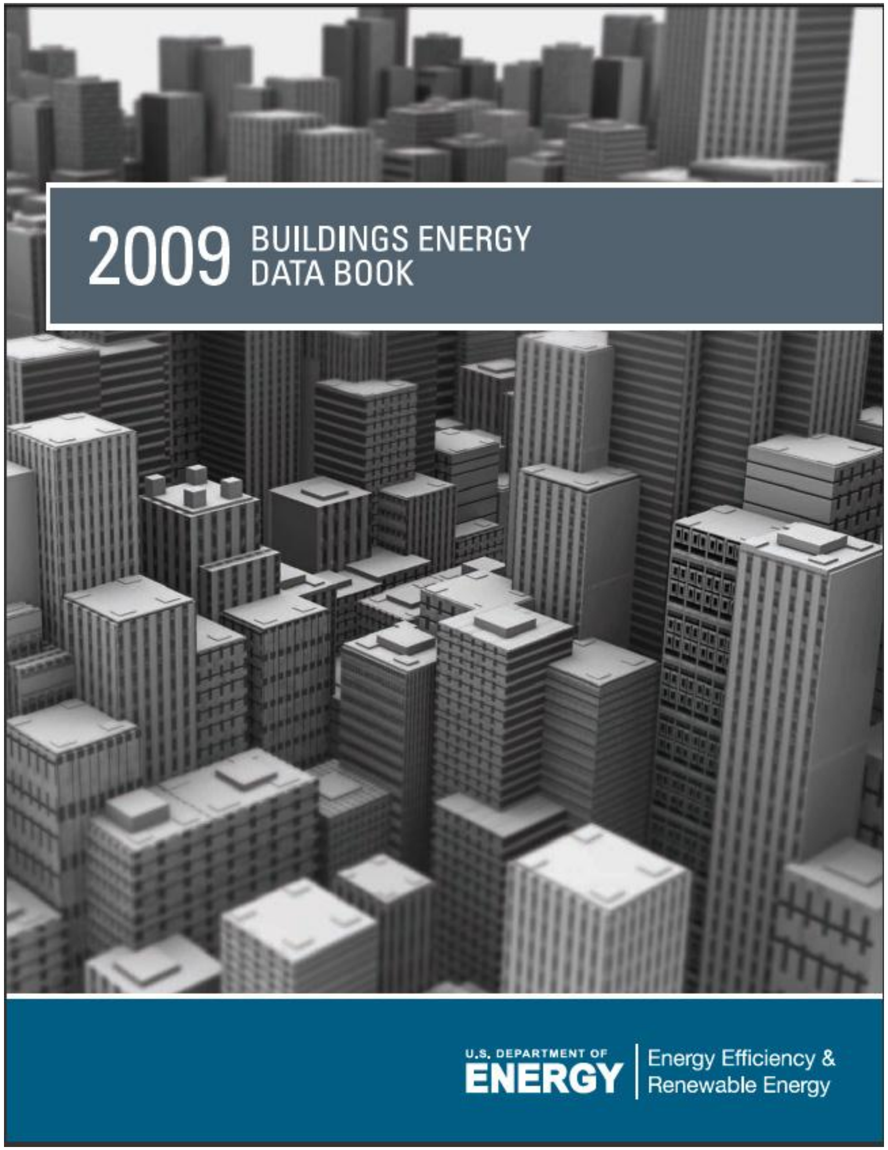
Innovations in Green Building Design

Dr. Michelle Addington
Hines Professor of Sustainable Architectural Design
Yale University



COMMERCIAL BUILDING DATABASE

4+ million buildings sorted by:

- size (floor area, number of floors)
- occupancy (number of employees and time)
- function
- location
- age
- construction type
- energy sources
- energy end-use
- energy efficient features

COMMERCIAL BUILDINGS SURVEY

DEPARTMENT OF ENERGY, 2009

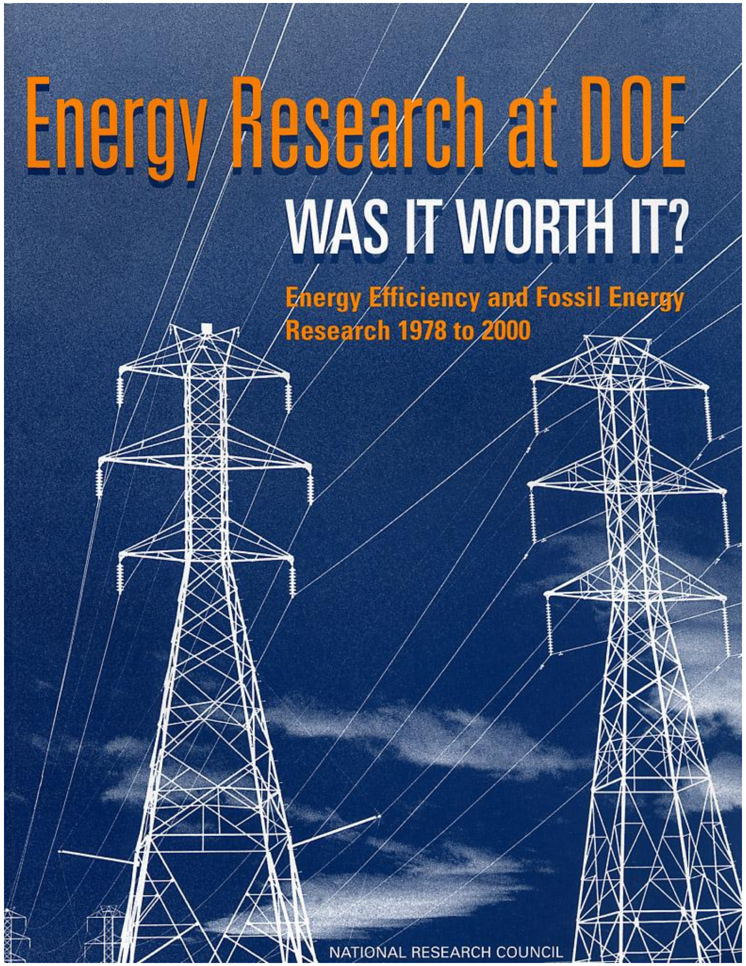
data from 4,675,000 buildings

buildings reporting energy efficient features used ***more*** energy per capita than buildings not reporting these features

findings were consistent for every building type and size, and for every energy efficient feature from economizer cycles to occupancy sensors

findings were also consistent with the 2007, 2005, 2003 and 1999 surveys

REVIEW OF DOE RESEARCH BY THE NATIONAL RESEARCH COUNCIL



$2 billion spent on building energy efficiency research since inception of DOE

auditors could only identify three programs in which energy savings could be *proven*:

- advanced refrigerators
- electronic ballasts
- low-e glass

Buildings are becoming larger in square meters per capita and per function

Ambient environmental systems are volumetric

-- increase in building dimensions increases HVAC by the cube

Lighting systems and materials are planar

-- increase in building dimensions increases these by the square

-- if ceiling height is increased, then lighting increases by the cube

Electricity loads in buildings have increased

More electrical equipment

- --computers and digital equipment
- --appliances

More electrical lighting

- --light levels are higher, more area is lit

More use of space cooling

- --air conditioning increasing at double digit rates in Europe

Primary energy for cooling is increasing at a faster rate than heating

most building strategies are intended to reduce heating

increase in electrical equipment increases cooling requirements

Urban Heat Island multiplies local heat load

distributing energy generation to buildings increases local heat load

WHY HAVENT WE BEEN ABLE TO TACKLE THE MAJOR PROBLEMS?

1. ASSUMPTIONS

Buildings are units of property, they are not energy systems

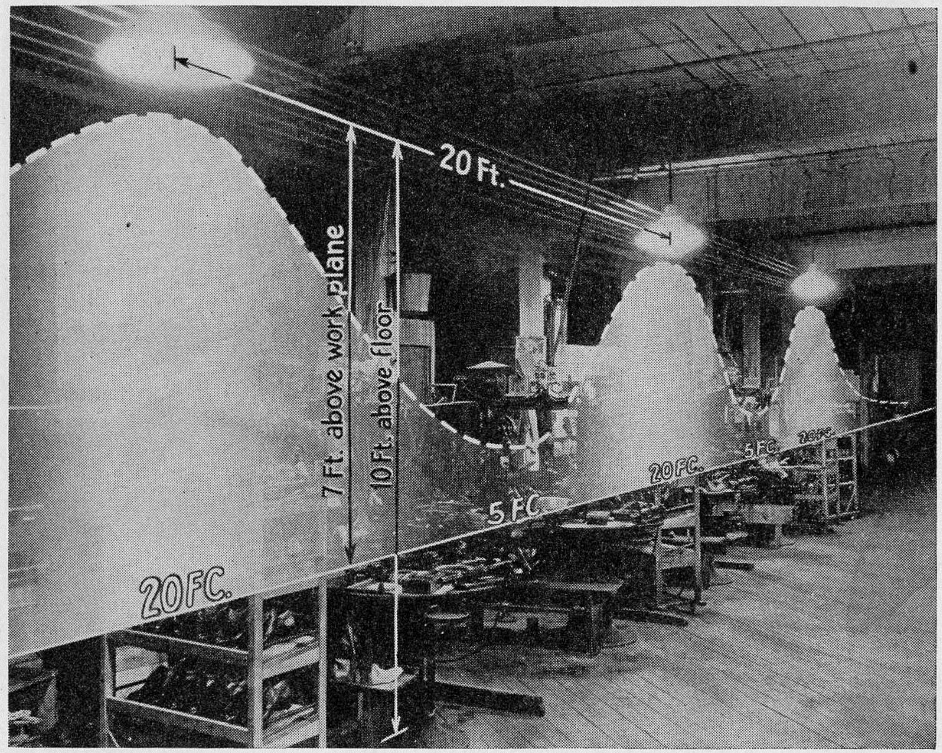
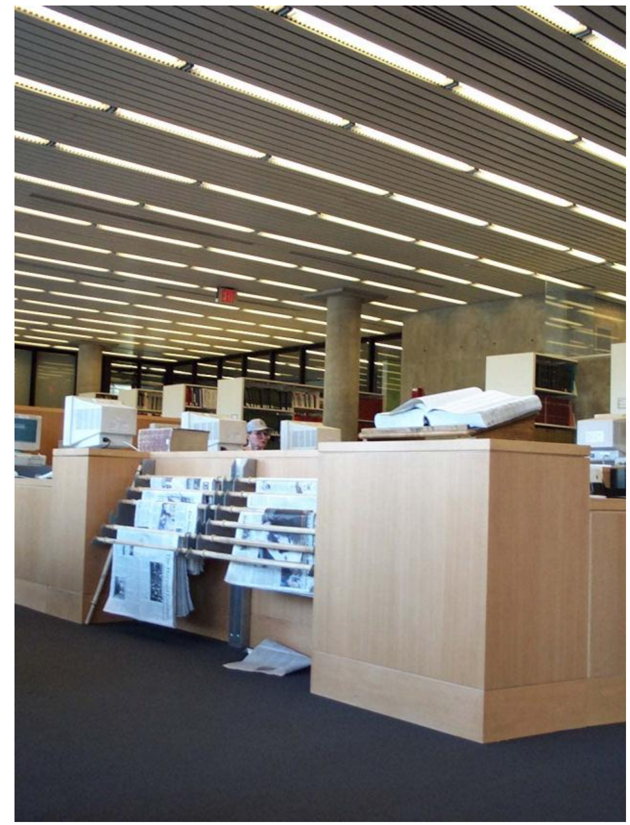


Fig. 127.—Nonuniform or "roller-coaster" lighting result when units are spaced too far apart for their mounting height.



