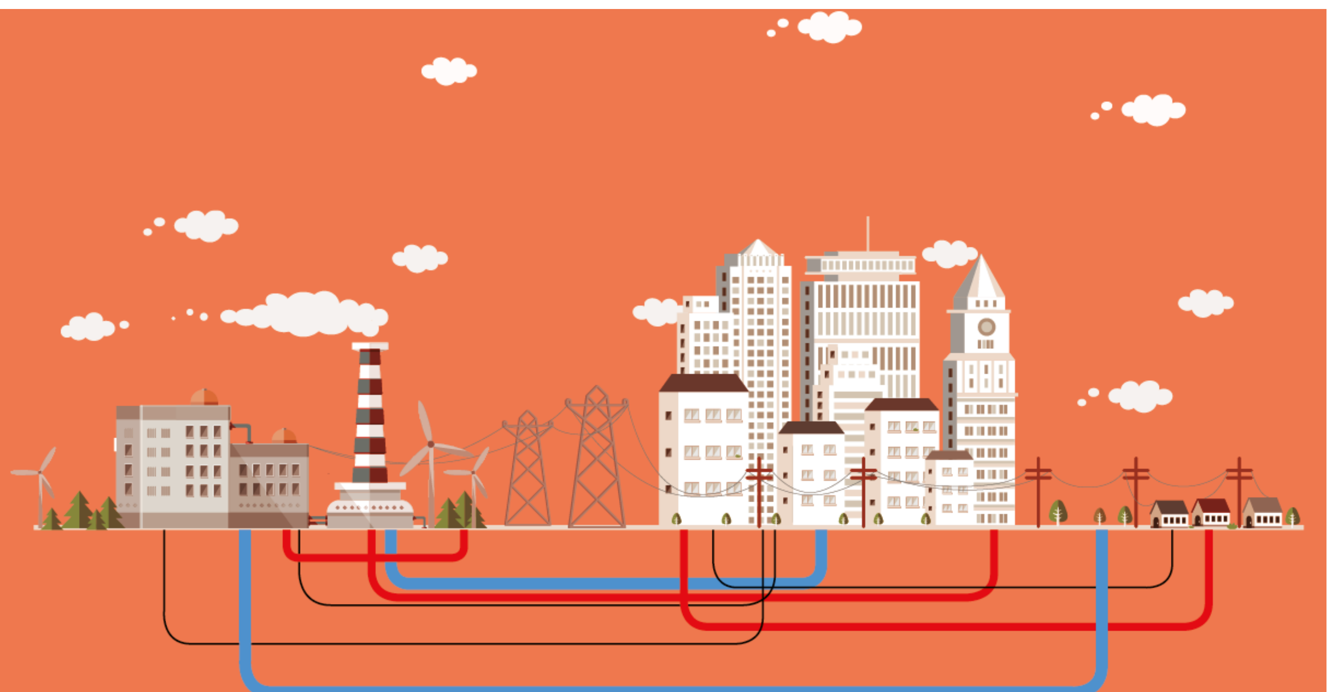
Urban Building Energy Model

Towards Designing Energy Self Sufficient Smart Cities:

A workflow for the generation of complete urban building energy demand models from urban geospatial datasets



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Urban Building Energy Model: A workflow for the generation of complete urban building energy demand models from urban geospatial datasets.

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100 SMART CITIES

SMART = ENERGY SELF SUFFICIENT

The inspiration for the project rose by the Indian govt's plan to develop 100 Smart Cities in India.

As the term 'Smart' could imply various meanings, the interpretition of 'Smart = Energy Self Sufficient' was chosen for the scope of this research.

45% SPACE COOLING

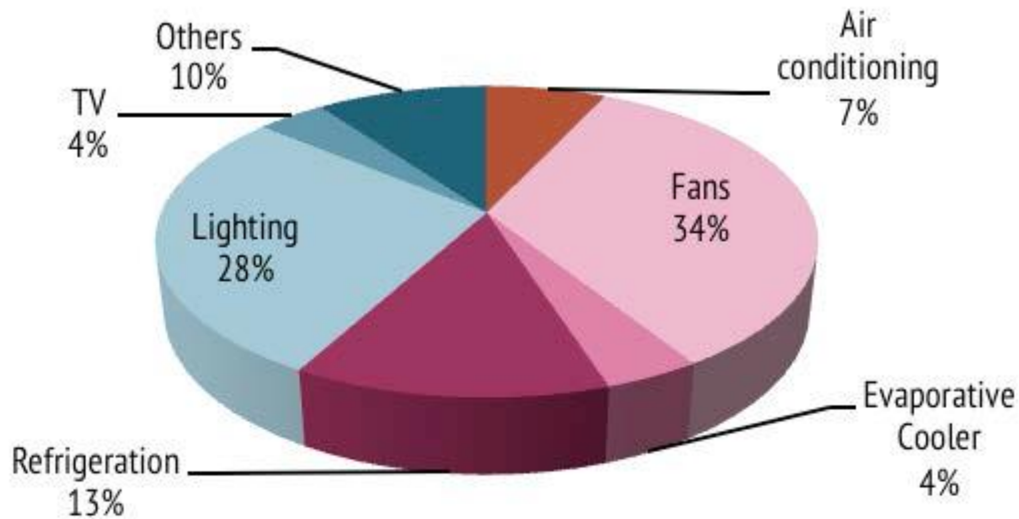


Fig: Energy Consumption in Residential Sector in India (Planning Commission, 2011)

**Soure: Climate Works Foundation, 2010*

Since India is predominantly a Tropical country, Space Cooling accounts for 45% of the Energy Consumption.

Thus, the aim of this research was to analyse the synergy & flow of:

i. Electric Energy

ii. Cooling Energy

iii. Heating Energy

at the Urban Scale.

Statistical Models vs Analytical Models

Predict Energy Use in Hourly Timesteps

+

Simulate Complex Scenario Development & Identify Synergies
(Combined Effect Of Energy Efficiency Measures & Modified Occupant Behavior)

Existing Statistical Models, although more robust since they are based on measured data, have 2 major shortcomings which can be now be overcome by Analytical Models such as UBEM.

