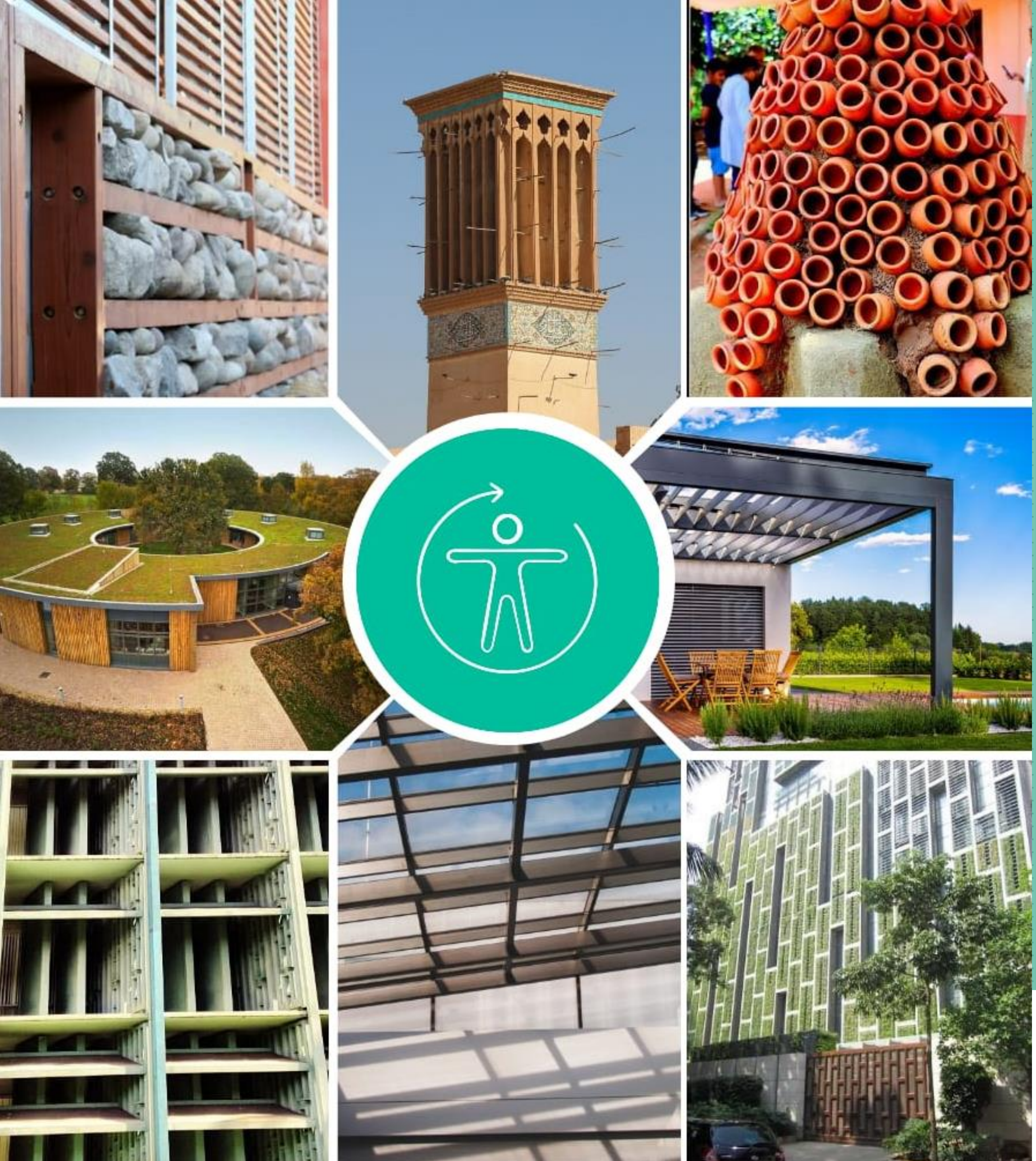


GGGI

ASIA LOW CARBON BUILDINGS TRANSITION PROJECT
Life Cycle Assessment for Transitioning to a Low-Carbon Economy

2.8 Tools for Planning and Design of Low Carbon Buildings

November 2024

ASEAN Centre for Energy · ACE
EESL
HEAT

Supported by:
Federal Ministry for Economic Affairs and Climate Action
IKI International Climate Initiative
on the basis of a decision by the German Bundestag

WHAT WILL YOU LEARN?

01 Integrated Design Process

02 Building Energy Simulation

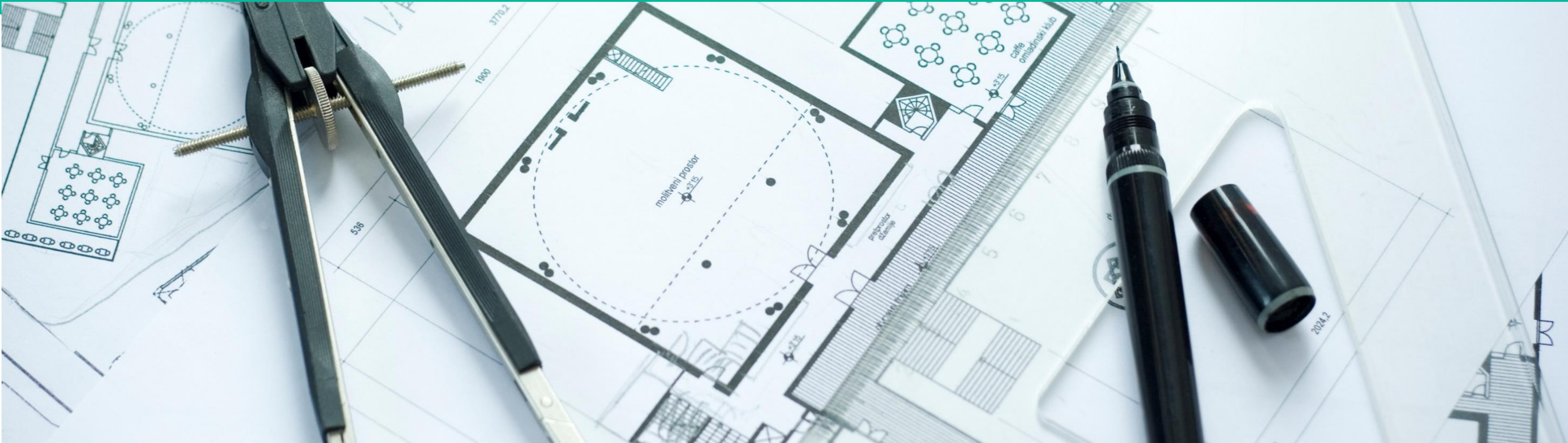
03 Daylight Simulation

04 Natural Ventilation Simulation

05 Case Examples

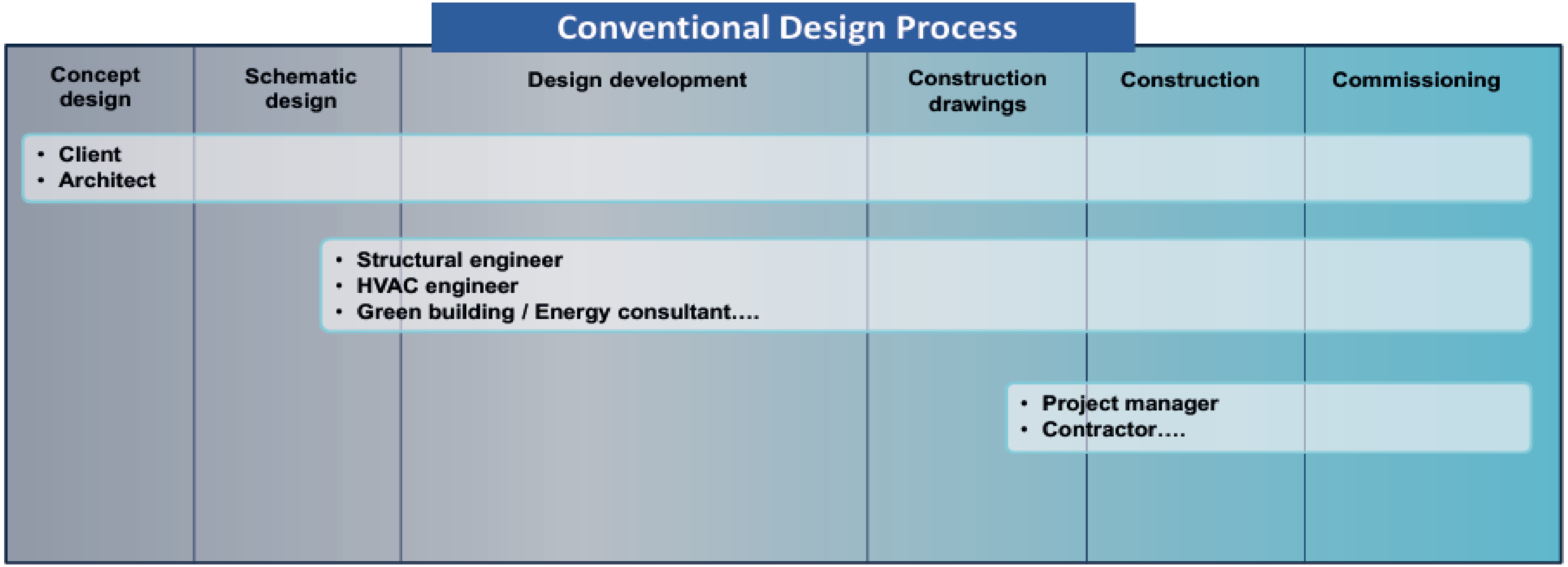
Integrated Design Process

A Design Tool



CONVENTIONAL DESIGN PROCESS

Lack of integrated view of the project



A **sequential process** where different specialist design consultants and stakeholders are brought in separately after much of the architectural design has been fixed to give their respective technical inputs

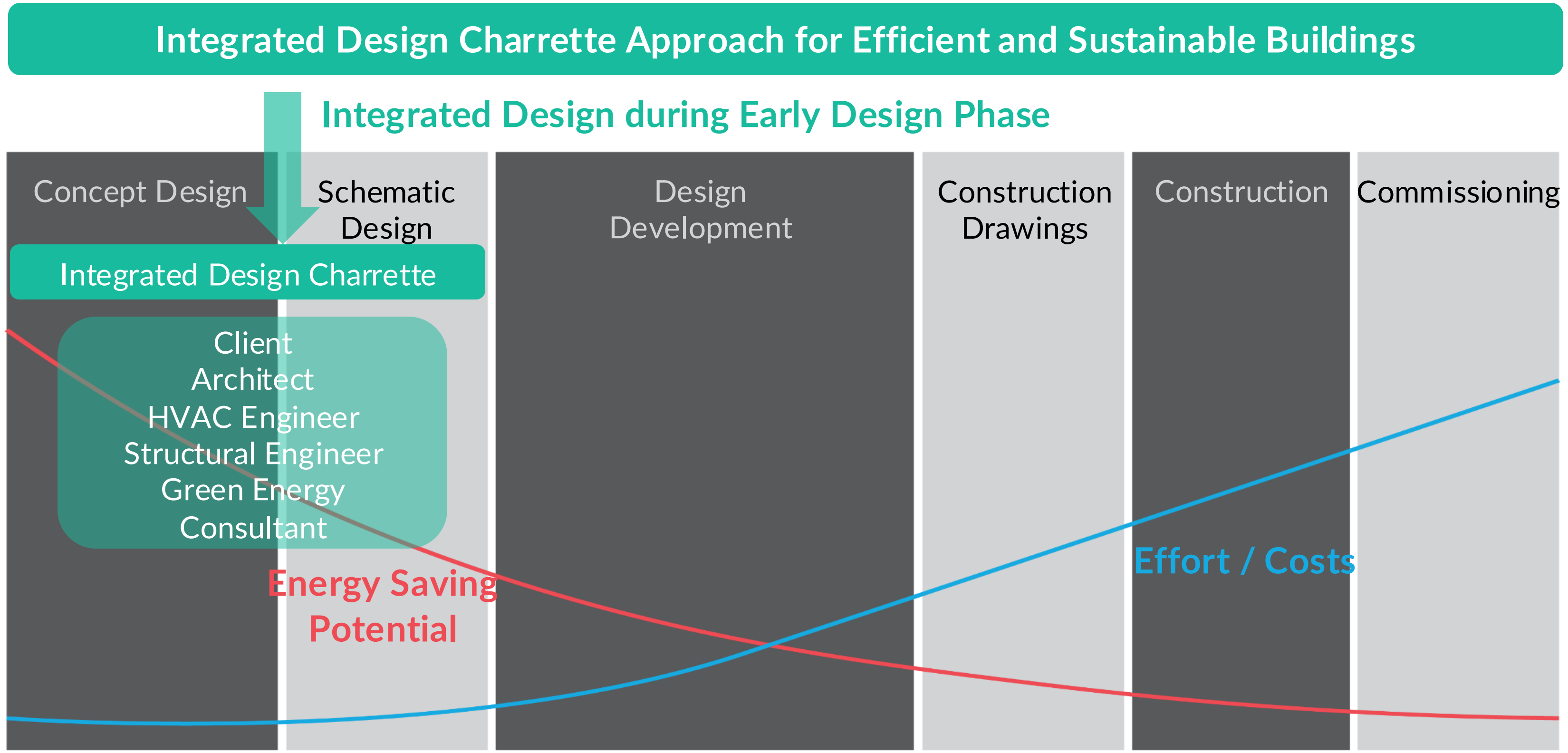
Source: BEEP Design Charrette Manual

INTEGRATED DESIGN PROCESS

When to have an integrated design charrette?

