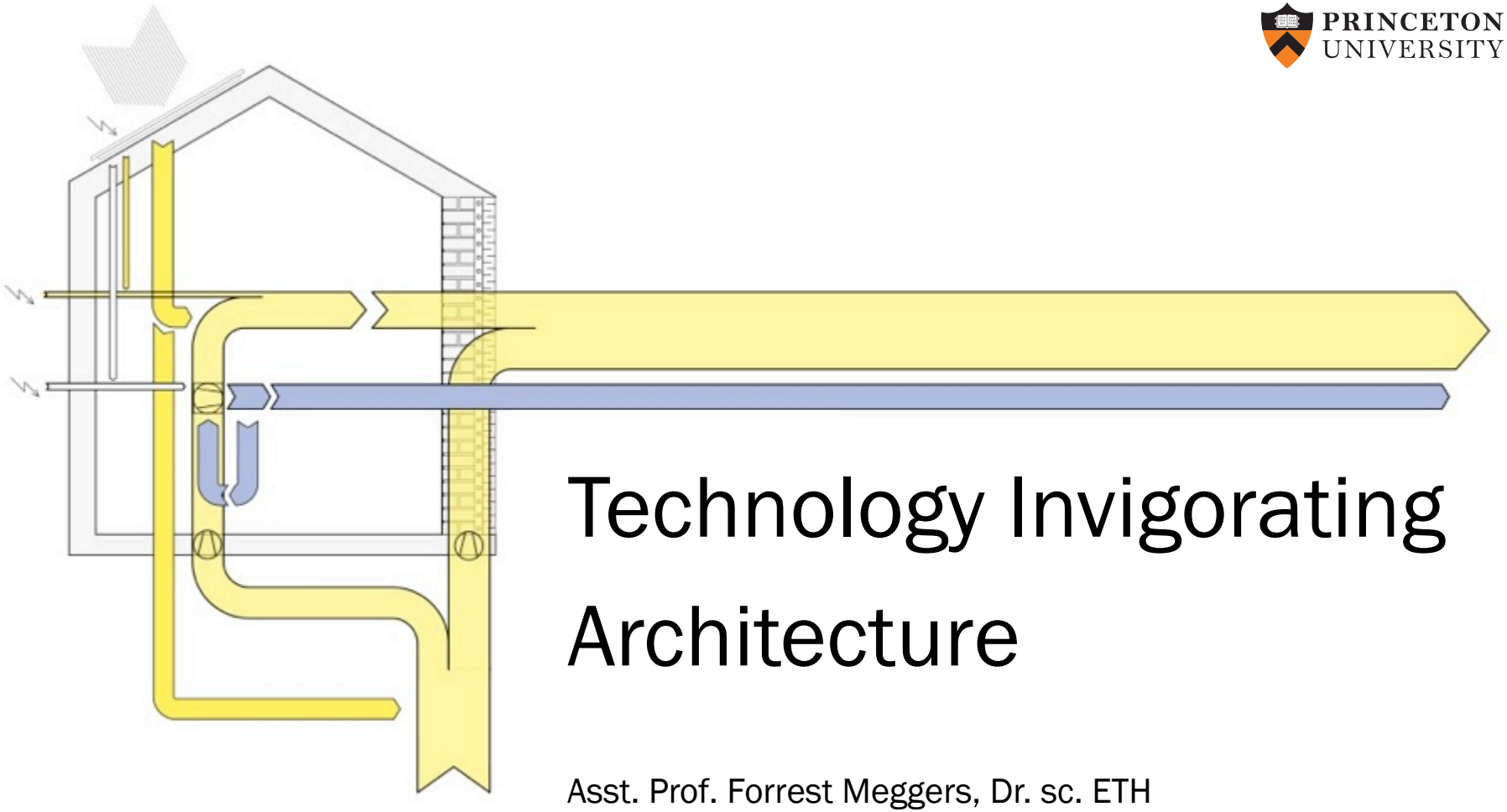
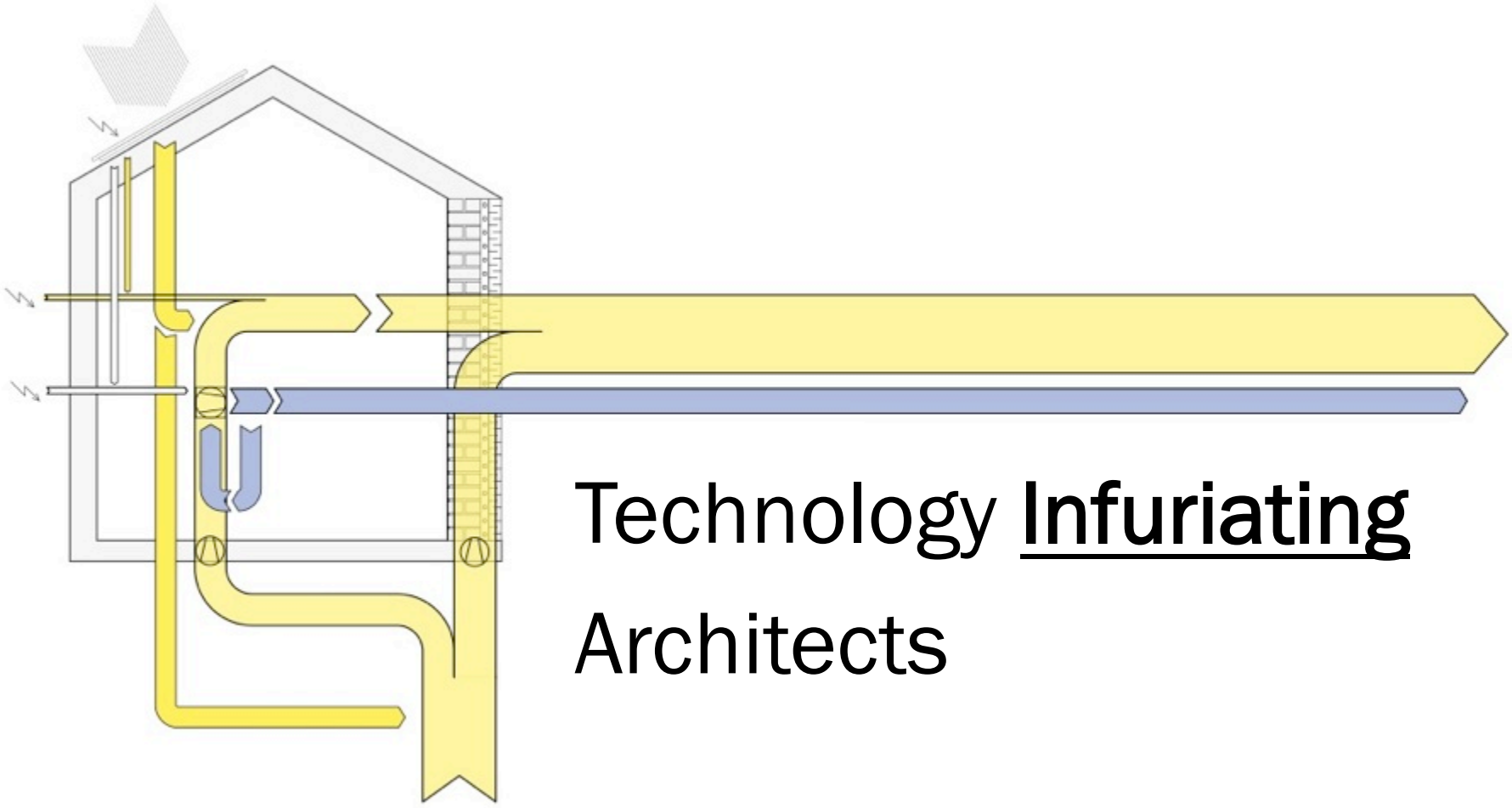


Technology Invigorating Architecture

Asst. Prof. Forrest Meggers, Dr. sc. ETH
School of Architecture +

andlinger center
for energy+the environment



Technology **Infuriating**

Architects

Technology + Architecture


Not add-on


Better?
Bullitt Center
Living Building:
Net Zero Energy
Net Zero Water

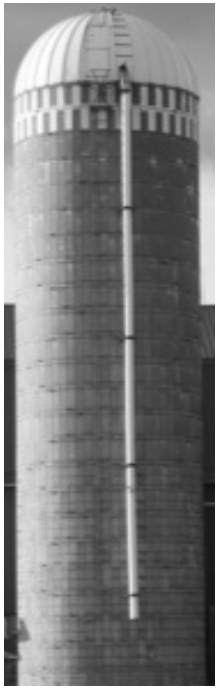

Better?
Bullitt Center
Living Building:
Net Zero Energy
Net Zero Water
AMAZING!


Better?
Bullitt Center
Living Building:
Net Zero Energy
Net Zero Water
“UGLY!”
says School of Architecture

Beyond technology development
… technology **integration**
across disciplines

Building design silos

Engineering



Iowa
Univ. of Iowa

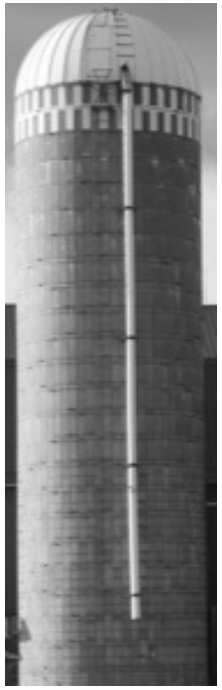
BSE Mech Eng
MS Env Eng

Architecture

New York
NASA GISS

Bridging the divide

Engineering



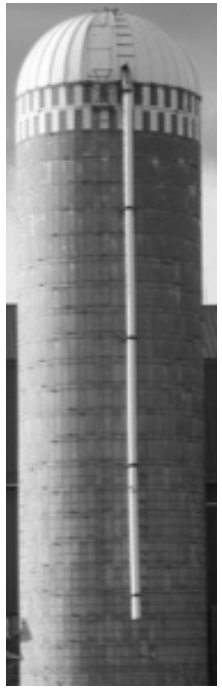
Dr. sc.

ETH Zurich

D-Arch ITA
Inst. for
Tech. in
Arch.

2006

Architecture



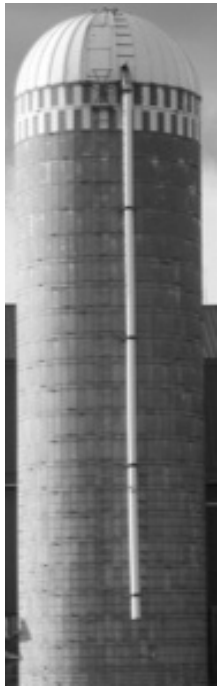
Bridging the divide

Engineering

Architecture

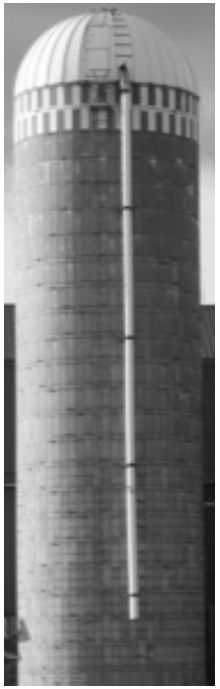
Andlinger Center

Applied Science
Technology
Analytics



Asst. Prof.

Forrest
Meggers

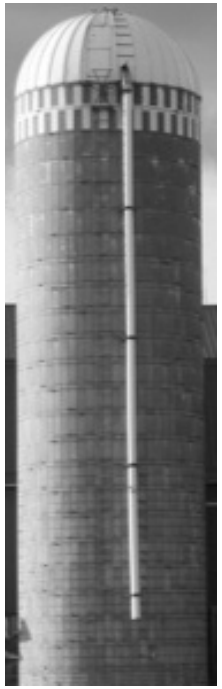


School of Architecture

Humanities
Technique
Aesthetics

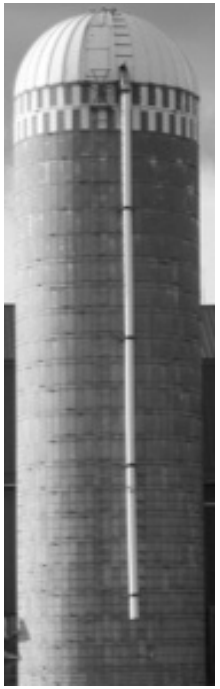
Bridging the divide

Engineering



Exergy
??

Architecture



for architects?

…not just a misspelling

… a better measure of energy potential

Understanding value

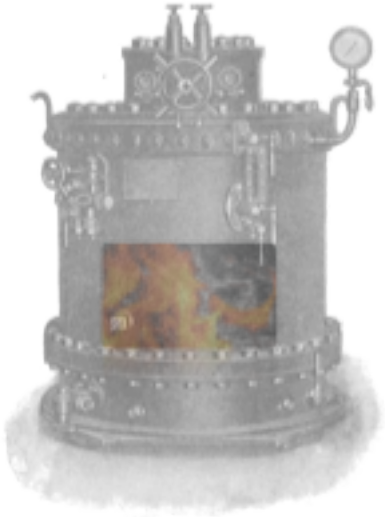
50 dollars

50 dollars

Both amount and value matter

50 dollars US ≠ 50 dollars Sing

What about energy?

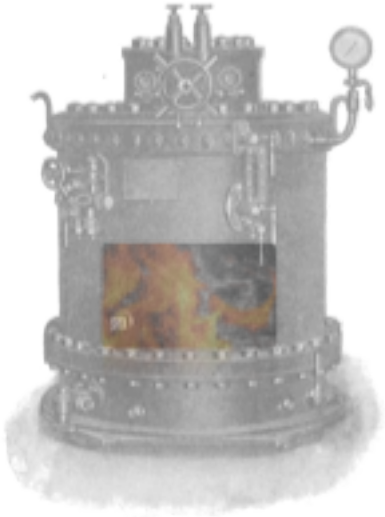


50 kWh

50 kWh

Must consider amount and value

value = quality



50 kWh heat ≠ 50 kWh elec

energy systems are designed with the **wrong exchange rate**

... thermodynamics can help

eXergy

Energy + Entropy

LowEx

Design with Thermodynamics

Exergy Balance
Energy balance + Entropy balance

$$[E_{out} - T_0 S_{out}] = [E_{in} - T_0 S_{in}] - [T_0 S_{gen}]$$

$$Ex_{out} = Ex_{in} - Ex_{destroyed}$$

Understanding irreversibility
Exergy and Anergy

$$Ex = [E - T_0 S]$$

$$Ex = [E - An]$$

$$\underline{E = Ex + An}$$

All architects need to know:
temperature matters

$$Ex = Q - T_0 S = Q - T_0 \int \frac{\delta Q}{T}$$

$$Ex = Q - T_0 \frac{Q}{T} = Q - Q \frac{T_0}{T} \Big\} Anergy$$

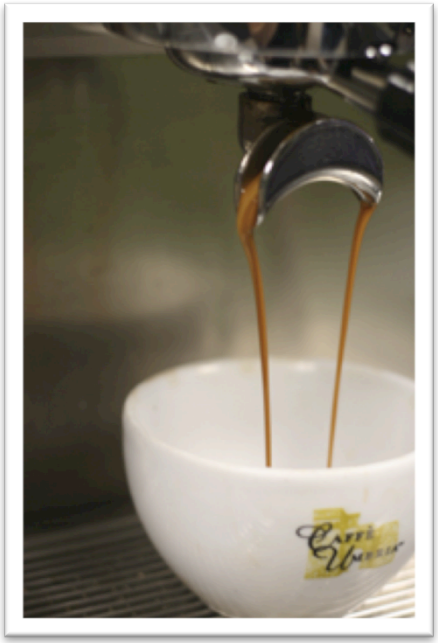
$$Ex = Q \left(1 - \frac{T_0}{T} \right) = Q \left(\frac{T - T_0}{T} \right)$$

European Exergy

300 mL @ **40 °C**
Luke warm Coffee

25 kJ Energy
800 J Exergy

@20°C
Reference
Temperature



30 mL @ **90 °C**
Espresso

9 kJ Energy
1000 J Exergy

For heating in Switzerland:

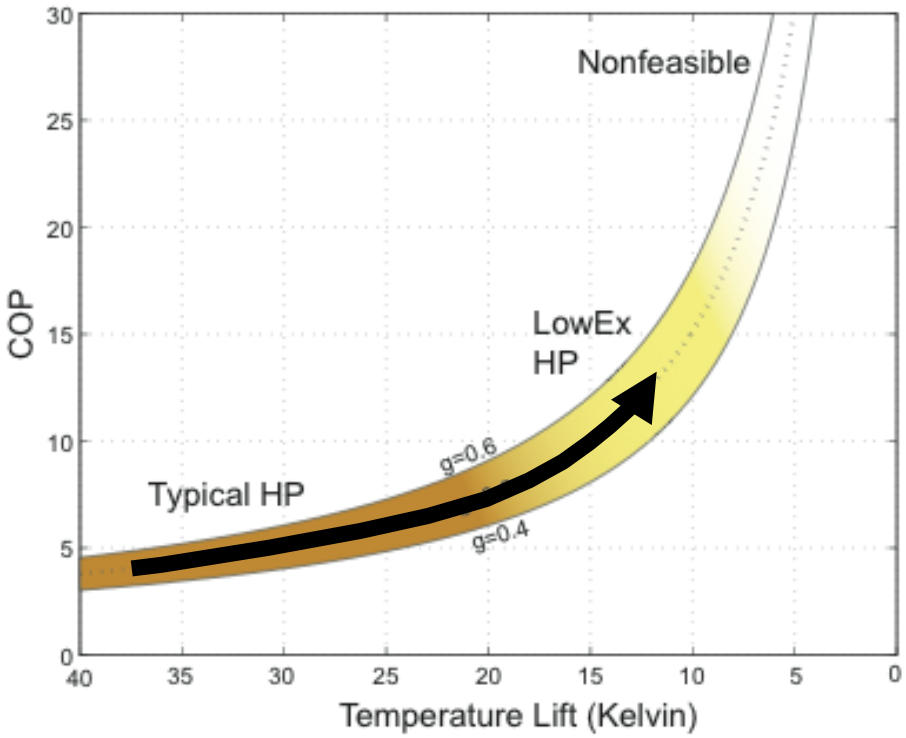
- Combustion in buildings wastes exergy!

