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Energy Modeling and Implementation of Complex Building Systems, Pt. 3

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Energy Modeling

- and implementation of -

Complex Building Systems

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Thesis Prep Fall 2014
Advisor: Bess Krietemeyer

Abstract

Complex/dynamic systems and technologies are gaining traction in architecture, but accurate analysis and simulation of conflicting dynamic systems within a building model has yet to be achieved. Most ideas of analysis and simulation revolve around a set process: model one instance of a building (i.e. without changing parameters) and analyze in a separate program. The use of a parametric base for analysis/simulation plugins, as well as an easily manipulatable and responsive model would not only further the accuracy of testing the effects of multiple dynamic systems, but become a new tool that merges model, behavior, analysis and simulation to strive for efficient implementation of these technologies and act as a platform for testing systems' compensation for introduced variables (bio-responsiveness, enviro-responsiveness, manipulability, system-responsiveness). My method for testing this system utilizes Grasshopper, which excels at: providing a base for parametric plugins linking 'static' software, using data trees for complex behavioral modeling, and easing the manipulability of a parametric model. This method for analysis and optimization would facilitate the efficient implementation of dynamic/advanced/sustainable technologies in any number of building typologies.

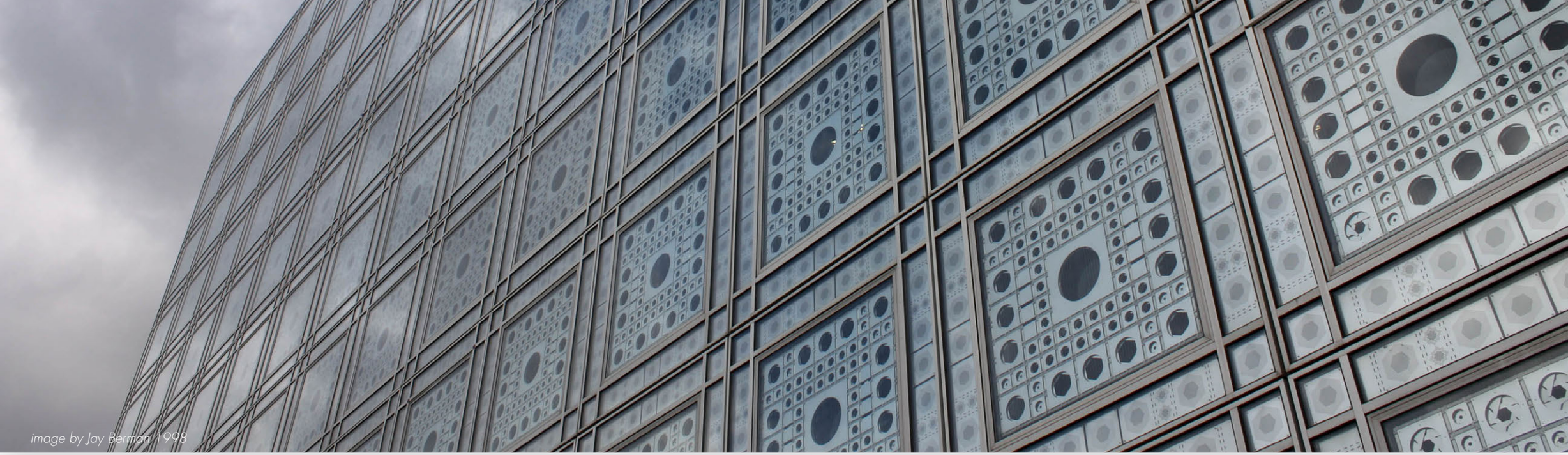


image by Jay Berman 1998

Issue of Interest

Accurate digital modeling and analysis of complex systems in architecture (across four dimensions: 1. A dynamic system affecting architectural conditions. 2. Multiple dynamic+static systems affecting architectural conditions. 3. The behavior of each system as it affects, and the resulting behavior of, architectural conditions. 4. The behavior of the dynamic systems as they respond to said architectural conditions) is, at the moment, mostly unachievable.

Simulation of complex systems and their performance holds merit within the design phase for many reasons:

Attributes of complex systems occur on a case-by-case basis. It is difficult to speculate the performance of a system before implementing it unless there is reference of a similar building type utilizing the same technology in the same way in an equivalent climate zone.

Taking this into account, an accurate simulation engine analyzing complex systems will foster more implementation: If a developer can see the system in action, he/she may be more likely to invest.

There are standards set for sustainable building design which require the analysis of complex systems pre-construction. LEED standards dictate: A whole-building energy simulation to find the minimum energy performance required & a simulation of spatial daylighting autonomy and annual sunlight exposure.

Arab World Institute - by Jean Nouvel 1987

A south-facing facade responds to lighting conditions by opening and closing motorized apertures.

Other Dynamic Systems Examples

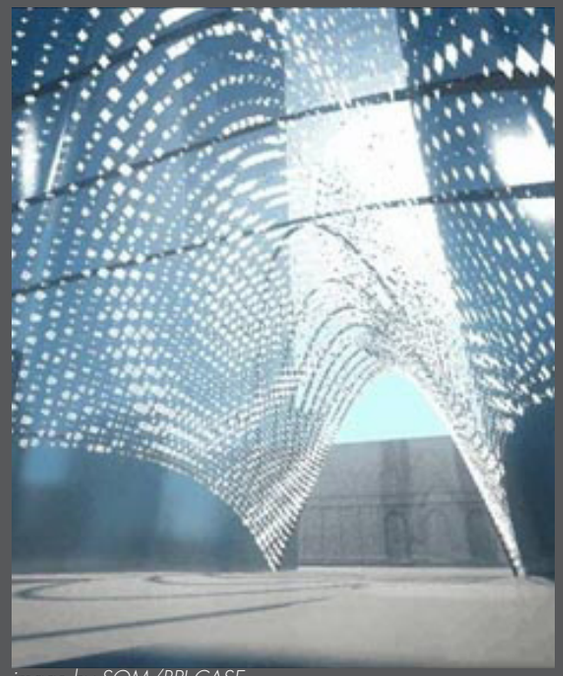


image by SOM/RPI CASE

image by David Benjamin

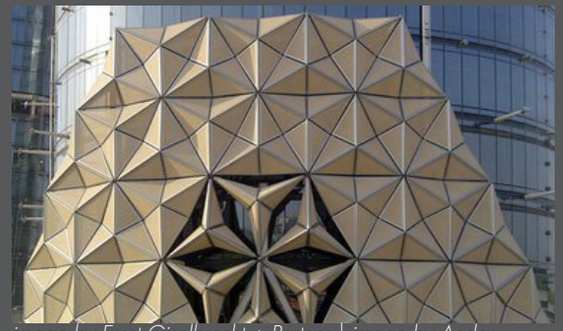


image by Ernst Giselbrecht + Partner | image by Aedas

Current question on dynamic systems:

1. How do we simulate the impact of these systems pre-construction?

2. How do we simulate theses systems' reactions to results from [1]?

3. How do we analyze data from simulation [2] to impact the use of the system?

Electroactive Dynamic Display Systems (EDDS)

With the potential to be bioresponsive, enviroresponsive, manually operated, dynamic or static, EDDS can be generalized to a manipulatable/ controlled facade of 'pixels' which can be turned transparent or opaque. On a building scale, this would affect interior air quality/temperature, and daylighting levels, and the system has potential as interior partitions, providing an atmospheric effect.

The Living: Breathing Facade

Flexible wall that 'breathes' according to shifting conditions outside. It could also be used as a system for interior airflow control. It is enviroresponsive.

Kiefer Technic Showroom & Al Bahr Towers

Both buildings utilize manipulative facades which can emulate a design strategy or simply be a performative aspect for the building.

Current Strategies

Daylighting/thermal/air quality/etc analysis and simulation software tools currently exist to accurately map out any number of pre-construction conditions. Two main software examples include EnergyPlus and OpenStudio, both developed/funded by the US Department of Energy, which import .idf digital models with .epw weather models for site to accurately analyze specified zones of a building. Within these programs are thousands of preset implementable building standards, from programmatic-based usage schedules, to HVAC systems.

Typical methods of achieving whole [or partial] building simulations rely on completed digital models which are exported to the aforementioned software tools for analysis. The resulting simulation only provides faults, and not recommendations for improvements.

More recent attempts, such as those by Christoph Reinhart, combat this model-then-analyze ideology. Plugins developed for 3D modeling programs facilitate the link between model and analysis/results in a way that allows the designer to keep manipulating parameters on the model until a desired analysis result is achieved.

EnergyPlus

EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model energy and water use in buildings. Modeling the performance of a building with EnergyPlus enables building professionals to optimize the building design to use less energy and water.

EnergyPlus models heating, cooling, lighting, ventilation, other energy flows, and water use. EnergyPlus includes many innovative simulation capabilities: time-steps less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multizone air flow, thermal comfort, water use, natural ventilation, and photovoltaic systems.

-energy.gov

OpenStudio

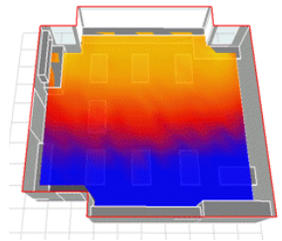
OpenStudio is a cross-platform collection of software tools to support whole building energy modeling using EnergyPlus and advanced daylight analysis using Radiance.

-openstudio.nrel.gov

Radiance

Radiance is a suite of programs for the analysis and visualization of lighting in design. There are no limitations on the geometry or the materials that may be simulated. Radiance is used by architects and engineers to predict illumination, visual quality and appearance of innovative design spaces, and by researchers to evaluate new lighting and daylighting technologies.

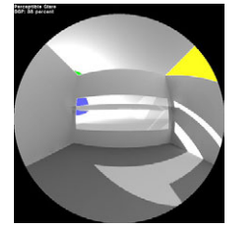
-radsite.lbl.gov/radiance/



DaySim

DAYSIM is a Radiance-based daylighting analysis software that models the annual amount of daylight in and around buildings. DAYSIM allows users to model dynamic facades systems ranging from standard venetian blinds to state-of-the-art light redirecting elements, switchable glazings and combinations thereof. Users may further specify complex electric lighting systems and controls including manual light switches, occupancy sensors and photocell controlled dimming.

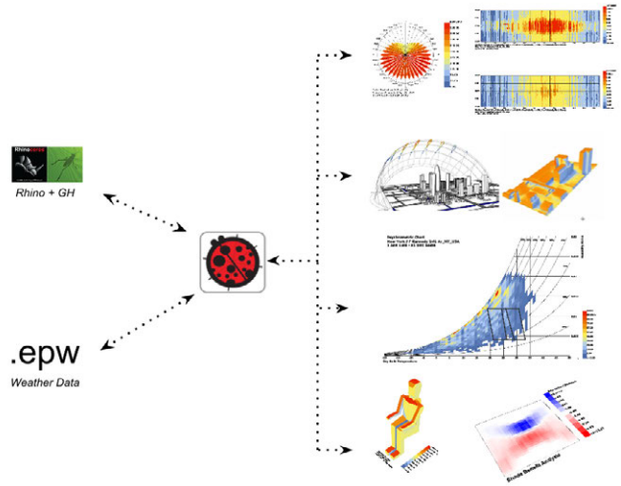
-daysim.ning.com



EvalGlare

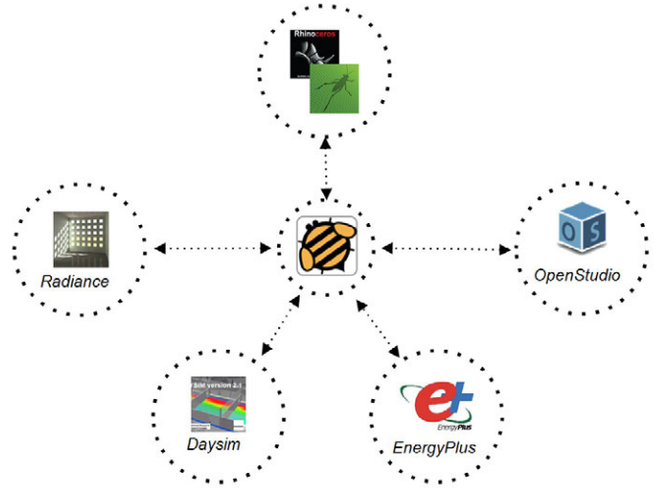
A Radiance-based tool to evaluate daylight glare in office spaces.

Grasshopper Plugins:



Ladybug

Ladybug is an open source environmental plugin for Grasshopper3D that helps architects and engineers create an environmentally-conscious architectural design. Ladybug imports standard EnergyPlus Weather files (.EPW) into Grasshopper and provides a variety of 3D interactive graphics to support the decision-making process during the initial stages of design.



Honeybee

Honeybee connects Grasshopper3D to EnergyPlus, Radiance, Daysim and OpenStudio for building energy and daylighting simulation. The Honeybee project intends to make many of the features of these simulation tools available in a parametric way.

ArchSim Energy Modeling for GH

Similar to Honeybee, Archsim Energy Modeling is a plugin that brings fully featured EnergyPlus simulations to Rhino/Grasshopper and thus links the EnergyPlus simulation engine with a powerful parametric design and CAD modeling environment. Archsim allows you to effortlessly create complex multi-zone energy models, simulate them and visualize results without ever switching between tools.

-archsim.com

UrbanDaylighting

Uses Radiance & daysim to simulate daylighting of large urban designs.

-archsim.com

DIVA for Rhino: GH Plugin

DIVA-for-Rhino is a highly optimized daylighting and energy modeling plug-in for Rhino and Grasshopper. DIVA-for-Rhino allows users to carry out a series of environmental performance evaluations of individual buildings and urban landscapes.

-diva4rhino.com

Reinhart Method for Daylighting Simulation

MIT Lecture: Daylighting Course

Goal: Assess the luminous environment in daylit spaces via simulation.

The scene consists of a three-dimensional geometric model of the investigated daylit object(s) including optical material descriptions for all surfaces in the scene.

Areas of interest in the scene can be selected viewpoints and/or discrete sensors such as a grid of upward facing illuminance sensors.

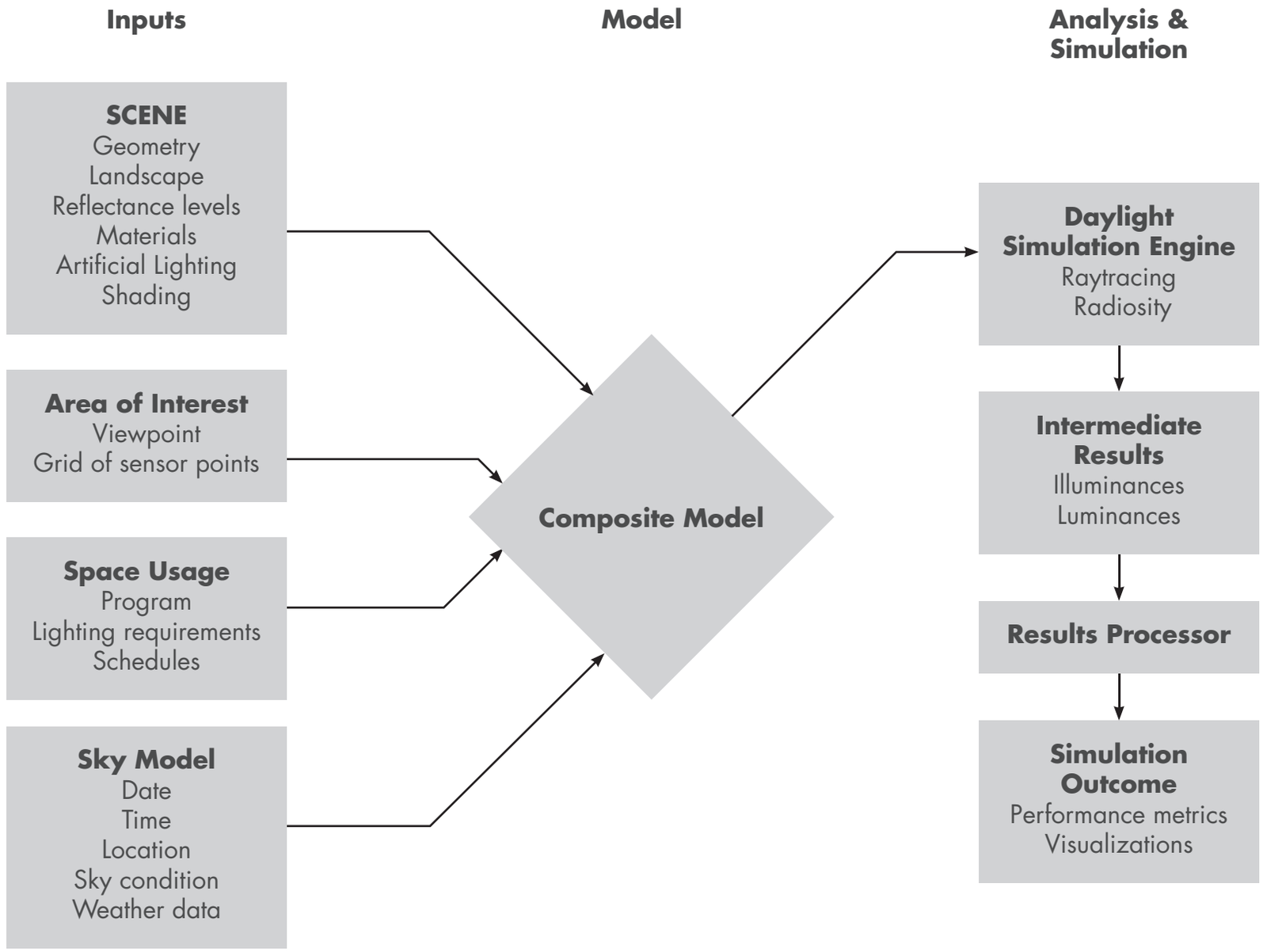
Space usage information describe the type of space investigated (office, classroom,...), required lighting levels and occupancy schedules.

The sky model quantifies the amount of direct sunlight and diffuse daylight coming from the different parts of the celestial hemisphere.

The composite model brings all information together into one defined set of data for export to the analysis/simulation engines.

The daylight simulation engine combines the sky model with the scene and calculates illuminances and/or luminances within the scene.

The results processor translates the raw simulation results into a format that can directly inform design decisions. Example formats are scene visualizations and false color maps of the daylight factor and/or other performance metrics including daylight autonomy and useful daylight illuminance



Reinhart Method Inputs

MIT Lecture: Daylighting Course

Goal: Assess the luminous environment in daylit spaces via simulation.

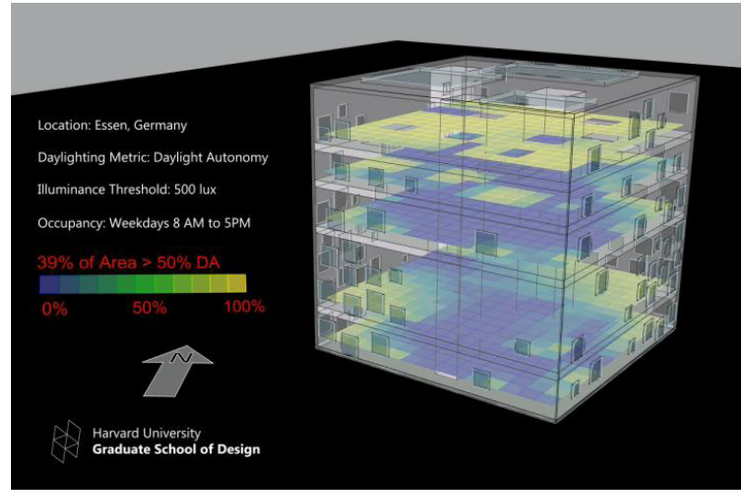
Inputs

SCENE
Geometry
Landscape
Reflectance levels
Materials
Artificial Lighting
Shading

Area of Interest
Viewpoint
Grid of sensor points

Space Usage
Program
Lighting requirements
Schedules

Sky Model
Date
Time
Location
Sky condition
Weather data



Reinhart Example (above):

Scene:
Skylights: Parametric controls
Windows: Parametric controls (cannot be changed when skylights are being changed).
Defined building form (unchangeable).

Area of Interest:
14X14 grid per floor = 980 total analysis nodes

Space Usage:
Weekdays 8am-5pm

Sky Model:
Indoor daylighting levels under overcast skies (info provided)

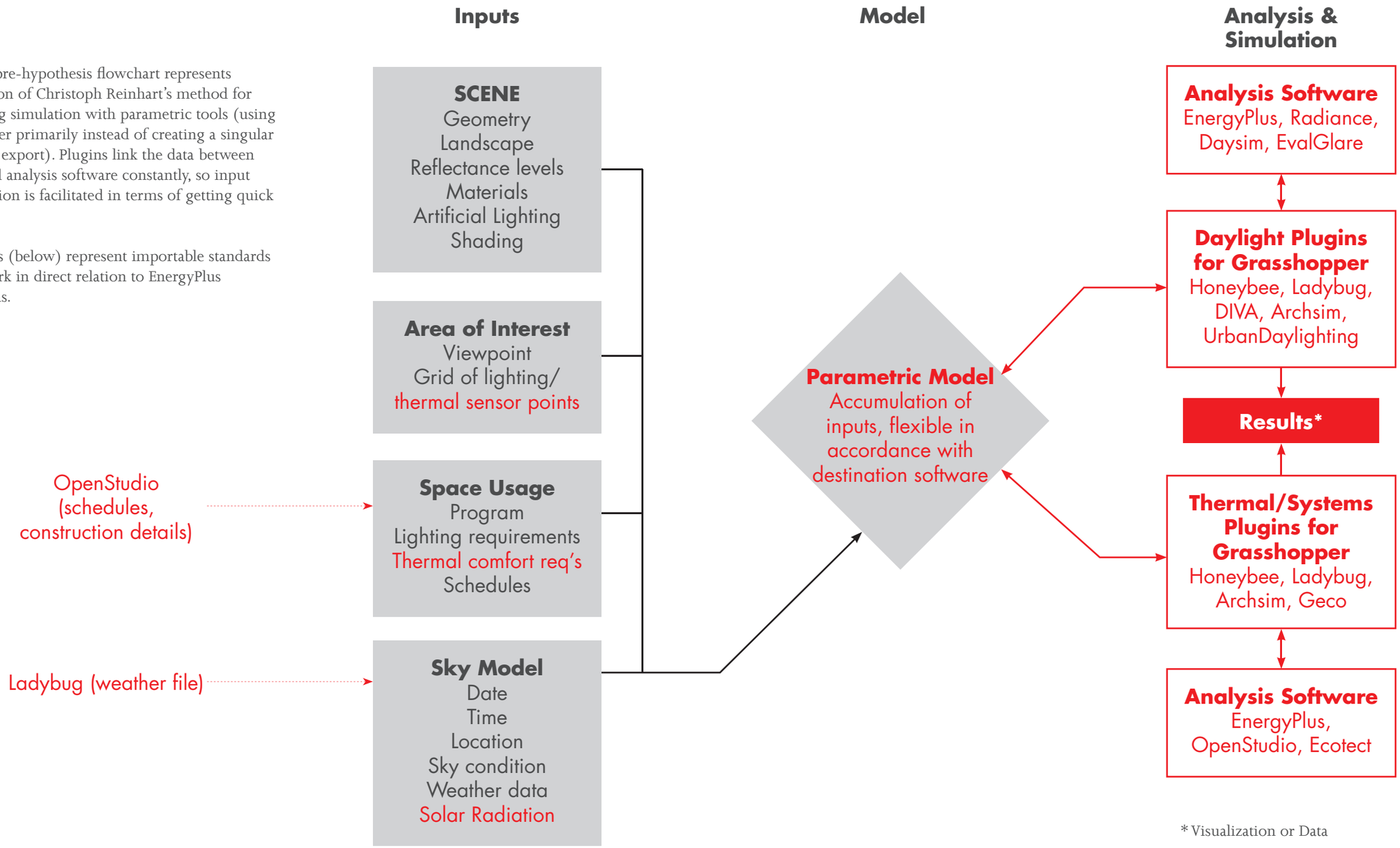
Hypothesis

The use of a parametric base for analysis/ simulation plugins, as well as a new component which facilitates behavioral modeling, would not only further the accuracy of testing the effects of multiple dynamic systems, but become a new tool that merges model, behavior, analysis and simulation to strive for efficient implementation of these technologies and a platform for testing systems' compensation for introduced variables (bio-responsiveness, enviro-responsiveness, manipulability etc).

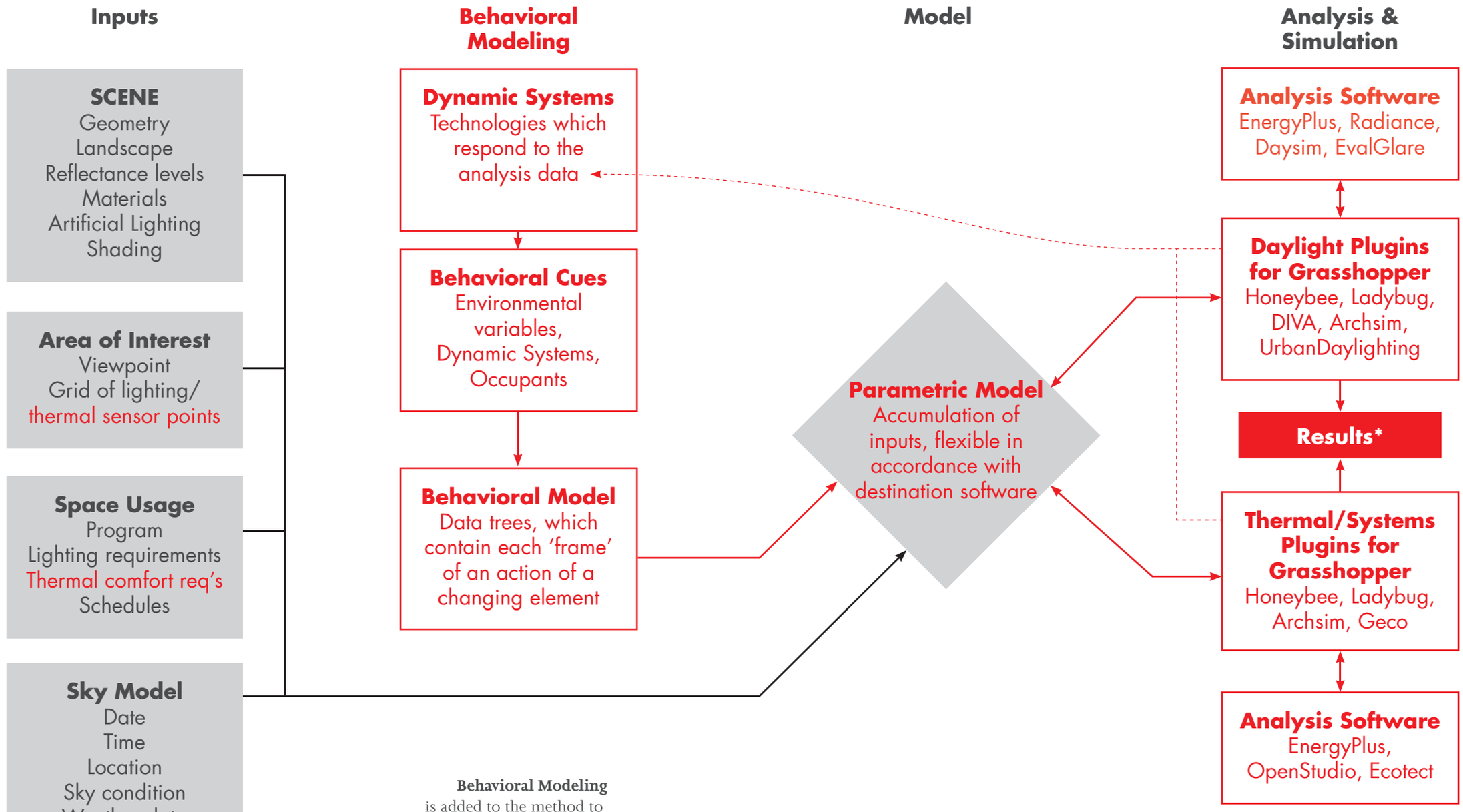
Reinhart + Grasshopper

This pre-hypothesis flowchart represents the adaption of Christoph Reinhart's method for daylighting simulation with parametric tools (using grasshopper primarily instead of creating a singular model for export). Plugins link the data between model and analysis software constantly, so input manipulation is facilitated in terms of getting quick results.

Inputs (below) represent importable standards which work in direct relation to EnergyPlus simulations.

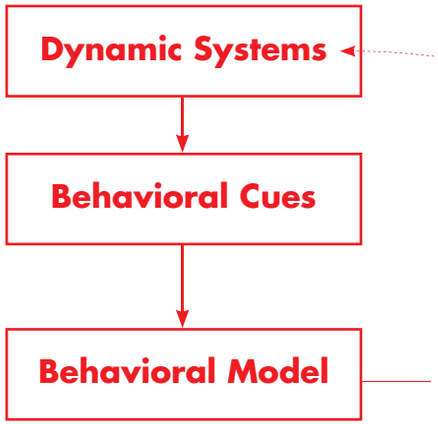


* Visualization or Data



Behavioral Modeling is added to the method to accommodate complex system(s) analysis and simulation.

* Visualization or Data

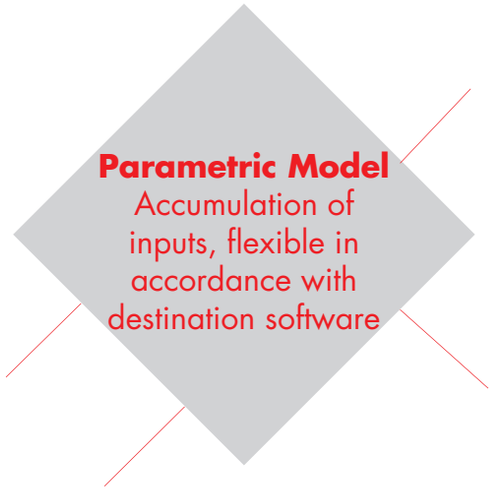


Dynamic systems examples: EDDS (my main focus), automated windows, manipulable lighting/heating/cooling fixtures...

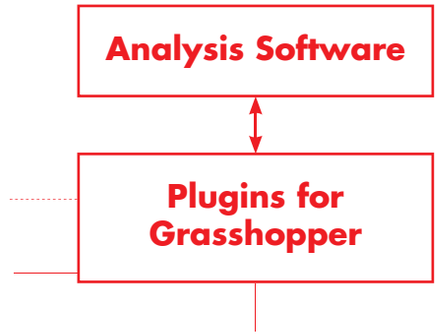
Behavioral cues come from many different possible variables:

1. Environmental variables, in relation to other behavioral cues, come into play when measuring a changing system over a period of time.
2. Other dynamic systems might impact the way another system might function. For example, an EDDS facade might have to overcompensate for thermal loads when an automated window system opens up to ventilate the space.
3. Occupant use, for example, might impact the way an EDDS facade changes when people interact with it.

The behavioral model quantifies sets of data from the behavioral cues and the behaviors of the dynamic systems in relation to those cues.



The parametric model replaces the composite model, as data flows received back from plug-ins become parameters which influence a change in either this parametric model, or the behavioral model.



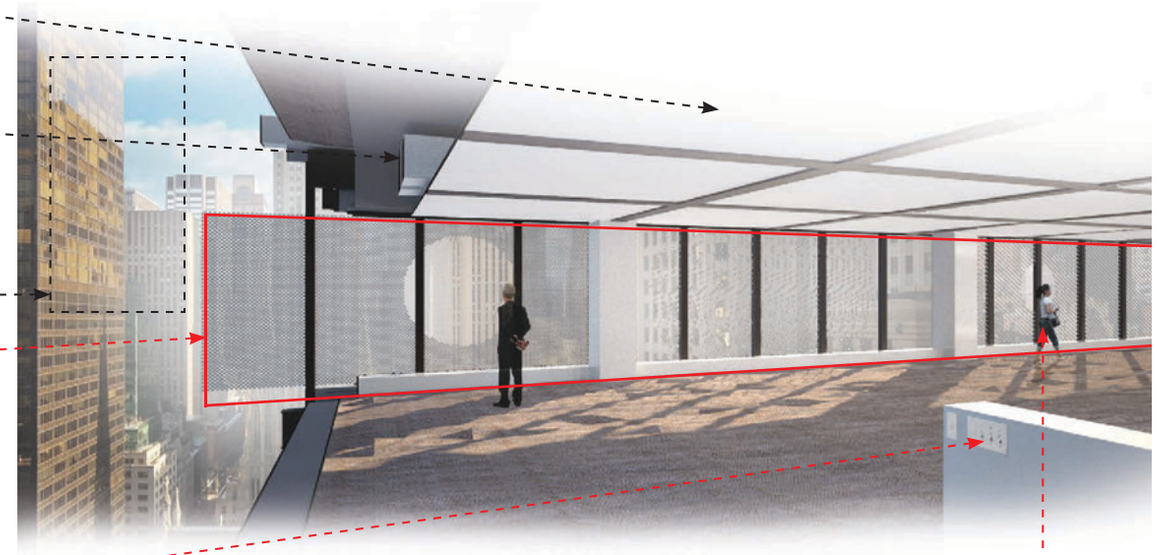
Plugins for Grasshopper allow the linkage between the parametric model and analysis softwares. In general, they seem to only be an export engine for the model as if one were to export the model manually and open it in these softwares. However, the benefit of the plugins is the ability to reload the model and simulation back into Grasshopper, along with comprehensive organized sets of resultant data from the analysis. This data can then inform dynamic systems layouts, optimization goals, or formal qualities of the model itself.

Analysis Software is pretty self explanatory: these are the traditional methods of daylighting/thermal/energy analysis and simulation, which, if functioning on their own, are limited to static (composite) model analyses.

Results are loaded back into Grasshopper as data sets from the plugins (which read the data from Analyses Software). These data sets are usually neatly organized and readable and easily visualized.