- **Integrated design** means that most of the stakeholders, if not all, start **working on the project together** right from the beginning, based on the design brief

- The best and most effective time to have the first charrette is at the **conceptual stage of the design**, with all or most of the stakeholders (the decision-makers, the people financing the project, the ones designing and constructing, and the ones operating and using it) on board

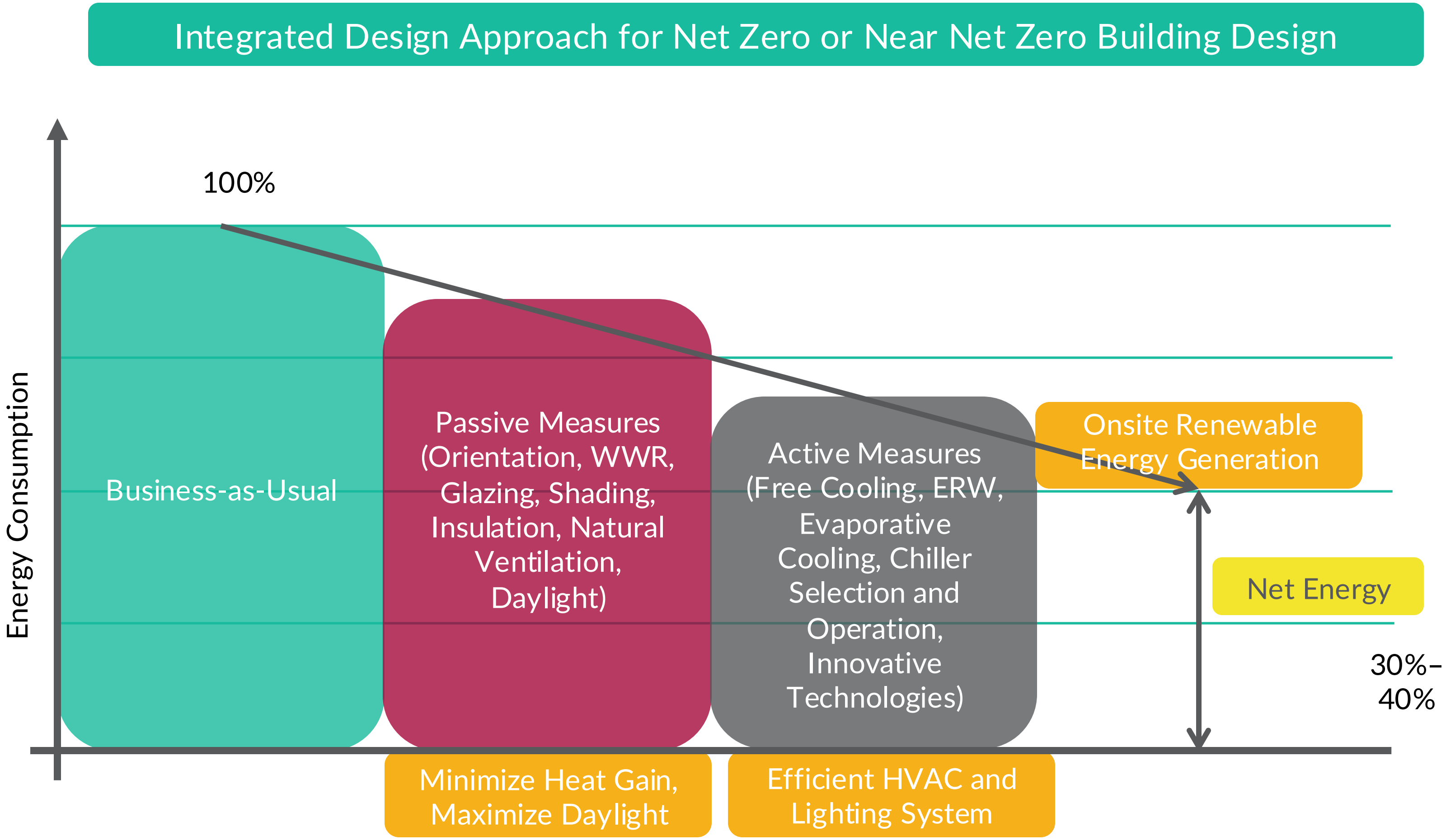


Source: BEEP Design Charrette Manual

WHAT DO YOU INTEGRATE?

Step-by-step strategies to reduce operational energy consumption

- An **Integrated design process** aims to get a **climate responsive design first**, and then complements it with efficient and sustainable mechanical technologies
- A **charrette** is a tool to implement an integrated design process, wherein all stakeholders work together in an intense manner over a short time period



Source: BEEP Design Charrette Manual

WHAT DO YOU INTEGRATE?

Integrating materials with low embodied carbon

Concept design	Schematic design	Design development	Construction	Commissioning
SET GOALS • Comfort & EPI • CO_2 intensity	**SHAPE & MASSING OPTIONS**	**REDUCTIONS IN CEMENT & STEEL**	**CONFIRM OPTIMISATIONS**	
DO YOU NEED TO BUILD NEW?	**STRUCTURAL SYSTEM**	**ENVELOPE HOT-SPOTS**	**REDUCE MATERIAL WASTE / RECYCLE**	
CAN YOU REUSE / RECYCLE MATERIALS OF EXISTING BUILDING?	**ENVELOPE DESIGN**	**INTERNAL LAYOUTS; AVOID ELEMENTS WITH LIMITED VALUE**		
	TYPE OF HVAC SYSTEM etc.	**DEVELOP SPECIFICATIONS & INCLUDE IN BID DOCS** • Material thermal properties • Material / Product EPDs or CO_2 intensity • Equipment efficiencies		
	DESIGN FOR DISMANTLING			

Operational & Embodied Carbon

Operational Carbon

Embodied Carbon

Source: BEEP Design Charrette Manual

INTEGRATED DESIGN CHARRETTE

Setting goals

Commercial buildings

- **Mostly air-conditioned**
- Narrow band of expected comfort
- Air conditioning used for longer duration and may be used throughout the year
- Heat loads in the building may have equal or more contribution from internal loads, i.e., from occupants and equipment

Charrette goals

- Reduction in Energy Performance Index (EPI), either in comparison to the base design as per an existing benchmark EPI, specifically cooling EPI
- Additional parameters evaluated for specific problem identification or problem solving:
  - Heat gains from different building components
  - HVAC system size and efficiency
  - Daylight
  - Free cooling potential

Residential buildings

- **May or may not be air-conditioned**
- Broader band of expected comfort
- Air conditioning intermittently during the day and used mainly in summer
- Heat loads in the building dominated by external loads i.e., those from the building envelope

Charrette goals

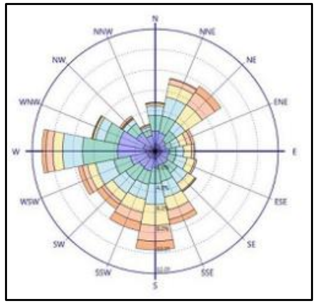
- Reduction in peak summer internal operative temperature, in comparison to the base design
- Minimizing the discomfort degree hours (DDH), mainly in summer, when assessed as per the IMAC (NV) or IMAC (MM) comfort bands
- Additional parameters evaluated for specific problem identification or problem solving:
  - Heat gains from different building components or building envelope as a whole (RETV)
  - Cooling energy if the assessed space is air conditioned
  - Natural ventilation potential

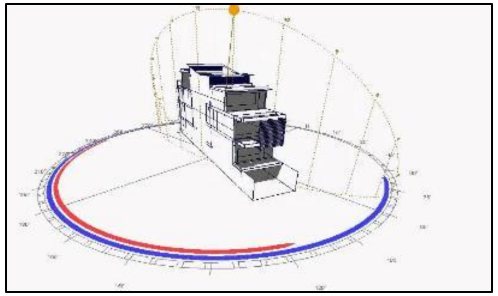
Source: BEEP Design Charrette Manual

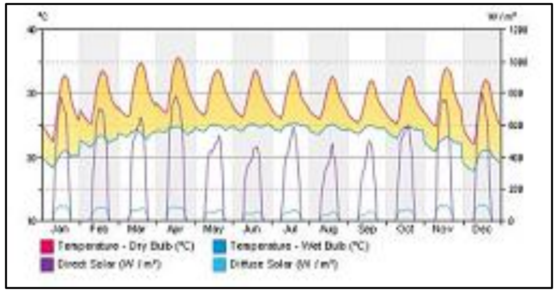
STRATEGIES AND ANALYSIS TOOLS

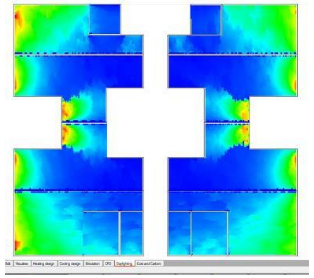
To reduce operational energy

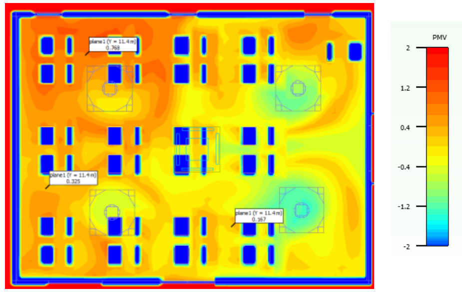
- **Weather data (.epw files, etc.)**
- **Climate analysis tool (ClimateConsultant, Rhino + grasshopper, etc.)**
- **Sun-path and solar radiation analysis (Rhino + grasshopper, etc.)**
- **Thermal comfort and energy simulation tool (EnergyPlus, DesignBuilder, etc.)**
- **Daylight simulation tool (Radiance, DesignBuilder, etc.)**
- **Natural ventilation potential**

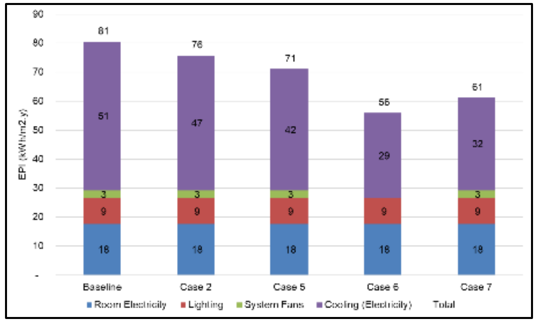


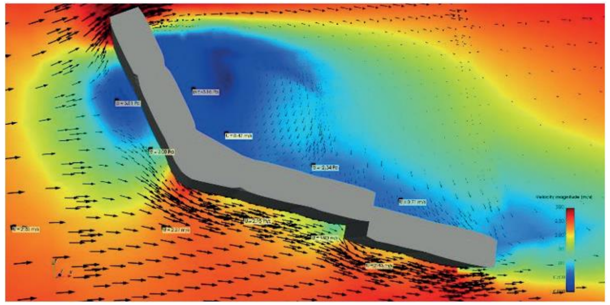












DESIGNERS’ ROLE

Elements to be addressed

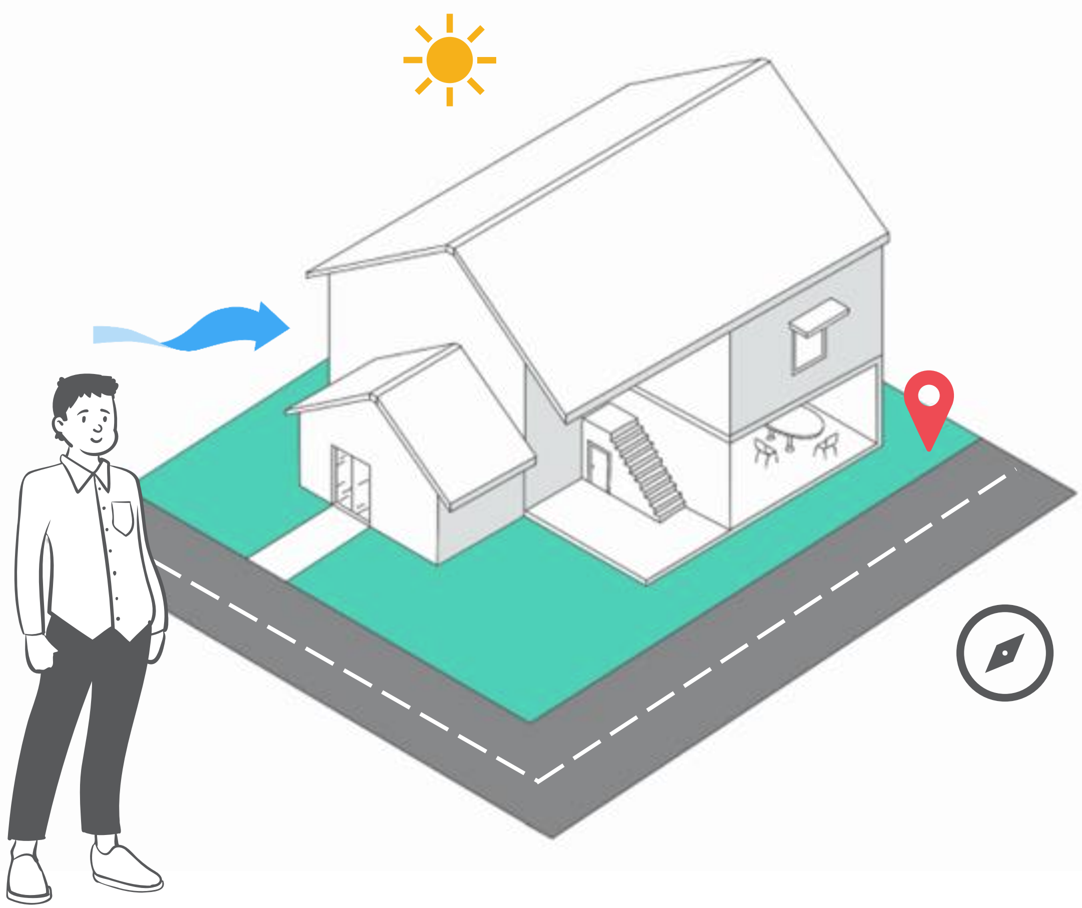
An architect’s primary function is to

‘create an environment’