THE DATA

GEOMETRIC ATTRIBUTES

- Building Footprint
- Building Heights
- Volumetric Geometry
- Floor to Floor Height
- Window to Wall Ratio
- Facade to Floor Ratio
- Core to Perimeter Area Ratio

NON-GEOMETRIC THERMAL ZONE ATTRIBUTES

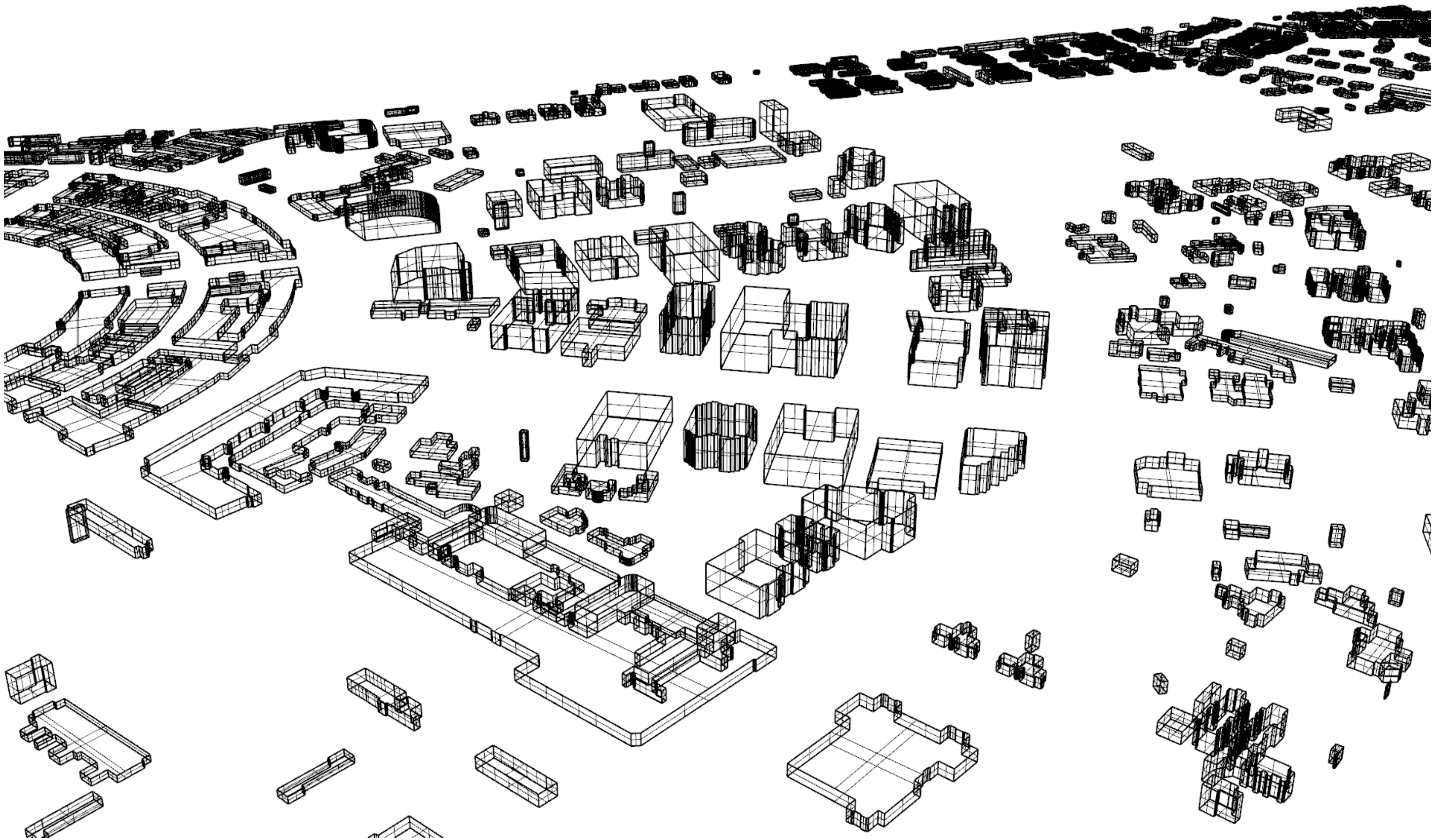
- Land Use / Building Program
- Materials & Construction:
  - Floors
  - Roofs
  - Exterior Facades
  - Interior Walls / Partitions
- Description of Blind / Shading System
- User Profile:
  - Number of Occupants
  - User Schedules
- HVAC Mode of Operation:
  - NV
  - Hybrid
  - Conditioned
- Space Conditioning Systems

Two categories of Datasets are required for any Building Energy Modelling Task, namely Geometric Attributes & Non-Geometric Thermal Attributes.

The availability of such datasets at an urban level is currently a challenge but is expected to become easier once UBEM are adopted frequently.