- 1000+ °C Flame, to heat a 20 °C room!
  - >75% Exergy lost
- Heat pumps have a higher potential

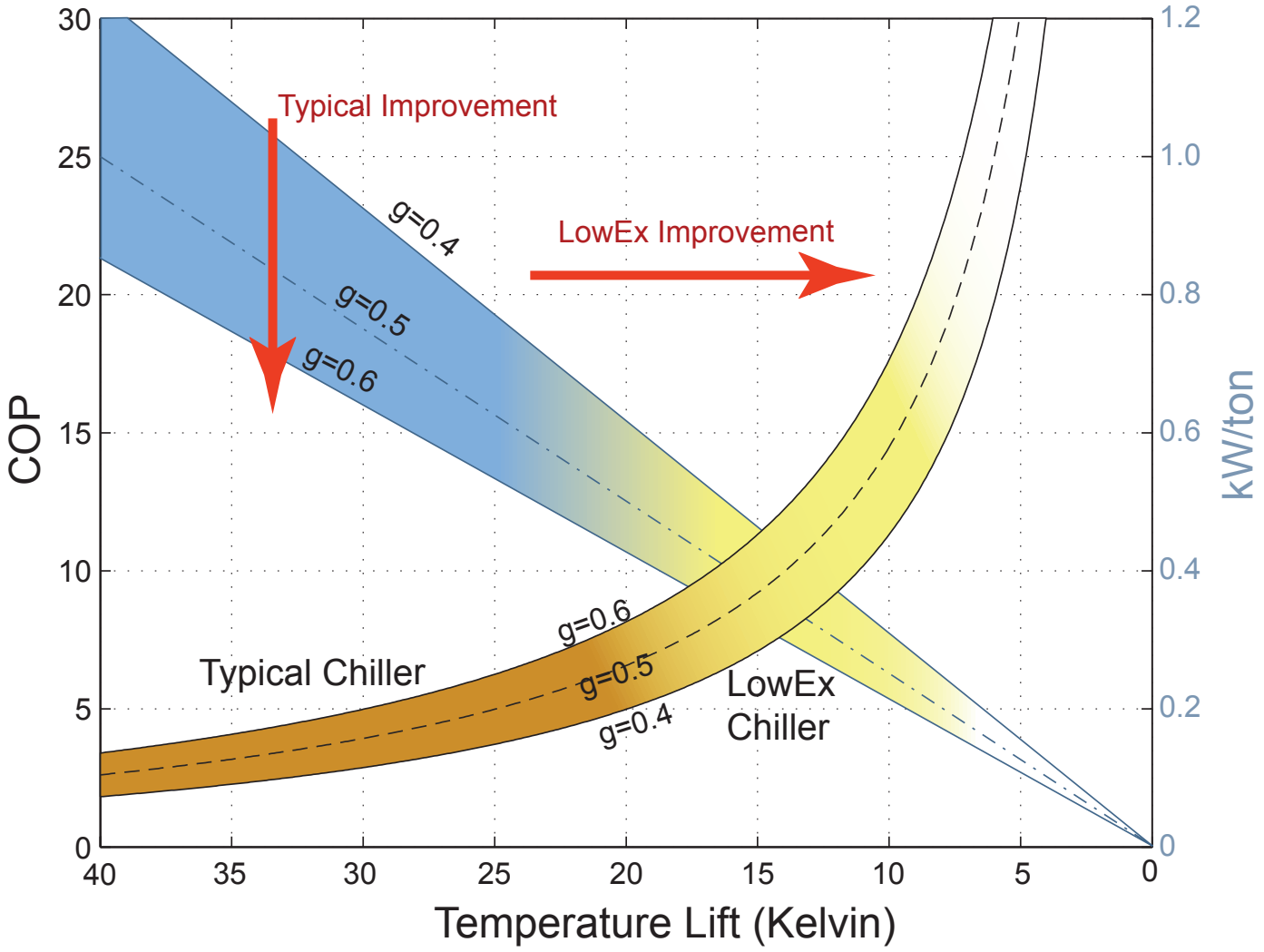
Performance and temp

$$COP = \frac{Q_{out}}{W_{in}} = g \cdot \boxed{\frac{T_{supply}}{T_{supply} - T_{source}}}$$

$$COP_{ideal} = \boxed{\frac{T_h}{T_h - T_c}}$$

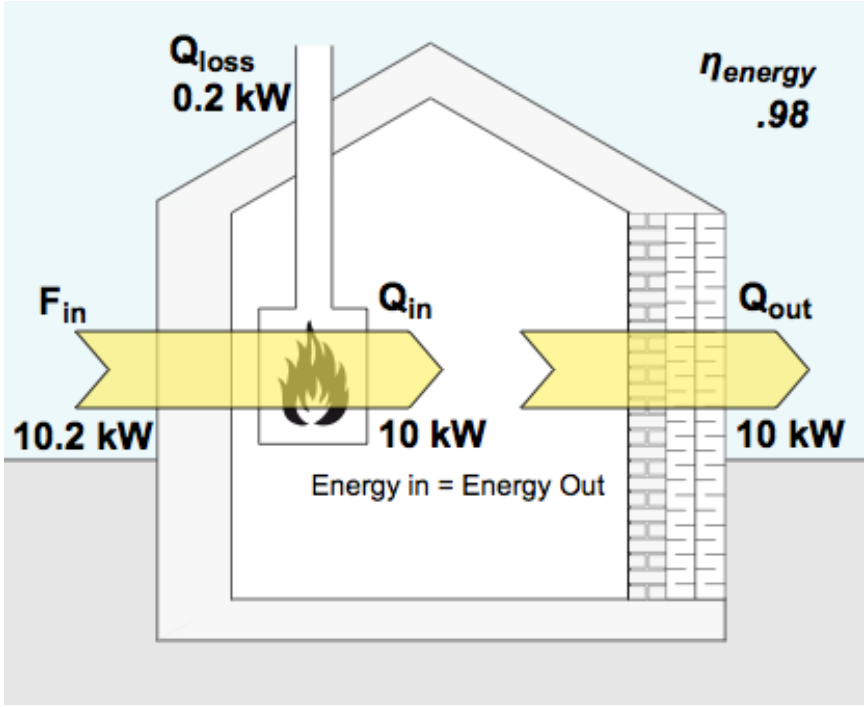


System and integrated performance

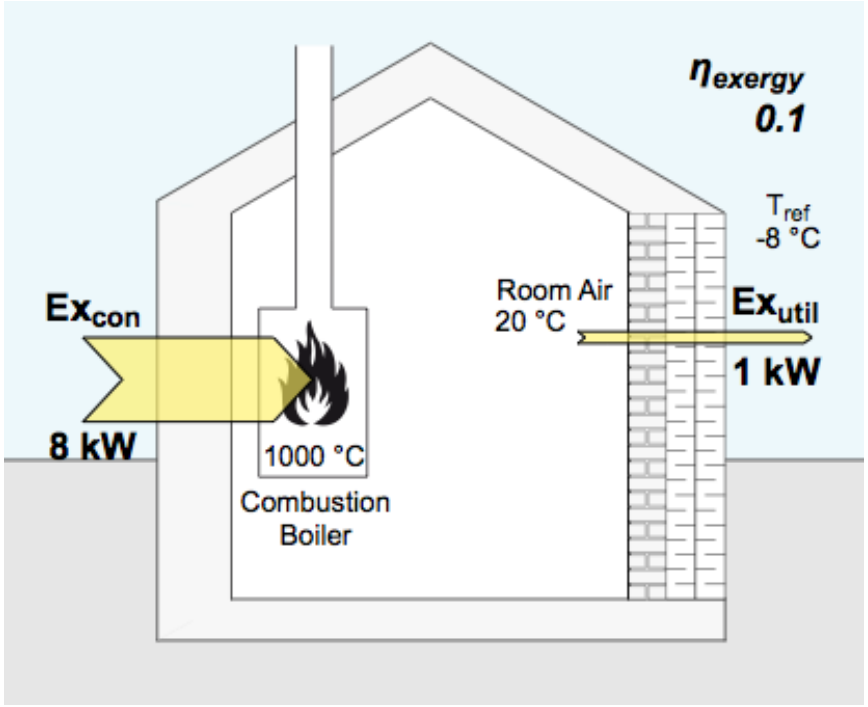


Exergy and Buildings

98% Energy Efficiency



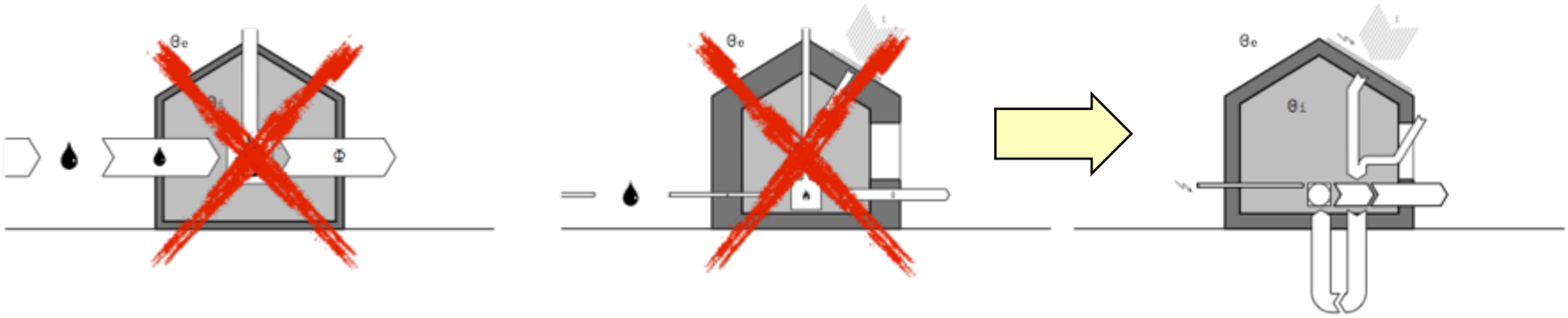
10% Exergy Efficiency



Meggers, Leibundgut: IJEX 2012

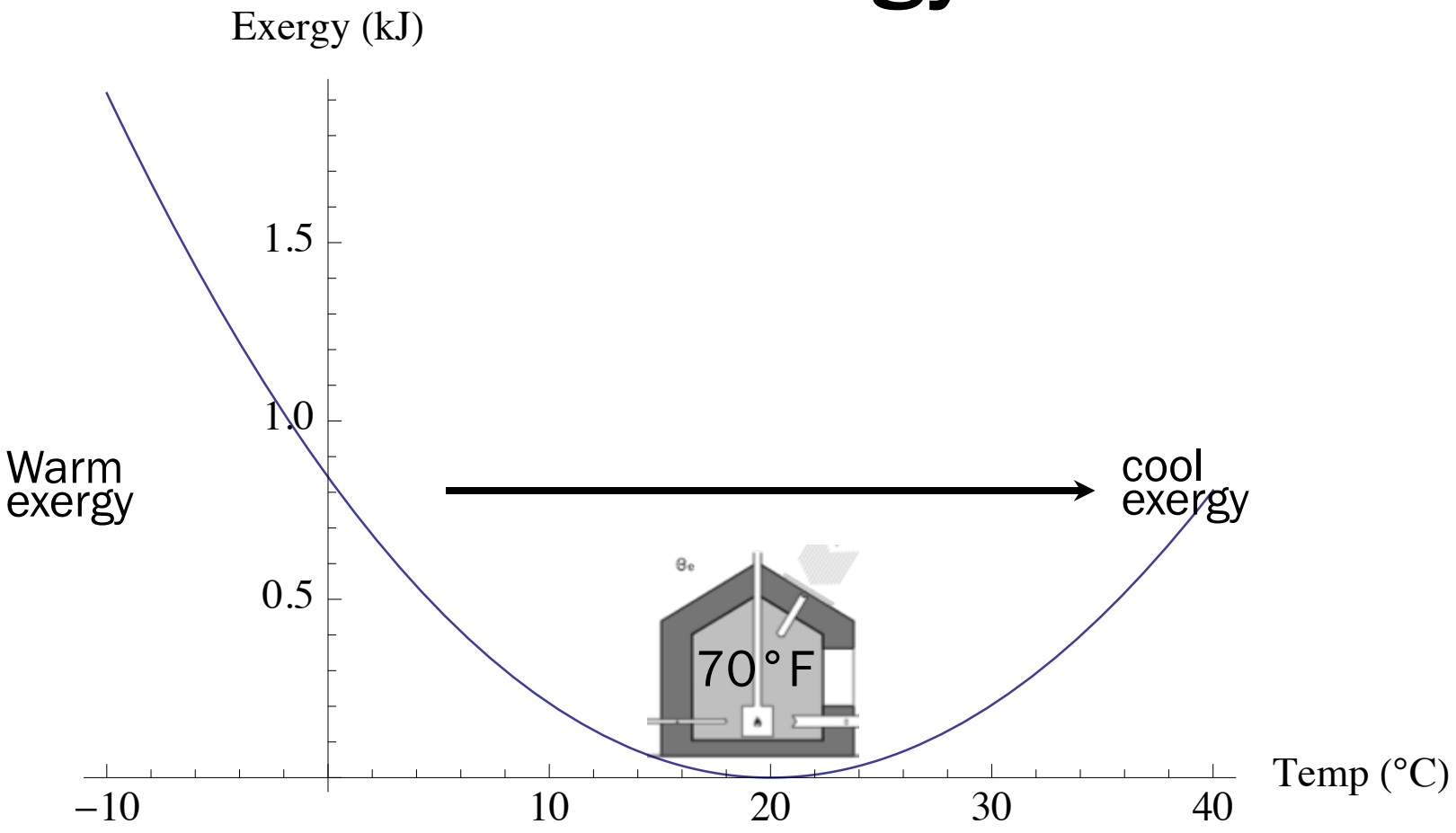
What are LowEx Buildings?

- Low Exergy (LowEx) buildings match quality of energy flows in buildings
  - Low temperature heating / High temperature cooling



- ... but LowEx buildings are also not Passive House
- *optimal* insulation, not *maximal* insulation

Cool Exergy



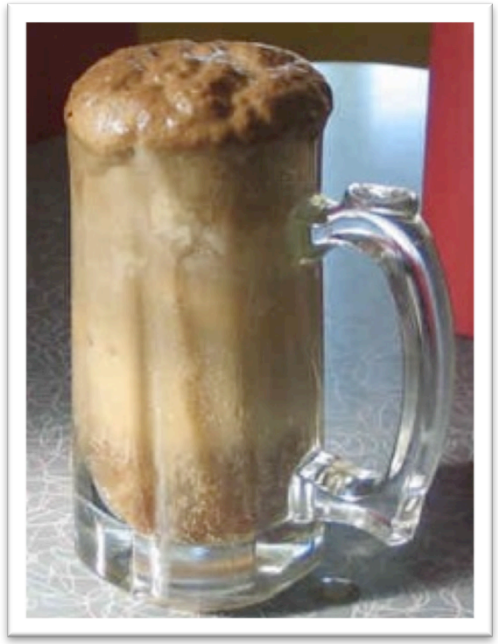
Environmental Temperature with 20°C indoor air