2. TECHNOLOGIES

The major energy consuming systems are designed for the building, not its occupants

U.S. Department of Energy

Builders Challenge

RECOGNIZING ENERGY LEADERSHIP IN HOMEBUILDING

A well-designed house should have an HVAC system properly sized to its demands. Equipment sizing ensures a comfortable environment and provides opportunities to recapture some of the expense of constructing an efficient building envelope. Rules of thumb for equipment sizing do not work in modern homes and should not be used.

The Air Conditioning Contractors of America (ACCA) has published simple but effective methods for determining loads and sizing ductwork and heating and cooling equipment. *Manual J* tells you how to calculate heating and cooling loads. *Manual D* tells you

Version 1.2 | November 2009 | PNNL-18009

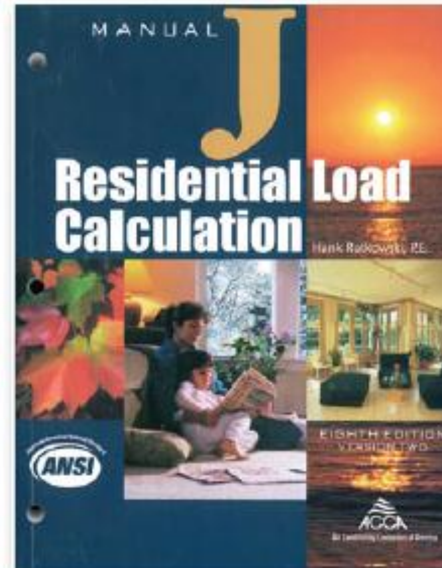
Builders Challenge
Quality Criteria Support Document

Building America Best Practices Series Volume 8 | Version 1.2 | November 2009 | PNNL-18009

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

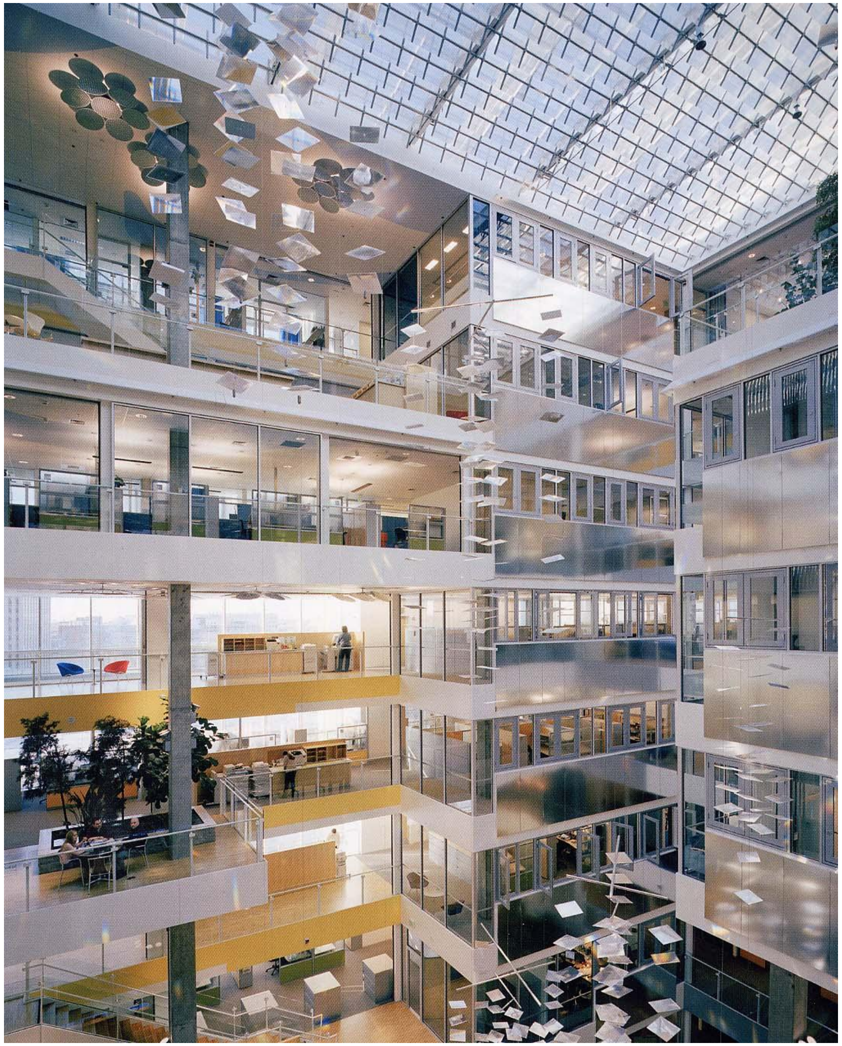
Building America | U.S. Department of Energy | Research Toward Zero Energy Homes

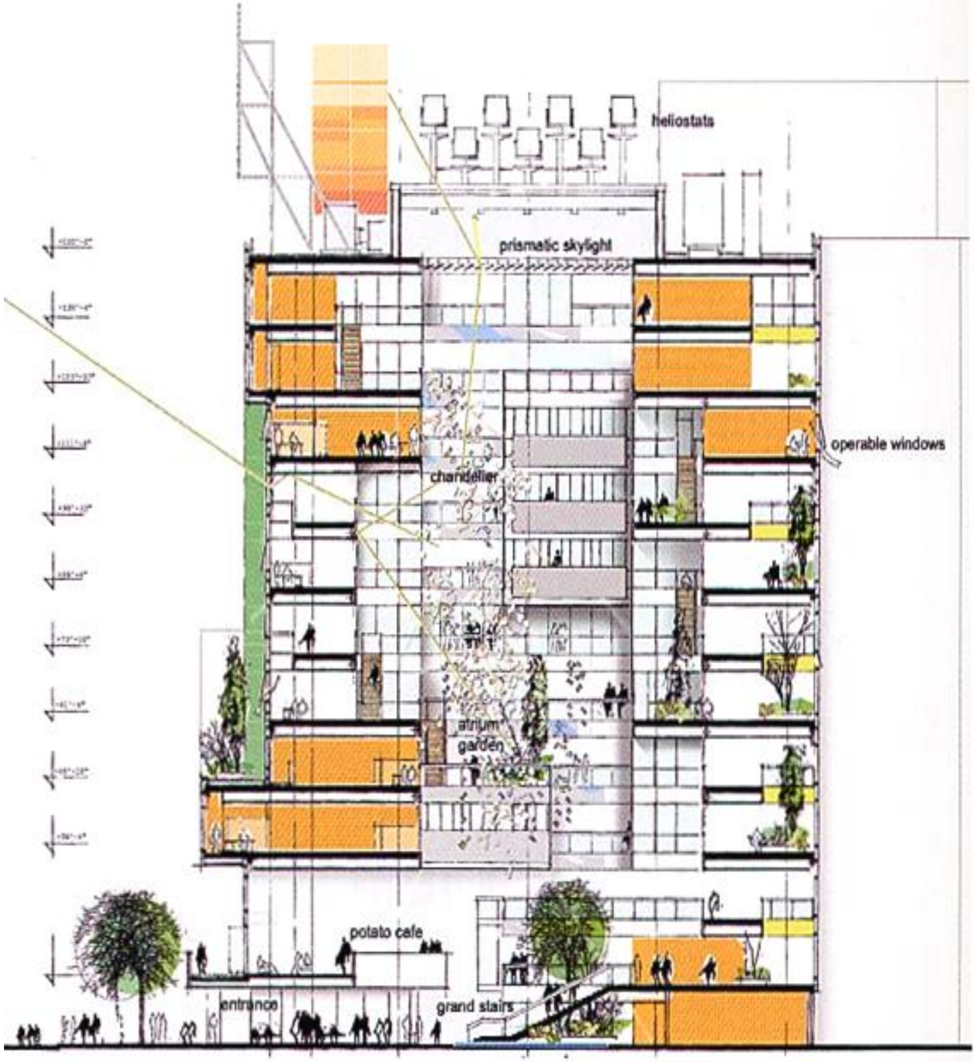
Builders Challenge | Recognizing Energy Leadership in Homebuilding



3. TOOLS

Energy analysis is based on conservative volumes which treats the building as a bounded energy system served by homogeneous environmental systems




heliostats
prismatic skylight
operable windows
chandelier
atrium garden
potato cafe
entrance
grand stairs

HOW DO WE MOVE FORWARD?