The Mammoth Task of Urban Building Modelling

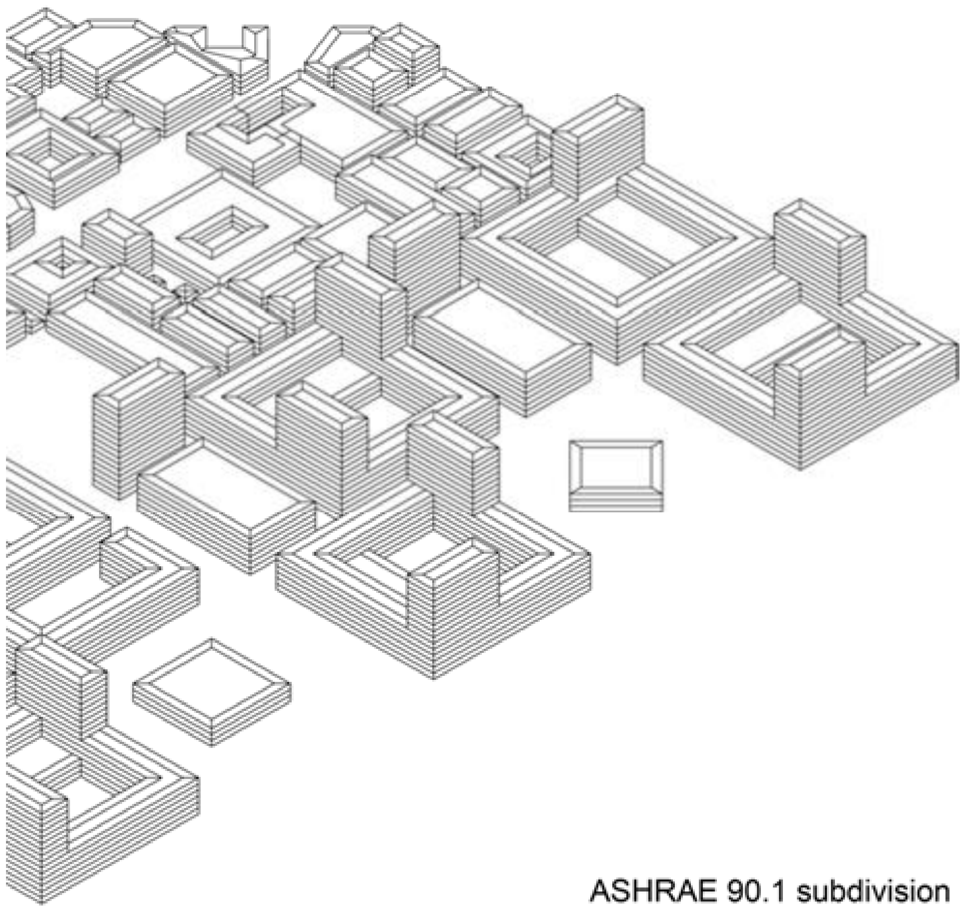
Use of GIS Datasets



GIS Datasets are usually available for major cities around the world. These contain at least the most essential geometric attributes such as building footprints, height etc.

To suit the purpose of energy modelling, these large datasets need to be rationalized.

SubDivision into Perimeter & Core Zones

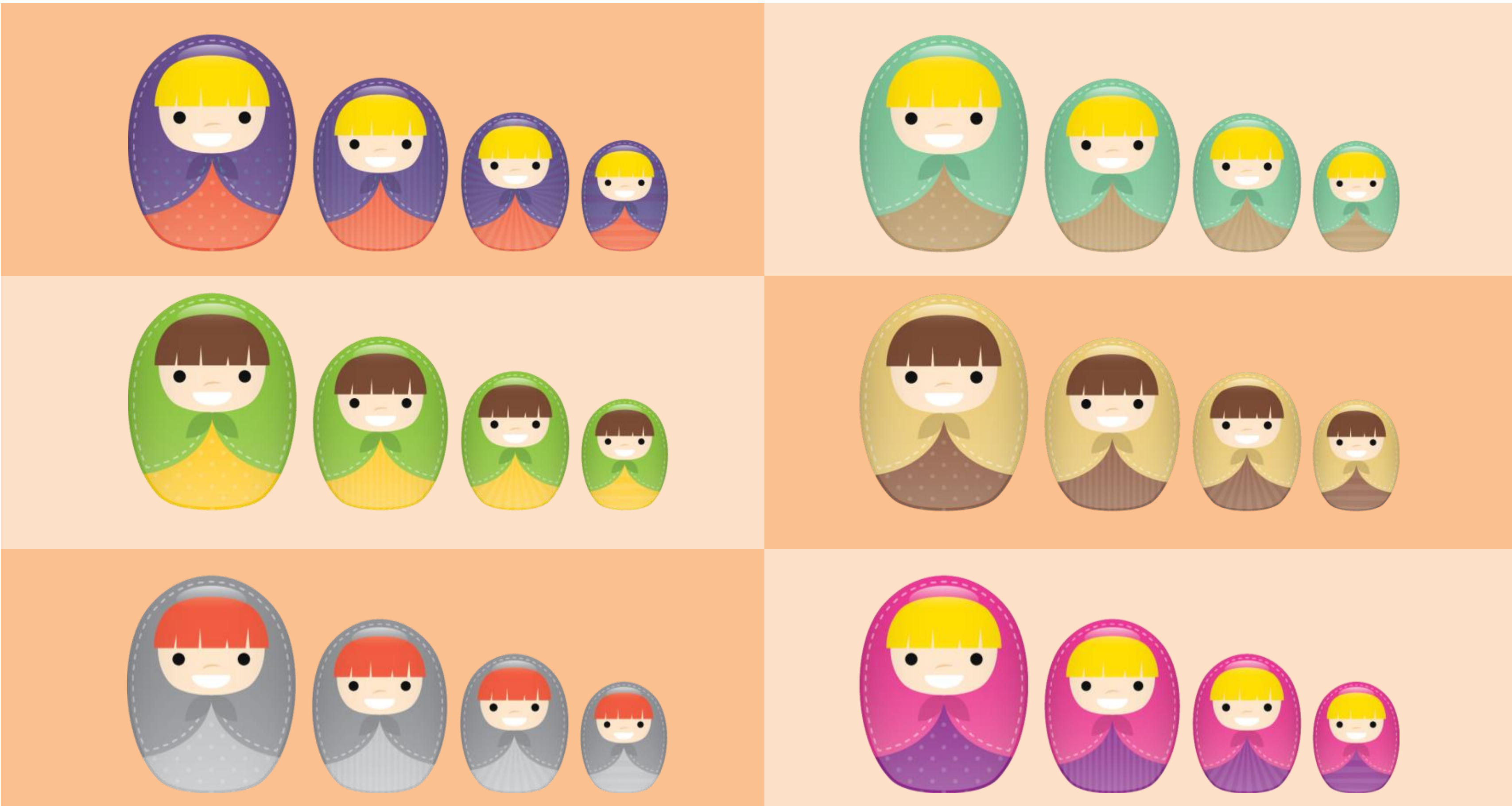


ASHRAE 90.1 subdivision

The most common rationalisation method is the division of the building geometry into Perimeter & Core Zones, as prescribed by ASHRAE 90.1

But this will still result in a very large number of simulation zones. Thus, further simplification is required.

