MEBS6020 Sustainable Building Design

http://ibse.hk/MEBS6020/

Analysis Methods and Tools (I)

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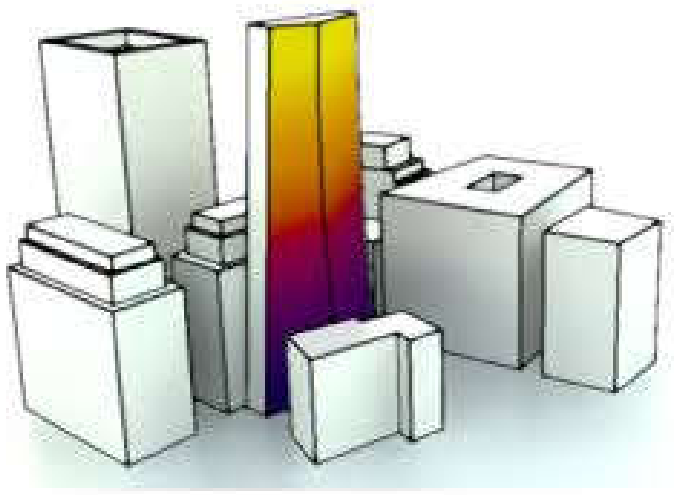
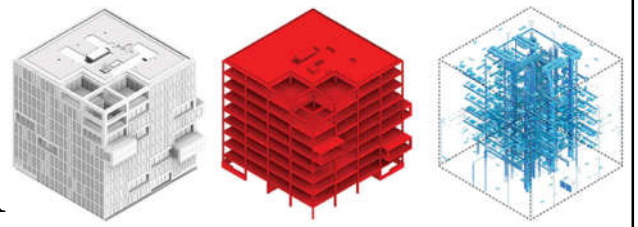
Project phases and analysis

- Sustainable Building Projects
  - Require evaluation of building performance
- Typical analyses for sustainable buildings:
  - Climate analysis
  - Solar & daylighting analysis
  - Building energy analysis
  - Air flow & ventilation analysis
  - Life cycle analysis
  - Carbon analysis



Project phases and analysis

- Building Information Modeling (BIM)
  - An approach to design that uses intelligent 3D computer models to create, modify, share, and coordinate information throughout the design process
  - BIM is useful for sustainable design

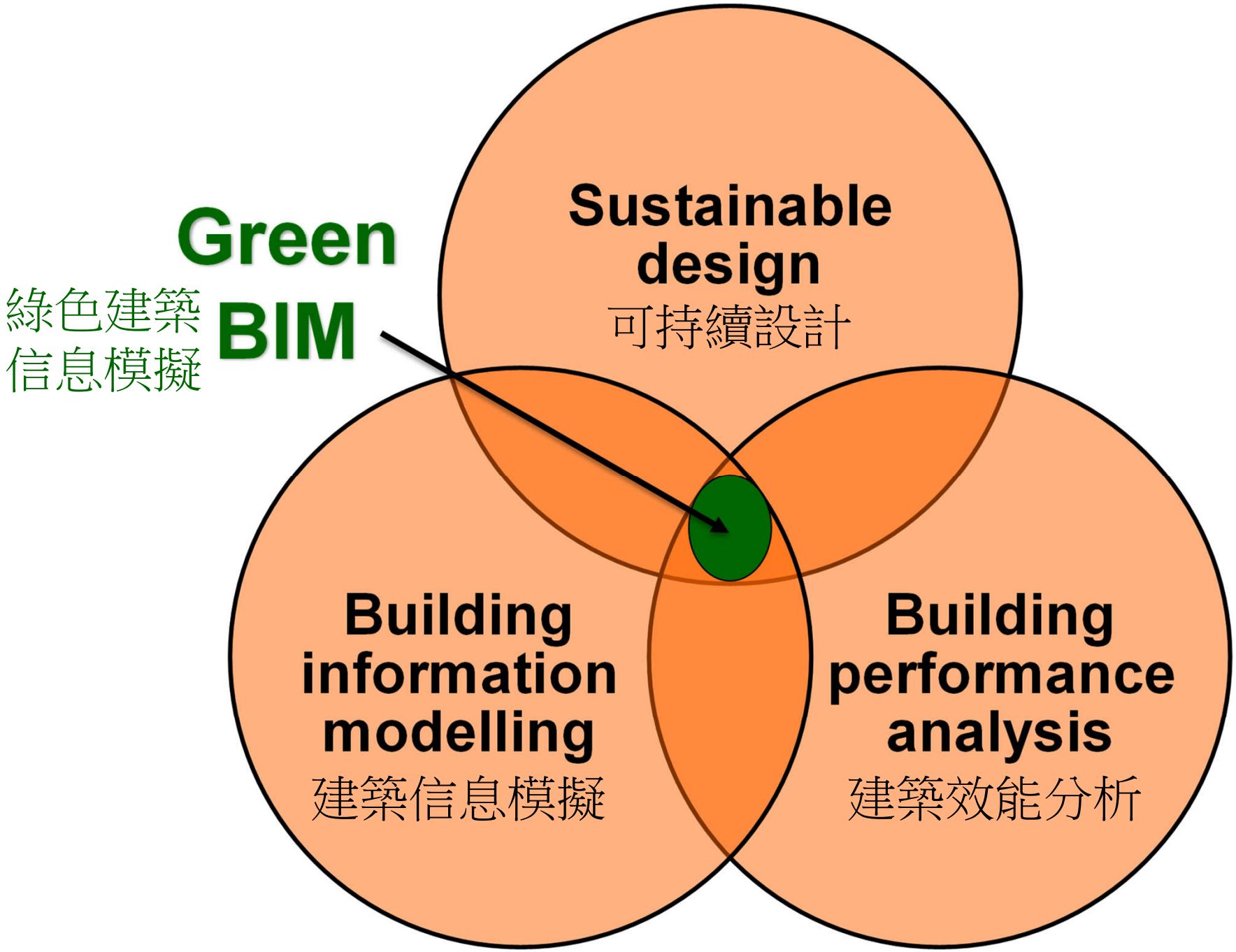


    - It can help people iteratively test, analyze, and improve the building design
    - It can be used for building performance analysis (BPA)

Green BIM

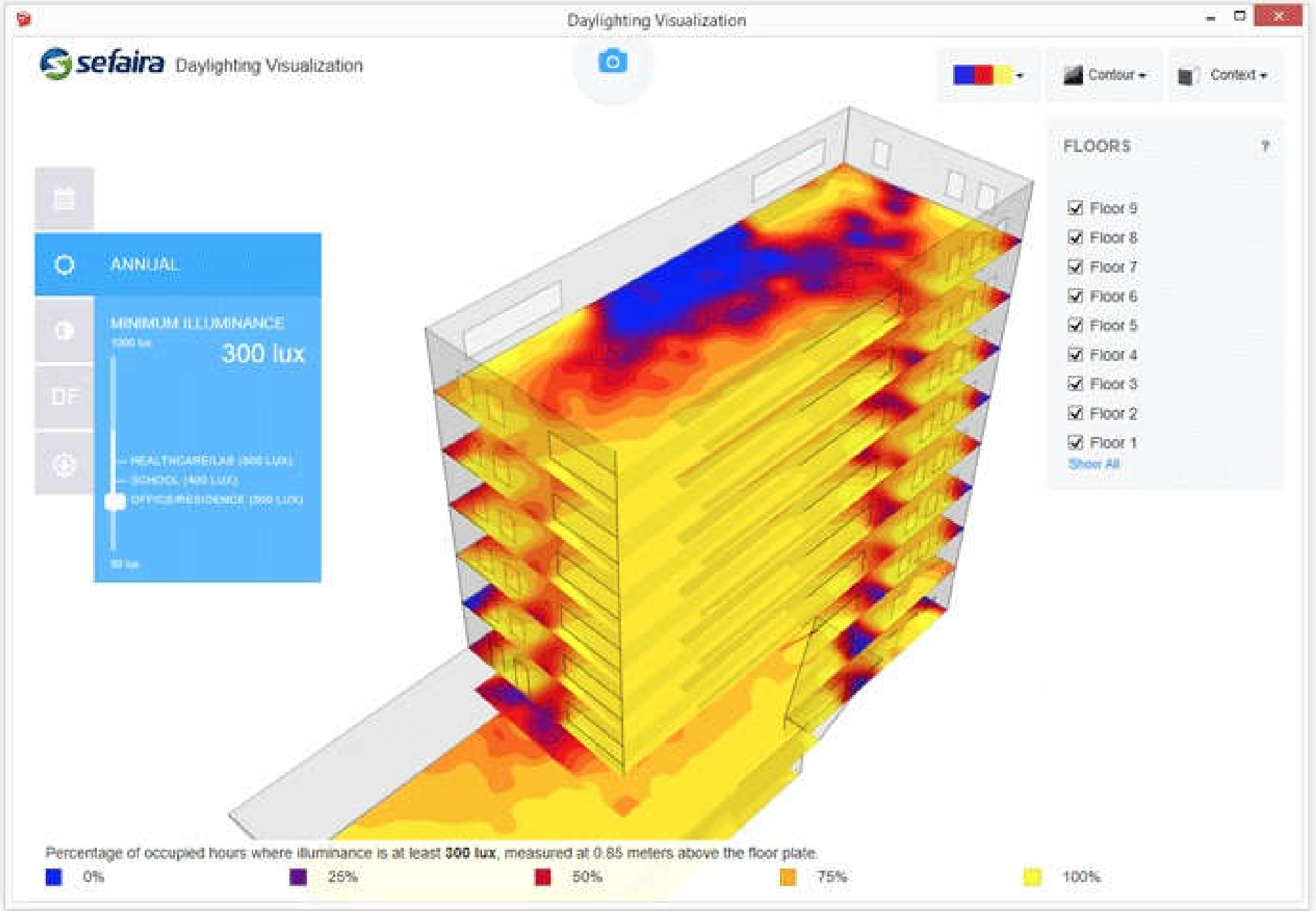
(See also: http://en.wikipedia.org/wiki/Building_information_modeling)

Basic concepts of Green BIM



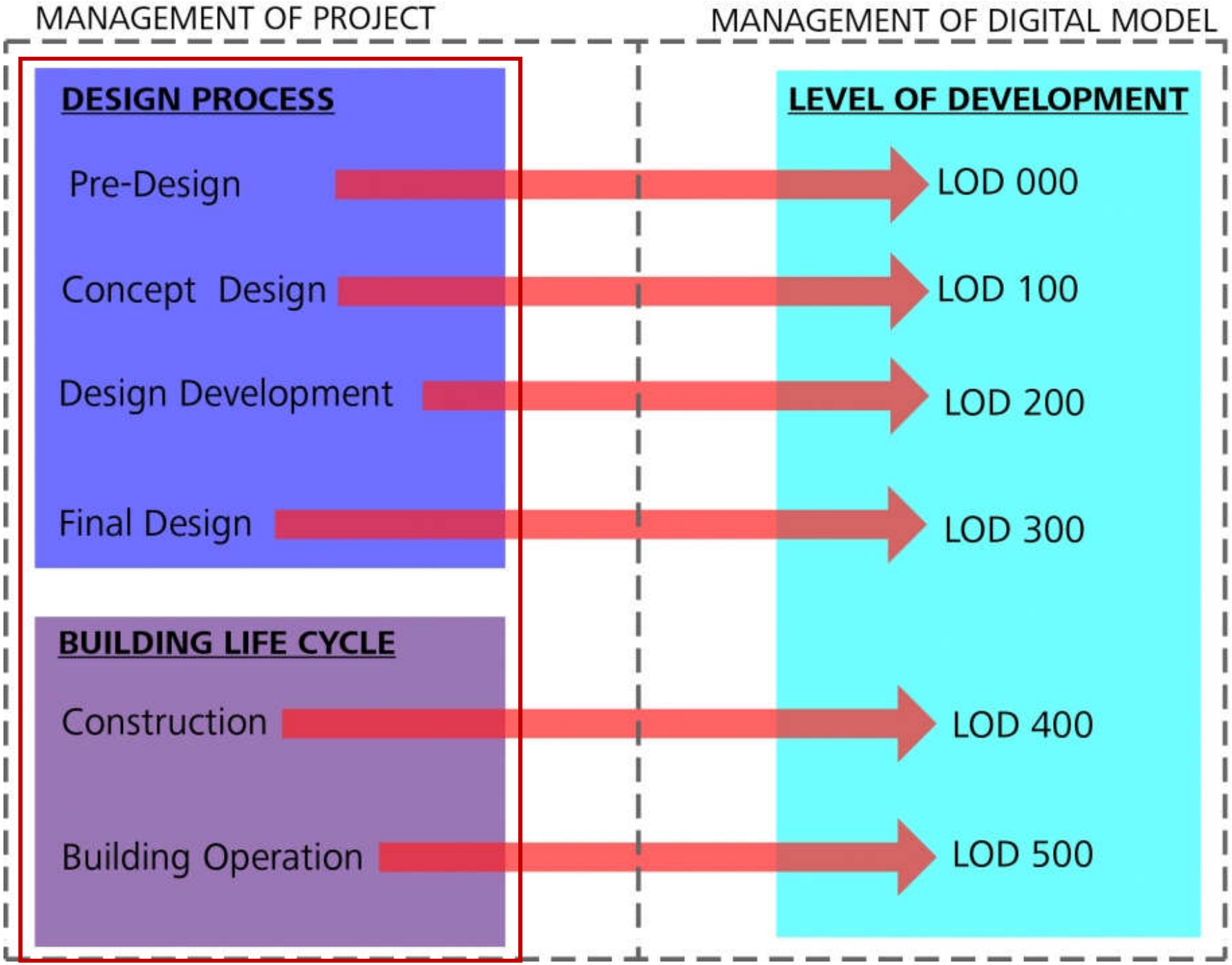
(Adapted from: ABRI (2015))

BIM-supported daylight visualization and analysis



(Source: https://architosh.com/2015/10/energy-modeling-what-you-need-to-know-about-green-building-design-and-leed/)

Design process of buildings and level of development (LOD)



(Source: https://knowledge.autodesk.com/community/collection/building-performance-analysis-0)

Pre-Design

Objectives:

Identify the requirements of the project, existing conditions, and unearth any essential information that will inform the design process.

Sustainable Design Inquires:

-What information will support building performance analysis (BPA) practices?
-What specific climate considerations should be brought to light?
-What passive sustainable design strategies should be considered in the building design?
-What environmental resources can the building design utilize?
-What are the energy/performance goals for the project?

Building Performance Analysis (BPA) Actions:

-Decide what climate data is most appropriate for the geographic location.
-Conduct a site analysis that minimally includes investigation of solar radiation, wind patterns, presence and condition of existing structures, inventorying existing vegetation, and documenting any acoustic challenges that exist.
-Analyze climate charts and determine if building is likely to be heating or cooling dominated.
-Research what sustainable design strategies would be applicable to both the geographic location, and climate zone of the project.
-Establish measurement matrices that are to be used throughout the duration of the project to confirm sustainable design goals are being accounted for (such as LEED).

(Source: https://knowledge.autodesk.com/community/collection/building-performance-analysis-0)

Conceptual Design

Objectives:

Decide on the direction of the design by experimenting, iterating, and obtaining integrated design input from all parties.

Sustainable Design Inquires:

-What is the most efficient building form?
-How is the building positioned on the building site?
-How is the floor plan organized?
-How do passive sustainable design strategies integrate with the building?

Building Performance Analysis (BPA) Actions:

-Run conceptual energy analysis using and modifying massing forms and determine how the Energy Use Intensity (EUI) can be reduced by changes in building form, and orientation. Doing so can help determine the most energy efficient building form.
-Conduct basic shade/shadow analysis of the massing model to determine what areas of the building could potentially support daylighting, and consequently inform interior space planning. This also informs the positioning of the building on the site.
-Do solar radiation studies of the mass model to maximize opportunities for solar collection (e.g. for solar photovoltaics and solar thermal systems).
-Study how the orientation of the massing model interacts with wind on the site. Orientation of the building can optimize opportunities for passive cooling and ventilation.

(Source: https://knowledge.autodesk.com/community/collection/building-performance-analysis-0)

Design Development

Objectives:

Verify and edit performative attributes of proposed design, while refining material, mechanical, and structural systems with specificity.

Sustainable Design Inquires:

-How should the floor plan be modified to improve the quality of day lighting?
-How can HVAC equipment be designed most efficiently?
-How can structural system be designed most efficiently?
-Do passive sustainable design strategies provide the expected performance?
-What materials are being used to construct the building?

Building Performance Analysis (BPA) Actions:

-Run whole building energy analysis of building model, and identify how changes in wall construction can reduce energy demands. This also presents a good opportunity to test the performance of HVAC systems that were initially selected in Concept Design.
-Complete simulations that determine the general geometry of performative features to determine if shades, light shelves, and solar chimneys are working as predicted.
-Run interior daylighting analysis of spaces, and confirm proper light levels are being achieved.
-After maximizing the efficiency of the building envelope, run cooling/heating load simulation so that HVAC equipment can be sized for efficiency.
-Perform structural analysis of model so that structural systems can be optimized.

(Source: https://knowledge.autodesk.com/community/collection/building-performance-analysis-0)

Final Design and Documentation

Objectives:

Provide detailed direction, and specification, to construct the most comprehensive iteration of the building. Assure that the constructed manifestation of the design will be as sustainable as feasibly possible.

Sustainable Design Inquires:

-Are sustainable design goals achieved?
-Are building owner's expectations of costs and performance achieved?
-What is the expected performance of the building?

Building Performance Analysis (BPA) Actions:

-Perform detailed whole building energy analysis of the final design to document expected performance, and measure against baselines. And compare final design against the measurement matrices that were defined in Pre-Design.
-Perform greenhouse gas emissions analysis to document expected environmental impact.
-Audit final building materials for costs and green qualities (recycled content, close proximity to construction site, low VOCs).

(Source: https://knowledge.autodesk.com/community/collection/building-performance-analysis-0)

Construction

Objectives:

Bring the building design into physical reality, by practicing sustainable construction methods and utilizing quality control methods.

Sustainable Design Inquires:

-How can waste be reduced in the construction process?
-How can fabrication methods reduce waste?
-How can construction be done in a sustainable manner?

Building Performance Analysis (BPA) Actions:

-Analyze building quantities to assure that exact material quantities are delivered to the project site. Doing so will avoid excess material that gets turned into waste.
-Analyze best fabrication methods with digital automation. This step reduces waste material in the production of building assemblies.
-Run construction scheduling simulations that identify how to reduce equipment operations on the project site. Less use of construction equipment reduces both energy consumption and air pollution.

(Source: https://knowledge.autodesk.com/community/collection/building-performance-analysis-0)

Operations and Maintenance

Objectives:

The building becomes occupied and has all equipment operating.

Sustainable Design Inquires:

-Are environmental control systems operating correctly?
-Is building able to maintain sustainable design goals when occupied?
-Is maintenance being done that assures environmental control systems can continue to perform at their optimum?

Building Performance Analysis (BPA) Actions:

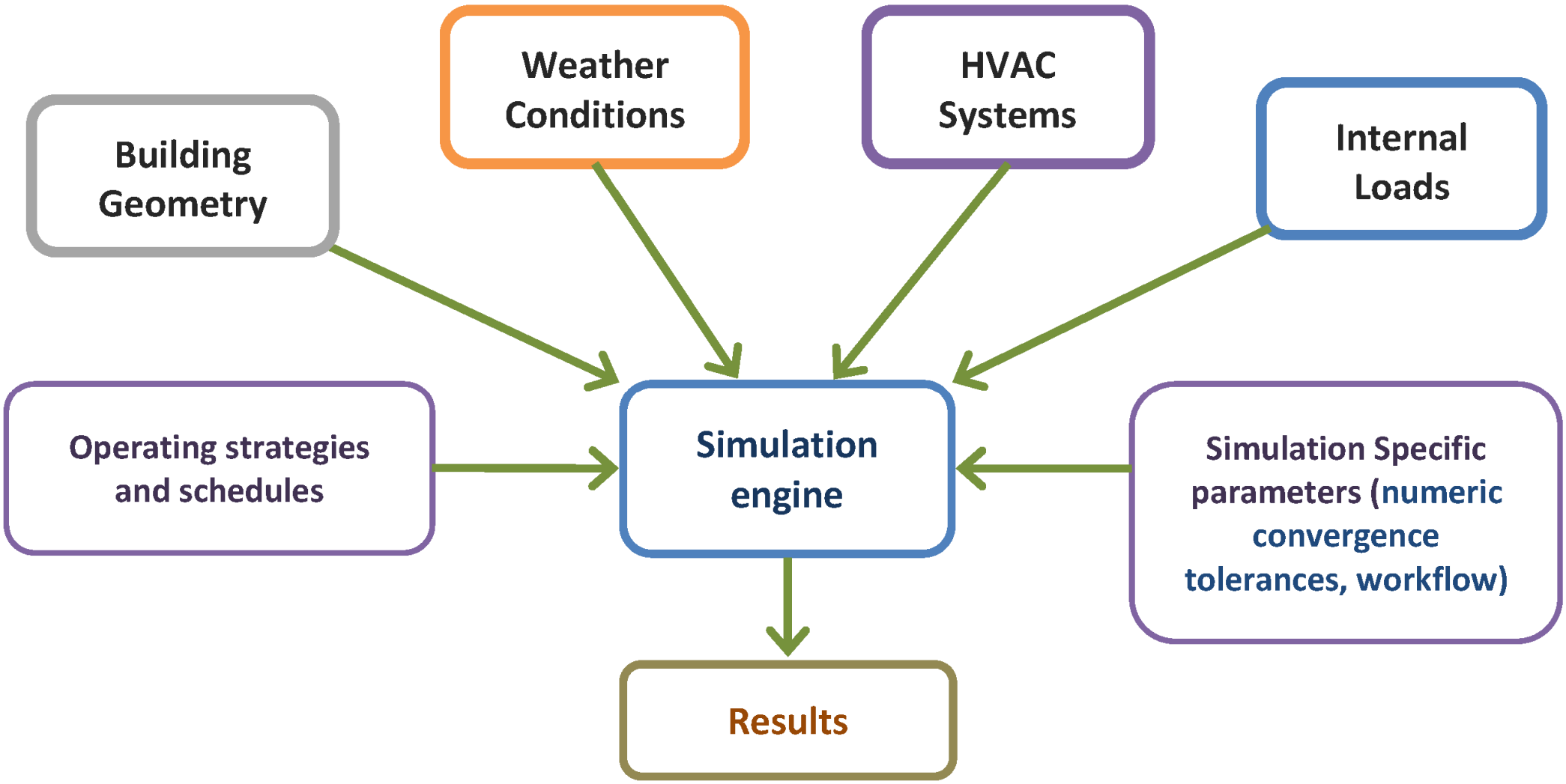
-Perform initial and ongoing commissioning of environmental systems to assure they are working as anticipated. Poorly performing environmental systems can result in compromised occupant comfort, and unnecessary energy consumption.
-Add ongoing utility cost/demand data to energy model, and compare/identify differences between designed and actual performance.
-Administer occupancy survey to verify occupant satisfaction, and make recommendations to facilities management for improving occupant satisfaction.

(Source: https://knowledge.autodesk.com/community/collection/building-performance-analysis-0)

Project phases and analysis

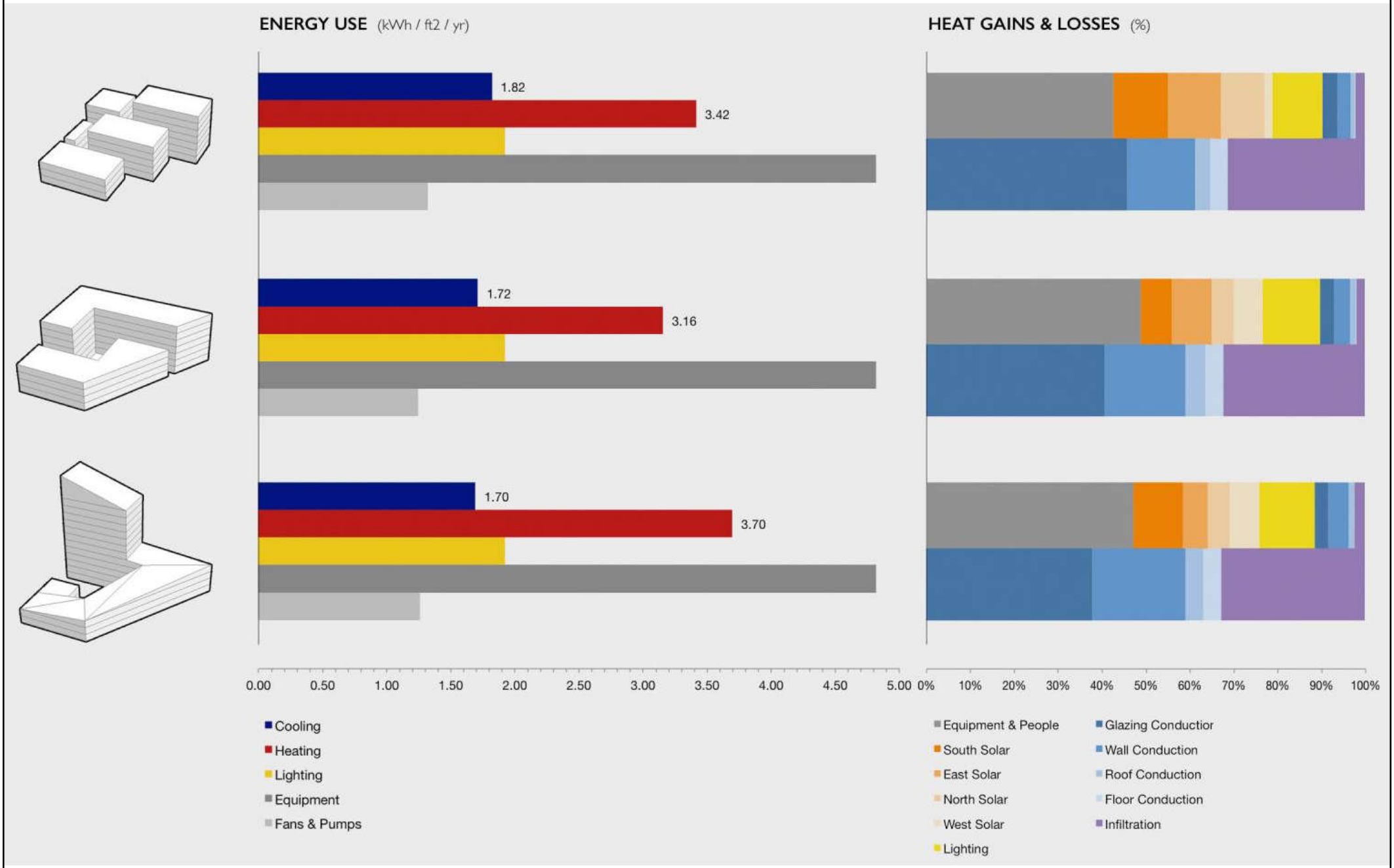
- Thermal analysis
  - Cooling & heating load calculations
  - HVAC plant and control systems
  - Dynamic thermal simulations
  - Wall/window make-ups & condensation analysis
  - Energy analysis
  - CO_2 emission calculations
  - Natural ventilation & mixed mode systems
- Model – Simulate – Results – Analysis