Dis-integrate systems at the individual building

Integrate systems as the appropriate phenomenological scales

ELECTRICITY A/C

ELECTRICITY D/C

THERMAL WATER

THERMAL MASS

1000 kilometers

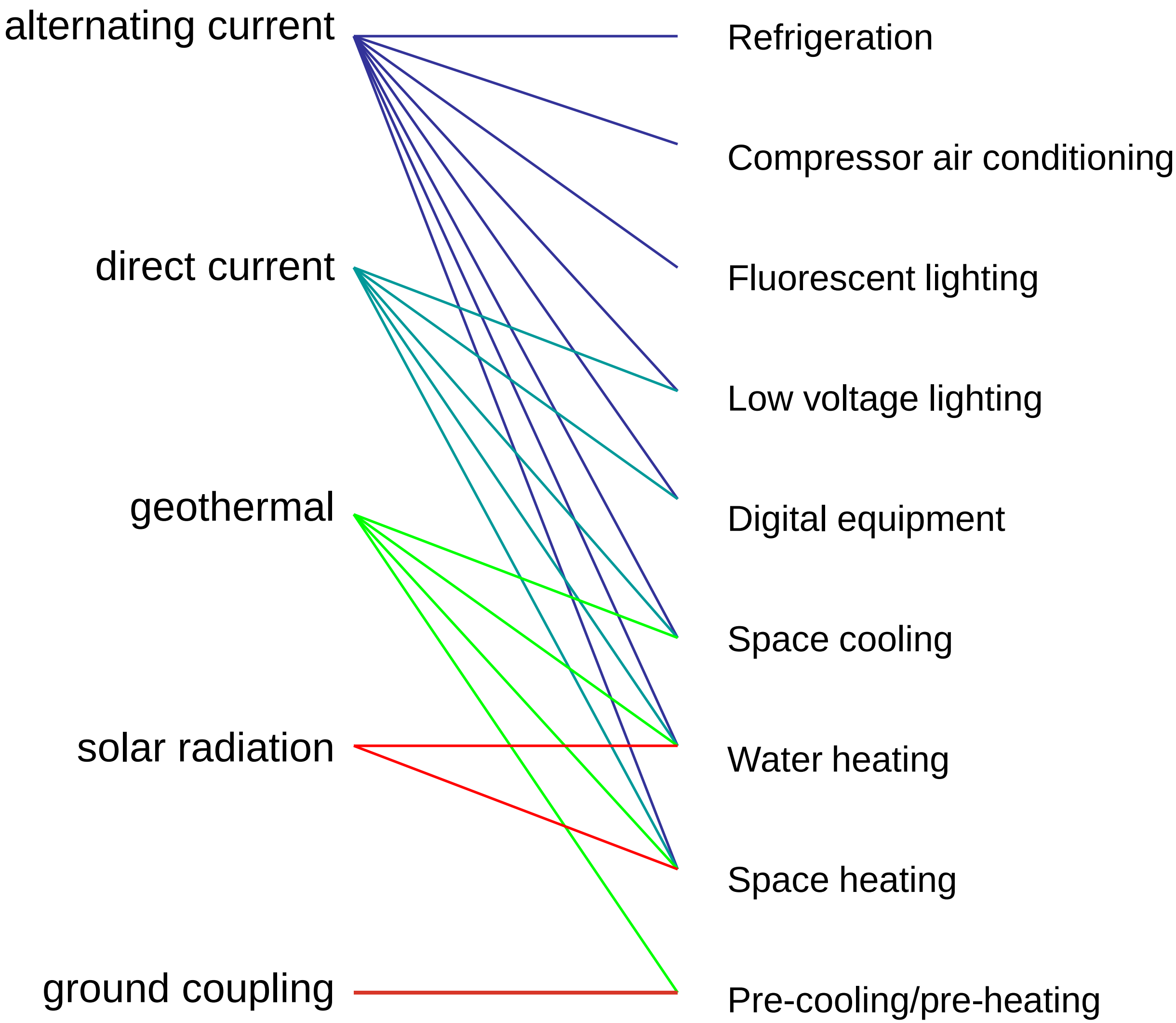
100 kilometers

10 kilometers

I000 meters

100 meters

10 meters



alternating current
direct current
geothermal
solar radiation
ground coupling
Refrigeration
Compressor air conditioning
Fluorescent lighting
Low voltage lighting
Digital equipment
Space cooling
Water heating
Space heating
Pre-cooling/pre-heating

national/regional

SUPRA-BUILDING

SOURCE

SUB-BUILDING

CONSUMER

component

Alternating Current

Direct Current

Low Temperature Geothermal

Solar (un-concentrated thermal)

Ground Coupling

SOURCE

SUPRA-BUILDING

SUB-BUILDING

CONSUMER

consumption type (exergy matching)

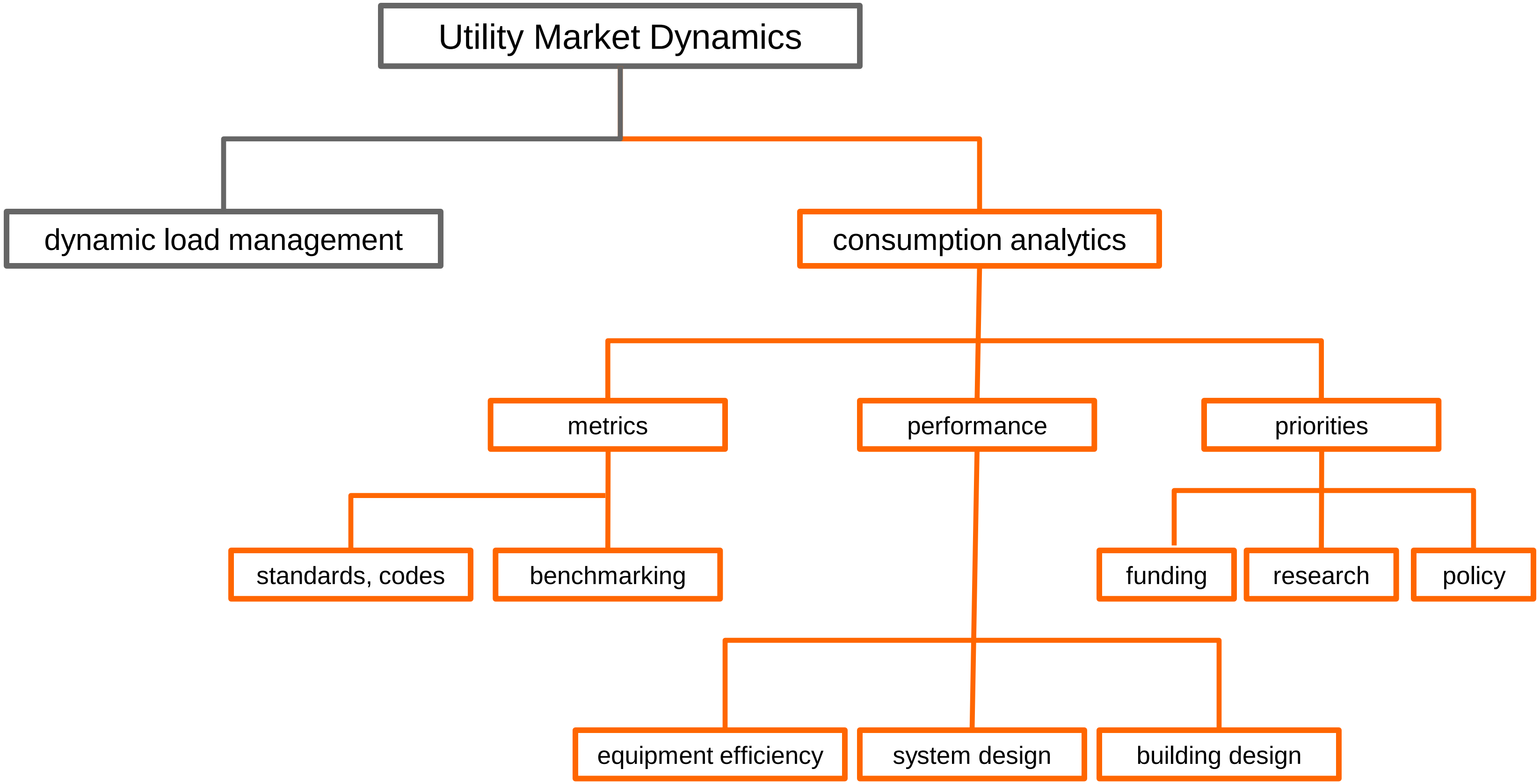
supply/consumption (de)coupling

source/sink distribution

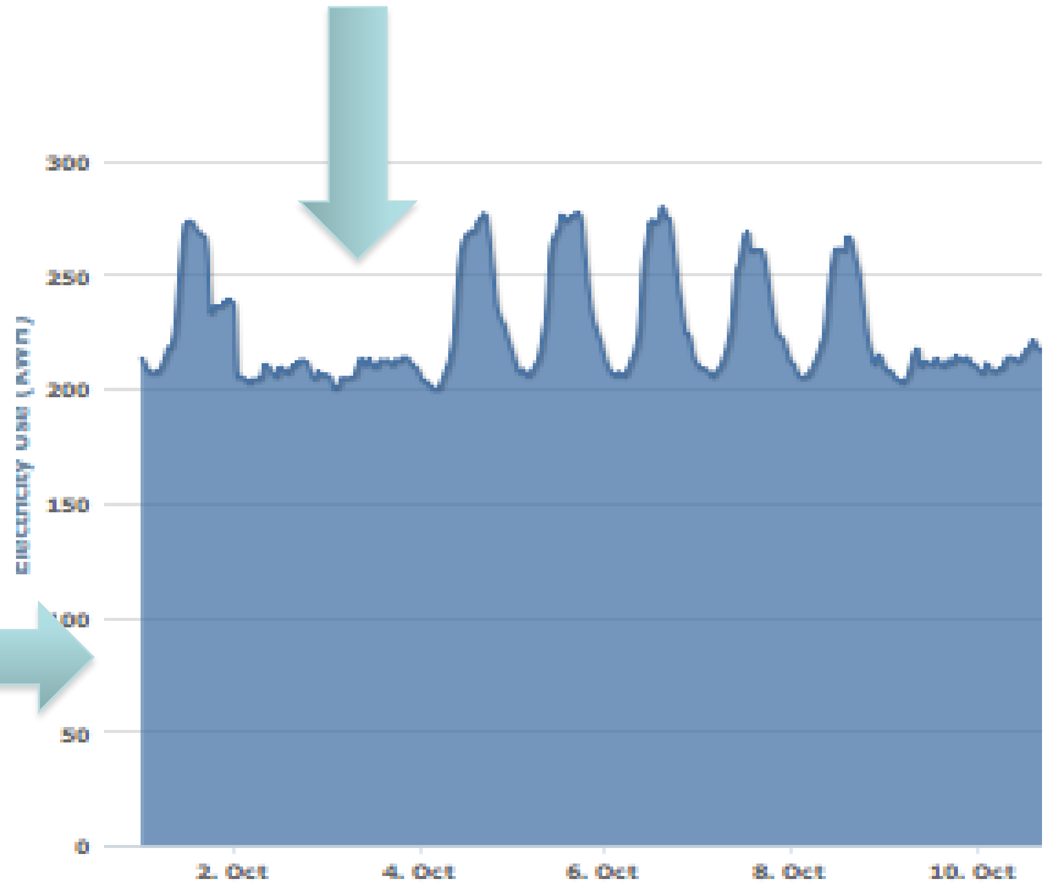
thermal “mining”

consumption quantity

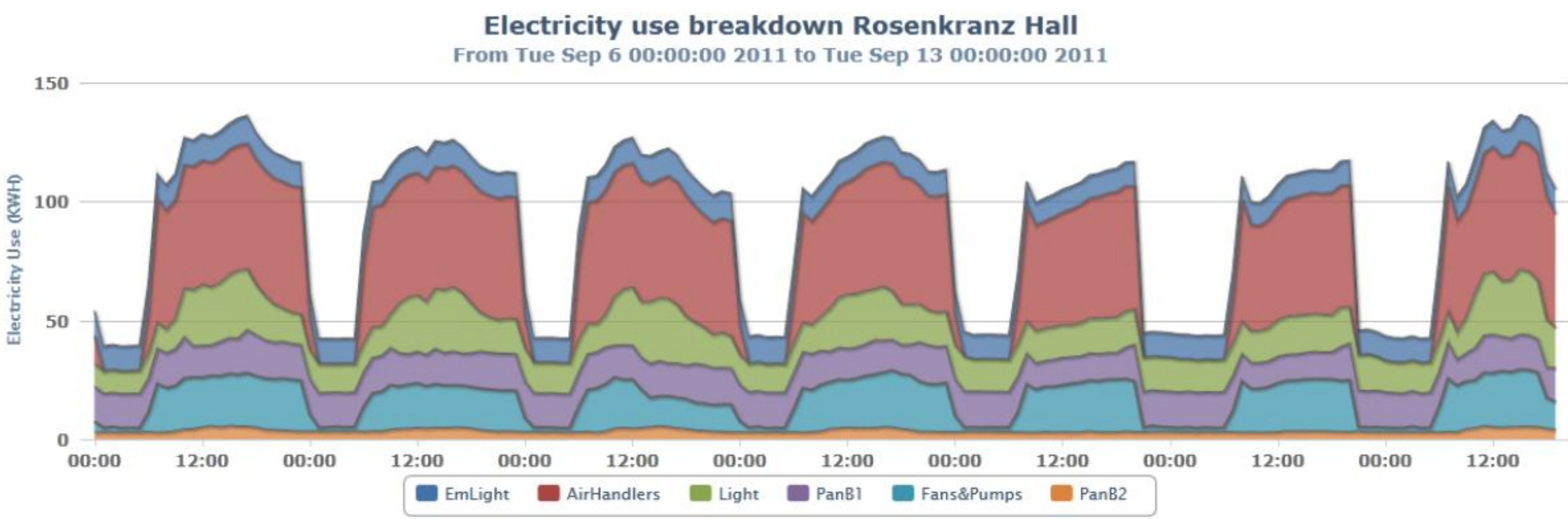
INTELLIGENT BUILDINGS PROJECT


Utility Market Dynamics
dynamic load management
consumption analytics
metrics
performance
priorities
standards, codes
benchmarking
funding
research
policy
equipment efficiency
system design
building design