The ARCHETYPE Approach For Simplification



One such effective simplification is by clustering the buildings into Archetypes.

The ARCHETYPE Approach For Simplification

1. Segmentation
2. Characterization
3. Quantification

This approach can be implemented in 3 steps:

1. Segmentation
2. Characterization
3. Quantification

SEGMENTATION

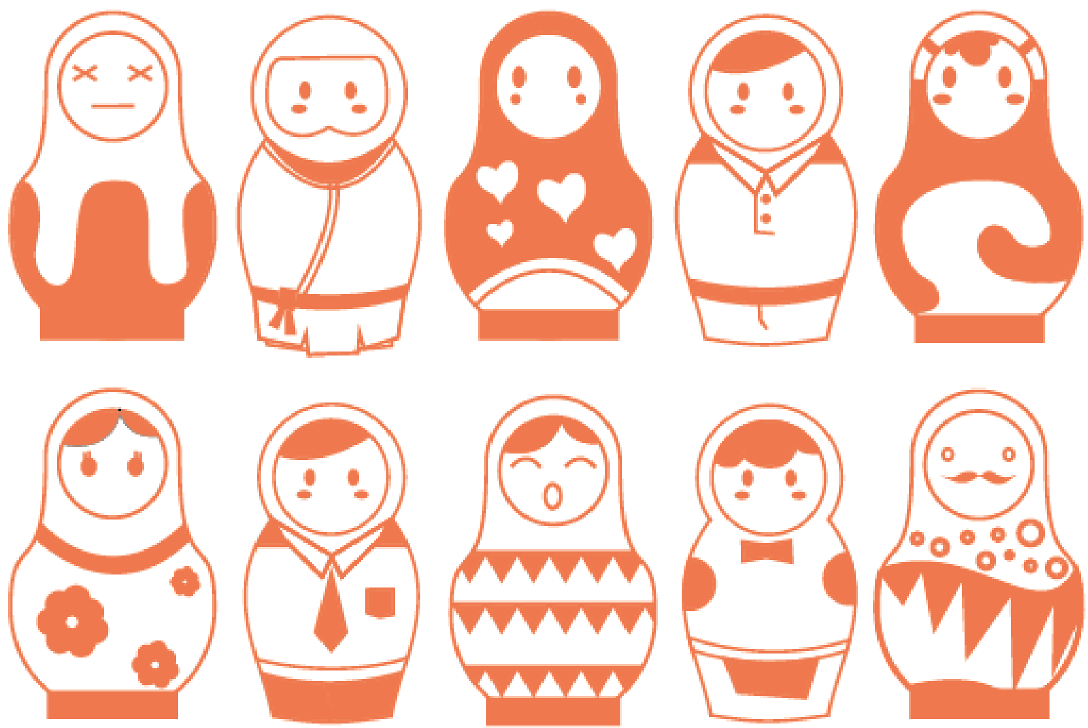
- Informed Simplification by ‚Clustering'

- ‚Clustering' means to Sort & Group Based On

  - Land Use / Building Program
  - Similar Geometric Properties: Volume, Facade to Floor Area Ratio, WWR
  - Envelope Properties
  - Ventilation Mode: Natural, Hybrid, Mechanical
  - Space Conditioning Systems

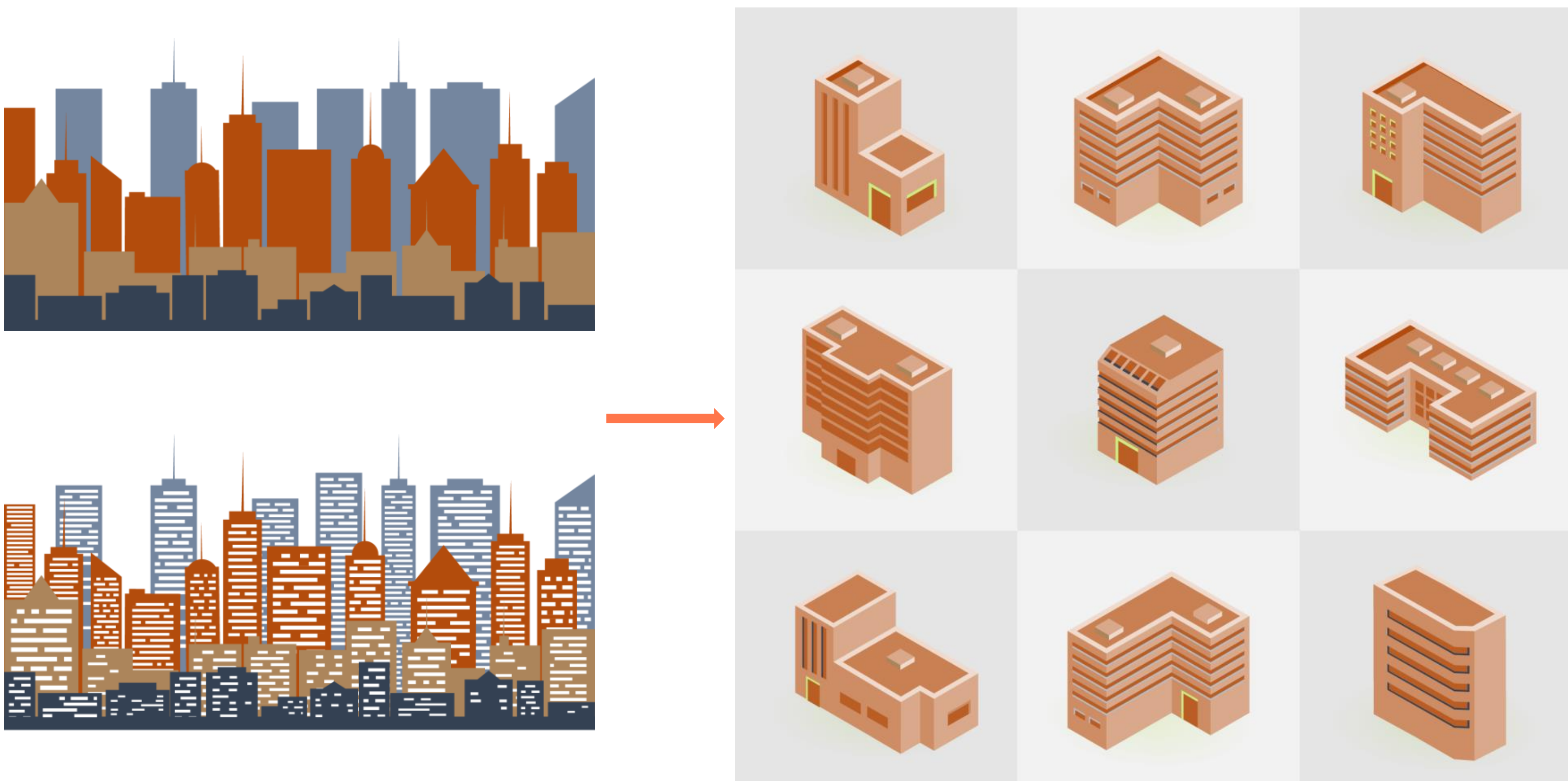
Segmentation is an automated procedure that makes informed simplifications to the urban datasets by clustering buildings by their internal program & building form-factor.