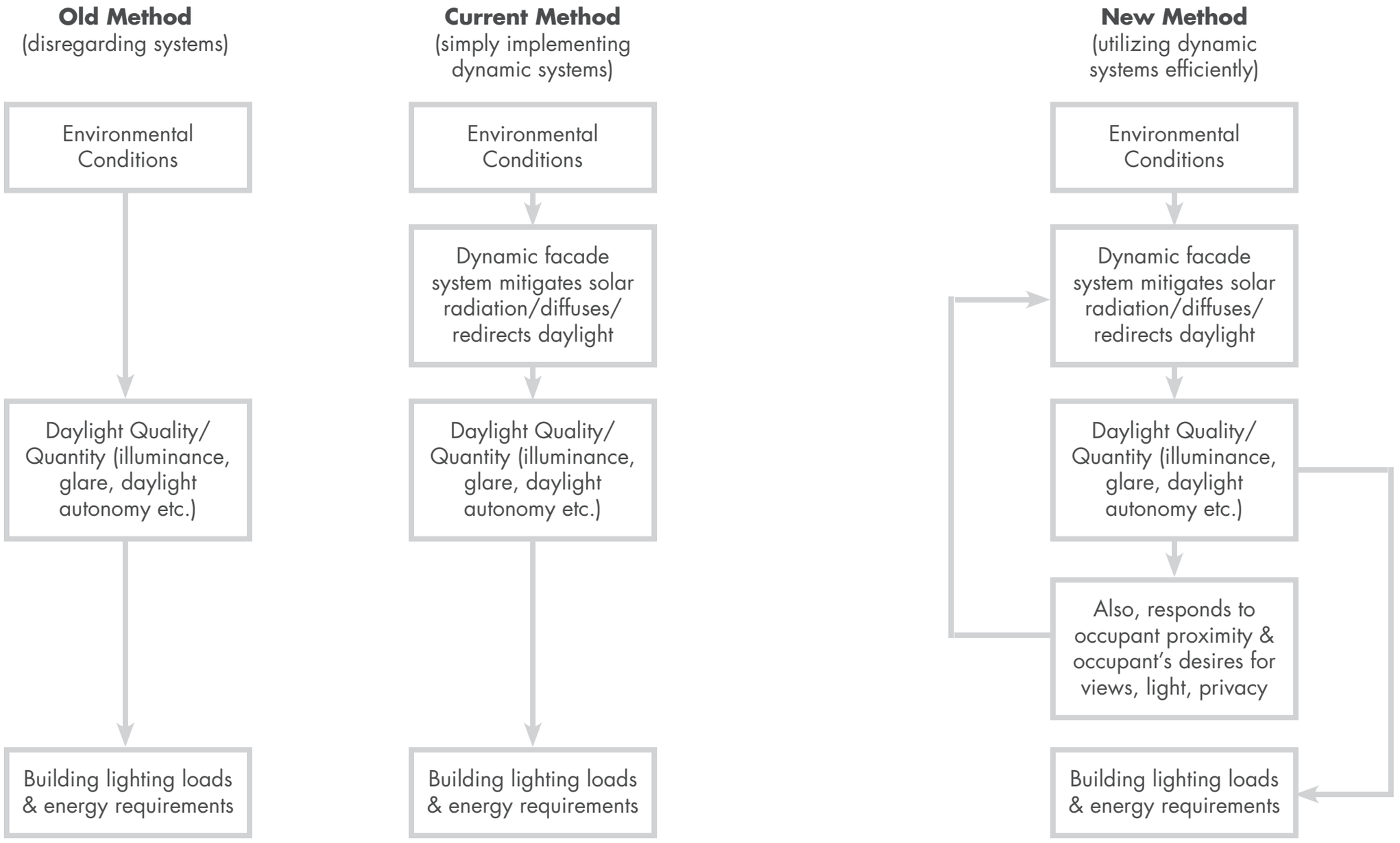
Appended Diagram of Inputs

- **Scene**
  - -Model
    - Building/Zones for implementation/analysis
    - Circulation paths for occupant use
    - Egress/Building Codes
  - -Landscape
    - Degree of slope
    - Ground cover
    - Vegetation/Trees
    - Water
  - -Materials and Reflectance levels
    - Glazing areas
    - Floor/Wall reflectance for diffuse light analysis/glare
    - Construction libraries imported from E+
  - -Artificial Lighting
    - User controllability levels
    - Amount/intensity of lighting systems
  - -Building Systems
    - HVAC
    - Natural ventilation opportunities
- **Area of Interest**
  - -Viewpoint of the area of interest
    - Analysis on a contextual level
    - Whole-building-analysis scope
    - Zoomed in section of building
  - -Grid of lighting & thermal sensor points
    - For whole building/or specified zone
- **Space Usage**
  - -Program
    - Use of the spaces
  - -Lighting requirements:
    - Lighting levels required by occupying program
  - -Thermal Comfort Requirements:
    - Thermal comfort levels required by occupying program
  - -Schedules:
    - Analysis period for simulation
    - Usage schedule, dependent on program typically
- **Sky Model**
  - -Date & Time
    - Day activity hours
    - Night activity hours
  - -Location
  - -Sky Condition
    - e.g. Clouds vs. Direct sunlight
  - -Weather Date:
    - .epw file. Location based
- **Dynamic Systems**
  - -Façade Systems
    - EDDS
      - 'pixel' size
      - Non-responsive pattern (optional)
      - Coverage
    - Coverage
    - Manipulability
    - Other automated systems
  - -Interior Systems
    - Partitions
    - Manipulatable lighting/thermal/comfort controls
    - Other automated systems
- **Behavioral Cues**
  - -Environmental variables
    - Climate variability
    - Wind loads
    - Cloudy-to-sunny transitions
    - Precipitation effects
  - -Dynamic Systems
    - Responsive EDDS
    - Façade/Interior Systems
  - -Occupants
    - Actions
    - Occupant load
    - Movement



Flowchart of Systems' Effects

With Proposed Behavioral Modeling:



Proposed Method

For the aforementioned parametric base, I propose Grasshopper, as it succeeds in combining cross-software plugins, 3D modeling capabilities, custom scripting (Python) if needed, with organized data trees (sets of data which become essential in behavioral modeling). Simulation brings together data from the analysis, 3rd-party programs and the parametric model in Grasshopper, and this data can be used to inform a response among any parametric aspect of the model (one system informing another system, or one system overcompensating for an introduced variable).

To focus my efforts, I will be looking at the analysis/optimization/simulation of technologies implemented in an office tower program in New York City. The dynamic system I will be modeling is an Electroactive Dynamic Display System (EDDS), developed by RPI's CASE with SOM. For the sake of ease, clarity and recognizability, I will be analyzing the implementation of EDDS on the Seagram Building (following page).

EDDS

Electroactive Dynamic Display System:
Technology to be analyzed

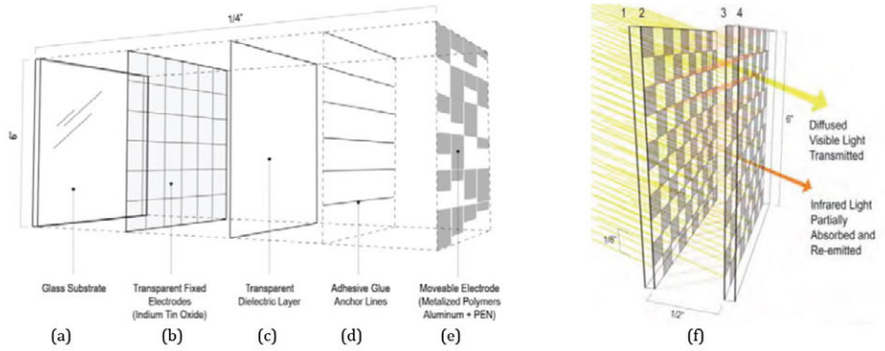
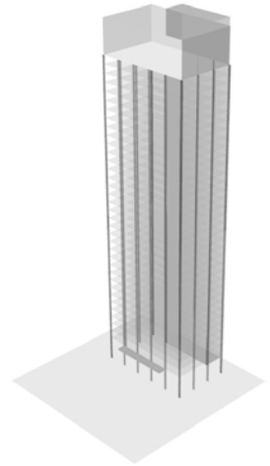
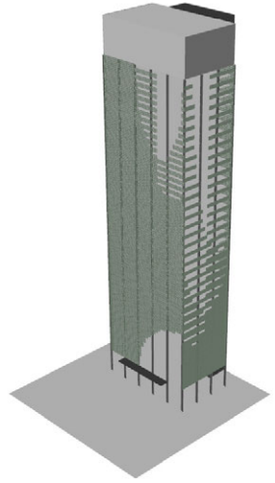


diagram by SOM/RPI CASE

Seagram Building

Testbed for analysis and simulation





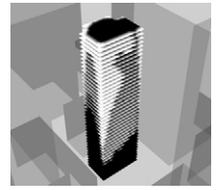
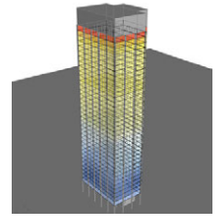
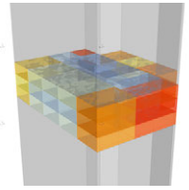
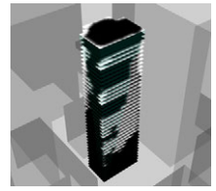
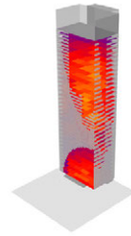
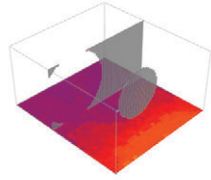
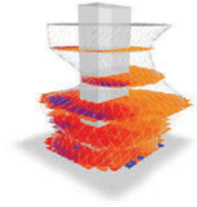
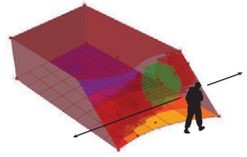
Scale and Depth of Analysis

Overview of the following analyses.

Scale

Systems Analysis	Urban Scale	Building Scale	Zoomed-in Scale
	No EDDS	No EDDS	No EDDS
	Static EDDS	Static EDDS	Static EDDS
	Dynamic EDDS	Dynamic EDDS	Dynamic EDDS

Scale

Systems Analysis			
			
			
	Not yet		

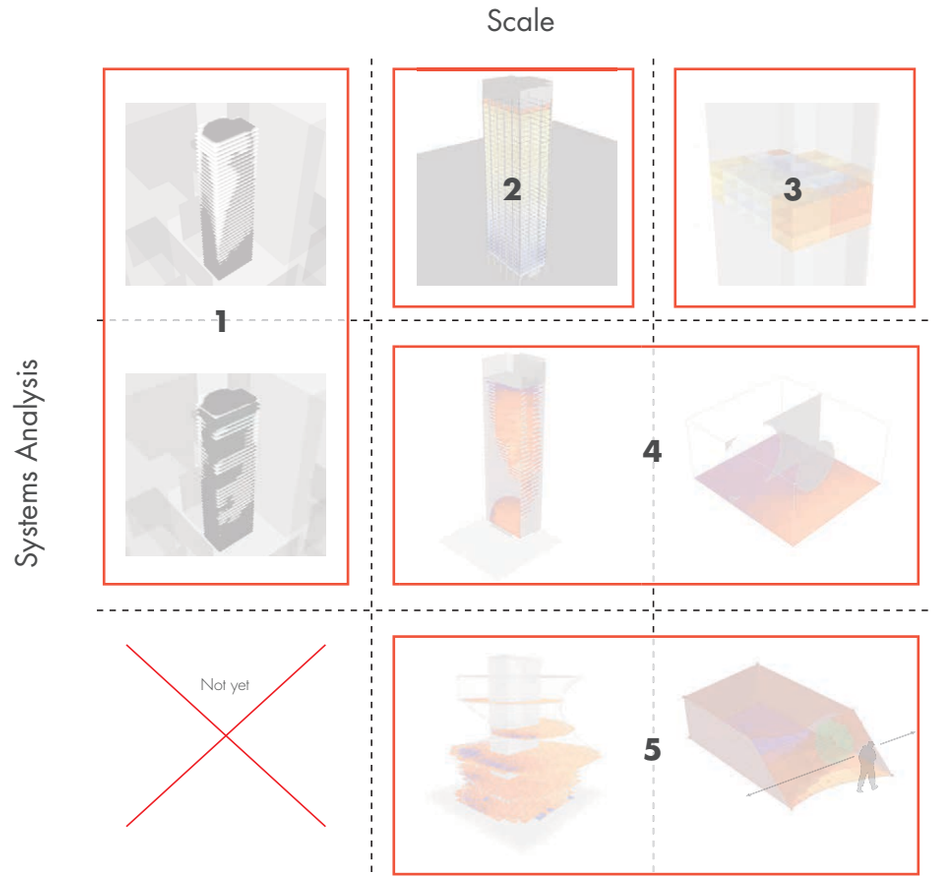
Scale and Depth of Analysis

Order of the following analyses.

First, the two Urban Scale analyses are shown together to compare results of adding an EDDS-like facade to an entire building.

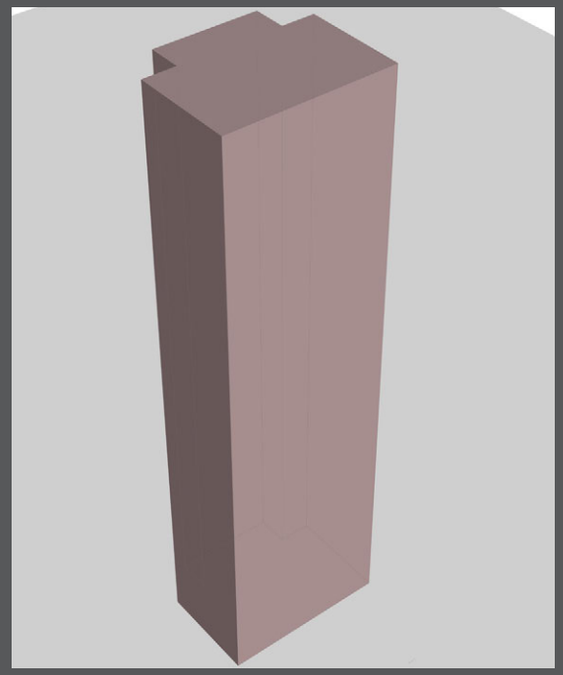
Second, the building and, third, zoomed-in scale are analyzed without EDDS. Both were analyzed and simulated mainly through the EnergyPlus Software.

Fourth and Fifth are Ecotect-analyzed models, which provides a very limiting amount of information data-wise, but shows the possibilities of behavioral modeling, however simple the analysis may be.

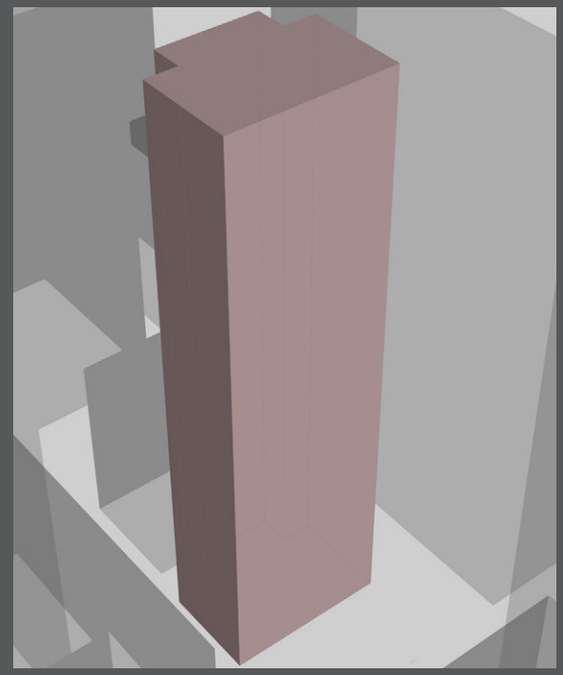


1. Urban Scale, No EDDS

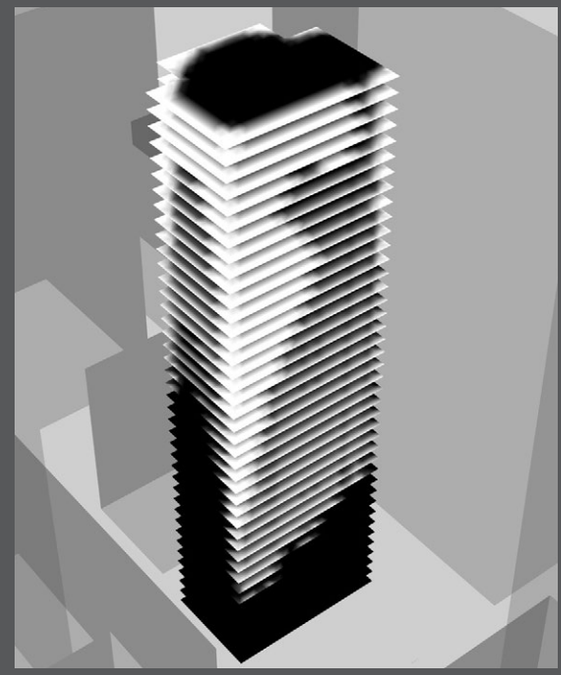
Building+Context Daylighting Analysis



1. Create simplified building mass. At this scale, it would take a long time for the computer to analyze every aspect of a detailed model. Fortunately, the UrbanDaylighting component for grasshopper, which links to DaySim, allows the user to split a mass roughly by floor height/number of floors.



2. Add context/shaders to the model.

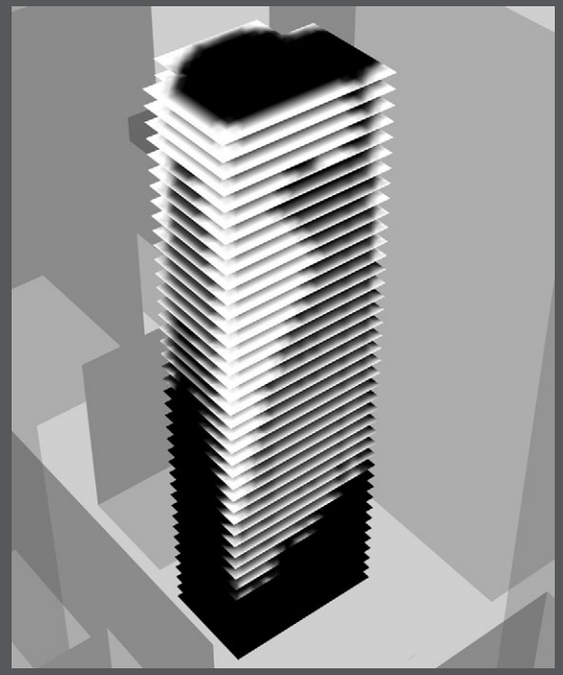


3. Run the simulation. This simulation measures the directly daylit area of the Seagram Building without any shading system implemented.

Results: Of the 54990 m2 floor area,
7142 m2 day-lit
Average 13.0% of floor is directly lit by sun

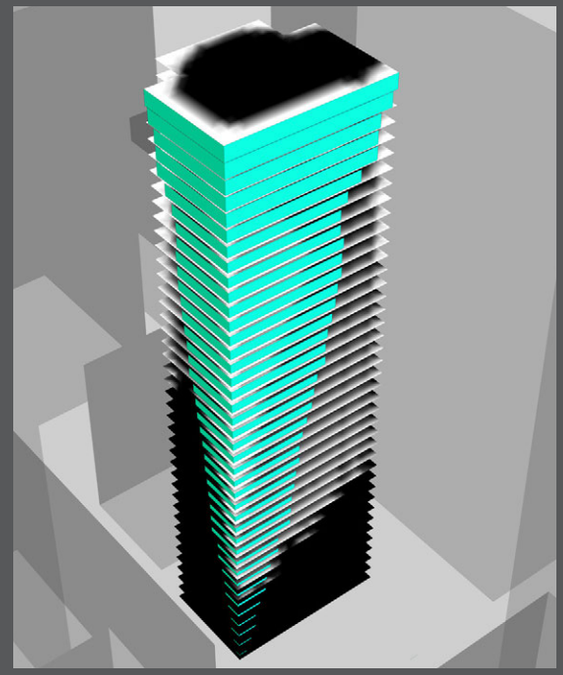
1. Urban Scale, Staic EDDS

Building+Context Daylighting Analysis with EDDS-like shaders added to the facade.

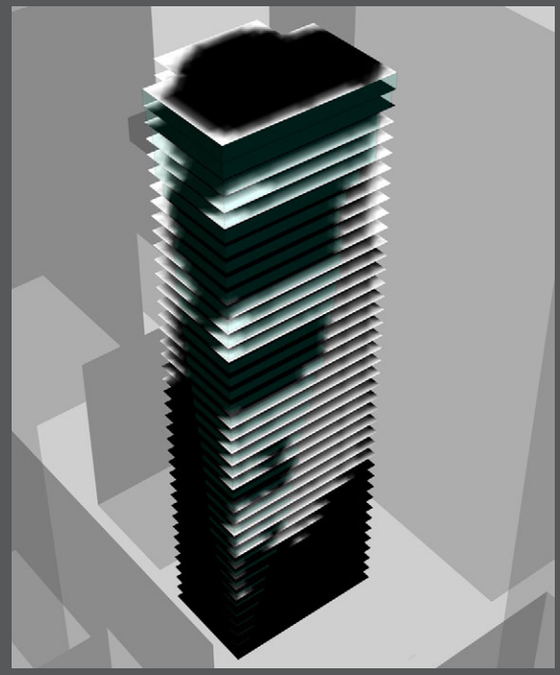


3. Previously-ran no EDDS simulation

Results: Of the 54990 m2 floor area,
7142 m2 day-lit
Average 13.0% of floor is directly lit by sun



4. Import results from simulation as a set of data, rearrange data on a per-floor basis, model the shading system with the size of each panel (shown in blue) customized relative to the amount of light penetrating the building.

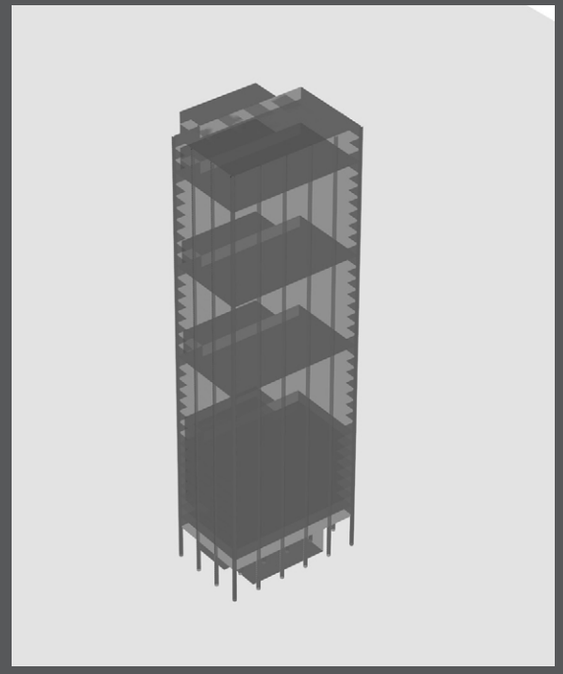


5. Run the simulation a second time.

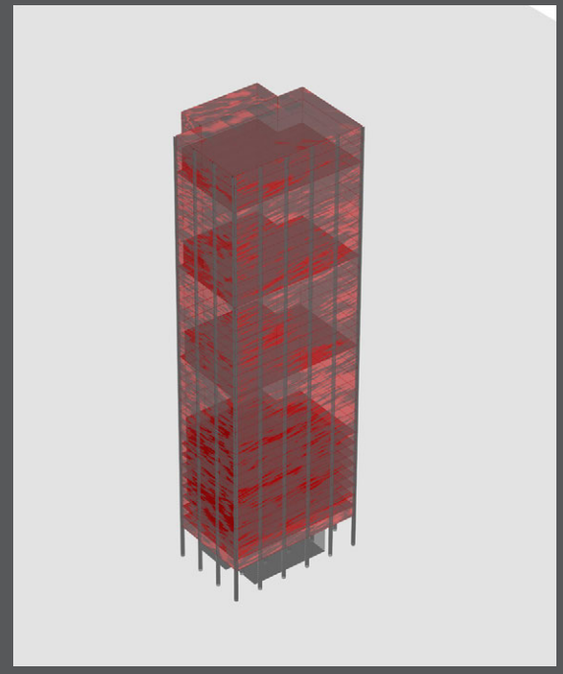
Results: Of the 54990 m2 floor area,
4351 m2 day-lit area
Average 7.9% of floor is directly lit by sun
2792m/60% direct daylighting decrease from non-EDDS analysis

2. Building Scale Setup

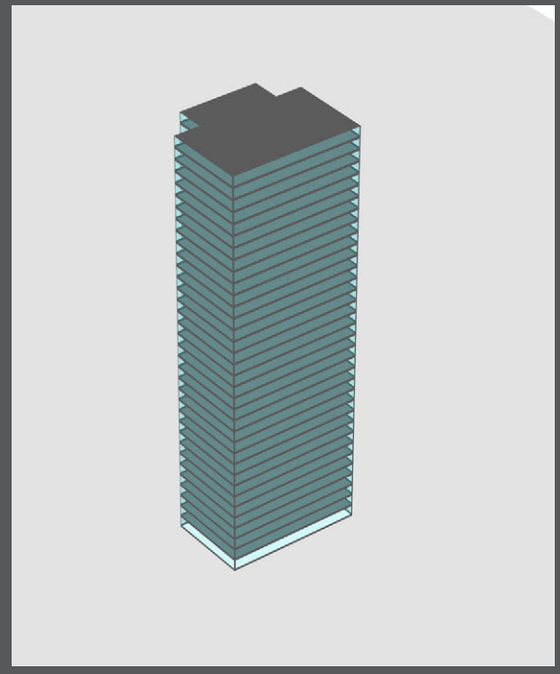
Seagram Building without context or EDDS.



1. Construct model building mass.



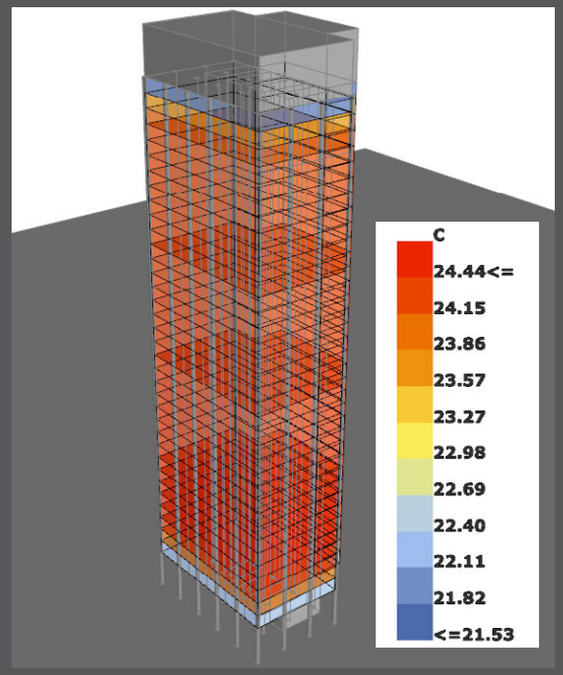
2. Set up EnergyPlus Zones based on the scale of the work. In this example, each floor is a zone, which should average out any values of implied zones on a per floor basis.

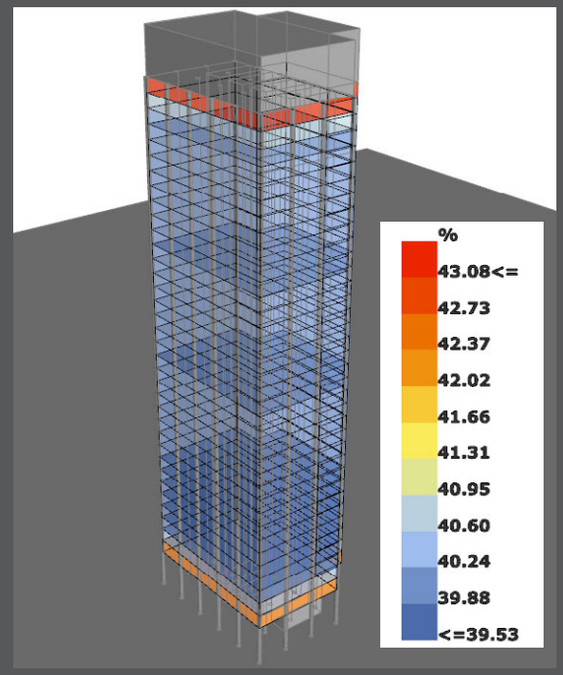


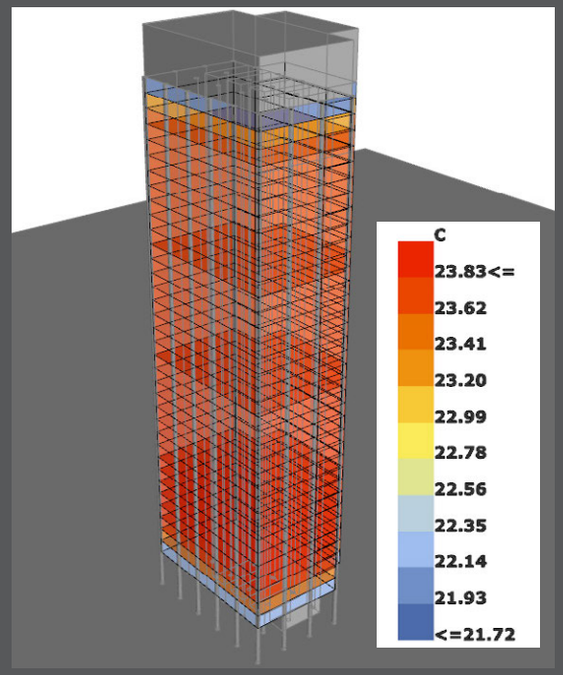
3. Create inputs for the zones, in this case a generalized glazing ratio representing the actual amount of fenestration on the facade.

2. Building Scale: Analyzed with E+

Seagram Building without context or EDDS.







Analyzing Temperature and Humidity:

Mean Radiant Temperature

The mean radiant temperature of each zone (degrees Celsius).

Relative Humidity

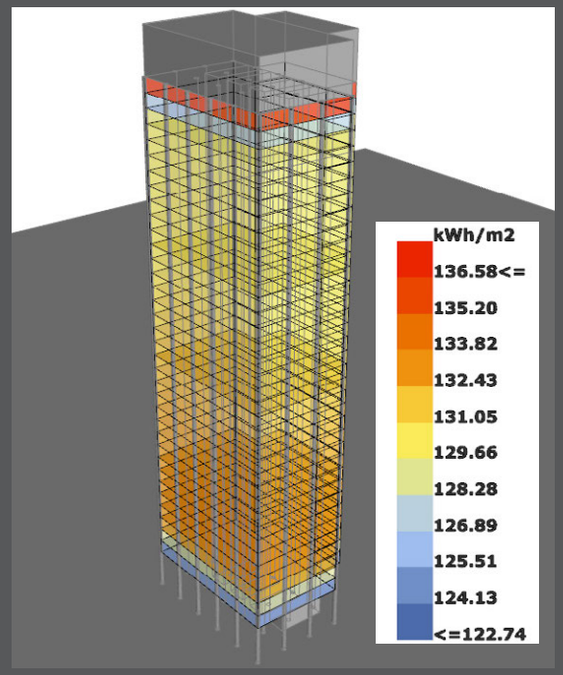
The relative humidity of each zone (%).

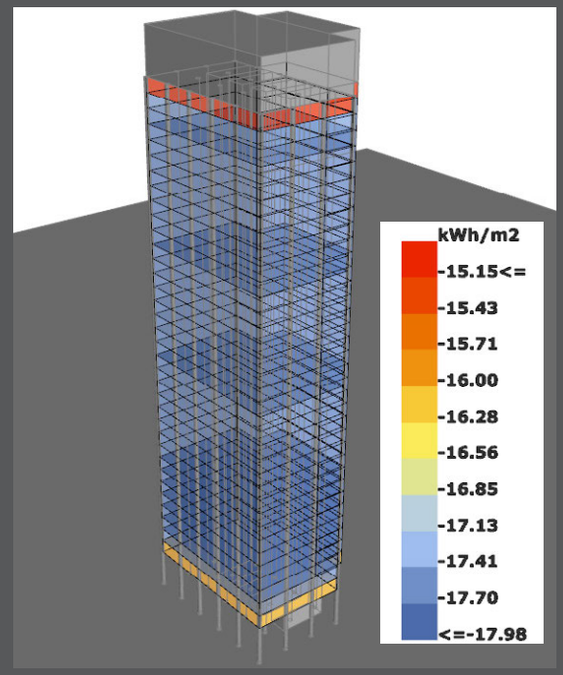
Operative Temperature

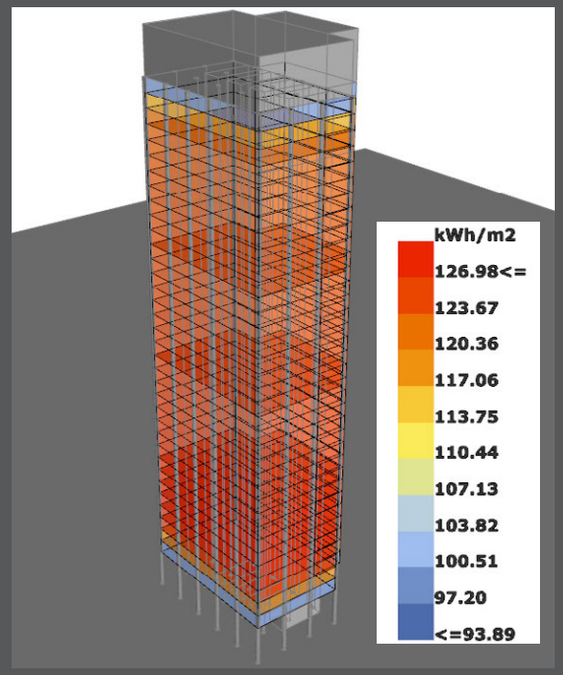
The mean operative temperature of each zone (degrees Celcius).

2. Building Scale: Analyzed with E+

Seagram Building without context or EDDS.







Analyzing Thermal Energy Loads:

Total Thermal Energy Loads

The total thermal energy used by each zone in kWh. This includes cooling and heating.

Heating Loads

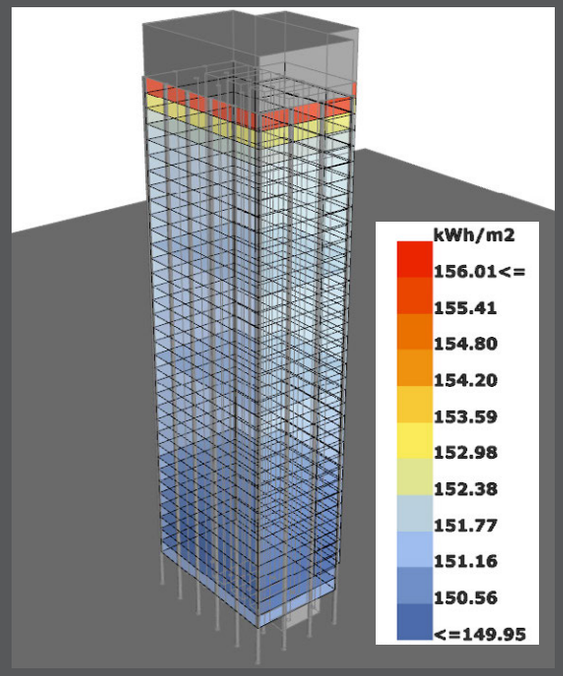
The heating energy needed in kWh. For Ideal Air loads, this is the sum of sensible heat that must be added to each zone. For distributed OpenStudio Systems like Packaged Terminal Heat Pumps (PTHP), this will be electric energy for each zone. For central OpenStudio systems, this output will be a single list for the whole building.