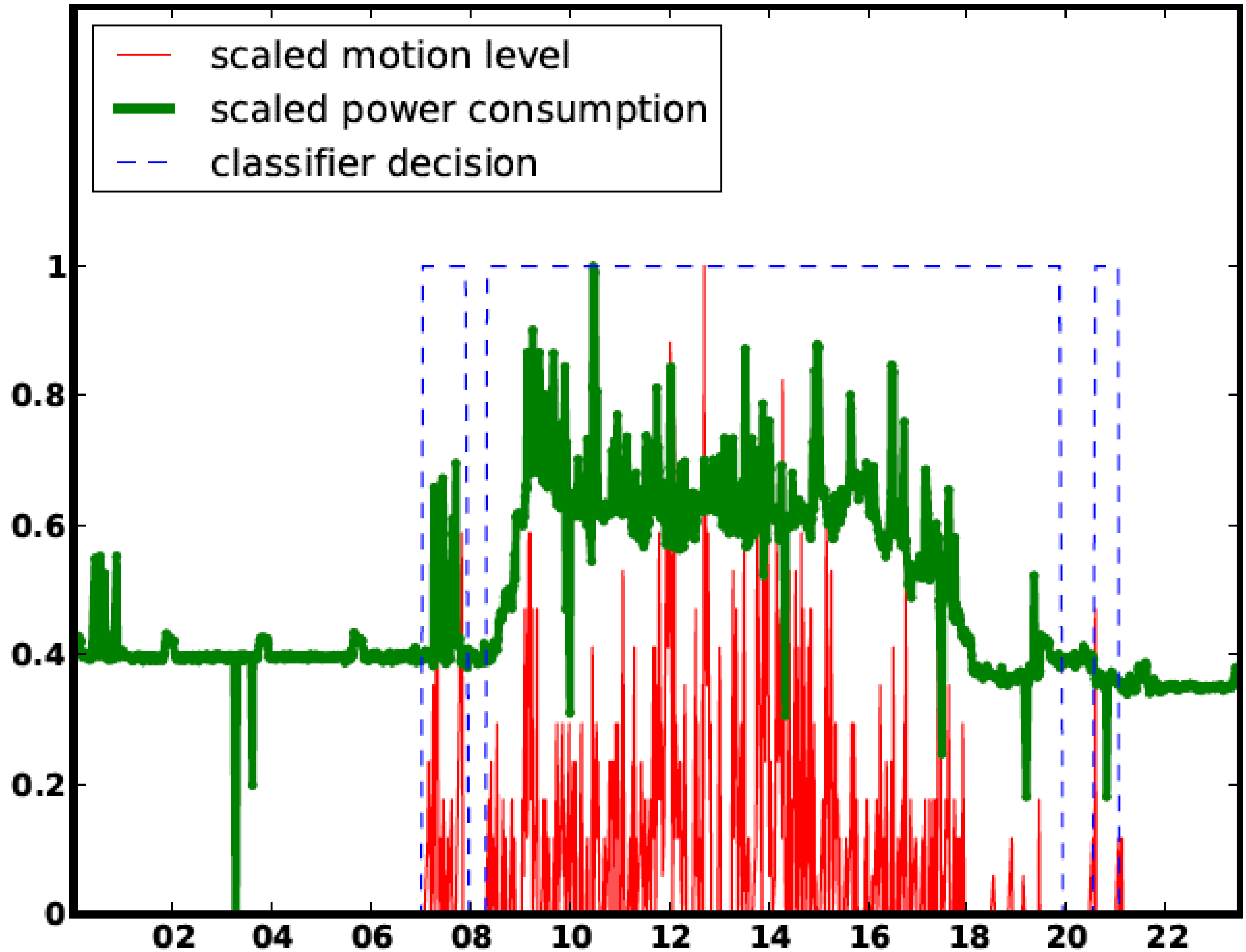
Dynamic Properties



Load Analysis &
Disaggregation



Electricity use breakdown Rosenkranz Hall
From Tue Sep 6 00:00:00 2011 to Tue Sep 13 00:00:00 2011
Electricity Use (KWH)
150
100
50
0
00:00
12:00
00:00
12:00
00:00
12:00
00:00
12:00
00:00
12:00
00:00
12:00
00:00
12:00
EmLight
AirHandlers
Light
PanB1
Fans&Pumps
PanB2



scaled motion level
scaled power consumption
classifier decision
1
0.8
0.6
0.4
0.2
0
02
04
06
08
10
12
14
16
18
20
22

MULTI-PART METRIC

1. Occupant Determined Loads (per capita)

    a) Occupant behavior
    b) Occupant determined equipment (computers, plug loads, …)

2. Technology Determined Loads (per item/system energy conversion)

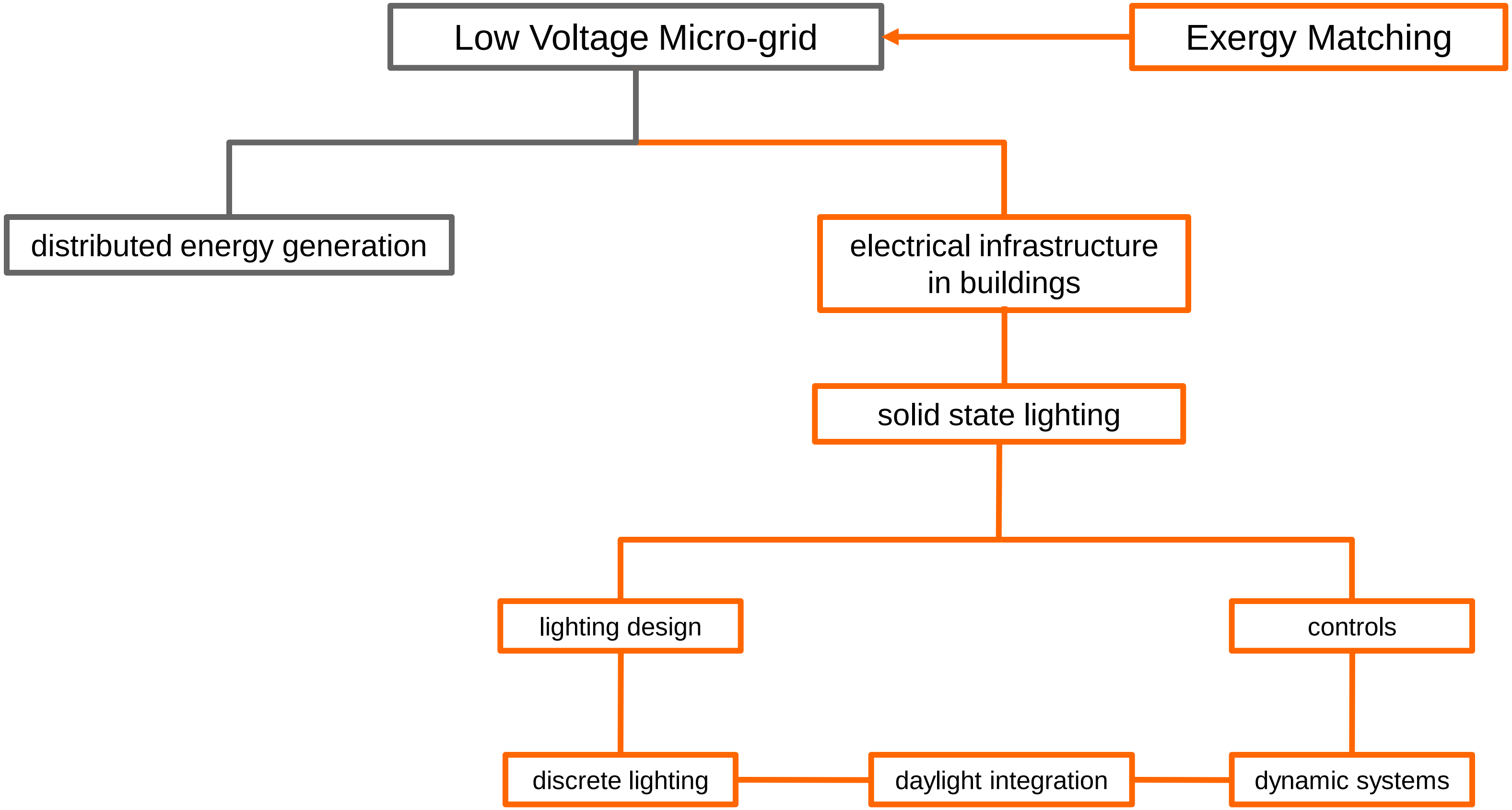
    a) Individual equipment efficiency
    b) Operational efficiency of systems (HVAC, lighting, hot water)

3. Building Determined Loads (per area normalized per capita)

    a) Lighting design
    b) Interior climate design

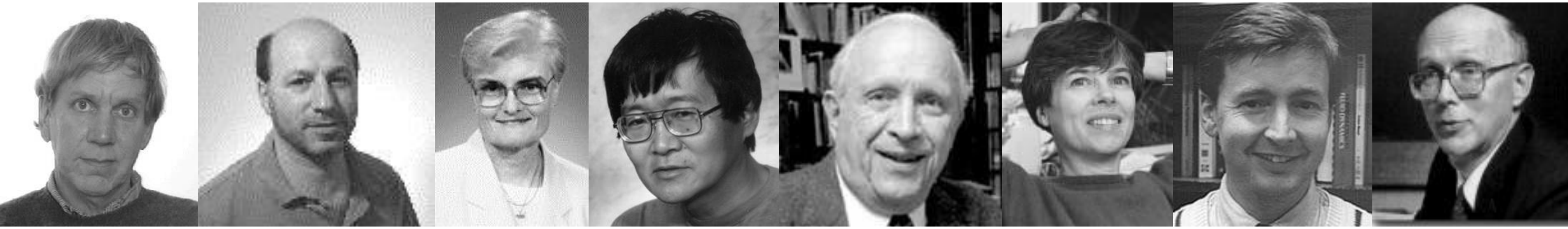
4. Envelope Determined Loads (surface area normalized by climatic conditions)

    a) Climatic source and sink
    b) Daylight utilization


Low Voltage Micro-grid
Exergy Matching
distributed energy generation
electrical infrastructure
in buildings
solid state lighting
lighting design
controls
discrete lighting
daylight integration
dynamic systems