The Unique Representative Unit for each Archetype



Once all the buildings have been sorted into groups, such that buildings in one group are more similar to each other than the buildings in other groups, the algorithm picks one building randomly from each group. This becomes the representative ‚Archtype Unit' for it's cluster.

Hundreds and Thousands of Buildings in a city are reduced to a couple dozen manageable Archetype Units



This enables us to ultimately reduce the thousands of buildings in a city to a few Archetype Units we can work with.

CHARACTERIZATION

Creating the Representative Energy Model

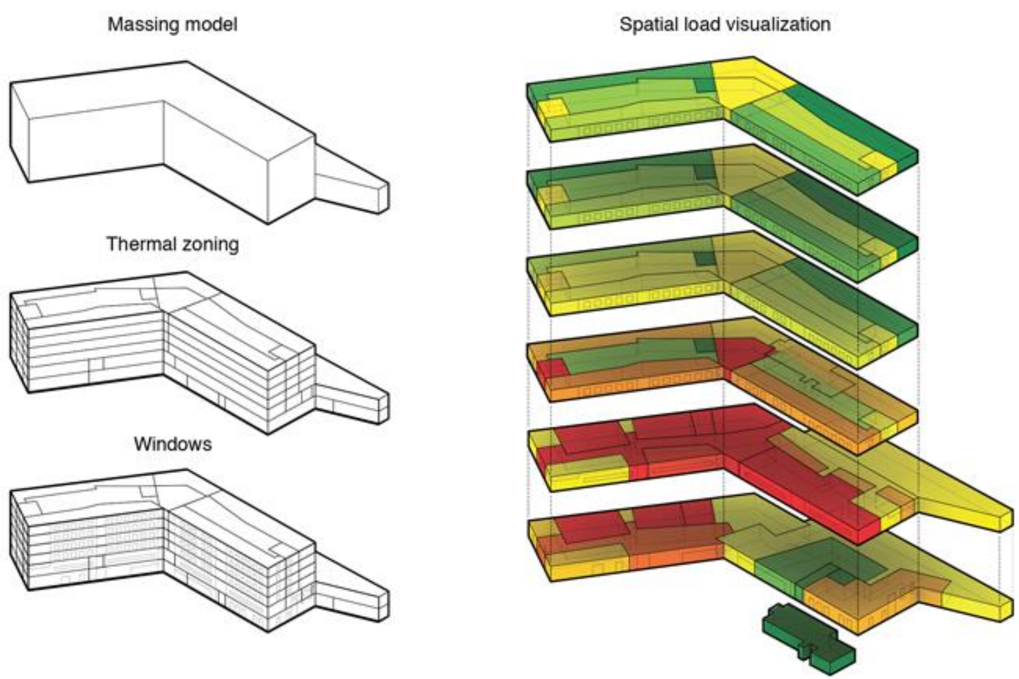
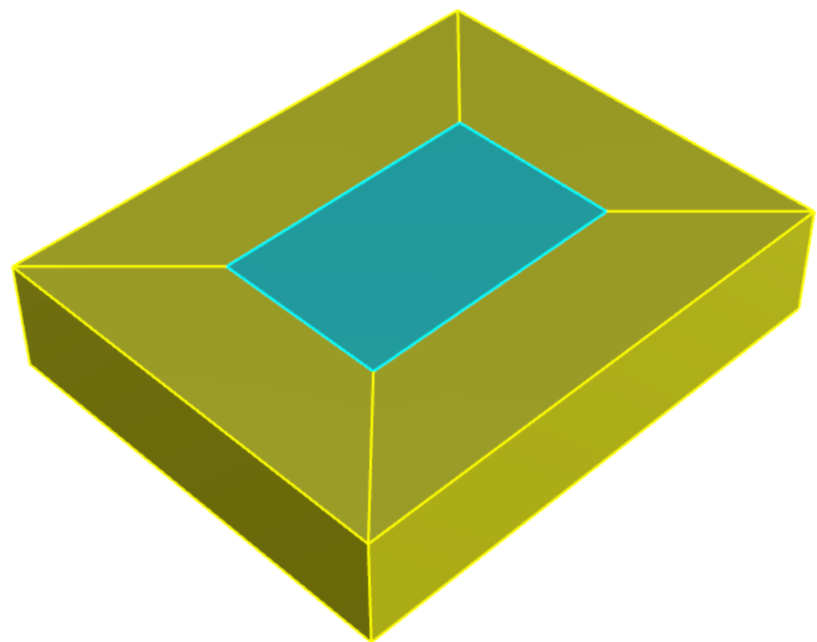


Image credits: Aiko Nakano, Denise Rivas, Manos Saratsis, Julia Sokol

Once we have the unique Archetype Units, the next step is to create accurate representative energy models. This step is known as Characterization.