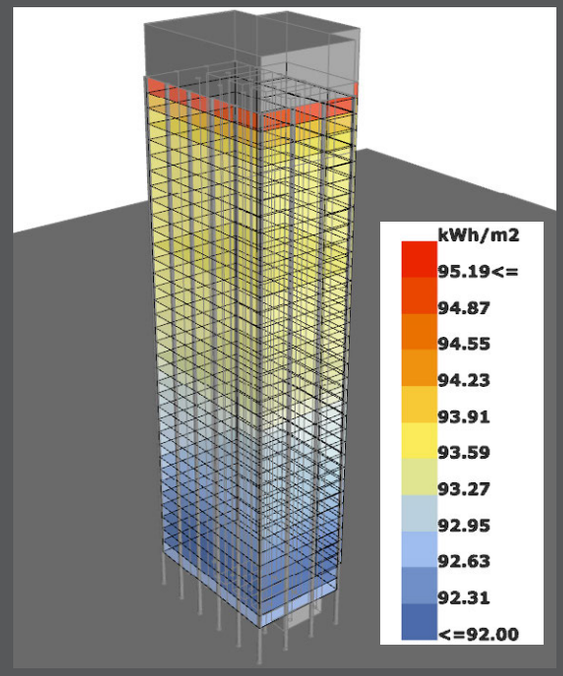
Cooling Loads

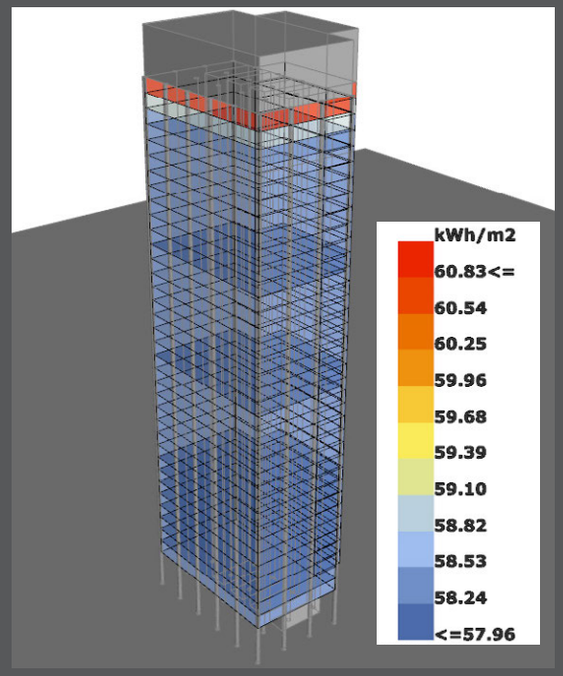
The cooling energy needed in kWh. For Ideal Air loads, this is the sum of sensible and latent heat that must be removed from each zone. For distributed OpenStudio systems like Packaged Terminal Heat Pumps (PTHP), this will be electric energy for each zone. For central OpenStudio systems, this output will be a single list for the whole building.

2. Building Scale: Analyzed with E+

Seagram Building without context or EDDS.







Analyzing Solar Radiation:

Total Solar Gains

The total solar gain in each zone(kWh).

Exterior Solar Diffuse Gains

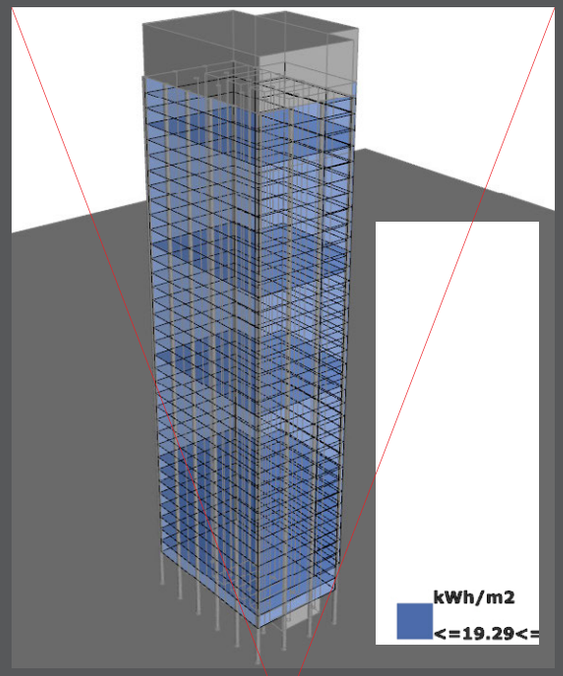
The diffuse solar gain in each zone from exterior windows (kWh).

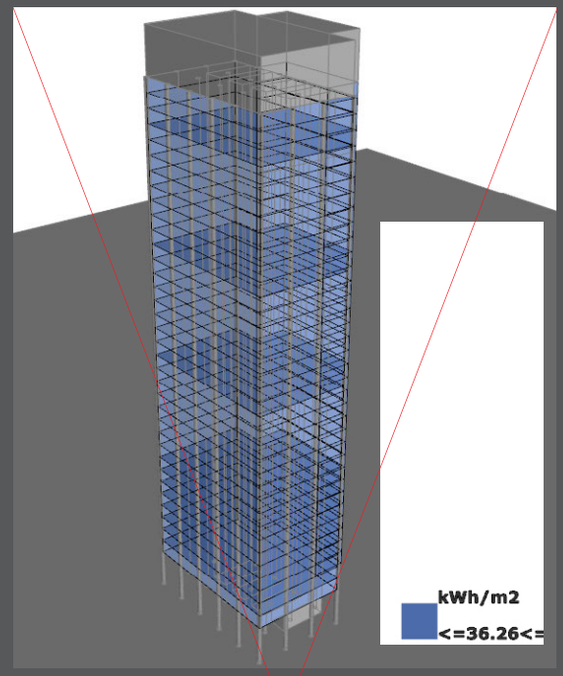
Exterior Solar Beam Gains

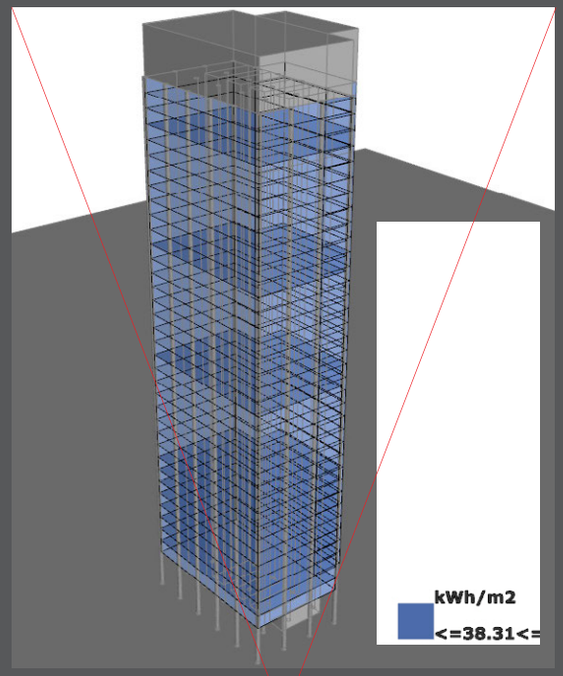
The direct solar beam gain in each zone from exterior windows (kWh).

2. Building Scale: Analyzed with E+

Seagram Building without context or EDDS.







Analyzing People/Systems:

People Gains

The internal heat gains in each zone resulting from people (kWh).

Electric Equip. Energy Usage

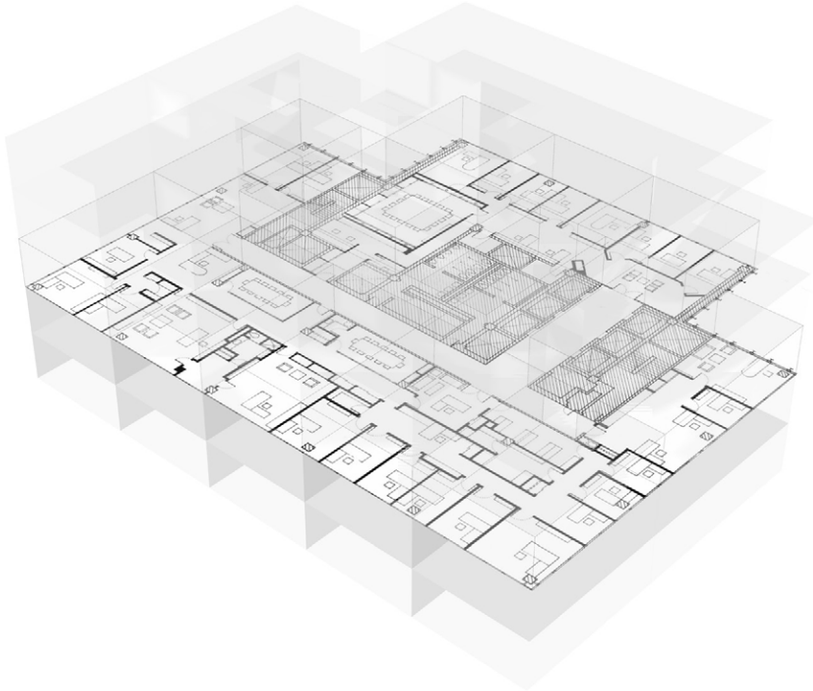
The electric equipment energy needed for each zone in kWh.

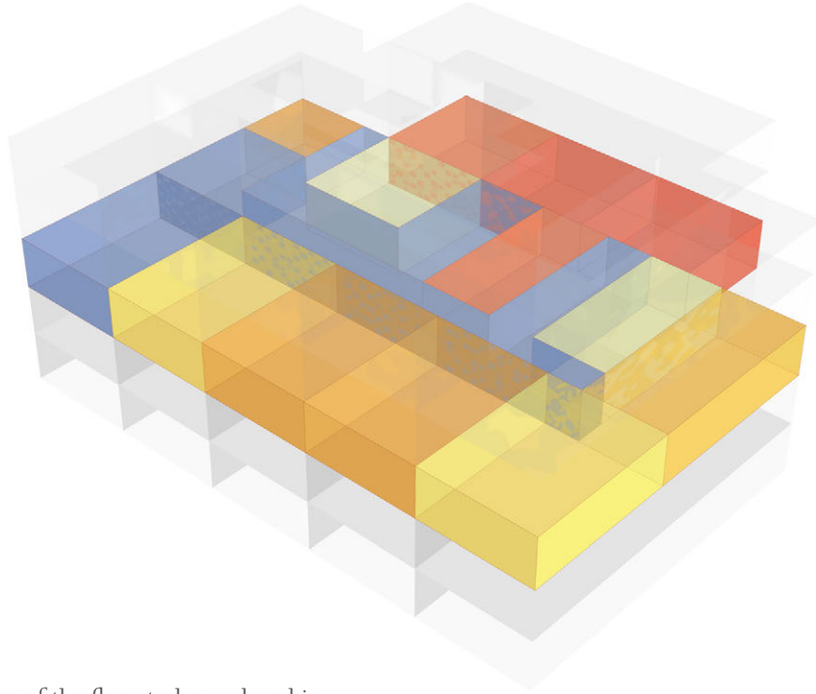
Electric Lighting Energy Usage

The electric lighting energy needed for each zone in kWh.

3. Zoomed-in Scale: Setup

Seagram Building floor without context or EDDS.

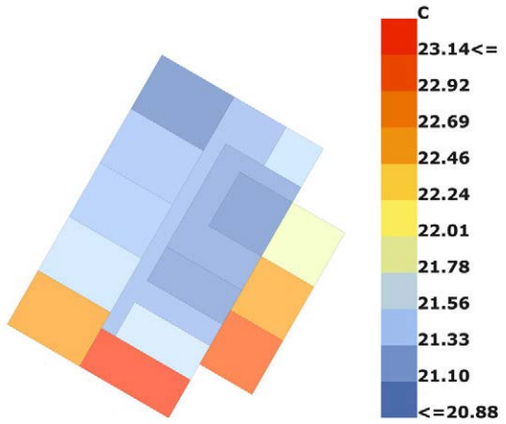




Design zones of the floor to be analyzed in place of proposed/existing rooms. This example has been generalized: 15 zones make up a floor containing 30+ rooms. Specify inputs/presets in accordance with the goal EnergyPlus simulation.

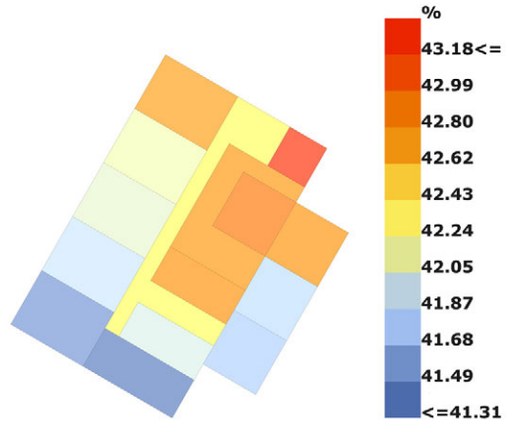
Seagram Building floor without context or EDDS.

Analyzing Temperature and Humidity:



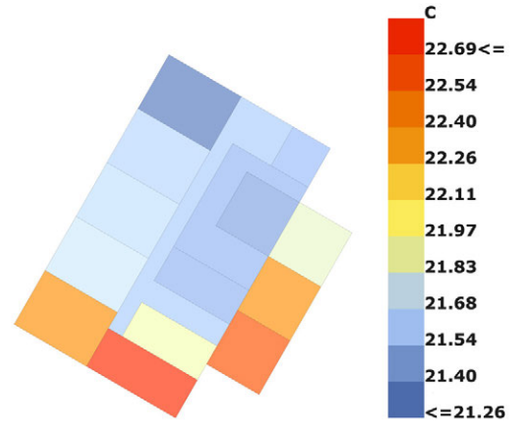
Mean Radiant Temperature

The mean radiant temperature of each zone (degrees Celsius).



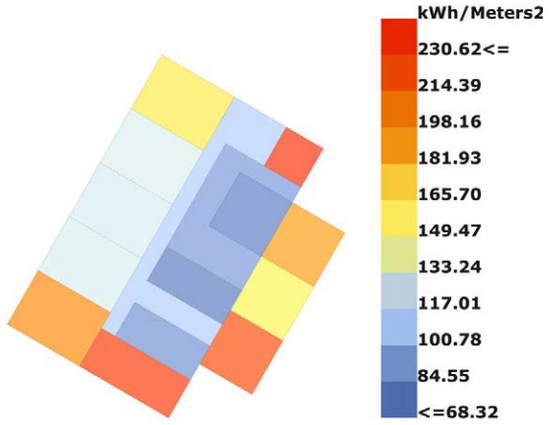
Humidity

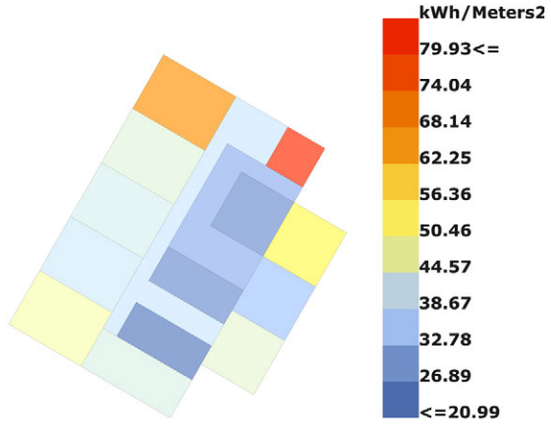
The relative humidity of each zone (%).

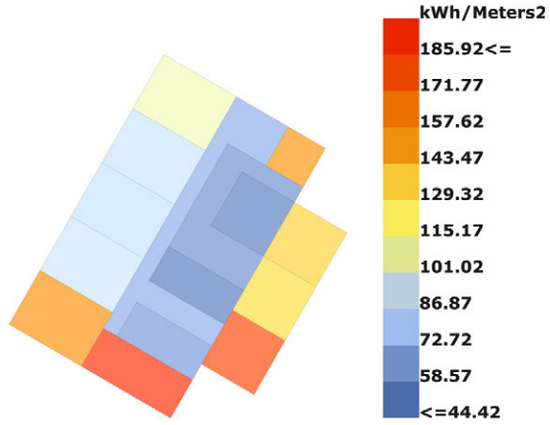


Operative Temperature

The mean operative temperature of each zone (degrees Celcius).







Analyzing Thermal Energy Loads:

Total Thermal Energy Loads

The total thermal energy used by each zone in kWh. This includes cooling and heating.

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The heating energy needed in kWh. For Ideal Air loads, this is the sum of sensible heat that must be added to each zone. For distributed OpenStudio Systems like Packaged Terminal Heat Pumps (PTHP), this will be electric energy for each zone. For central OpenStudio systems, this output will be a single list for the whole building.

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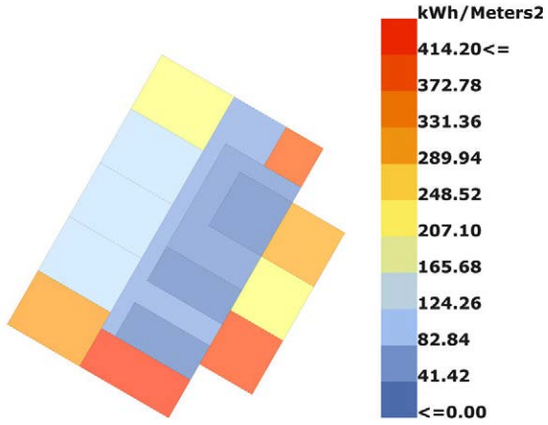
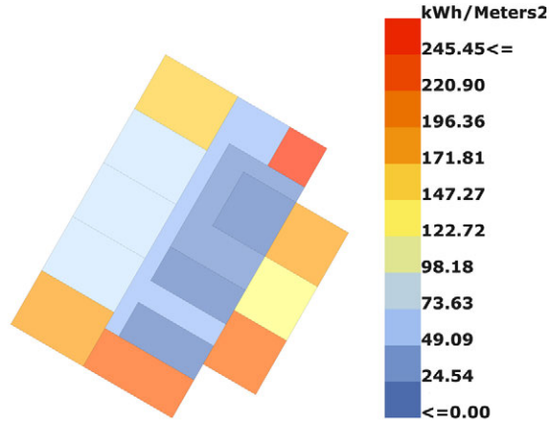
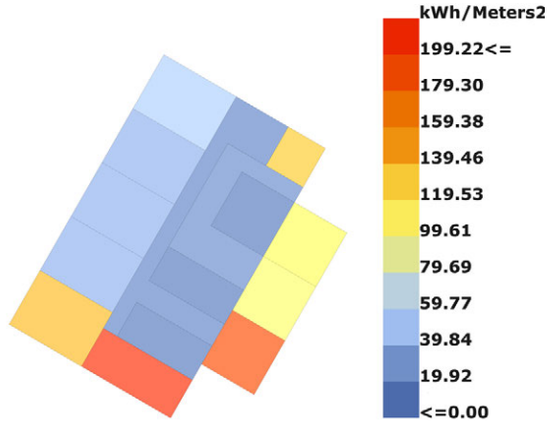
The cooling energy needed in kWh. For Ideal Air loads, this is the sum of sensible and latent heat that must be removed from each zone. For distributed OpenStudio systems like Packaged Terminal Heat Pumps (PTHP), this will be electric energy for each zone. For central OpenStudio systems, this output will be a single list for the whole building.

3. Zoomed-in Scale: Analyzed with E+

Seagram Building floor without context or EDDS.







Analyzing Solar Radiation:

Total Solar Gains

The total solar gain in each zone(kWh).

Exterior Solar Diffuse Gains

The diffuse solar gain in each zone from exterior windows (kWh).

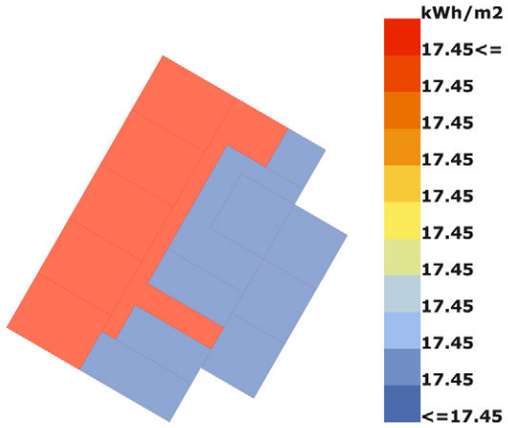
Exterior Solar Beam Gains

The direct solar beam gain in each zone from exterior windows (kWh).

3. Zoomed-in Scale: Analyzed with E+

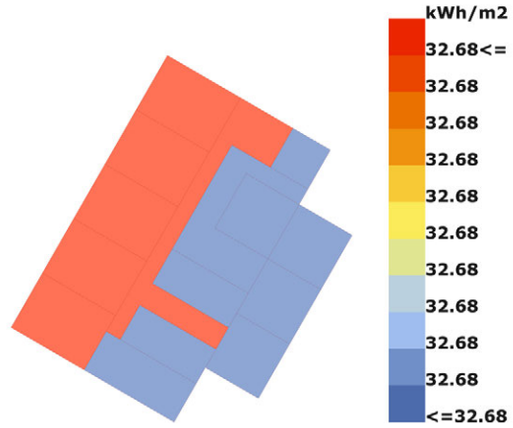
Seagram Building floor without context or EDDS.

Analyzing People/Systems:



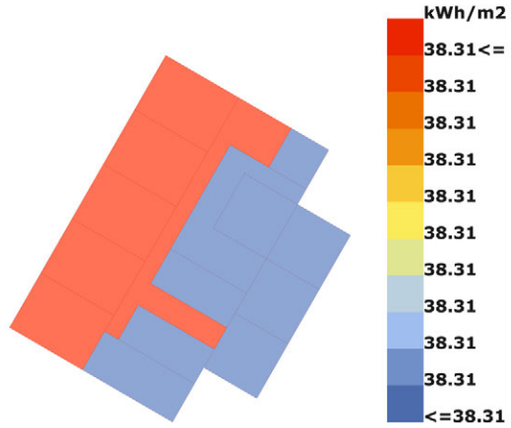
People Gains

The internal heat gains in each zone resulting from people (kWh).



Electric Equip. Energy Usage

The electric equipment energy needed for each zone in kWh.

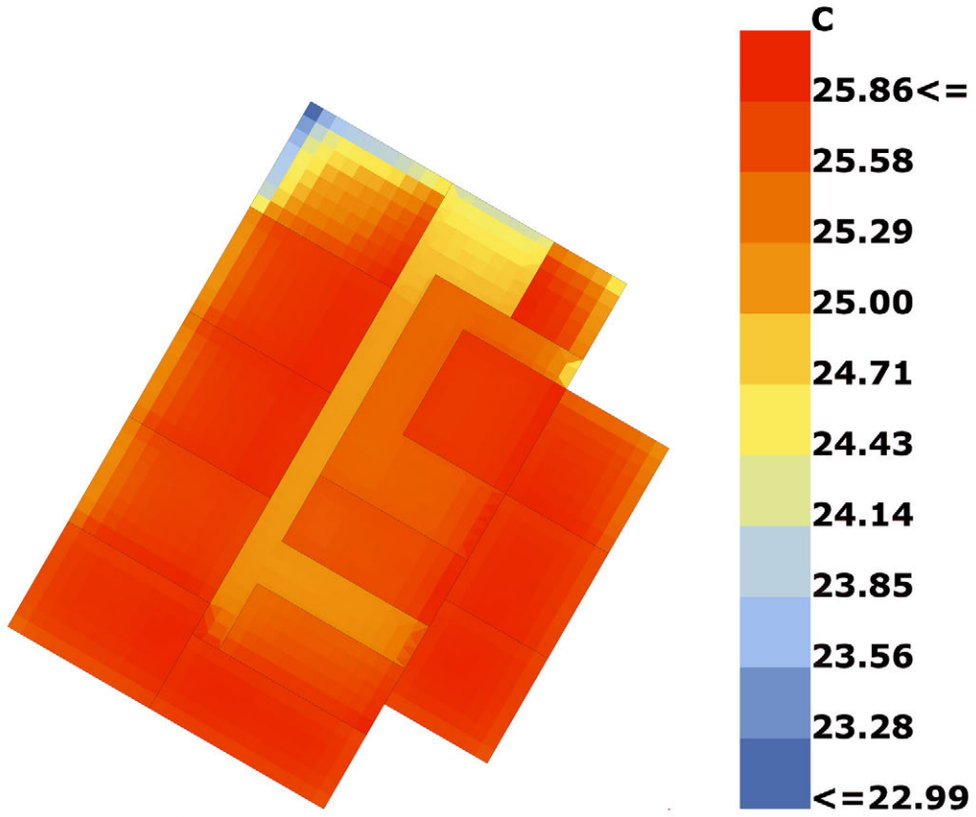


Electric Lighting Energy Usage

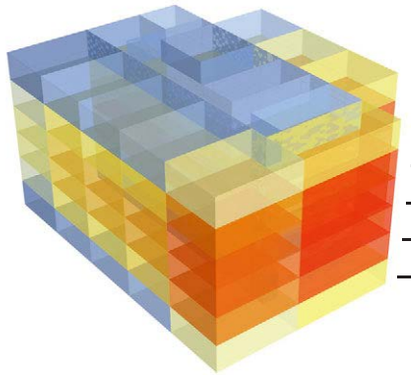
The electric lighting energy needed for each zone in kWh.

Indoor Radiant Temperature Map

1meter by 1meter grid of sensor points each provide a result post-analysis to be merged into an indoor radiant temperature map. Note the corridor penetrating the center of the building (with the least amount of area-to-glazing ratio). The cooler sensory points at the north corner of the building may be an anomaly, or an accurate representation of the cooler north-side zones.

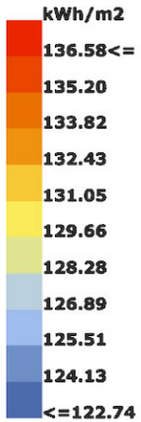


Looking at the results of a section of the Seagram Building



Levels: 15 zones each

Level 1
Level 2
Level 3
Level 4
Level 5



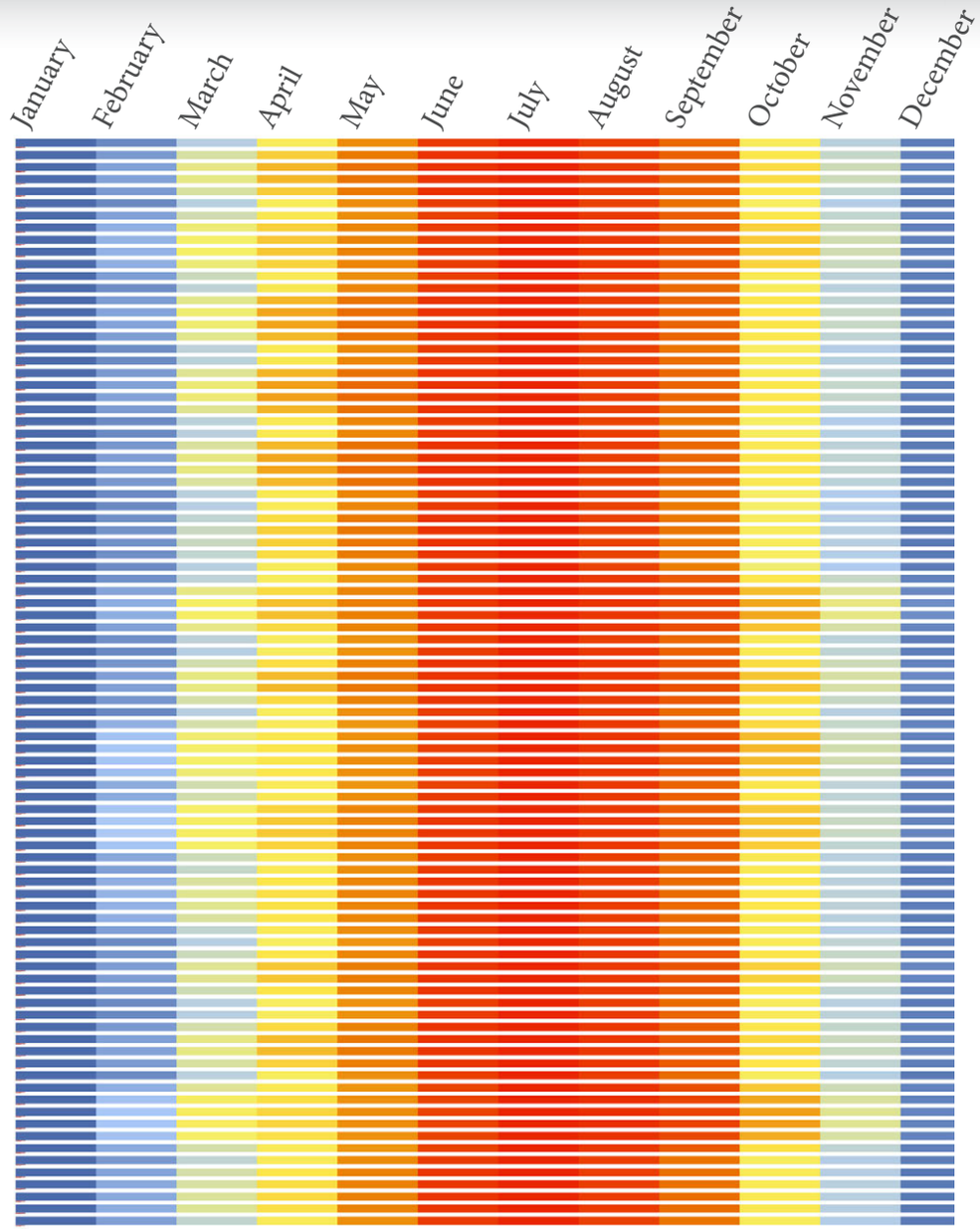


Diagram of results mapped out over time

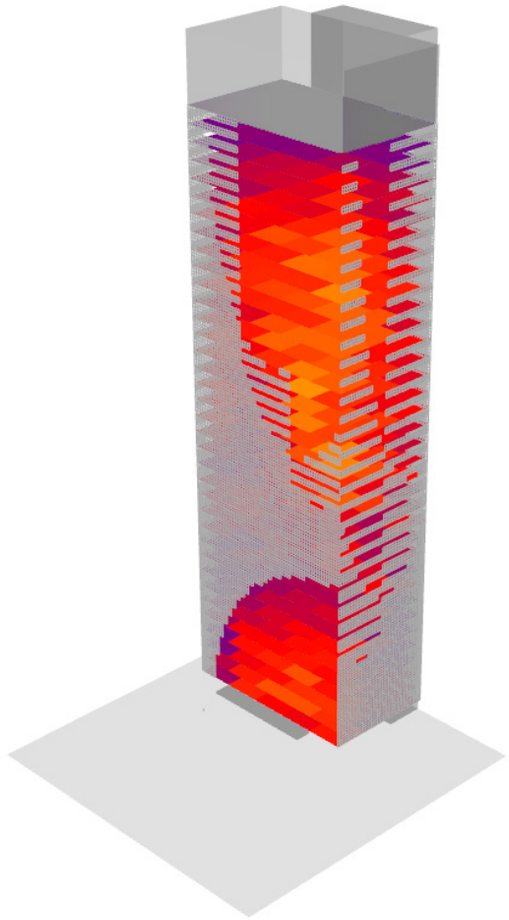
EnergyPlus provides results on a zone-by-zone basis, with data for each zone representable for every hour of the year (in this case, an averaged total hourly thermal energy required per zone per m^2 per month per year).

4. Building & Zoomed-in Scale

Seagram Building and building section analyzed with a static instance of EDDS implemented.

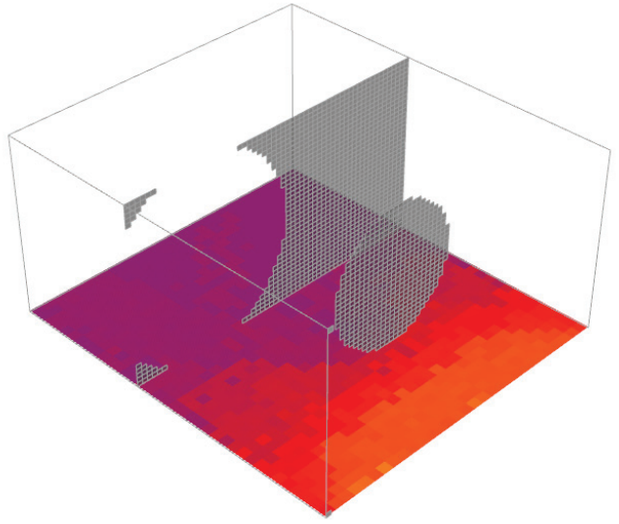
Building Scale Analysis

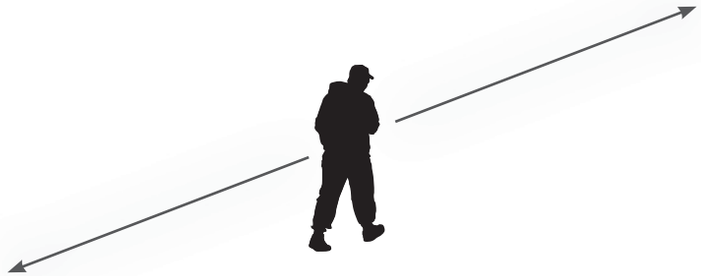
Seagram Building typical direct/diffuse daylighting levels analyzed without contextual influence. One instance of a non-moving EDDS facade is analyzed.



Zoomed-in Analysis

Test of daylighting analysis in a space with two EDDS-like partitions. Context and building are not taken into account. This study represents an instance of light diffusing around temporary or potentially moving EDDS obstructions.



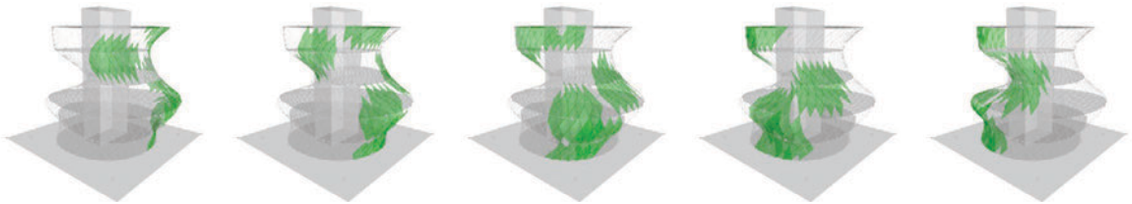


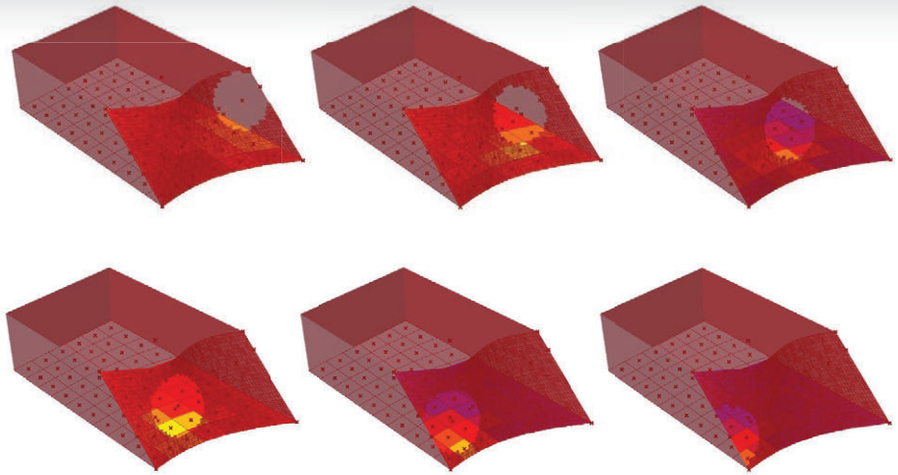
Behavioral Modeling - My Proposal

Part 5 looks at applying a dynamic system to a building and building section, and analyze each's impact on the space.