RESEARCH AREAS	POSSIBLE COLLABORATORS
Exergy matching waste heat recovery water heating *electrical infrastructure*	Mechanical engineering Electrical engineering
Sink/source management surroundings—load shedding discrete—direct control of heat transfer thermal inertia	Mechanical engineering Physical geography
Building environments mean radiant temperature thermal environment field of view lighting—*discrete lighting* functional zoning indoor air quality	Neurobiology Visual Psychology *MIT Media Lab* Public Health

Climate model for building design—in progress
Advanced technologies and materials in lighting—in progress



astronomy

applied physics

fluid mechanics

materials science

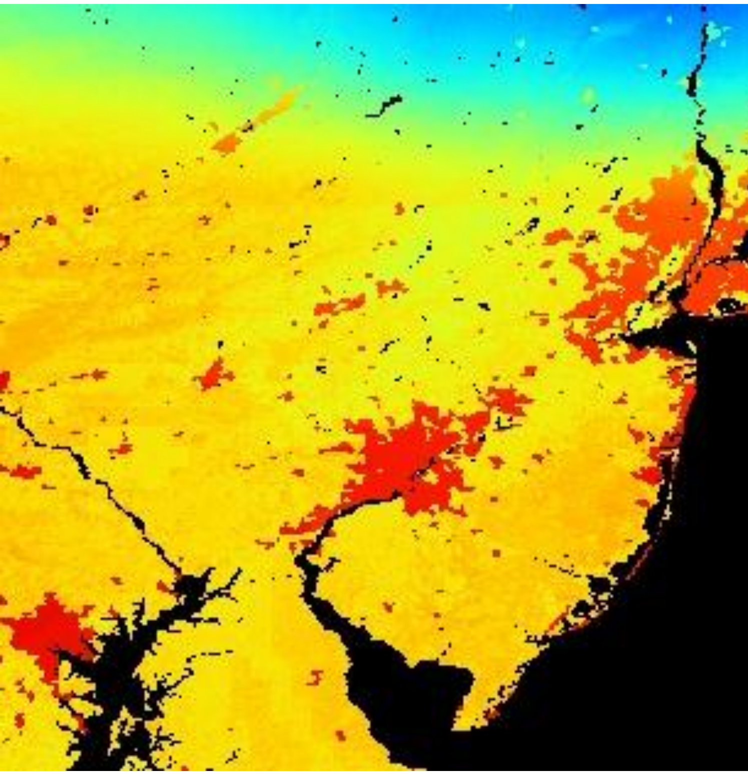