General input data of thermal simulation engines



(Source: https://www.mdpi.com/2075-5309/3/2/380/htm)

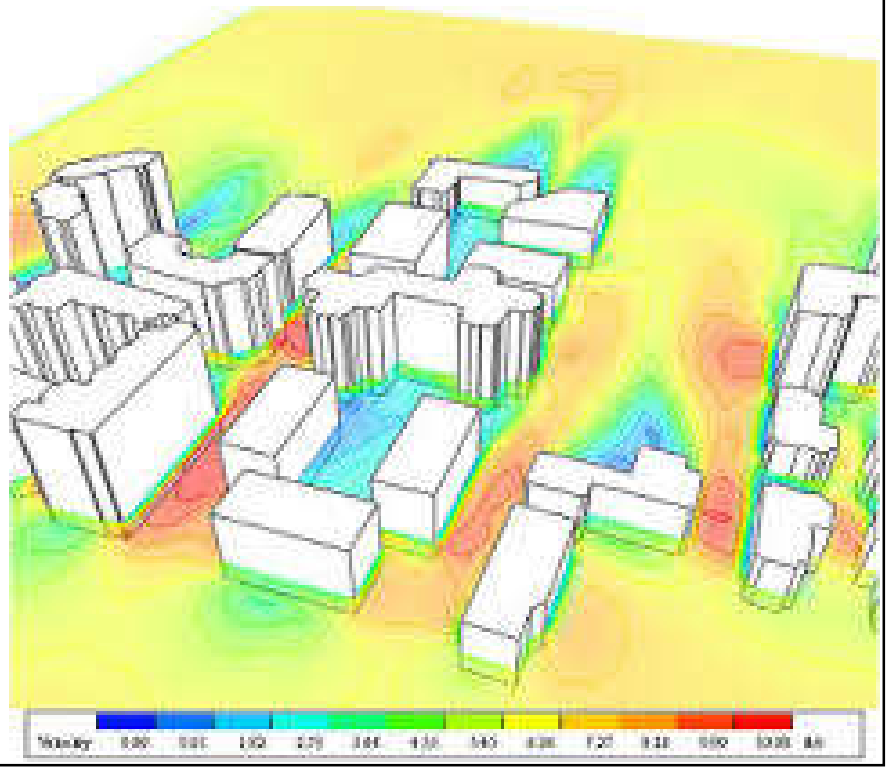
Design option comparison for schematic design studies



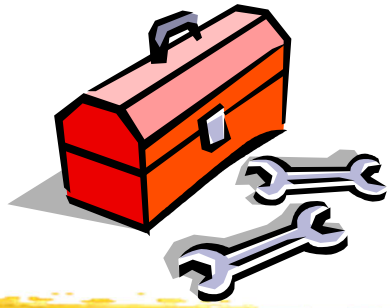
(Source: https://blog.sketchup.com/article/four-schematic-design-studies-every-architect-should-do)

Project phases and analysis

- Computational fluid dynamics (CFD)
  - Predict complex air flow inside & around buildings
  - Visualization of results
  - Comfort analysis
  - Ventilation airflow analysis
  - Wind pattern studies



Building design tools



- Examples of design and analysis tools
  - Autodesk Insight for Revit
  - Autodesk Green Building Studio
  - IES Virtual Environment
  - Sefaira

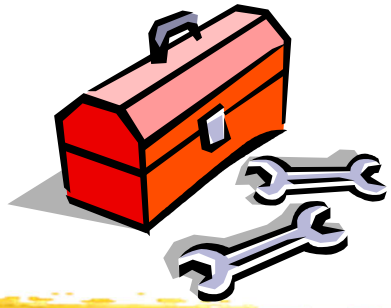
AUTODESK® INSIGHT™

IES

AUTODESK® GREEN BUILDING STUDIO®

sefaira

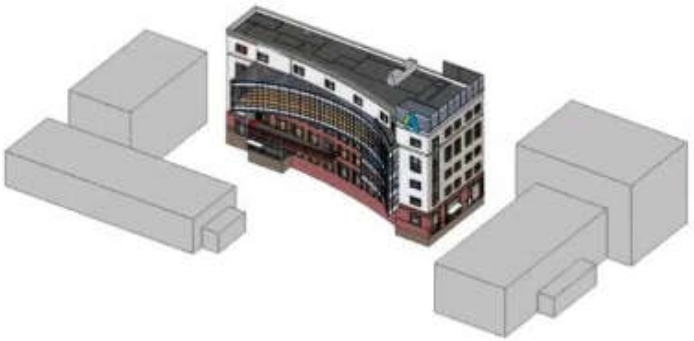
Building design tools



- Autodesk Revit
(https://www.autodesk.com/products/revit/overview)
  - Building Information Modeling (BIM) software
  - To support design, analysis, collaboration, documentation and visualization
- Insight: Building Performance Analysis
  - https://www.autodesk.com/products/insight/overview
  - Integrated with Revit
    - Autodesk Insight Overview (1:43)
https://youtu.be/QZchfkbSwG8

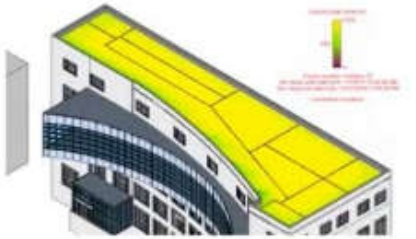
Autodesk Revit and Insight for Building Performance Analysis

What is Insight?

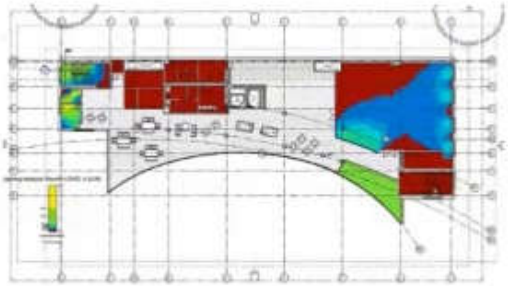


From any Revit Model
(FormIt – Conceptual)

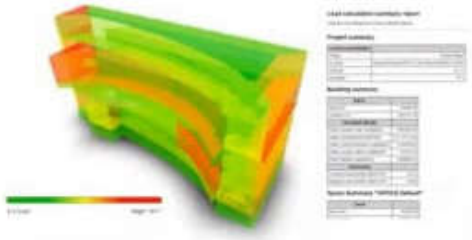
Building Energy



Solar Radiation



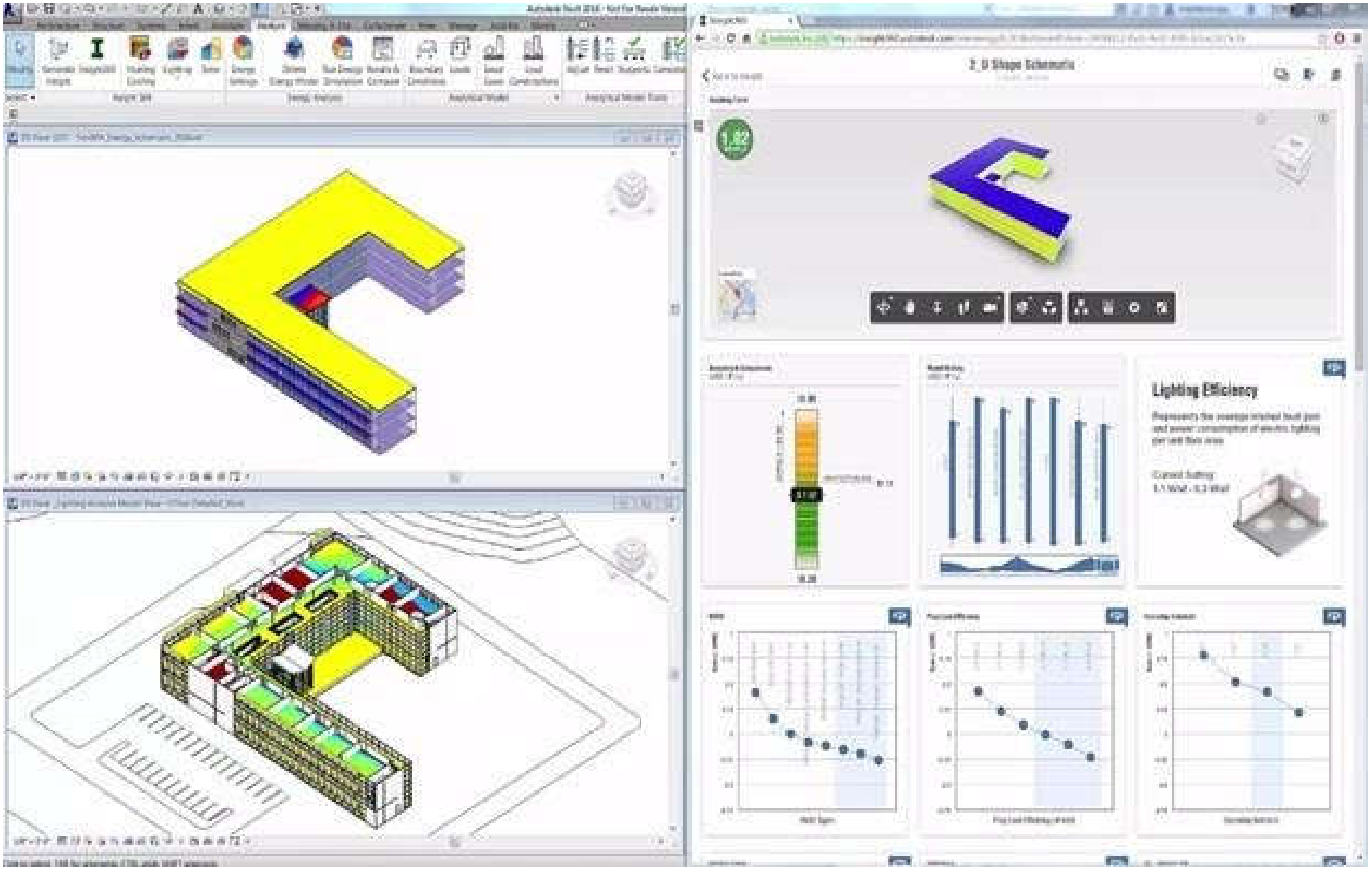
Daylighting



Heating/Cooling

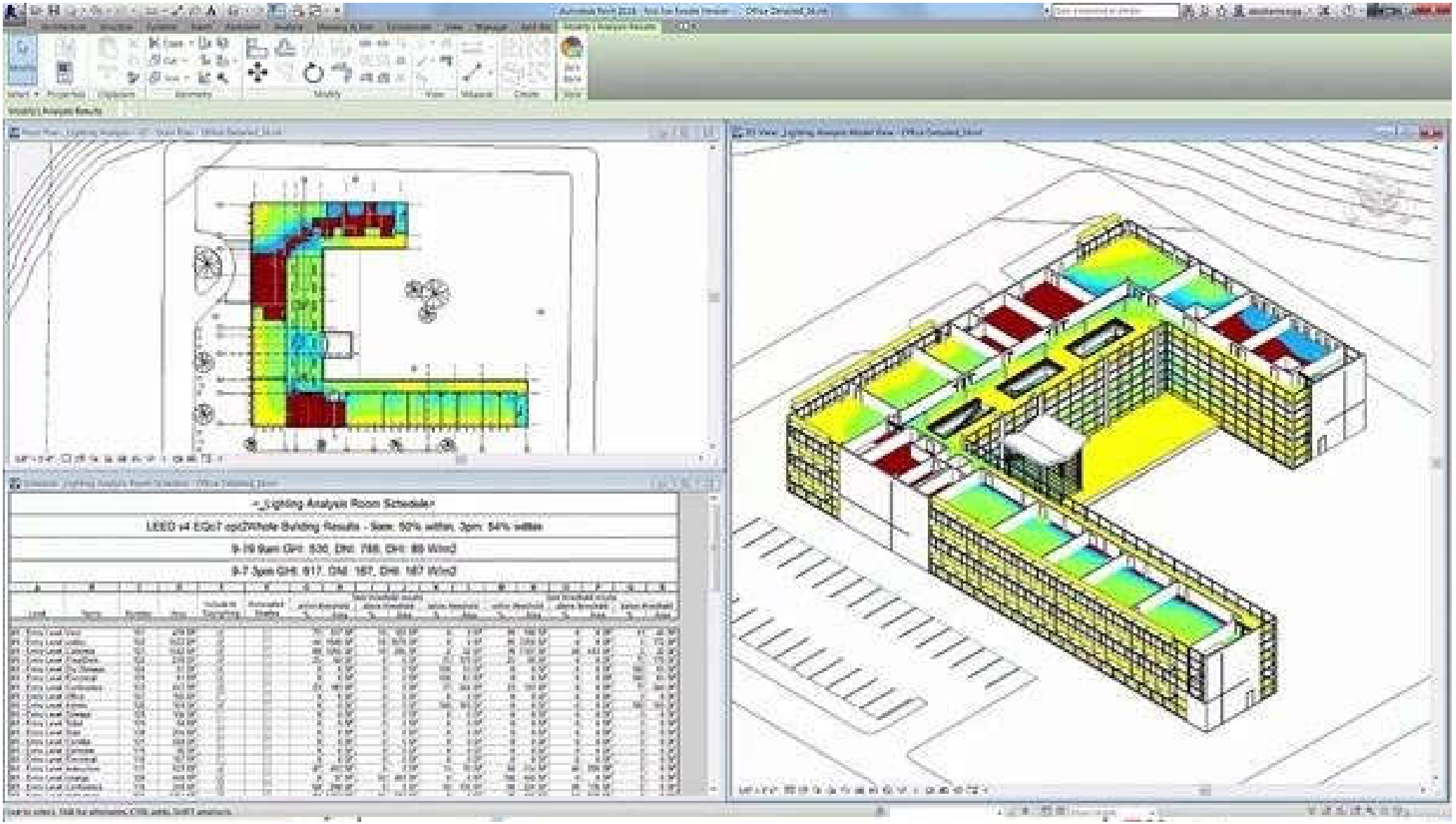
(Source: https://blogs.autodesk.com/revit/2018/07/06/autodesk-insight-webinar-series/)

Whole building energy analysis using Insight for Revit



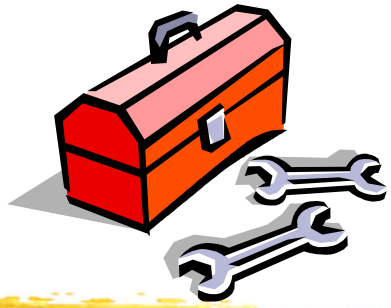
(Source: Autodesk)

Daylighting analysis using Insight for Revit



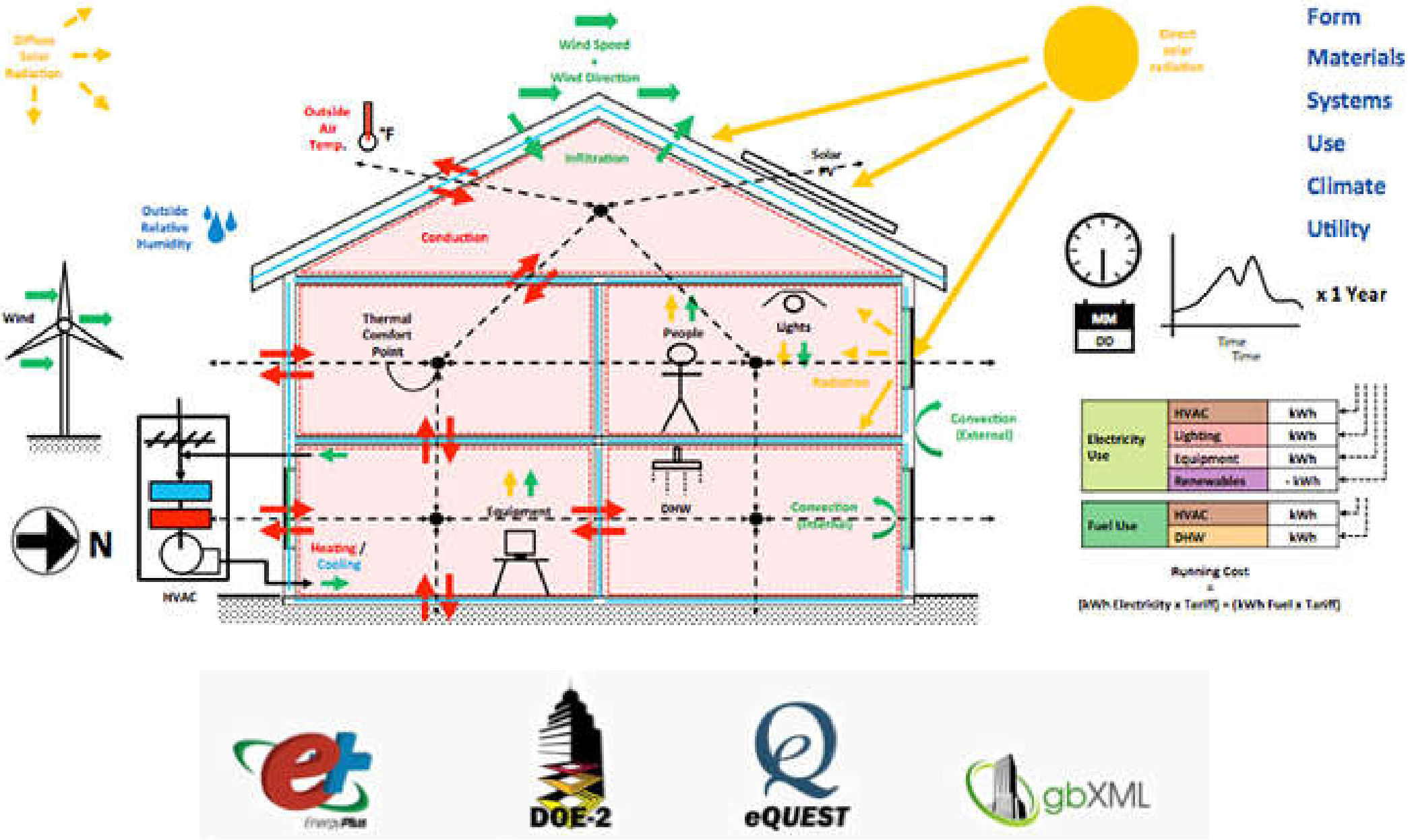
(Source: Autodesk)

Building design tools

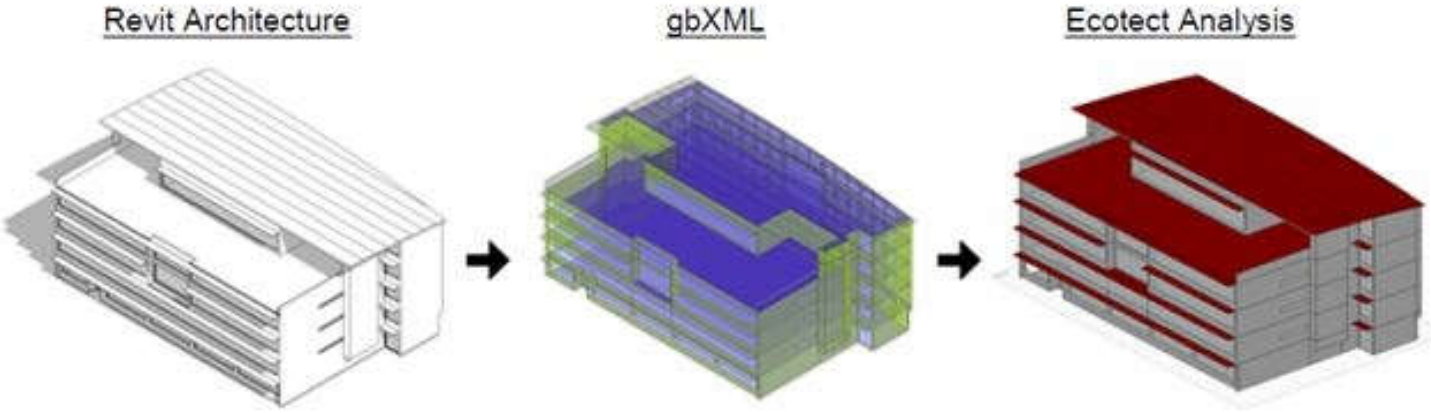


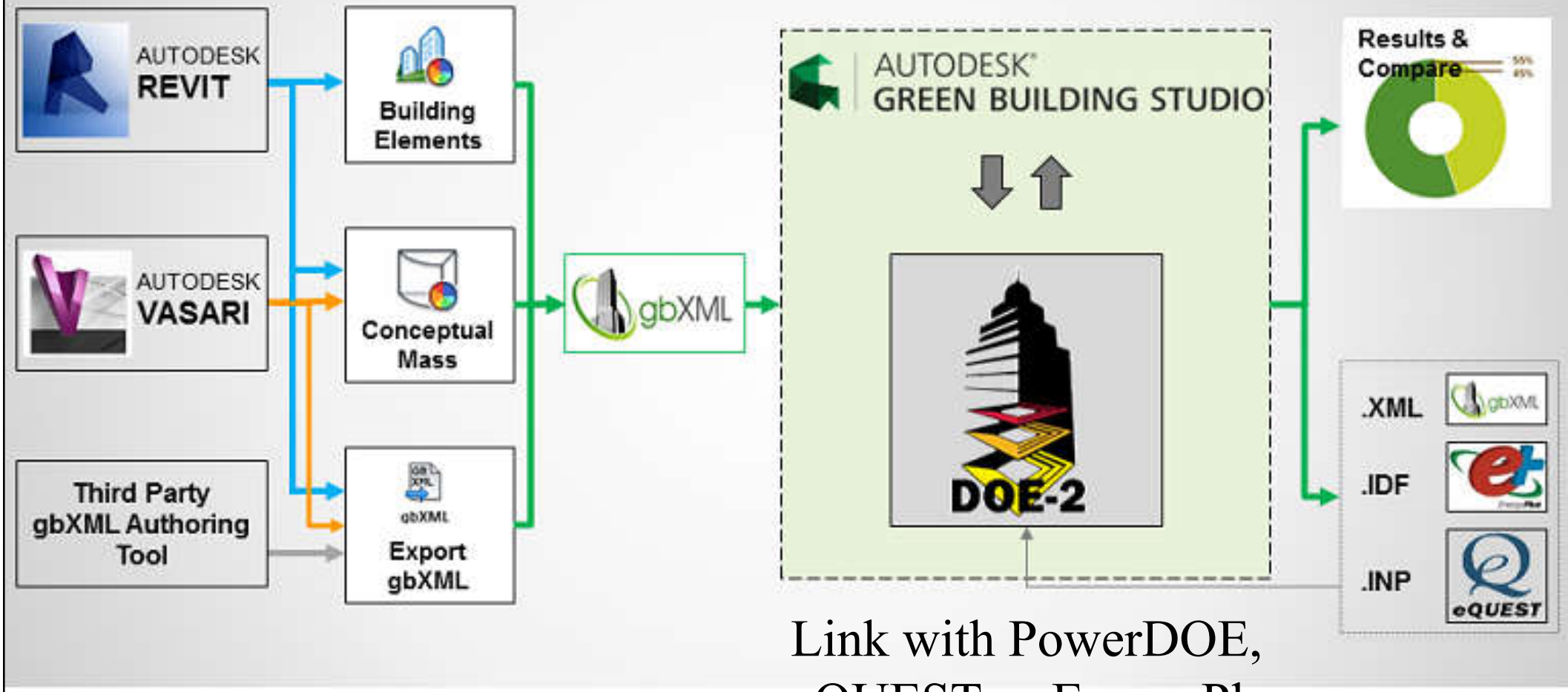
- Autodesk Green Building Studio
  - https://gbs.autodesk.com/GBS/
  - A web-/cloud-based service for use in evaluating the environmental impact of building design and design alternatives. It can assess:
    - Energy and carbon results (e.g. EnergyPlus, eQUEST)
    - Water usage data
    - Photovoltaic potential
    - Daylighting results, natural ventilation potential
  - The results are often reported in monetary terms

Dynamic whole building energy analysis using Green Building Studio



(Source: https://gbs.autodesk.com/GBS/)

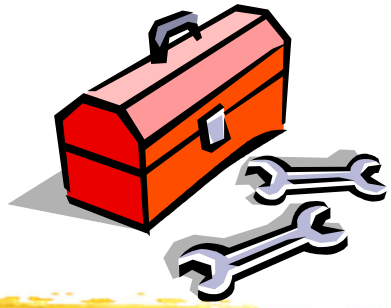




Link with PowerDOE, eQUEST or EnergyPlus

(Source: Autodesk)

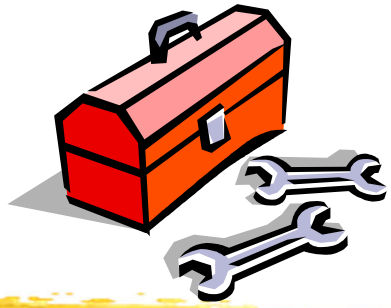
Building design tools



- gbXML (green building extensible markup language) [http://www.gbxml.org/]
  - Open schema designed to transfer essential information contained within a 3D building information model BIM (such as walls, windows, and room areas)
  - Allows for a consistent way to share information for engineering analysis tools

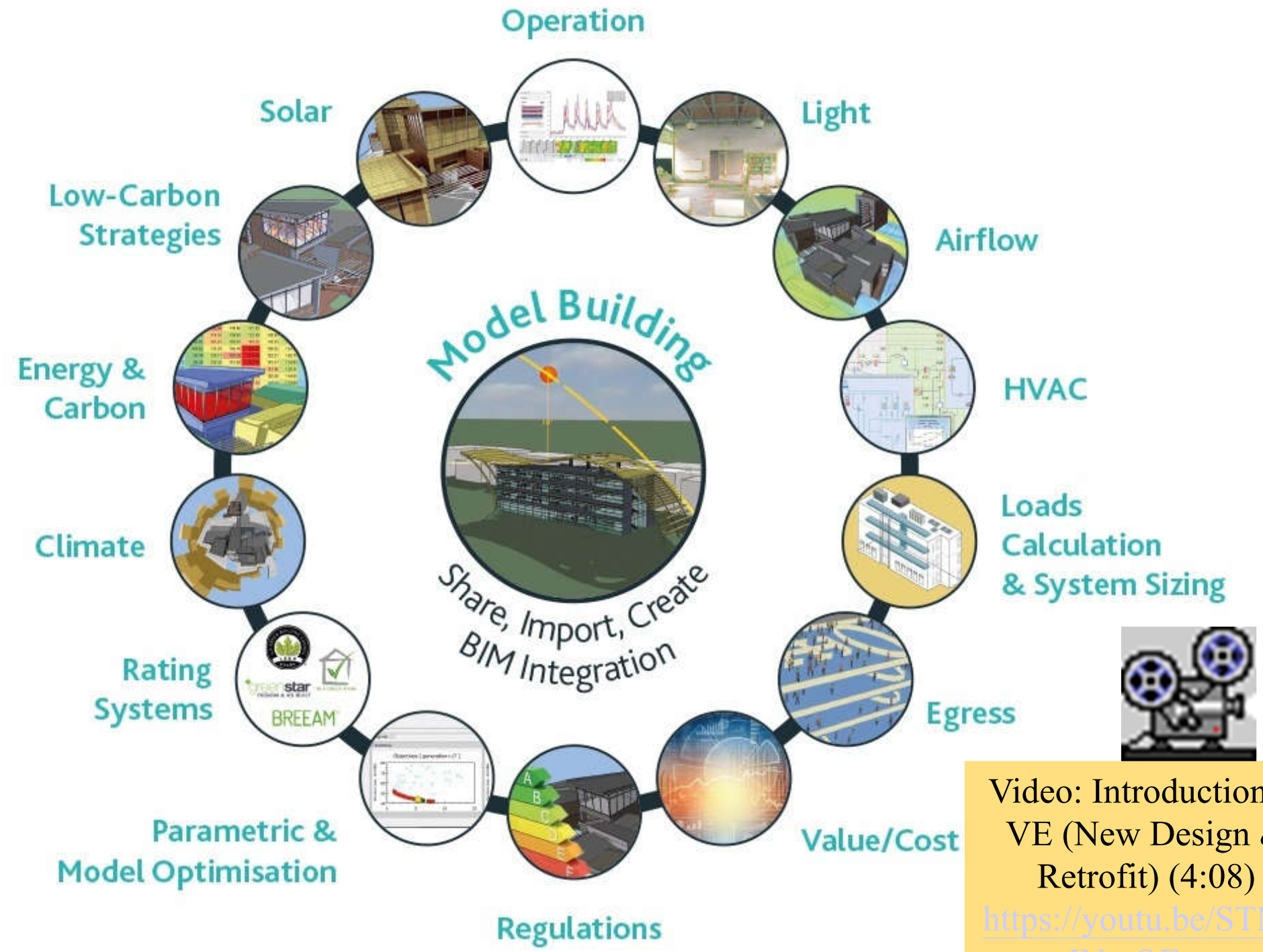
gbXML

Building design tools



- IES Virtual Environment VE (www.iesve.com)
  - IES = Integrated Environmental Solutions
  - Applications:
    - Energy Modelling & Compliance
      - Whole building energy simulation; LEED, UK, North America & global compliance
    - Building & Systems Design
      - Solar shading, daylight simulation & lighting design, HVAC sizing & optimization, airflow, climate analysis & weather, renewable energy design & optimization, life cycle analysis
    - 3D Modelling & BIM Interoperability