5. Building Scale & Zoomed-in Analysis

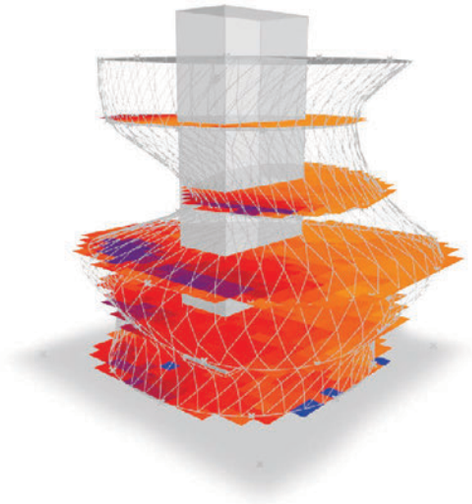
~~Seagram Building~~ Test building and zoomed-in model analyzed with a dynamic instance of EDDS implemented.





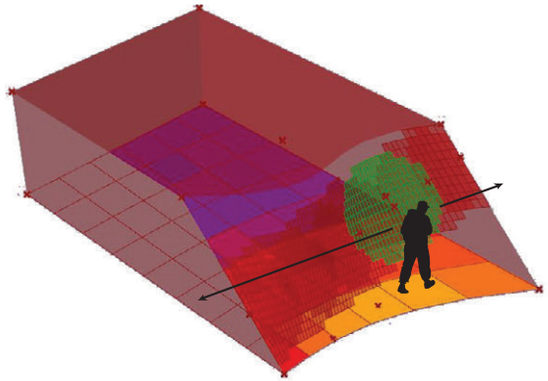
Building Scale Analysis

Composite analysis of 5 facade iterations, meant to simulate EDDS movement.

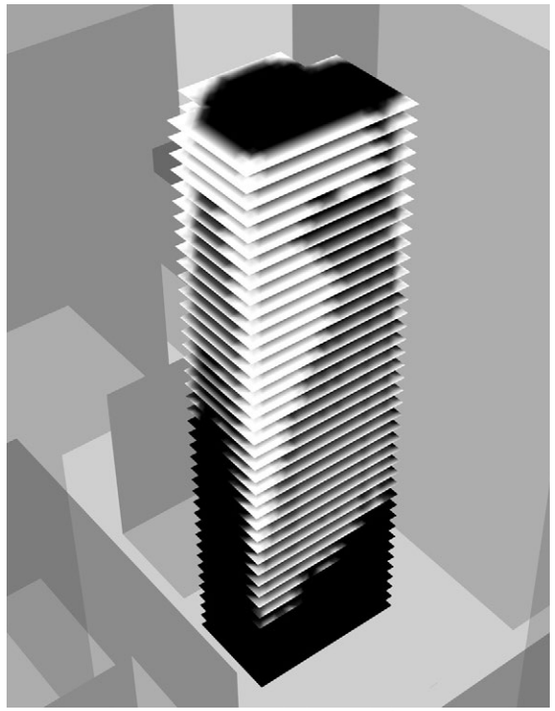


Zoomed-in Analysis

Behavior: Person walking in front of responsive EDDS facade. 7 points along the way compiled into a composite analysis.

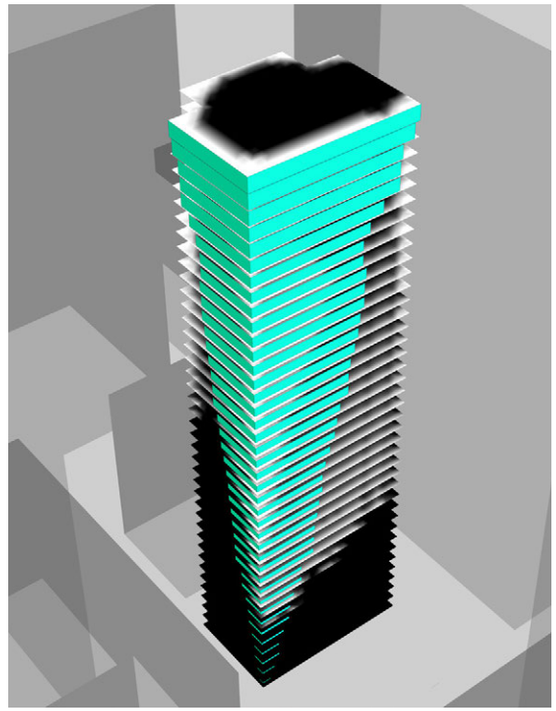


Systematic Compensation Example 1
Building Scale



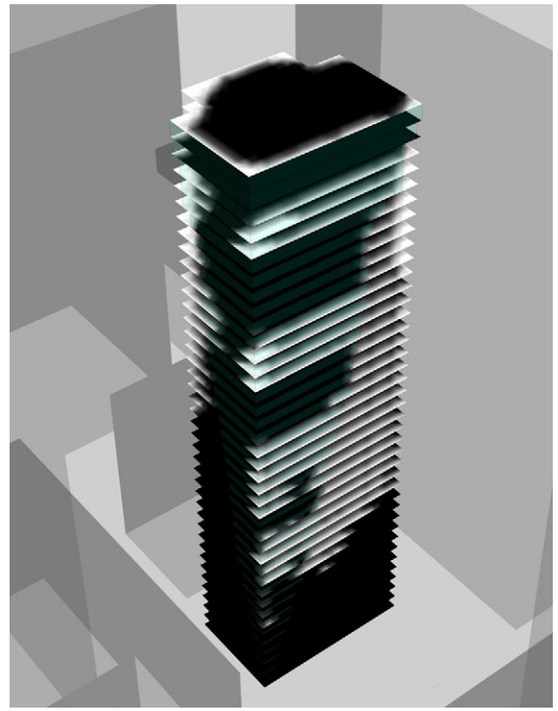
Analysis with no EDDS

Results: Of the 54990 m2 floor area,
7142 m2 day-lit
Average 13.0% of floor is directly lit by sun



EDDS responding to areas of too much direct lighting

After the first simulation, the results are read and the new model rebuilds itself to accommodate the results: to lessen direct daylighting loads.

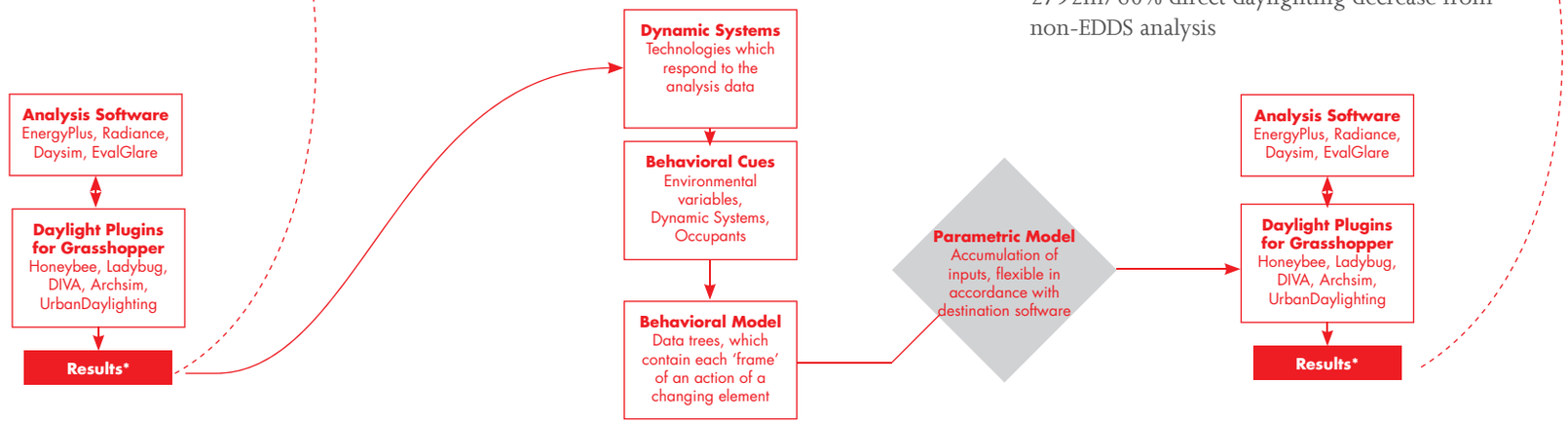


Resultant simulation

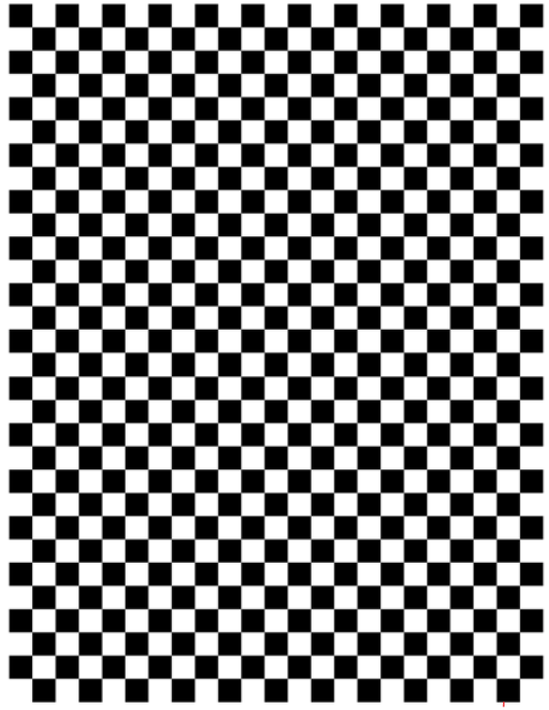
Results: Of the 54990 m2 floor area,
4351 m2 day-lit area
Average 7.9% of floor is directly lit by sun
2792m/60% direct daylighting decrease from non-EDDS analysis

What could a dynamic system, such as EDDS compensate for in a space/building?

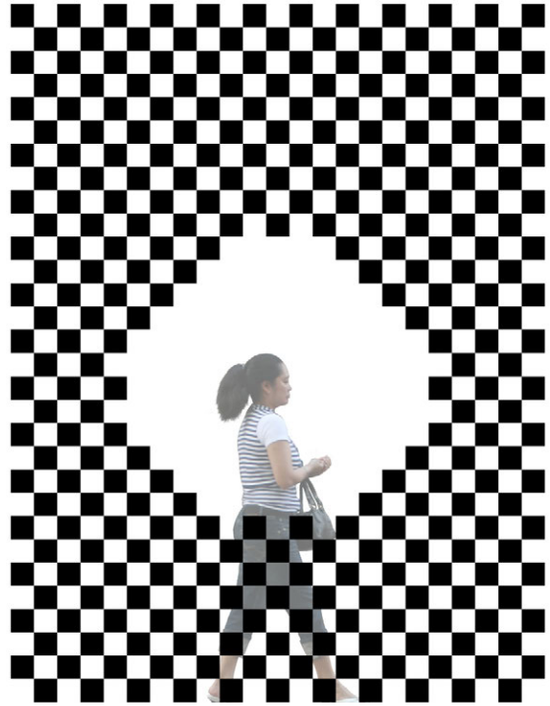
- Heat/Cooling/Lighting gains due to:
- Increase of Occupants
- Changing weather patterns
- An influx of machines in a space (computers etc)
- Changing thermal properties on nearby floors/ in nearby zones
- More…



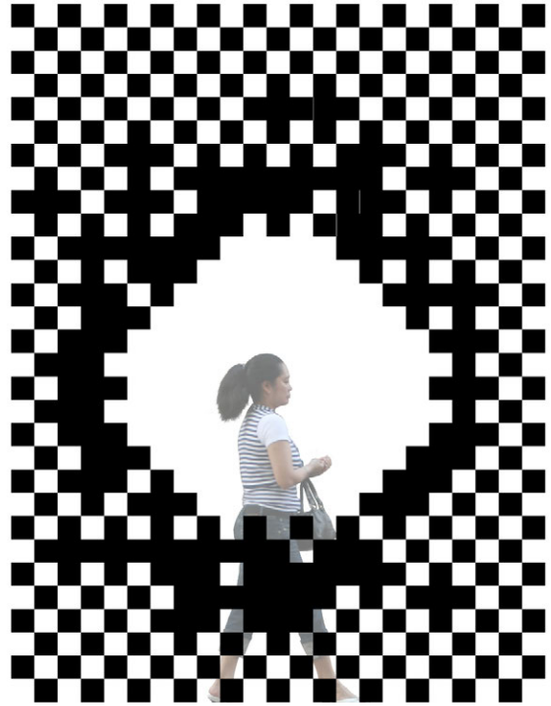
Systematic Compensation Example 2
Zoomed-in Scale



EDDS non-responsive pattern



EDDS responding to an occupant



EDDS compensating for the previous response

What could a dynamic system, such as EDDS compensate for in a space/building?

- Heat/Cooling/Lighting gains due to:
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- An influx of machines in a space (computers etc)
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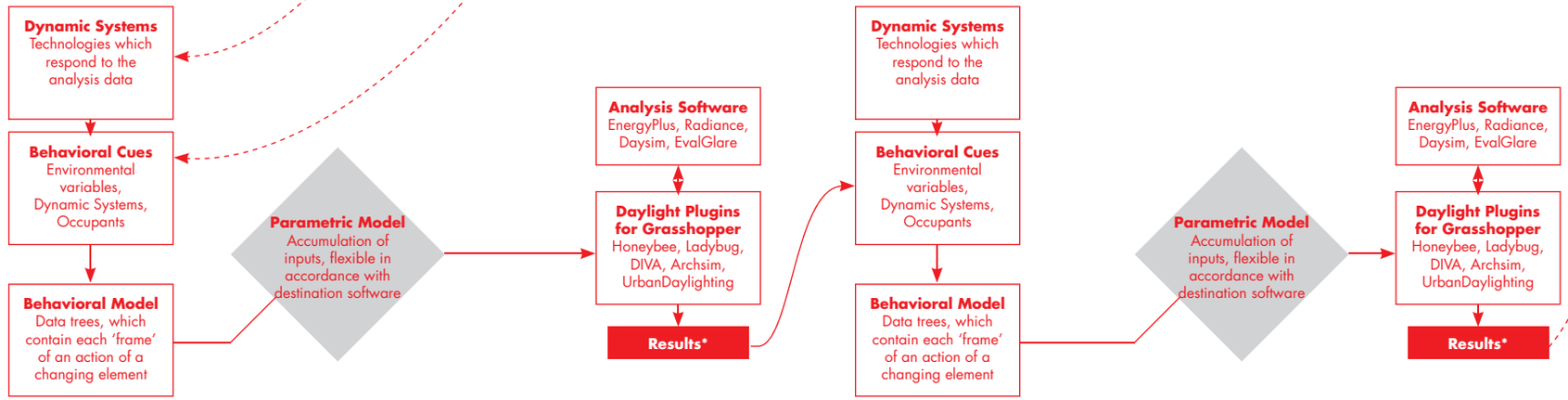
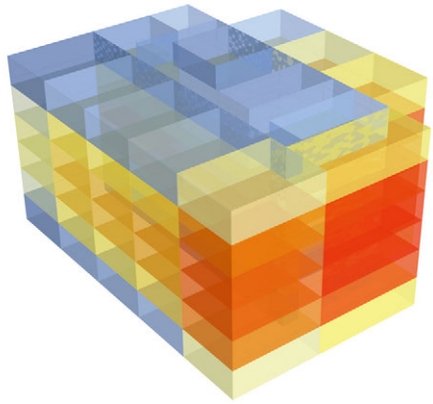
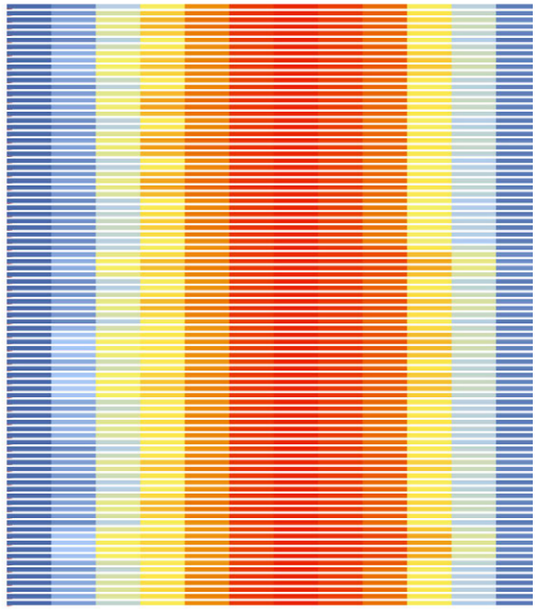
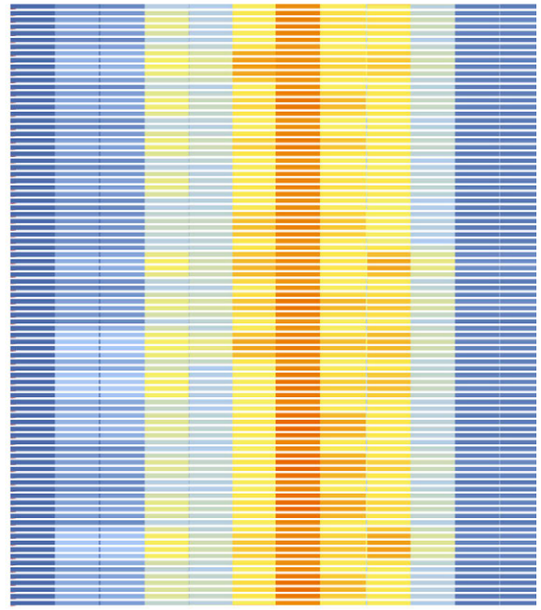
- More…

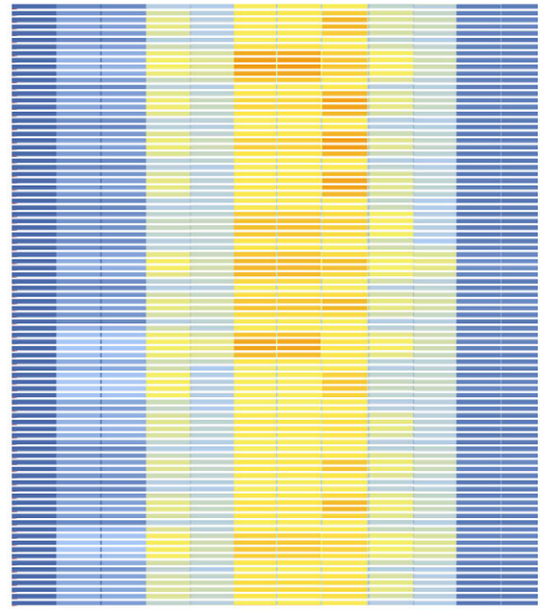


Analysis Speculation:





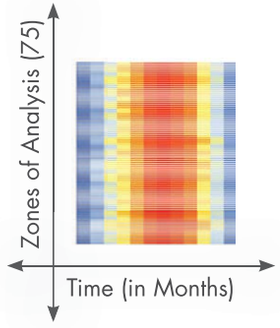




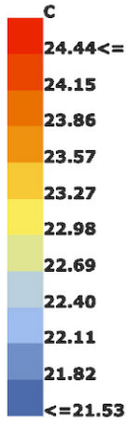
Example: Mean Radiant Temp Analysis

The mean radiant temperature of each zone (degrees Celsius).

Result diagram key:



Color key:



No EDDS/Shaders - Actual Analysis

A representation of the average radiant temperature in all zones over the span of a year (monthly values are determined from hourly results). Clearly the simulation shows that there is a rise in temperature during the summer months as is expected.

Static Instance of EDDS - Speculation

Implementing any shading device, including a static instance of EDDS, would result in a decrease of average radiant temperatures during the summer months.

Dynamic/Responsive EDDS - Speculation

Moving beyond static shading devices, however, we get into the territory of responsive systems. I speculate an improvement in average temperature during summer months with the implementation of a fully dynamic EDDS system. In this case, EDDS would respond to occupant movement, other systems, environmental cues etc.

Moving Forward

I hope to further develop a method for analyzing and simulating complex building systems in architecture. This method for analysis and optimization would facilitate the efficient implementation of dynamic/advanced/sustainable technologies in all building typologies.

SCENE
Geometry
Landscape
Reflectance levels
Materials
Artificial Lighting
Shading

Area of Interest
Viewpoint
Grid of lighting/
thermal sensor points

Space Usage
Program
Lighting requirements
Thermal comfort req's
Schedules

Sky Model
Date
Time
Location
Sky condition
Weather data
Solar Radiation

Dynamic Systems
Technologies which respond to the analysis data

Behavioral Cues
Environmental variables, Dynamic Systems, Occupants

Behavioral Model
Data trees, which contain each 'frame' of an action of a changing element

Proposal:
A New Grasshopper Component

The main potential of this research, I feel, is to create a method for implementing and analyzing dynamic systems in design. The proposal for bringing behavioral modeling into the parametric design realm might best be captured by creating a new grasshopper component which facilitates this idea.

This component would separate dynamic input into data sets readable by EnergyPlus & Radiance.

Parametric Model
Accumulation of inputs, flexible in accordance with destination software

Analysis Software
EnergyPlus, Radiance, Daysim, EvalGlare

Daylight Plugins for Grasshopper
Honeybee, Ladybug, DIVA, Archsim, UrbanDaylighting

Results*

Thermal/Systems Plugins for Grasshopper
Honeybee, Ladybug, Archsim, Geco

Analysis Software
EnergyPlus, OpenStudio, Ecotect

Bibliography:

Dogan, T., Reinhart, C., & Michalatos, P. (2012). Urban Daylight Simulation: Calculating the Daylit Area of Urban Designs. Fifth National Conference of IBPSA-USA.

Hensel, Michael, Achim Menges, and Michael Weinstock. 2010. Emergent Technologies and Design: Towards a Biological Paradigm for Architecture. 1 edition. Oxon, U.K. ; New York, NY: Routledge.

Herkel, S., & Reinhart, C. (2000). The Simulation of Annual Daylight Illuminance Distributions. Energy and Buildings, 167-187.

Jakubiec, J. A., & Reinhart, C. F. (2011). Integraing Daylight and Thermal Simulations Using Rhionceros 3D, Daysim and Energyplus. 12th Conference of International Building Performance Simulation Association.

Jong, Kenneth A. de De, and Kenneth A. De Jong. 2002. Evolutionary Computation. 1st edition. Cambridge, Mass: A Bradford Book.

Loukissas, Yanni. 2012. Co-Designers: Cultures of Computer Simulation in Architecture. 1 edition. Abingdon, Oxon England ; New York, NY: Routledge.

Malkawi, Ali, and Godfried Augenbroe, eds. 2004. Advanced Building Simulation. New York: Routledge.

Peters, Terri, and Brady Peters. 2013. Inside Smartgeometry: Expanding the Architectural Possibilities of Computational Design. 1 edition. Chichester, West Sussex, United Kingdom: Wiley.

Probst, Maria Cristina Munari, and Christian Roecker. 2011. Architectural Integration and Design of Solar Thermal Systems. Pap/Chrt edition. New York: EPFL Press.

Rawn, Evan. “Emerging Voices: David Benjamin of The Living” 05 Oct 2014. ArchDaily. Accessed 05 Nov 2014. <http://www.archdaily.com/?p=553776>

Reas, Casey, and Chandler McWilliams. 2010. Form+Code in Design, Art, and Architecture. 1st edition. New York: Princeton Architectural Press.

Reinhart, C. (2012). Daylighting Lecture. MIT, Caimbridge, Massachusetts, USA.

Modeling and Analyzing Unpredictable Building Systems

Real-Time Whole Building Performance Impacts of Occupant Interaction with Dynamic Façade Systems

SuperJury Presentation
Spring 2015
Kurt Rogler
Advisor Bess Krietemeyer

Contention

Problems:

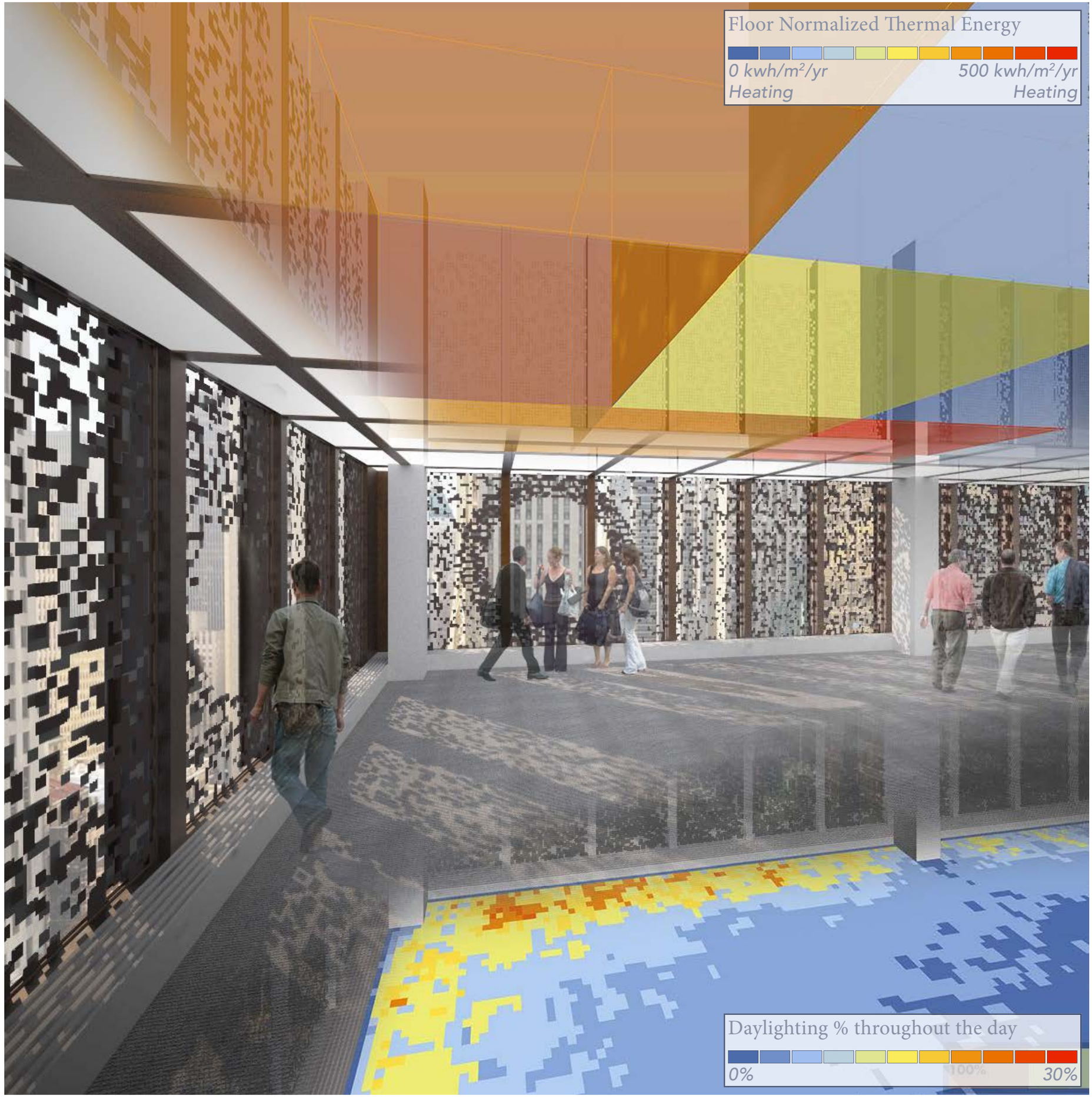
Current tools don't support analyzing unpredictable systems' effects on buildings.

Building performance analyses are usually centered around static resultant data and they don't necessarily account for unpredictable human behavior.

I contend:

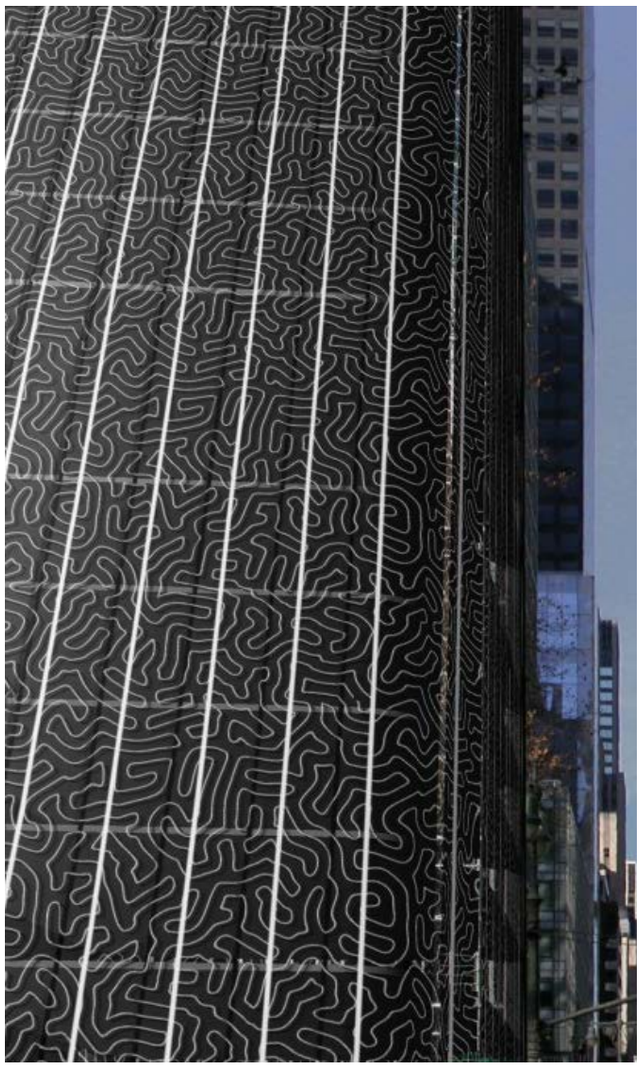
By developing a new workflow that links energy analysis tools to parametric modeling tools which can represent human behavior, we can better design and implement new building façade technologies that deal with a broader range of architectural performance criteria.