epidemiology

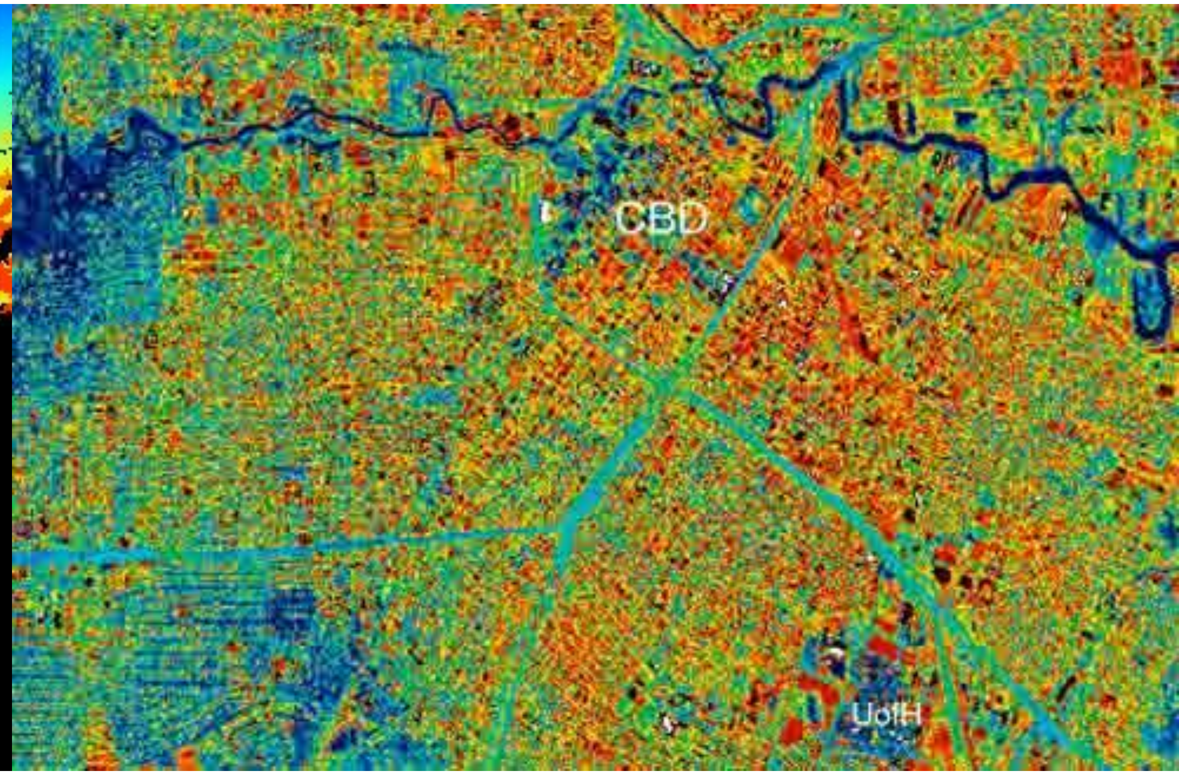
neurobiology

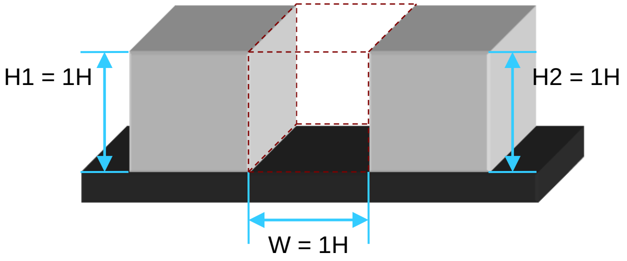
organic chemistry

theoretical physics

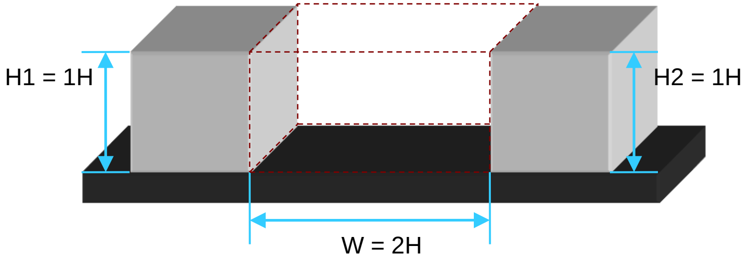
visual psychology




CBD
UofH

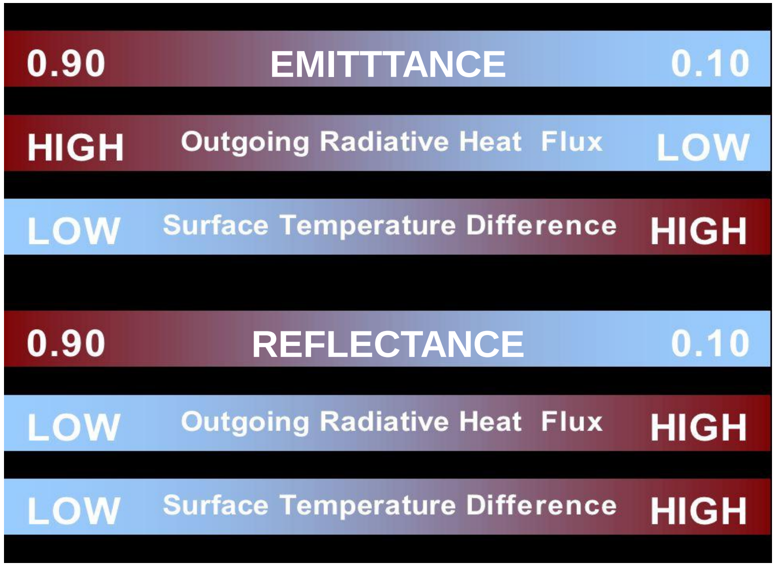


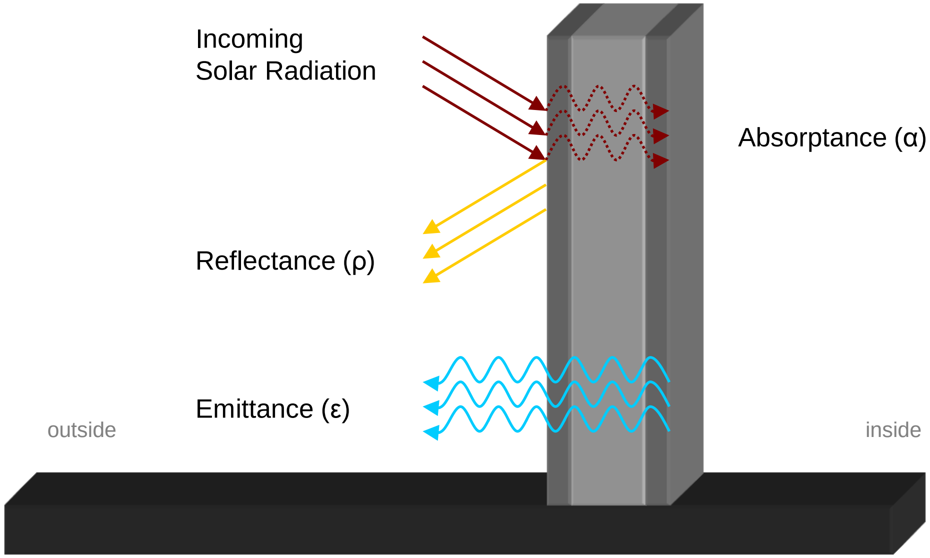
a. H/W = 1.0



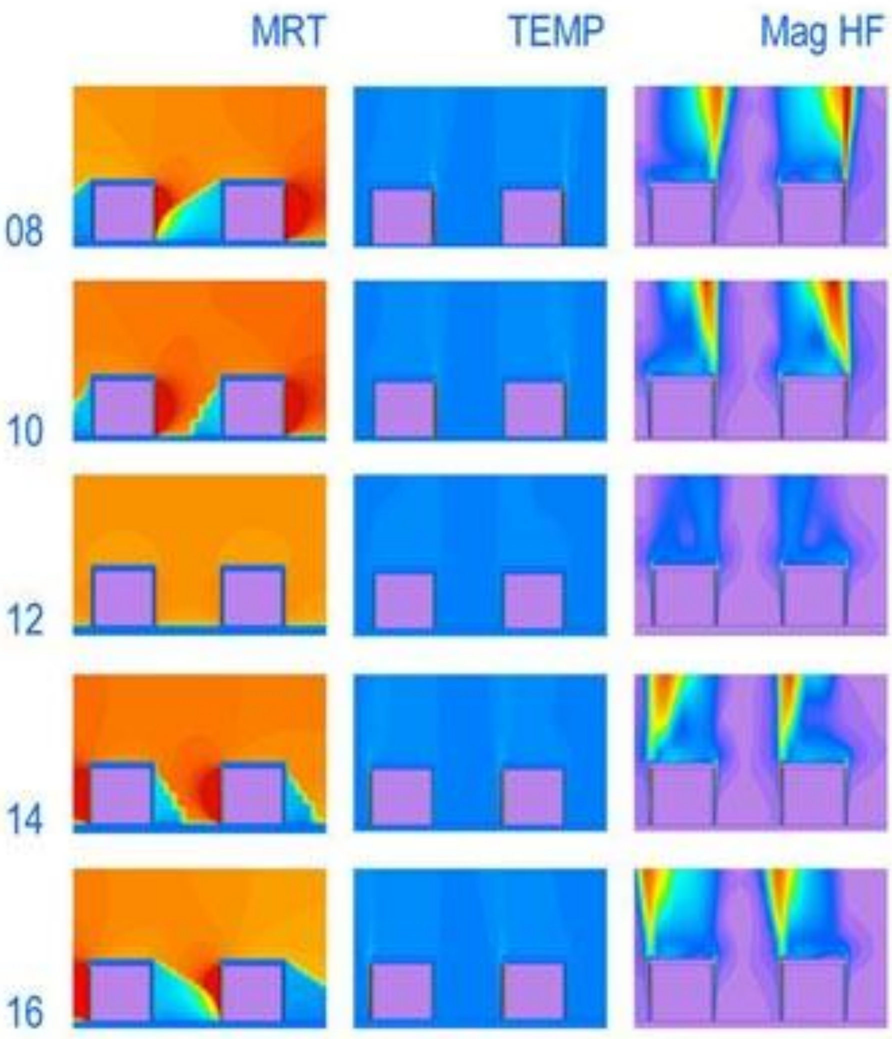
b. H/W = 0.5

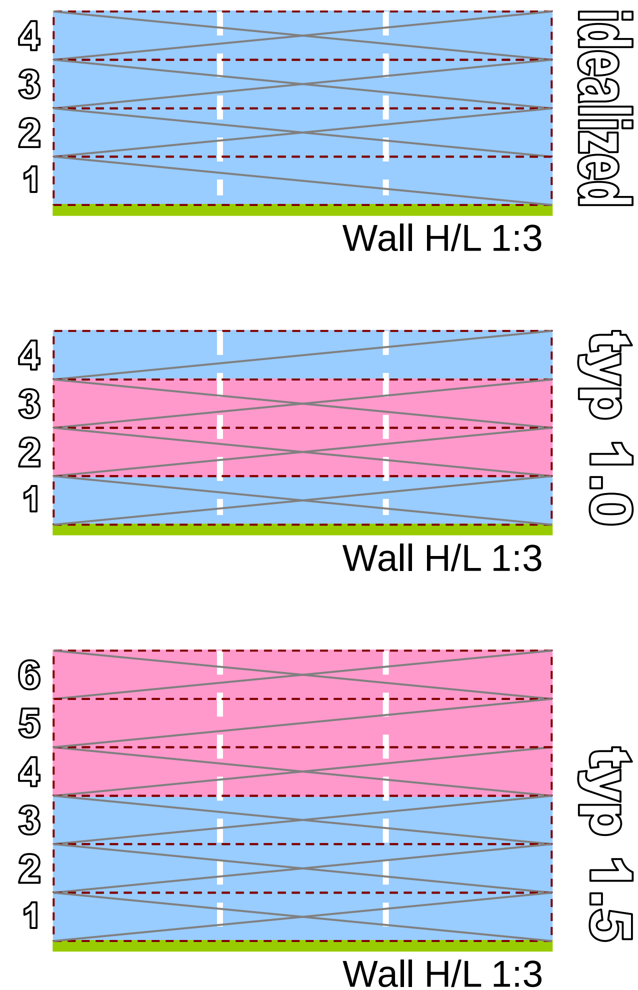


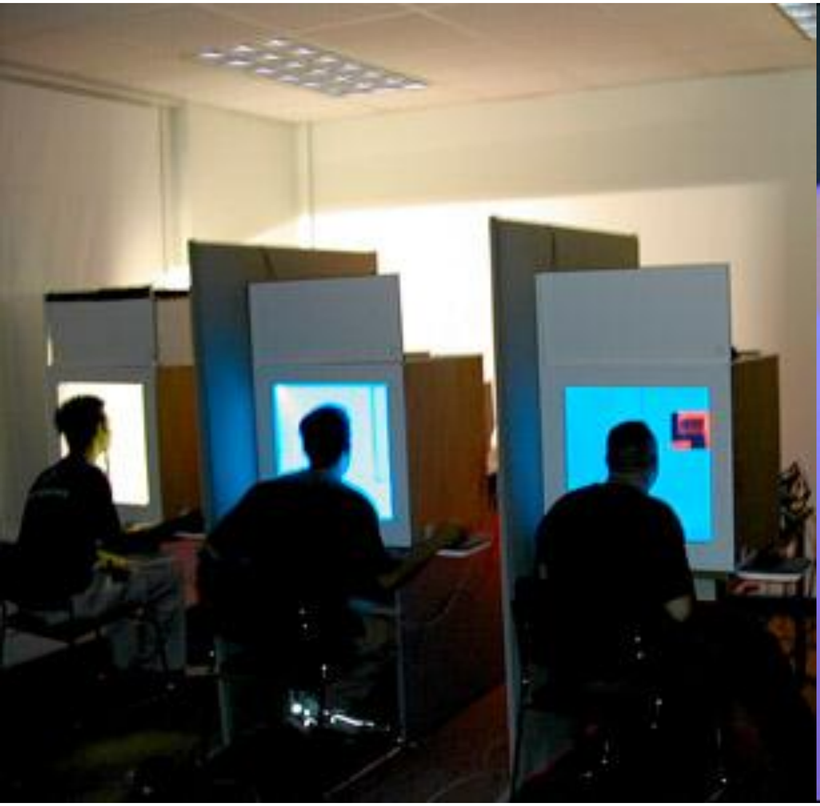




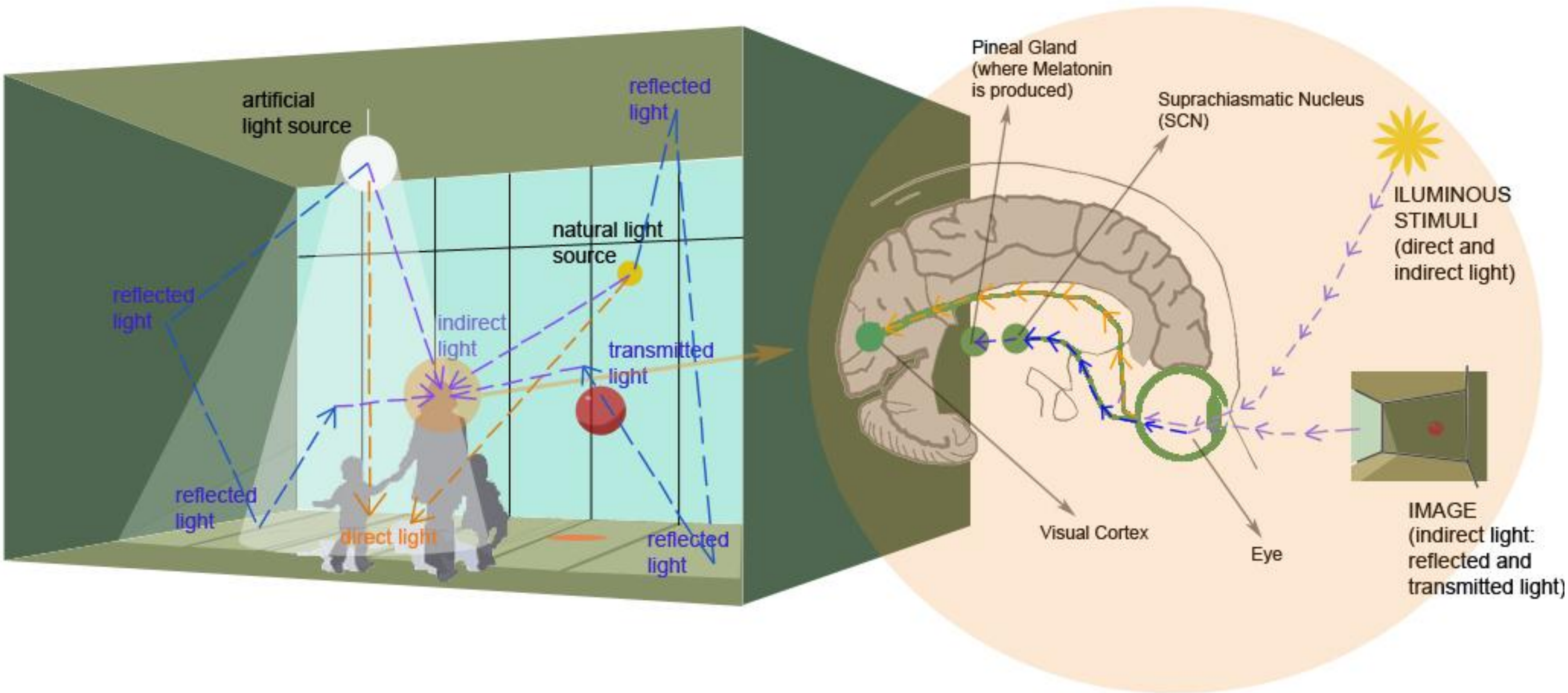
Radiative Surface Material Properties


MRT
TEMP
Mag HF
08
10
12
14
16

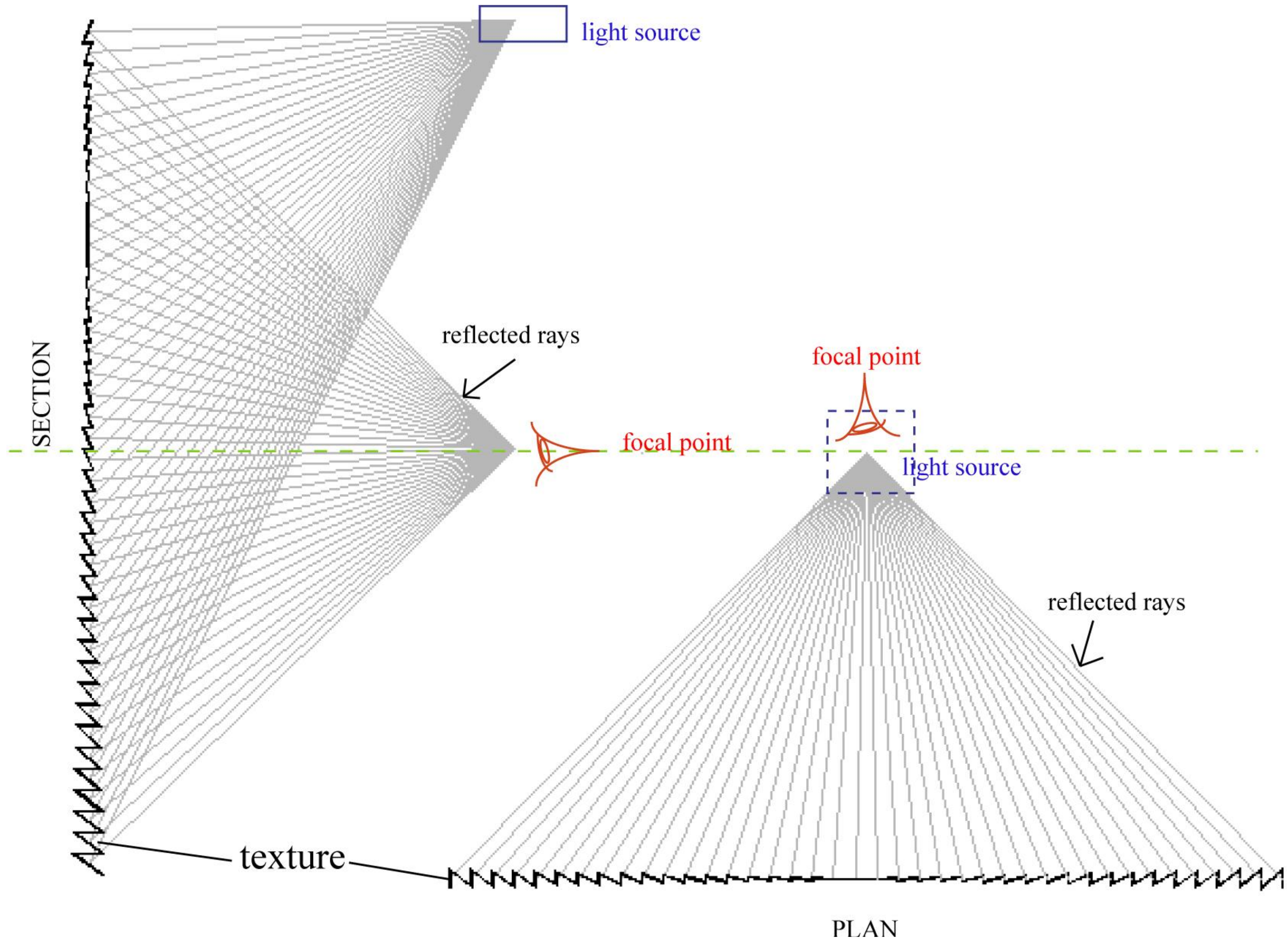

4
3
2
1
idealized
Wall H/L 1:3
4
3
2
1
typ 1.0
Wall H/L 1:3
6
5
4
3
2
1
typ 1.5
Wall H/L 1:3