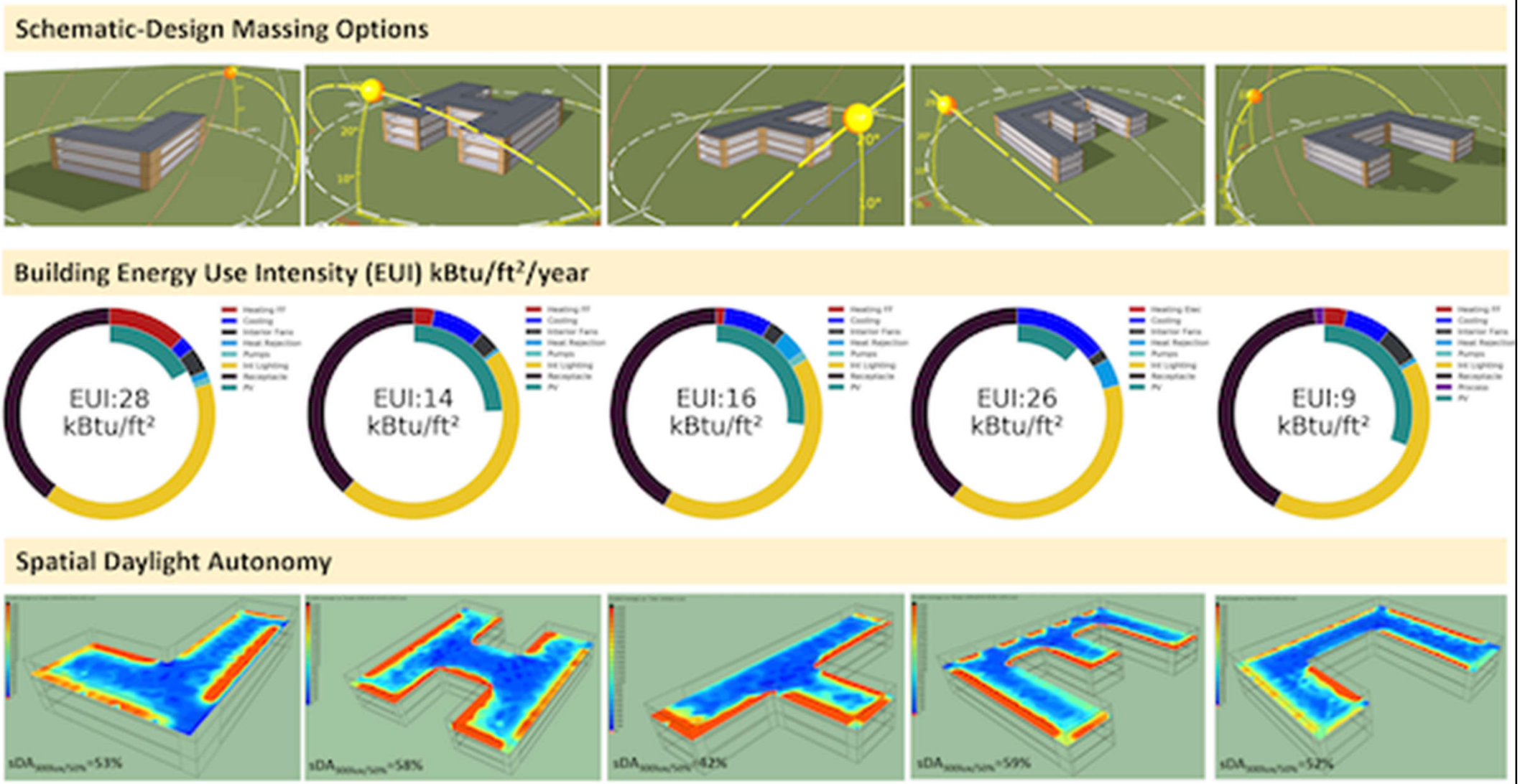
IES Virtual Environment (VE): integrated analysis



Video: Introduction to VE (New Design & Retrofit) (4:08) https://youtu.be/STMLINmQExw

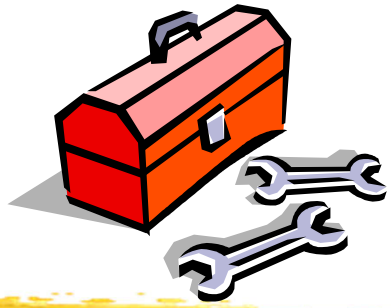
(Source: https://www.iesve.com/icl/ve)

IESVE 2019 schematic geometry wizard for building performance analysis (massing, building energy use & daylighting)

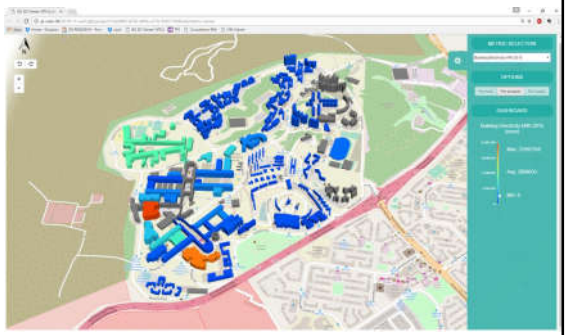


(Source: https://www.ibpsa.us/news/new-software-release-ies-ltd-iesve-2019-available-download-now)

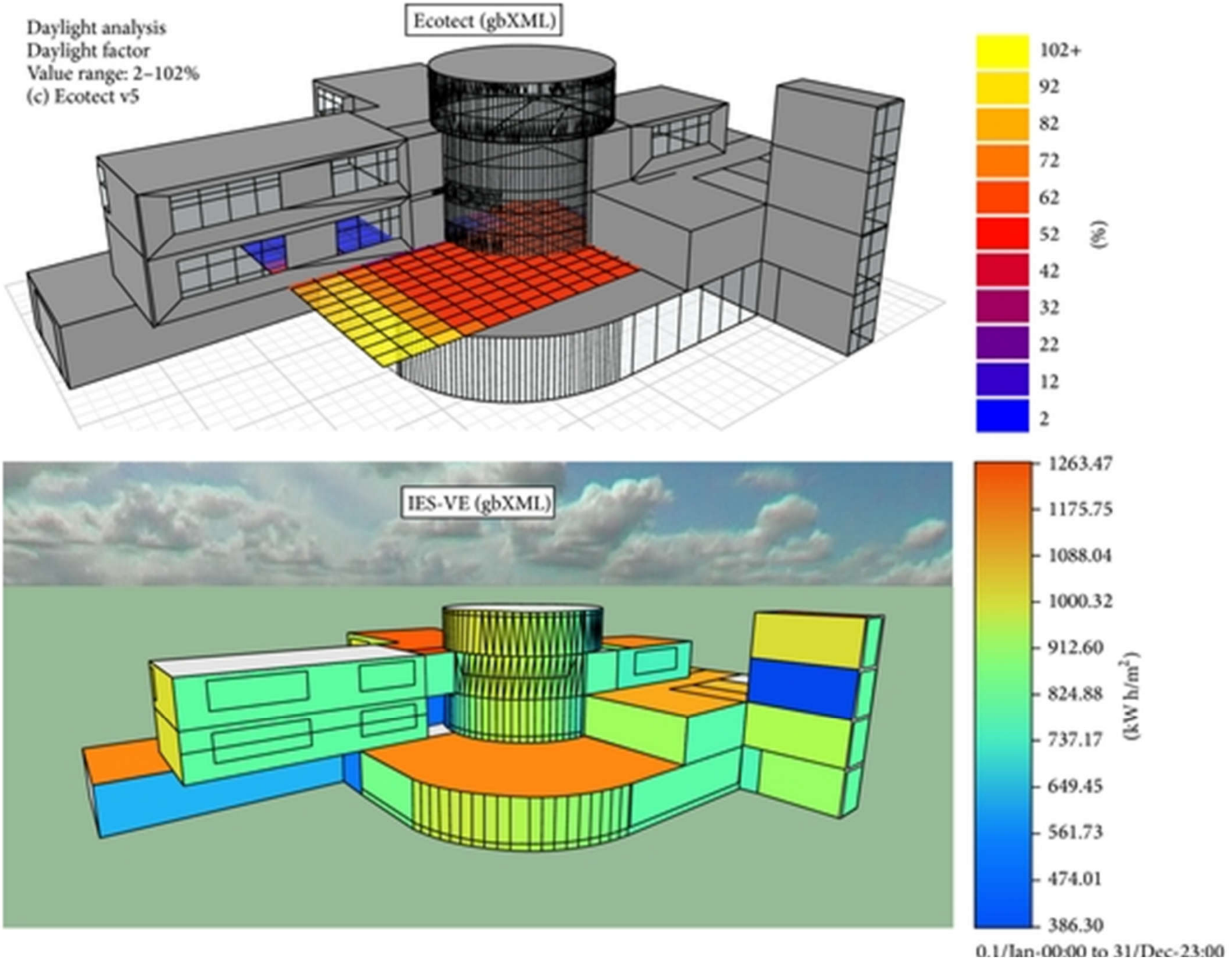
Building design tools



- IES VE case studies (in Singapore)
  - NTU EcoCampus https://www.iesve.com/icl/case-studies/2835/NTU-EcoCampus
    - 3D masterplanning and visualization
  - BCA Academy Campus https://www.iesve.com/icl/case-studies/2836/BCA-Academy-Campus
    - Energy modelling and performance optimisation

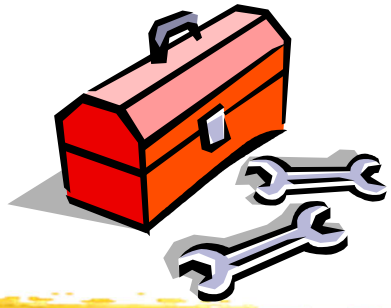


Snapshot of the sample daylighting simulation in Ecotect and IES-VE



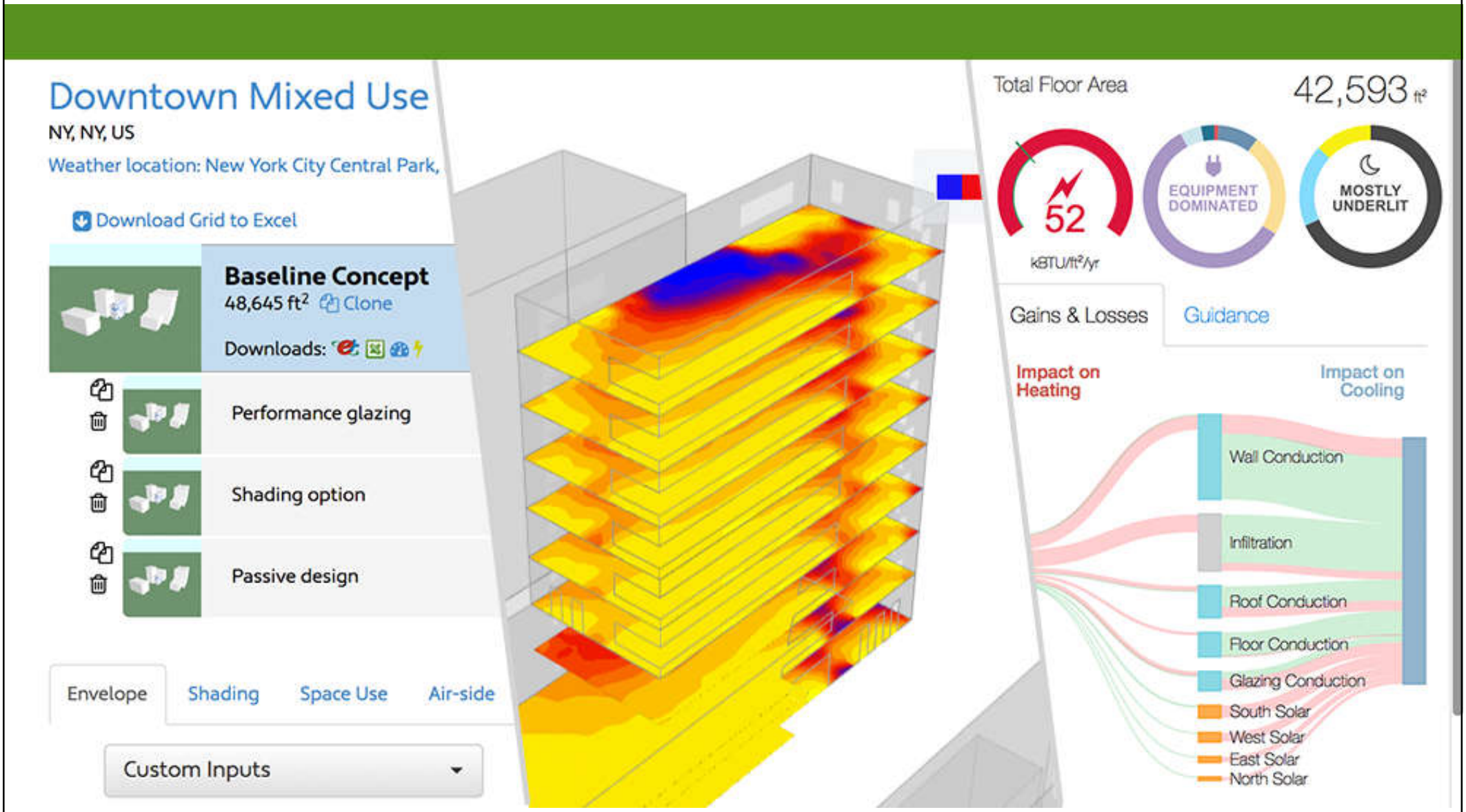
(Source: https://www.researchgate.net/figure/Snapshot-of-the-sample-daylighting-simulation-in-Ecotect-and-IES-VE_fig7_286297458)

Building design tools



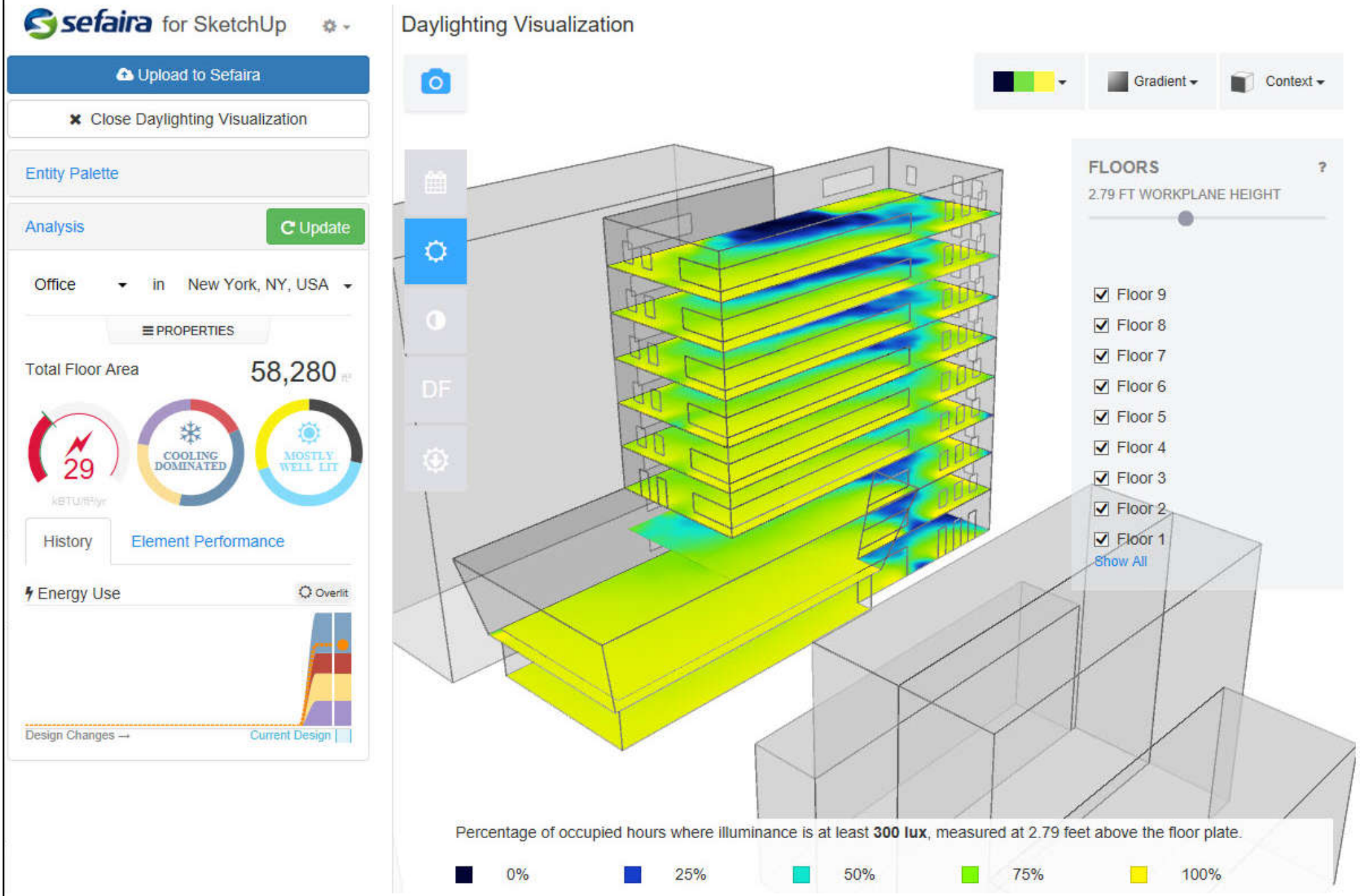
- Sefaira https://sefaira.com/
  - Early stage analysis
    - Compare massings, layout and envelope options
    - Study natural ventilation & HVAC systems
  - Use EnergyPlus and Radiance
  - Applications:
    - Energy (use, cost, CO_2, renewables)
    - Daylighting (daylight factor, direct sunlight)
    - Thermal comfort
    - HVAC sizing (heating & cooling loads)

Sefaira building performance analysis



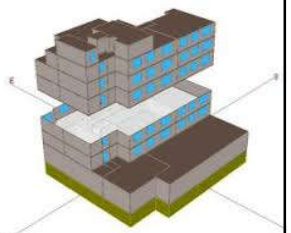
(Source: https://sefaira.com/interested-in-a-demo-of-sefaira-architecture/)

Sefaira daylighting analysis and visualization



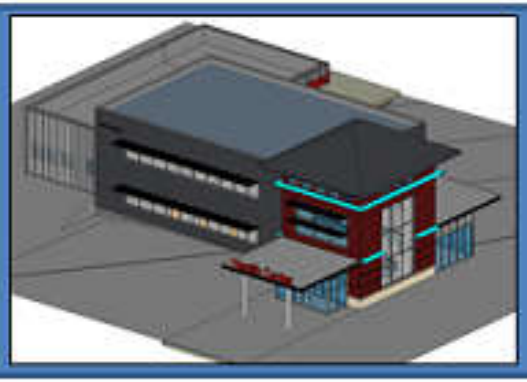
(Source: https://sefaira.com/resources/june-product-update-2016/)

Building performance analysis



- Building Performance Analysis (BPA)
  - Building performance studies to assess how the building is performing, what is driving that performance, and what you can do to influence it
  - Typical tasks:
    - Climate & weather analysis
    - Building load & energy modelling
    - Solar analysis & strategies
    - Daylighting/lighting analysis & strategies
    - Wind & airflow analysis

BIM
Building
Information
Modeling

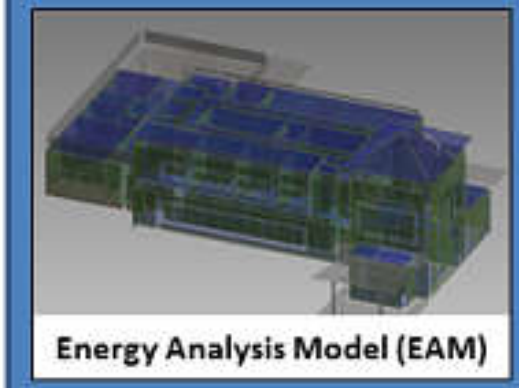


- Visualization
- Structural analysis
- Cost
- Documentation
- Fabrication/ Construction
- Etc...

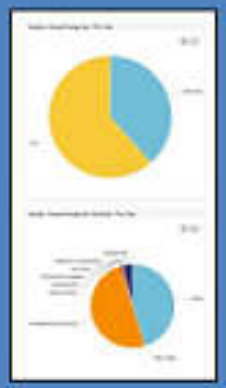
Building Performance Analysis (BPA)

Whole Building Energy Analysis

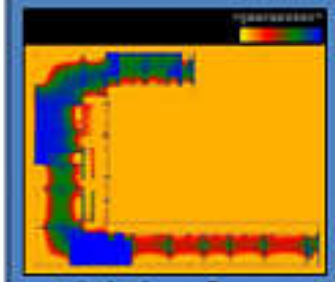
- Conceptual Models
- Detailed Models



Energy Analysis Model (EAM)