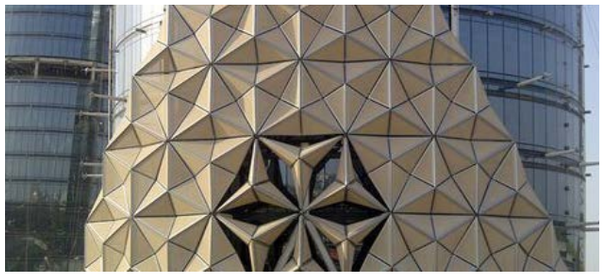
- Introduction
  - Contention
- Dynamic Facade Systems
- Analysis Inputs
- The Method
- Software Used
- The Building Testbed
- Single Zone Analysis
- Multiple Zone Analysis
- Building Visualizations
- Conclusions

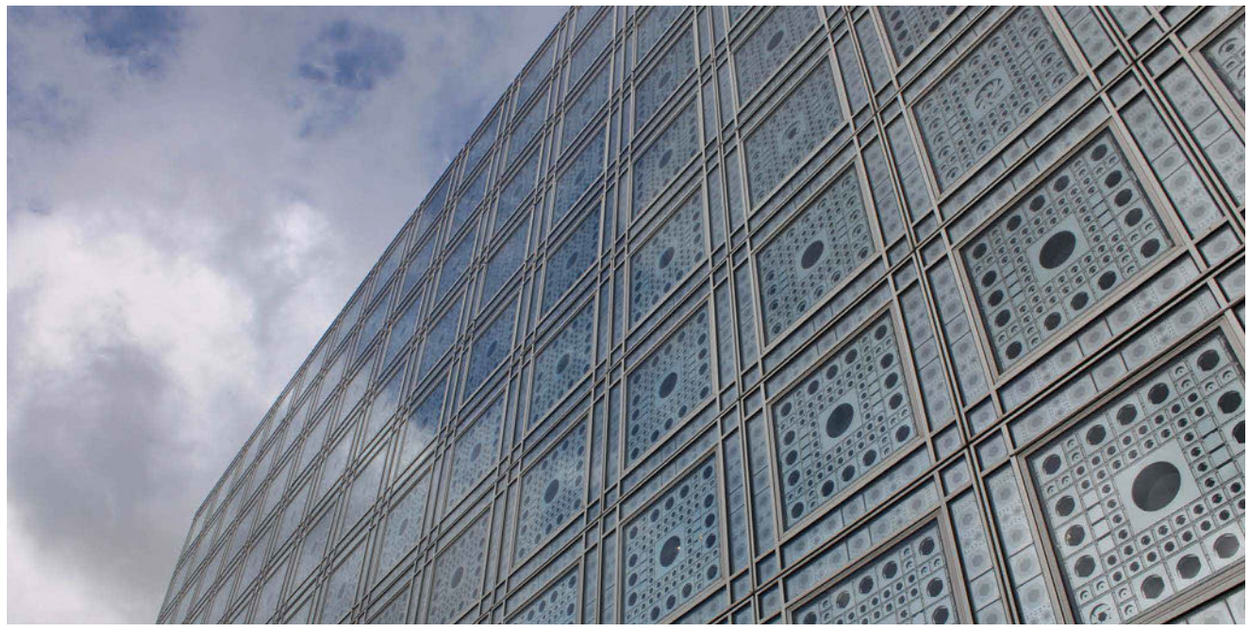


Part 1:
Project Background

Dynamic Glazing Systems







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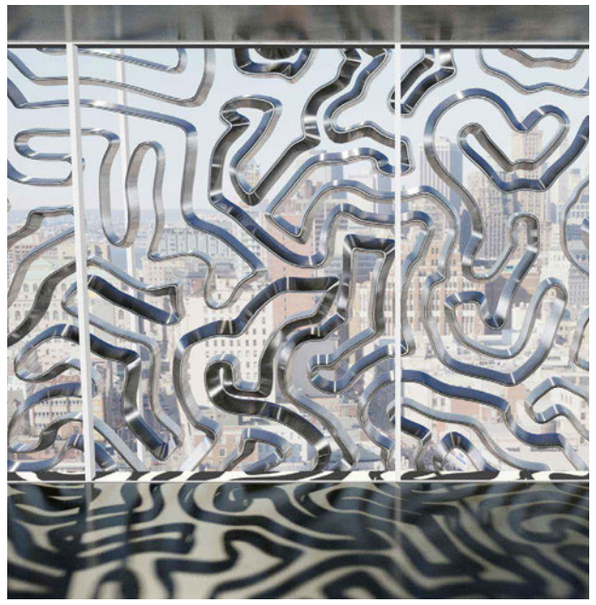
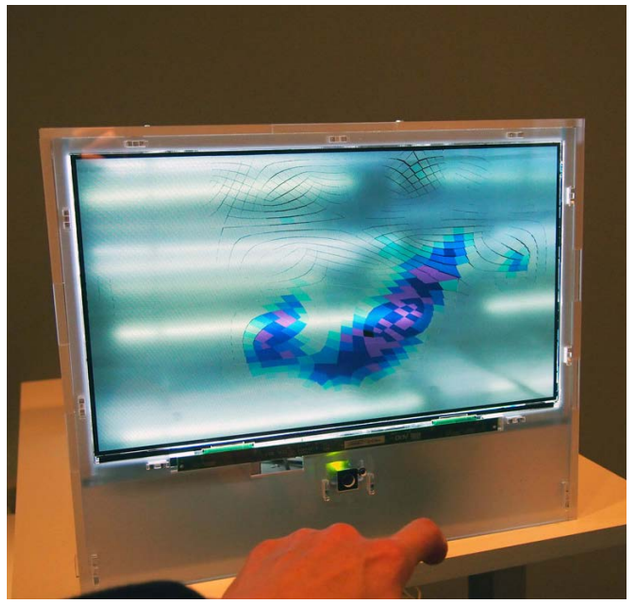
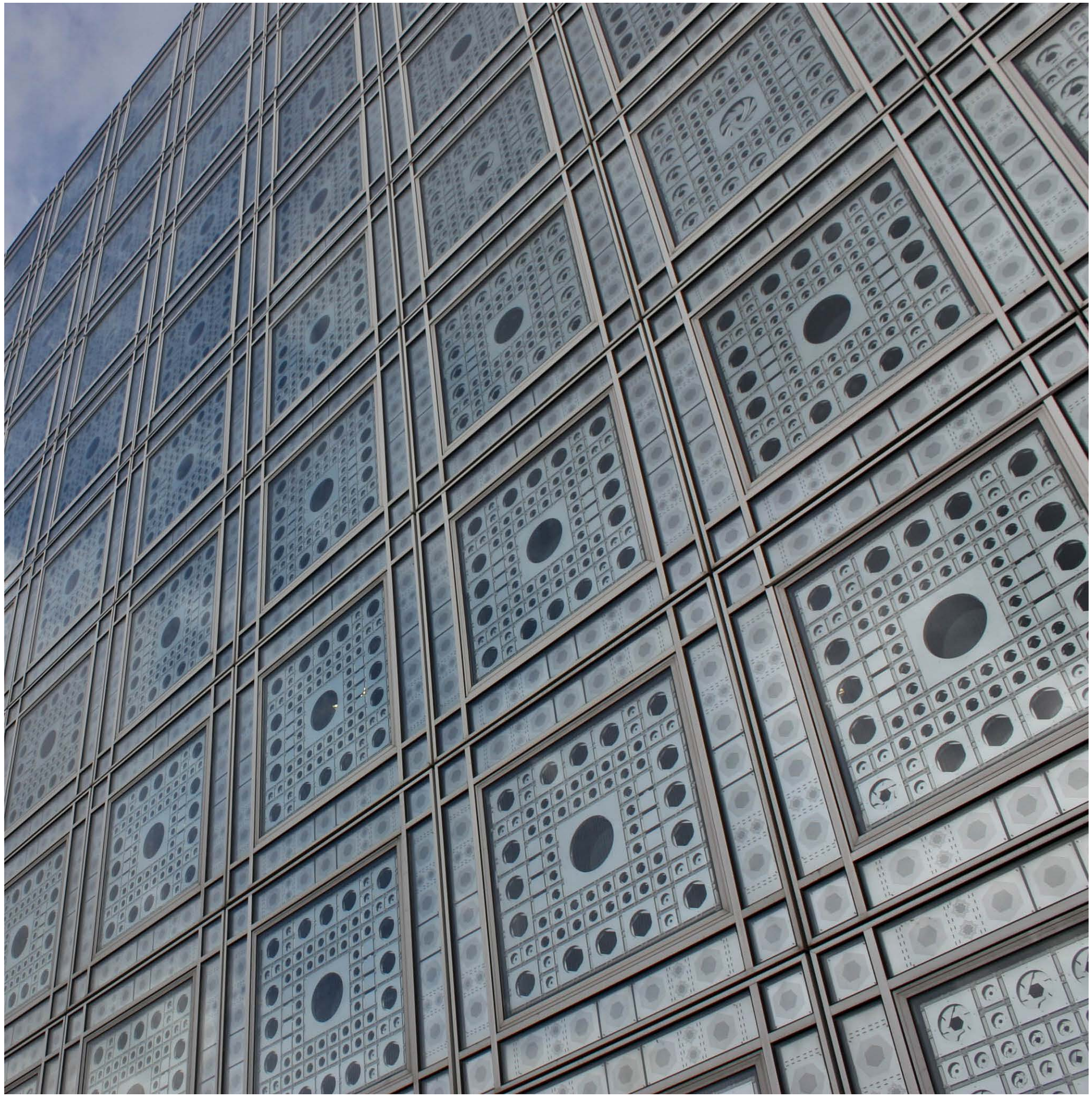




Dynamic Glazing Systems Example 1

The Arab World Institute
by Jean Nouvel



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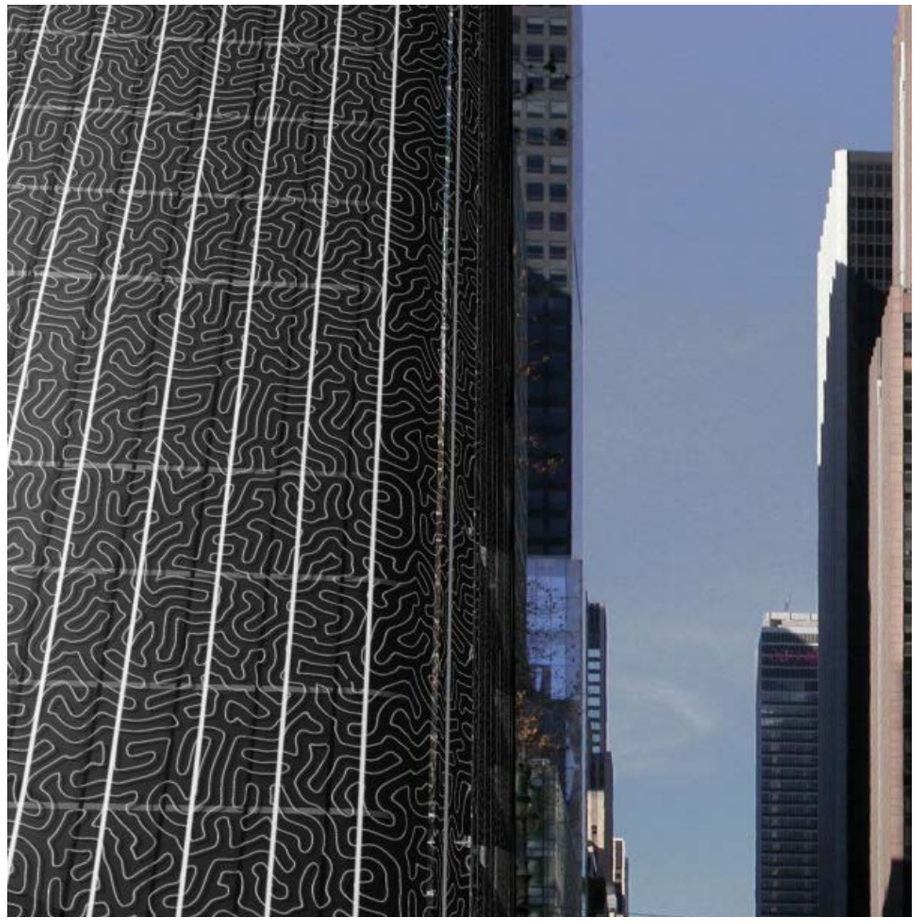
Dynamic Glazing Systems Example 2

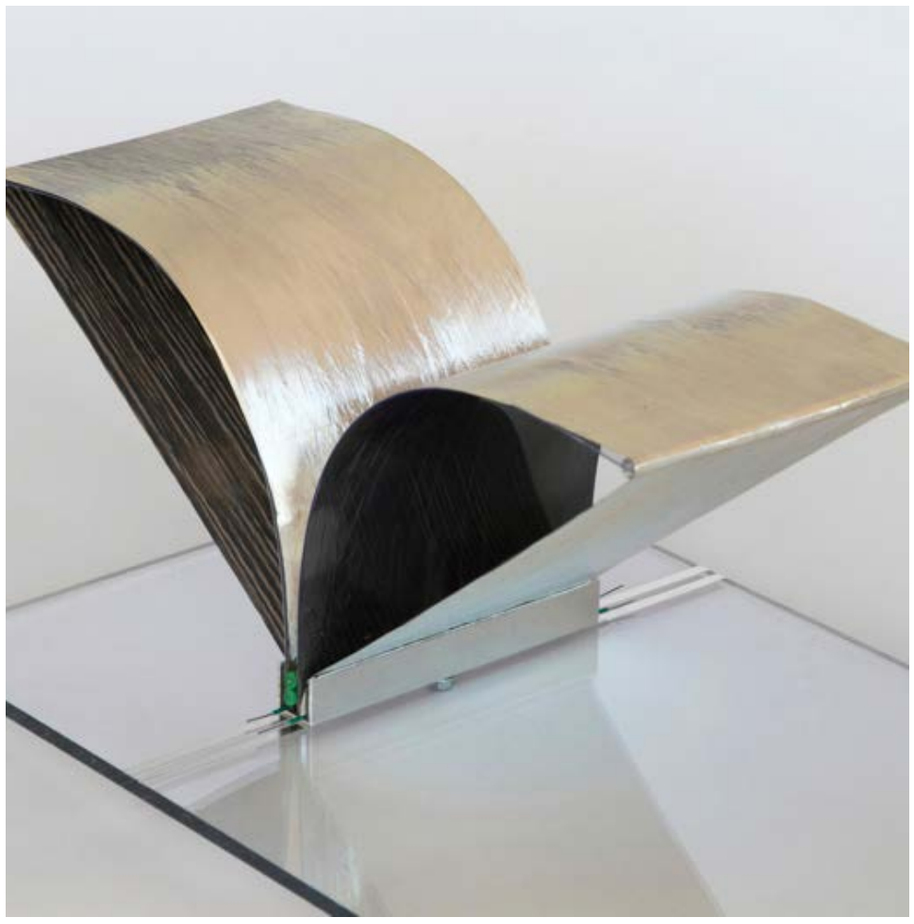
Syracuse Center of Excellence
by Toshiko Mori

- Introduction
- Dynamic Facade Systems
  Center of Excellence
- Analysis Inputs
- The Method
- Software Used
- The Building Testbed
- Single Zone Analysis
- Multiple Zone Analysis
- Building Visualizations
- Conclusions

Dynamic Glazing Systems Example 3

Homeostatic Facade System
by Decker Yeadon LLC





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  - Homeostatic Facade System
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- Software Used
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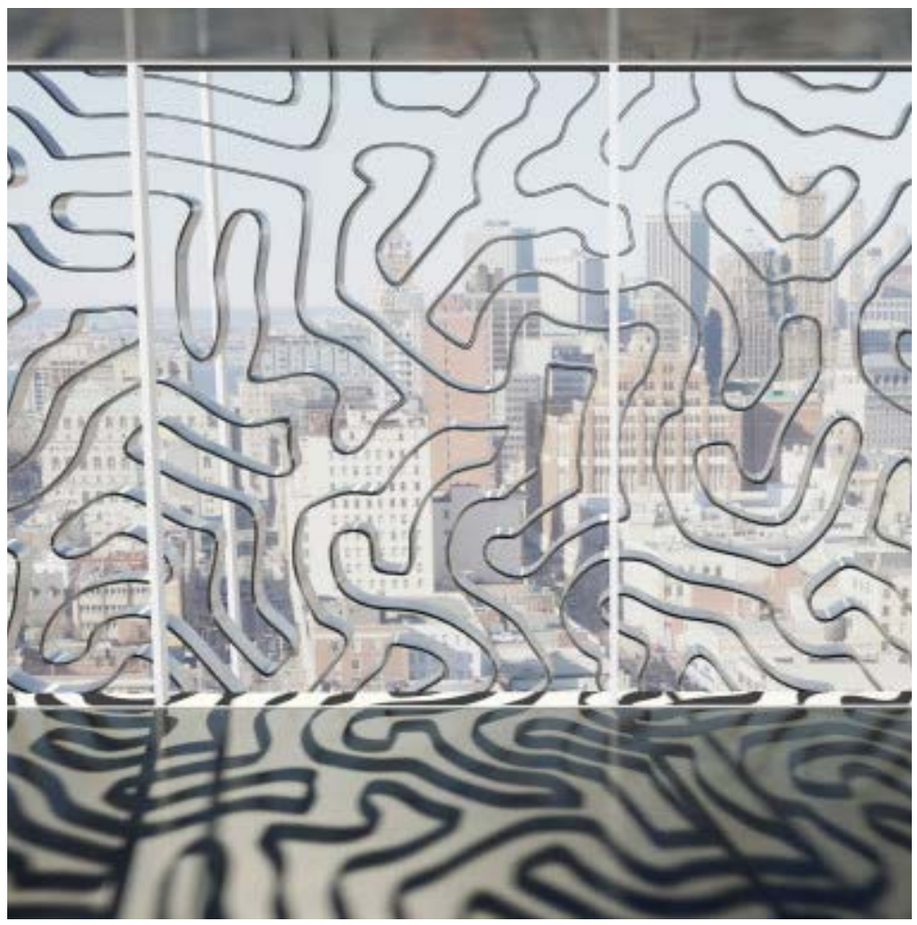
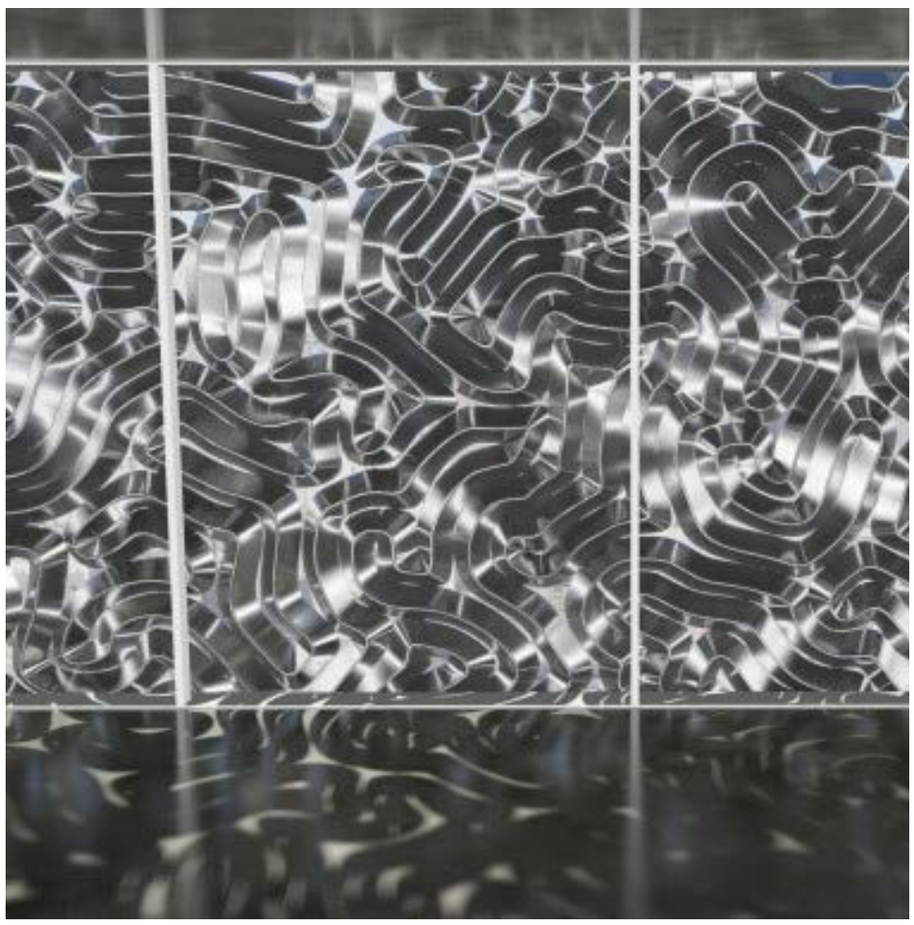
- Single Zone Analysis
- Multiple Zone Analysis
- Building Visualizations
- Conclusions





Dynamic Glazing Systems Example 4

Electroactive Dynamic Display System (EDDS)
by the Center for Architecture Science and Ecology

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  - EDDS
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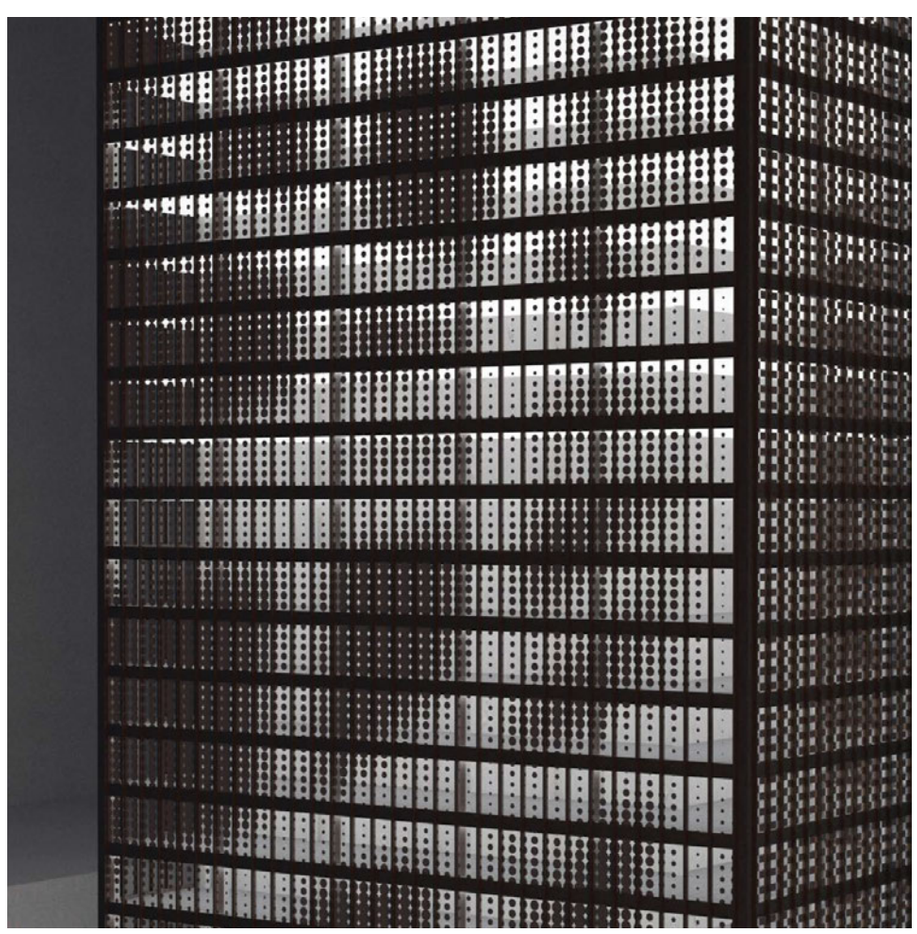
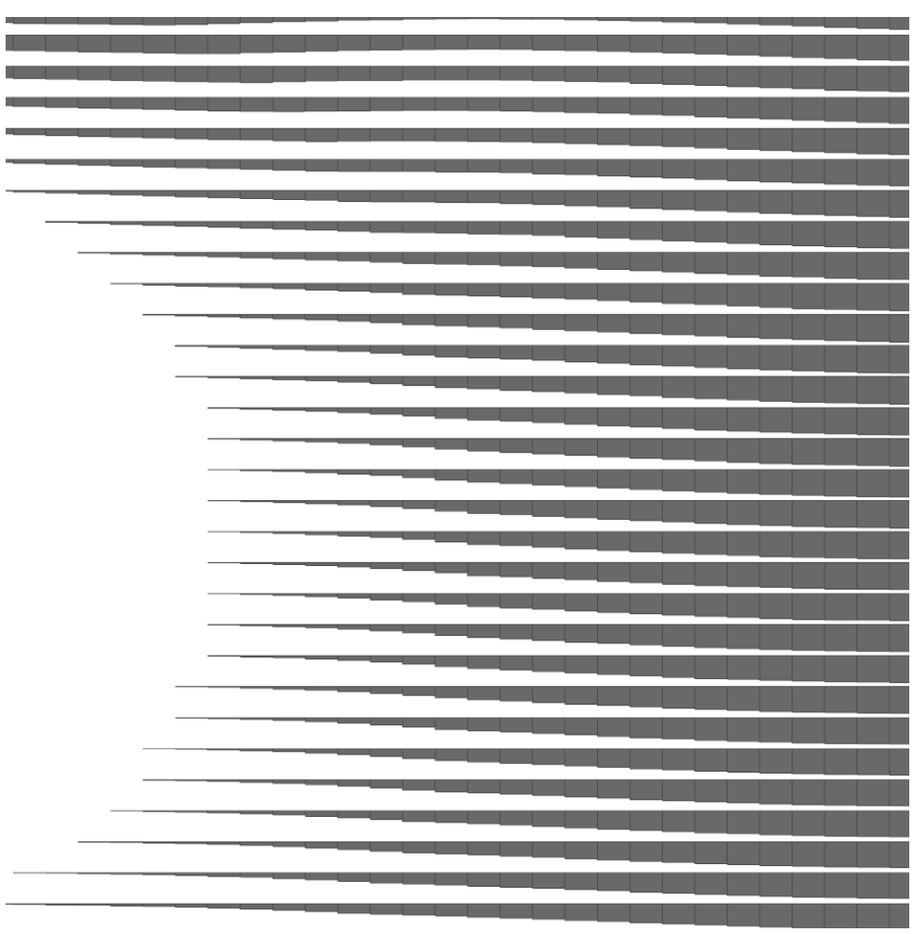
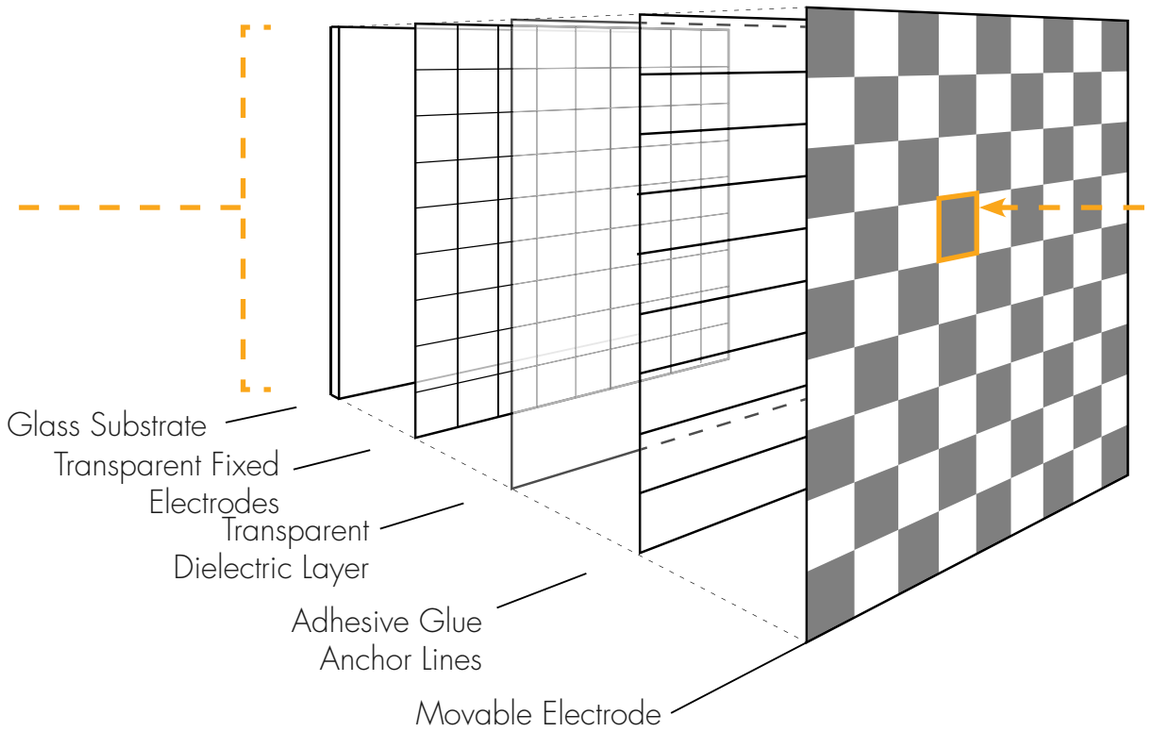


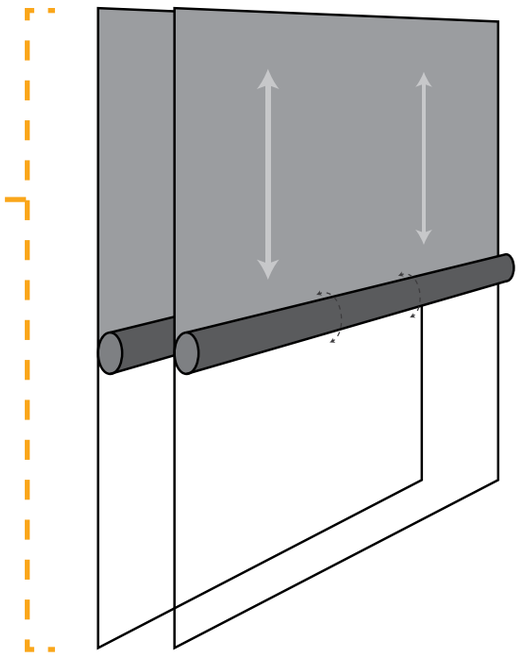


Dynamic Glazing Systems
Example 4 Continued

EDDS details

Patent #: US 8,134,112 B2





Rolled Metalized Polymer
-possibility for multiple layers

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- Contained within an IGU
- Switches (rolls) easily
- Default position is up
- Low cost to fabricate/operate
- ~$10-$80 per ft^2 (electrochromic glass is $100+ per ft^2)
- High voltage, low current system

Accommodates:

- Solar tracking
- Glare/Daylighing control
- Design variability
- Occupant interaction
- Much more...

Dynamic Glazing Systems Example 4 Continued

EDDS visualization

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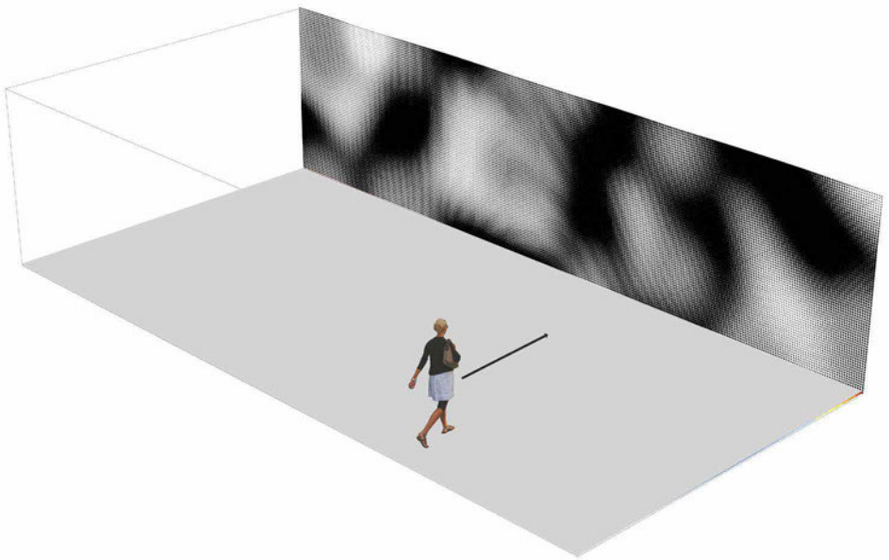
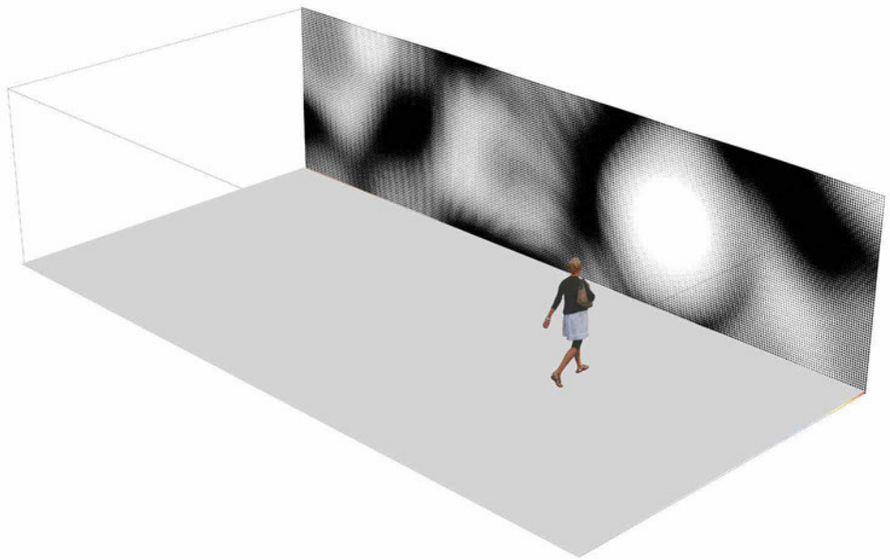
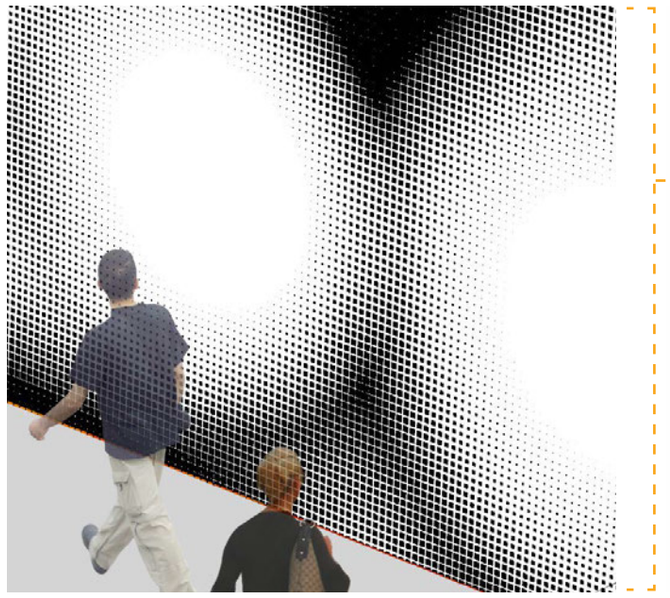
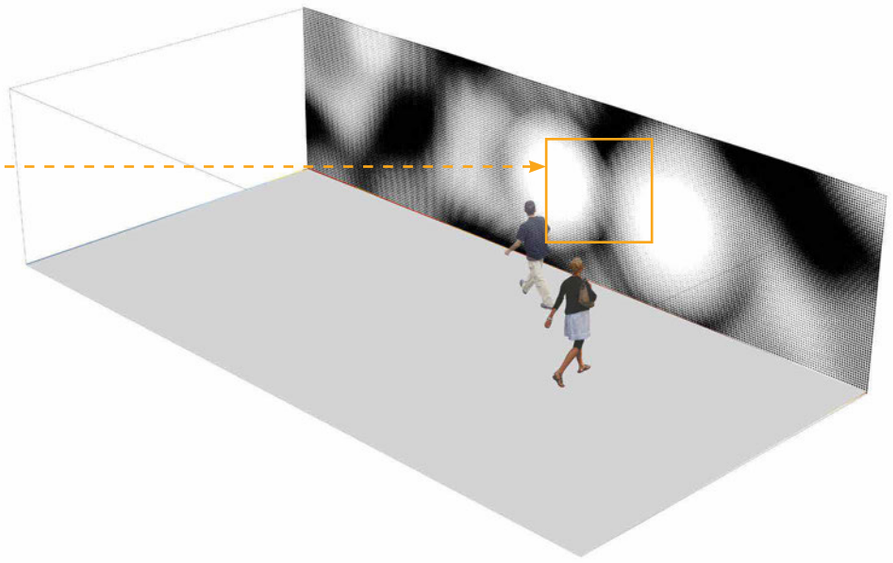
Dynamic Glazing Systems Example 4 Continued

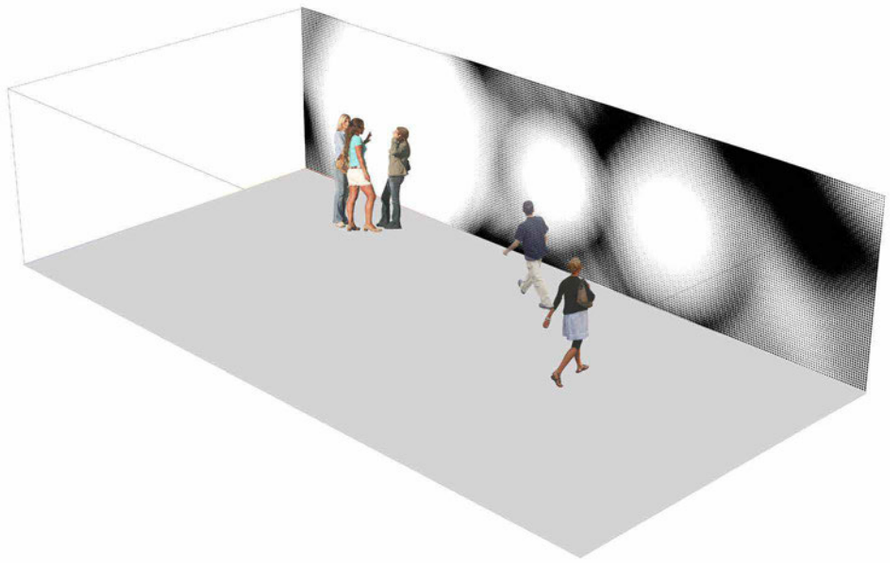
Occupant Viewing & Privacy Screens











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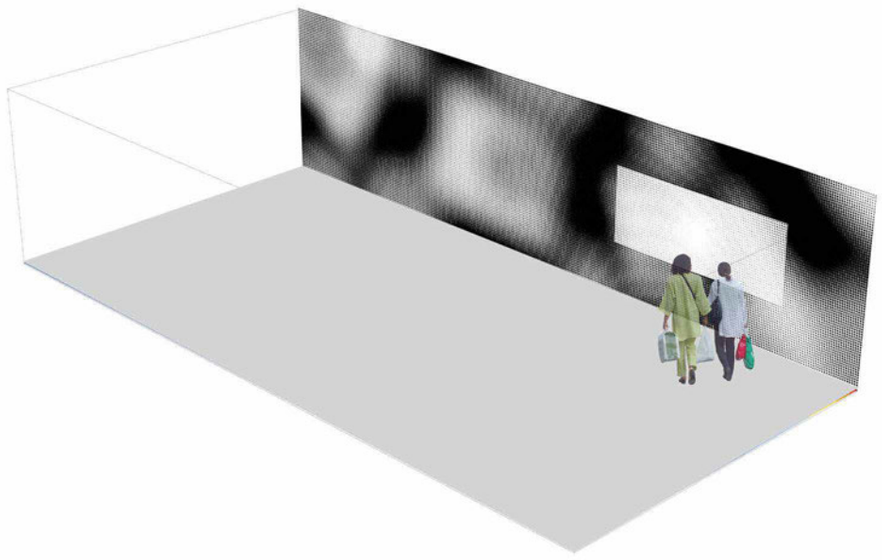