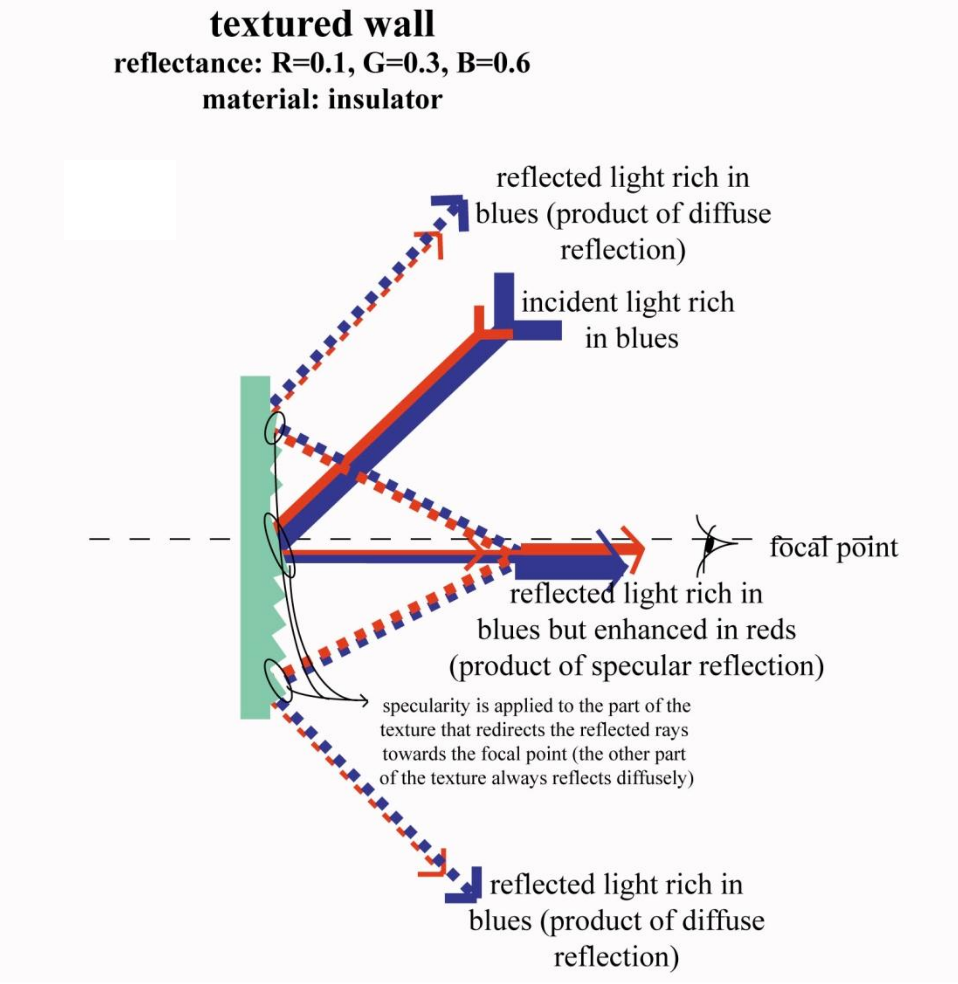
Mark Rea Steven Lockey

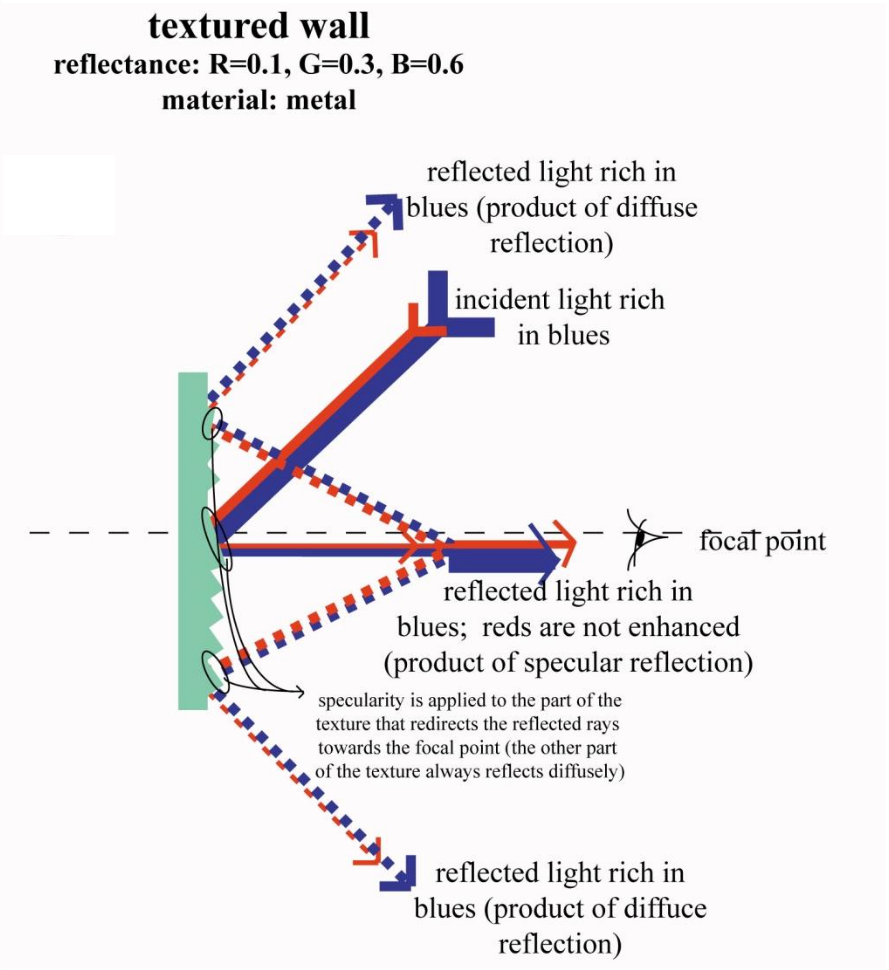


Adriana Lira Doctoral and Post-doctoral Research

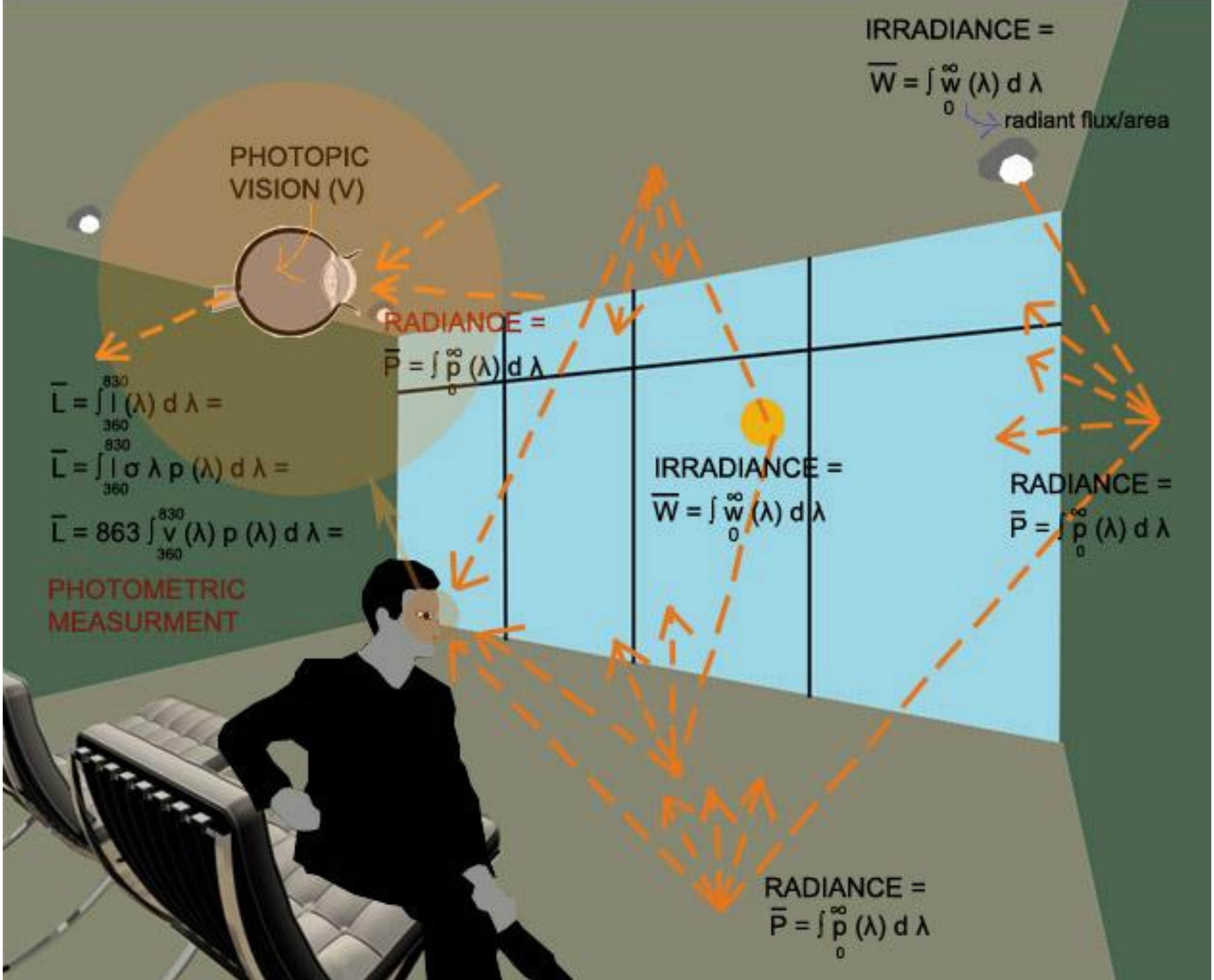


Adriana Lira Doctoral and Post-doctoral Research

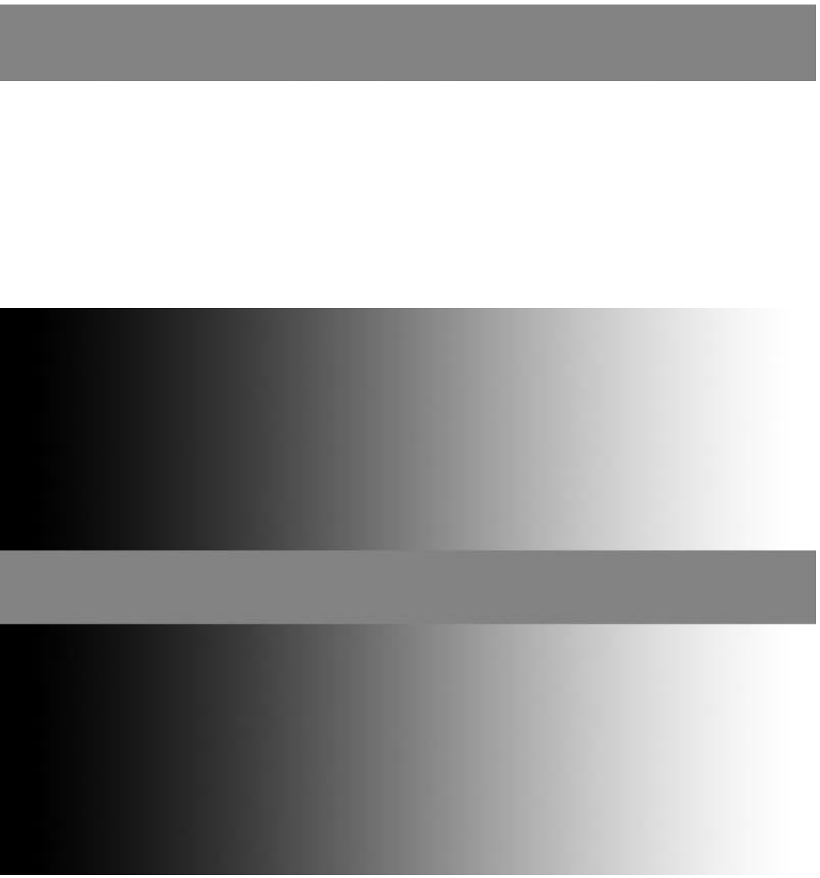


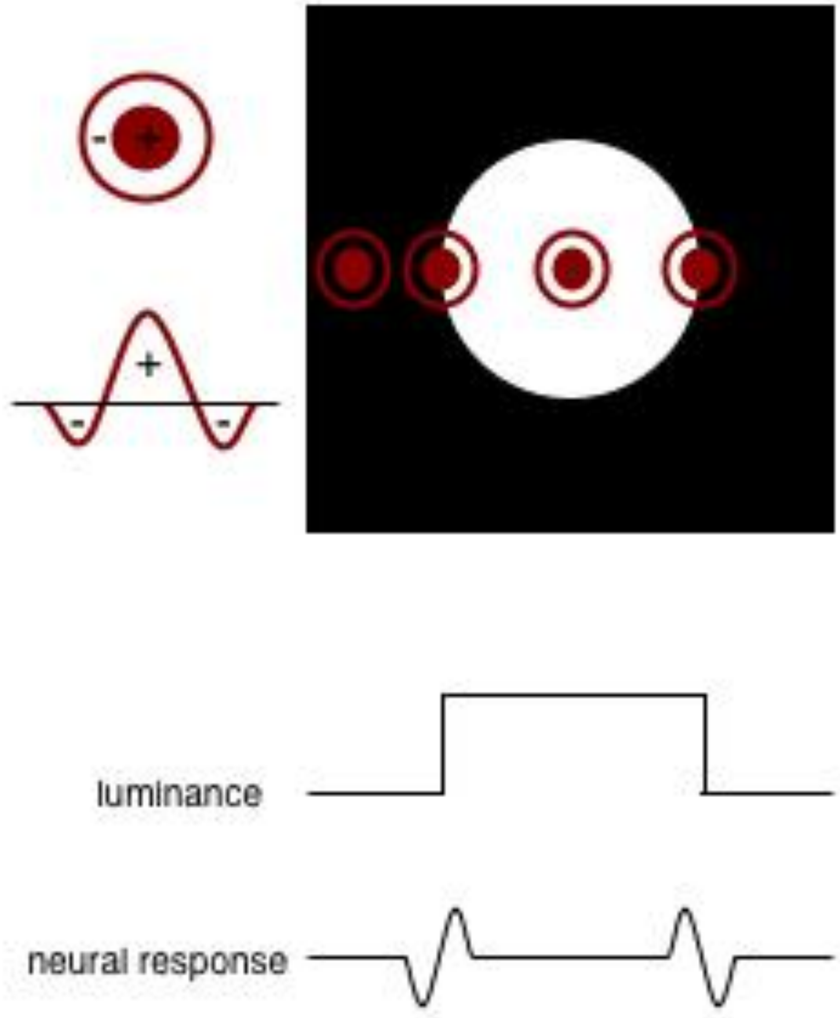


Adriana Lira Doctoral and Post-doctoral Research


IRRADIANCE =
W = ∫ w (λ) d λ
radiant flux/area
PHOTOPIC VISION (V)
RADIANCE =
P = ∫ p (λ) d λ
L = ∫ l (λ) d λ =
L = ∫ l σ λ p (λ) d λ =
L = 863 ∫ v (λ) p (λ) d λ =
PHOTOMETRIC MEASURMENT
IRRADIANCE =
W = ∫ w (λ) d λ
RADIANCE =