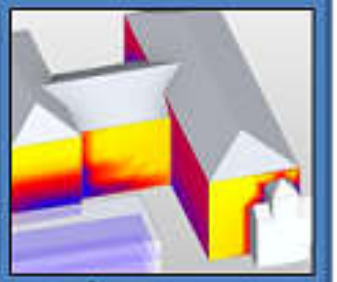


Other Performance Studies

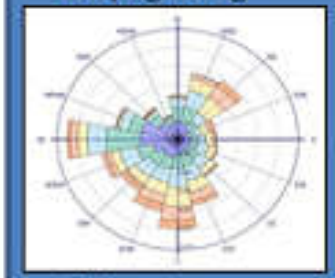


Lighting & Daylighting

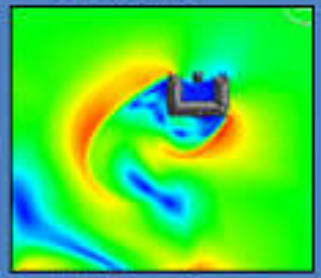
Sun & Shadows



Solar Radiation



Climate Analysis

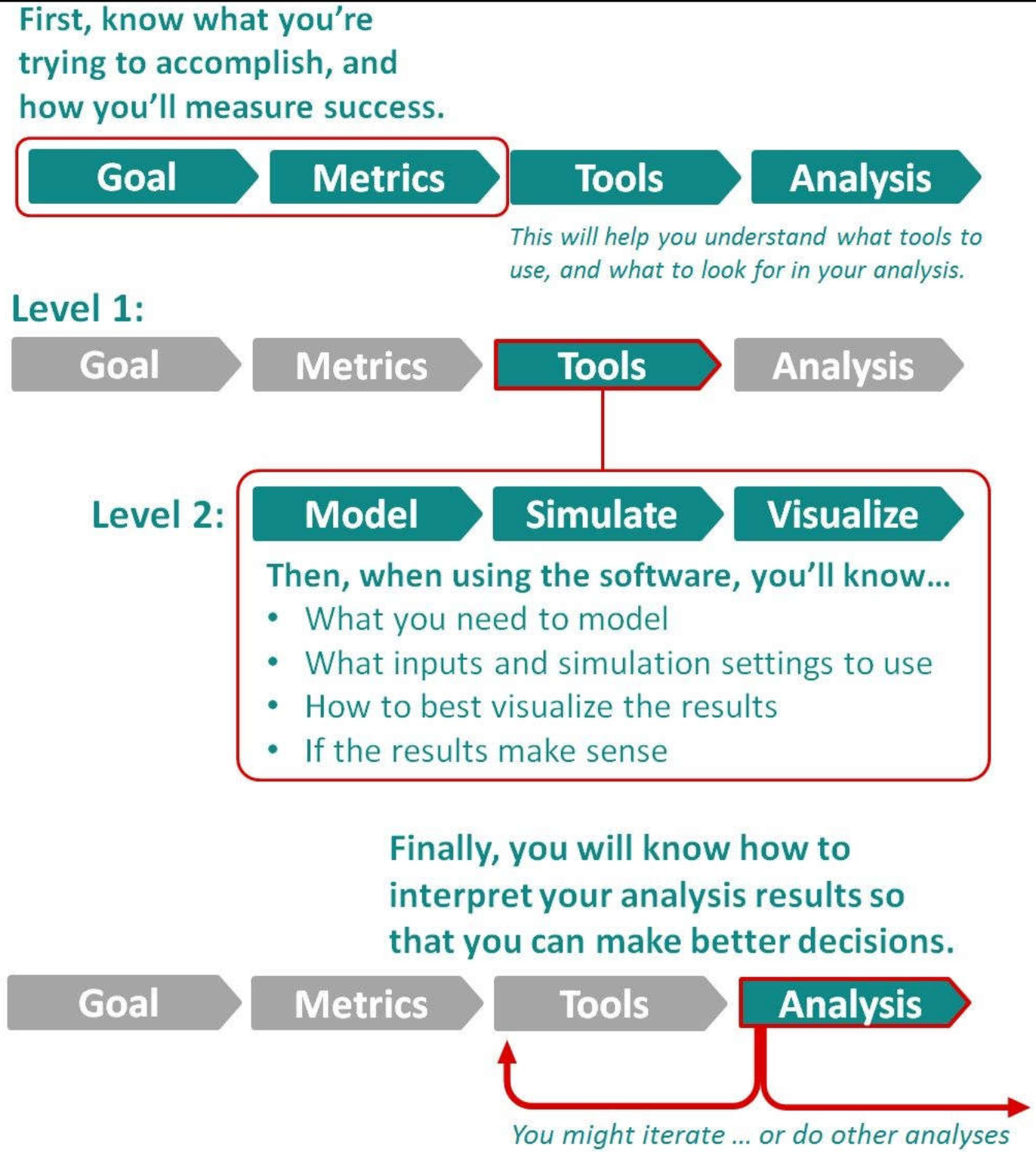


Airflow & Ventilation

Lifecycle Analysis

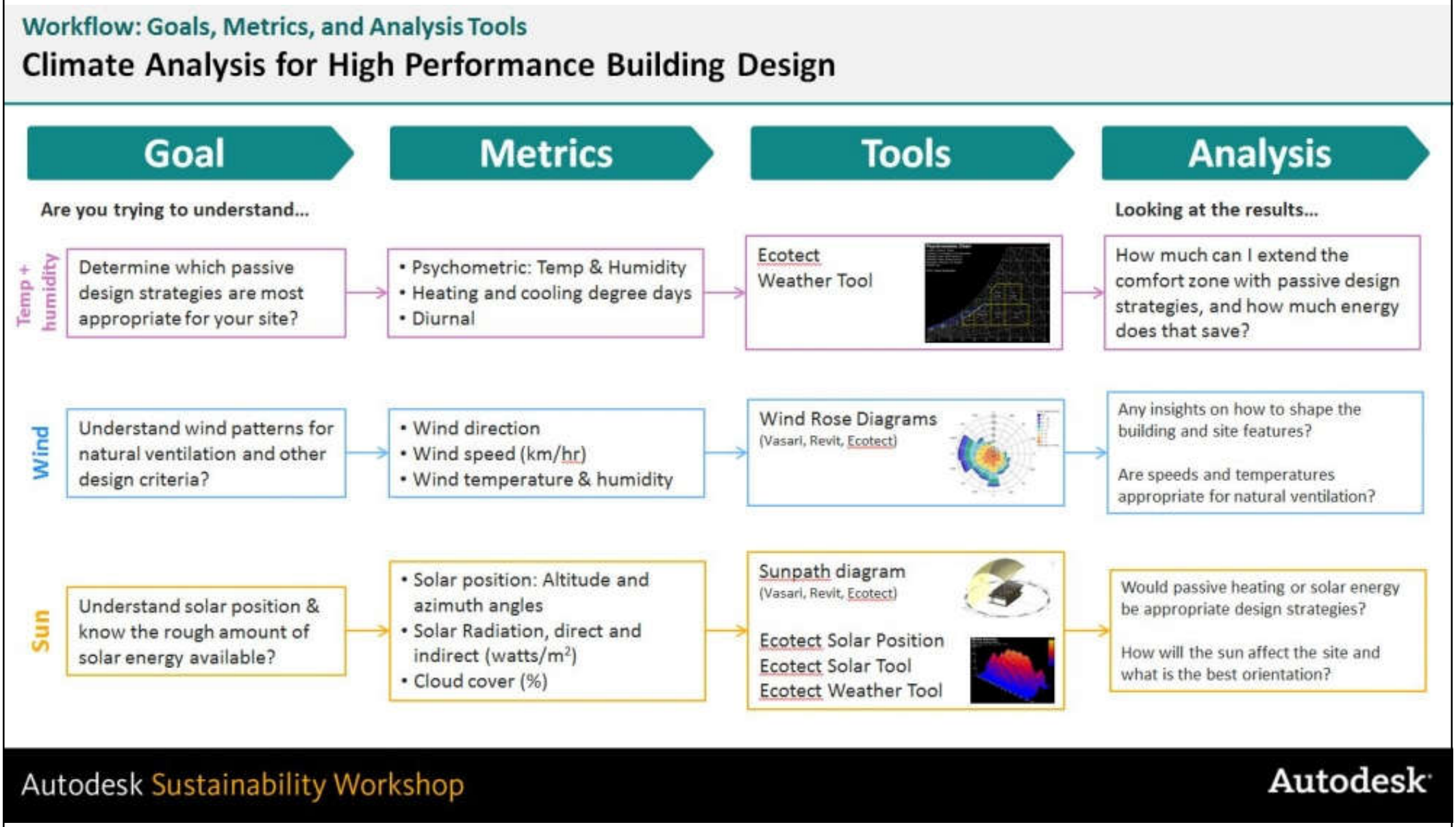
(Source: Autodesk)

Building performance analysis workflows



(Source: http://sustainabilityworkshop.autodesk.com/buildings/bpa-workflows)

Climate analysis



(Source: Autodesk)

Sun and shadow studies

Workflow Part 1: Goals, Metrics, and Analysis Tools

Sun and Shadow Studies for High Performance Building Design

Goal

Are you trying to...

Understand available sun for:
- Passive solar heating
- Daylighting
- Electricity generation
- Exterior spaces & courtyards

Get early insights on passive design strategies that can take advantage of the sun's heat and light:
- Massing and orientation
- Building Materials
- Openings
- Shading/façade design
- Site features

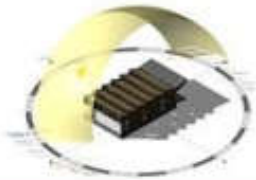
Metrics

Visual & Qualitative
- Solar position
  Azimuth and altitude angles
- Shadow visualizations
  Is sunlight where we want it? Based on still images and animations

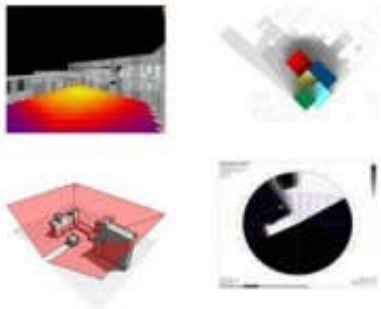
Detailed & Quantitative
- Sunlight hours on a surface
  # of hours
- Full shadow ranges
  Is sunlight where we want it?
- Right to light
  What is blocking solar access?
- Overshadowing
  Shading obstructions and % overshadowed.

Tools

Autodesk Revit or Vasari
Autodesk Ecotect



Autodesk Ecotect



Analysis

Looking at the results...

Based on your goals and climate, where and how should you focus future design efforts?
- *Problems:* Too much or not enough sun
- *Opportunities:* Free energy and light

Consider:
- *The context shading the building.*
- *The building shading the context.*
- *Shades and self-shading.*

Harness the sun's energy...
Solar Radiation Analysis

Harness the sun's light...
Solar Radiation Analysis

Autodesk Sustainability Workshop

Autodesk

(Source: Autodesk)

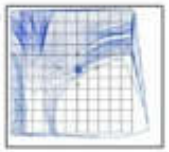
Sun and shadow studies (cont'd)

Workflow Part 2: Modeling, Simulation, and Visualization Settings

Autodesk Vasari - Sun and Shadow Studies for High Performance Building Design

Model

Model Site & Context
Surrounding buildings, site features, and topography.
Import underlay image



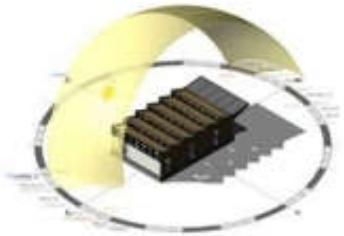
Set Location
Dictates latitude, longitude, and climate.

Building Geometry
If it exists
Mass model

Simulate

Sun Settings
Based on analysis goals
- *Times of day*
- *Seasons*
- *Extremes (solstices)*
- *Single day or range*

Visualize Shadows & Sun Path



Visualize

Still Images
A specific time and date
Export as image or screen clipping

Animations
A range of times or days
Export as movie file

Autodesk Sustainability Workshop

Autodesk

(Source: Autodesk)

Sun and shadow studies (cont'd)

Workflow Part 3: Modeling, Simulation, and Visualization Settings

Autodesk Ecotect - Sun and Shadow Studies for High Performance Building Design

Model

Model Site & Context
Surrounding buildings, site features, and topography. Import underlay image

Set Location
Dictates latitude, longitude, and climate.

Building Geometry
If it exists
Mass model - .xml
Detailed model - .fbx to .dxf

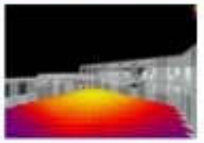
Simulate

Sun Settings
Based on analysis goals

- *Visualize Shadows (also in Vasari)*
- **Sunlight Hours**
  Hours of sunlight falling on a surface
- **Shadow Range**
  Full daily profile of the shadow path
- **Right to Light/ Solar Envelope**
  Access to daylight based on context
- **Overshadowing**
  What is shading the building when

Visualize

- Visualized on a grid or object
- Ensure comparable scale
- Study key surfaces like direct gain windows, or courtyards



- Ensure same time range
- Locate features like pools or landscaping

- Planes cut through model
- What blocks your access?
- Blocking others' access?
- Vertical sky component

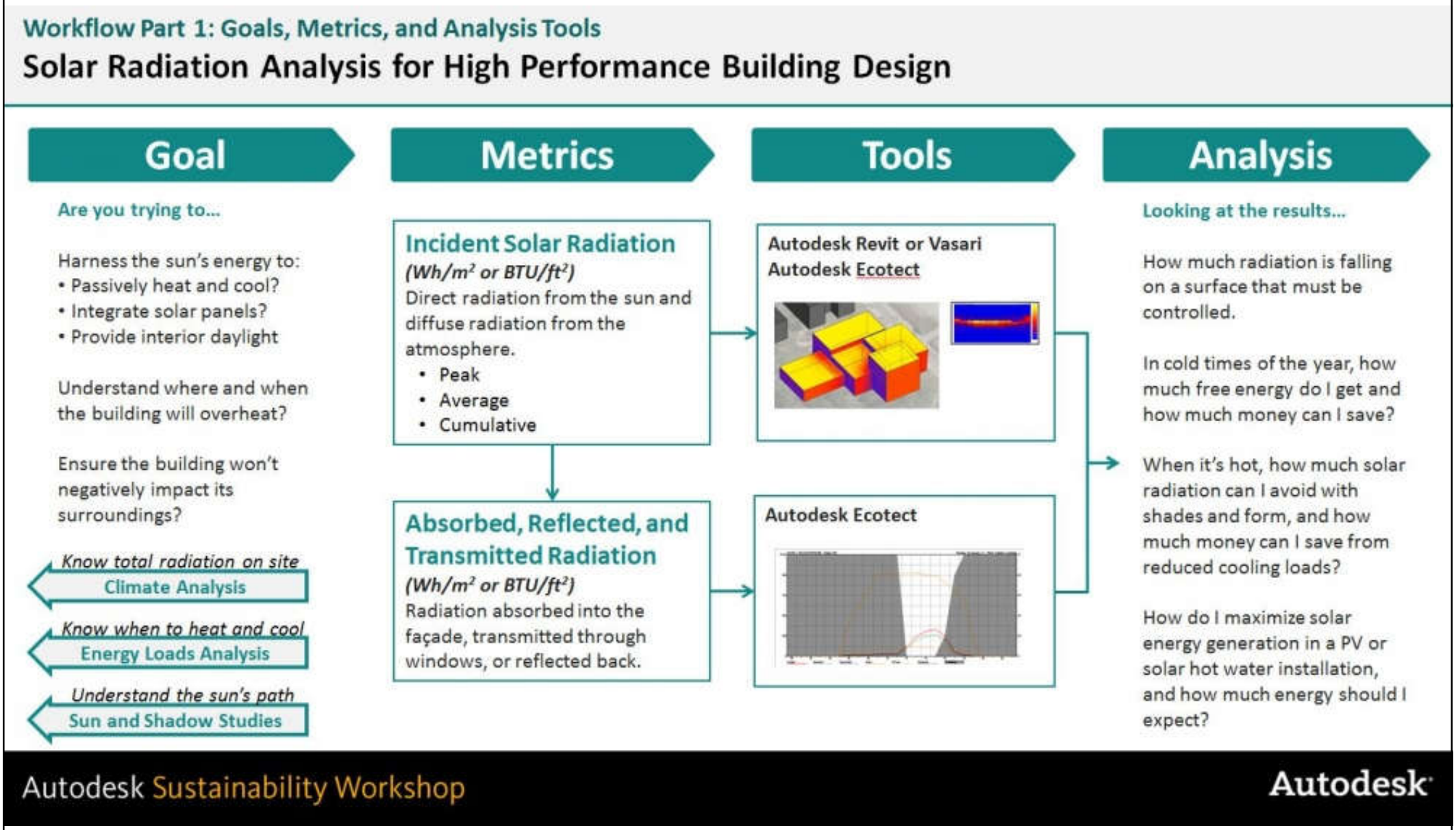
- Study points or surfaces
- What is the solar window?
- Percentage of a surface in sun or shade

Autodesk Sustainability Workshop

Autodesk

(Source: Autodesk)

Solar loads/solar radiation analysis



(Source: Autodesk)

Analysis of exterior airflow for buildings and building sites

Workflow Part 1: Goals, Metrics, and Analysis Tools

Exterior Airflow for Buildings and Building Sites: Vasari Wind Tunnel Tool

Goal

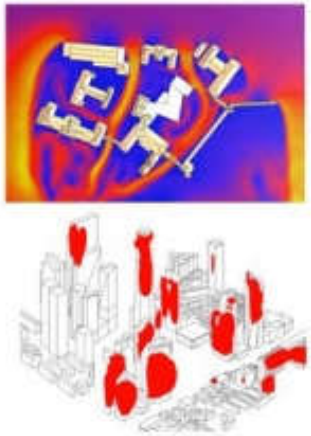
Are you trying to...

- Create comfortable outside areas and courtyards by strategically locating walls, trees, and landscaping?
- Design your building and site to reduce unwanted airflow acceleration on walkways?
- Get a basic understanding of where to place openings to get the most out of cross ventilation?
- Roughly estimate air pressure distribution on structures?

Metrics

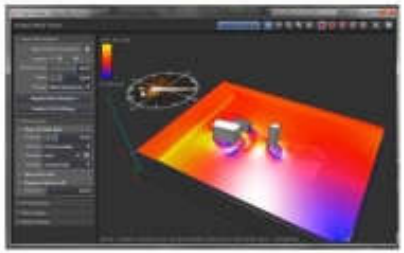
Rough qualitative comparison between design options of:

- Wind patterns (false color)
- Wind speeds (m/s)
- Pressures (Pa)



Tools

Vasari Wind Tunnel Tool



(Autodesk Simulation CFD should be used for more advanced and rigorous analysis.)

Analysis

Looking at the results:

- Are there areas that are getting too much or not enough airflow based on the design objectives?
- What is the ratio of the initial air velocity and the maximum air velocity on my site? Are there areas where the wind is being channeled and accelerated?
- In areas I want to shelter, what is the best relative airspeed reduction I can achieve?

(Source: Autodesk)

Analysis of exterior airflow for buildings and building sites (cont'd)

Workflow Part 2: Modeling, Simulation, and Visualization Settings

Vasari Wind Tunnel Tool for Exterior Airflow for Buildings and Building Sites

Model

Model Site Context
Surrounding buildings and topography (as masses)

Create Conceptual Mass Model
Exterior form, orientation on the site

Choose a Weather Station
Dictates wind data and rose diagram.

Simulate

Set Analysis Grid
- *Make boundary conditions large enough.*

Wind Speed & Direction
- *Use wind rose diagram data for guidance.*
- *Consider time of year & day*
- *Be careful of the scale & units*

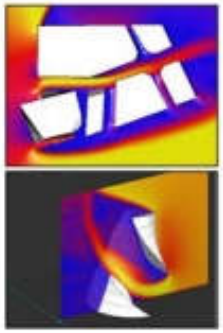
2D vs. 3D Analysis
- *3D analysis is recommended for more accurate results, but takes longer.*

Run the simulation until it stabilizes.
- *When the image is moving, it's not showing the wind. It's calculating.*

Visualize

(Screen captures are the only way to export data)

False-color 2D Slices Horizontal and Vertical
- *Qualitative differences in flow patterns.*
- *Clear visualizations of areas of interest (i.e. head height, wake of a building)*
- *Adjust color scales to probe and compare results*



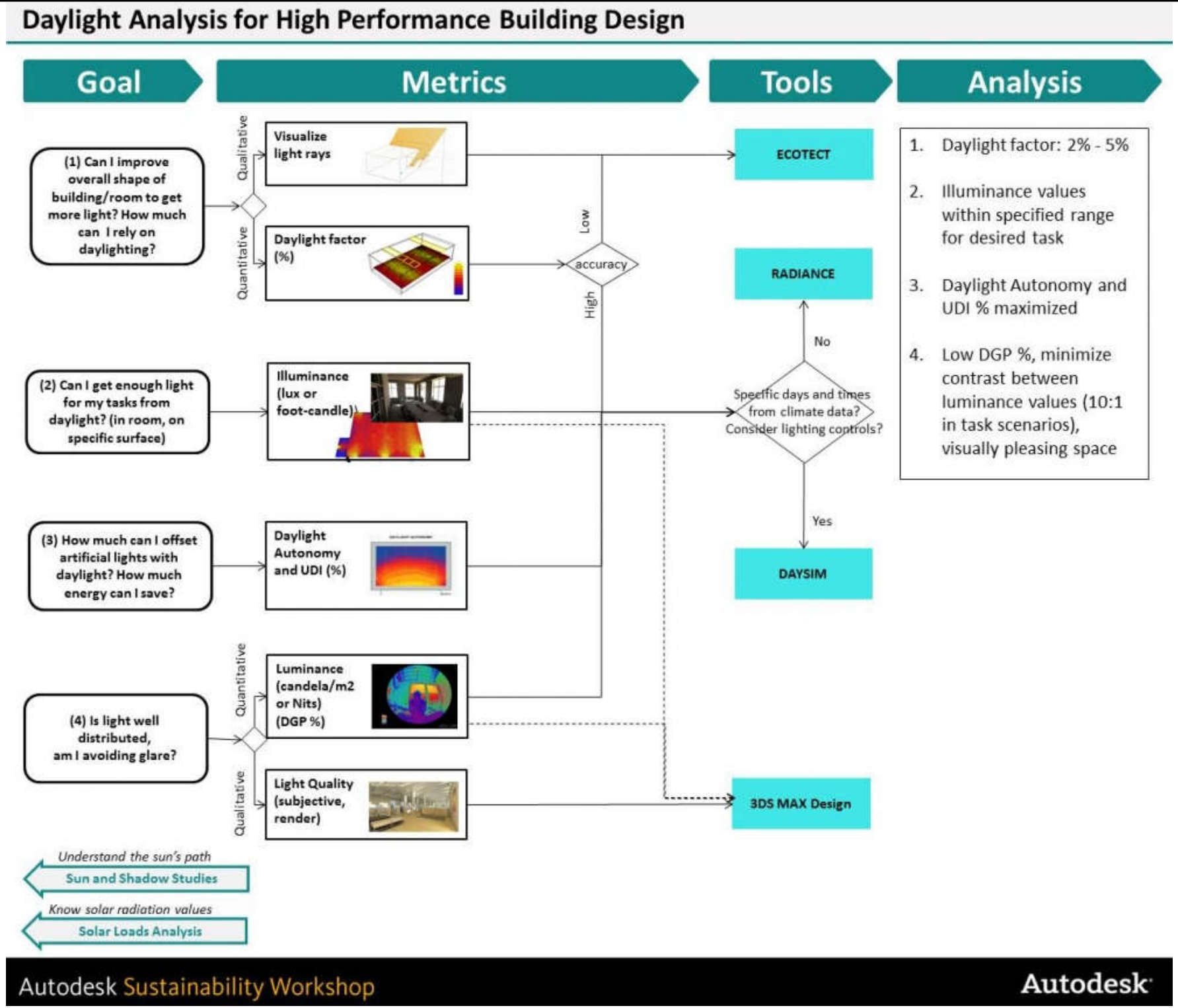
3D Volumetric Traces
- *More dynamic way of visualizing 3D flow.*

Point cloud & ISO Surf.
- *Interrogate the model to better understand patterns of specific speeds and pressures.*

Autodesk Sustainability Workshop

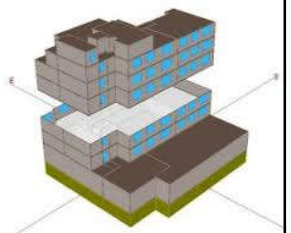
Autodesk

(Source: Autodesk)



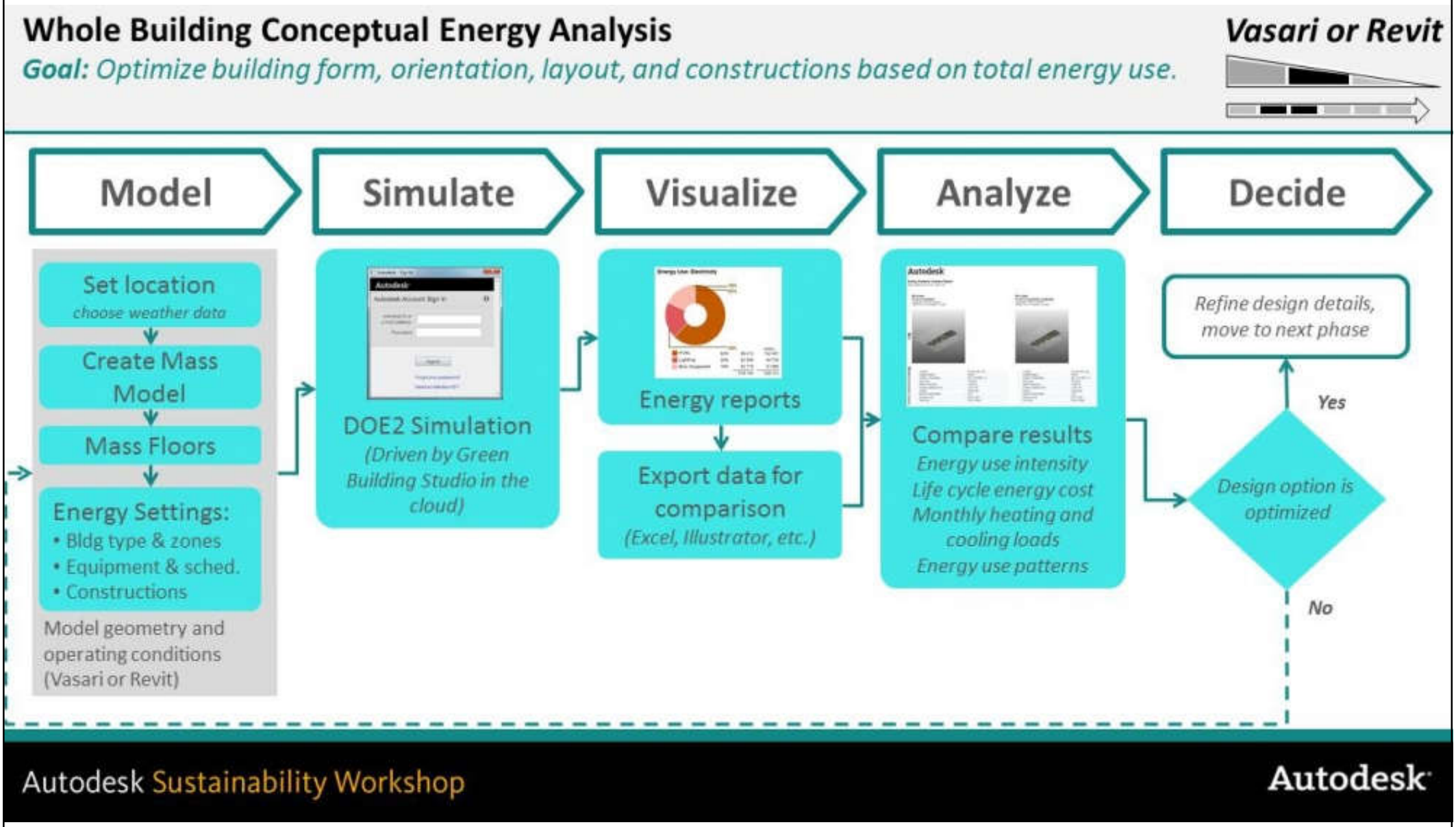
(Source: Autodesk)

Building performance analysis



- Whole building energy analysis
  - Simulate expected energy use in the building
  - Track the effectiveness of individual passive design strategies and energy efficiency measures
  - The sophistication and precision of the tools and analysis will increase as one moves along
    - Conceptual energy analysis (early design stage)
    - Detailed energy analysis
    - Energy retrofit analysis (for existing buidings)

Whole building conceptual energy analysis

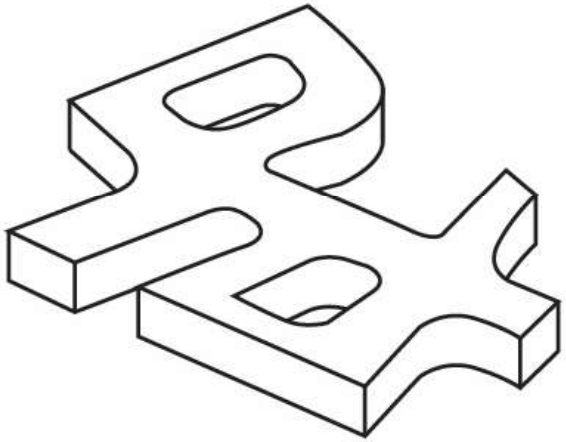


(Source: Autodesk)

Performance based conceptual design and energy analysis

1

Conceptual 3d Sketch



2

Project + Shared Parameters

-Creating Parametric Massing

-Tracking Program + Area

- Controlling Materials,

- Defining Environmental Control Systems

3

Conceptual Energy Analysis

-Orienting the Building Sensitive to the Solar Path

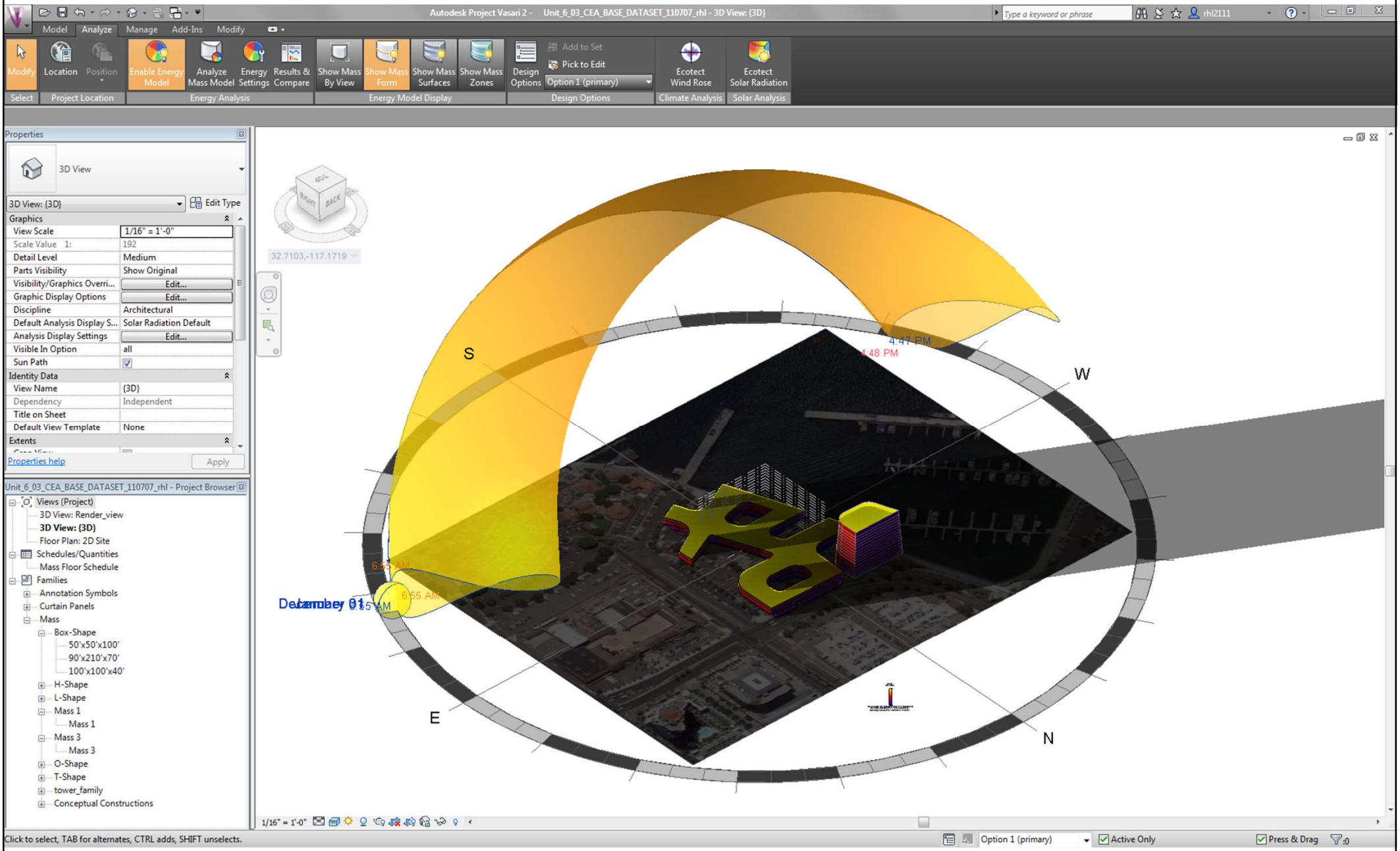
-Exploring Different Shading and Material Options

- Iterating through Design Options to Attain the Lowest Energy Use Intensity (EUI)

Do you know why conceptual energy analysis is important?