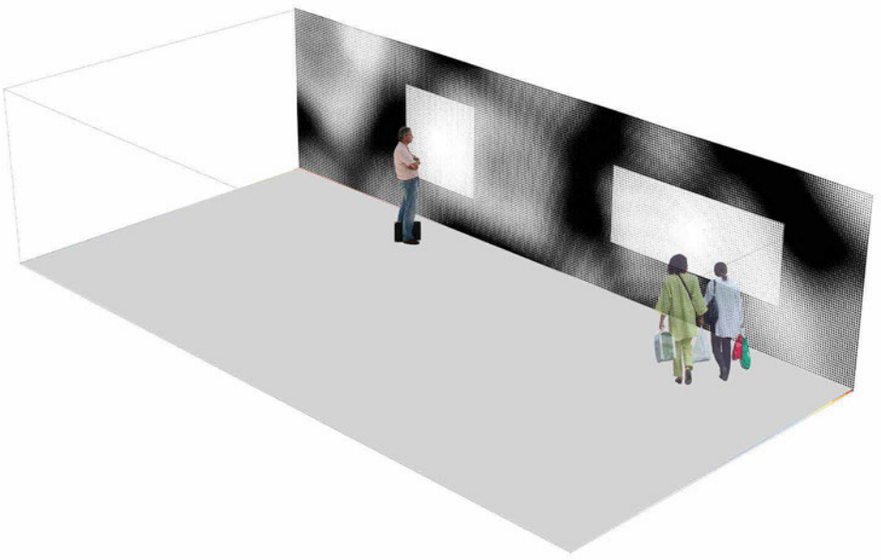

Dynamic Glazing Systems Example 4 Continued

Occupant Interaction

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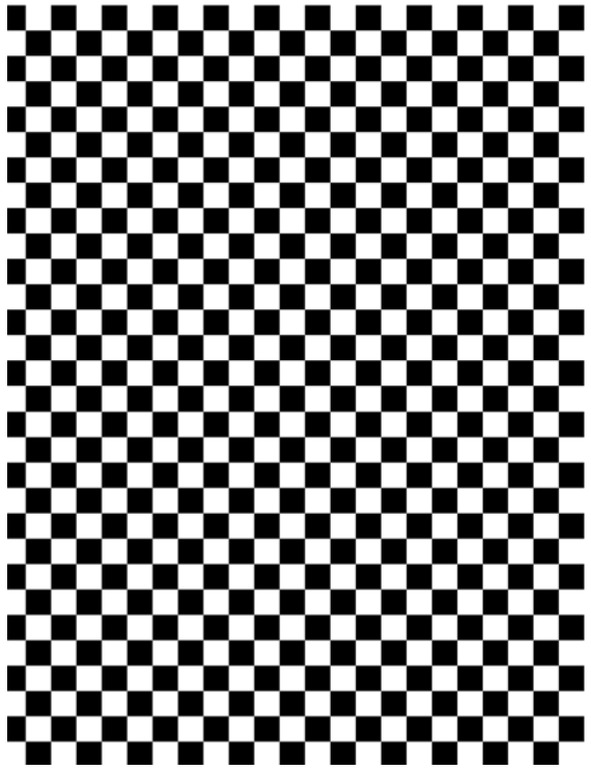
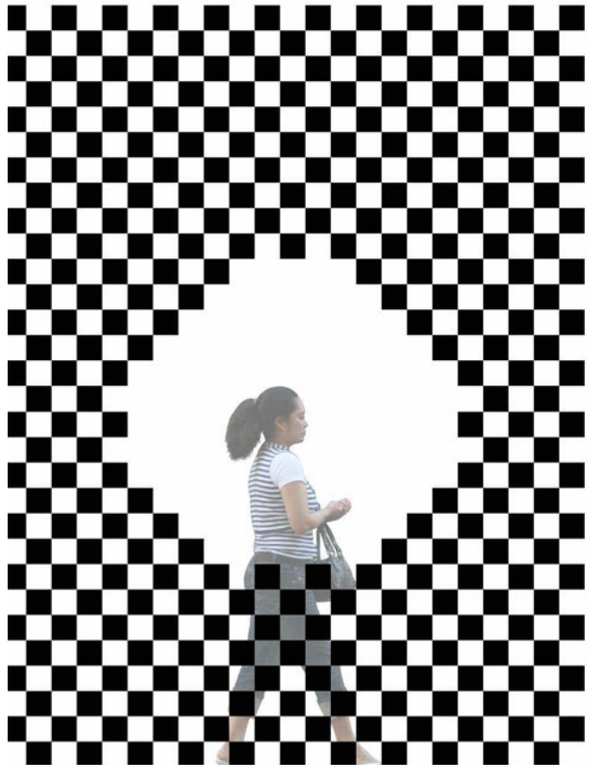
Dynamic Glazing Systems Example 4 Continued

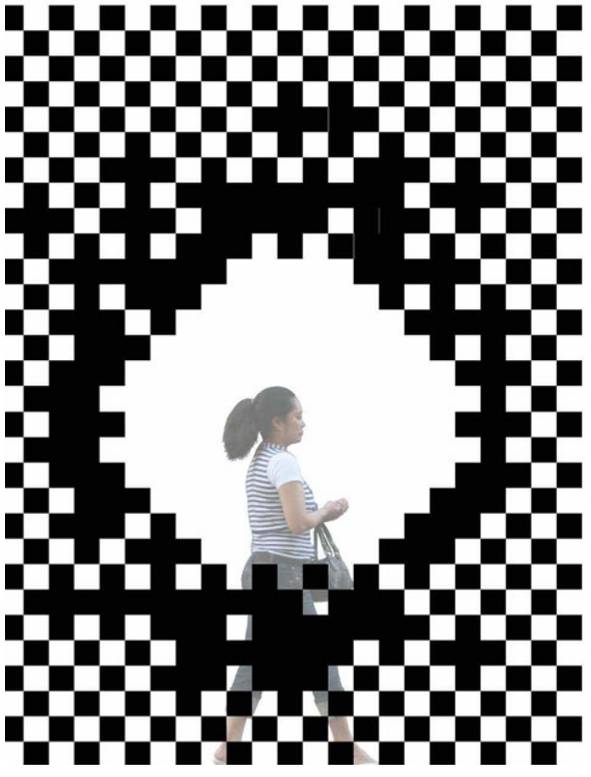
System Compensation



EDDS default state

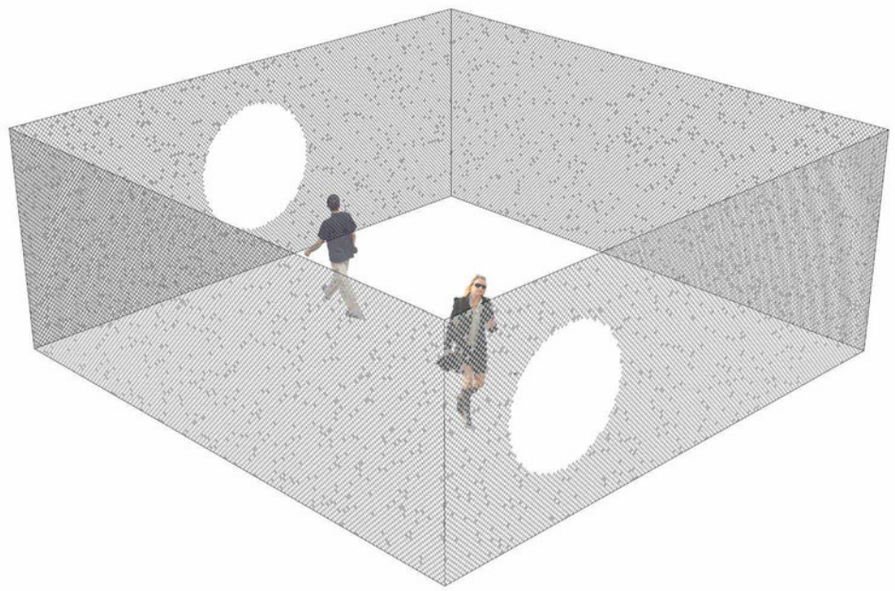


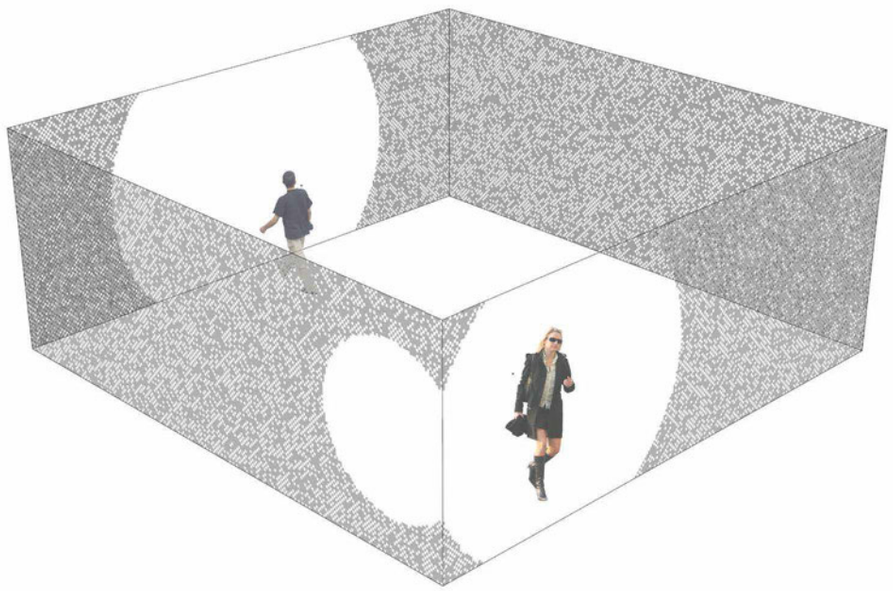
EDDS responding to an occupant



EDDS compensating for the previous response

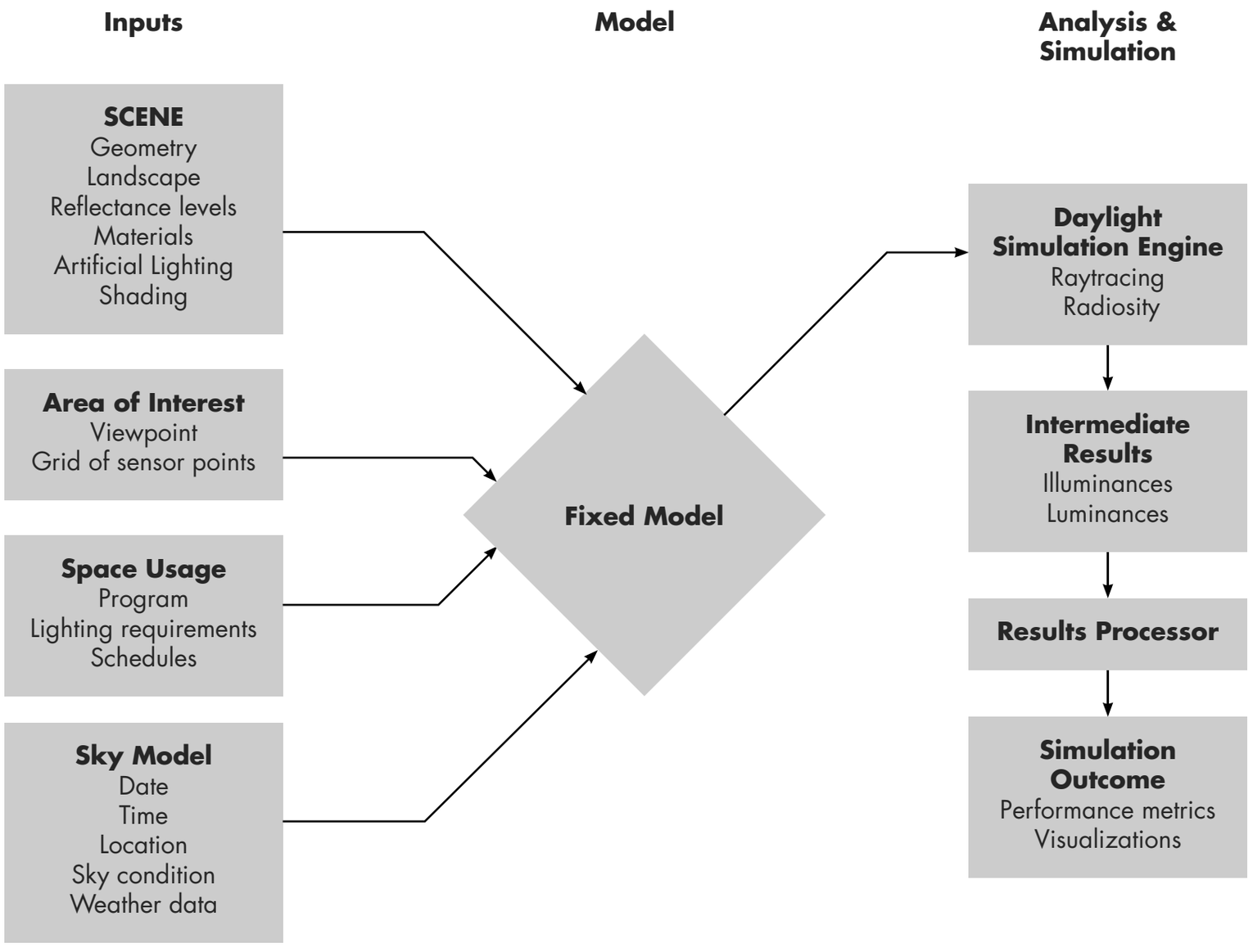
- Introduction
- Dynamic Facade Systems
  - EDDS
- Analysis Inputs
- The Method
- Software Used
- The Building Testbed
- Single Zone Analysis
- Multiple Zone Analysis
- Building Visualizations
- Conclusions





The Traditional Building Analysis

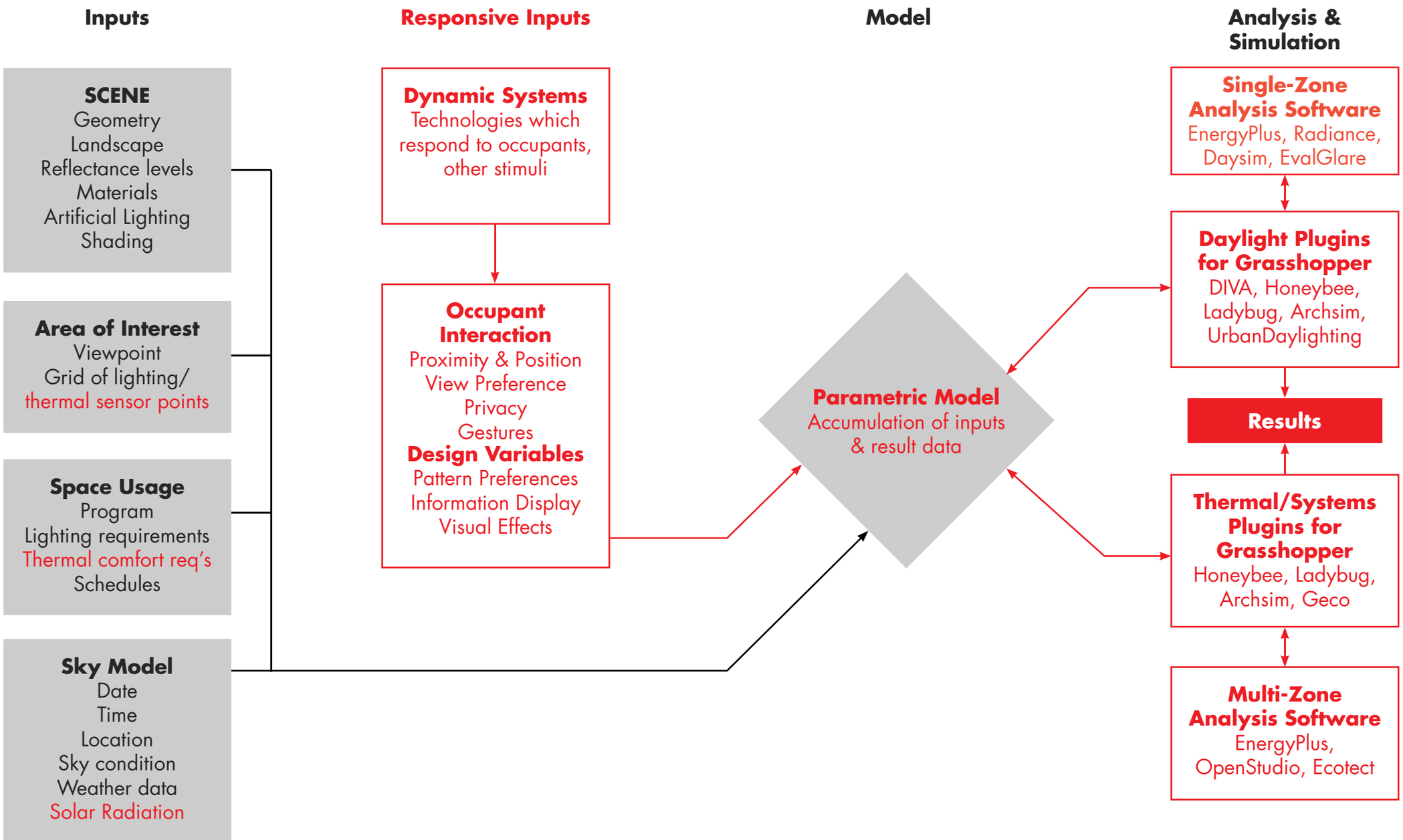
C. Reinhart's Daylighting Analysis Example



- Introduction
- Dynamic Facade Systems
- Traditional Analysis
  - Current Method Used
- The Method
- Software Used
- The Building Testbed
- Single Zone Analysis
- Multiple Zone Analysis
- Building Visualizations
- Conclusions

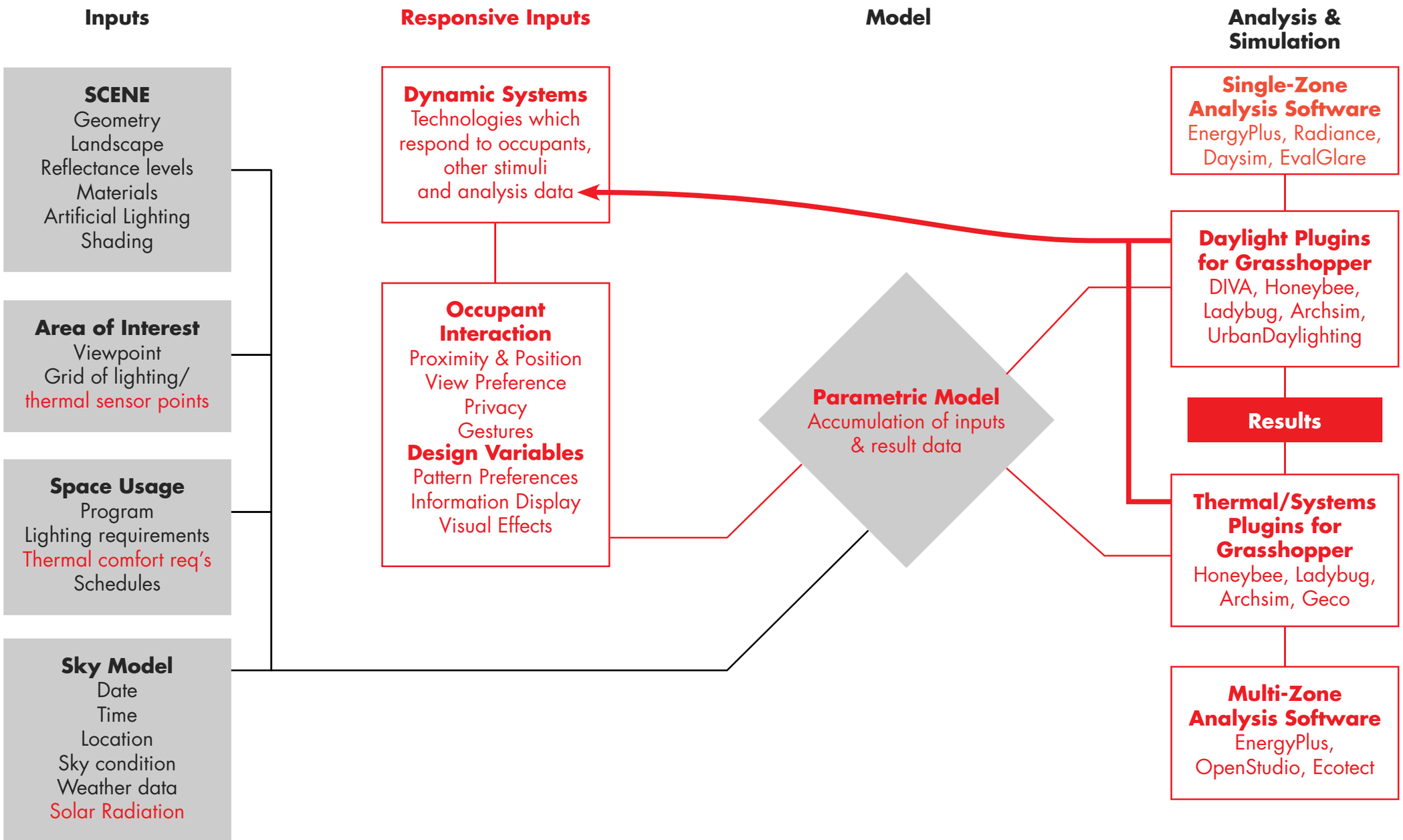
The Method for Complex Building System Analysis

Amending the Traditional Model



The Method for Complex Building System Analysis

The Feedback Loop

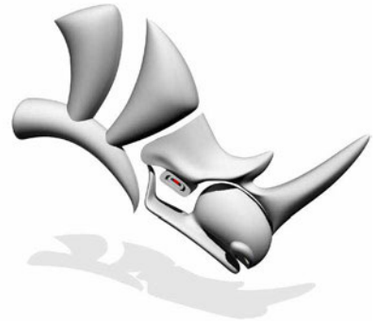


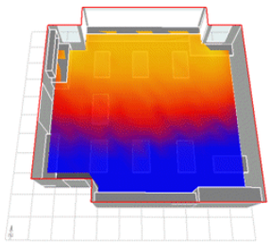
Software Tools

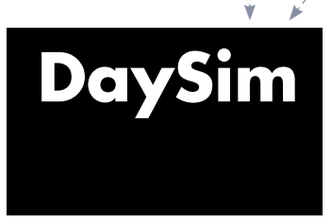
All programs that can be linked into this method

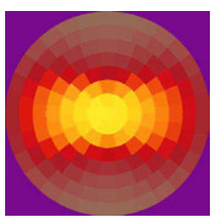
3D Modeling Platform:
Rhinoceros
Parametric Modeling Platform:
Grasshopper
Analysis Plugins:
Honeybee
Ladybug
DIVA
ArchSim
UrbanDaylighting
Geco
Analysis Software:
EnergyPlus
OpenStudio
Radiance
DaySim
EvalGlare
EcoTect

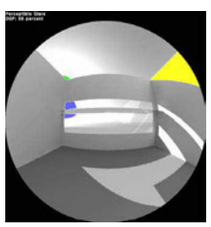
- Introduction
- Dynamic Facade Systems
- Analysis Inputs
- The Method
- Software Used
  - Linkages
- The Building Testbed
- Single Zone Analysis
- Multiple Zone Analysis
- Building Visualizations
- Conclusions

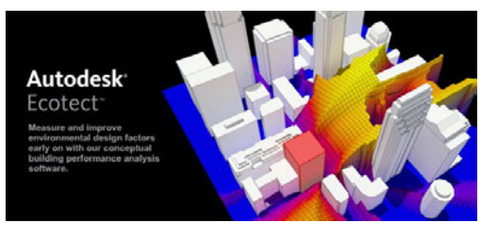






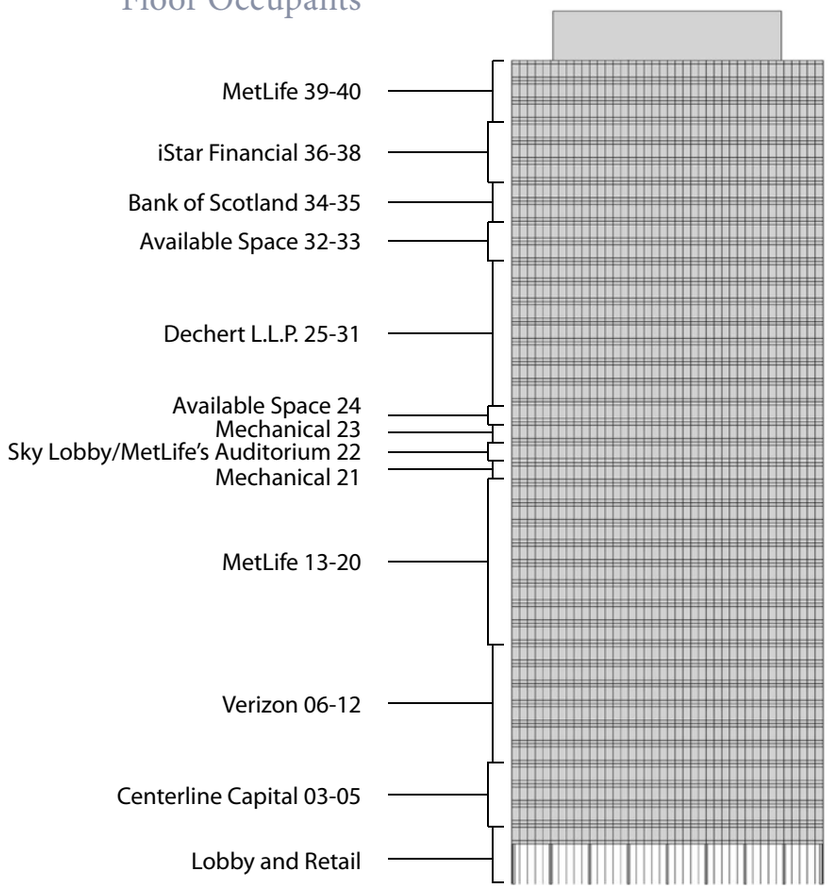






The Building

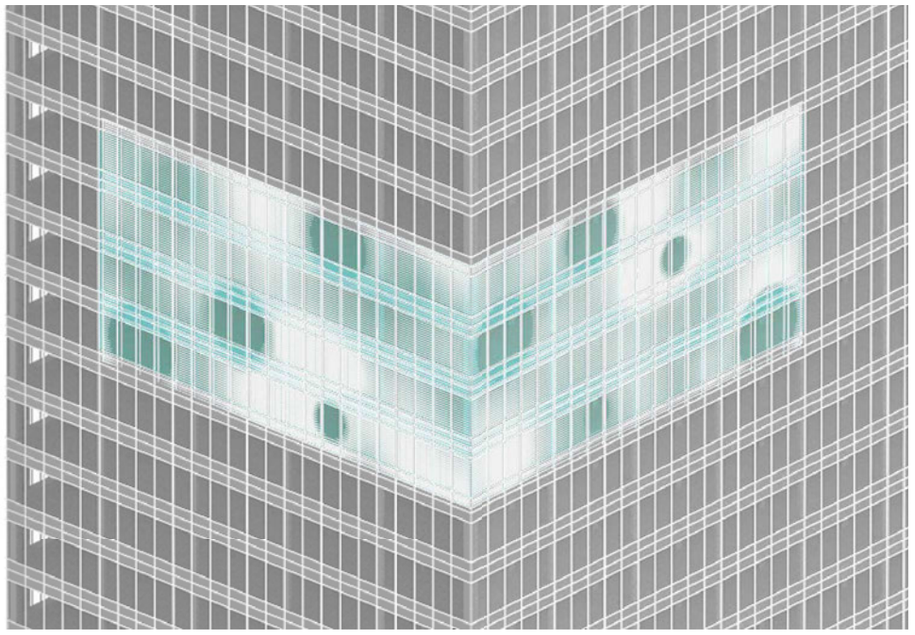
1095 Ave. of the Americas



- Introduction
- Dynamic Facade Systems
- Analysis Inputs
- The Method
- Software Used
- The Building Testbed
  - Why the tower?
- Single Zone Analysis
- Multiple Zone Analysis
- Building Visualizations
- Conclusions

Part 2:
Building Analyses

1: Single Zone Scale



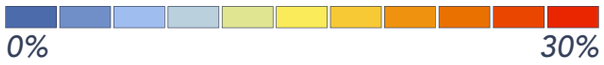
2: Multiple Zone Scale

Single-Zone Analysis

Single-Zone Analysis Intro

Daylighting Analysis Animation

Daylighting Infiltration %

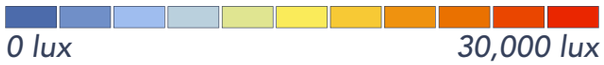


- Introduction
- Dynamic Facade Systems
- Analysis Inputs
- The Method
- Software Used
- The Building Testbed
- Single Zone Analysis
  - Intro to Daylighting Analysis
- Multiple Zone Analysis
- Building Visualizations
- Conclusions

Single-Zone Analysis Intro

Daylighting Analysis Animation

Illuminance

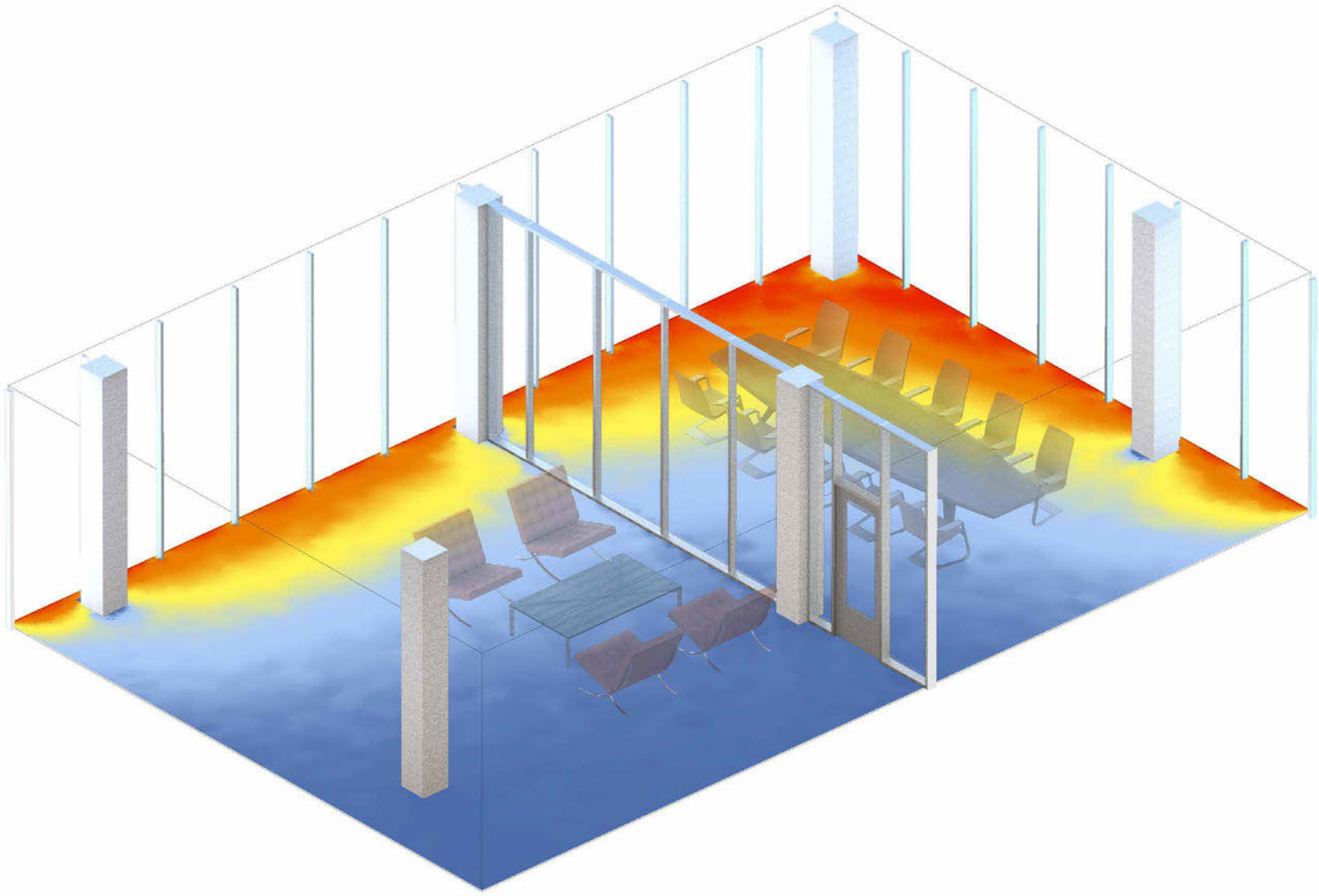


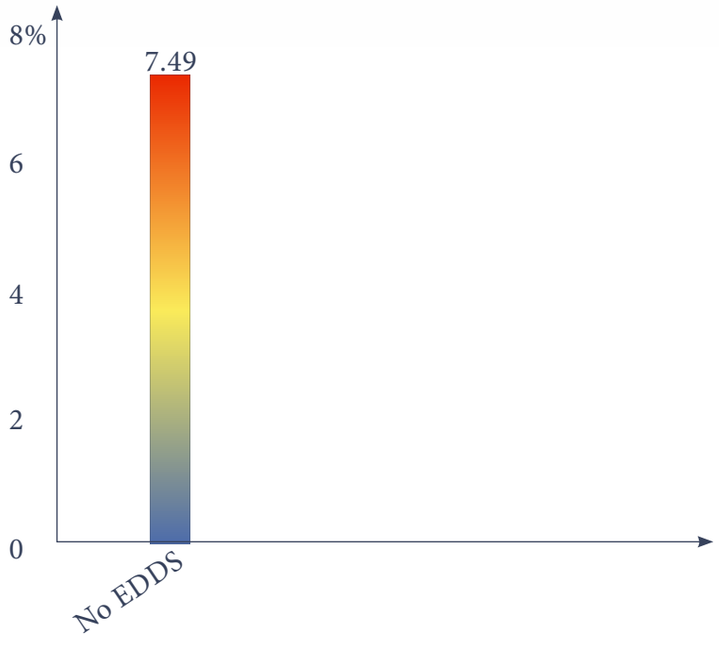
- Introduction
- Dynamic Facade Systems
- Analysis Inputs
- The Method
- Software Used
- The Building Testbed
- Single Zone Analysis
  - Intro to Daylighting Analysis
- Multiple Zone Analysis
- Building Visualizations
- Conclusions