Singapore Exergy

500 mL @ **0 / 20 °C**
½ Ice cream ½ root beer mix

21 kJ Energy
1.4 kJ Exergy

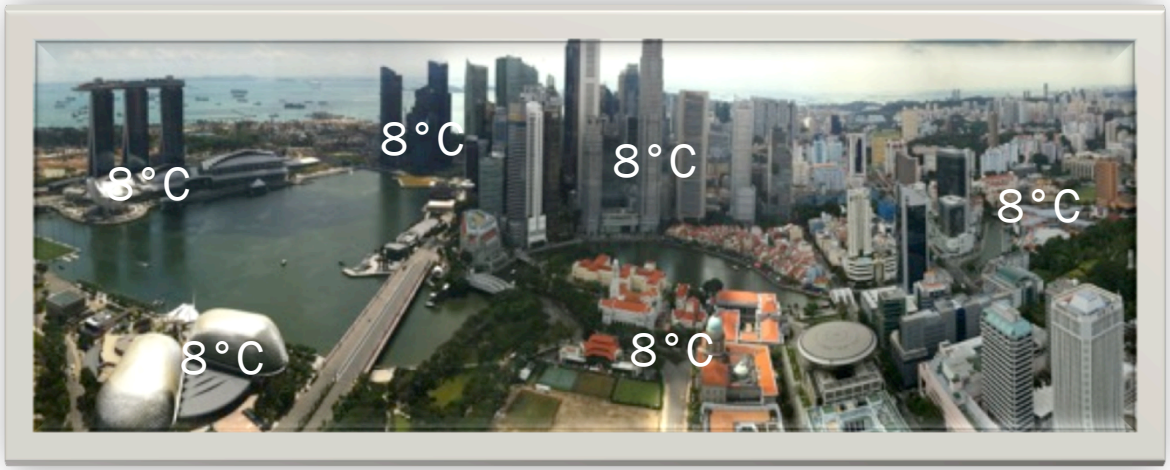
@20°C
Reference
Temperature



500 mL @ **10 °C**
Melted ice cream and root beer

21 kJ Energy
0.72 kJ Exergy

Singapore Exergy



Air Cooling @ **8°C**

Standard

Radiant Cooling @ **18°C**

Low Exergy

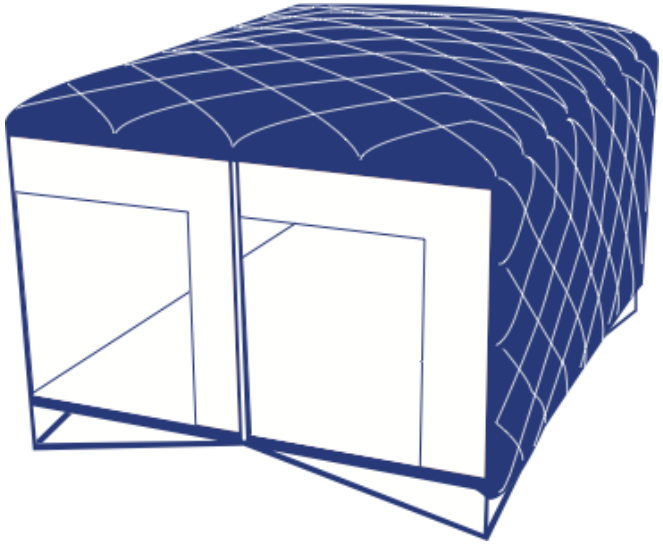
LowEx Tropics Prototype

ETH zürich

(SEC) SINGAPORE-ETH CENTRE 新加坡-ETH 研究中心

(FCL) FUTURE CITIES LABORATORY 未来 城市 实验室

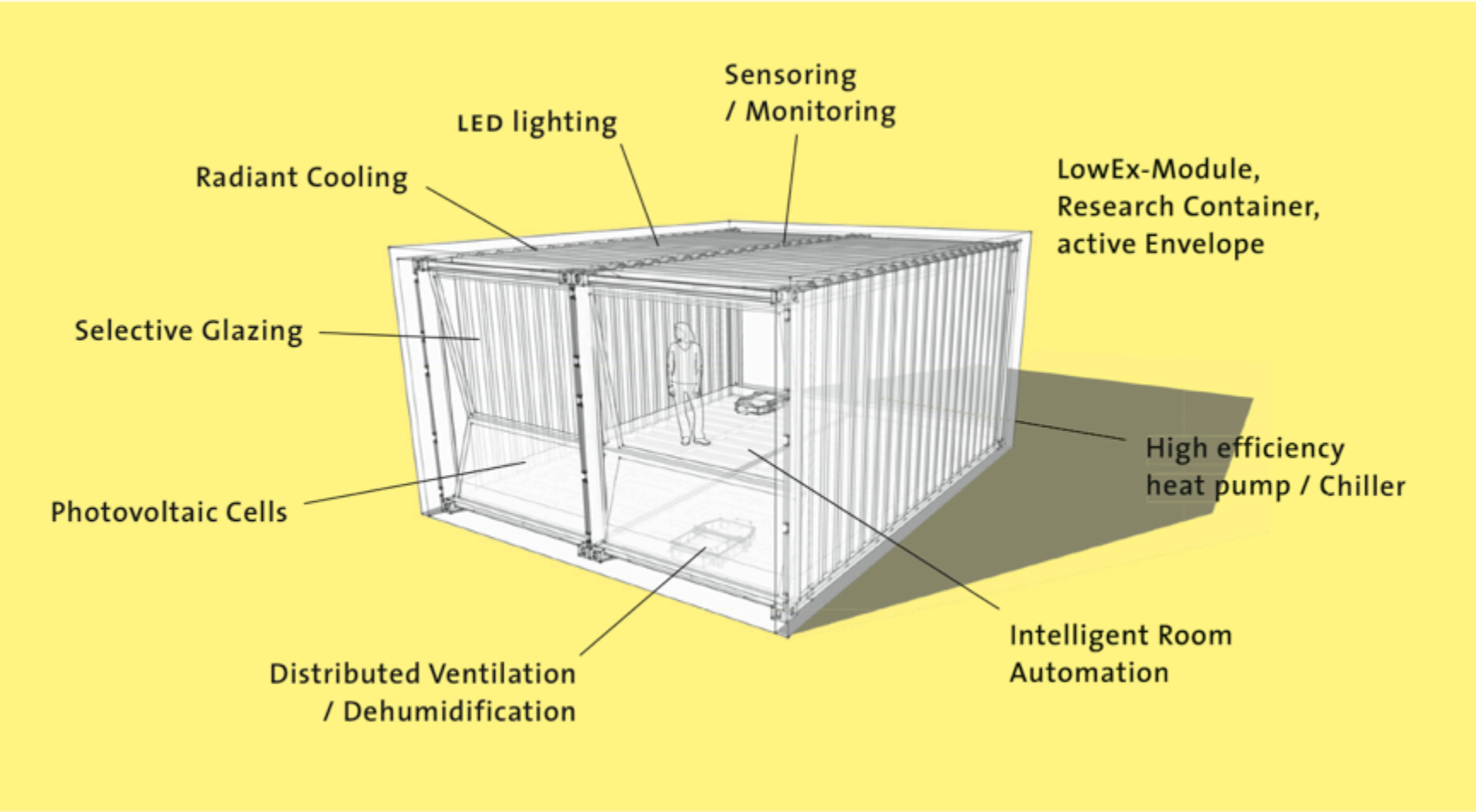
Low Exergy Module



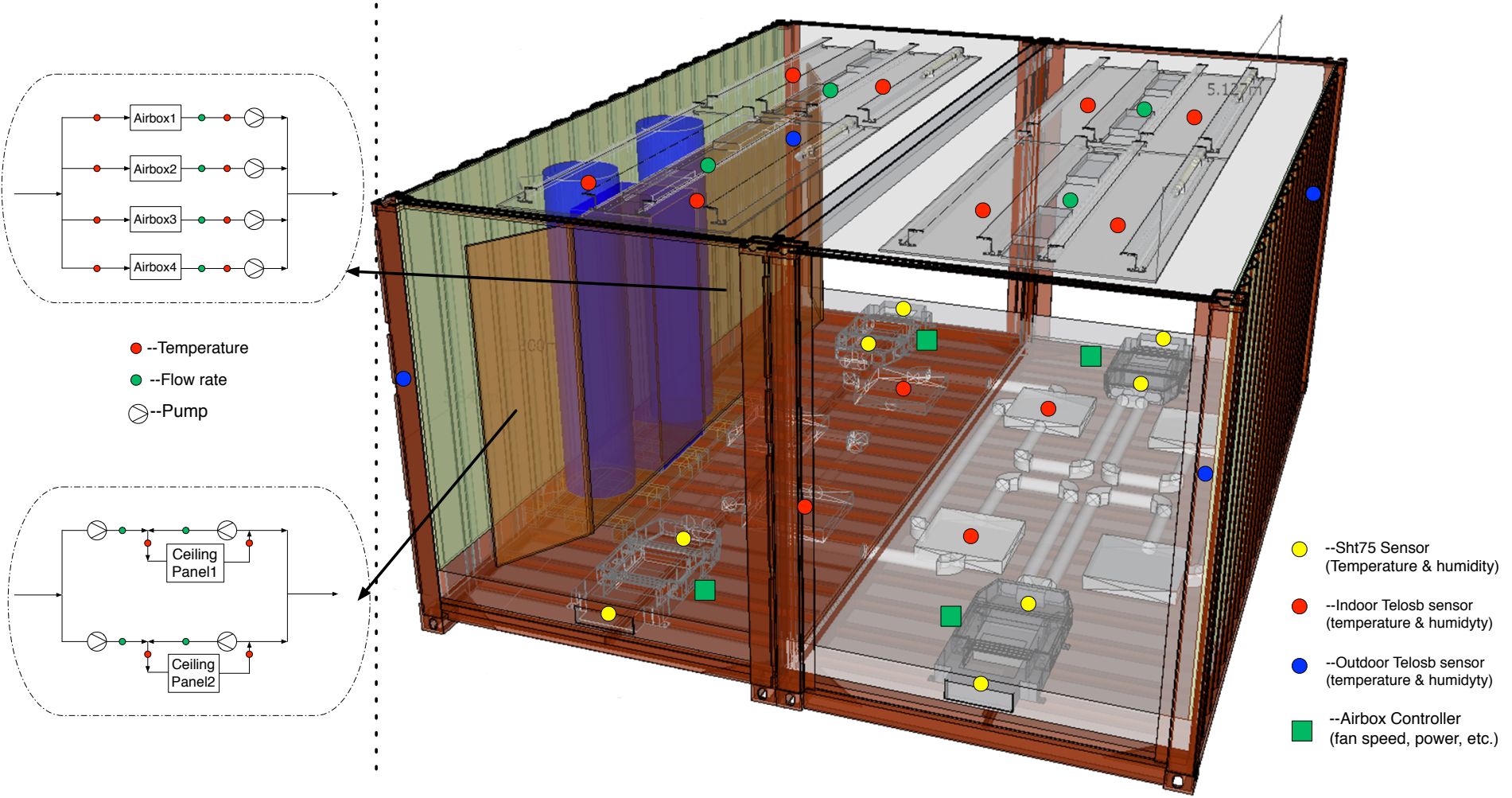
BubbleZERO

Zero Emission Research Operation

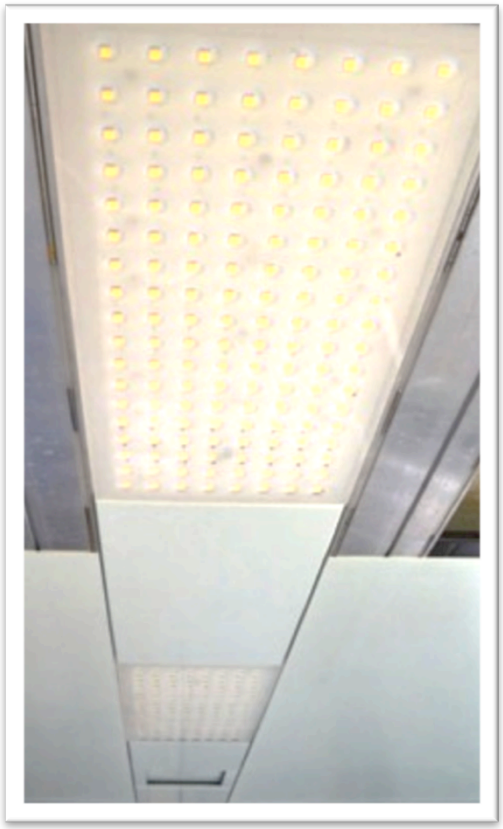
BubbleZERO Initial plan



Implementation



Special lighting and glazing



LEDs in exhaust

M-Glass

How to build a research lab in 2 months that can be shipped to Singapore


DOW

ICOU 309026 2561

MAX. GR. 30,480 KG 67,200 LB

TARE 2,450 KG 5,400 LB

NET 28,030 KG 61,800 LB

CU. CAP 37.1 CUM 1,310 CUFT

CAUTION 9'6" HIGH CONTAINER

DOW
DOW
DOW
DOW
DOW
DOW
DOW
DOW
DOW
DOW

Pneumatex - Hydrometer

bar


RL
P2
F1
R
BAUART GEPRÜFT
TÜV
MAGRA
Heizungsverteiler
Ölverteiler
Sanitärverteiler


FASSI F300XP
ICOU 309026 4
2561
ICOU 309024 3
2561


APL
APL AUSTRIA

...then 4 months of sweating in Singapore


TADANO


CAUTION
9'6" HIGH
CONTAINER


CAUTION
9'6" HIGH
CONTAINER


CAUTION
9'6"HIGH
CONTAINER


CAUTION
9'6" HIGH
CONTAINER


CAUTION
9'6" HIGH
CONTAINER
9024 3
25G1
2,480 KG
5,200 LB
2,450 KG
5,400 LB
29,030 KG
61,800 LB
37.1 CUM
1,310 CUFT
CAUTION
9'6" HIGH
CONTAINER
309026


ETH


ETH
DARCH
SuAT


309026
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
DARCH


ETH
Eidgenössische Techeische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
DARCH
SuRT


PAL-LINK CONSTRUCTION PTE LTD


CAUTION
9'6" HIGH
CONTAINER


DARCH
SuRT

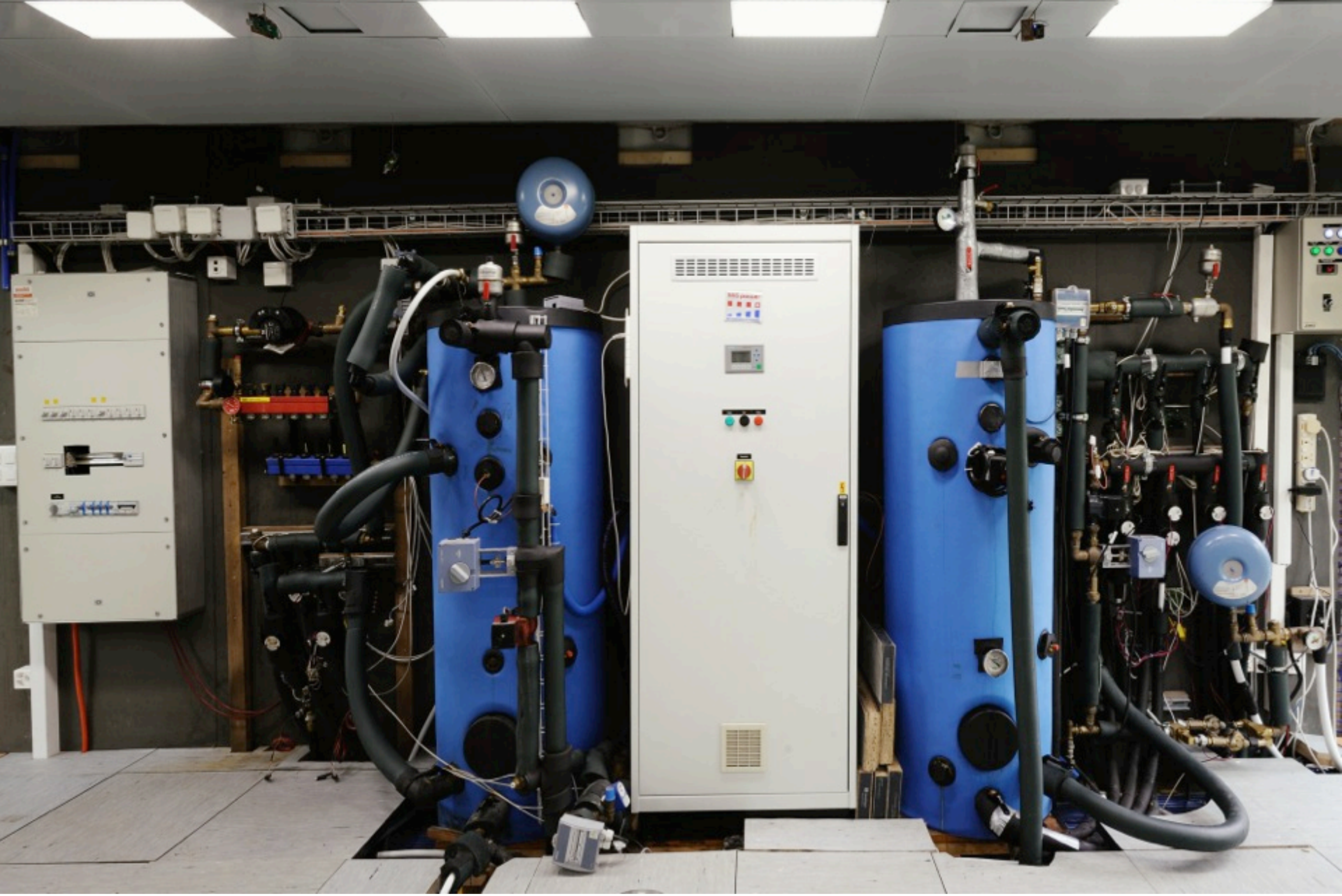
...and you have to get evicted once


ONE WAY
Bok Seng


DARCH
SuAT

NEW FAÇADE for solar angle SHGC testing

Full Installation



BubbleZERO – The complexity reduction, elegance generation machine

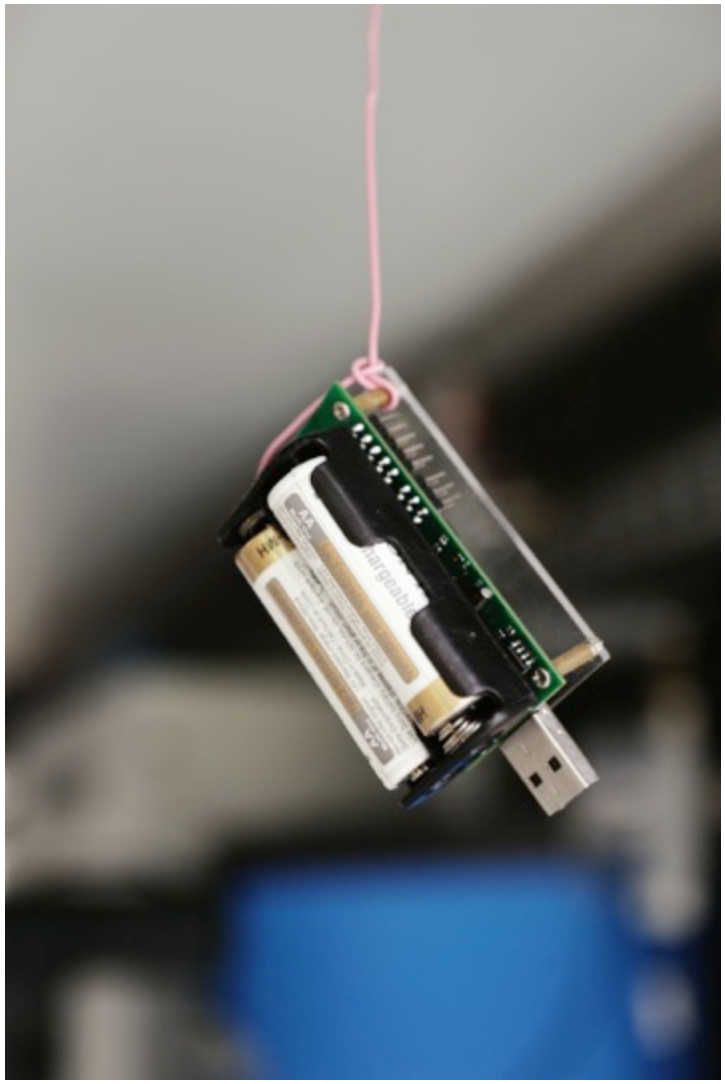
Elegance?

Elegant operation

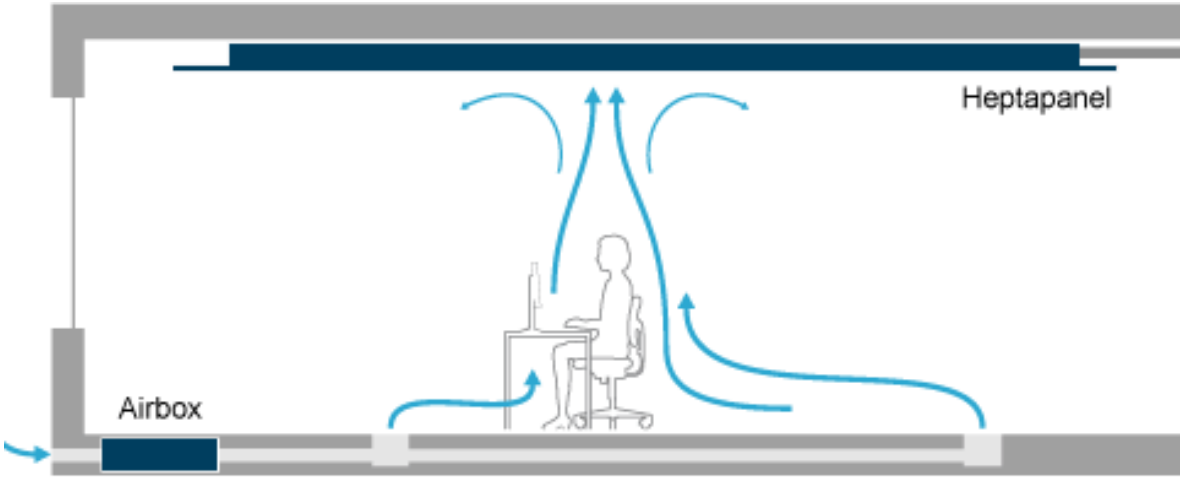
Indoor rain: not so elegant

CHALLENGE: Humidity

Sensors

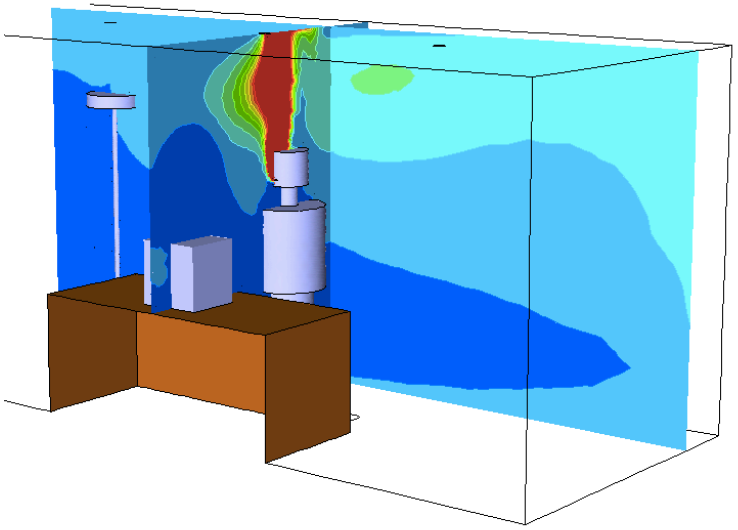


Operation



Path to improvement:

- Demand Optimization: CO2 Control
- Recovery systems: Enthalpy recovery
  - A2 AirFlow Panel (Breshears)
- Optimal: Desiccant dehumidification
  - CHALLENGE: LowEx regen.



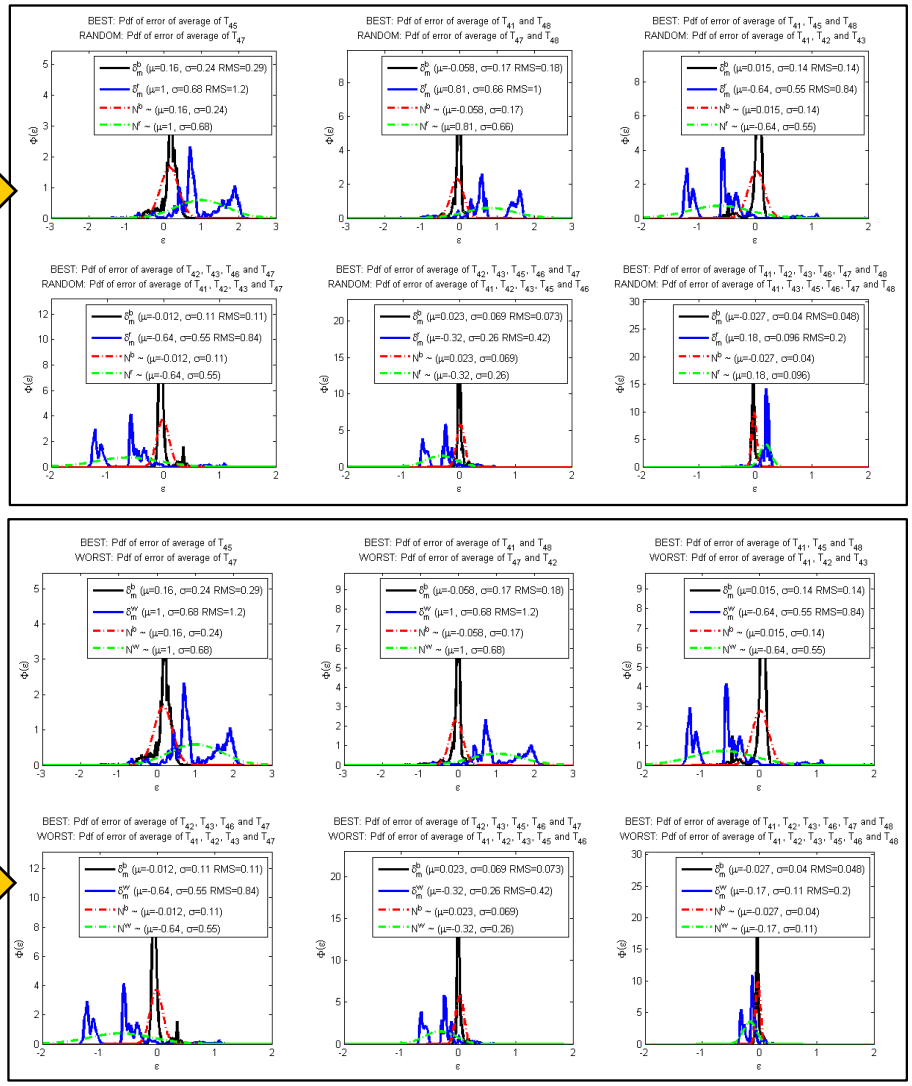
SinBearBest Sensor Collaboration

Inaccuracy Characterizations for sensors

Average error of k sensors for the Minimal error set of sensors and a **random** choose of sensors.

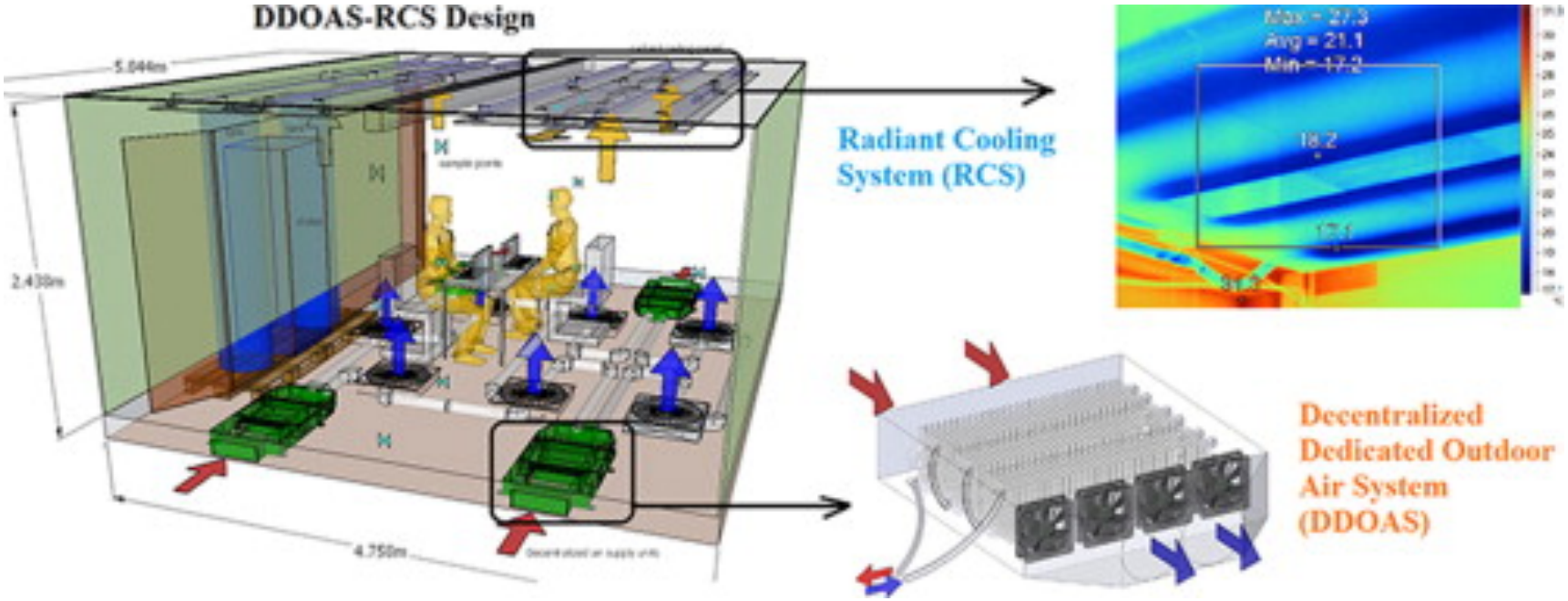
Each figure plots the *pdf* of the difference of the average of k sensor readings with the average of all n_{ts}=7 sensor readings. The best, worst and random set of sensors are selected based on their resulting Δ_{rms} error.

