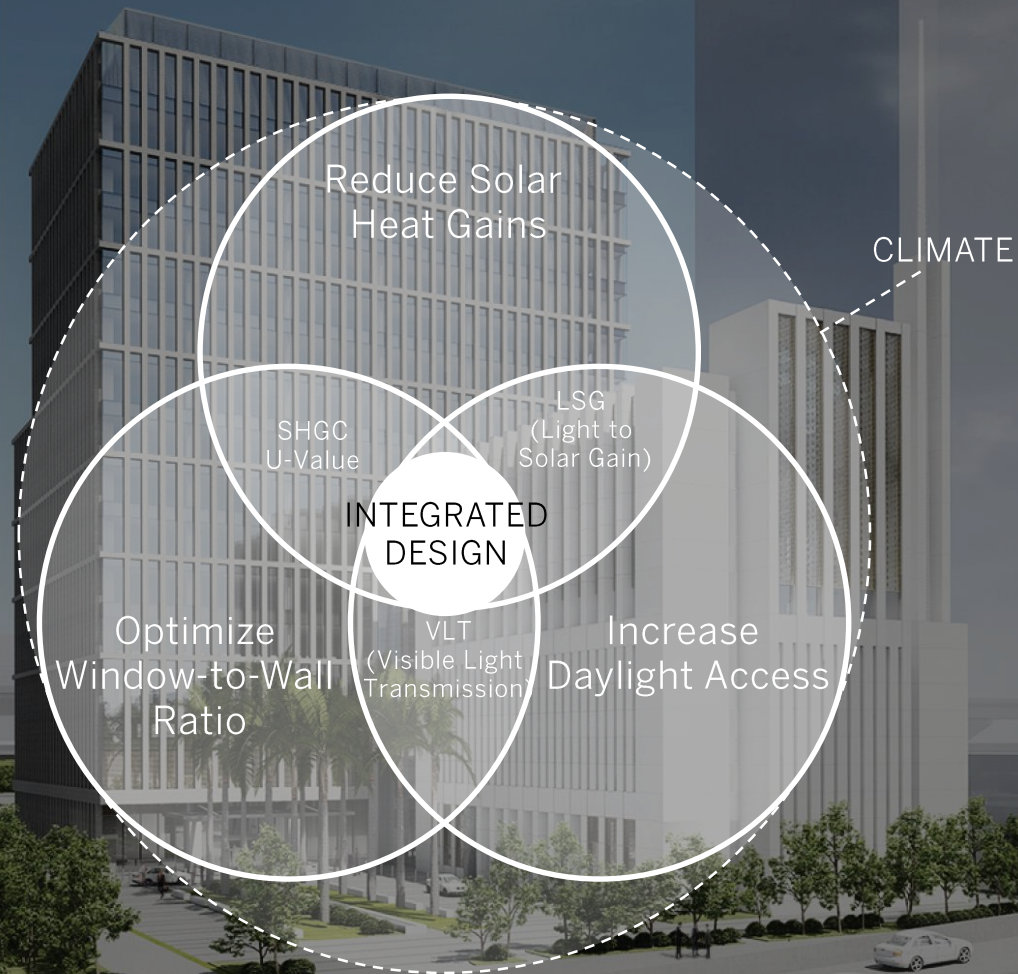


# RENEWABLES ASSESSMENT

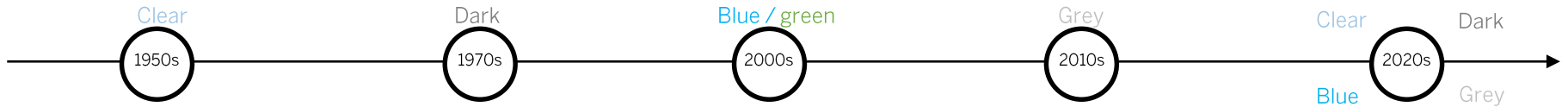


OVERALL FLOOR PLAN - ROOF 16  
SCALE: 1 : 200

# TAKEAWAY



# FAÇADE RESILIENCY



Monolithic



Laminated tinted



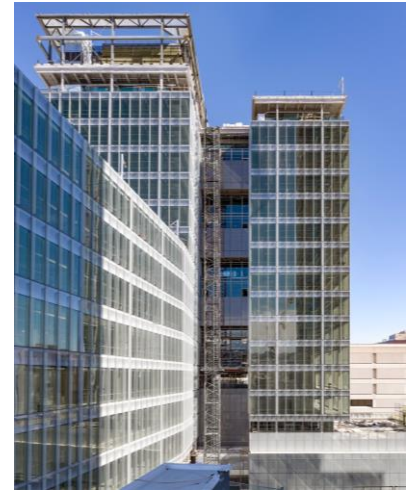
Double pane insulated w/ low-e



Double pane insulated w/ low-e



Double pane insulated w/ low-e Electrochromic Glass



SOM

# SWEAT EQUITY

Facade System Considerations for Hot and Humid Climates

## SPEAKERS



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