This environment has both **psychological and physiological** effects on the occupants

The environment impacts

- **Human productivity**
- **Visual comfort**
- **Thermal comfort**



- Site location
- Building orientation and geometry
- Building envelope
- Arrangement of space
- Local climatic characteristics

Building Energy Simulation

Tool for Whole Building Analysis

Image source: https://www.azobuild.com/article.aspx?ArticleID=8520

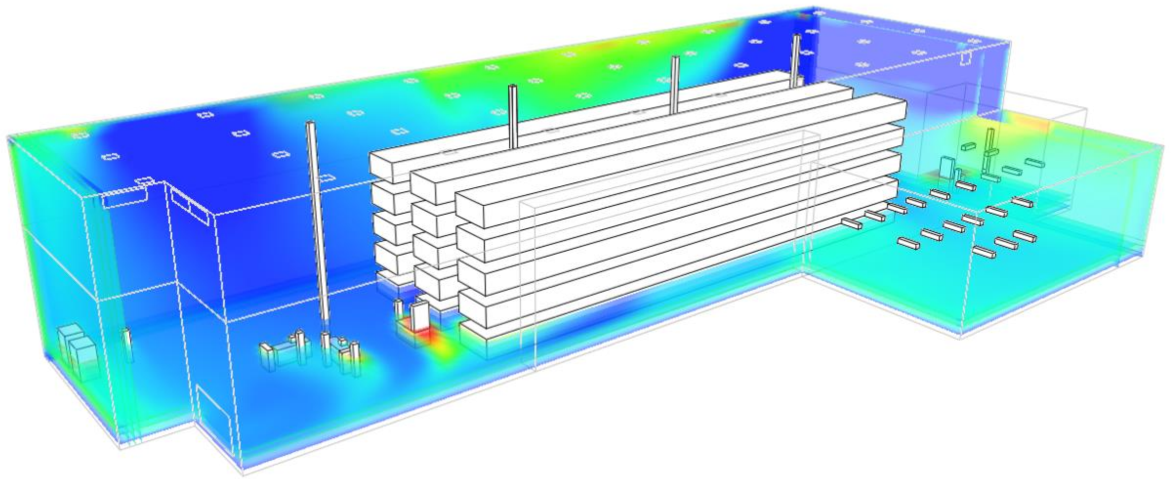
BUILDING PERFORMANCE SIMULATION

Understanding fundamentals

Simulation: An **approximate imitation** of the operation of a **process or system**; that represents its operation over time

Computer simulation: To **model a real-life or hypothetical situation on a computer** so that it can be **virtually** studied to see how the system works with **change in variables**

Building performance simulation: The replication of aspects of building performance using a **computer-based mathematical model** created on the basis of **fundamental physical principles** and **sound engineering practice**. The objective of building performance simulation is the quantification of aspects of **building performance** that are relevant to the design, construction, operation and control of buildings



Sources: https://en.wikipedia.org/wiki/Simulation; https://en.wikipedia.org/wiki/Building_performance_simulation
Image source: https://baumann-us.com/services/building-performance-simulations/

BUILDING PERFORMANCE SIMULATION

Why is it needed?

To arrive at the **best possible** building design solution by **quantitative evaluation** of various design options

To estimate **energy performance:**

Energy consumption by different end uses such as lighting, air conditioning, etc.

To understand the **impact of climate** on energy performance

To **quantify** energy saving and improvement in thermal comfort through different energy conservation measures (ECMs); helping in **decision-making**

To estimate the **thermal comfort** inside the building

To identify **key areas** that has more **potential**

To **save time** (manual calculations are complex and require more time)

BUILDING SIMULATION SOFTWARE

Selecting the right package

List of software packages

- **Energy Plus** (graphical user interface e.g., Design Builder, Sefaira, Simergy)
- DOE 2.2 based (e.g., eQUEST, VisualDOE)
- ApacheSim based IES
- TRNSYS
- IDA Indoor Climate and Energy (IDA ICE)
- ESP-r
- TRACE700
- HAP

Selecting a software

- Must be a validated or approved software
- Modeling capability
  - HVAC
  - Advanced components
  - Natural ventilation
  - Adiabatic, evaporative cooling
  - Parametric analysis
  - Possibility to add specific capability?
    - Source code well described? Accessible?
    - Co-simulation capabilities?
- Technical support, user forum, tutorials, etc.

Source: https://www.ibpsa.us/best-directory-list/
_https://climate.onebuilding.org/papers/2005_07_Crawley_Hand_Kummert_Griffith_contrasting_the_capabilities_of_building_energy_ performance_simulation_programs_v1.0.pdf

BUILDING SIMULATION SOFTWARE

Proceeding with the simulation

Early design stage

- Simulate a small portion of the building in detail

  E.g., typical floor of an office building, typical spaces of an apartment building

- Simulate specific parts or features of the building

  E.g., consider a specific model for down-draft evaporative cooling, CFD

- Simulate the whole building in less detail

  Look at global orientations, façades, solar gains

What to check?

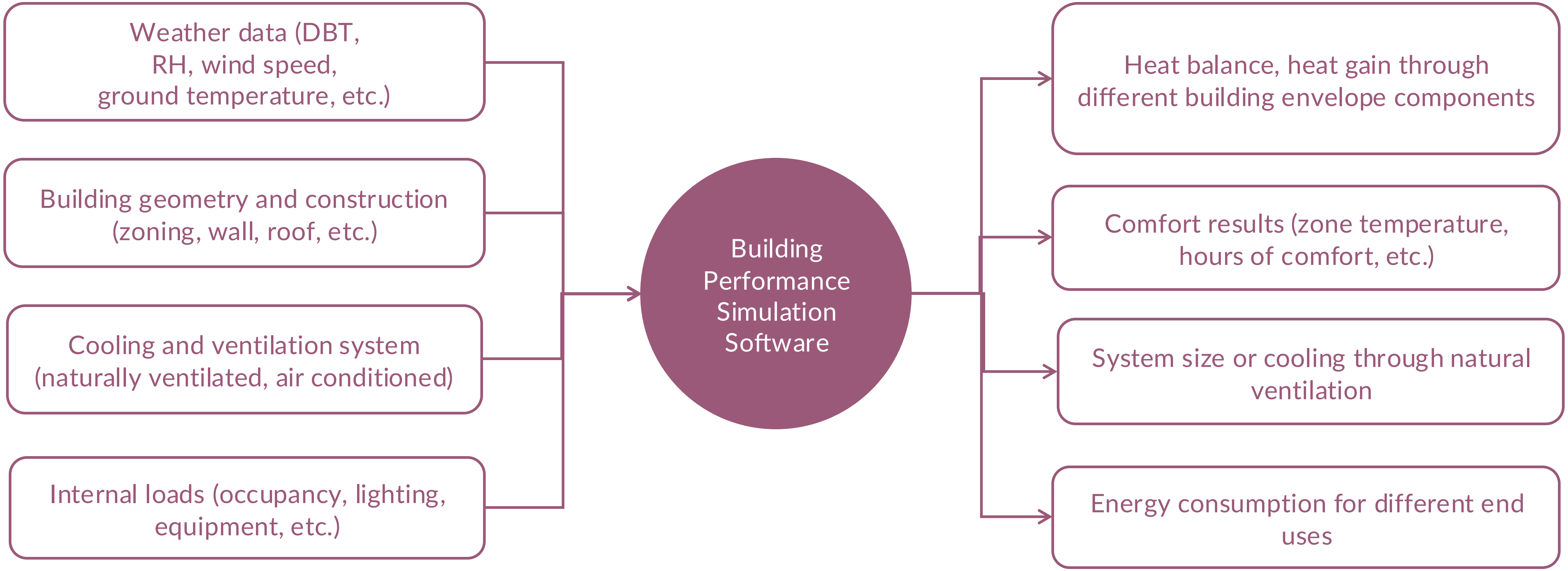
- Feasibility of different options
- Extreme conditions
- Focus on extreme conditions to check feasibility of different option
- Quick check of energy performance for comparison

Later stages

- Provide a more detailed focus on energy performance and more complete modeling for the zones

BUILDING SIMULATION SOFTWARE

Inputs and outputs



BUILDING SIMULATION SOFTWARE

Essential skills required

User

- Knowledge and understanding of the building physics, HVAC
- Good technical common sense:
  - Ability to relate results to physical understanding, memory of previous situations
  - Ability to analyze results and question them
- Ability to make quick parallel calculations
  - Simple back of the envelope
  - Equation-based models
- Representation of results data for coherent checking
- Ability to identify important parameters upfront
  - Define relevant parametric studies
- Willingness to discuss inputs and results with others
- Needs patience

Guidelines and Tips

- Weather data:
  - Be careful with synthetic data
  - When using weather data for the first time for a location, plot the data to be sure that they are consistent
- Check for non-library materials, components and systems
- Check for extreme conditions, then conduct an annual run:
  - Identify hottest, most humid and coldest weeks
  - Prepare outputs to compare the results of different runs on these weeks on the same plot (post treatment may be needed)
- Check the hourly results:
  - Check if set-points are met
  - Check if strategies play out as expected e.g., sequence of natural ventilation, evaporative cooling and active cooling
  - Check if movable blinds are operated

Daylight Simulation

Tools for Visual Comfort

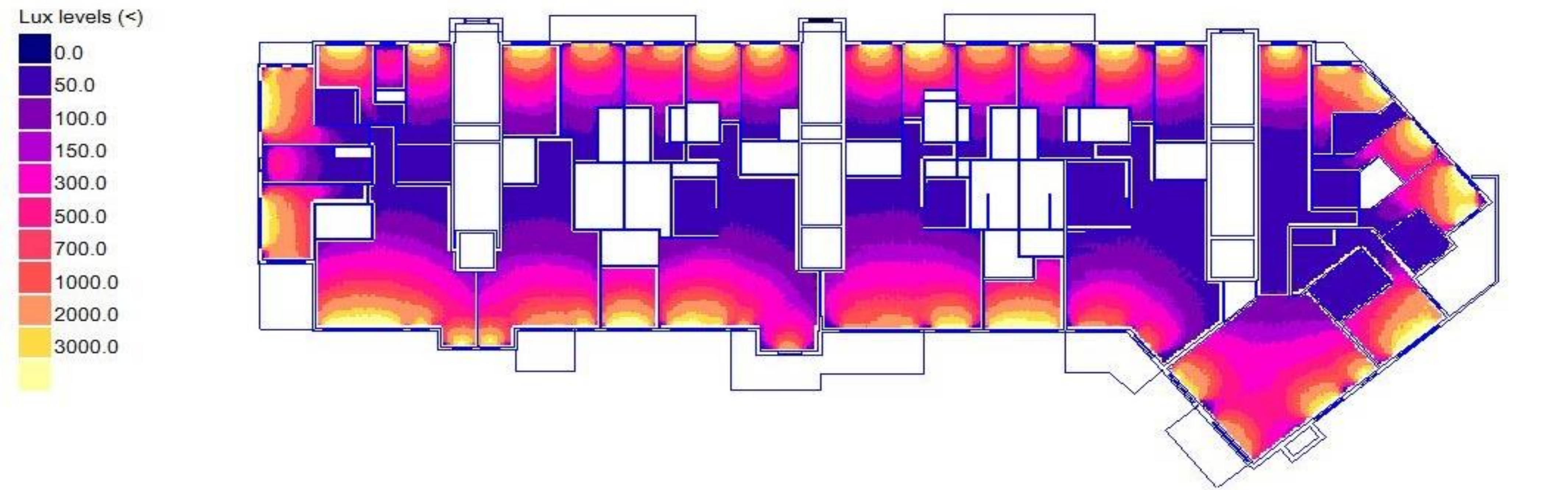


Image source: https://egreenideas.com/green-ideas-daylight-modeling-services/

DAYLIGHT SIMULATION

Understanding objectives

- Daylight analysis and simulation are processes that help determine the amount and quality of natural light in a building, and how it affects the occupants and energy consumption
- It involves simulating light behavior, using physical models or digital tools to predict light distribution, intensity and impact on interior spaces
- Helps to understand how building form interacts with light availability at different times of day and seasons. It can help reduce the need for artificial lights, which can lower energy costs and emissions
- These processes are often used in the early stages of the design process to optimize designs and meet sustainability goals