Average error of k sensors for the Minimal error set of sensors and the **worst** choose of sensors.



Maasoumy Et al, ICCPS 2013

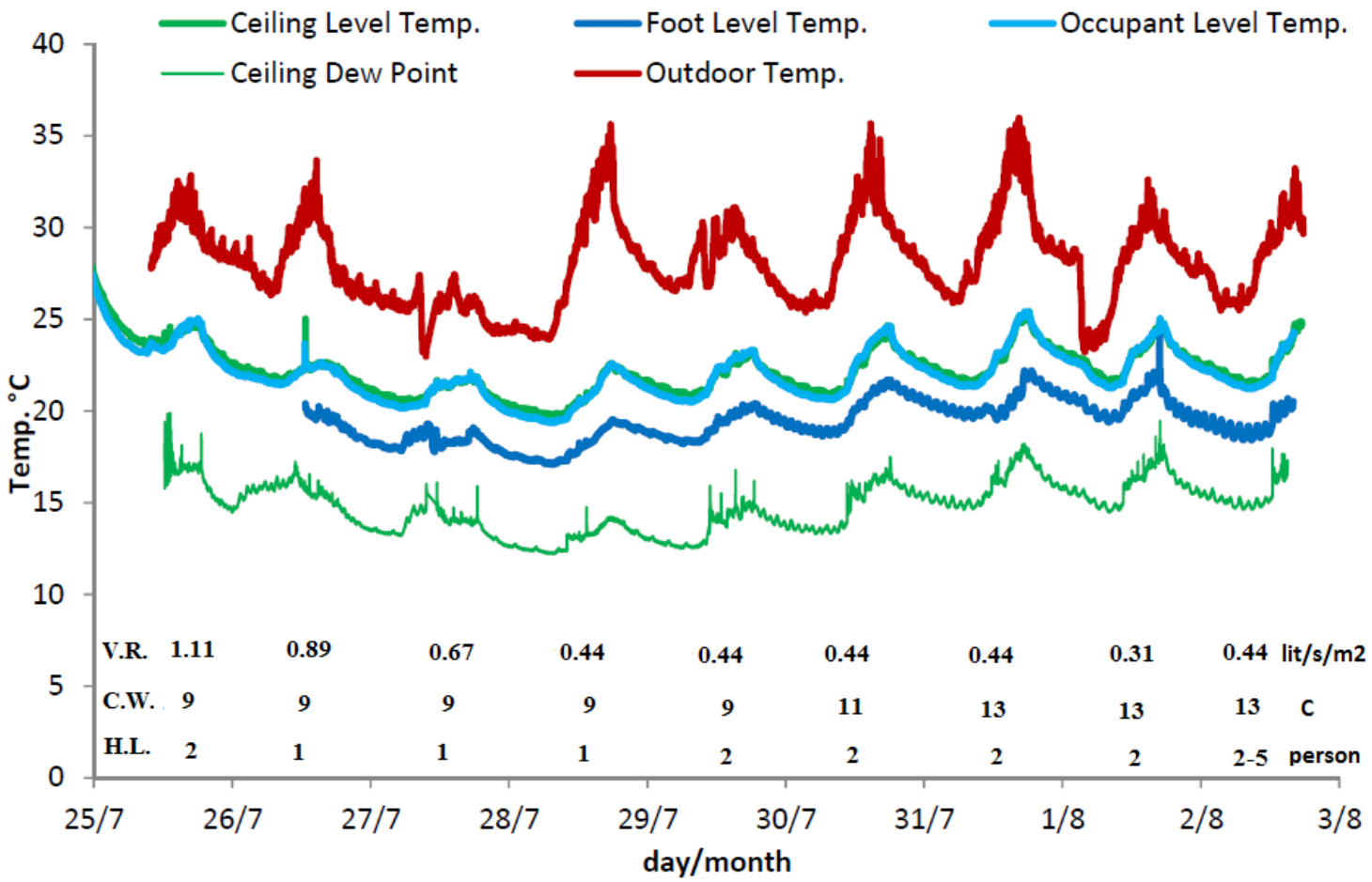
Cooling Analysis



EM Saber et al. Building and Environment, Volume 82, 2014, 361 - 370

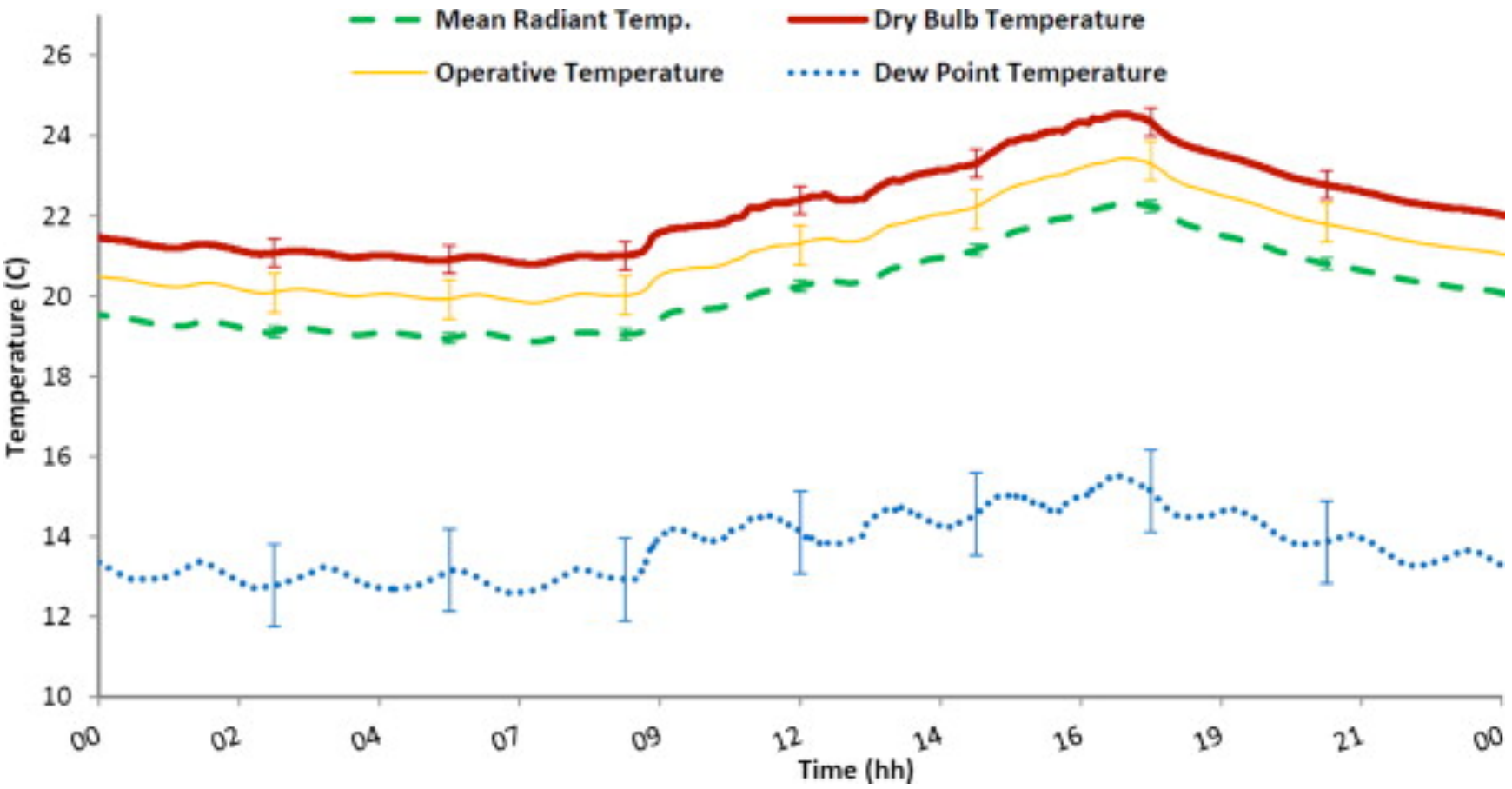
http://dx.doi.org/10.1016/j.buildenv.2014.09.001

Temperature Analysis



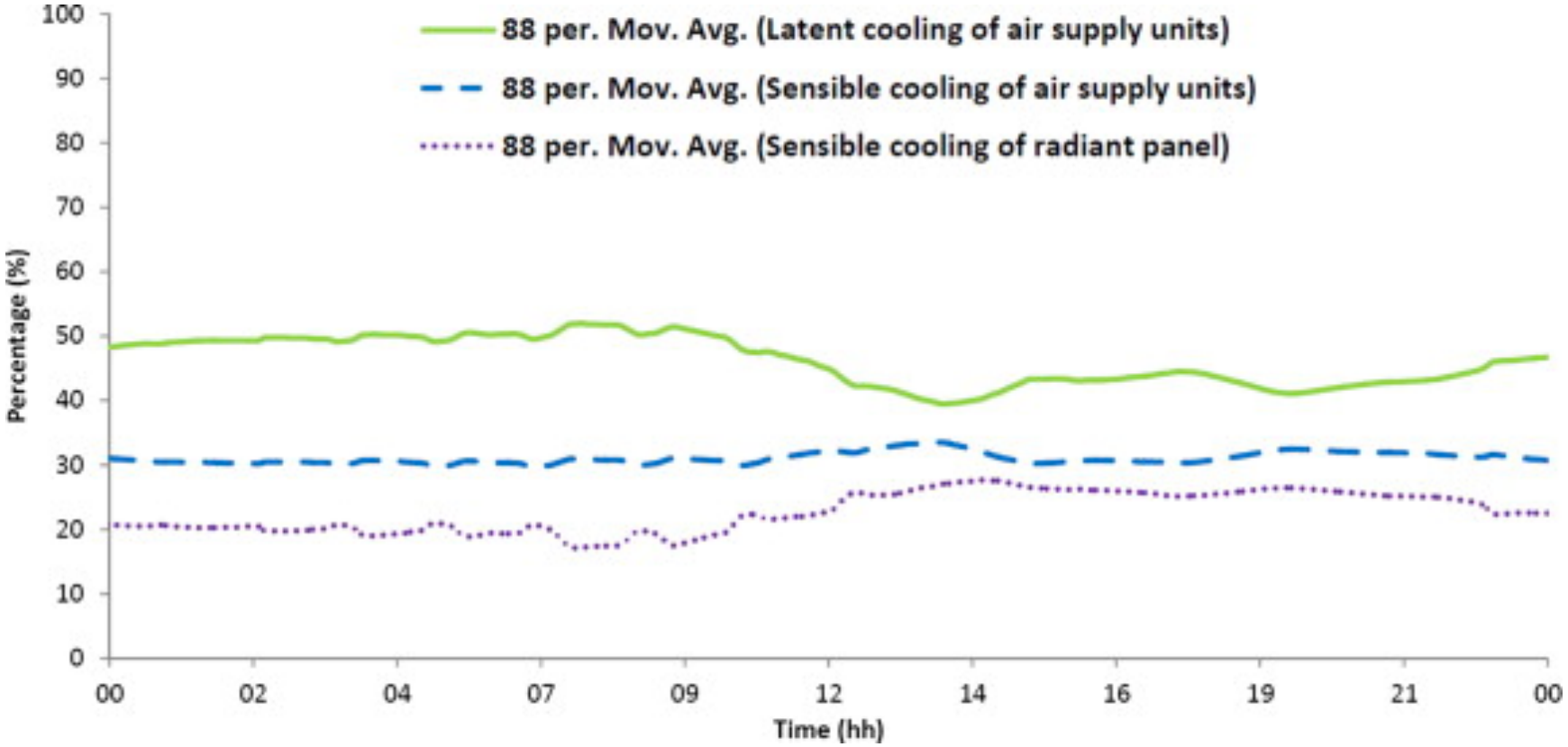
EM Saber et al. Building and Environment, Volume 82, 2014, 361 - 370

Temperature Analysis



EM Saber et al. Building and Environment, Volume 82, 2014, 361 - 370

Temperature Analysis



EM Saber et al. Building and Environment, Volume 82, 2014, 361 - 370

From prototype to pilot

… sometimes eviction is good!

Pilot Project

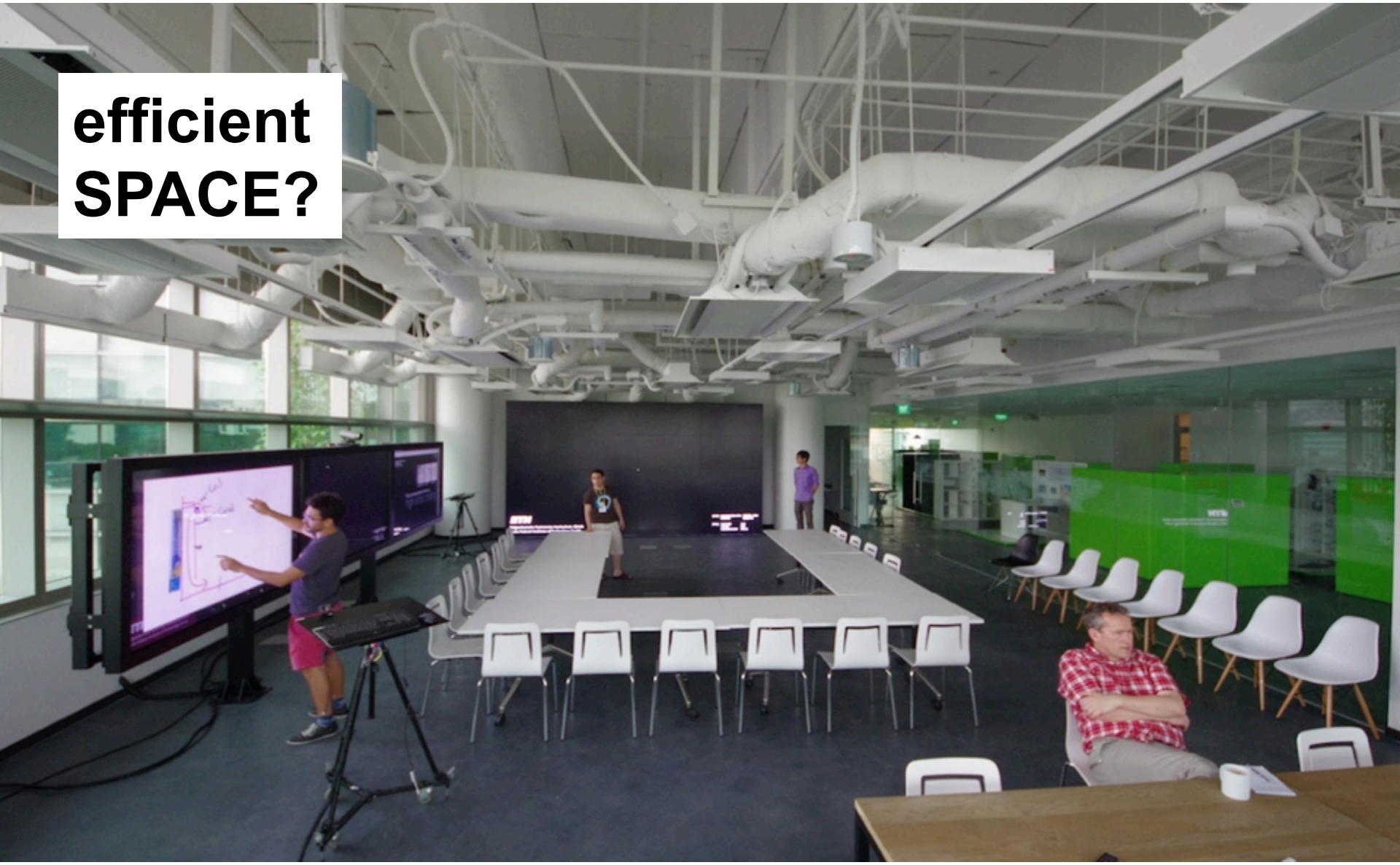
- Collaboration on large campus building at United World College in Singapore

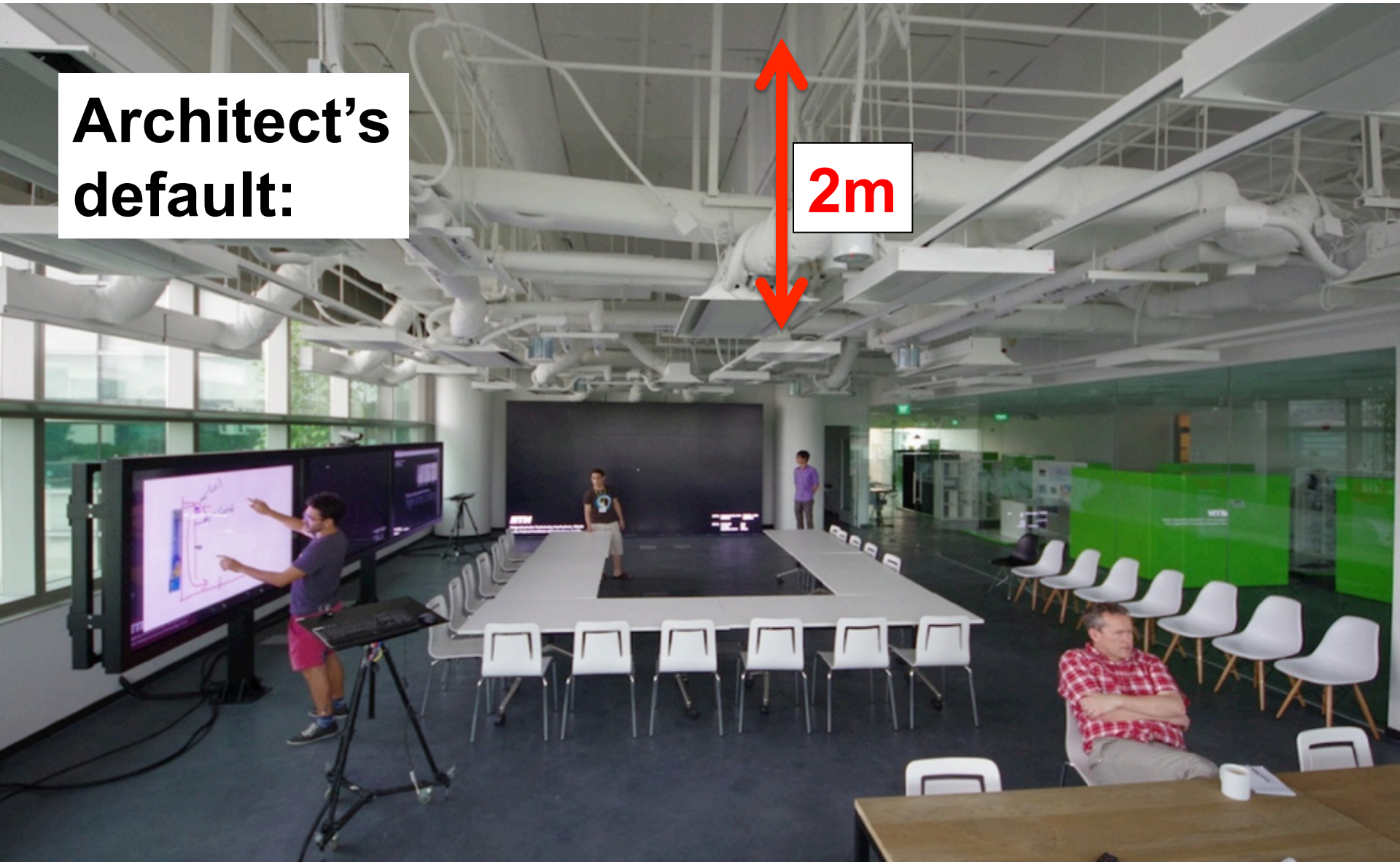
Systems across scales

… and space

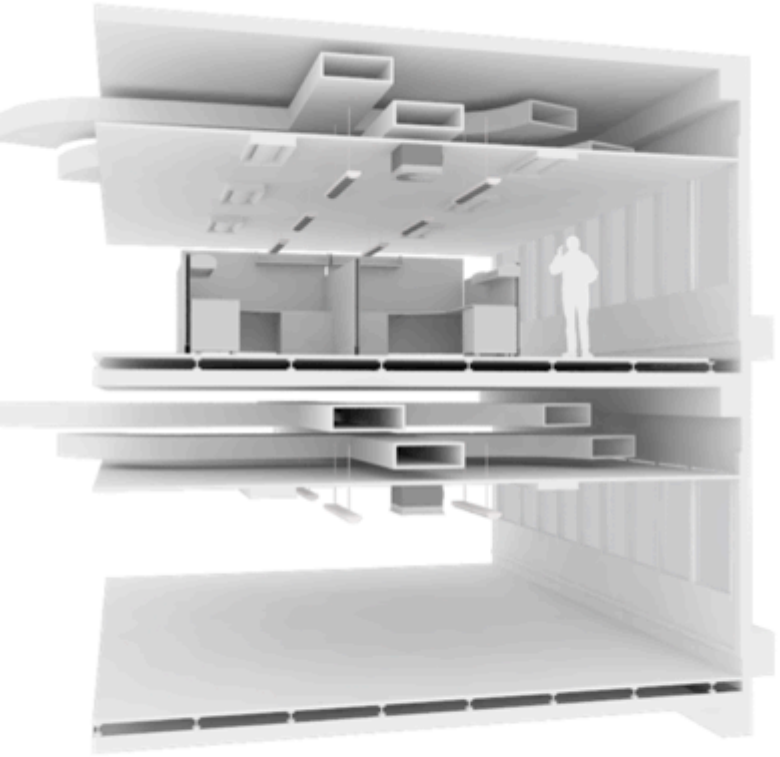
Beyond Efficiency

3 for 2 in Singapore


efficient
SPACE?