(Source: Autodesk)

Conceptual energy analysis: study how the sun affects the design



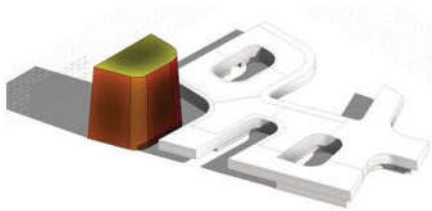
(Source: Autodesk)

Solar study and solar response for different design options

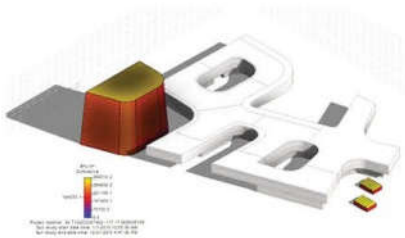
3.2

Main Building Solar Study

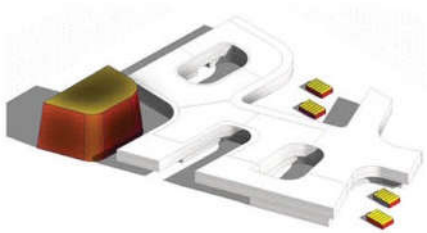
Tower Option A Solar Study



Tower Option B Solar Study



Tower Option C Solar Study

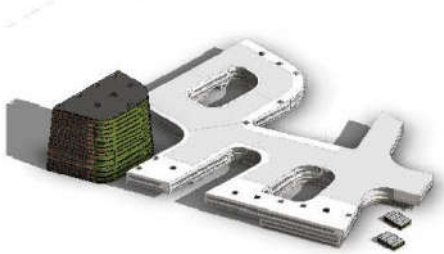


3.3

Main Building Solar Response

Tower Option A Solar Response

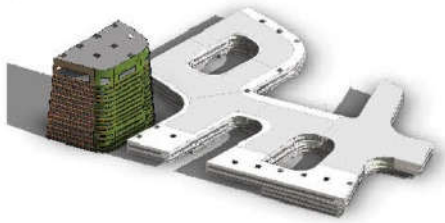
Tower Option B Solar Response



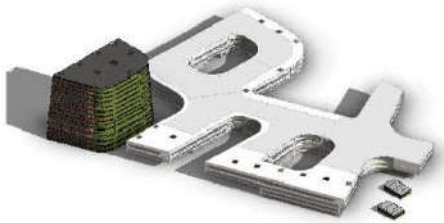
Tower Option C Solar Response

3.4

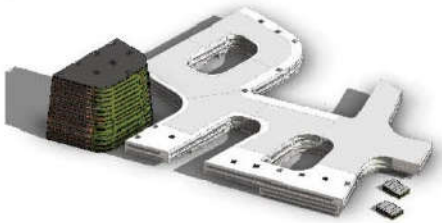
CEA of A Solar Response



CEA of B Solar Response

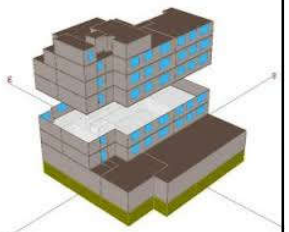


CEA of C Solar Response



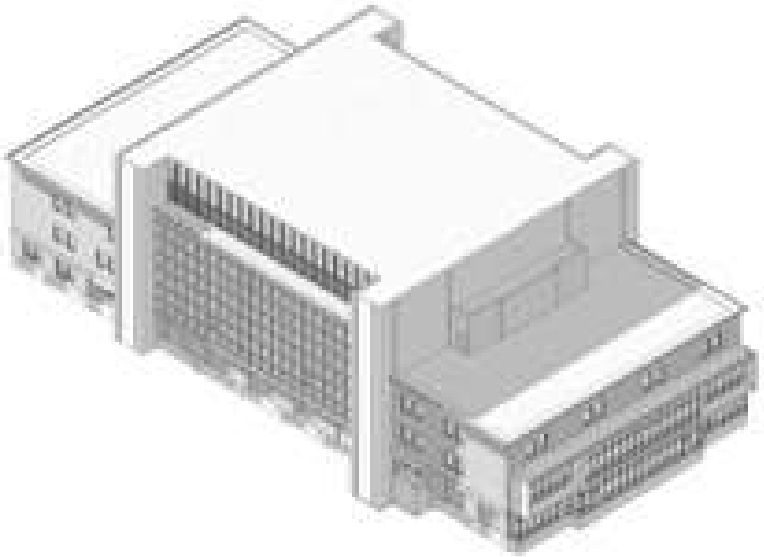
(Source: Autodesk)

Building performance analysis

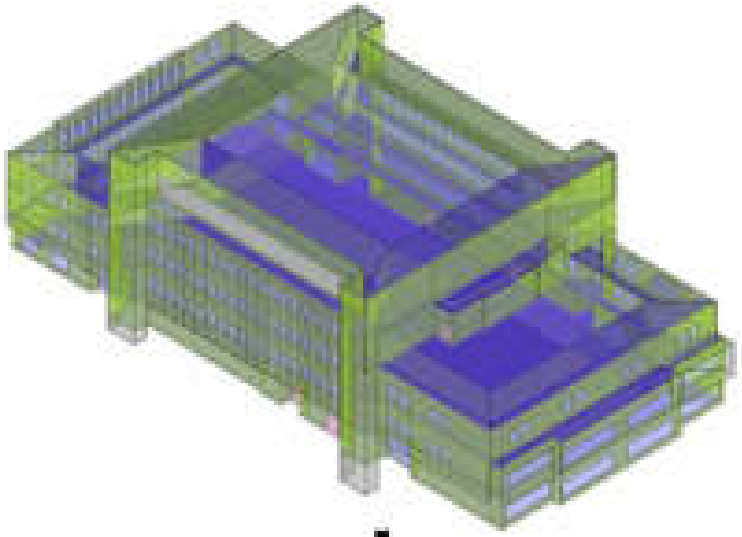


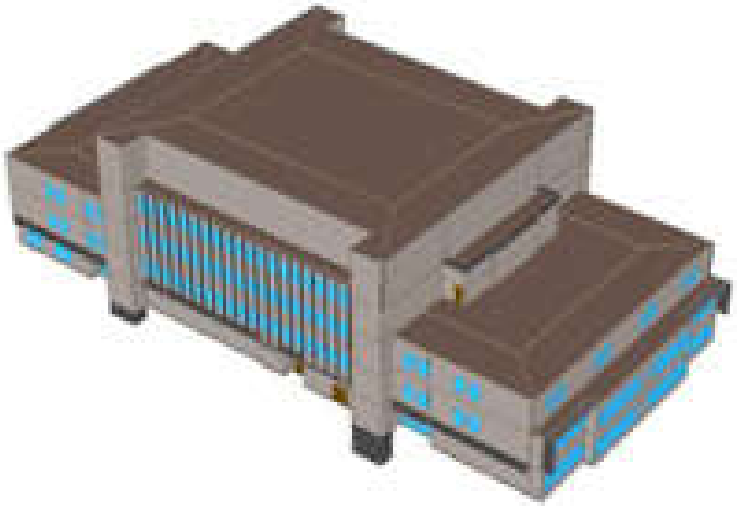
- Workflow of building energy analysis
  - Model geometry analysis (architectural elements)
  - Data input (energy model)
  - Dynamic energy calculation
  - Result sheet
- Early design phase:
  - Quick evaluation for different design solutions
- Detailed design phase:
  - Standard-compliance analysis

Architectural building elements

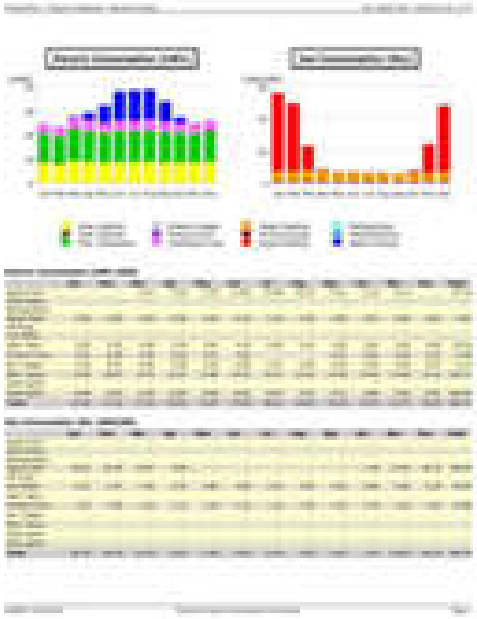


Energy analytical model





Energy model viewed in eQUEST



Energy analysis results

(Source: Autodesk)

Shading & Peak Load Reduction

Glare & Visual Comfort

Electric Lighting Design & Integration

Computational Fluid Dynamics (CFD)

Life Cycle Cost Analysis (LCCA)

Two Dimensional Heat Flow Modeling

Hygrothermal Modeling

Fenestration Design & Analysis

Assembly Detailing & Specification

EnergyPlus Software

Iterative Whole Building Energy Simulation

Cooling Load Reduction Analysis

HVAC System Optimization

Energy Consumption Optimization

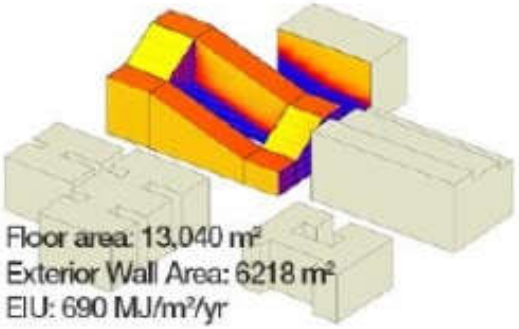
Thermal Comfort Analysis

Passive Systems Integration

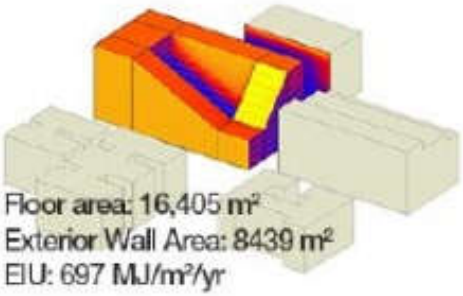
(Source: www.synergyefficiency.solutions)

Autodesk Vasari

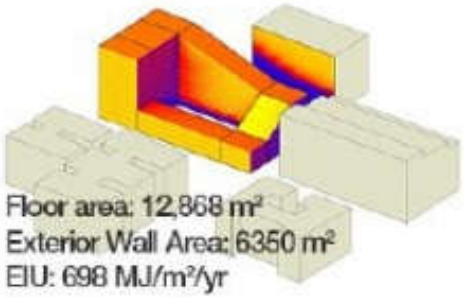
COURTYARD STUDY



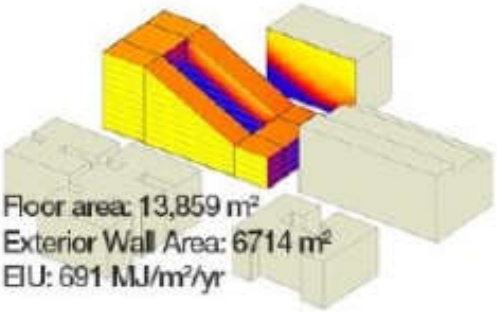
Floor area: 13,040 m²
Exterior Wall Area: 6218 m²
EIU: 690 MJ/m²/yr



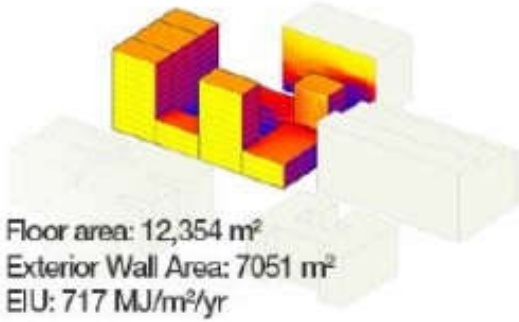
Floor area: 16,405 m²
Exterior Wall Area: 8439 m²
EIU: 697 MJ/m²/yr



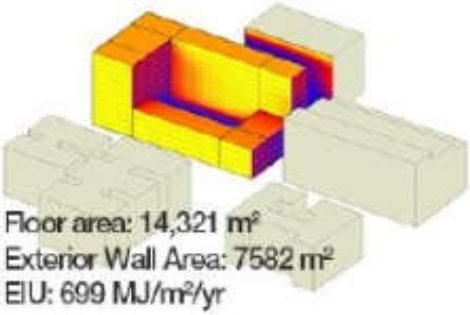
Floor area: 12,868 m²
Exterior Wall Area: 6350 m²
EIU: 698 MJ/m²/yr



Floor area: 13,859 m²
Exterior Wall Area: 6714 m²
EIU: 691 MJ/m²/yr

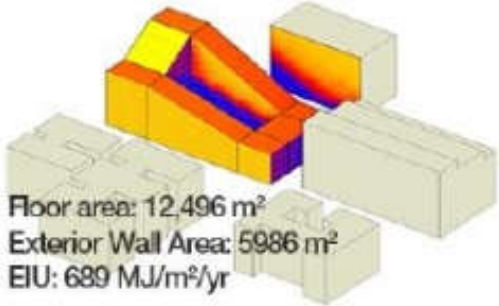


Floor area: 12,354 m²
Exterior Wall Area: 7051 m²
EIU: 717 MJ/m²/yr



Floor area: 14,321 m²
Exterior Wall Area: 7582 m²
EIU: 699 MJ/m²/yr

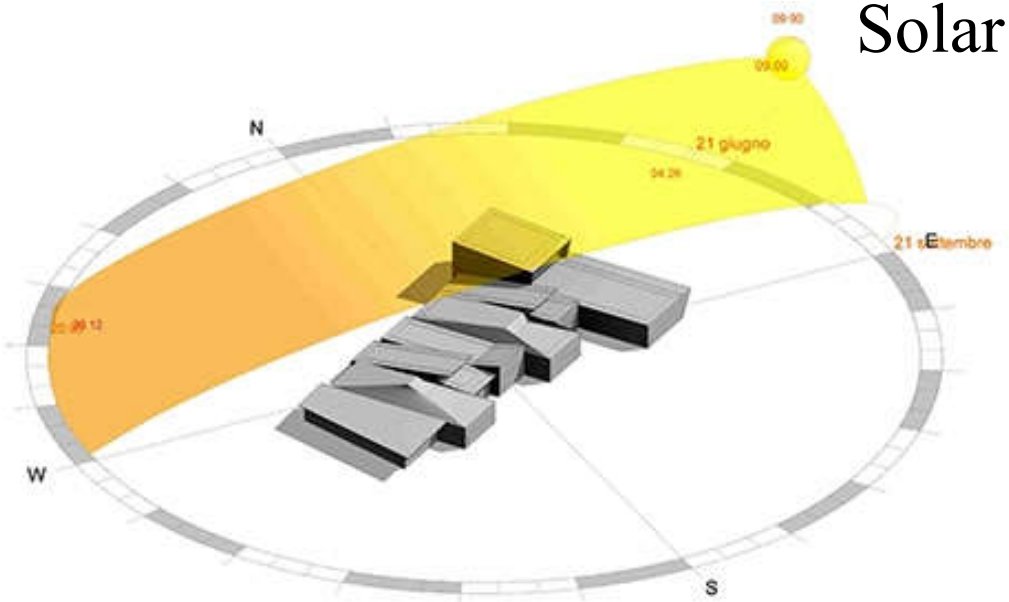
Floor area: 14,321 m²
Exterior Wall Area: 8882 m²
EIU: 699 MJ/m²/yr

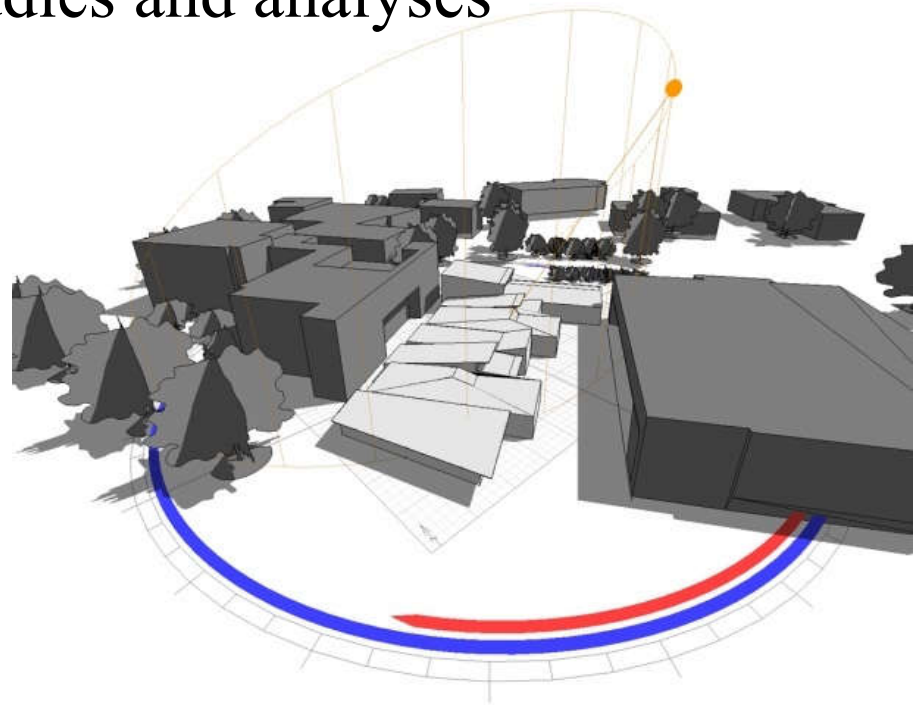


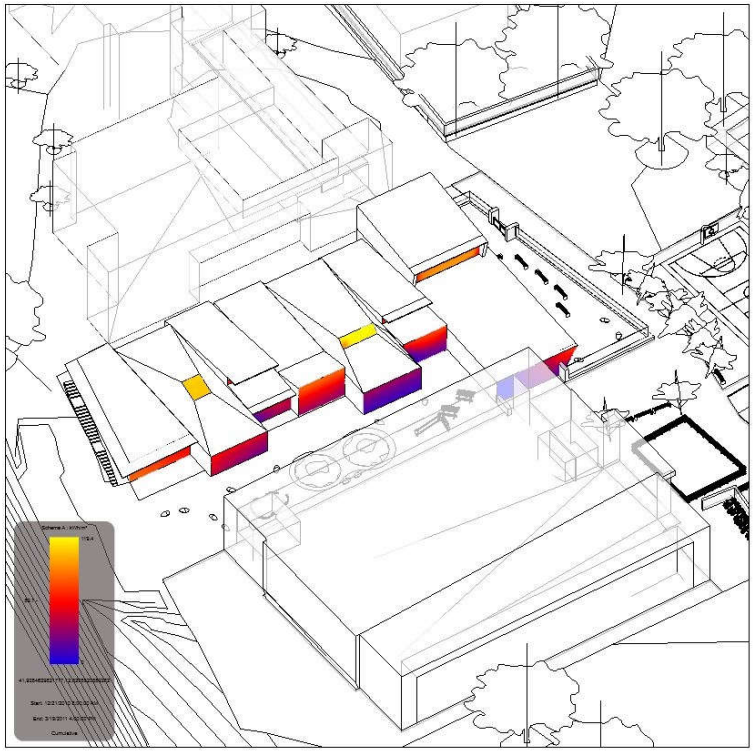
Floor area: 12,496 m²
Exterior Wall Area: 5986 m²
EIU: 689 MJ/m²/yr

(Source: Autodesk)

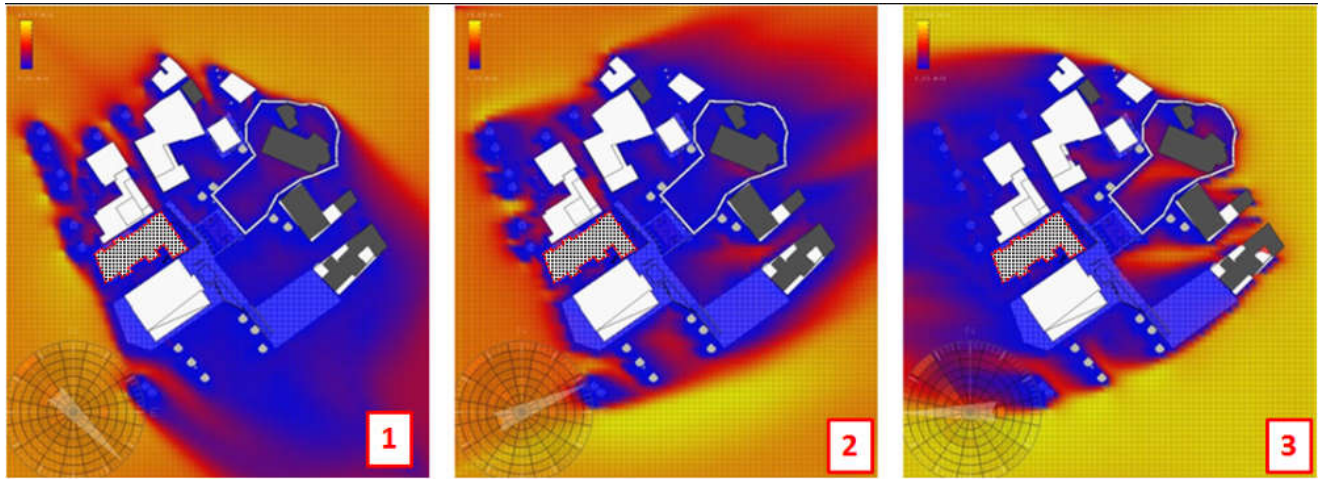
Solar studies and analyses







Solar insolation

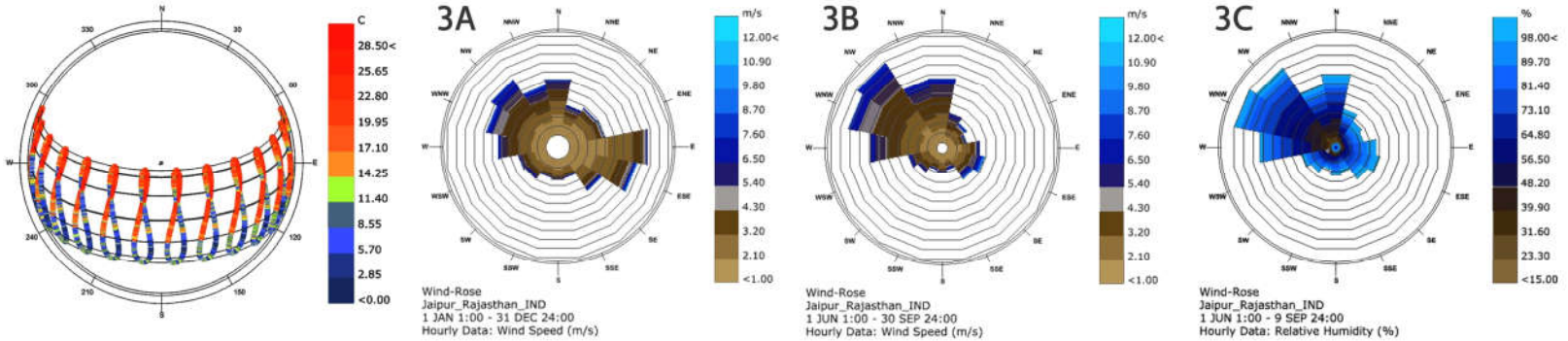


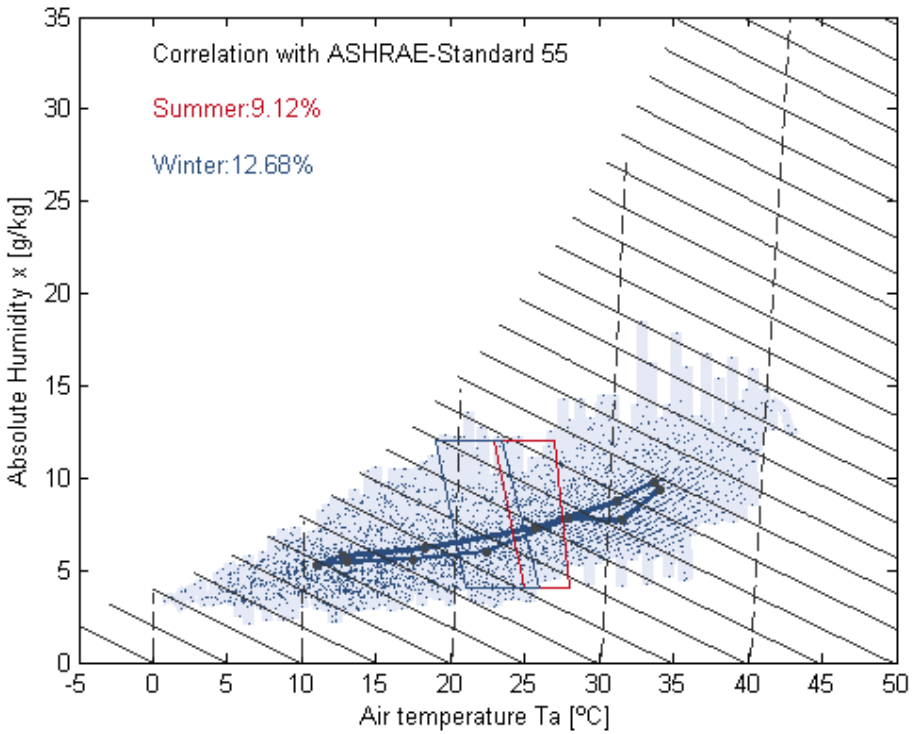
Wind tunnel analysis

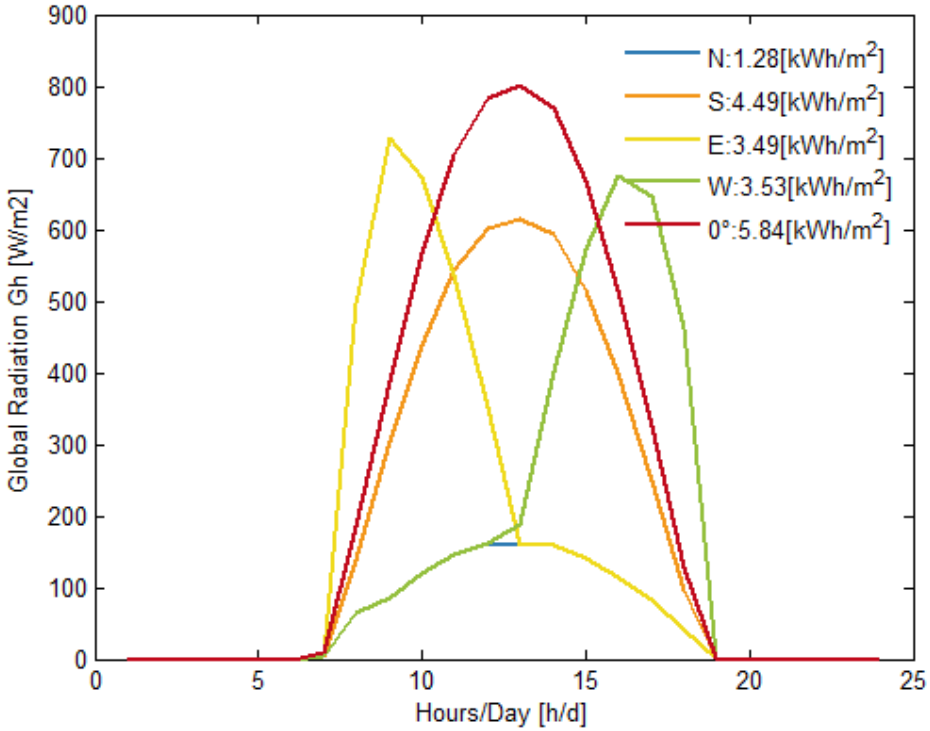
(Source: Autodesk)