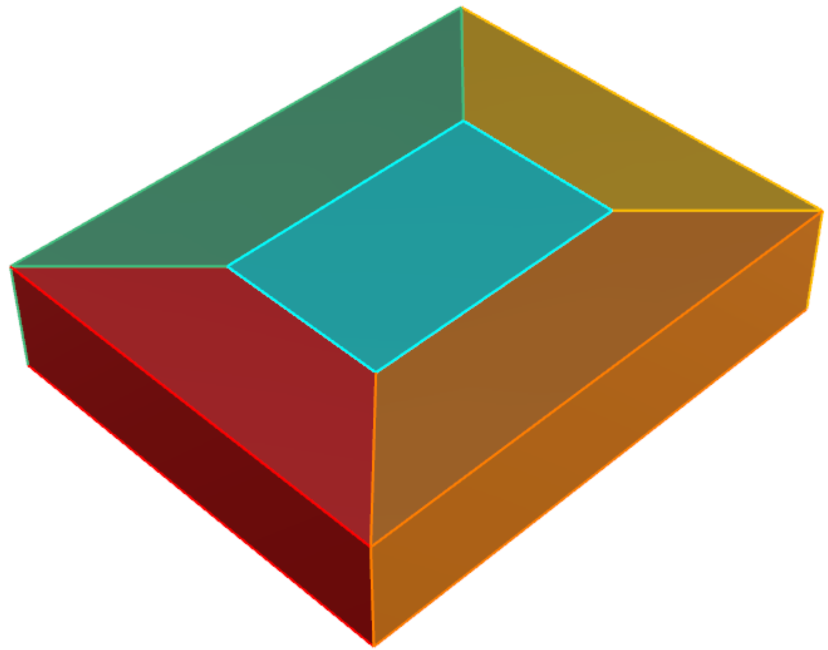
The Most Common Simplification



Dividing into Perimeter and Core Zones
(As prescribed by ASHRAE 90.1 Appendix G)

As discussed earlier, the usual way of creating representative energy models of large spaces or for spaces whose interior partitions arenot known, is by dividing each floor into a Perimeter and Core Zone. Let us take a closer look at the idea behind such zoning.

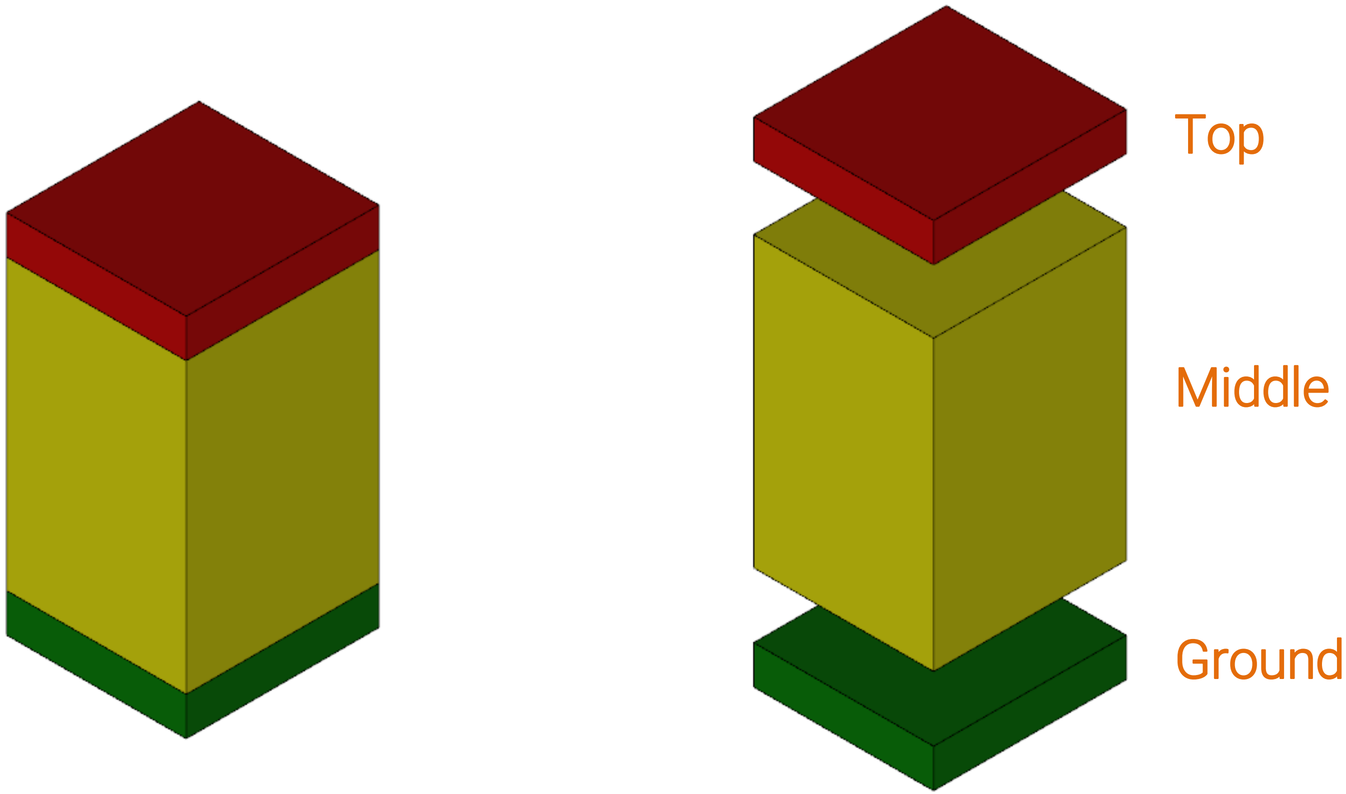
The Goal of Perimeter & Core Zoning



Capture the Different Micro-Climatic Boundary Conditions

The aim of such zoning is to accurately capture the different microclimatic conditions that may develop on different perimeter facade orientations and the internal core, owing to variations in the amount of radiation received. So if that is the intent, let us develop an efficient way doing it at the urabn scale.