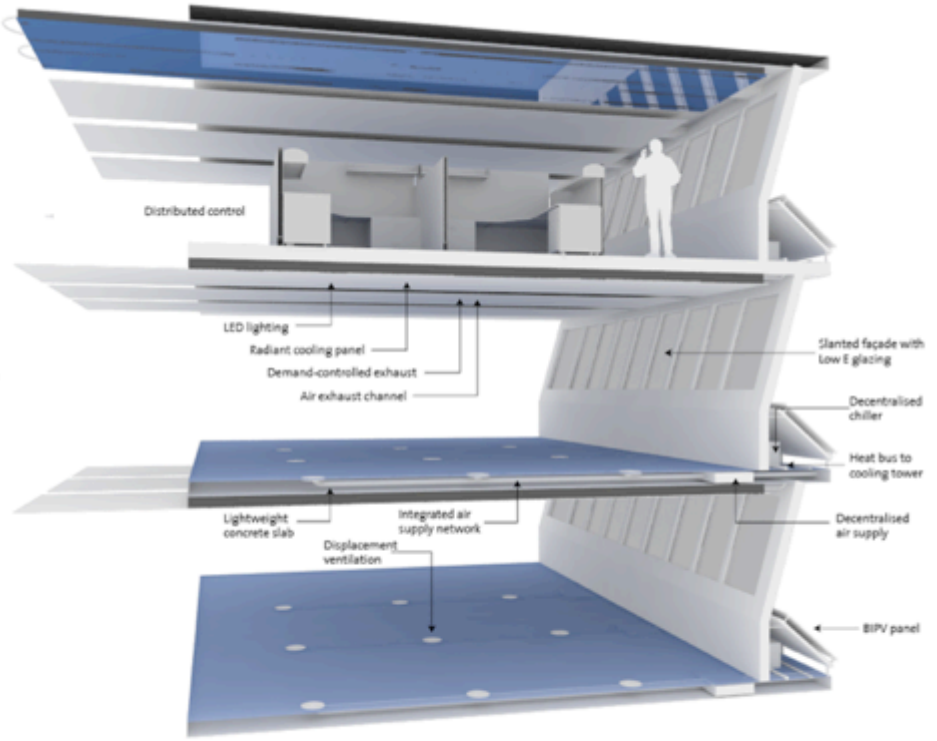

Architect's default:
2m

3 for 2 Project



Conventional

2 floors



3-for-2 concept

3 floors

Conventional high-rise

Conventional building
(baseline scenario)

- 40 % cooling energy
+ 20% office space
- 16% facade material
- 30% struct. concrete
- 18% installations space
+ user comfort

3-for2 approach

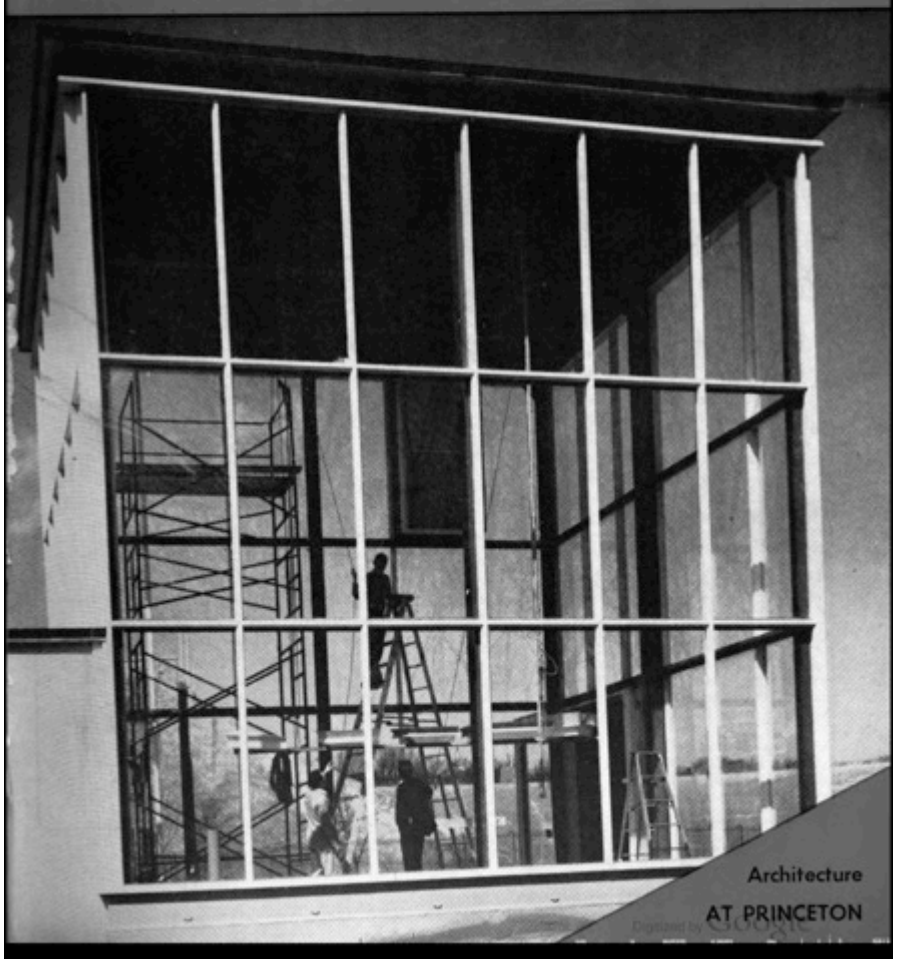
Free space in Singapore

http://beyondefficiency.blogspot.com

... getting back to Princeton
learning this summer what
Olgyays knew in the 1950s

PRINCETON ALUMNI WEEKLY

Vol. LI · APRIL 20, 1951 · No. 23



Architecture AT PRINCETON

Twin Olgyay Brothers Engage Here In Radical Architectural Research

Sir Winston Churchill once said that "we shape our buildings and then our buildings shape us."

This interplay between men and the homes in which they live is the field of study for two architects, twin brothers, now working at the Architectural Laboratory here.

The brothers, Victor and Aladar Olgyay, hope that by a study of physical environmental factors they can form factual bases for design in building.

"Too many houses," says Aladar, "are built by custom. We often do as our forefathers did, but we do not live where our forefathers did.

Climatical Conditions

"Housing varies according to climatical conditions throughout the world because only those forms best adapted to their environment survived."

The Olgyay brothers have both received Guggenheim Fellowships, Prix de Rome Fellowships, and the Columbia University Kendall Fellowships. Both graduated from the Royal Polytechnical University in Budapest.

Since then, their careers have paralleled each other closely. They have worked together on five town planning projects and numerous individual buildings.

Adaptability

When a bird gets cold, it can adjust its feathers and warm up. A bear, bothered by winter breezes, goes to sleep and dreams of the spring. When a man gets cold, he builds a house.

Man's physical adaptability is pretty feeble, the Olgyays say, and his homes must take advantage of the factors of specific climates.

The Olgyays are studying the effects of light and sound, as well as of climate. These three factors will be isolated and analyzed, and the synthesis "of these requirements will result in truly rational architecture."

The ideal home, they say, is one in which the "comfort zone" of human beings is related to the physiological and psychological feelings."

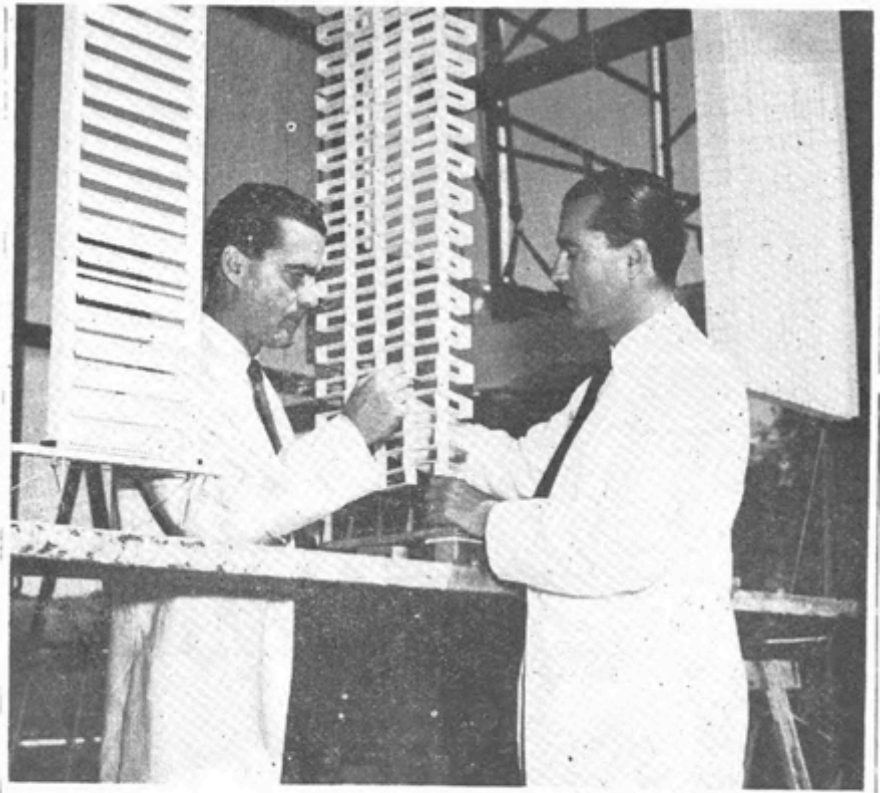


Photo by Alan W. Richards

TWIN ARCHITECTS, the Olgyay brothers, now working at the Architectural Laboratory, predict radical changes in coming years.

Architects Build Thermoheliodon To Try Houses for Climate Fitness

Olgyay Twins Seek Ideal Home Types

By ROBERT D. BOLGARD '57

"We require from buildings, as from men, two kinds of goodness: first, the doing of their practical duty well; then, that they be graceful and pleasing in doing it."

—John Ruskin

Adhering to Ruskin's principle, twin brothers Aladar and Victor Olgyay of the Princeton Architecture School are attempting to discover what architectural features make a building both comfortable and artistic.

The Olgyays, assisted by Associate Professor Alfred E. Sorenson of the Mechanical Engineering Department, are constructing a device—christened the Thermoheliodon—to test model houses in a laboratory.

Weather Maker

The Thermoheliodon, to be finished in six weeks, is a weather-maker which simulates primarily the temperate climatic conditions found in the United States.

A plexiglass dome mounted on an insulated cylindrical base provides the test area and protects it from outside atmospheric conditions.

"Sunlight" is provided by a 5000-watt lamp, which is mounted on steel arcs above the model houses placed on the base.

Fans mounted under the base provide "wind." The arcs and the top of the base rotate to account for geographical latitude, time of day, and seasonal solar positions.

Measuring instruments inside the test models will determine what materials, shapes, shading, windows, heating and cooling units, and directional orientation best maintain man's comfort zone, 70-80 degrees according to biologists.

The Olgyays will conduct experiments for a year after the Thermoheliodon is finished. Subsidized by a federal grant from the National Science Foundation, the researchers estimate that the cost of the project will exceed $19,000.

With their findings the brothers hope to provide "a factual basis for the expression of individuality in architecture." By balancing "human qualities," such as emotions and aesthetic tastes, with "the discoveries of natural science, engineering and economics," they hope to design houses which will be, as Ruskin advised, both "practical" and "pleasing."

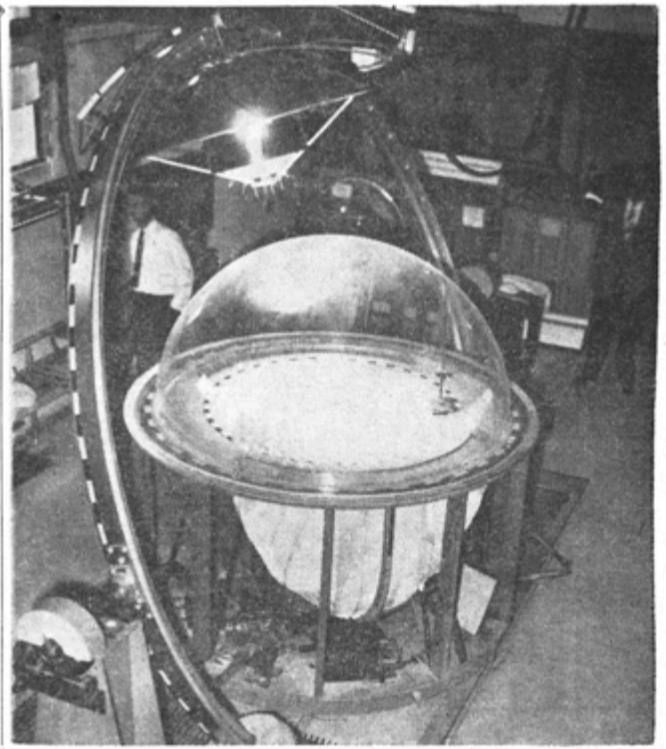


Photo by Henry F. Olds Jr. '58

"THE THING": Victor Olgyay (l.) and Engineering Professor Alfred E. Sorenson prepare Thermoheliodon for climate fitness tests of model homes.

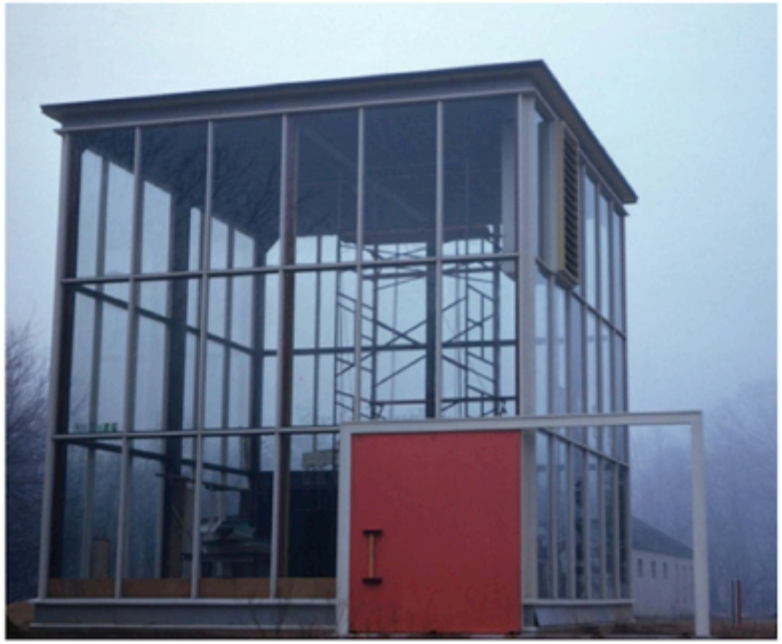
Princeton
ALUMNI WEEKLY
JANUARY 25, 1982

Energy-Saving Designs for the Future

Architectural Laboratory

Architectural Laboratory

2013, A new tenant:



Embodied Computation Lab
Axel Kilian

Backwards + Forwards in Arch Lab

Backwards + Forwards in Arch Lab

2014: Meggers summer research

- Beyond Shading
  - Experiments in radiant cooling pavilion
  - Radiant Umbrella
  - ThermoHelioDome (Foam Dome)
- Geothermal potentials
  - Exploring new USGS geothermal database
- Aerial Vehicles for energy analysis
  - Summer student initiated research concept

2014: Meggers summer research

CHAOS team

CHAOS team

Exploring radiant exchanges: Beyond shading

- Combine standard radiant concrete with indirect evap
- New evaporative membrane surface
  - CBE Senior Thesis
- New reflective radiant system

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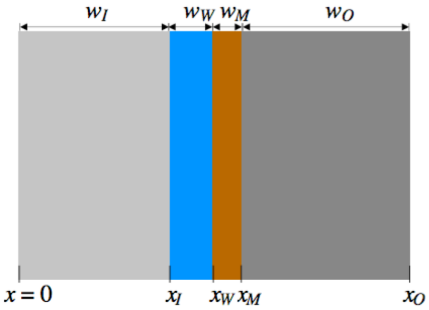

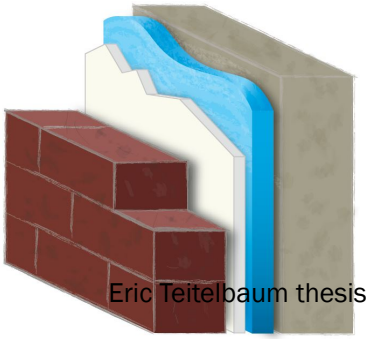

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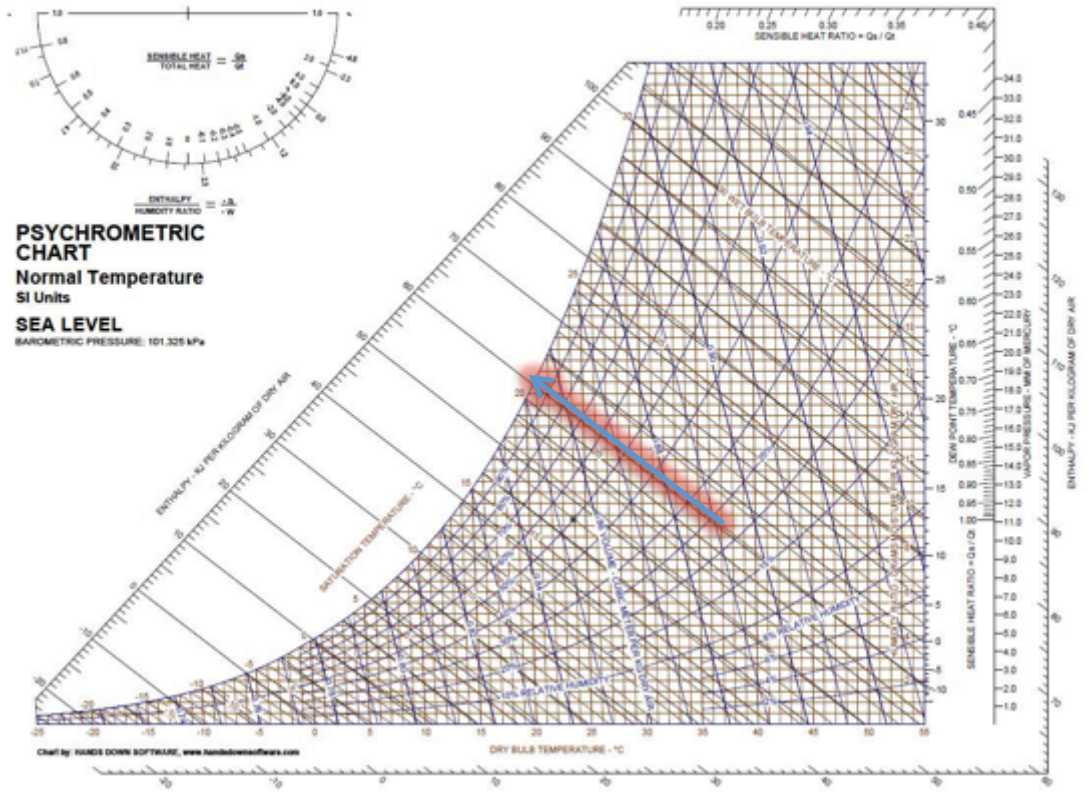
Evaporative Cooling

- Adding water to air causes the temperature to drop adiabatically (no change in heat)