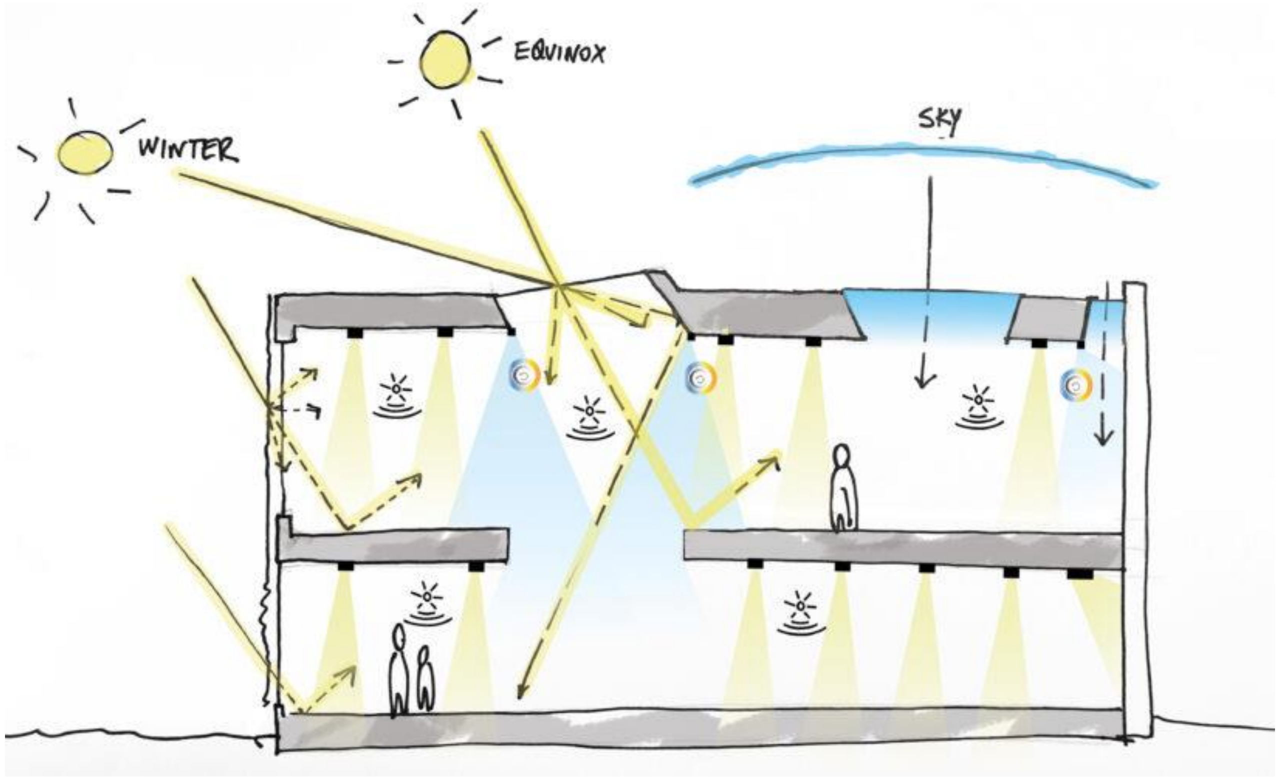


Image source: https://whitearkitekter.com/news/daylight-simulation-tools-and-their-integration-in-the-design-workflow/

DAYLIGHT ANALYSIS

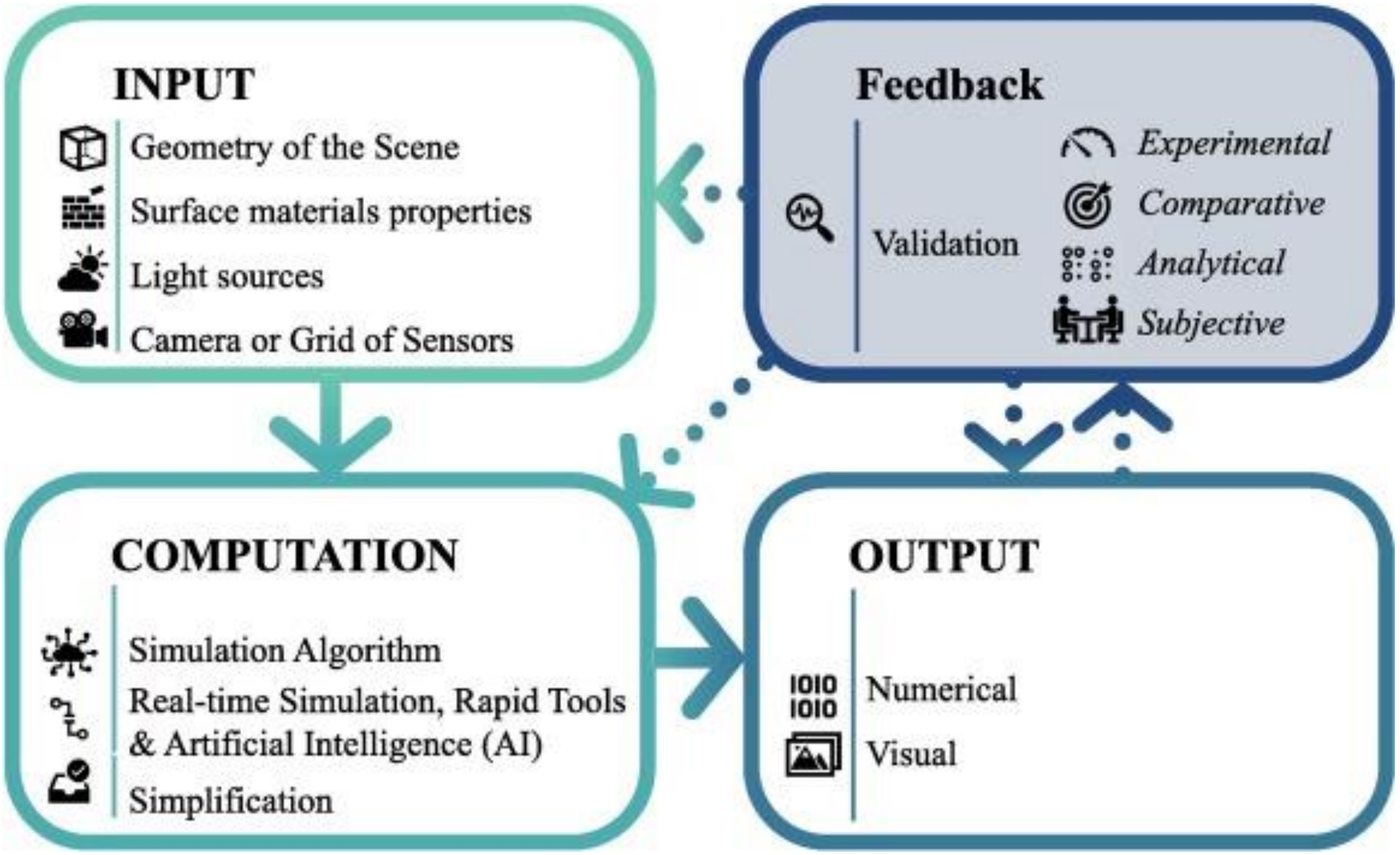
Inputs required

Input parameters for simulation:

- Building geometry
- Surface material properties (color, texture, reflectance)
- Light source (location, sky model)
- Sensors grid location and size

Software used in the simulation:

- Radiance
- LightStanza
- Ladybug Tools (Honeybee)
- Daysim
- Open Studio
- VELUX Daylight Visualizer
- IESve, etc.



DAYLIGHT ANALYSIS

Metrics

Illuminance (Lux)

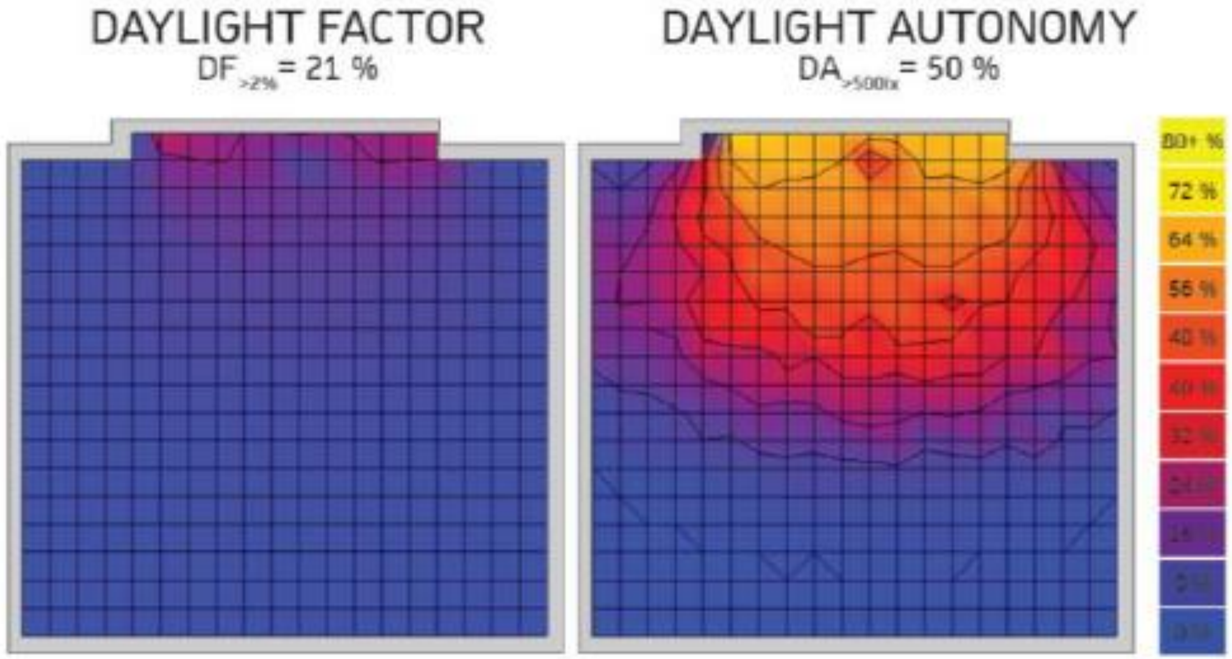
The amount of light that falls on a surface per unit area. Daylight illuminance levels <100 lux are generally insufficient for most tasks

Daylight Factor (DF)

The ratio of indoor illuminance to available outdoor illuminance under overcast sky conditions indicates daylight availability

Daylight Autonomy (DA)

The percentage of time that a building or space's daylight levels are above a specified illuminance level



DAYLIGHT ANALYSIS

Metrics

Annual Sunlight Exposure (ASE)

Measures areas that receive excessive direct sunlight over a year, useful for glare and overheating analysis

Spatial Daylight Autonomy (sDA)

The percentage of an area that receives sufficient daylight (usually 300 lux) for a specific period, measuring daylight sufficiency

Useful Daylight Illuminance (UDI)

The percentage of annual occupied hours that falls within predefined lower and higher illuminance limits (100 to 3000 lux)