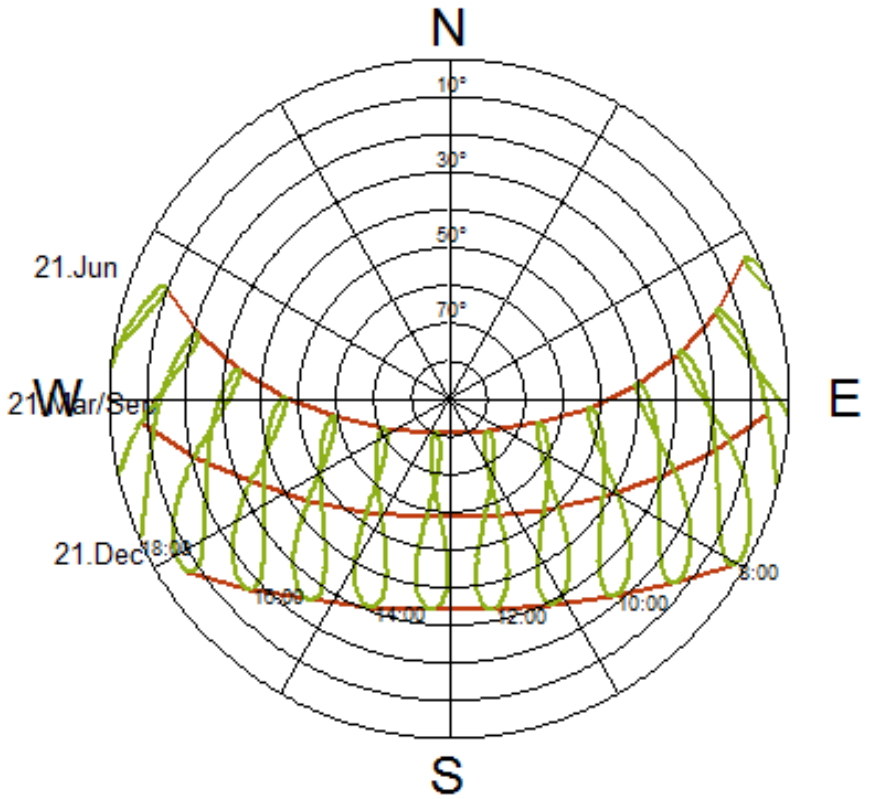
Climate analysis examples

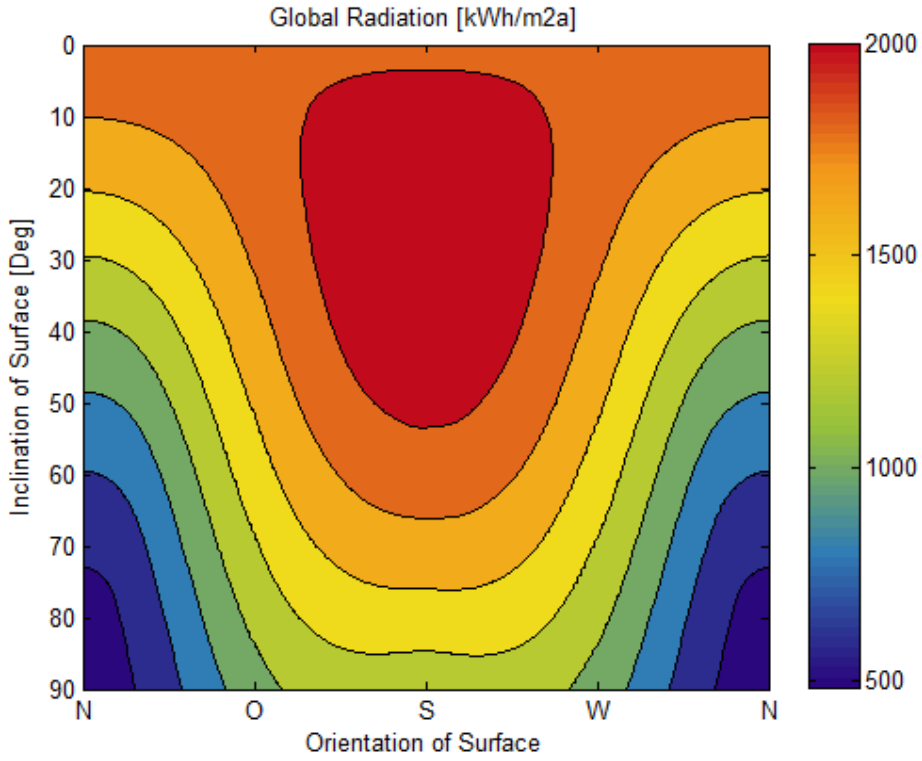
- Climate can influence building design and dictate what passive design strategies are most suitable and effective for the building site
  - Climate refers to the average atmospheric conditions over a long period of time
  - Weather refers to the daily temperatures and atmospheric conditions



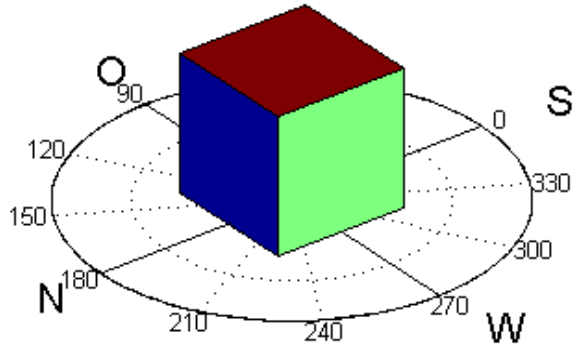

Correlation with ASHRAE-Standard 55
Summer:9.12%
Winter:12.68%
Absolute Humidity x [g/kg]
Air temperature Ta [°C]

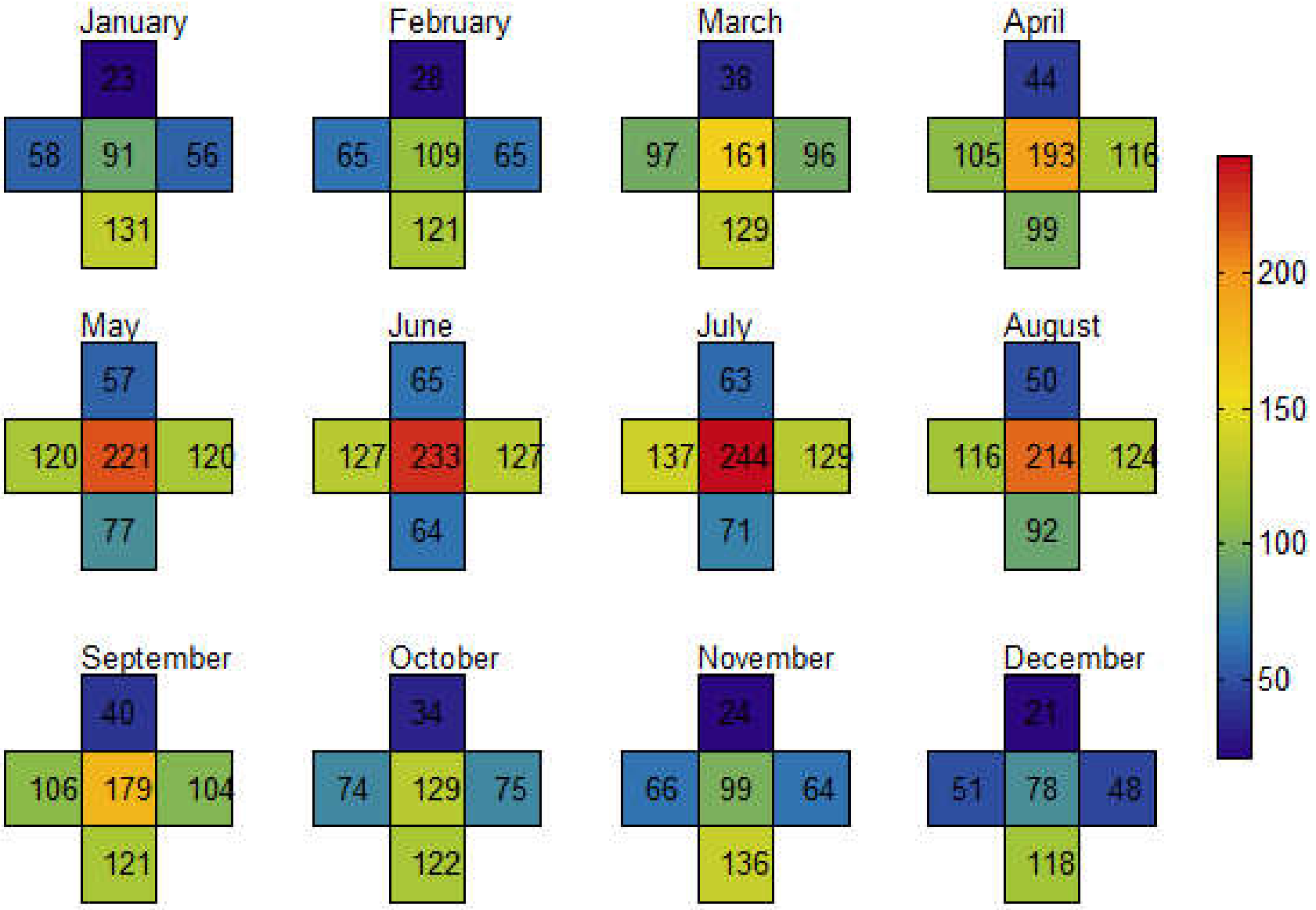

N:1.28[kWh/m²]
S:4.49[kWh/m²]
E:3.49[kWh/m²]
W:3.53[kWh/m²]
0°:5.84[kWh/m²]
Global Radiation Gh [W/m2]
Hours/Day [h/d]


N
S
W
E
21.Jun
21.Mar/Sep
21.Dec

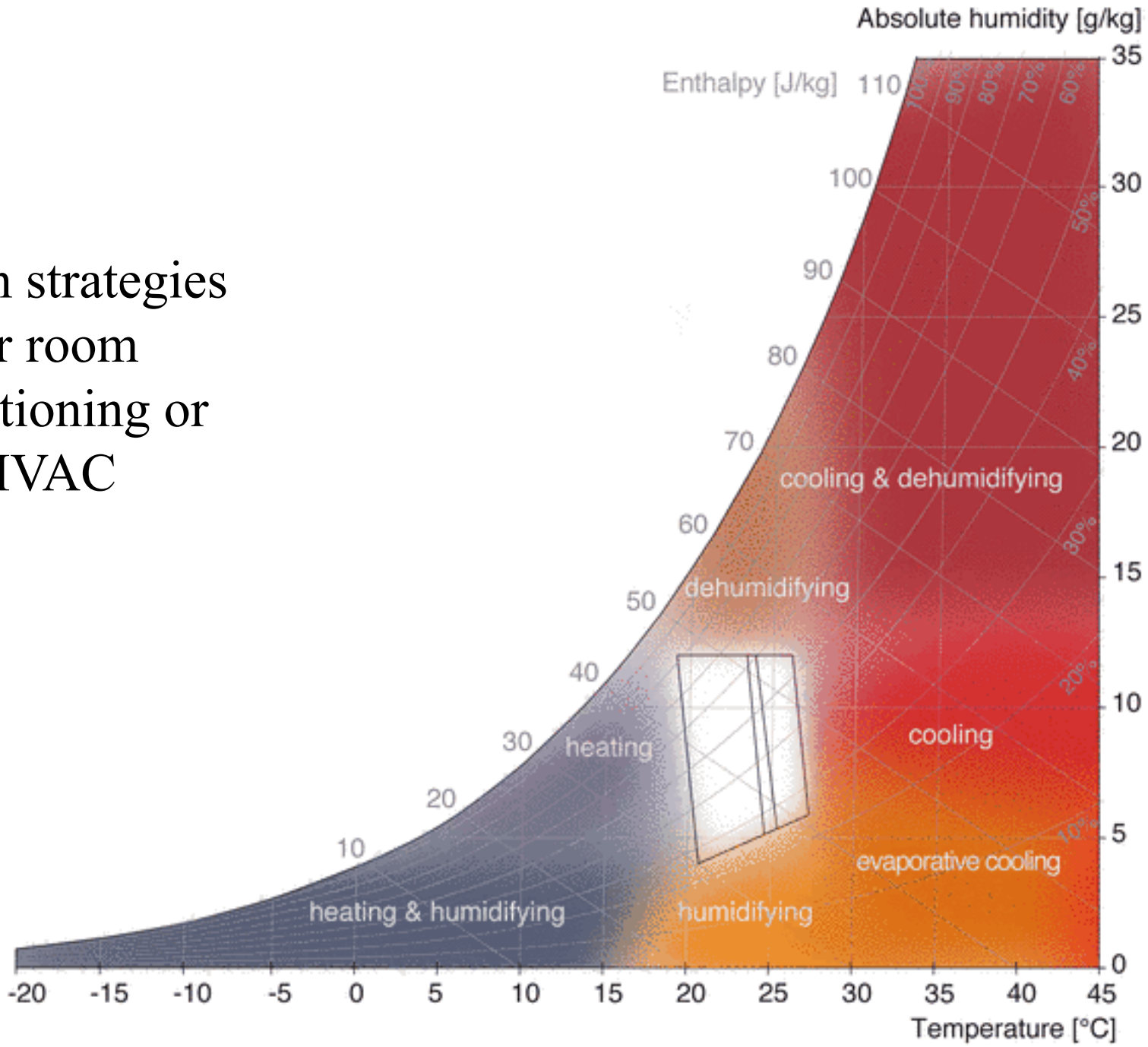

Global Radiation [kWh/m2a]
Inclination of Surface [Deg]
Orientation of Surface
N
O
S
W
N

Solar radiation analysis (façade month)





Design strategies for room conditioning or HVAC



Room conditioning according to the outdoor climate shown in psychometric chart
(cf. Olgay, 1963)

Liedl, 2011
www.climate-tool.com

Climate analysis examples

- Energy Design Tools, University of California, Los Angeles (UCLA)
  - http://www.energy-design-tools.aud.ucla.edu/
  - Climate Consultant (version 6.0)
    - Organize and represent climate information in easy-to-understand ways that show the subtle attributes of climate, and its impact on built form
    - http://www.energy-design-tools.aud.ucla.edu/climate-consultant/request-climate-consultant.php
    - Video: Climate Consultant V6.10 (20:46) https://youtu.be/bc0dIPP0SBg

Climate Consultant 5.5 (Build 5, Sep 3, 2014)

File Criteria Charts Help

WEATHER DATA SUMMARY

LOCATION: HONG KONG, SAR, CHN
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	235	239	244	268	280	288	373	340	329	353	316	286	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	159	123	112	107	133	146	243	201	186	267	251	233	Wh/sq.m
Diffuse Radiation (Avg Hourly)	142	157	161	185	173	178	182	187	186	176	163	155	Wh/sq.m
Global Horiz Radiation (Max Hourly)	717	856	881	919	969	936	972	953	933	864	797	725	Wh/sq.m
Direct Normal Radiation (Max Hourly)	780	794	750	728	751	735	754	752	774	799	803	795	Wh/sq.m
Diffuse Radiation (Max Hourly)	323	367	401	414	407	411	411	411	397	370	335	309	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	2538	2691	2906	3370	3670	3855	4925	4331	3999	4048	3460	3056	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	1719	1387	1335	1354	1745	1952	3216	2558	2270	3063	2746	2482	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	1533	1763	1921	2325	2269	2375	2407	2381	2263	2016	1787	1659	Wh/sq.m
Global Horiz Illumination (Avg Hourly)													lux
Direct Normal Illumination (Avg Hourly)													lux
Dry Bulb Temperature (Avg Monthly)	16	16	19	22	26	27	28	28	27	25	21	17	degrees C
Dew Point Temperature (Avg Monthly)	11	12	15	19	22	25	24	24	23	19	15	10	degrees C
Relative Humidity (Avg Monthly)	74	80	82	84	81	84	79	81	80	72	69	66	percent
Wind Direction (Monthly Mode)	90	90	100	90	60	90	250	240	80	90	90	90	degrees
Wind Speed (Avg Monthly)	2	3	2	3	2	3	3	2	3	3	2	2	m/s
Ground Temperature (Avg Monthly of 3 Depths)	18	19	20	21	24	26	26	26	25	23	20	19	degrees C

Climate Consultant 5.5 (Build 5, Sep 3, 2014)

File Criteria Charts Help

CRITERIA: (Metric Units)

LOCATION: **HONG KONG, SAR, CHN**
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

ASHRAE Standard 55, current Handbook of Fundamentals Comfort Model (select Help for definitions)

1. COMFORT: (using ASHRAE Standard 55)

1.0	Winter Clothing Indoors (1.0 Clo=long pants,sweater)
0.5	Summer Clothing Indoors (.5 Clo=shorts,light top)
1.1	Activity Level Daytime (1.1 Met=sitting,reading)
90.0	Predicted Percent of People Satisfied (100 - PPD)
20.3	Comfort Lowest Winter Temp calculated by PMV model(ET* C)
24.3	Comfort Highest Winter Temp calculated by PMV model(ET* C)
26.7	Comfort Highest Summer Temp calculated by PMV model(ET* C)
84.6	Maximum Humidity calculated by PMV model (%)

2. SUN SHADING ZONE: (Defaults to Comfort Low)

23.8	Min. Dry Bulb Temperature when Need for Shading Begins (°C)
315.5	Min. Global Horiz. Radiation when Need for Shading Begins (Wh/sq.m)

3. HIGH THERMAL MASS ZONE:

8.3	Max. Outdoor Temperature Difference above Comfort High (°C)
1.7	Min. Nighttime Temperature Difference below Comfort High (°C)

4. HIGH THERMAL MASS WITH NIGHT FLUSHING ZONE:

16.7	Max. Outdoor Temperature Difference above Comfort High (°C)
1.7	Min. Nighttime Temperature Difference below Comfort High (°C)

5. DIRECT EVAPORATIVE COOLING ZONE: (Defined by Comfort Zone)

20.0	Max. Wet Bulb set by Max. Comfort Zone Wet Bulb (°C)
6.6	Min. Wet Bulb set by Min. Comfort Zone Wet Bulb (°C)

6. TWO-STAGE EVAPORATIVE COOLING ZONE:

50.0	% Efficiency of Indirect Stage

7. NATURAL VENTILATION COOLING ZONE:

2.0	Terrain Category to modify Wind Speed (2=suburban)
0.2	Min. Indoor Velocity to Effect Indoor Comfort (m/s)
1.5	Max. Comfortable Velocity (per ASHRAE Std. 55) (m/s)

8. FAN-FORCED VENTILATION COOLING ZONE:

0.8	Max. Mechanical Ventilation Velocity (m/s)
3.0	Max. Perceived Temperature Reduction (°C)
	(Min Vel, Max RH, Max WB match Natural Ventilation)

9. INTERNAL HEAT GAIN ZONE (lights, people, equipment):

12.8	Balance Point Temperature below which Heating is Needed (°C)

10. PASSIVE SOLAR DIRECT GAIN LOW MASS ZONE:

157.7	Min. South Window Radiation for 5.56°C Temperature Rise (Wh/sq.m)
3.0	Thermal Time Lag for Low Mass Buildings (hours)

11. PASSIVE SOLAR DIRECT GAIN HIGH MASS ZONE:

157.7	Min. South Window Radiation for 5.56°C Temperature Rise (Wh/sq.m)
12.0	Thermal Time Lag for High Mass Buildings (hours)

12. WIND PROTECTION OF OUTDOOR SPACES:

8.5	Velocity above which Wind Protection is Desirable (m/s)
11.1	Dry Bulb Temperature Above or Below Comfort Zone (°C)

13. HUMIDIFICATION ZONE: (defined by and below Comfort Zone)

14. DEHUMIDIFICATION ZONE: (defined by and above Comfort Zone)

Climate Consultant 5.5 (Build 5, Sep 3, 2014)

File Criteria Charts Help

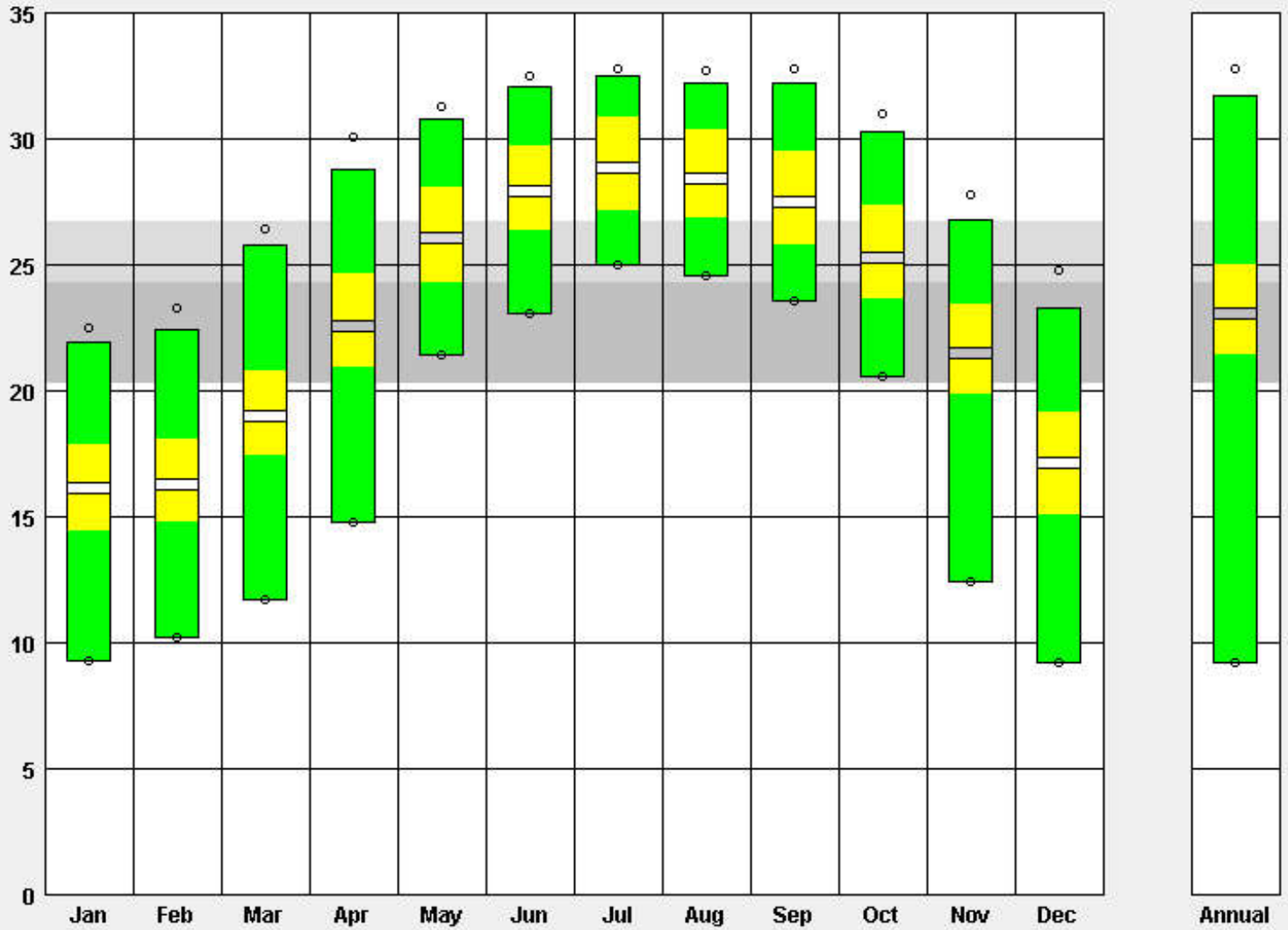
TEMPERATURE RANGE
ASHRAE Standard 55

LOCATION: **HONG KONG, SAR, CHN**
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

RECORDED HIGH -
DESIGN HIGH -
AVERAGE HIGH -
MEAN -
AVERAGE LOW -
DESIGN LOW -
RECORDED LOW -

COMFORT ZONE
SUMMER
WINTER
(At 50% Relative Humidity)



DESIGN HIGH:
- 1% of Hours Above
- .5% of Hours Above
- 0% of Hours Above

DESIGN LOW:
- 1% of Hours Below
- .5% of Hours Below
- 0% of Hours Below

TEMPERATURE RANGE:
- -10 to 40 °C
- Fit to Data

Climate Consultant 5.5 (Build 5, Sep 3, 2014)

File Criteria Charts Help

MONTHLY DIURNAL AVERAGES
ASHRAE Standard 55

LOCATION: **HONG KONG, SAR, CHN**
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