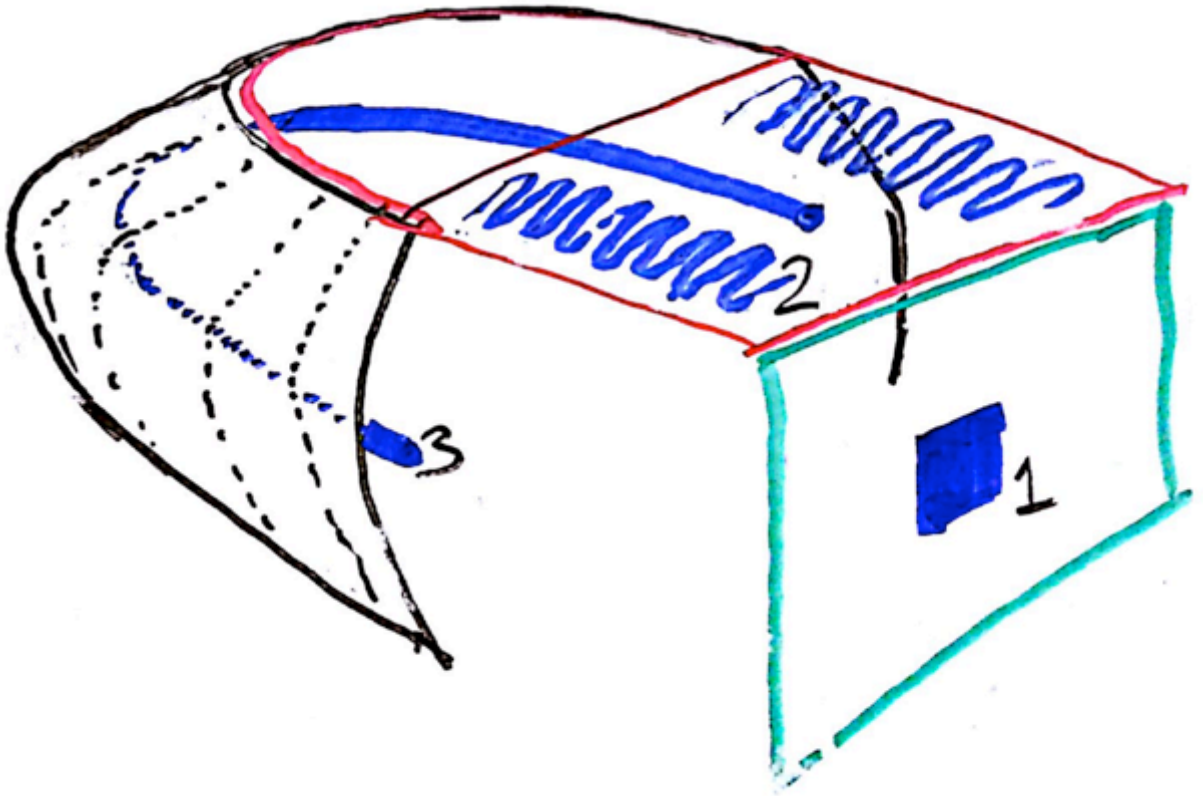
= Sweating

= Swamp Cooler



Beyond Shading Preliminary Concept

1. Evap
2. Radiant
3. Reflect



Cool Pavilion 2-week prototype

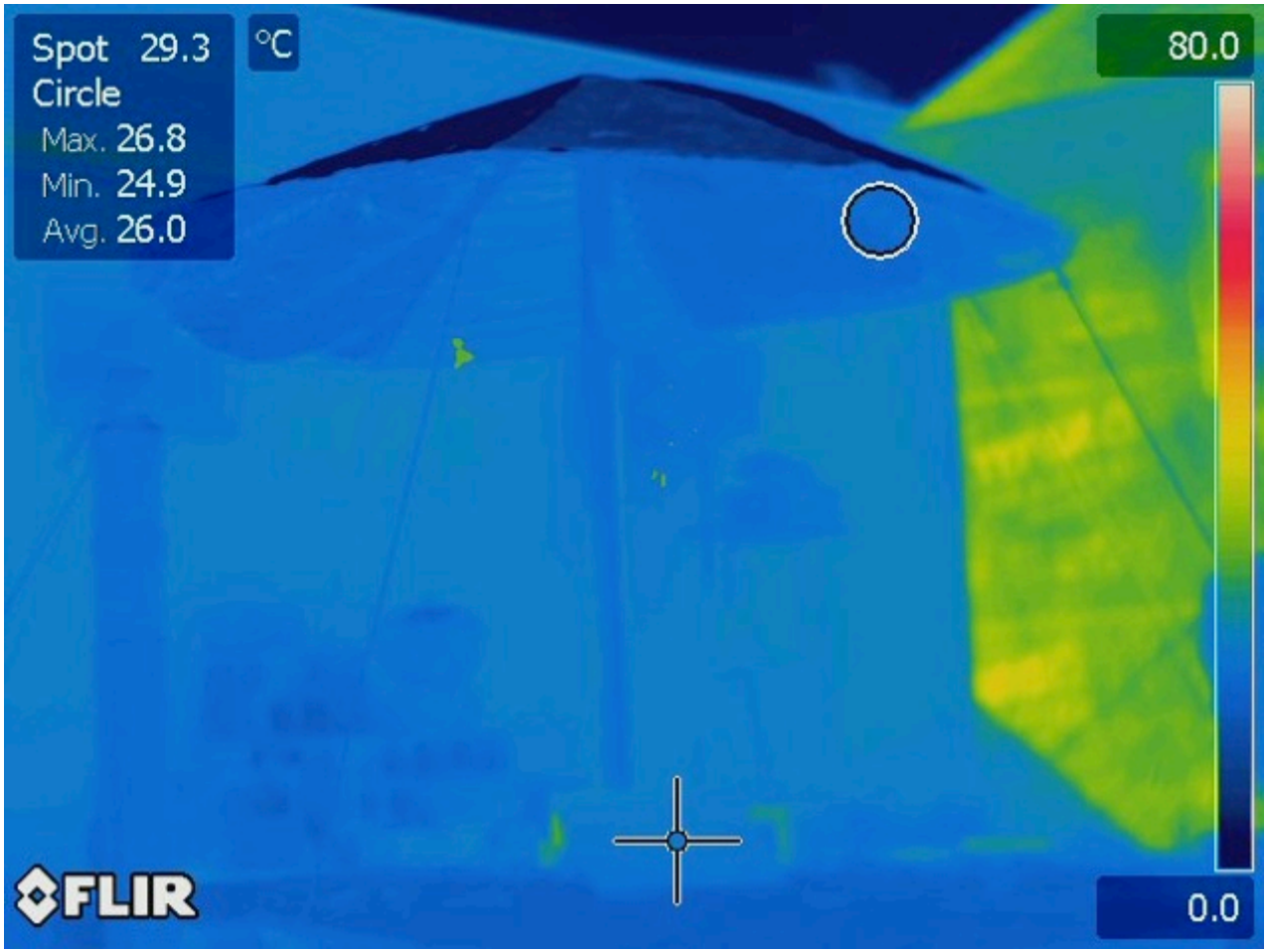
Radiant cooling reflecting umbrella

Thermal Camera

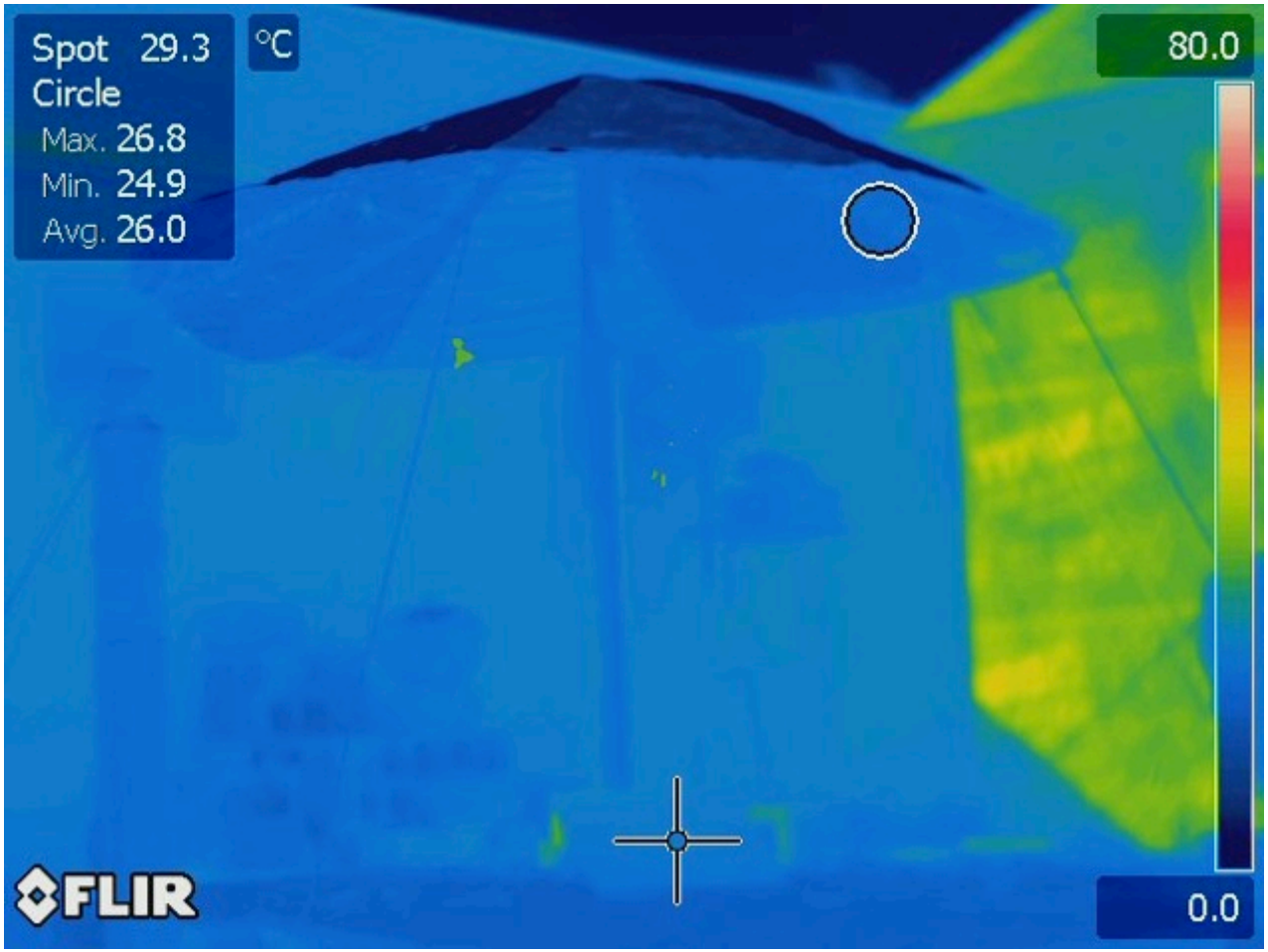
thanks Prof Gmachl and Germano

Thermal (IR) Imaging

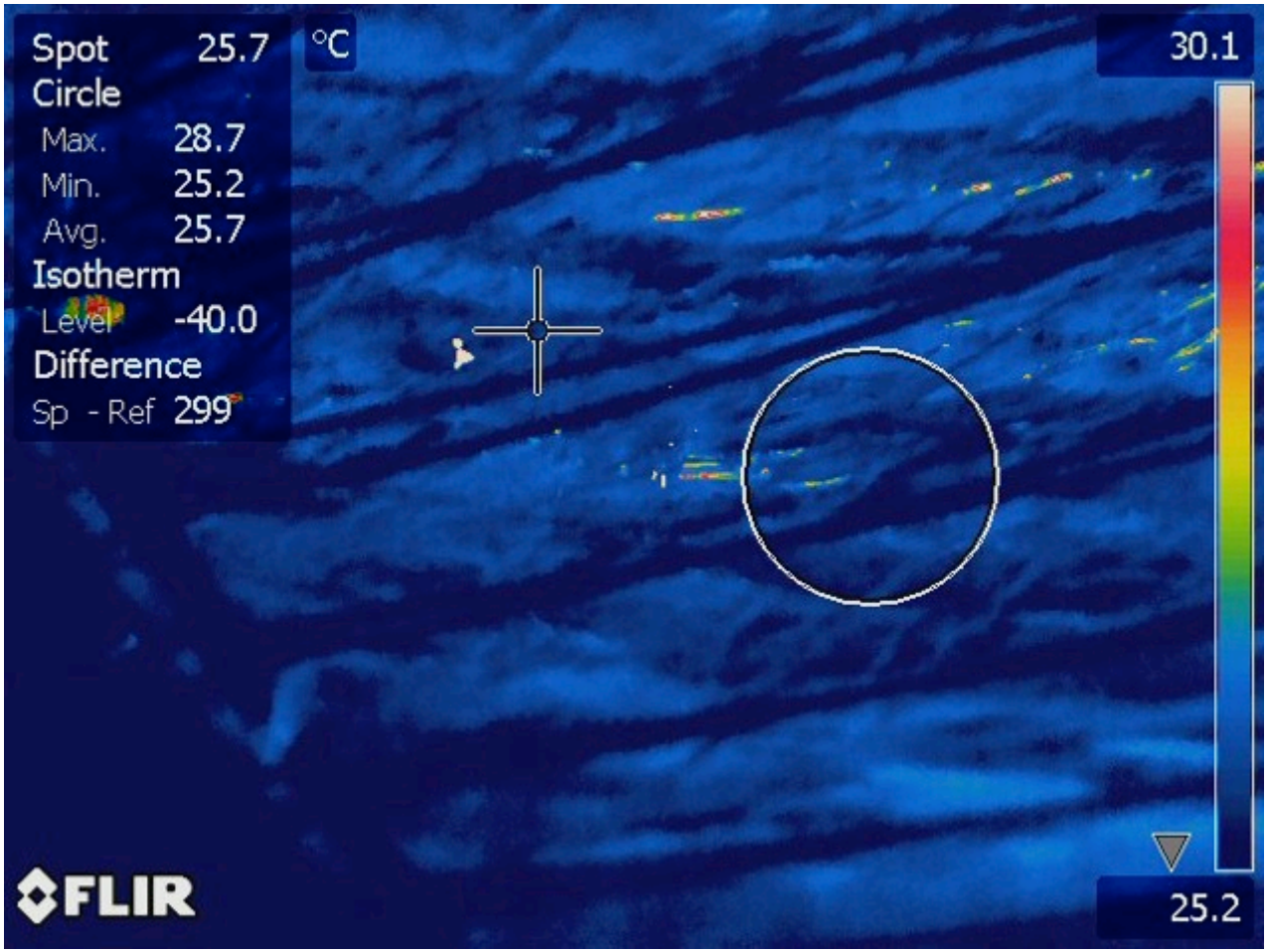
Thermal (IR) Imaging



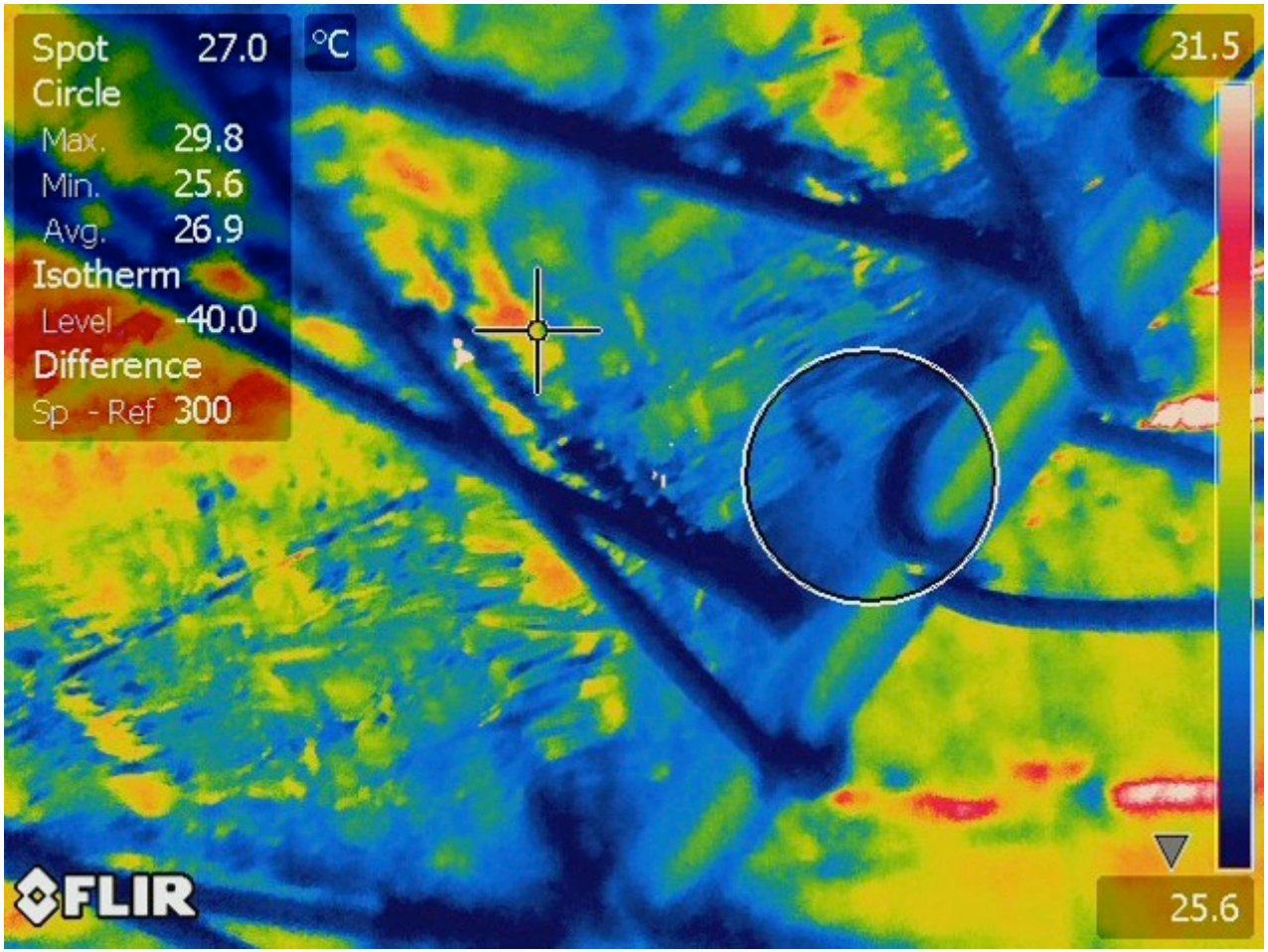
Thermal (IR) Imaging



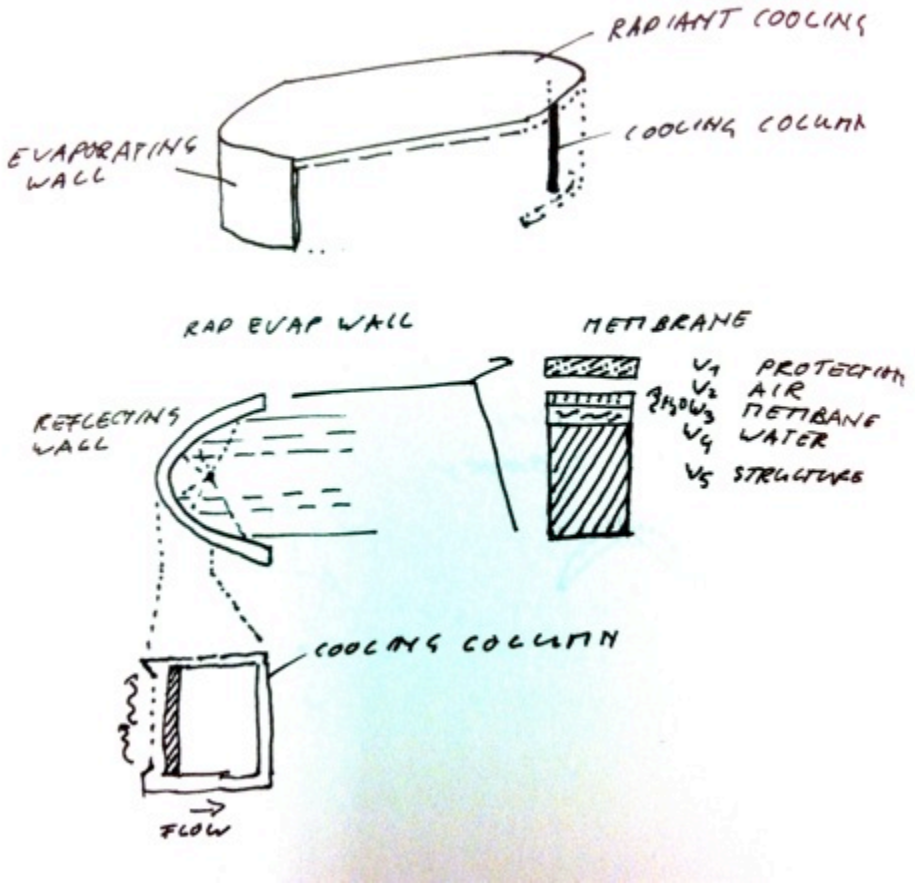
Thermal (IR) Imaging