Single-Zone Analysis #1

1 zone daylighting analysis
NO EDDS

Average Daylighting = 7.49%





Daylighting Infiltration %

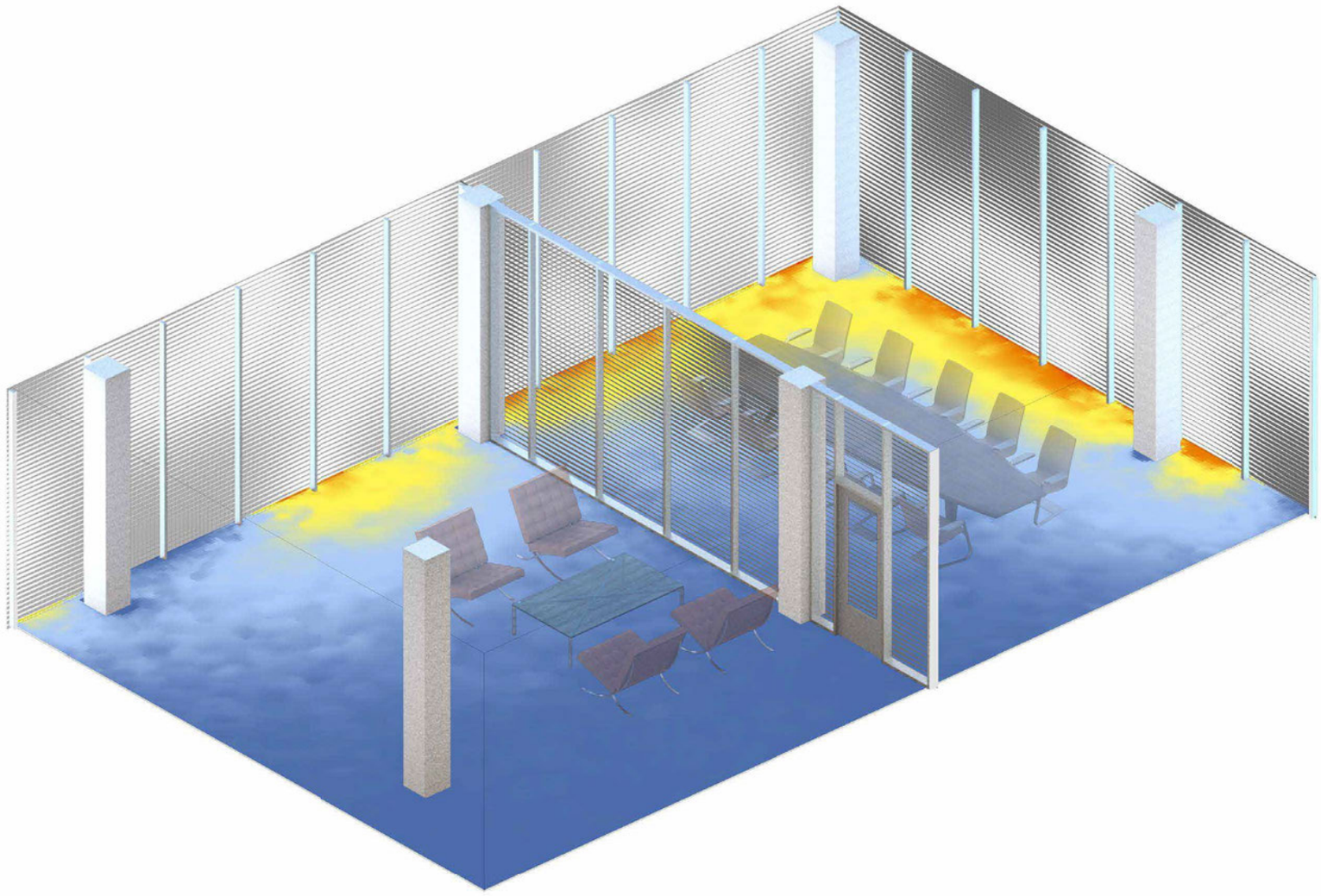
0% 30%

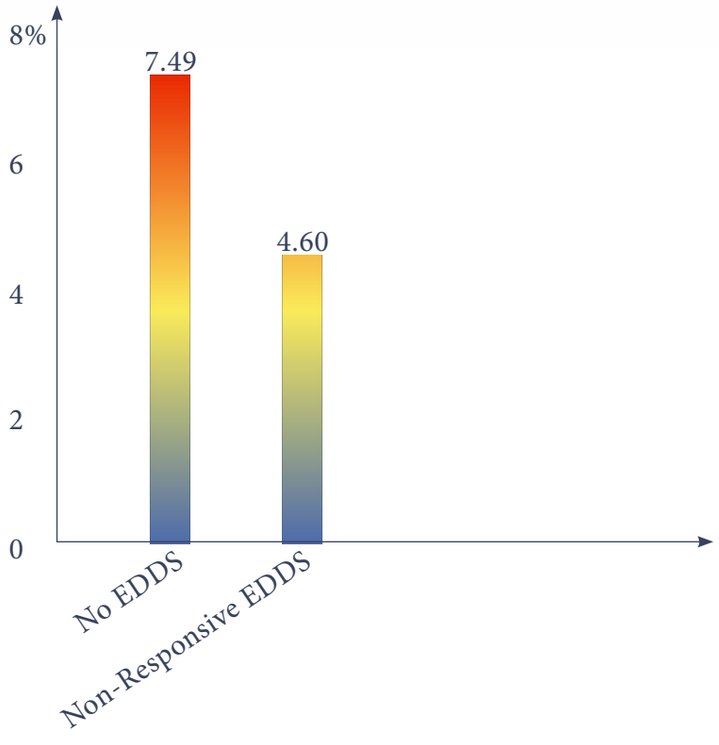
- Introduction
- Dynamic Facade Systems
- Analysis Inputs
- The Method
- Software Used
- The Building Testbed
- Single Zone Analysis
  - No EDDS
- Multiple Zone Analysis
- Building Visualizations
- Conclusions

Single-Zone Analysis #2

1 zone daylighting analysis
NON-RESPONSIVE EDDS

Average Daylighting = 4.60%



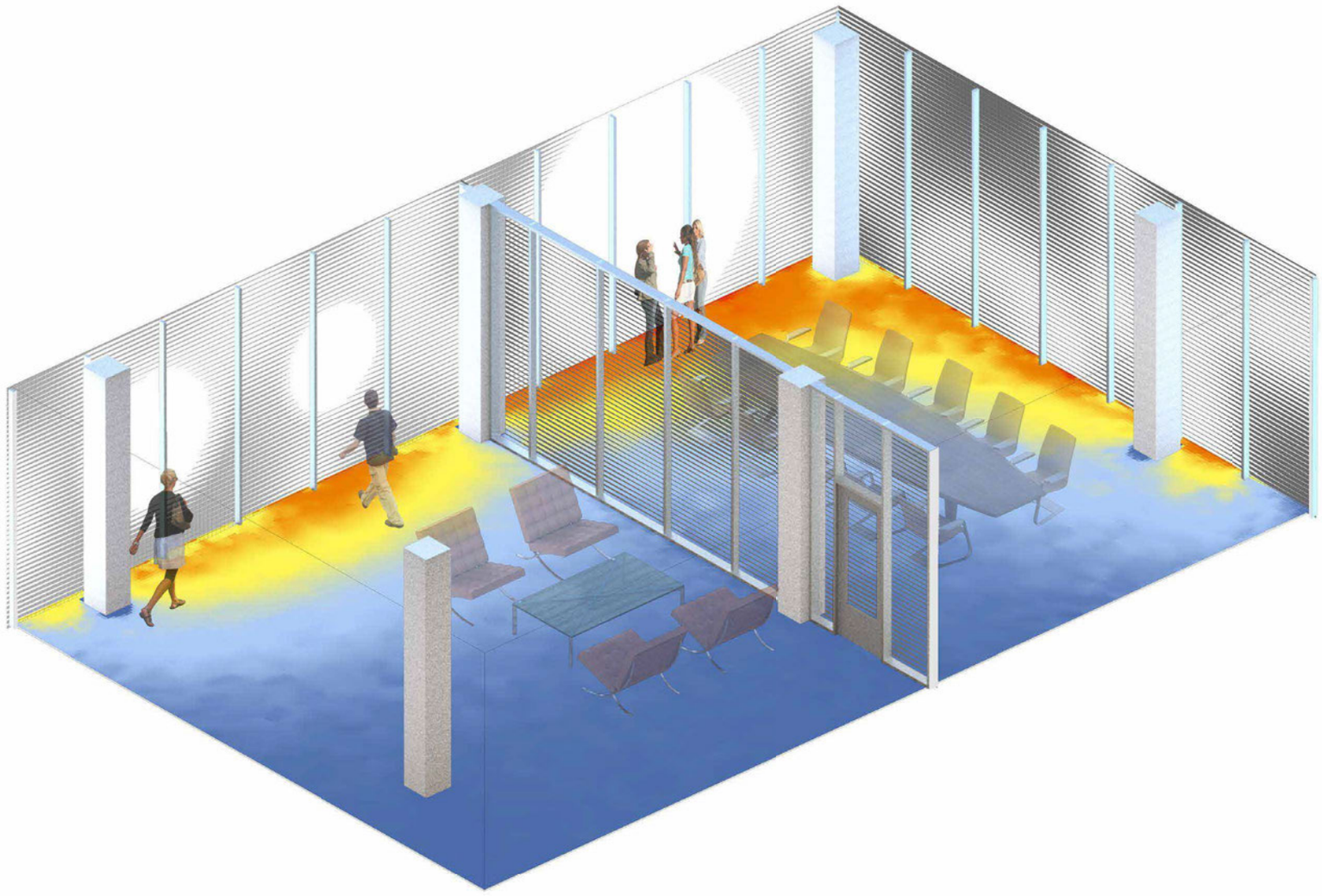


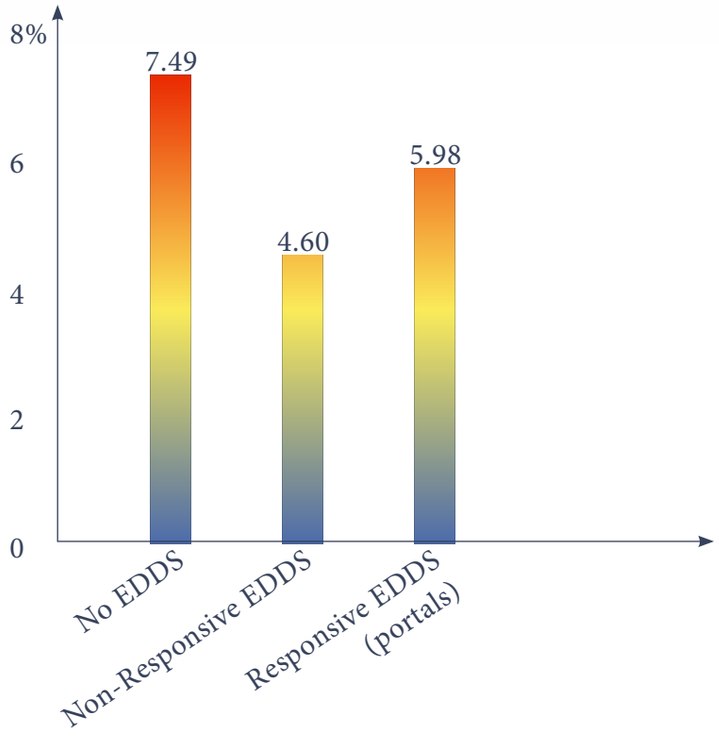
- Introduction
- Dynamic Facade Systems
- Analysis Inputs
- The Method
- Software Used
- The Building Testbed
- Single Zone Analysis
  - Non-Responsive EDDS
- Multiple Zone Analysis
- Building Visualizations
- Conclusions

Single-Zone Analysis #3

1 zone daylighting analysis
RESPONSIVE EDDS

Average Daylighting = 5.98%





Daylighting Infiltration %

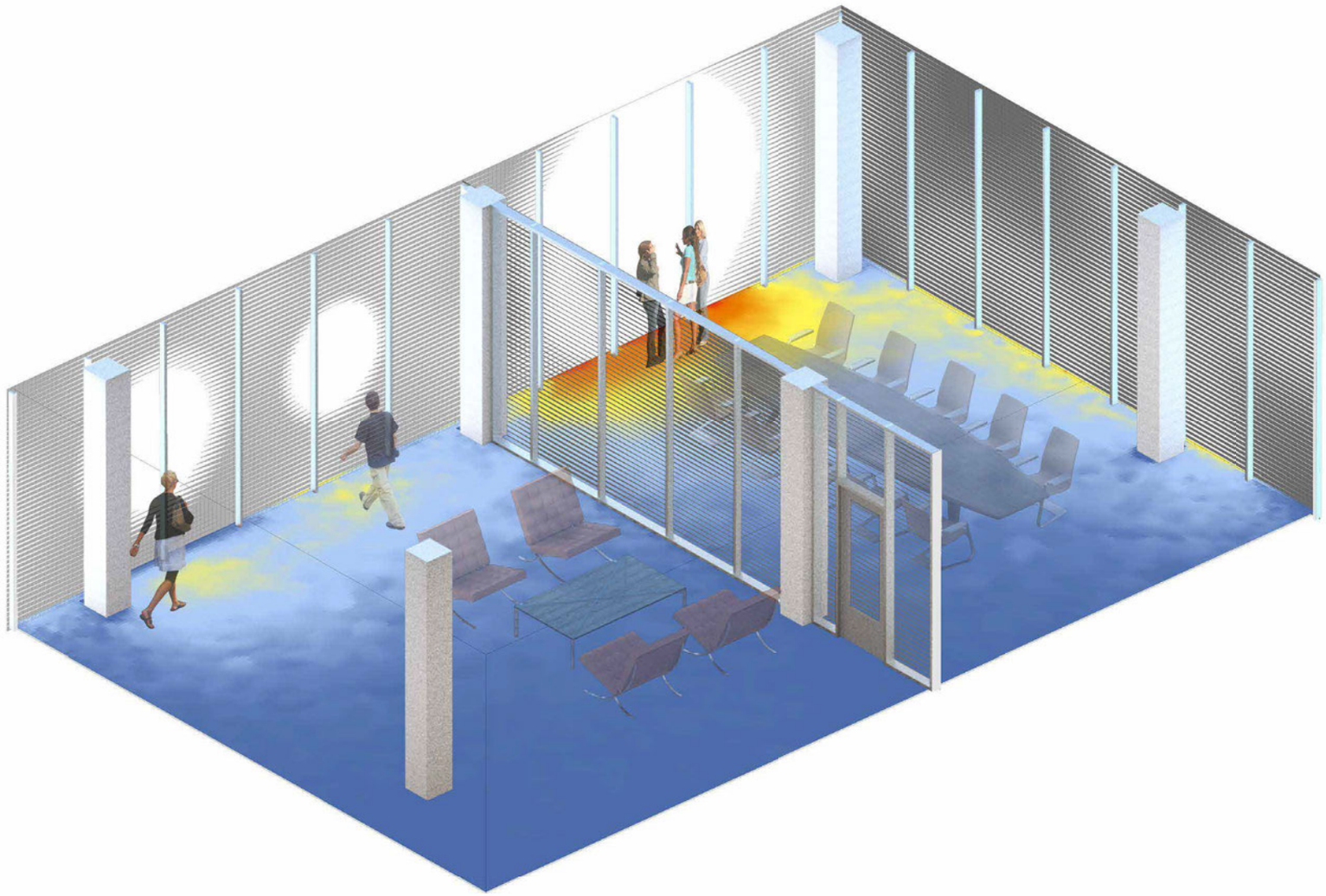
0% 30%

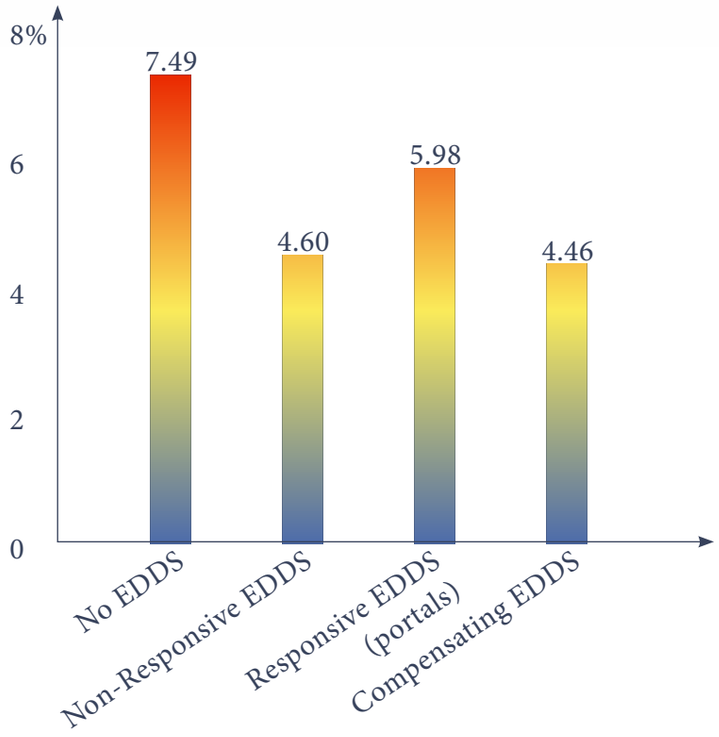
- Introduction
- Dynamic Facade Systems
- Analysis Inputs
- The Method
- Software Used
- The Building Testbed
- Single Zone Analysis
  - Responsive EDDS
- Multiple Zone Analysis
- Building Visualizations
- Conclusions

Single-Zone Analysis #4

1 zone daylighting analysis
COMPENSATING EDDS

Average Daylighting = 4.46%





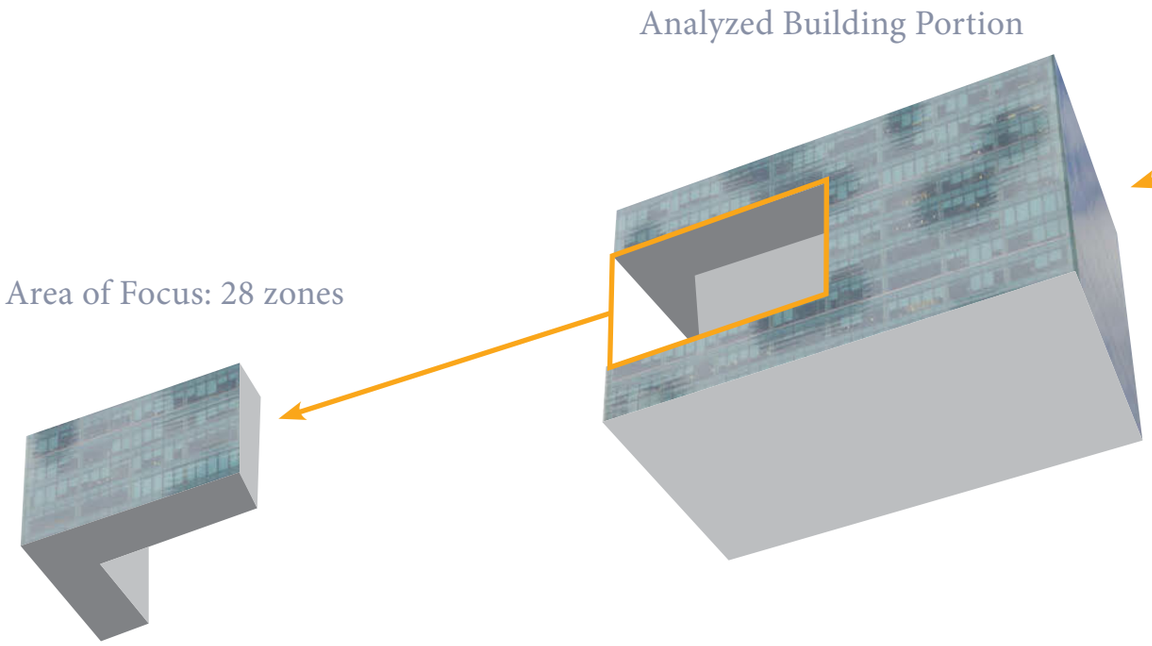
Daylighting Infiltration %

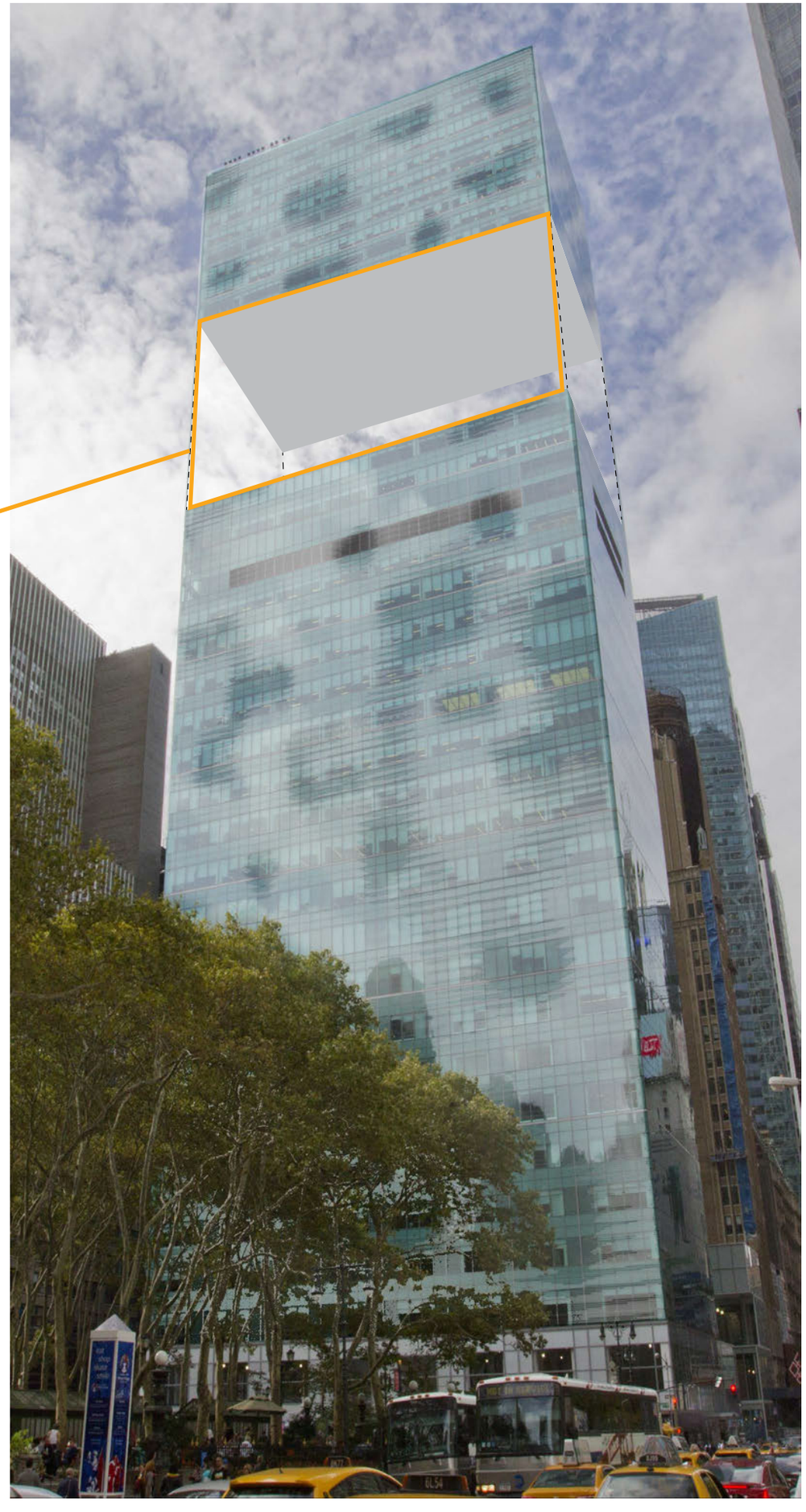
0% 30%

- Introduction
- Dynamic Facade Systems
- Analysis Inputs
- The Method
- Software Used
- The Building Testbed
- Single Zone Analysis
  Compensating EDDS
- Multiple Zone Analysis
- Building Visualizations
- Conclusions

Multi-Zone Analysis Intro

Scale of Analysis



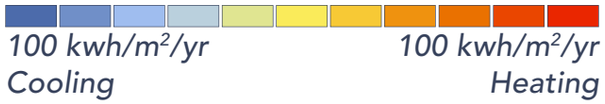


- Introduction
- Dynamic Facade Systems
- Analysis Inputs
- The Method
- Software Used
- The Building Testbed
- Single Zone Analysis
- Multiple Zone Analysis
  - Intro
- Building Visualizations
- Conclusions

Multi-Zone Analysis #1

28 zones analyzed with
NO EDDS

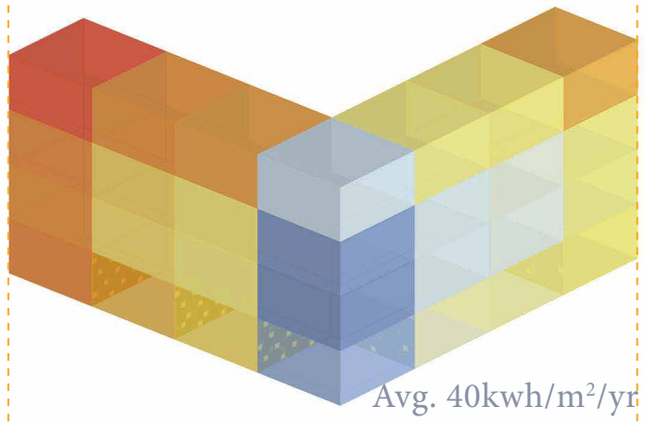
1. Thermal Energy Requirements



2. Interior Air Temperature
3. Mean Radiant Temperature
4. Radiant Heat Map

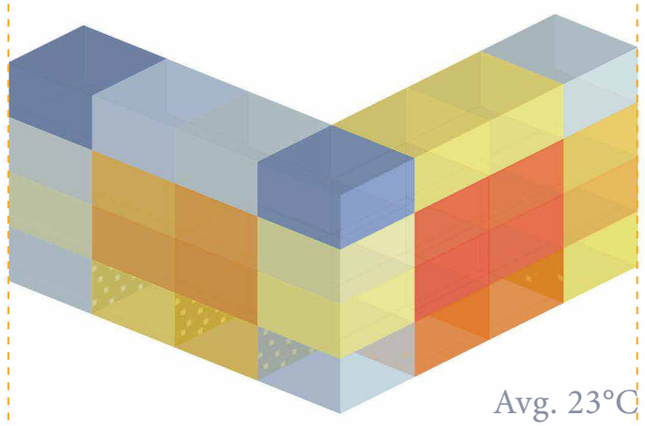
- Introduction
- Dynamic Facade Systems
- Analysis Inputs
- The Method
- Software Used
- The Building Testbed
- Single Zone Analysis
- Multiple Zone Analysis
  - No EDDS
- Building Visualizations
- Conclusions

1.



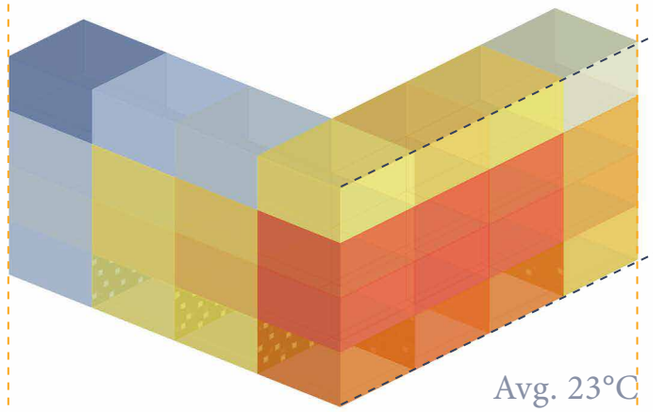
Avg. 40kwh/m²/yr

2.



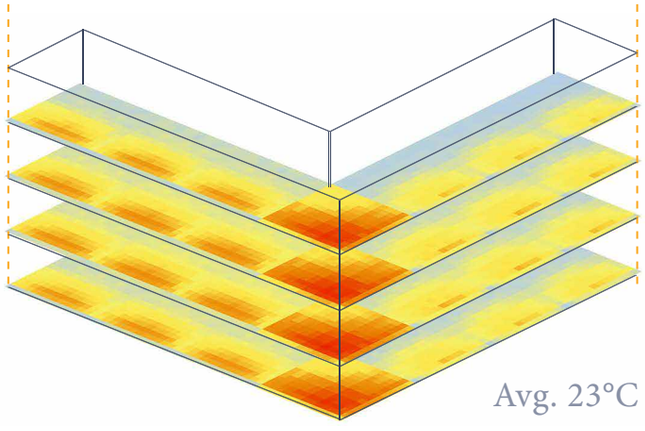
Avg. 23°C

3.

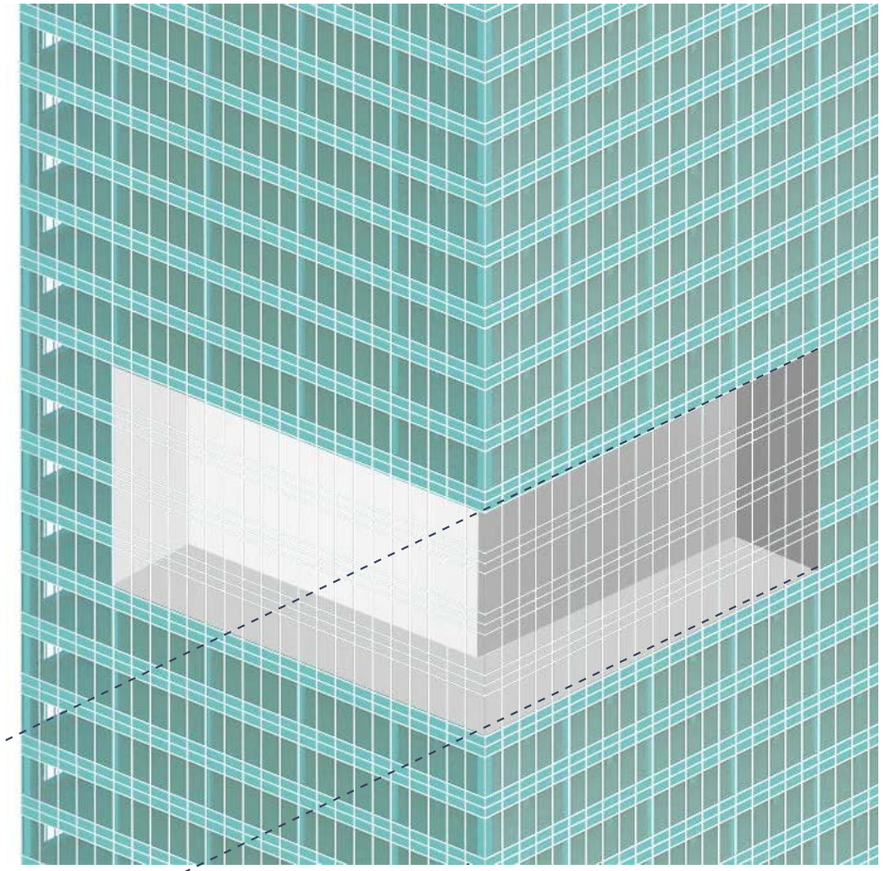


Avg. 23°C

4.

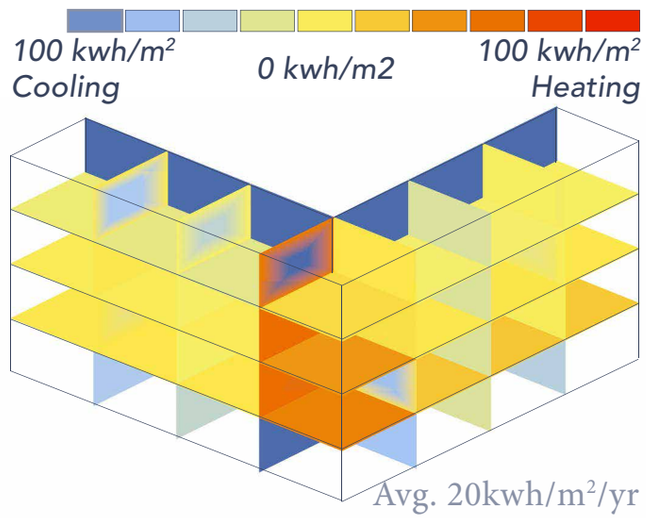


Avg. 23°C



Zonal Energy Flux:

Mapping thermal energy passing
through interior walls between spaces



Avg. 20kwh/m²/yr

Multi-Zone Analysis #3

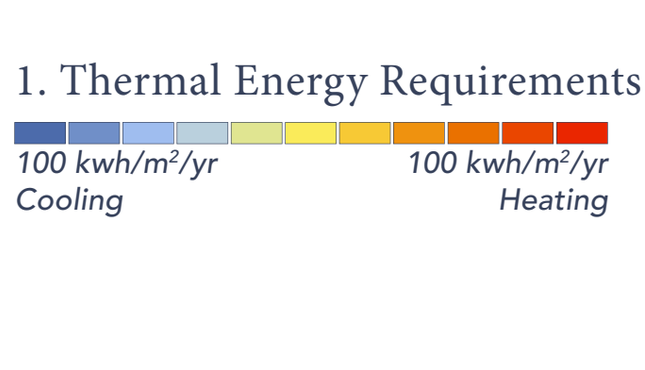
28 zones analyzed with NON-RESPONSIVE EDDS

1. Thermal Energy Requirements

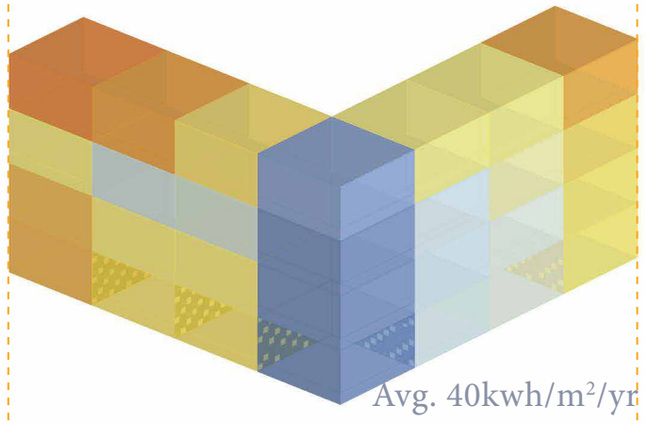
100 kwh/m²/yr Cooling — *100 kwh/m²/yr Heating*

2. Interior Air Temperature
3. Mean Radiant Temperature
4. Radiant Heat Map

18°C — *24°C*

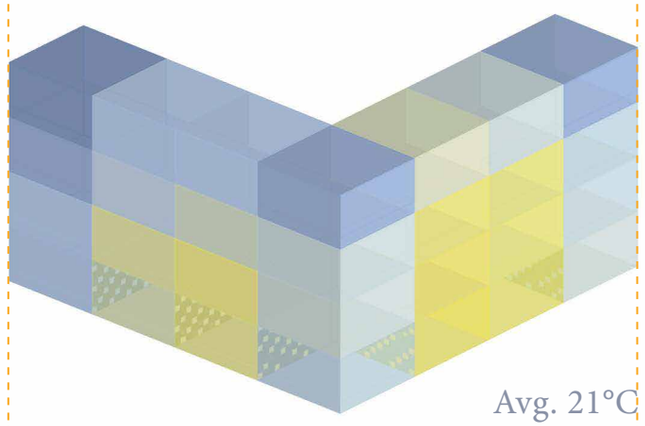


1.