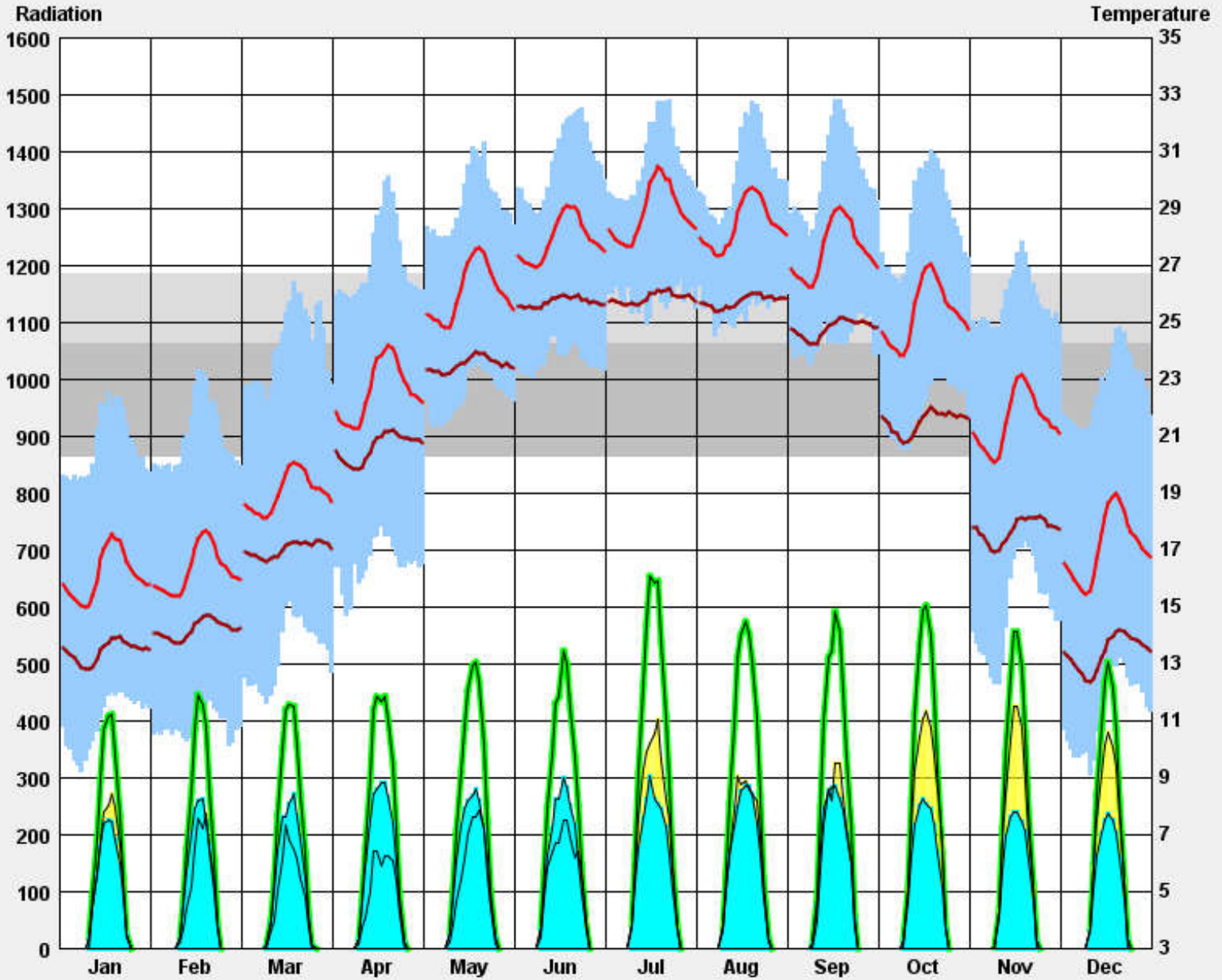
HOURLY AVERAGES

TEMPERATURE: (degrees C)
- DRY BULB MEAN
- WET BULB MEAN
- DRY BULB (all hours)

COMFORT ZONE
- SUMMER
- WINTER

(At 50% Relative Humidity)

RADIATION: (Wh/sq.m)
- GLOBAL HORIZ
- DIRECT NORMAL
- DIFFUSE



☑ Display Dry Bulb Temp (all hours)

TEMPERATURE RANGE:
- ○ -10 to 40 °C
- ◉ Fit to Data

Climate Consultant 5.5 (Build 5, Sep 3, 2014)

File Criteria Charts Help

RADIATION RANGE

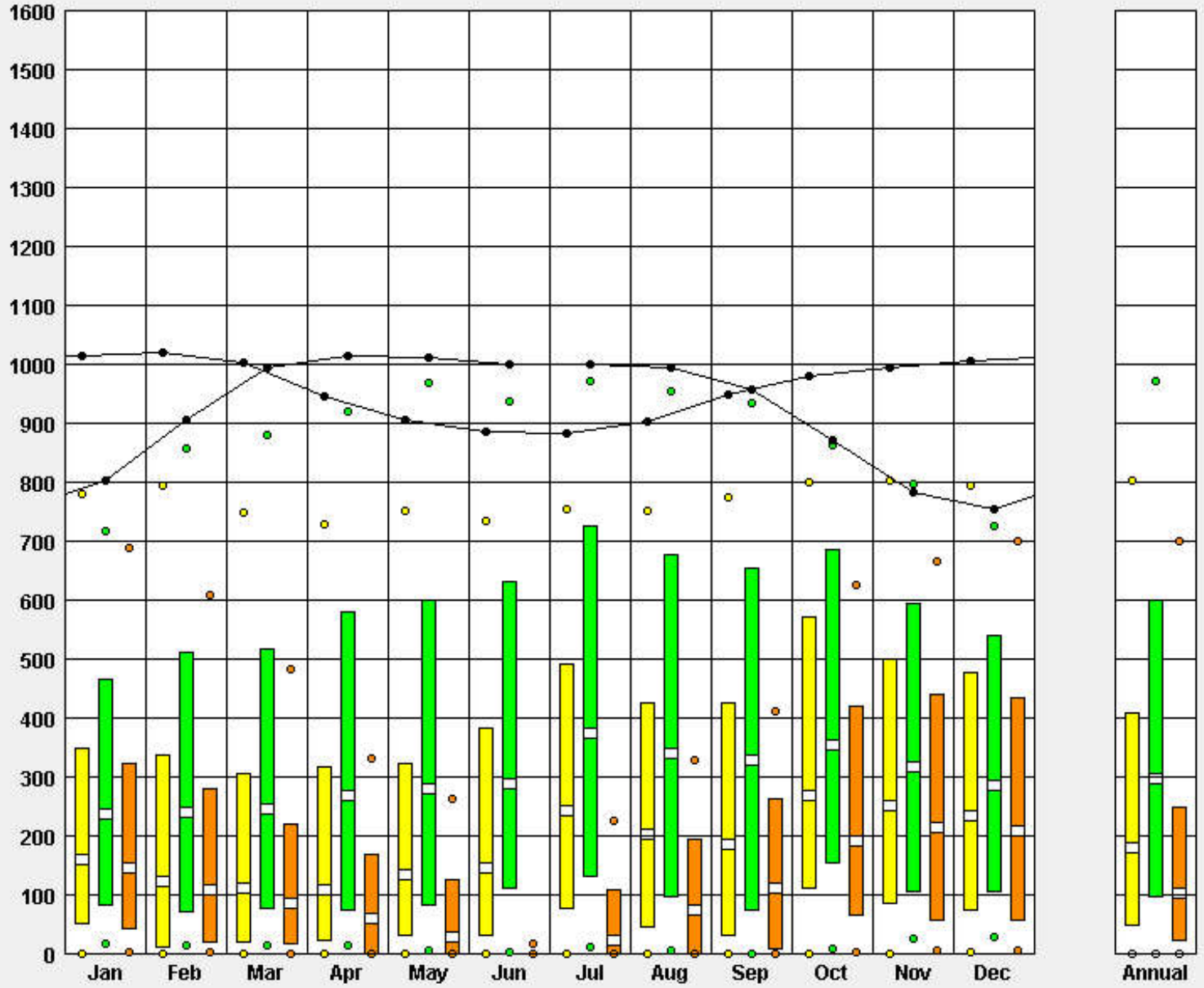
LOCATION: **HONG KONG, SAR, CHN**
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

HOURLY AVERAGES
DAYLIT HOURS ONLY

RECORDED HIGH -
AVERAGE HIGH -
MEAN -
AVERAGE LOW -
RECORDED LOW -

RECORDED:
DIRECT NORMAL
GLOBAL HORIZONTAL
TOTAL SURFACE
(Wh/sq.m per hour)
THEORETICAL:



Tilted Surface Radiation Input:

90.0 Tilt degrees from Horizontal
(Vertical = 90°)

0.0 Bearing degrees from South
(South = 0°,West = +90°)

20.0 % Ground Reflectance
(20% = grass)

PLOT:
(•) Hourly Avg ( ) Daily Total

Climate Consultant 5.5 (Build 5, Sep 3, 2014)

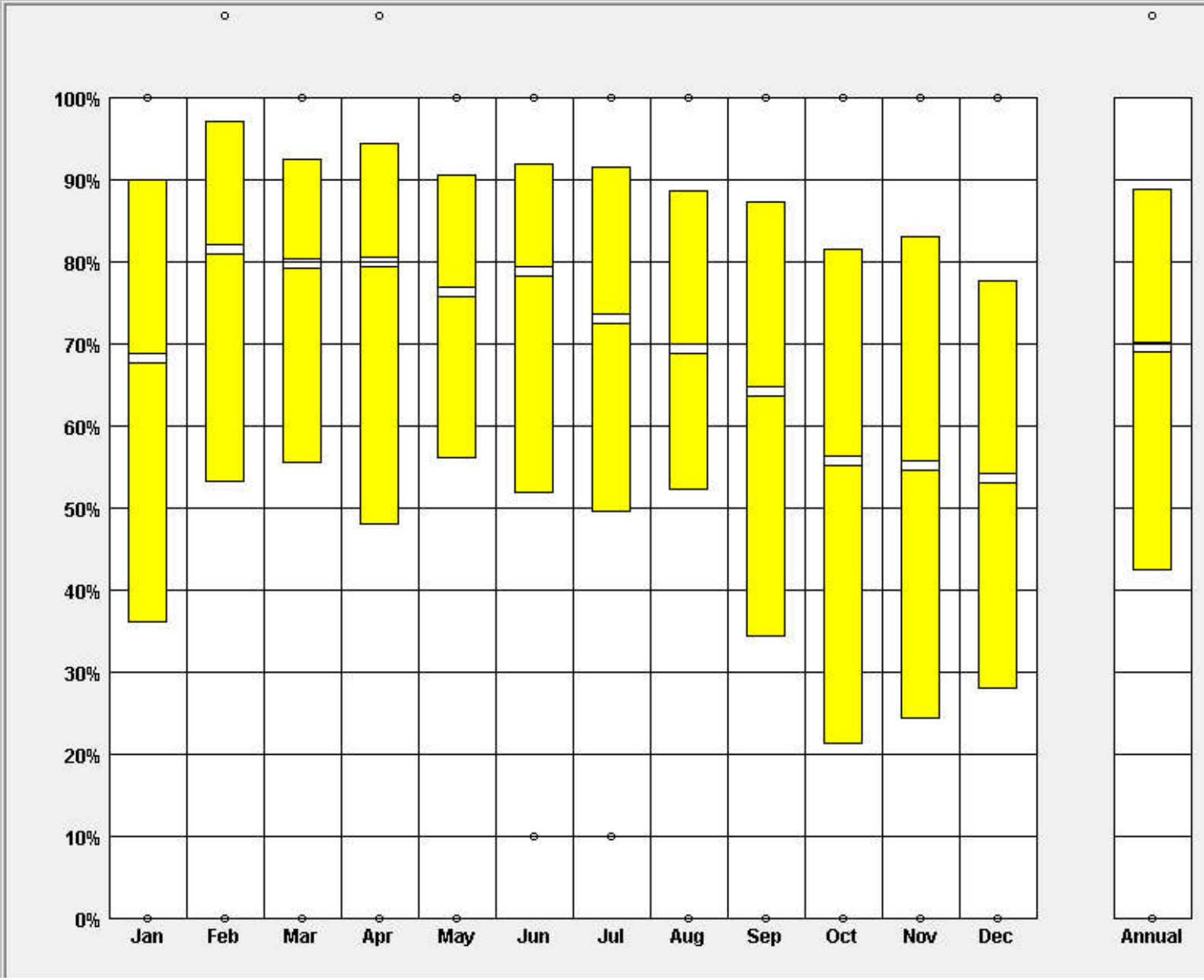
File Criteria Charts Help

SKY COVER RANGE

LOCATION: **HONG KONG, SAR, CHN**
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

Total Cloud Cover	100%
RECORDED HIGH -	○
AVERAGE HIGH -	▭
MEAN -	▭
AVERAGE LOW -	▭
RECORDED LOW -	○
Clear Skies	0



Climate Consultant 5.5 (Build 5, Sep 3, 2014)

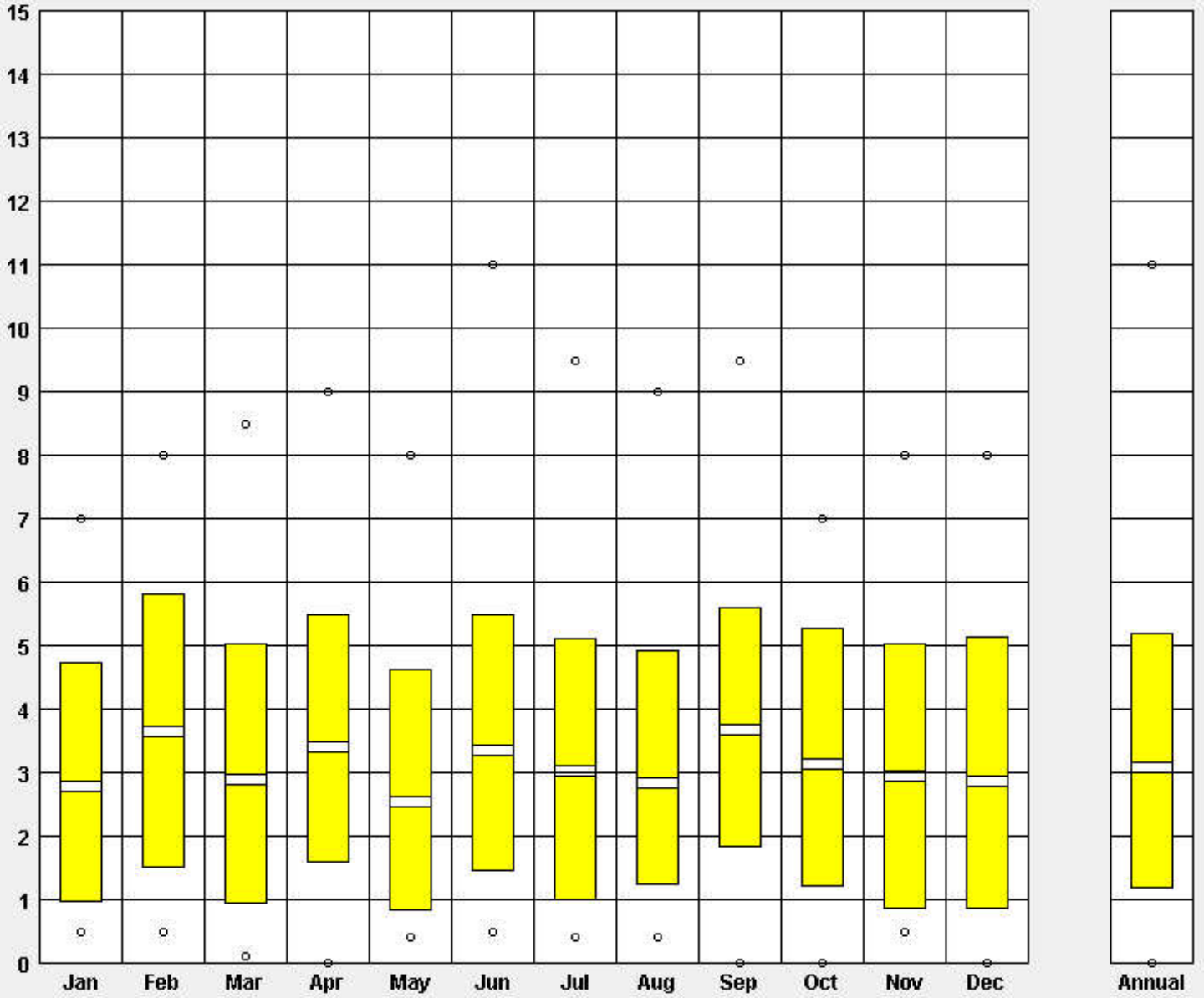
File Criteria Charts Help

WIND VELOCITY RANGE

LOCATION: **HONG KONG, SAR, CHN**
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

RECORDED HIGH -
AVERAGE HIGH -
MEAN -
AVERAGE LOW -
RECORDED LOW -
(m/s)



WIND VELOCITY:
- 0 to 27 m/s
- Fit to Data

Climate Consultant 5.5 (Build 5, Sep 3, 2014)

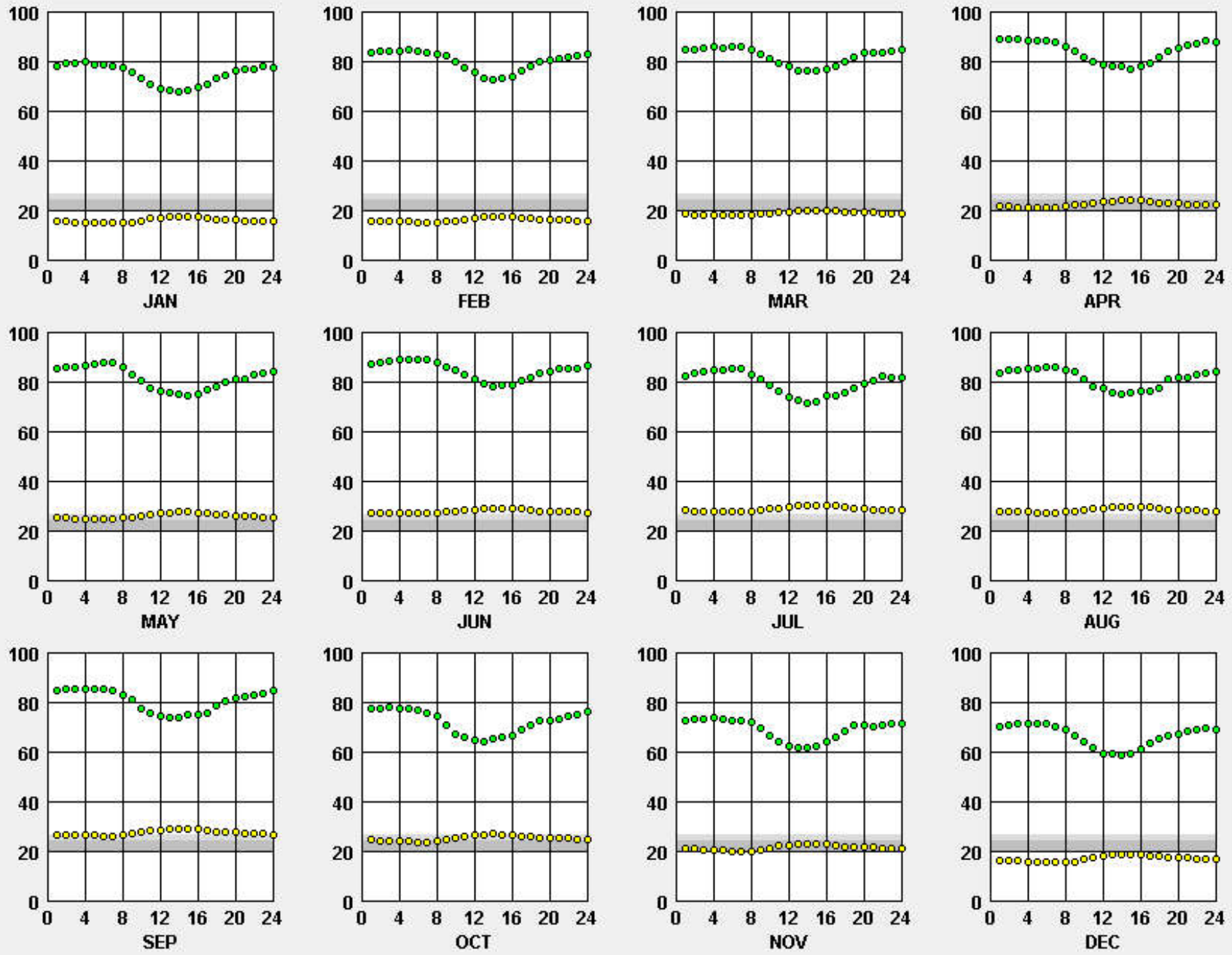
File Criteria Charts Help

DRY BULB X RELATIVE HUMIDITY
ASHRAE Standard 55

LOCATION: HONG KONG, SAR, CHN
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

Dry Bulb
Humidity
Comfort Zone
Summer
Winter
At 50%
Relative Humidity



Climate Consultant 5.5 (Build 5, Sep 3, 2014)

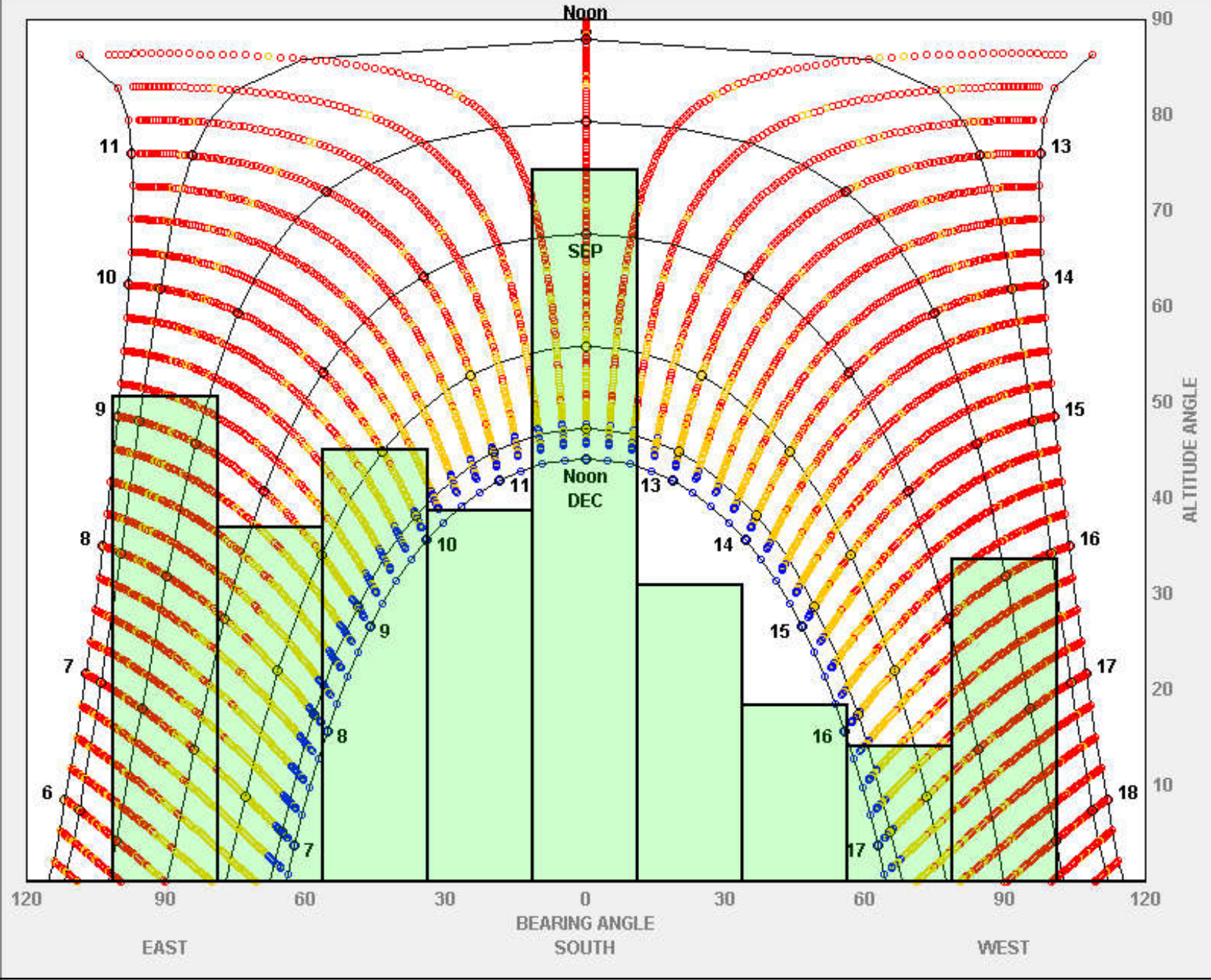
File Criteria Charts Help

SUN SHADING CHART

LOCATION: HONG KONG, SAR, CHN
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

- WARM/HOT > 27°C
  (SHADE NEEDED)
  1052 Hours Exposed
  375 Hours Shaded
- COMFORT > 20°C
  (SHADE HELPS)
  432 Hours Exposed
  362 Hours Shaded
- COOL/COLD < 20°C
  (SUN NEEDED)
  121 Hours Exposed
  236 Hours Shaded



PLOT MONTHS:

WINTER SPRING

- ( ) December 21 to June 21

SUMMER FALL

- (•) June 21 to December 21

- [ ] Display Grid
- [ ] Display Shading Calculator
- [x] Display Obstruction Elevation

Input Obstructions

- [ ] Display Opposite Direction

Climate Consultant 5.5 (Build 5, Sep 3, 2014)