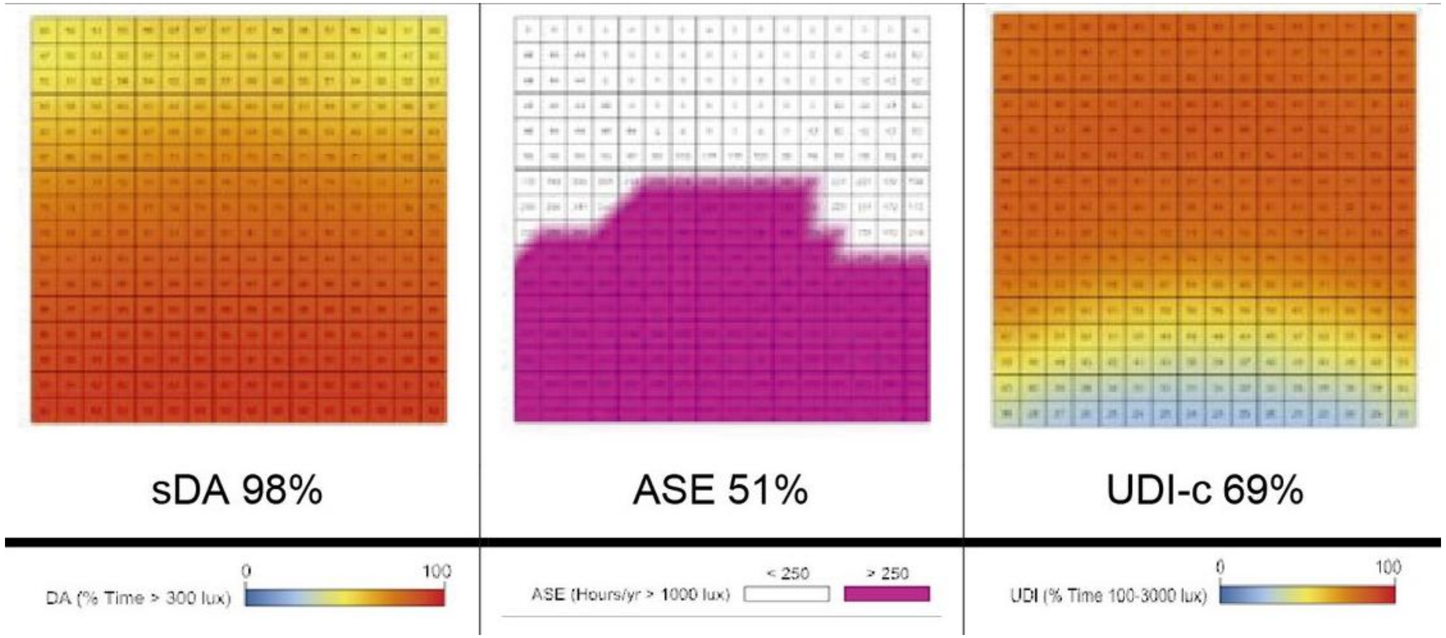


Image source: https://solarlits.com/jd/7-107

DAYLIGHT ANALYSIS

Metrics

Glare Metrics (DGP)

- Daylight glare probability (DGP) is a metric that predicts the likelihood of an observer experiencing discomfort glare at a given orientation and view position
- DGP is typically calculated using a fisheye rendering with an opening angle of 180 degrees. The values for DGP range from 0% to 100% and are divided into four bands:

DGP	
< 0.34	Imperceptible
0.34 – 0.38	Perceptible
0.38 – 0.45	Disturbing
> 0.45	Intolerable

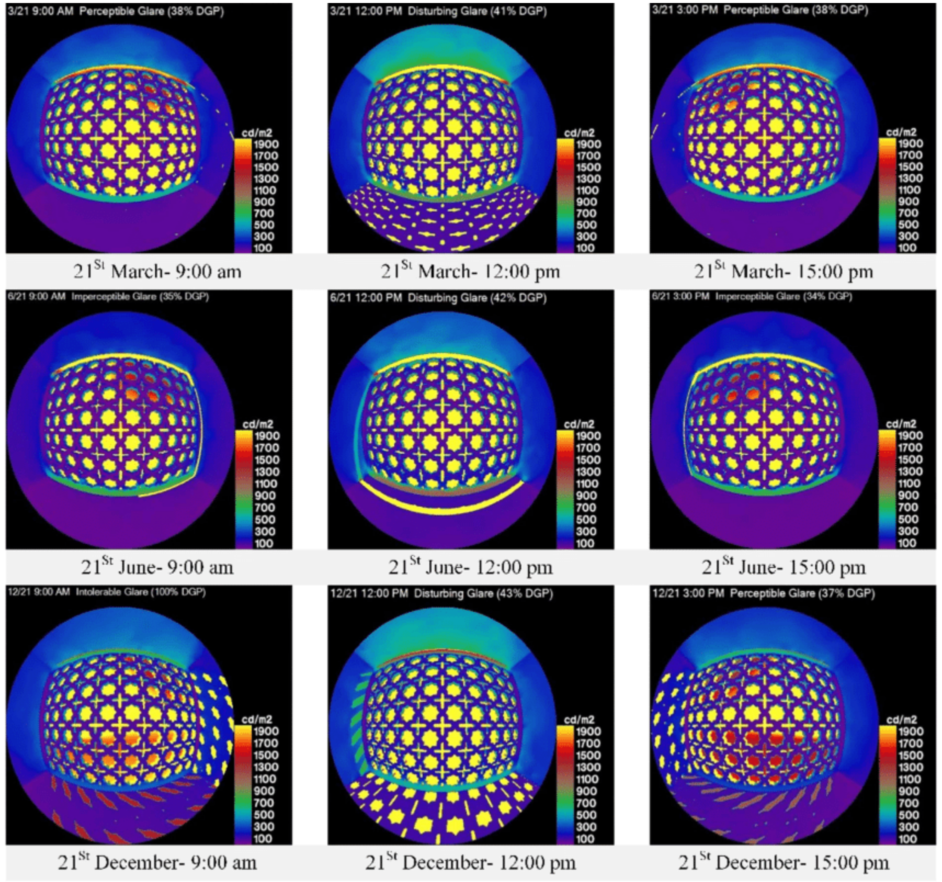


Image source: https://www.researchgate.net/figure/Daylight-Glare-Probability-DGP-in-three-different-days-of-8-Point-Star-for-south-facade_fig8_345505966

CFD Simulation

Tools for Ventilation Potential

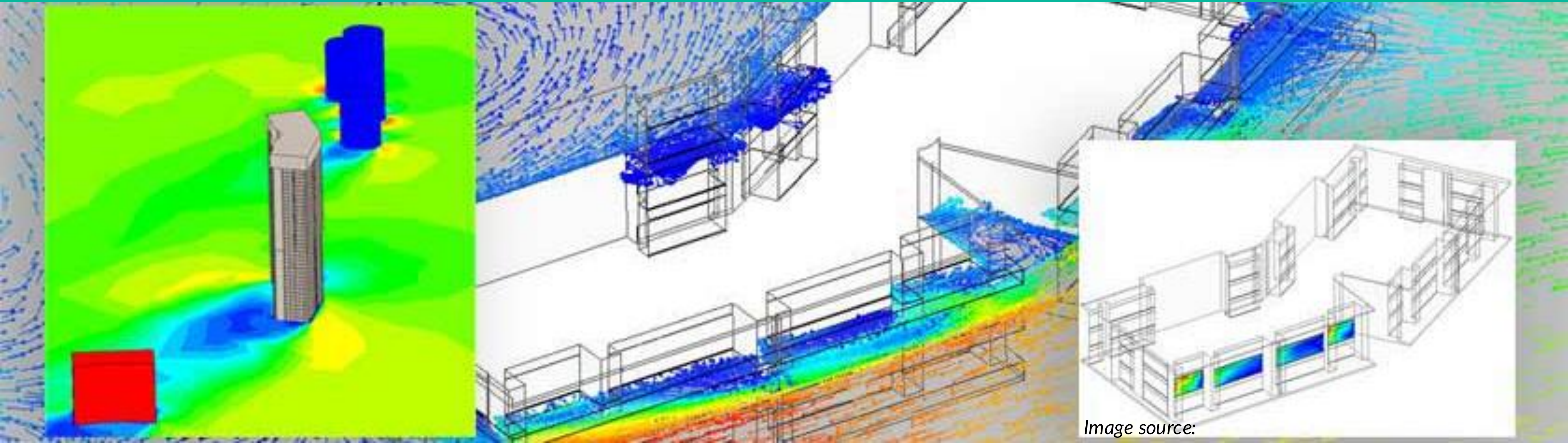
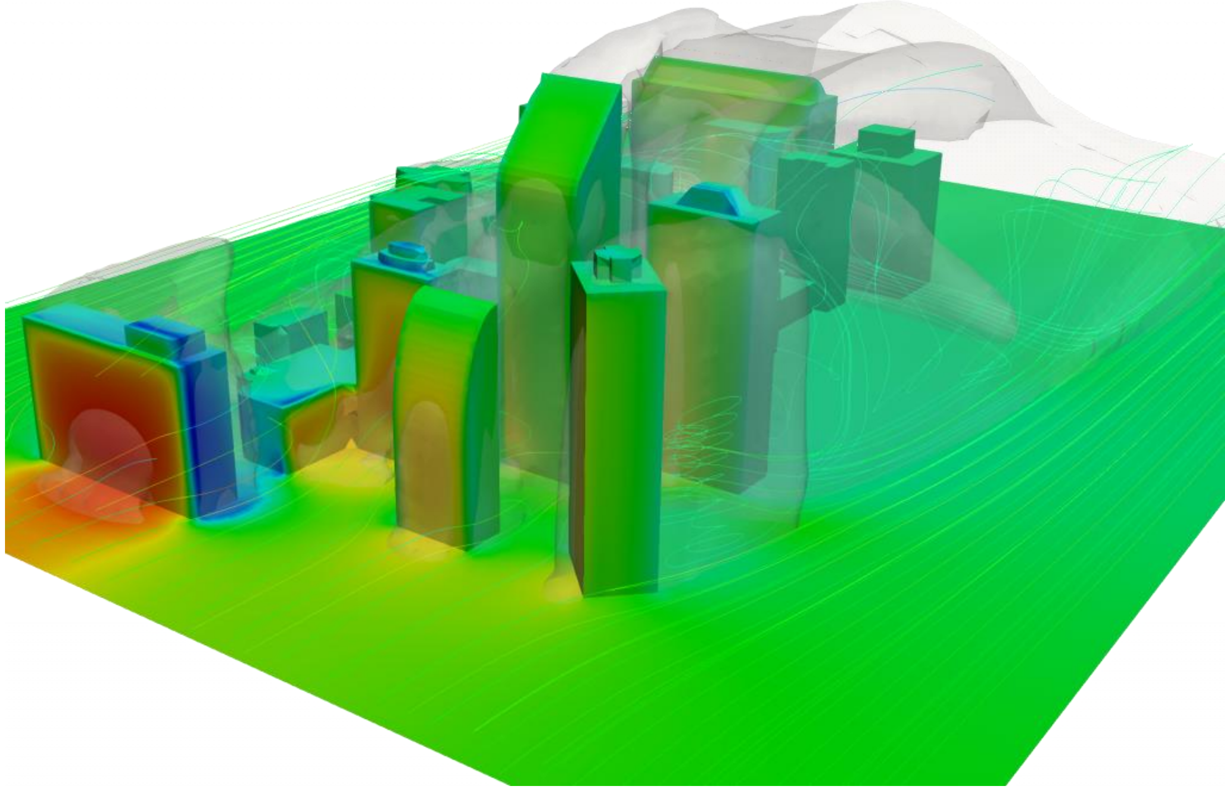


Image source:

CFD SIMULATION

Utility of computational fluid dynamics (CFD)

- CFD is used to **visualize and quantify** velocity and pressure profiles in and around buildings
- The effect of both **mechanical and wind-driven** natural ventilation can be accessed
- It is seen as an **early design** decision tool
- Useful for architects, engineers, town/city planners and consultants



Quick decision-making to optimize building design with better **wind-driven ventilation**

Image source: https://www.idealsimulations.com/applications/architecture/

CFD SIMULATION SOFTWARE

Software packages and considerations for simulation

List of software packages

- **Energy Plus** (graphical user interface e.g., Design Builder, Sefaira, Simergy)
- TRNSYS
- Vayu Pravah (an OpenFOAM software)
- MicroFlo-CFD
- SimFlow
- Ansys Fluids