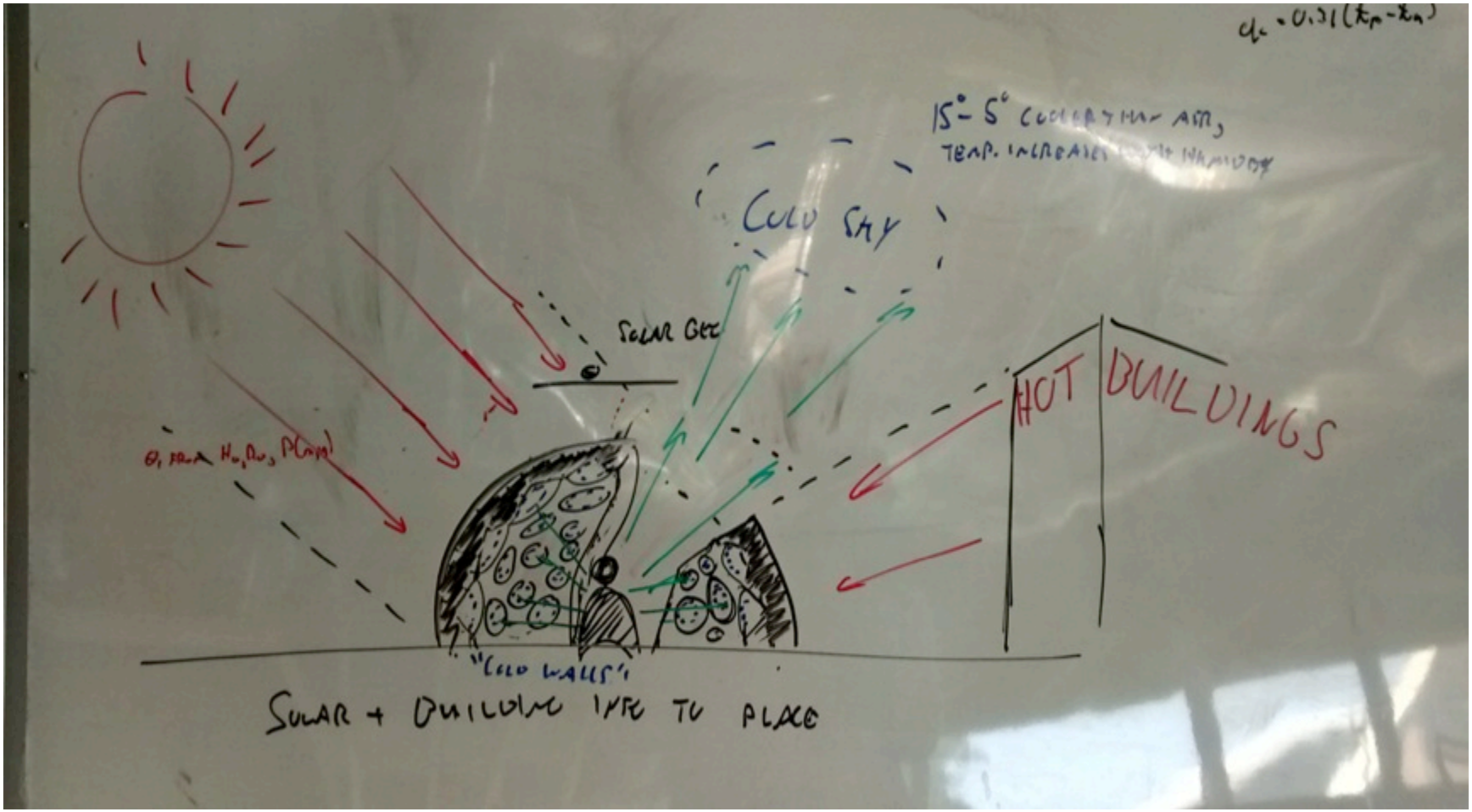
Thermal (IR) Imaging



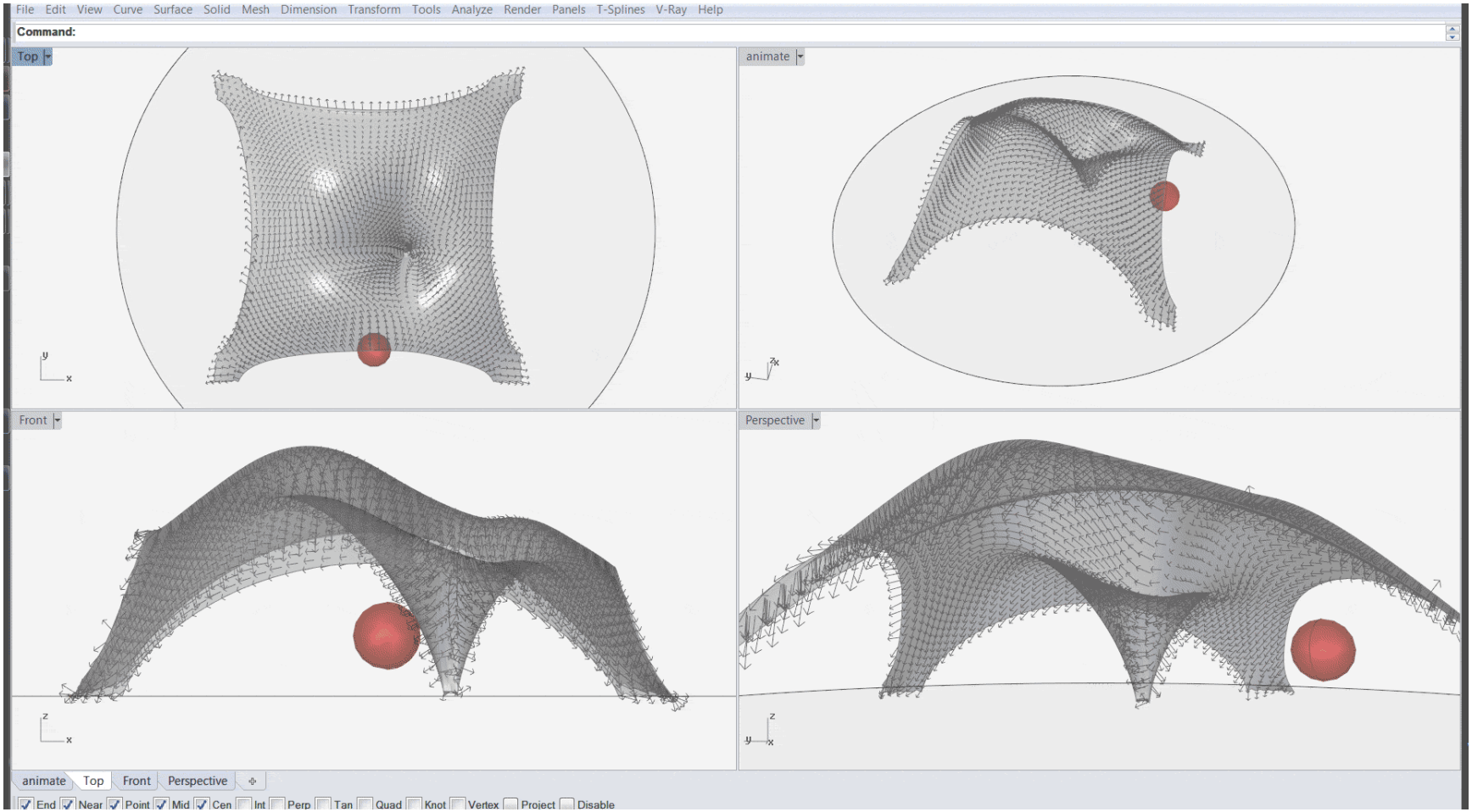
Beyond Shading version 2.0



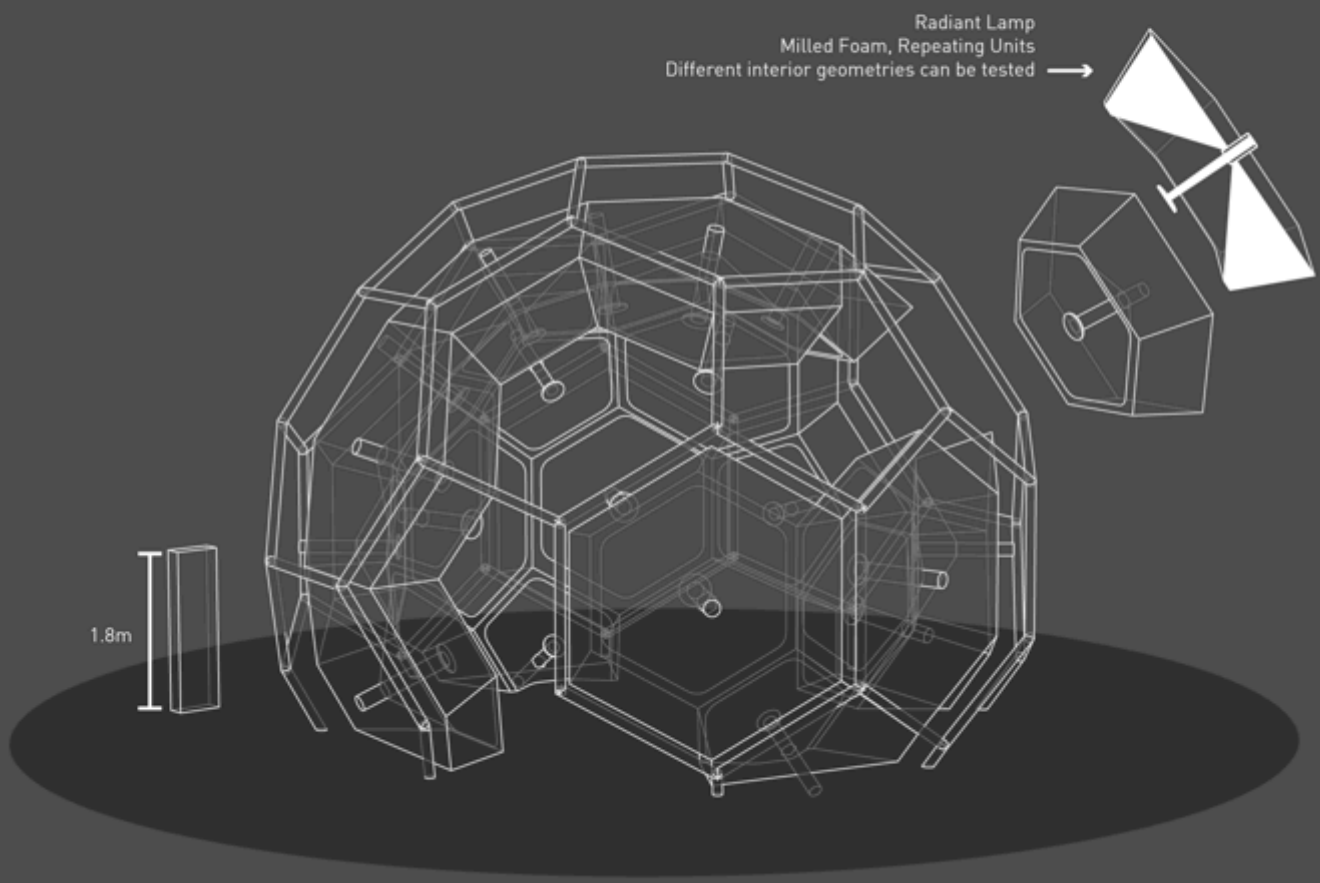
Parabola to Done with cones



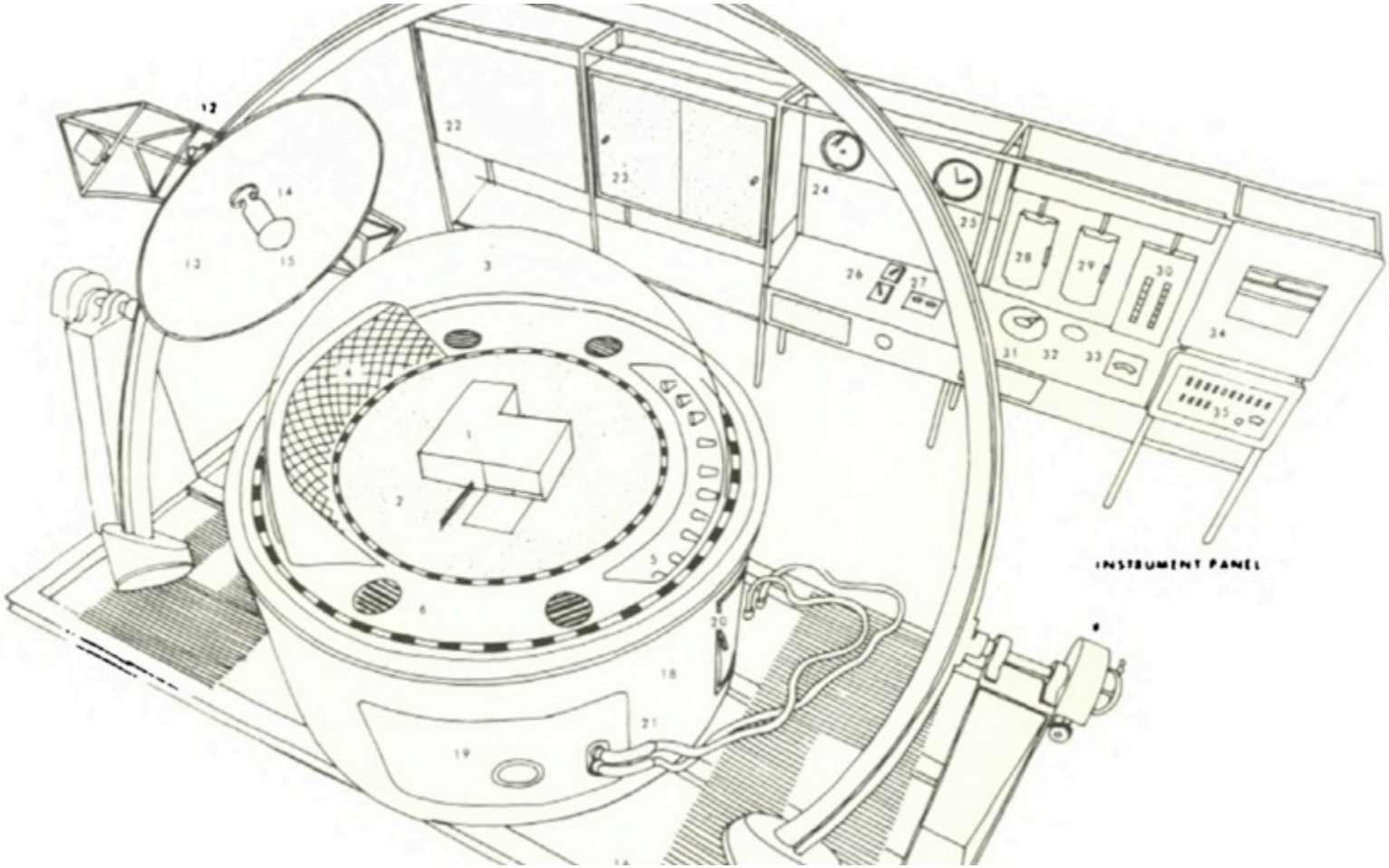
Parabola to Done with cones



Radiant Igloo

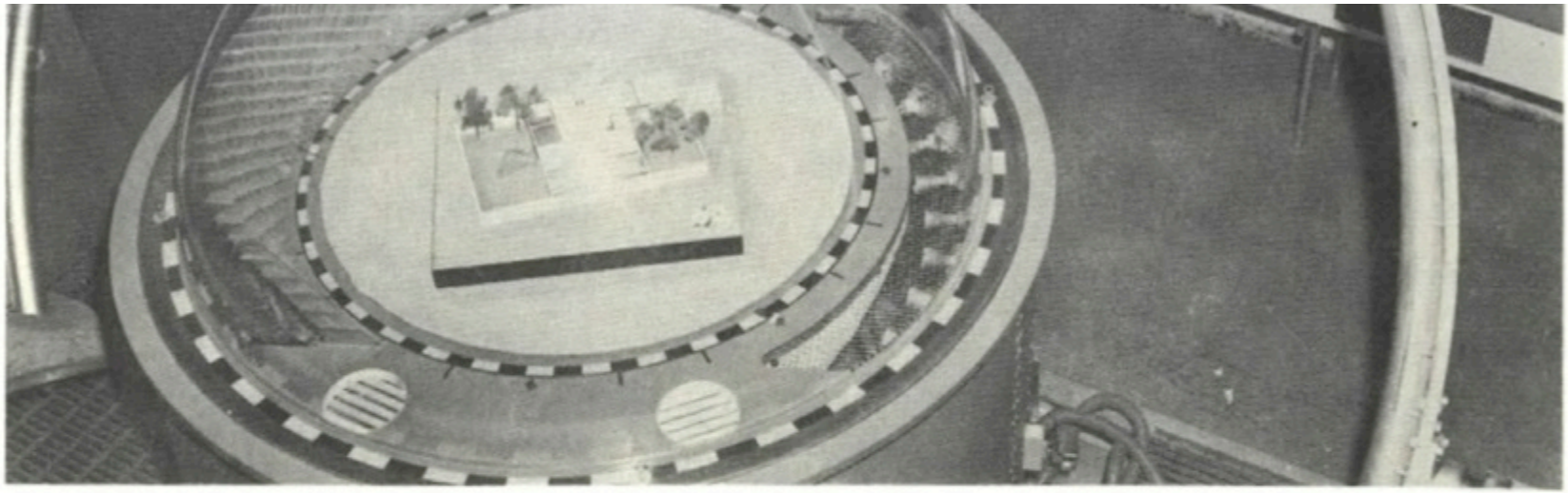


ThermoHelioDon

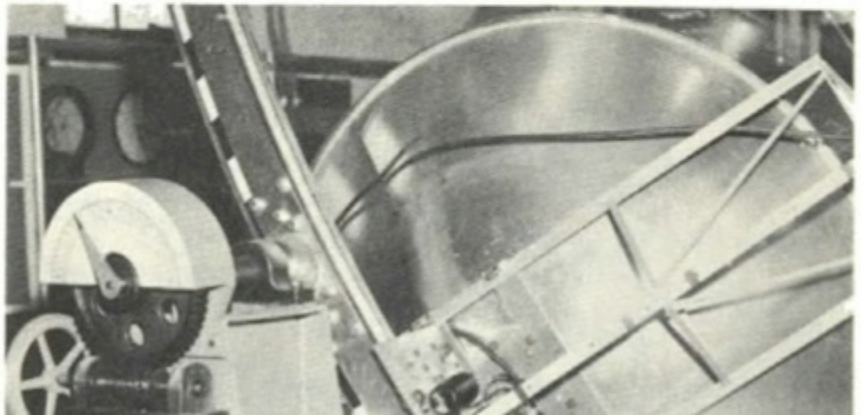


Olgyay. *Design with Climate*, 1963

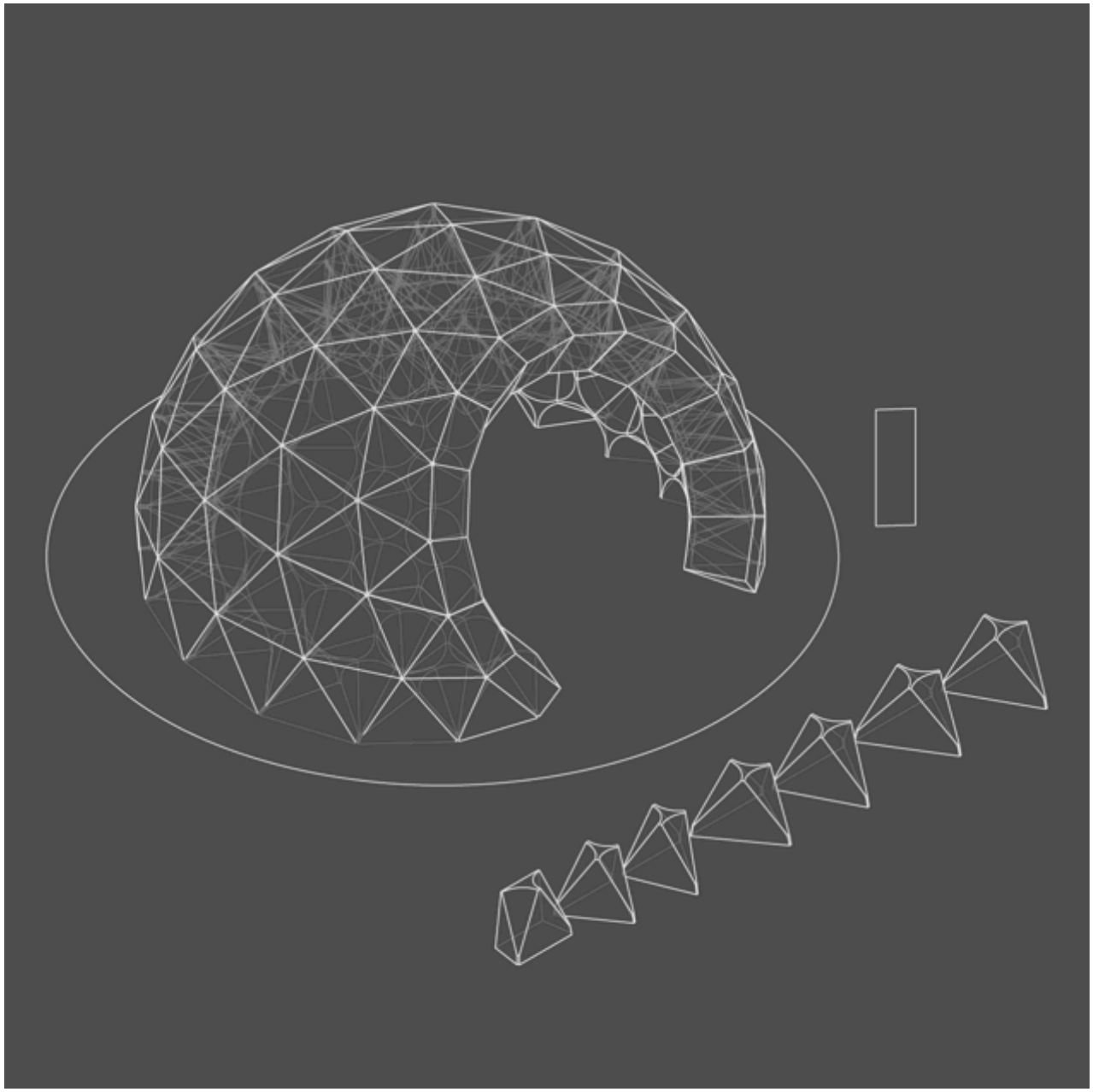
ThermoHelioDon



B–9. View of the Thermoheliodon and instrument panel.