File Criteria Charts Help

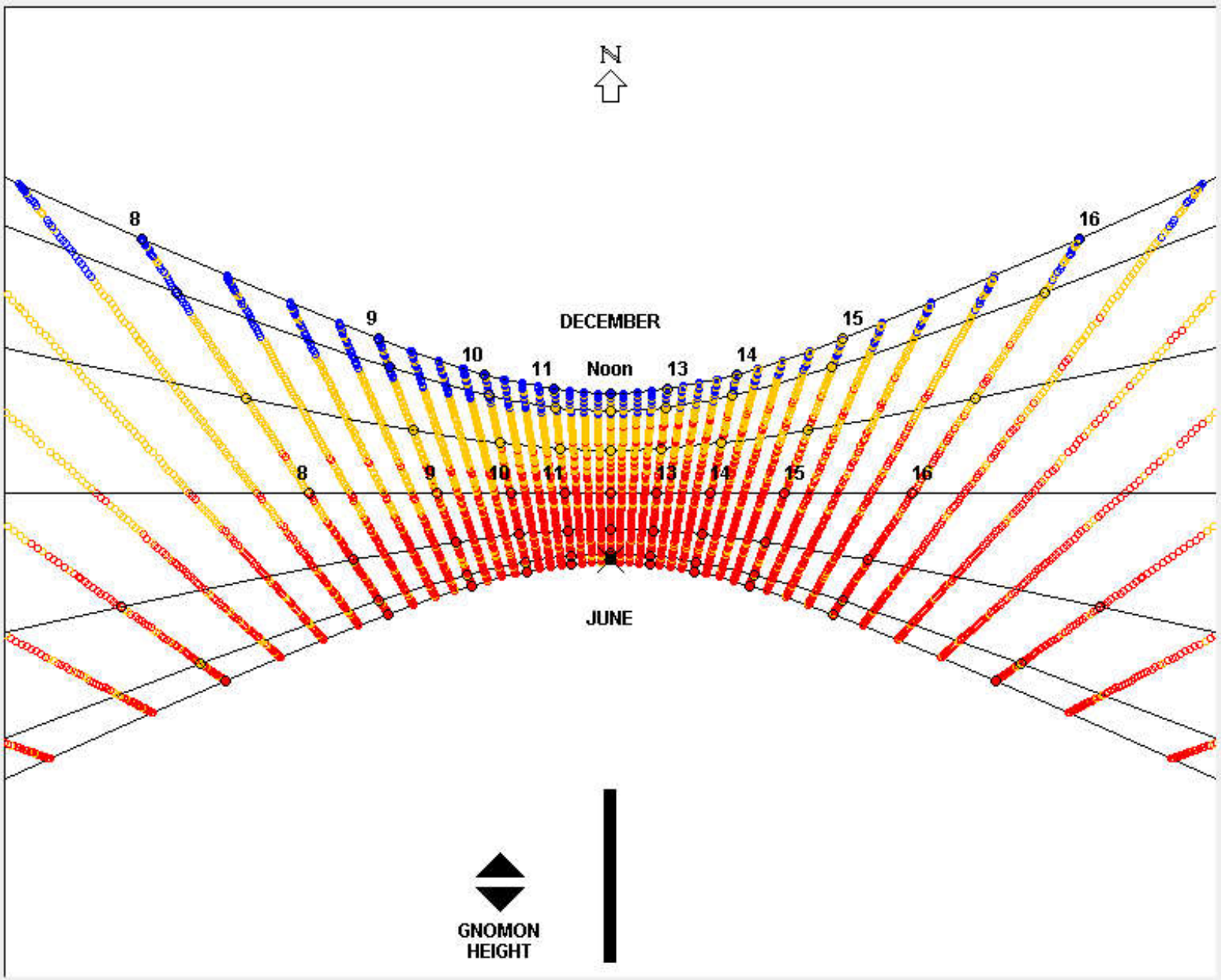
SUN CHART

LOCATION: HONG KONG, SAR, CHN
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

- WARM/HOT > 27°C (SHADE NEEDED)
- COMFORT > 20°C (SHADE HELPS)
- COOL/COLD < 20°C (SUN NEEDED)

GNOMON POSITION



PLOT MONTHS:

WINTER SPRING

- December 21 to June 21

SUMMER FALL

- June 21 to December 21

Climate Consultant 5.5 (Build 5, Sep 3, 2014)

File Criteria Charts Help

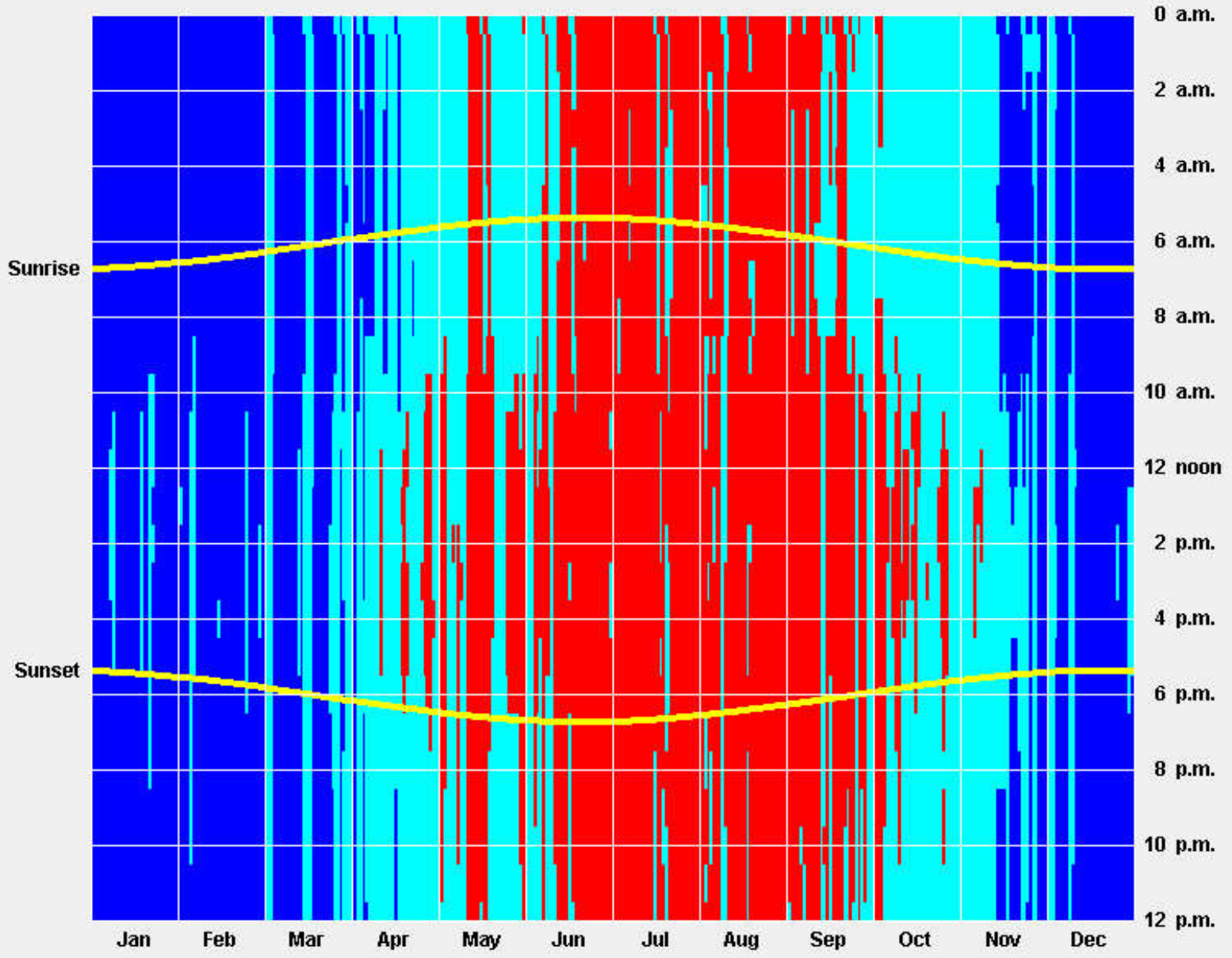
TIMETABLE PLOT

LOCATION: **HONG KONG, SAR, CHN**
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

DRY BULB TEMP
(degrees C)

67%	< 0	
21%	0 -	21
6%	21 -	27
3%	27 -	38
1%	> 38	



PLOT:

DRY BULB TEMP

Monthly Avg Daily

Climate Consultant 5.5 (Build 5, Sep 3, 2014)

File Criteria Charts Help

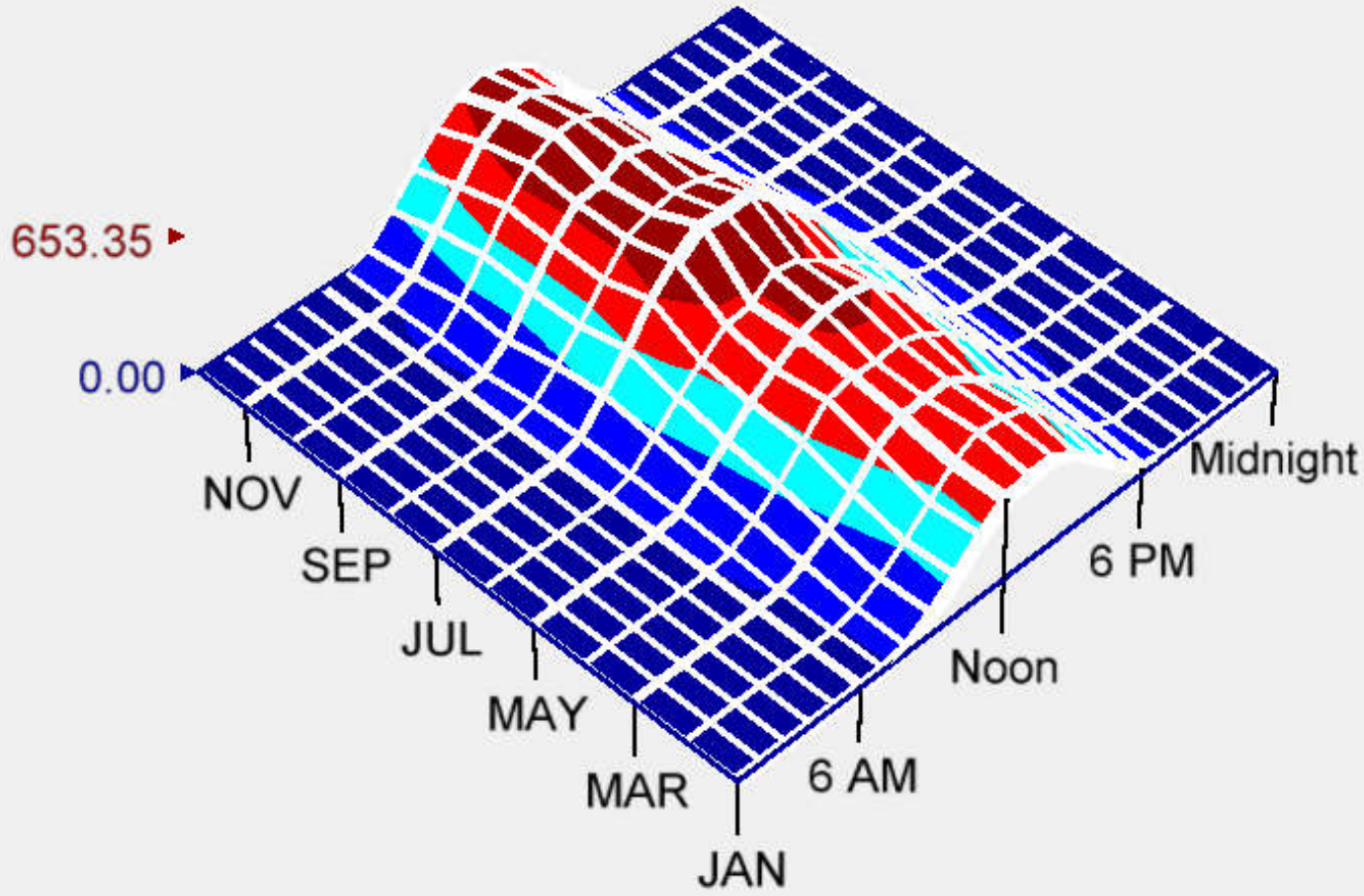
3D CHARTS

LOCATION: HONG KONG, SAR, CHN
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

GLOBAL HORIZ RADIATION
(Wh/sq.m)

49%		Night Time
15%	4 -	158
10%	158 -	316
14%	316 -	474
9%	> 474	



PLOT: Not Shaded Shaded

GLOBAL HORIZ RADIATION

Monthly Avg Daily

Climate Consultant 5.5 (Build 5, Sep 3, 2014)

File Criteria Charts Help

PSYCHROMETRIC CHART
ASHRAE Standard 55

LOCATION: HONG KONG, SAR, CHN
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

COMFORT INDOORS
100% COMFORTABLE
0% NOT COMFORTABLE

PLOT: COMFORT INDOORS

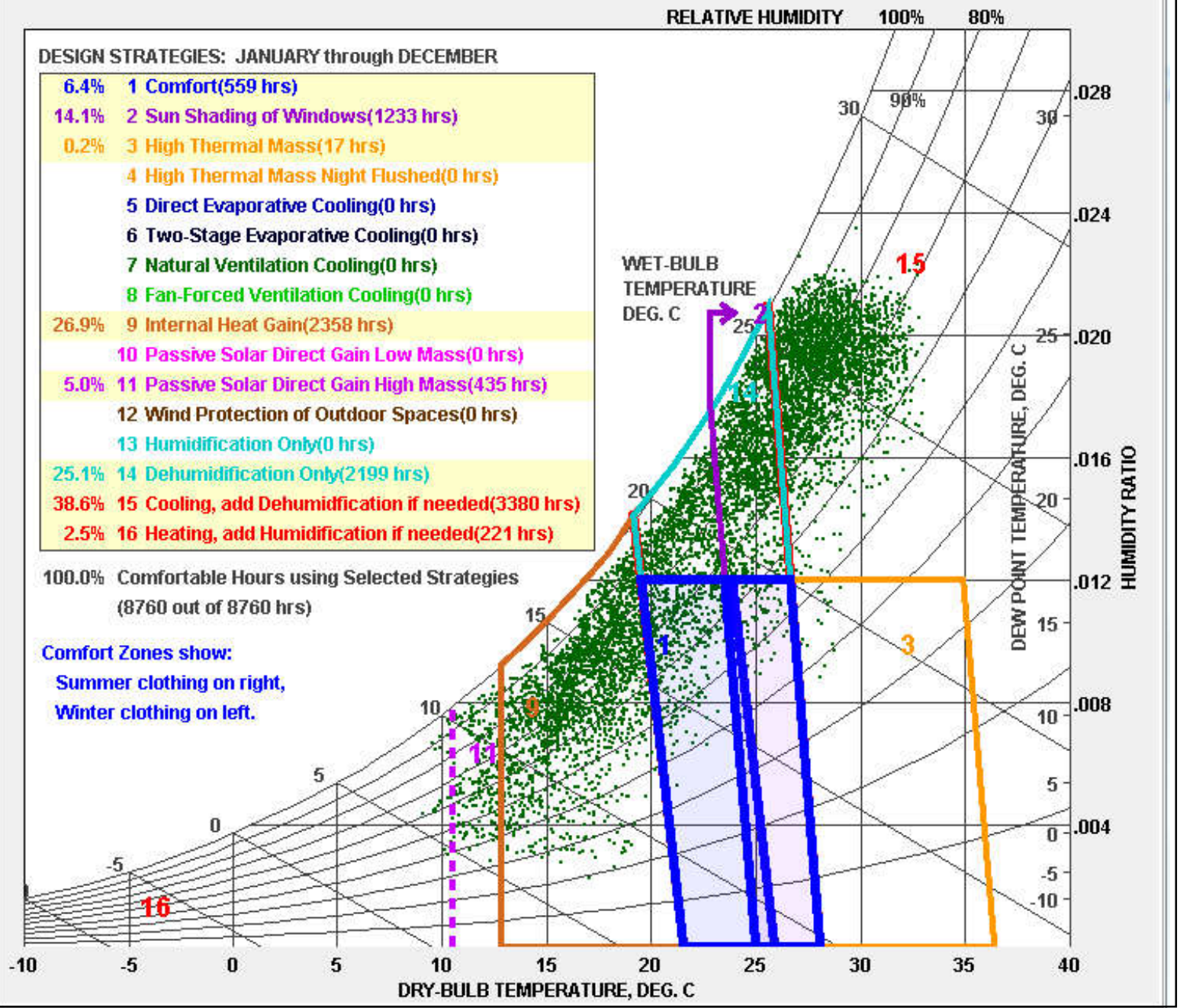
Hourly / Daily Min/Max

All Hours / Selected Hours
1 a.m. through midnight

All Months / Selected Months
JAN through DEC
One Month JAN Next Month
One Day 1 Next Day
One Hour 1 a.m. Next Hour

TEMPERATURE RANGE:
-10 to 40 °C / Fit to Data

Display Design Strategies
Show Best set of Design Strategies



Climate Consultant 5.5 (Build 5, Sep 3, 2014)

File Criteria Charts Help

WIND WHEEL

LOCATION: HONG KONG, SAR, CHN
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

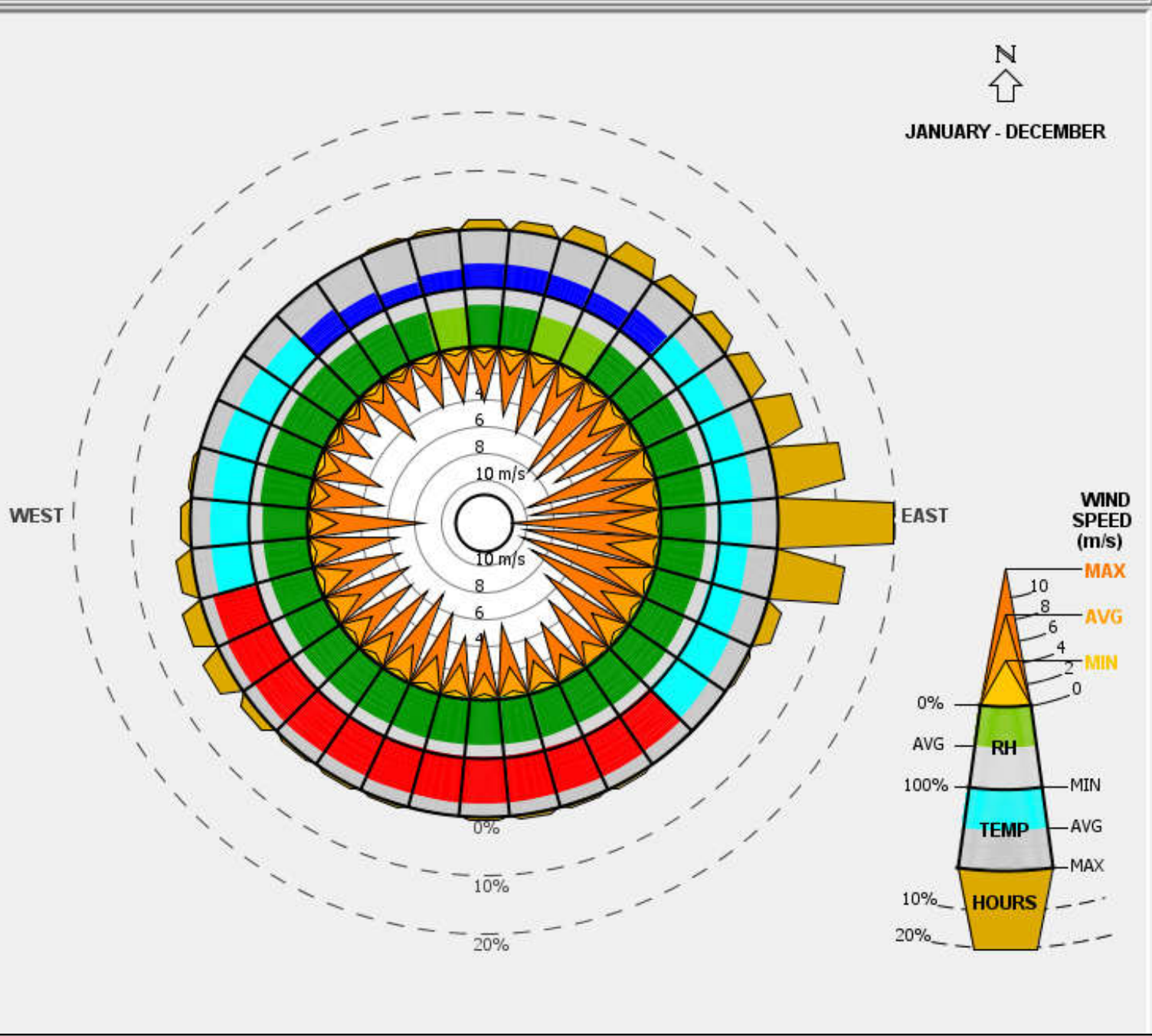
TEMPERATURE (Deg. C)
- < 0
- 0 - 21
- 21 - 27
- 27 - 38
- > 38

RELATIVE HUMIDITY (%)
- <30
- 30-70
- >70

All Hours / Selected Hours
1 a.m. through midnight

All Months / Selected Months
JAN through DEC
One Month JAN Next Month
One Day 1 Next Day

Animate
Monthly / Daily / Hourly
Start / Pause / Stop



Climate Consultant 5.5 (Build 5, Sep 3, 2014)

File Criteria Charts Help

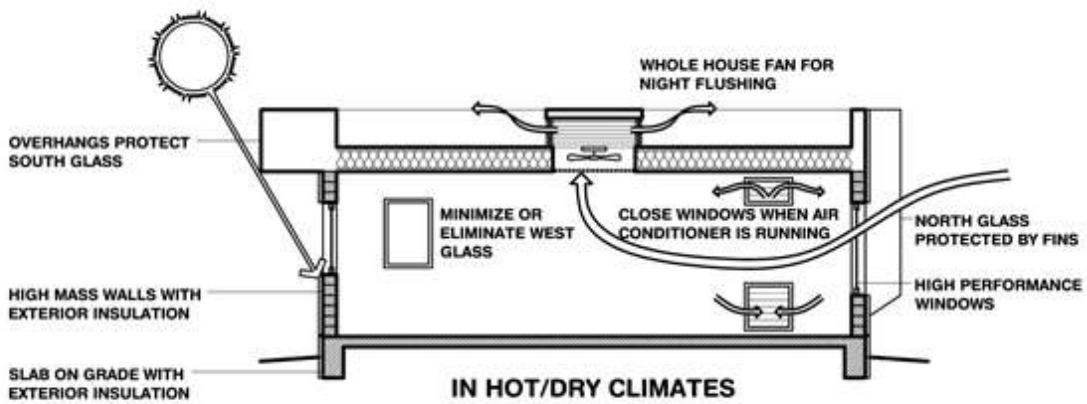
DESIGN GUIDELINES (for the Full Year)
ASHRAE Standard 55
User Modified Design Strategies, User Modified Criteria

LOCATION: **HONG KONG, SAR, CHN**
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

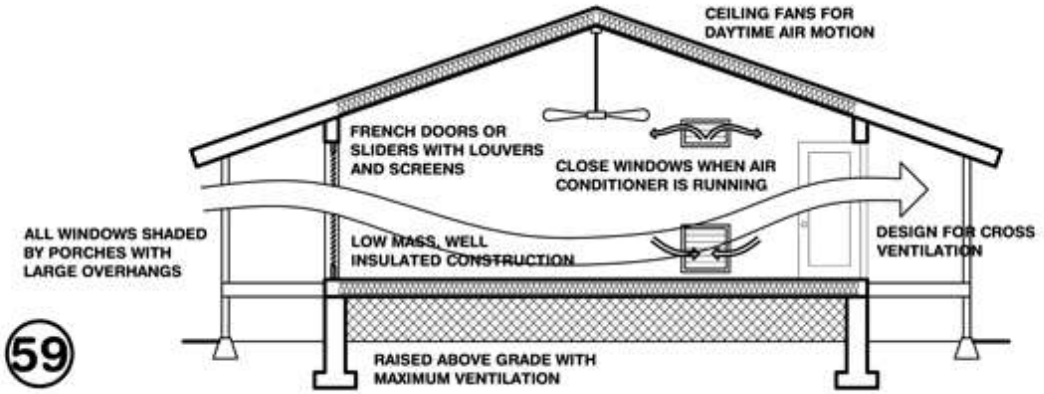
Assuming only the Design Strategies that were selected on the Psychrometric Chart, 100.0% of the hours will be Comfortable.
This list of Design guidelines applies specifically to this particular climate, starting with the most important first. Click on a Guideline to see a sketch of how this Design Guideline shapes building design. (See Help for more details.)

59	In this climate air conditioning will always be
68	Traditional passive homes in hot humid clim
65	Traditional passive homes in warm humid cl
30	High performance glazing on all orientations
37	Window overhangs (designed for this latitude
38	Raise the indoor comfort thermostat setpoint
56	Screened porches and patios can provide pa
17	Use plant materials (bushes, trees, ivy-cover
32	Minimize or eliminate west facing glazing to r
57	Orient most of the glass to the north, shaded
46	High Efficiency air conditioner or heat pump (
26	A radiant barrier (shiny foil) will help reduce r
25	In wet climates well ventilated attics with pitch
11	Heat gain from lights, people, and equipmen
18	Keep the building small (right-sized) becaus
33	Long narrow building floorplan can help max
35	Good natural ventilation can reduce or elimin
43	Use light colored building materials and cool
27	If soil is moist, raise the building high above
42	On hot days ceiling fans or indoor air motion

Design Guideline 59



IN HOT/DRY CLIMATES

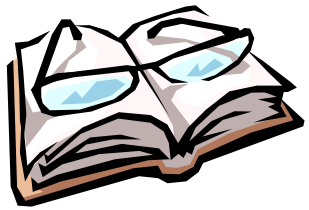


IN HOT/HUMID CLIMATES

In this climate air conditioning will always be needed, but can be greatly reduced if building design minimizes overheating

CLOSE

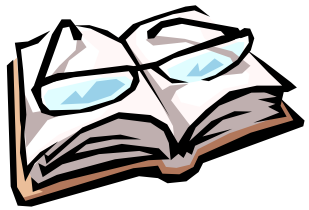
Further Reading



- Learn everything about building performance analysis: Autodesk Insight webinar series https://blogs.autodesk.com/revit/2018/07/06/autodesk-insight-webinar-series/
  - Autodesk Insight webinar part 1: Learn everything about Insight (1:02:20) https://youtu.be/1nkK4yjqCfQ
  - Autodesk Insight webinar part 2: Tips and Tricks (1:01:53) https://youtu.be/7CrG6hw1Wdo
  - Autodesk Insight webinar part 3: Practical examples (58:53) https://youtu.be/ftJtJ2DUlOI

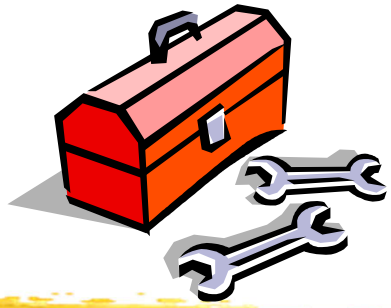
AUTODESK INSIGHT

Further Reading



- IES VE YouTube Channel https://www.youtube.com/user/IESVE
  - Climate Analysis & Weather (1:26) https://youtu.be/wjfLM4wBoec
  - Solar Shading (2:42) https://youtu.be/KmRUa3MpUbU
  - Daylight Simulation and Lighting Design (2:22) https://youtu.be/SdwROMRN2Bk
  - Daylighting Visualisation (1:39) https://youtu.be/lqdM3lxW0J0
  - Dynamic Daylighting (3:41) https://youtu.be/XIJFLQI4SLI
  - Airflow (3:16) https://youtu.be/L_NlsqZ4LIM
  - Whole Building Energy Simulation (2:45) https://youtu.be/h1aISHcg-yg
  - Renewable Energy Design & Optimization (1:56) https://youtu.be/h2O_YGwBLto

Useful Tools



- ClimateTool http://www.climate-tool.com
- Software by Andrew Marsh http://andrewmarsh.com/software/
  - Psychrometric Chart http://andrewmarsh.com/software/psychro-chart-web/, https://drajmarsh.bitbucket.io/psychro-chart2d.html
  - Weather Data http://andrewmarsh.com/software/weather-data-web/, https://drajmarsh.bitbucket.io/weather-data.html
  - 2D Sun-Path http://andrewmarsh.com/software/sunpath2d-web/, https://drajmarsh.bitbucket.io/sunpath2d.html
  - 3D Sun-Path http://andrewmarsh.com/software/sunpath3d-web/, https://drajmarsh.bitbucket.io/shading-box.html
  - Dynamic Daylighting http://andrewmarsh.com/software/daylight-box-web/, https://drajmarsh.bitbucket.io/daylight-box.html
  - Dynamic Overshadowing http://andrewmarsh.com/software/shading-box-web/, https://drajmarsh.bitbucket.io/shading-box.html