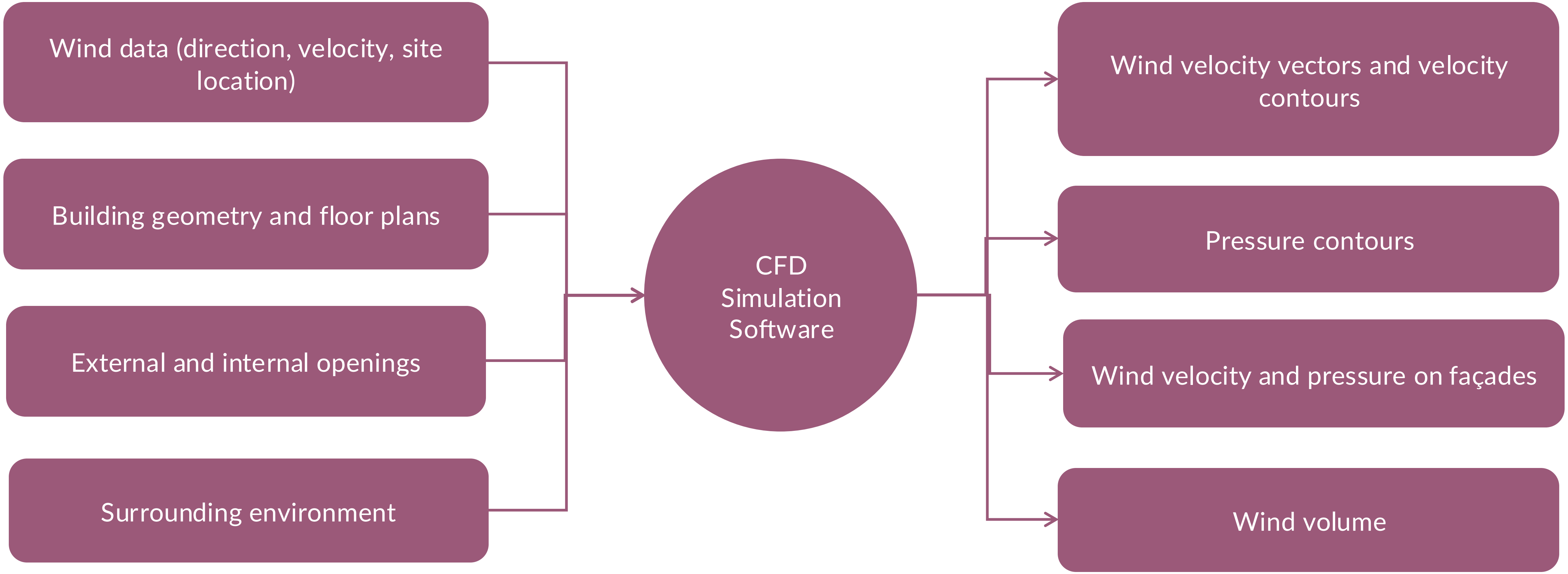
Simulation and other considerations

- Simulate at neighborhood level
  - Identify the target and surrounding buildings for the analysis (cover up to 3H radius)
- Simulate at building
  - Refer to Google Earth for site details
- Consider ground slope of each block
- Set surrounding environment
- The predominant wind direction with magnitude
- The reference wind height of magnitude
- Optional custom wind profile

Source: https://www.ibpsa.us/best-directory-list/
_https://climate.onebuilding.org/papers/2005_07_Crawley_Hand_Kummert_Griffith_contrasting_the_capabilities_of_building_energy_ performance_simulation_programs_v1.0.pdf

CFD SIMULATION SOFTWARE

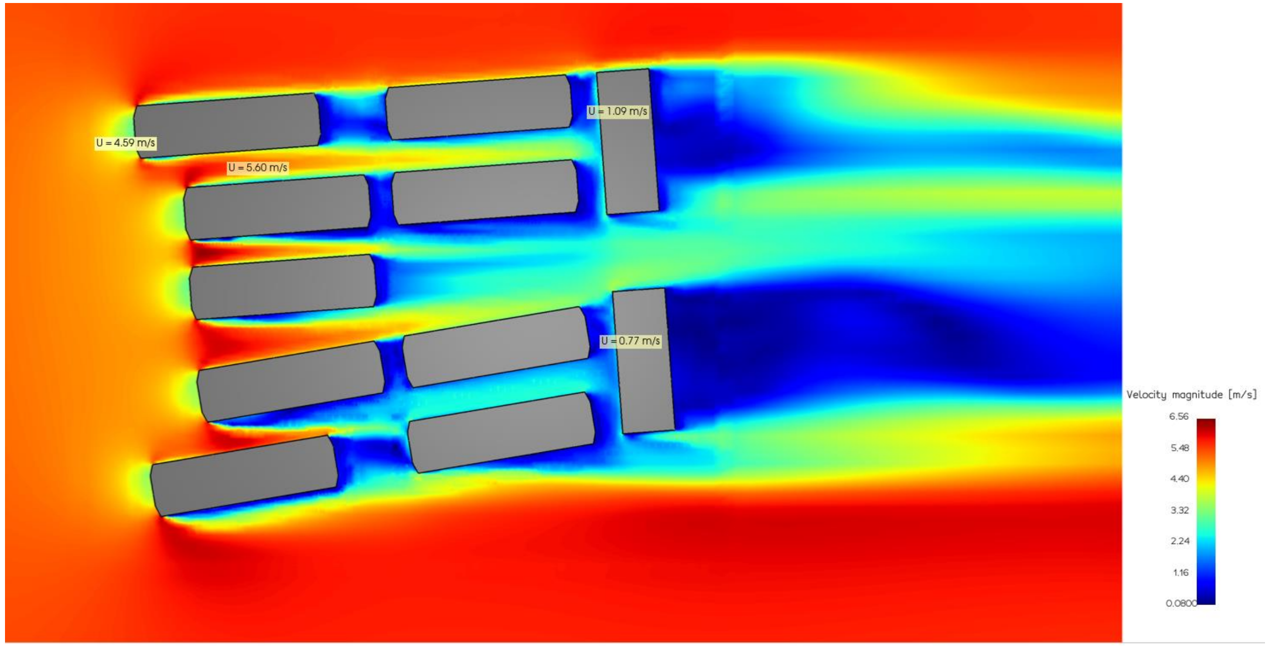
Inputs and outputs



CFD SIMULATION SOFTWARE

Using the results

- Identification of **strong and weak spots** for utilizing natural ventilation potential
- **Variation** of wind potential from bottom ground floor to top floor
- Data representation using various techniques for better explanation of results
- Identification of **strong spots** for assisted mechanical ventilation
- Ideas for **design alteration** to improve wind-driven ventilation



Representation of wind movement around multiple buildings

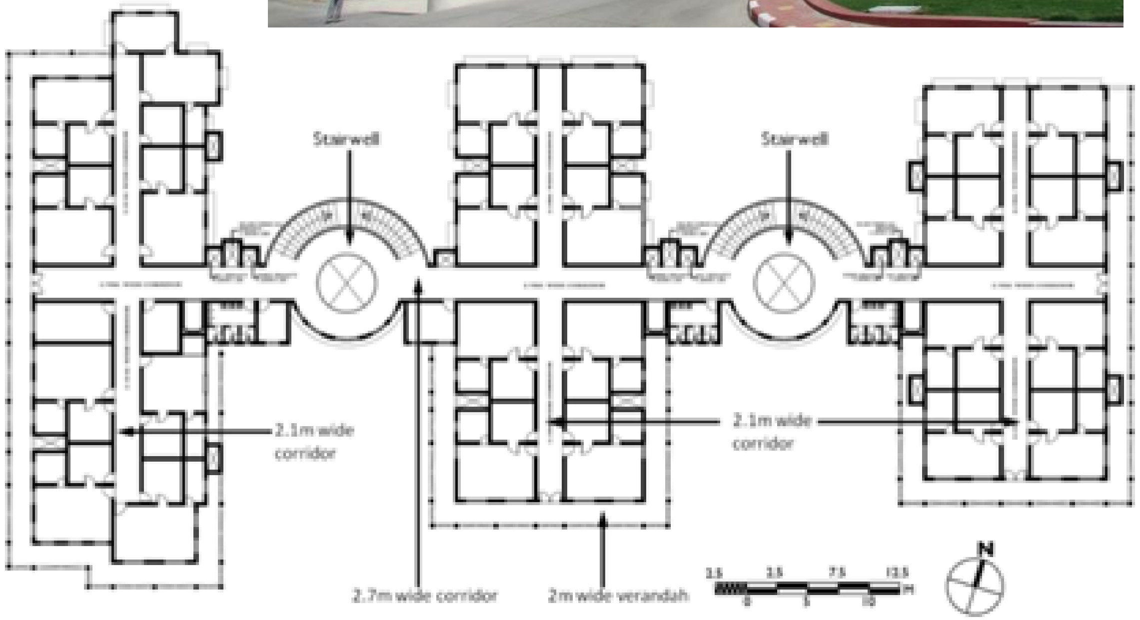
Case Example

Aranya Bhawan, Jaipur, India

ARANYA BHAWAN

Case example: Government office building

- **Client:** Rajasthan Forest Department
- **Executing Agency:** Rajasthan State Road Development and Construction Corporation Ltd. (RSRDC)
- **Architects:** Mathur, Ugam and Associates
- **Built-up area:** ~10,000m^2 (excluding basement parking and service area)
- **Number of floors:** 5 (Ground + 4 floors) + one basement level for parking and services
- **Number of users:** ~350
- **Types of spaces:** Offices, auditorium, guest rooms, museum and library



ARANYA BHAWAN

Project timeline

December 2012
- Design Charrette

2013–2015
- Construction
- Technical Support by BEEP

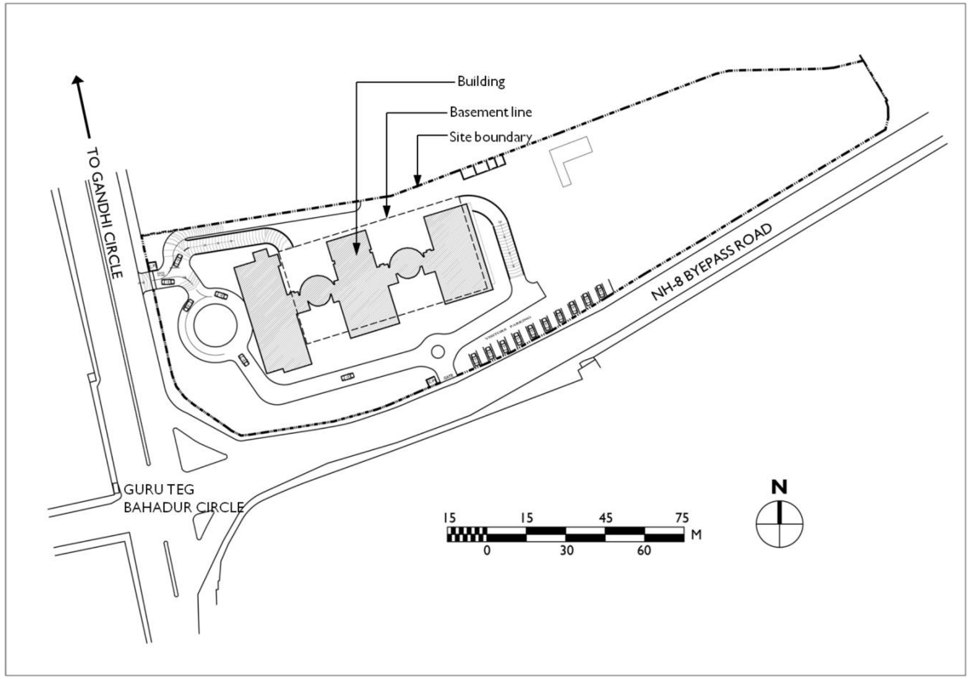
March 2015
- Inauguration

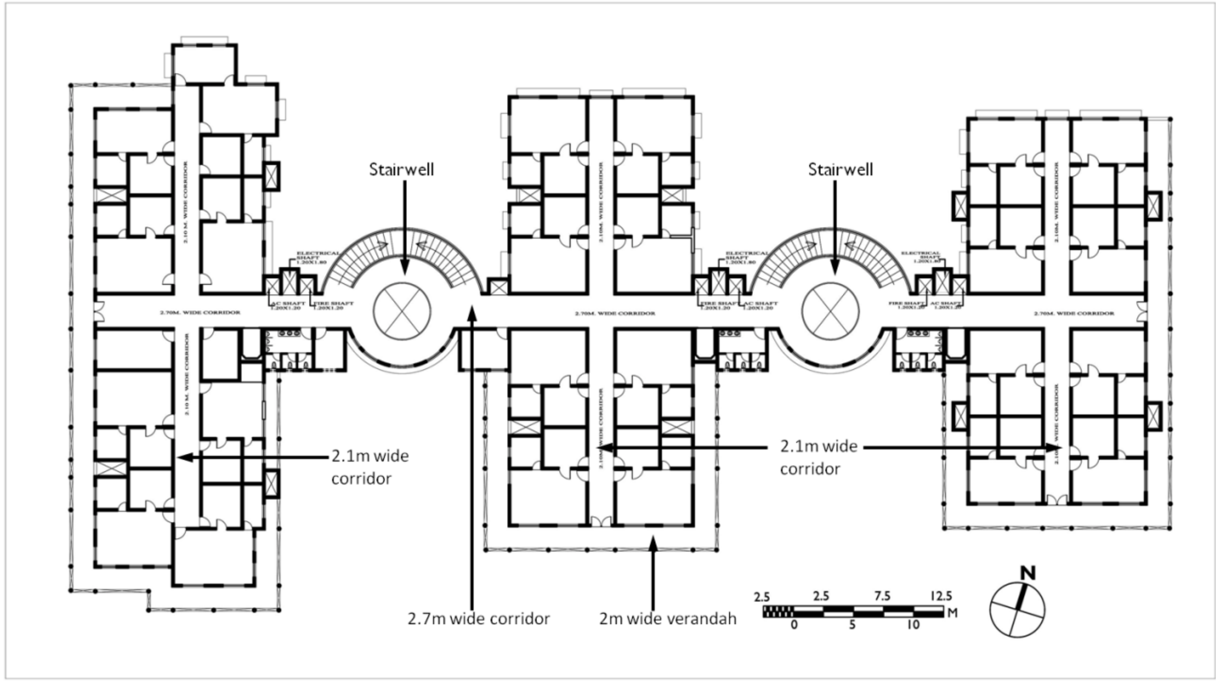
2015–2016
- Energy Monitoring

ARANYA BHAWAN

Original building design

Approved architectural drawings





ARANYA BHAWAN

Original building design

Key specifications

Building envelope:

- Walls: 230mm brick wall (U-value: 2.05 W/m^2.K)
- Roof: 150mm RCC slab (U-value: 3.2 W/m^2.K)
- Glazing: Single glazing 5mm clear glass (U-value: 5.8 W/m^2.K ; SHGC: 0.8 ; VLT: 85%)
- Veranda on each floor for shading of walls and windows

LPD: ~7 W/m^2

EPD: ~10 W/m^2

HVAC system:

- Air cooled VRV system (COP: 2.75)
- Cooling system size: 230 TR (~320 ft^2/TR)

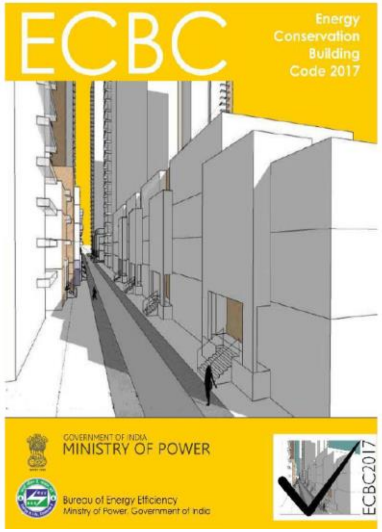
Budget: INR 300 million (~INR3,000/ft^2, including services)

Charrette goals

- Budget: Should not deviate much from the approved budget
- ECBC compliance
- Target EPI: <90 kWh/m^2.year (5-star rating as per BEE star rating for air-conditioned office buildings)

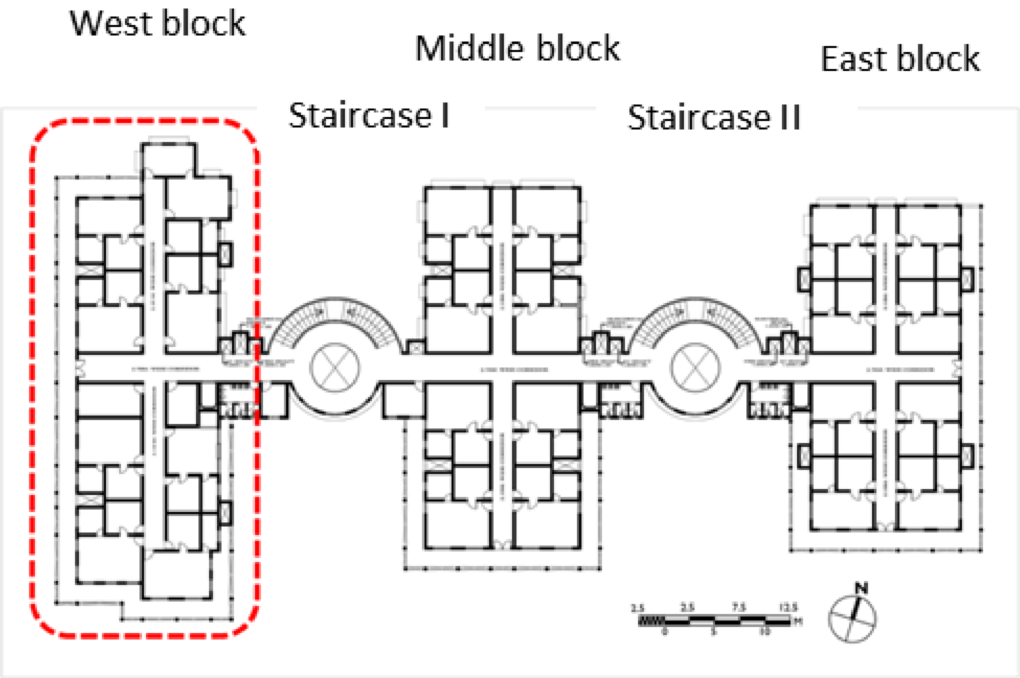
Energy Star Rating Program
(more than 50% air-conditioned built-up area)
Climatic Zone: Composite

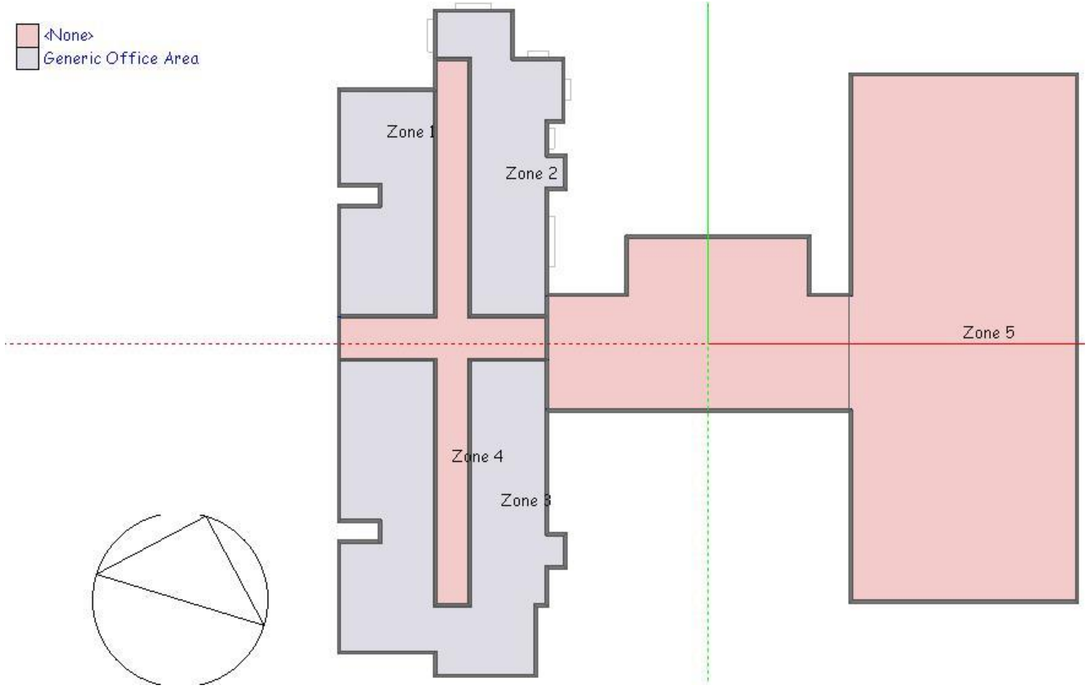
EPI(Kwh/sqm/year)	Star Label
190-165	1 Star
165-140	2 Star
140-115	3 Star
115-90	4 Star
Below 90	5 Star



ARANYA BHAWAN

Area simulated under charrette





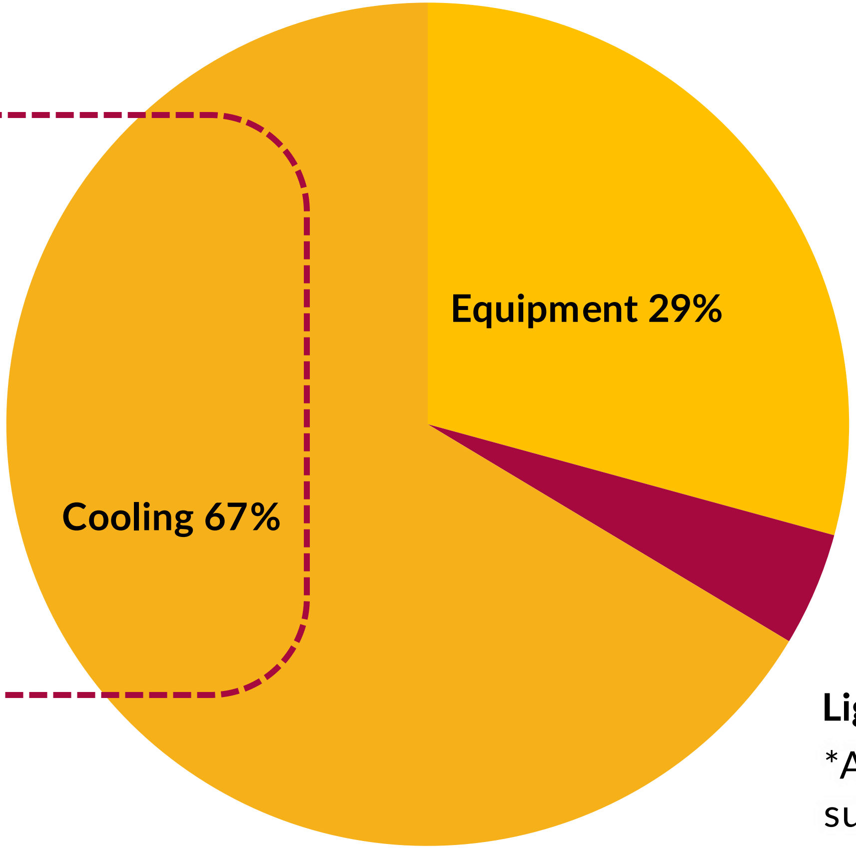
Occupancy: 25 people in one typical floor of the western block (09:30 am to 05:30 pm)

ARANYA BHAWAN

Original design: Energy demand break-up

EPI: 77 kWh/m².year

- **Reduce cooling load**
  - **Reduce heat ingress**
- **Provide cooling efficiently**



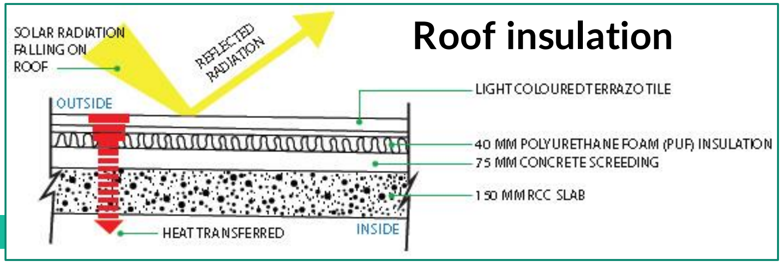
Lighting 4%

*Artificial lighting remains OFF, if daylight is sufficient

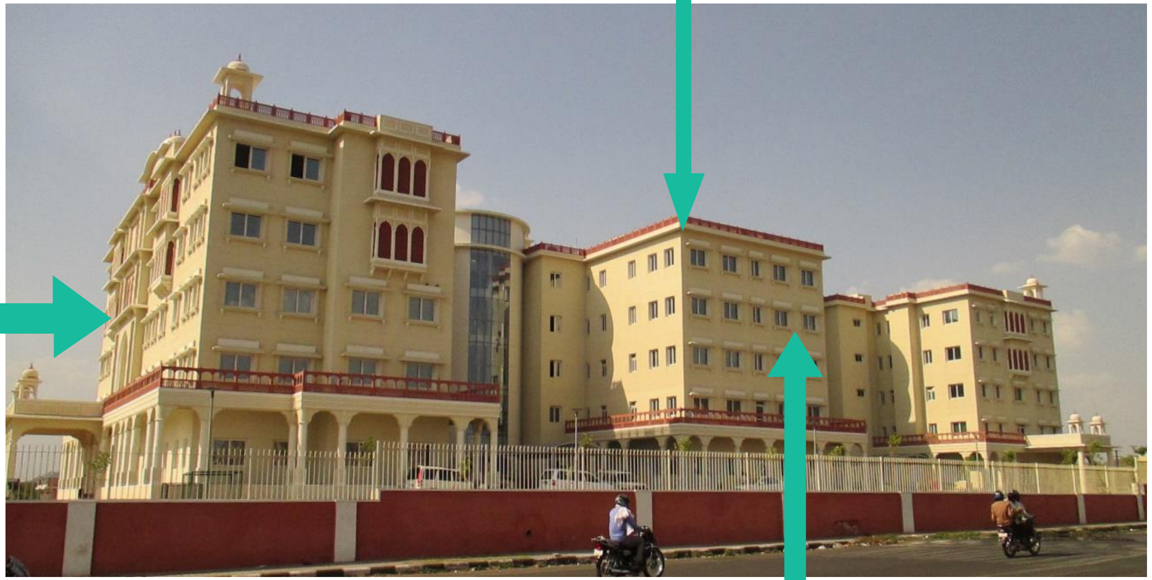
ARANYA BHAWAN

Proposed design: With passive measures

Roof insulation



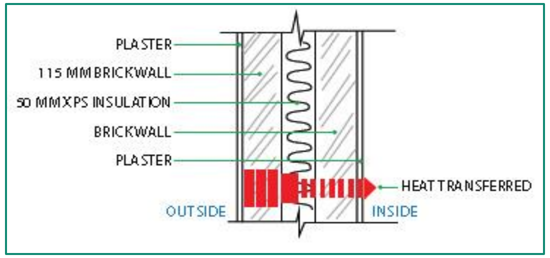
Roof U-value: 0.6 W/m^2.K



Reduction in glazed area (WWR: ~20%)