P = ∫ p (λ) d λ
RADIANCE =
P = ∫ p (λ) d λ

Emirates Hotel Tower, Dubai



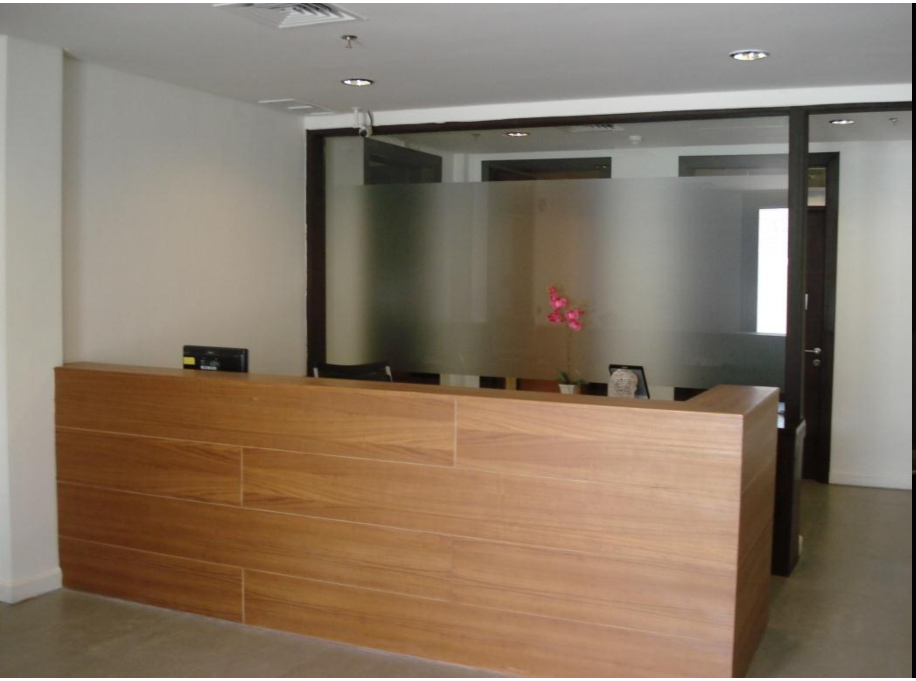


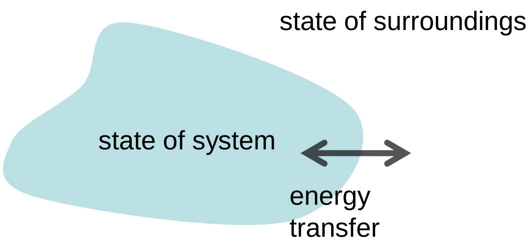
from Ken Nakayama

wall panel, option 1

wall panel, option 2

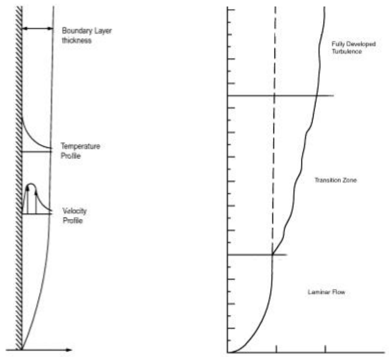
wall panel, option 3





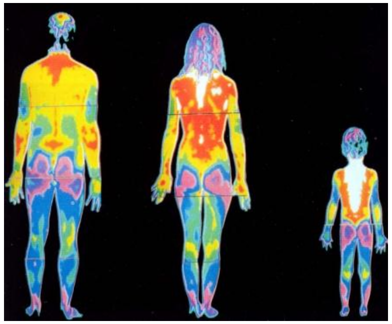
physical phenomena

heat transfer, mass transfer



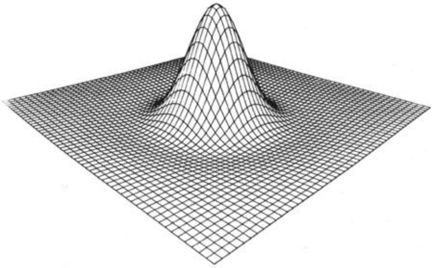
inducement of phenomenological behaviors

buoyancy, stratification, (…)-phoresis



human physiology

thermo-regulation, neuro-biology



human perception

zero-crossing, somatic sensations