Olgyay. *Design with Climate*, 1963

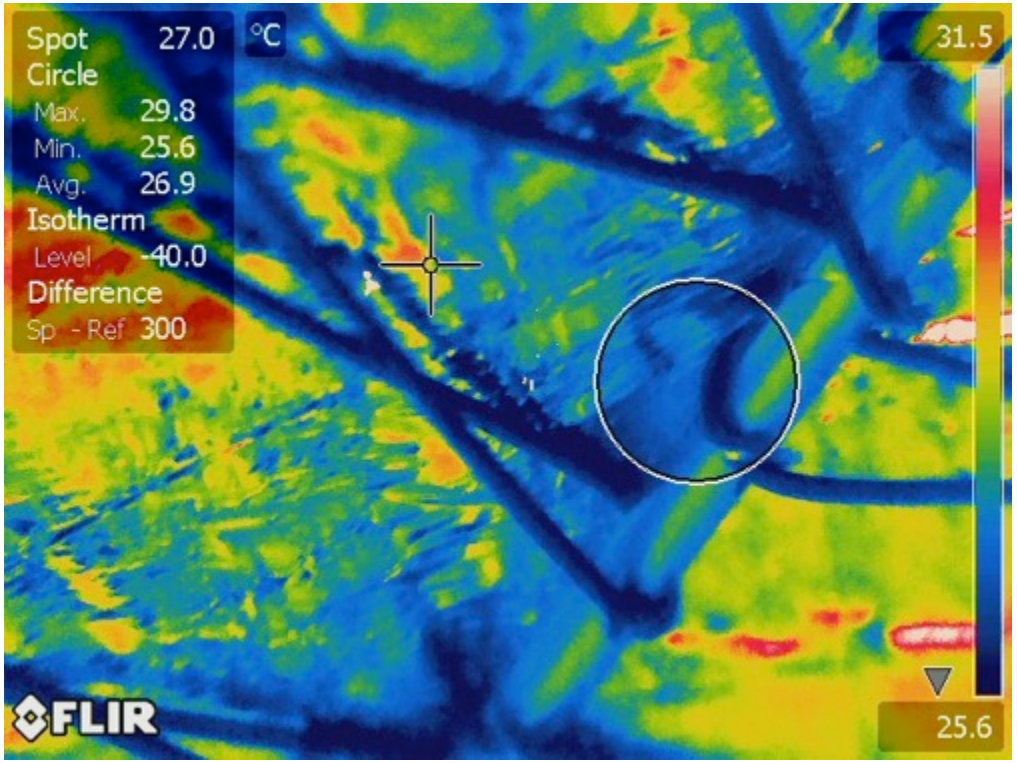


ThemoHelioDome (foam dome)

Where do we go from here?

Re-radiation - playing with surfaces

- Playing with emissivity and absorptivity



Deep-ish Geothermal Potential

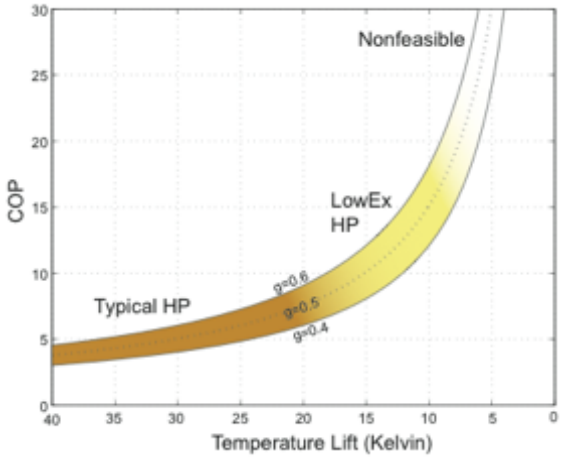
About 1°F / 100 ft

Neglected potential

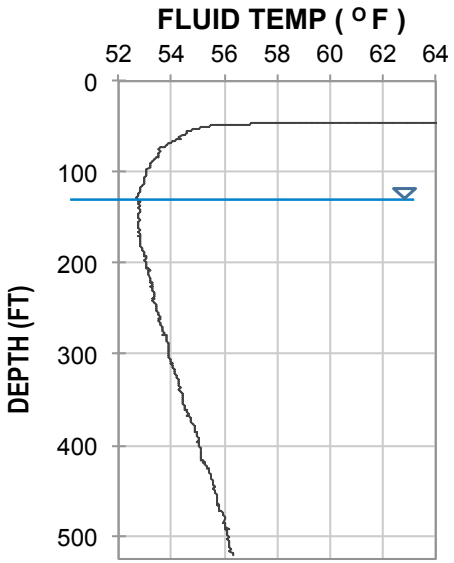
Deeper better for community scal

District heating & cooling

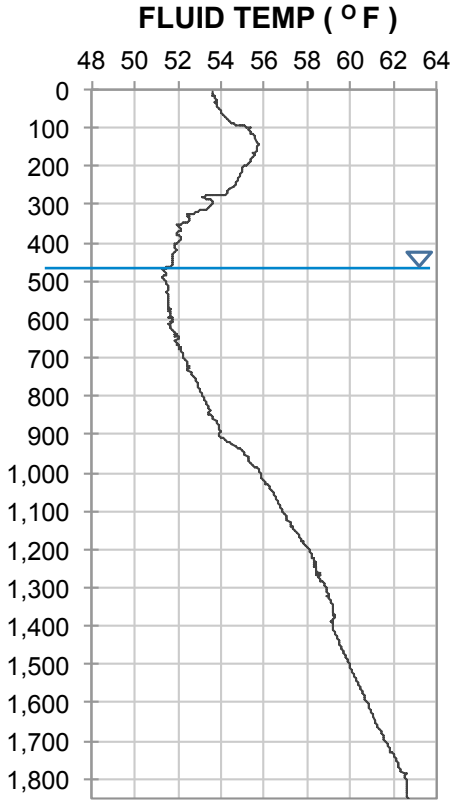
Thermal battery



Princeton



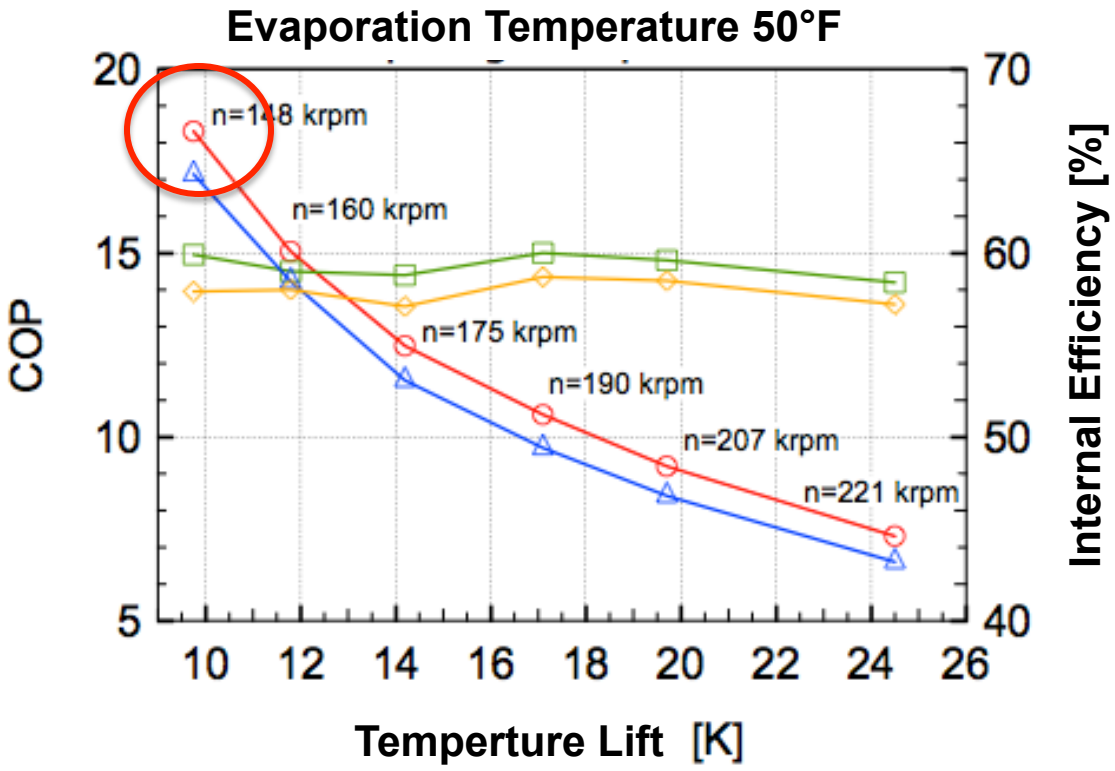
Elizabeth



Turbo Heat Pump

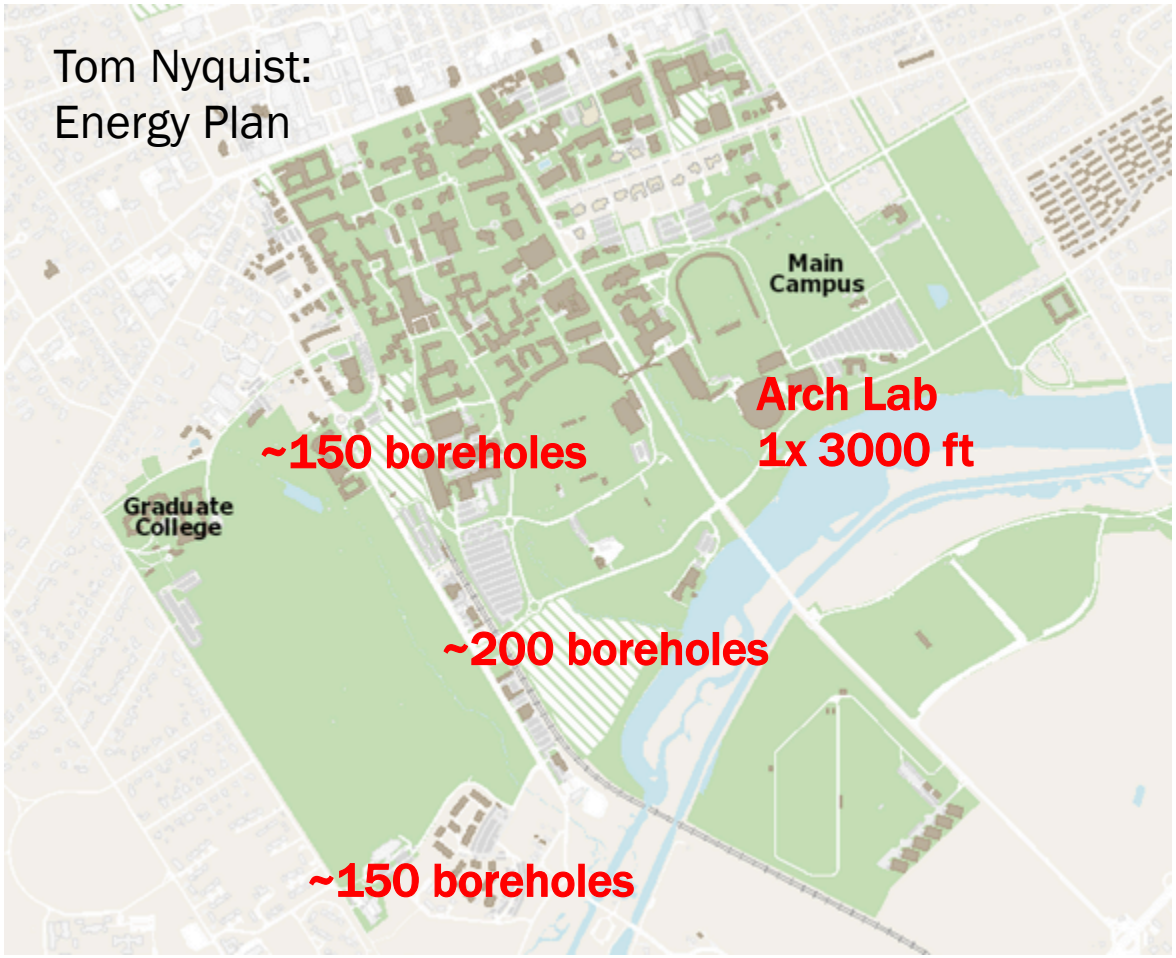
Heating
COP = 18

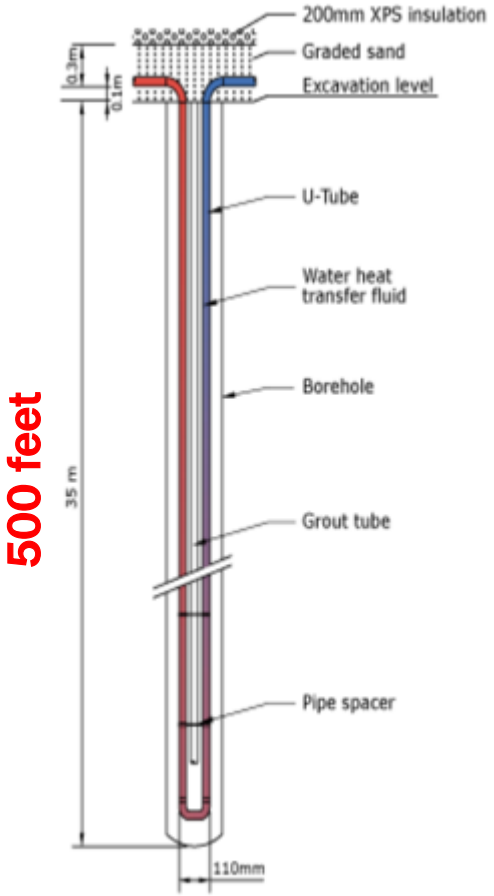
Best avail:
COP = 5-8



Source: Wyssen et al, Hochschule Luzern, Switzerland

Princeton campus as a (LowEx) lab

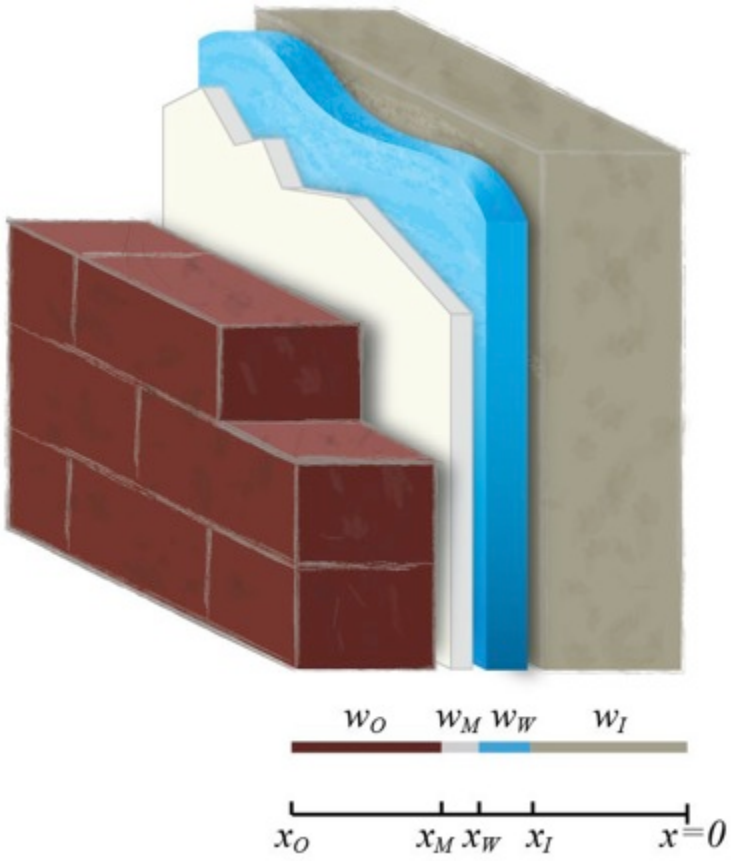


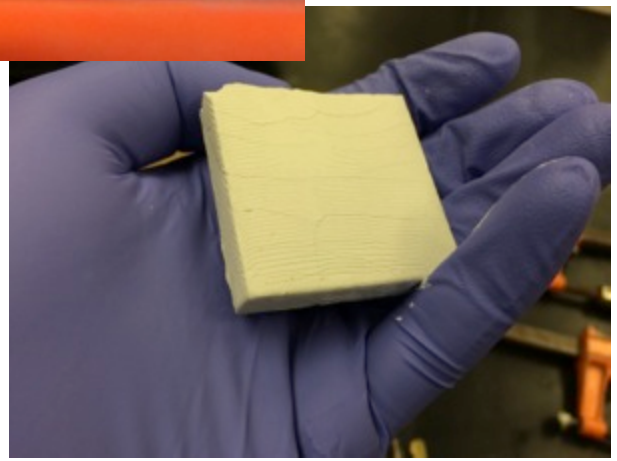


IEA ECB Annex 64 – LowEx Communities Subtask comparing to CoGen

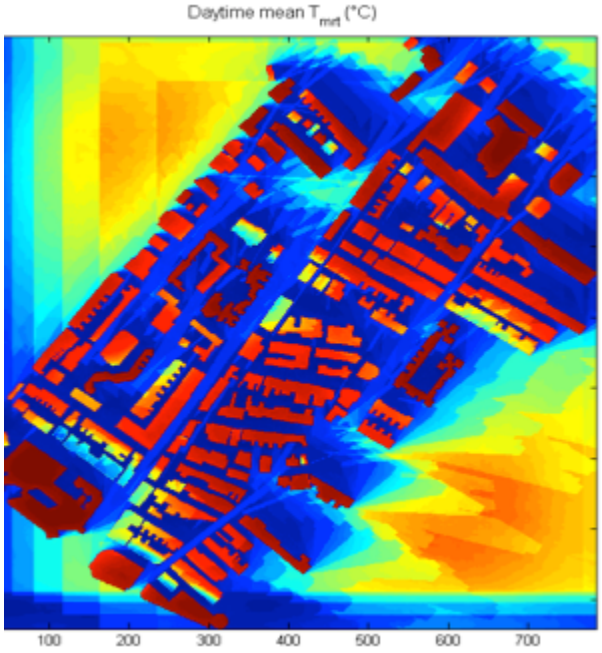
Evaporative cooling facade

- Evaporate *through* a dry façade structrue





“Natural” airflows of the built environment



Stack and *stuck* effect

Bruelisauer, Meggers, Saber, Li, Leibundgut; EnB 2013

IR + Aerial Vehihle

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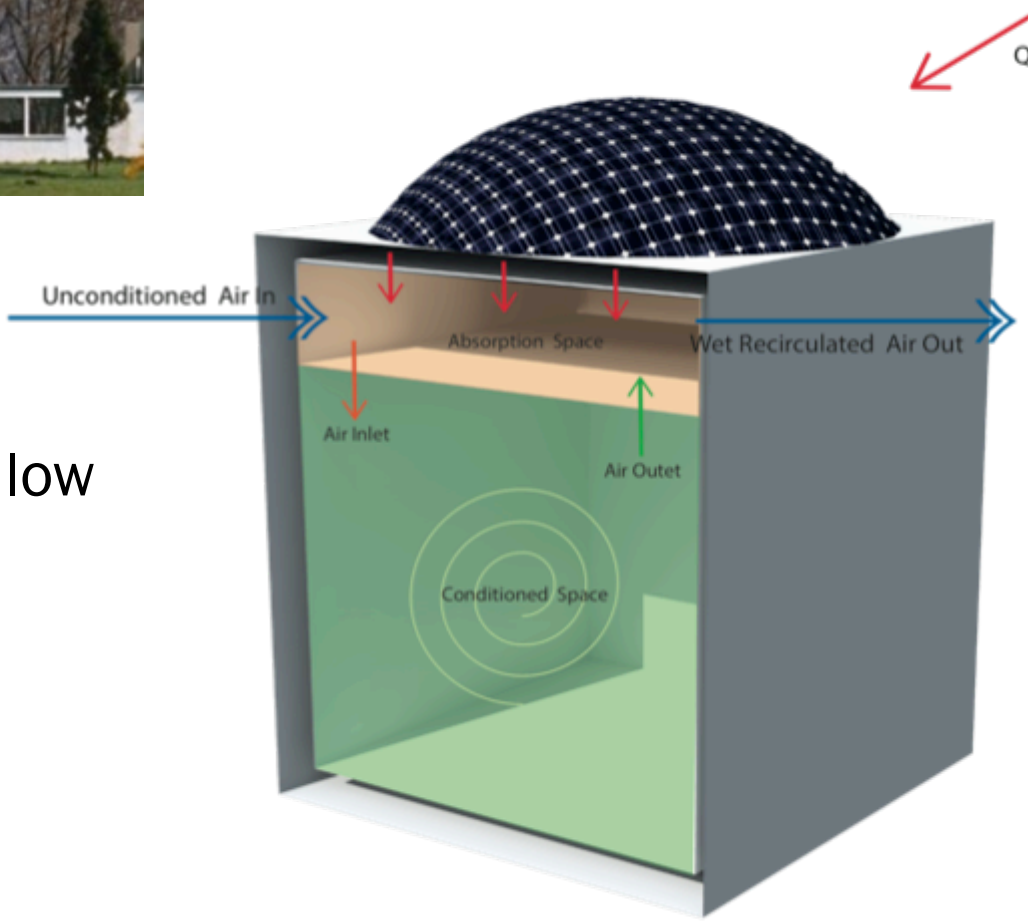
Desiccant LowEx regeneration

Test a new desiccant with low regeneration temperature



Conclusion = Potential

Thermodynamic potential

can instigate novel design potential