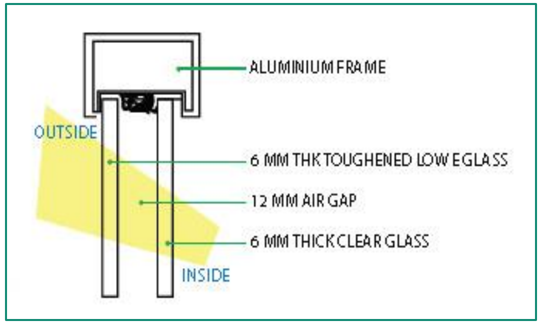
Wall U-value: 0.5 W/m^2.K

Wall insulation



Window U-value: 1.8 W/m^2.K
SHGC: 0.24
VLT: 36%

Double-glazed windows



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Proposed design: Active measures and renewable energy

Energy efficient lighting

- LEDs and T5
- Lighting power density (LPD) of ~6 W/m^2

Energy efficient cooling system

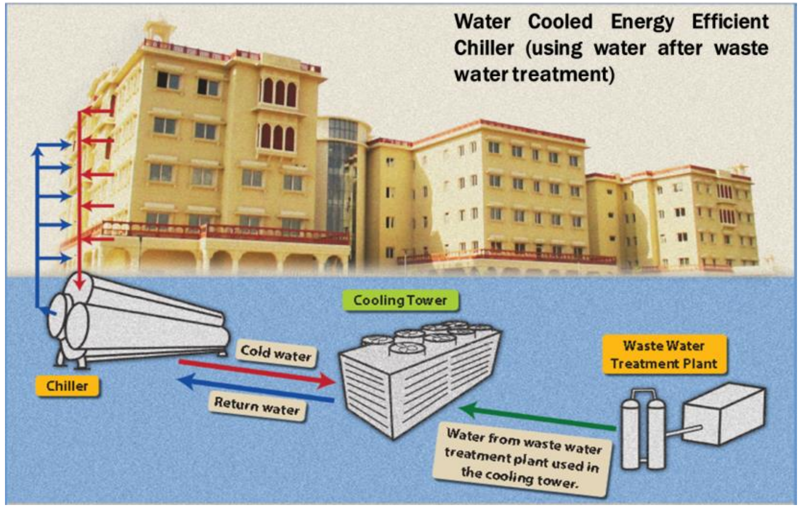
- Centralized high efficiency water-cooled chiller (COP: 5.8)
- Sewage treatment plant (capacity: 15 m^3/d) to provide water for cooling towers

Solar photovoltaic (SPV) system

- Rooftop 45 kWp grid-connected SPV system with net-metering

Solar photovoltaic: Thumb rules

- **Area required:** ~10 m^2/kWp
- Only shadow-free area should be considered for solar photovoltaic system
- **Energy generation:** 1,400–1,600 kWh/kW per year
- **Cost:** INR40,000 per kWp (without batteries)



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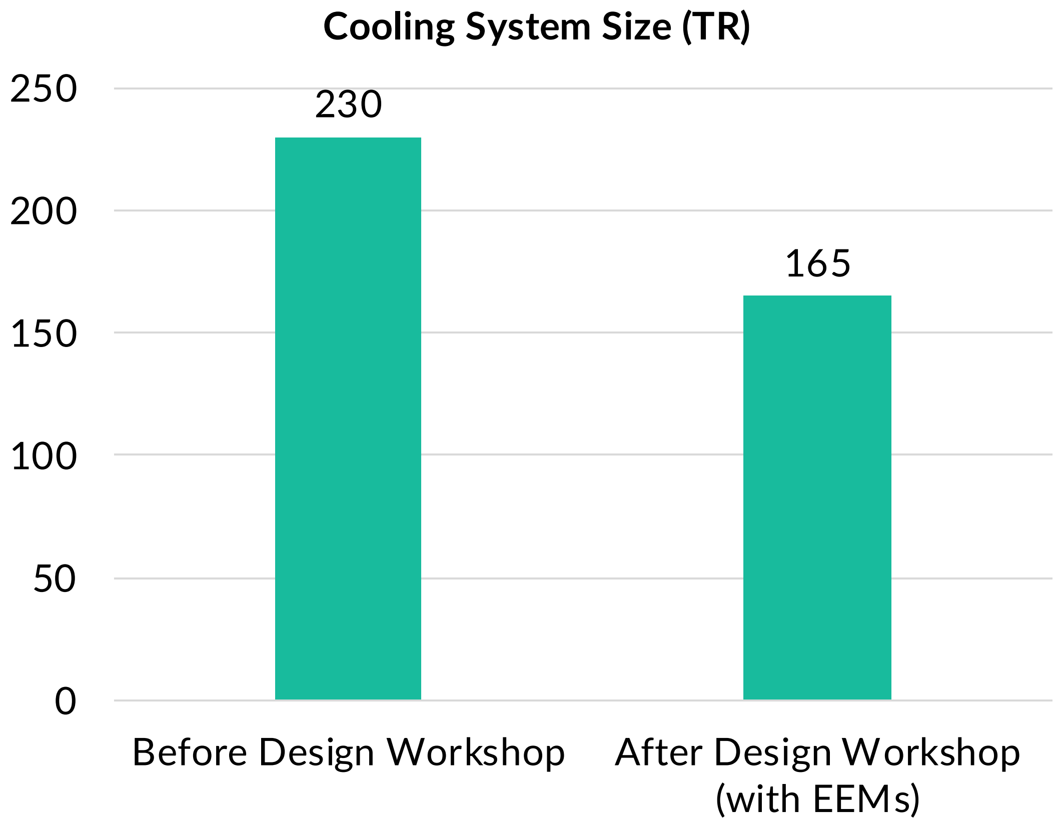
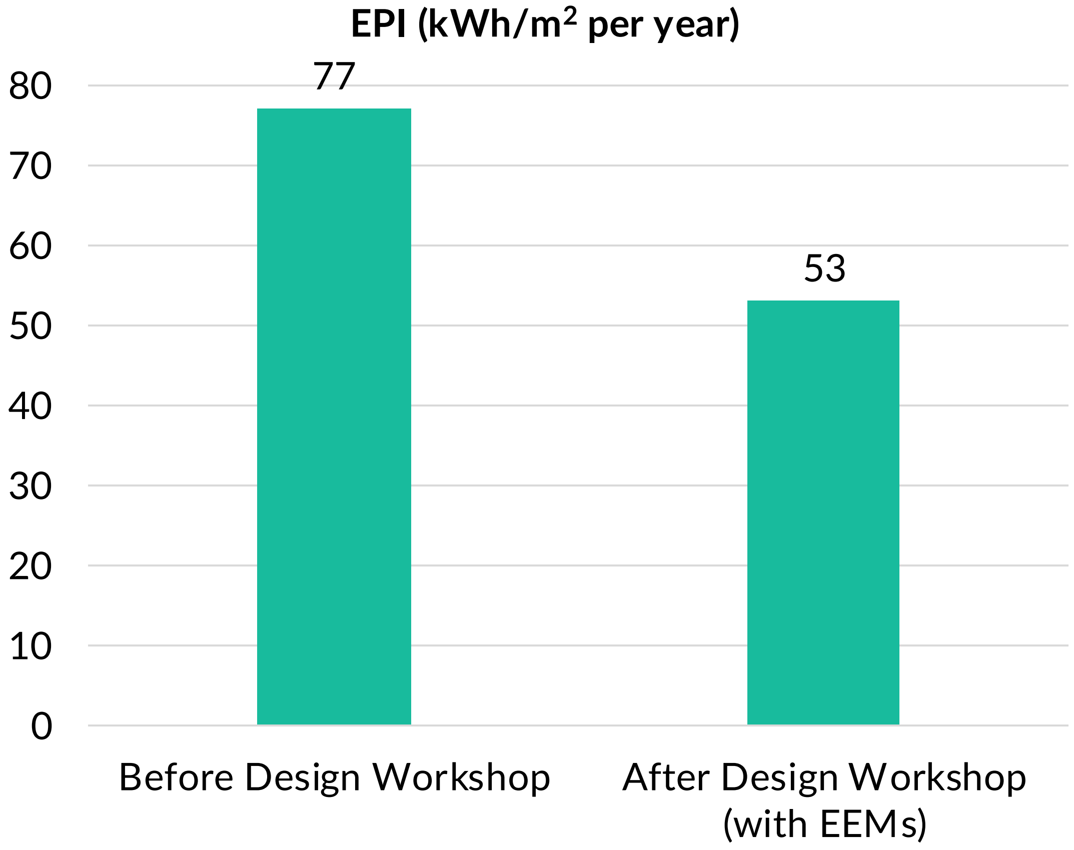
Calculated savings through simulation



28% reduction



**(Solar Photovoltaic contribution not included)*

31% reduction

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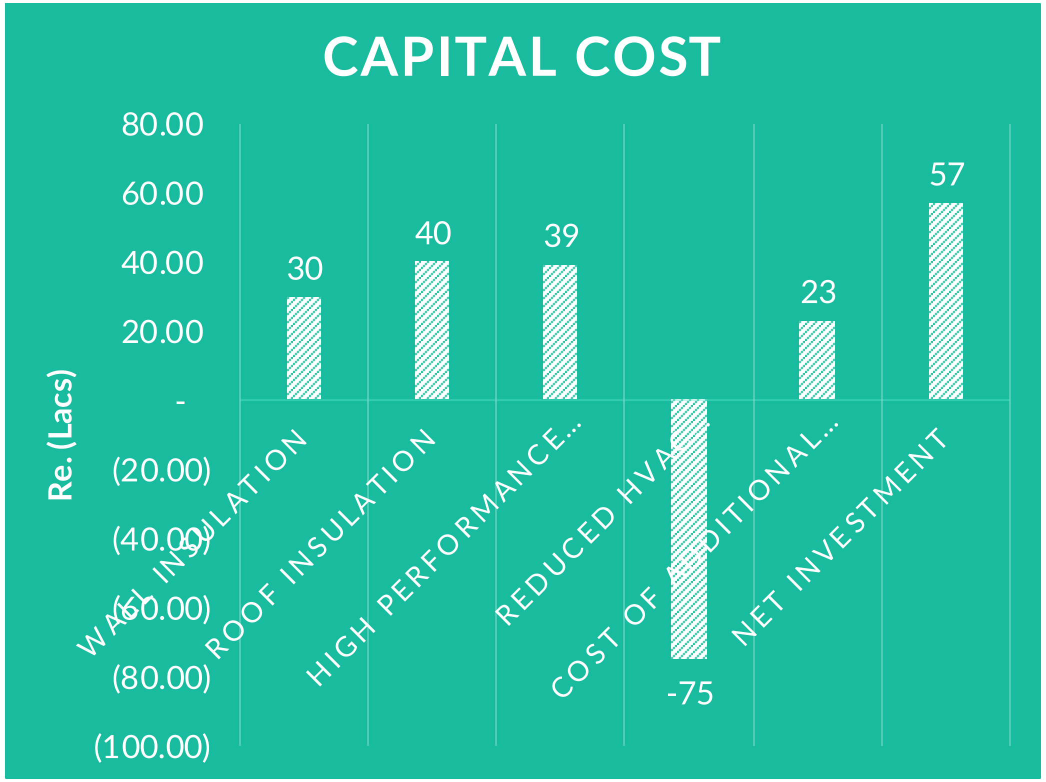
Cost estimates and payback calculation

- **Increase in budget**: ~INR 6 million
- **Approved budget:** INR 300 million
- **Increase in budget**: 2% (acceptable ☺)
- **Typical cost for envelope measures:**
  - Cost of adding 50mm EPS in brick cavity wall: ~INR700/m^2
  - Cost of adding 50mm PUF insulation on roof slab: ~INR900/m^2
  - Additional cost of high performance (low SHGC) glazing as compared to single clear glazing: ~INR3,000/m^2
- **Savings from operational energy:** ~INR2.0 million/year
- **Payback period:** ~3 years



Note: Additional equipment includes cost of STP and additional cost for improved lighting system

Thank you!

For more information, visit us at https://ALCBT.GGGI.ORG
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Any person who believes they may be harmed by an IKI project or who wish to report corruption or the misuse of funds, can lodge a complaint to the IKI Independent Complaint Mechanism at IKI-complaints@z-u-g.org. The IKI complaint mechanism has a panel of independent experts who will investigate the complaint. In the course of the investigation, we will consult with the complainant so as to avoid unnecessary risks for the complainant. More information can be found at https://www.international-climate-initiative.com/en/about-iki/values-responsibility/independent-complaint-mechanism/.

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