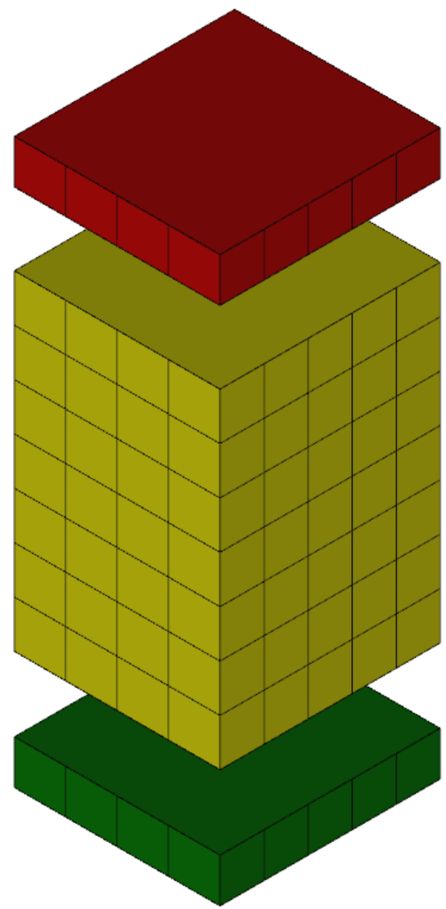
Split the Building



We begin by dividing each representative archetype unit into the Roof, Ground and Intermediate Fllors to account for the different boundary conditions. (Top floor roof + facades exposed to radiation ; Intermediate floors only facdes exposed ; Ground floor facades exposed and heat exhange with the ground)

The Facade Grid

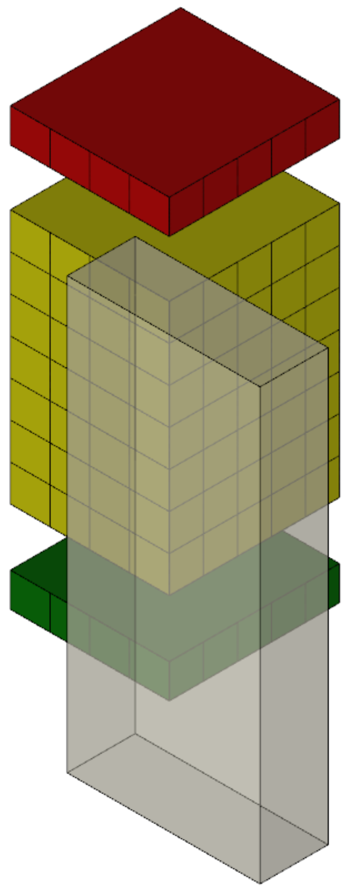
Cell Size =
3 x 3 m



Next, we extract the facade and divide it into a square grid of smaller facade patches (3x3m)

Identify Micro Climatic Zones

Urban Contextual Shading



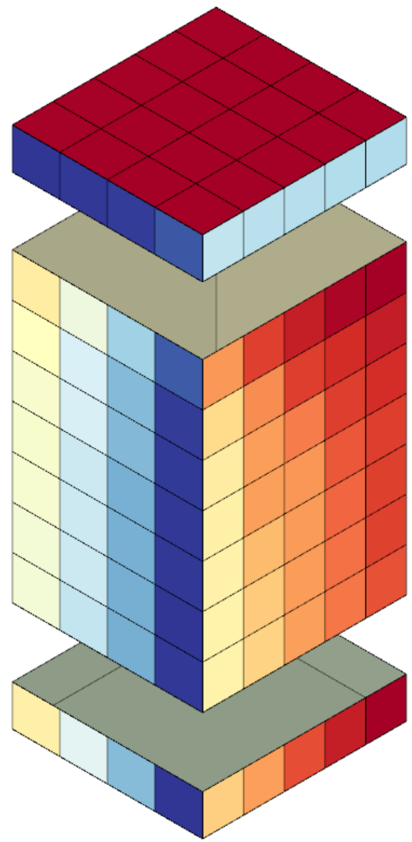
Our aim is to identify the different micro-climatic zones that may develop in the building due to:

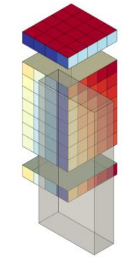
i. Different Orientations

ii. Urban Contextual Shading

To identify this, we run an annual solar radiation analysis on all facades.

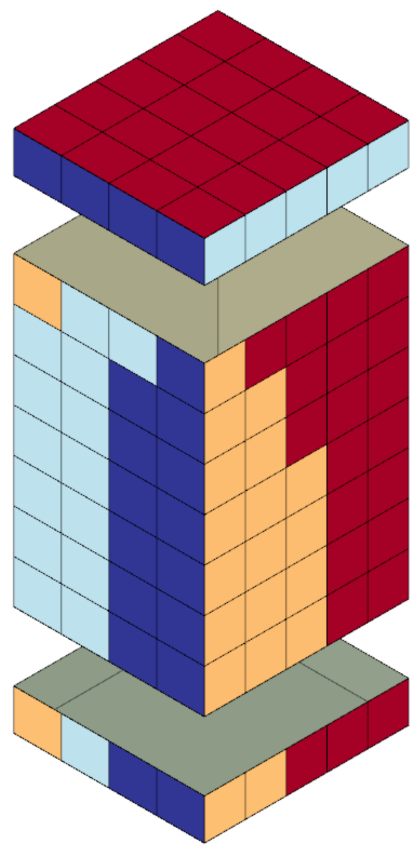
Total Annual Radiation @ Each Facade Patch

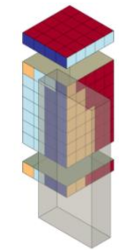




Then we rationalise the radiation results into insolation groups or clusters. eg if max radiation is 1000 kWh & we rationalise all the results into say 5 groups, with 5 range segments of 0-200 , 200-400 ... 800-1000. Then for rationalising, all the facade patches that lie in a particular range, say 400-600, will take a new value which will be the avergae value of the group.