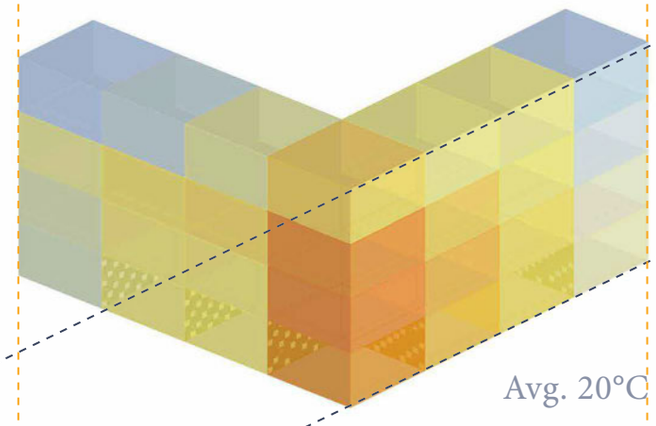
Avg. 40kwh/m²/yr

2.



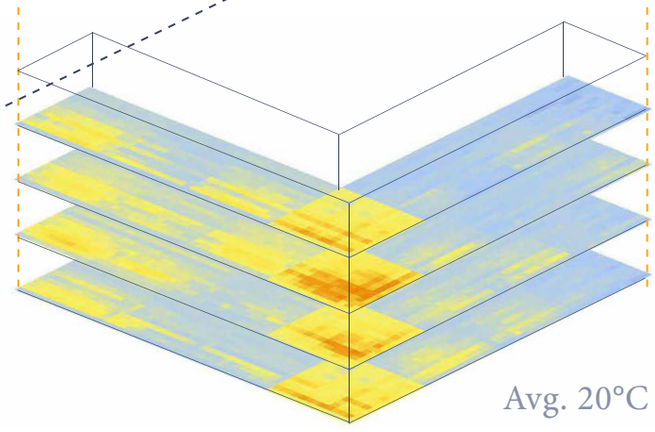
Avg. 21°C

3.

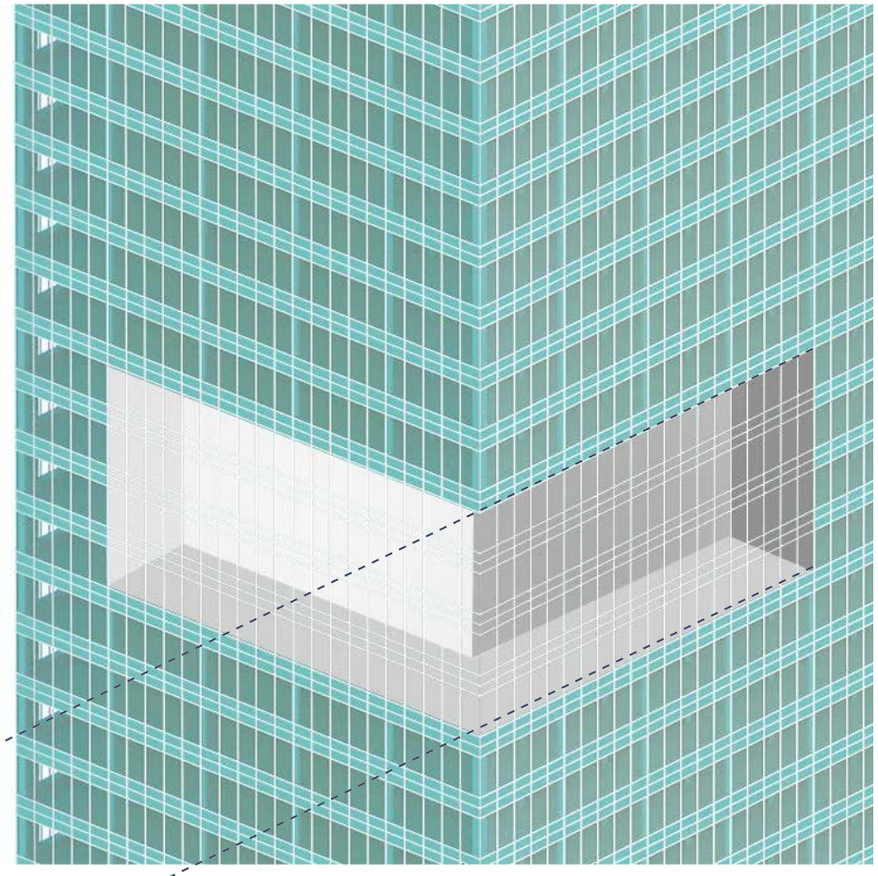


Avg. 20°C

4.



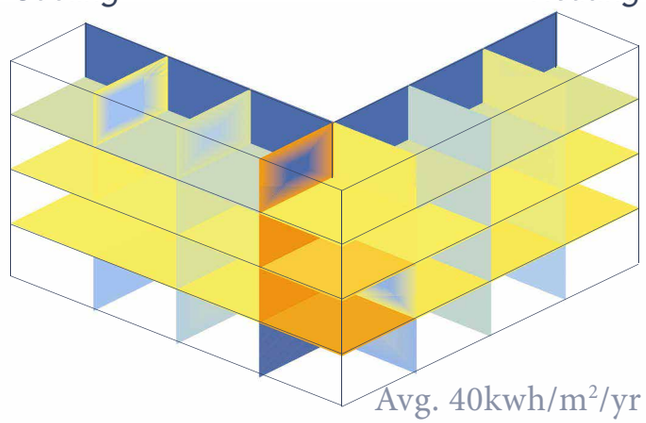
Avg. 20°C



Zonal Energy Flux:

Mapping thermal energy passing through interior walls between spaces

100 kwh/m² Cooling — *0 kwh/m2* — *100 kwh/m² Heating*



Avg. 40kwh/m²/yr

Multi-Zone Analysis #3

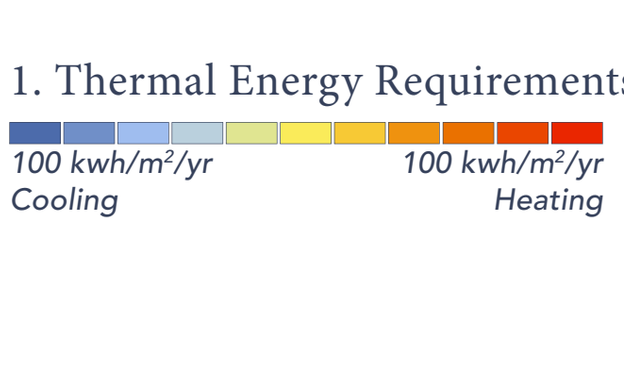
28 zones analyzed with RESPONSIVE EDDS

1. Thermal Energy Requirements

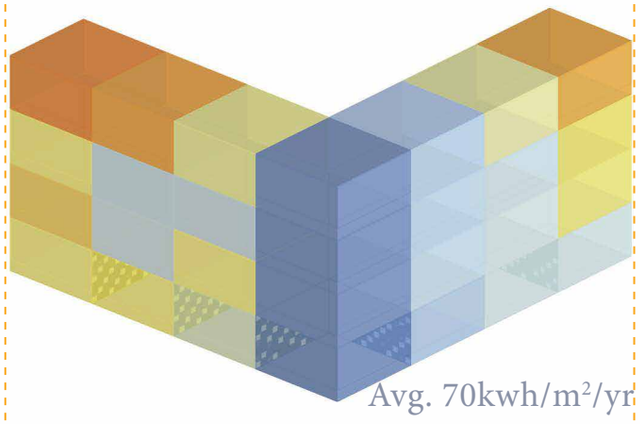
100 kwh/m²/yr Cooling — *100 kwh/m²/yr Heating*

2. Interior Air Temperature
3. Mean Radiant Temperature
4. Radiant Heat Map

18°C — *24°C*

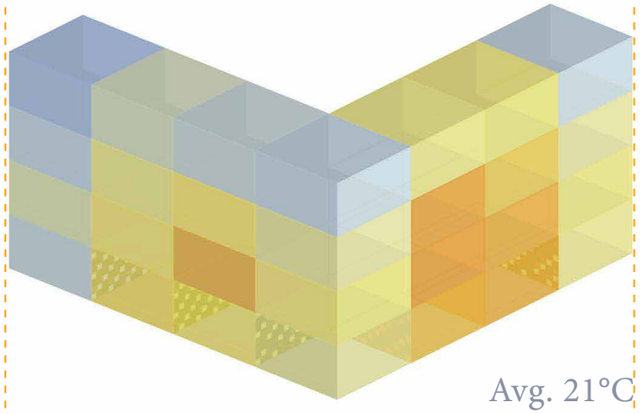


1.



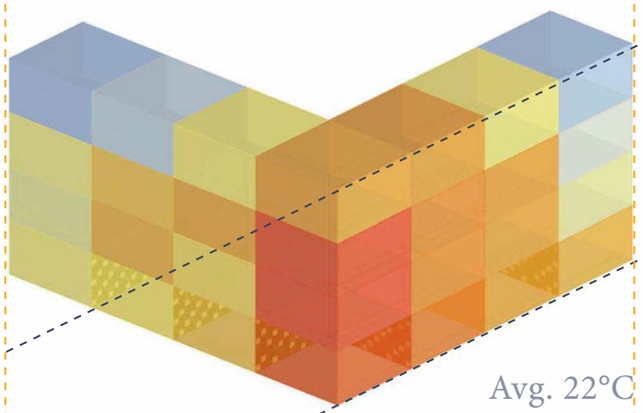
Avg. 70kwh/m²/yr

2.



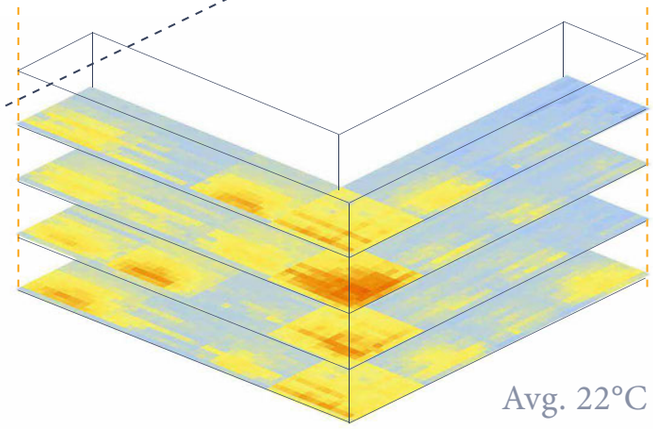
Avg. 21°C

3.

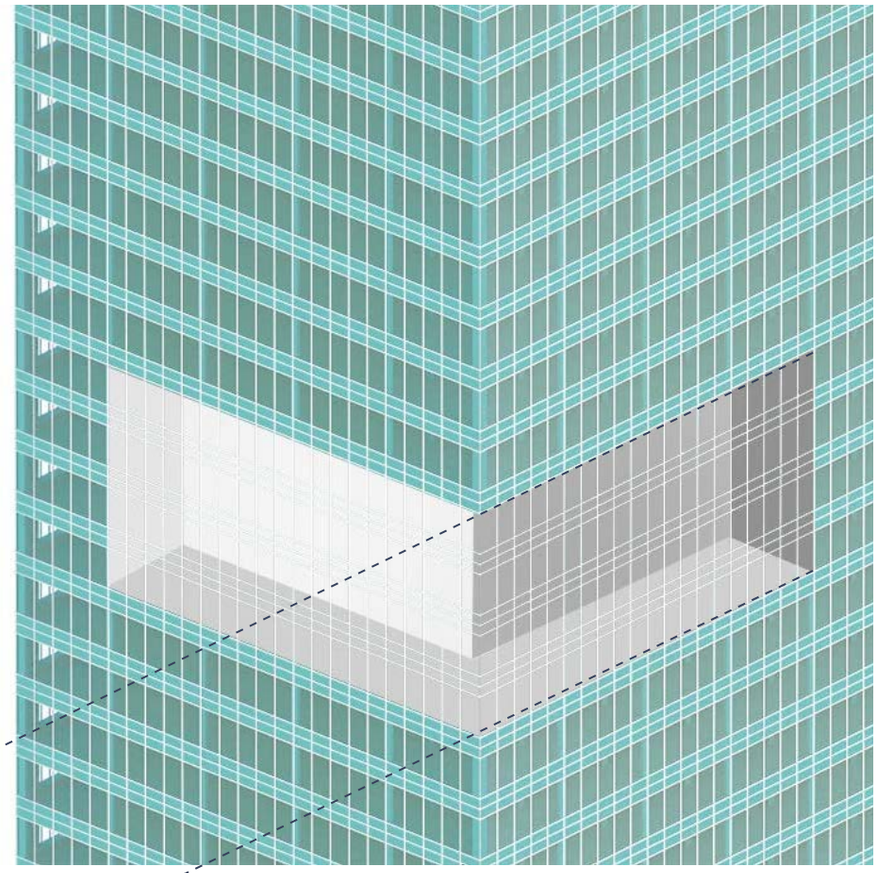


Avg. 22°C

4.



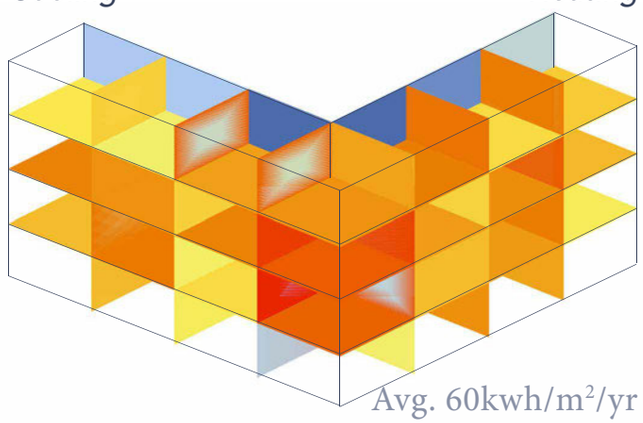
Avg. 22°C



Zonal Energy Flux:

Mapping thermal energy passing through interior walls between spaces

100 kwh/m² Cooling — *0 kwh/m2* — *100 kwh/m² Heating*



Avg. 60kwh/m²/yr

Multi-Zone Analysis #4

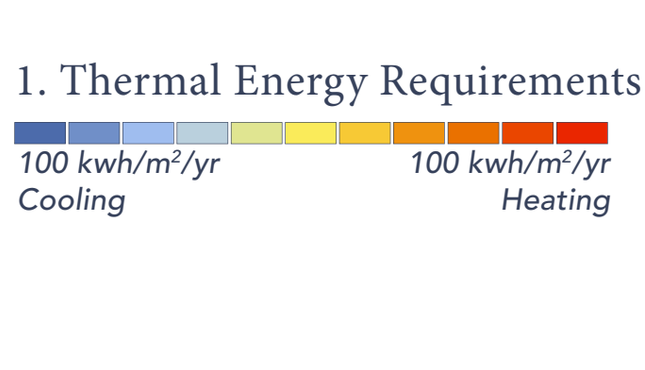
28 zones analyzed with COMPENSATING EDDS

1. Thermal Energy Requirements

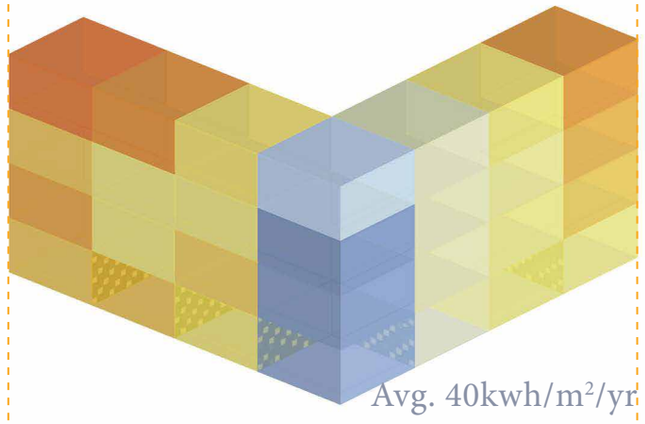
100 kwh/m²/yr Cooling — *100 kwh/m²/yr Heating*

2. Interior Air Temperature
3. Mean Radiant Temperature
4. Radiant Temperature Map

18°C — *24°C*

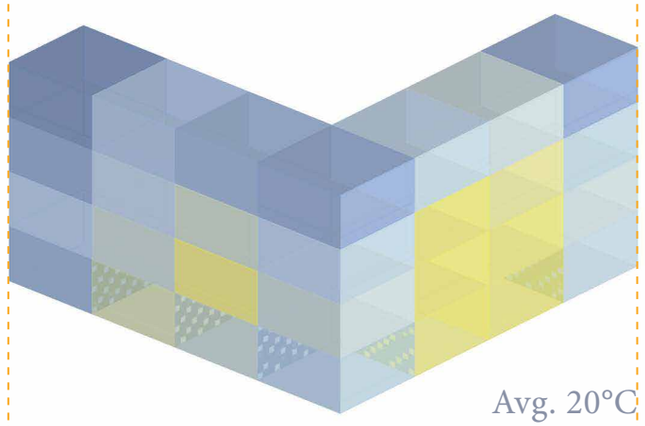


1.



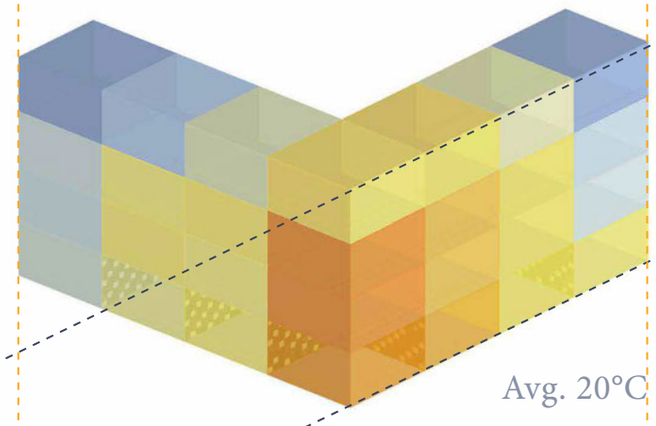
Avg. 40kwh/m²/yr

2.



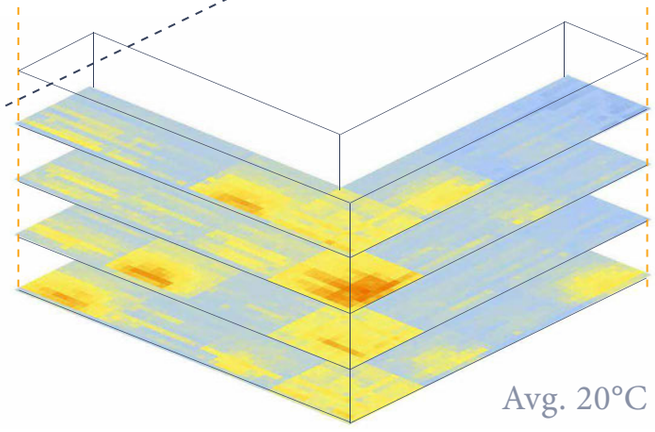
Avg. 20°C

3.

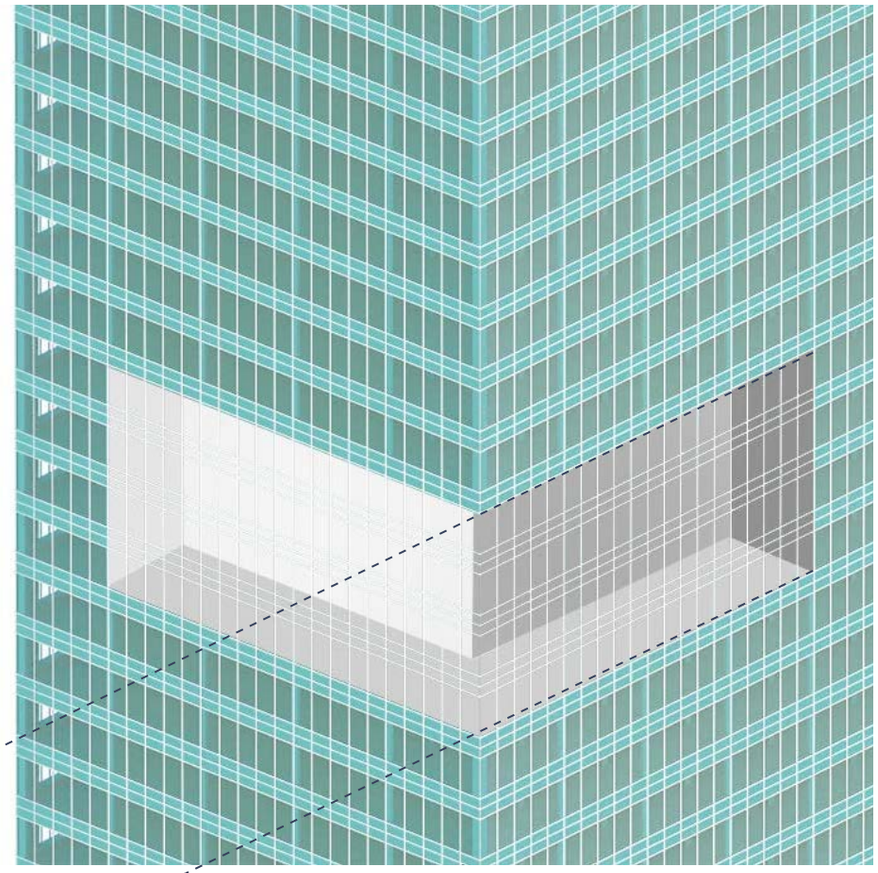


Avg. 20°C

4.



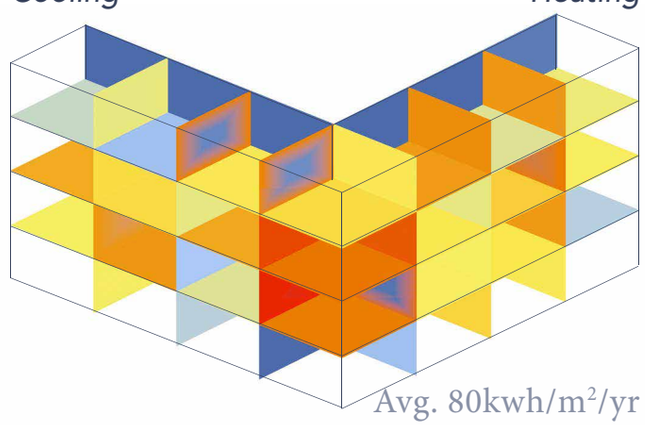
Avg. 20°C



Zonal Energy Flux:

Mapping thermal energy passing through interior walls

100 kwh/m² Cooling — *0 kwh/m2* — *100 kwh/m² Heating*



Avg. 80kwh/m²/yr

Multi-Zone Analysis

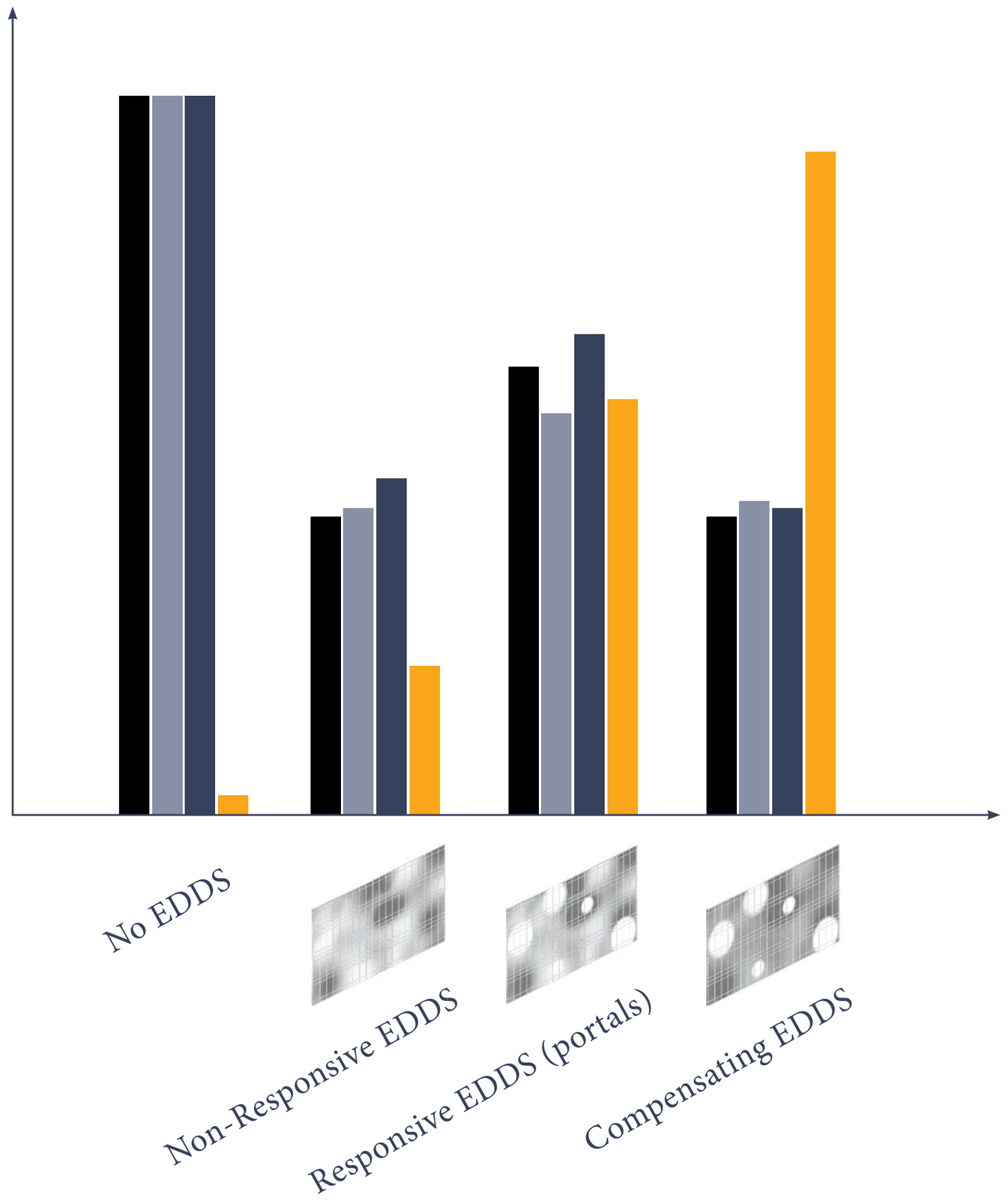
RESULTS for 28 Adjacent Zones

Avg. Thermal Energy Requirements

Avg. Interior Air Temperature

Avg. Mean Radiant Temperature

Avg. Energy Flux Between Zones



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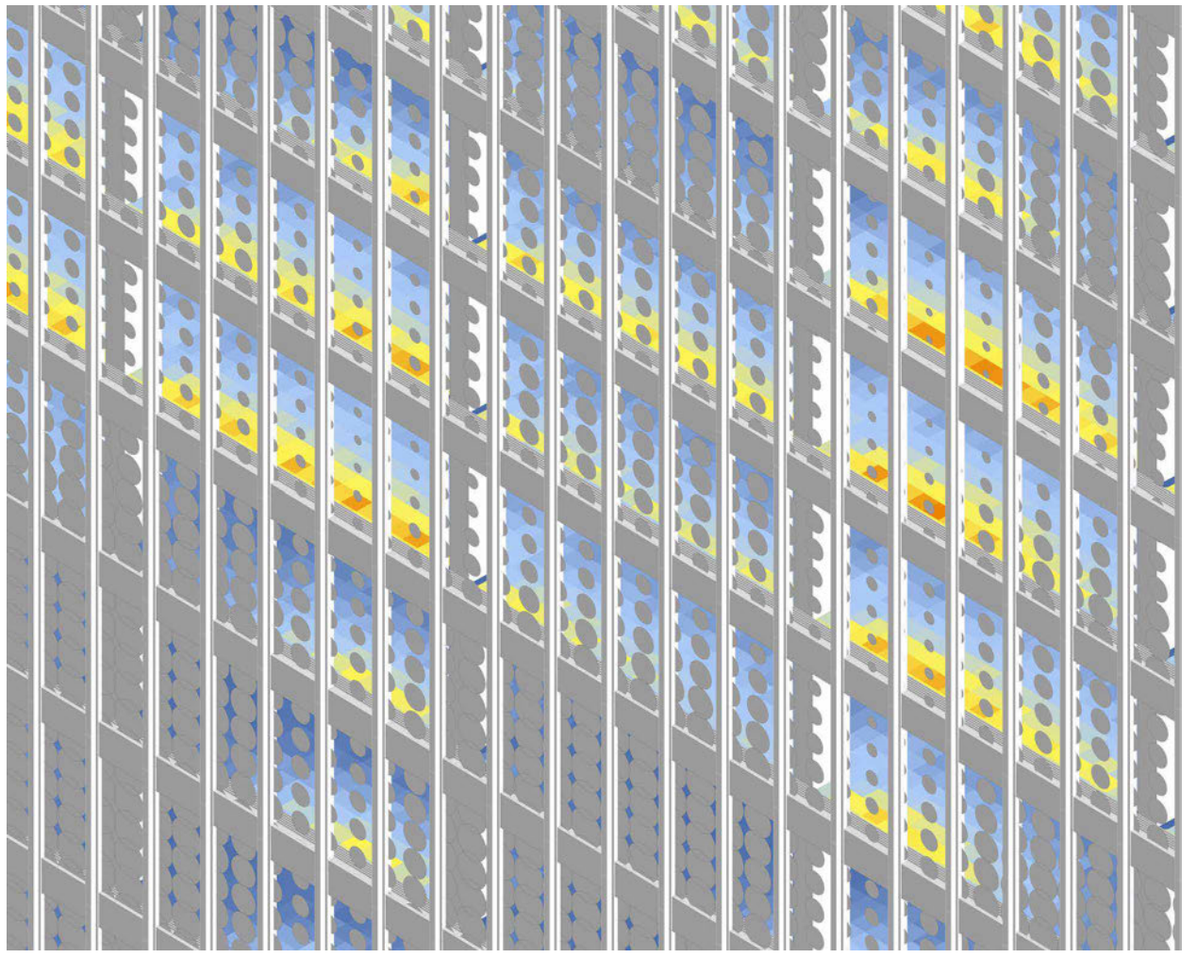
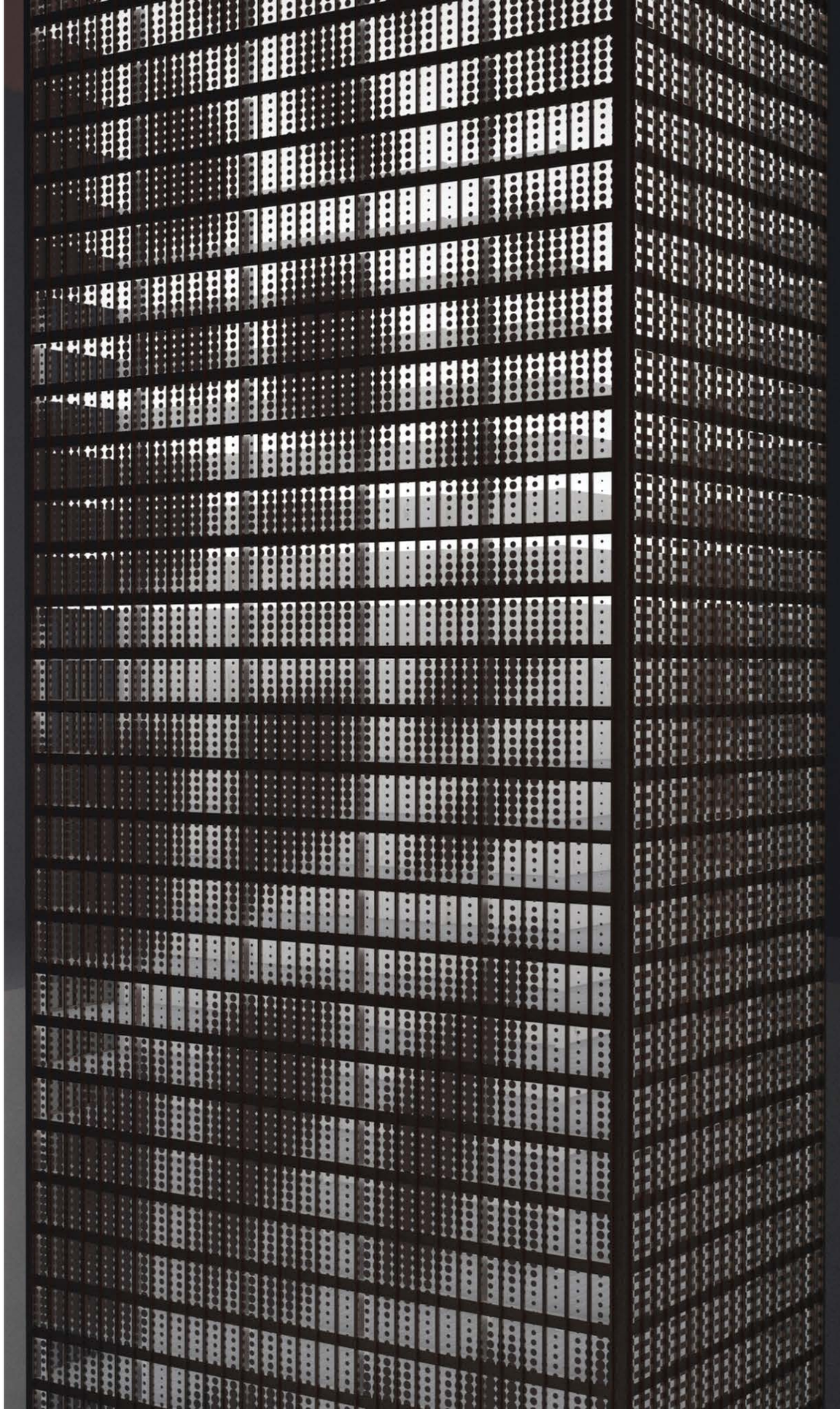
Part 3:
Building Visualizations

Building Visualizations

Seagram Concept Facade
with Daylighting Analysis





Building Visualizations

Institute of Contemporary Art

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Indianapolis Airport

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5th Ave. Apple Store

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Building Visualizations

Center of Excellence

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Conclusions

Highly responsive systems can dramatically reduce building energy consumption, improve the well-being of occupants, and explore the architectural design potential of programmable material technologies.

The methods presented provide significant opportunities for combining the design and analysis process to support the integration of next-generation dynamic façade systems.

The ability to support real-time analysis of complex building systems in the design phase reduces the risk of blind implementation that could lead to inefficiency.

It also encourages investment into multifunctional ecological building systems that promote participatory occupant engagement while offering a wide range of architectural design possibilities.

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