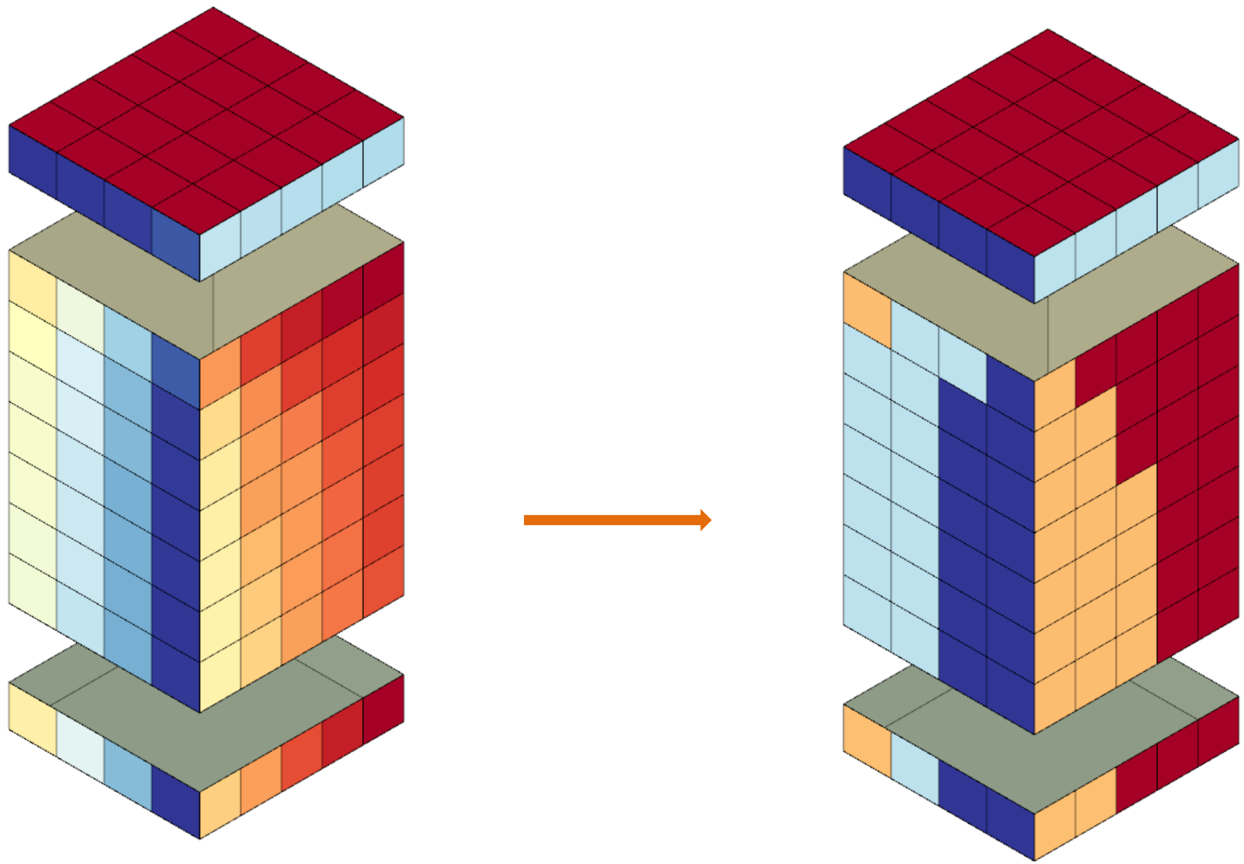
Cluster Similar Insolation

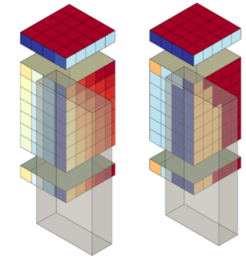




Thus we end up creating facade clusters, where each facade patch in a cluster recieves the same radiation.

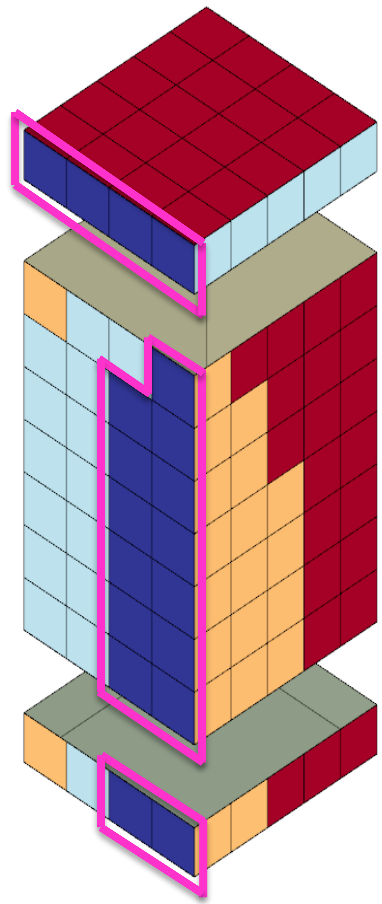
Micro-Climatic Boundary Conditions Identified

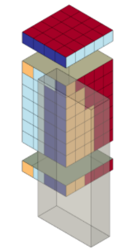




This helps us to identify the different micro-climatic zones that may develop in a building.

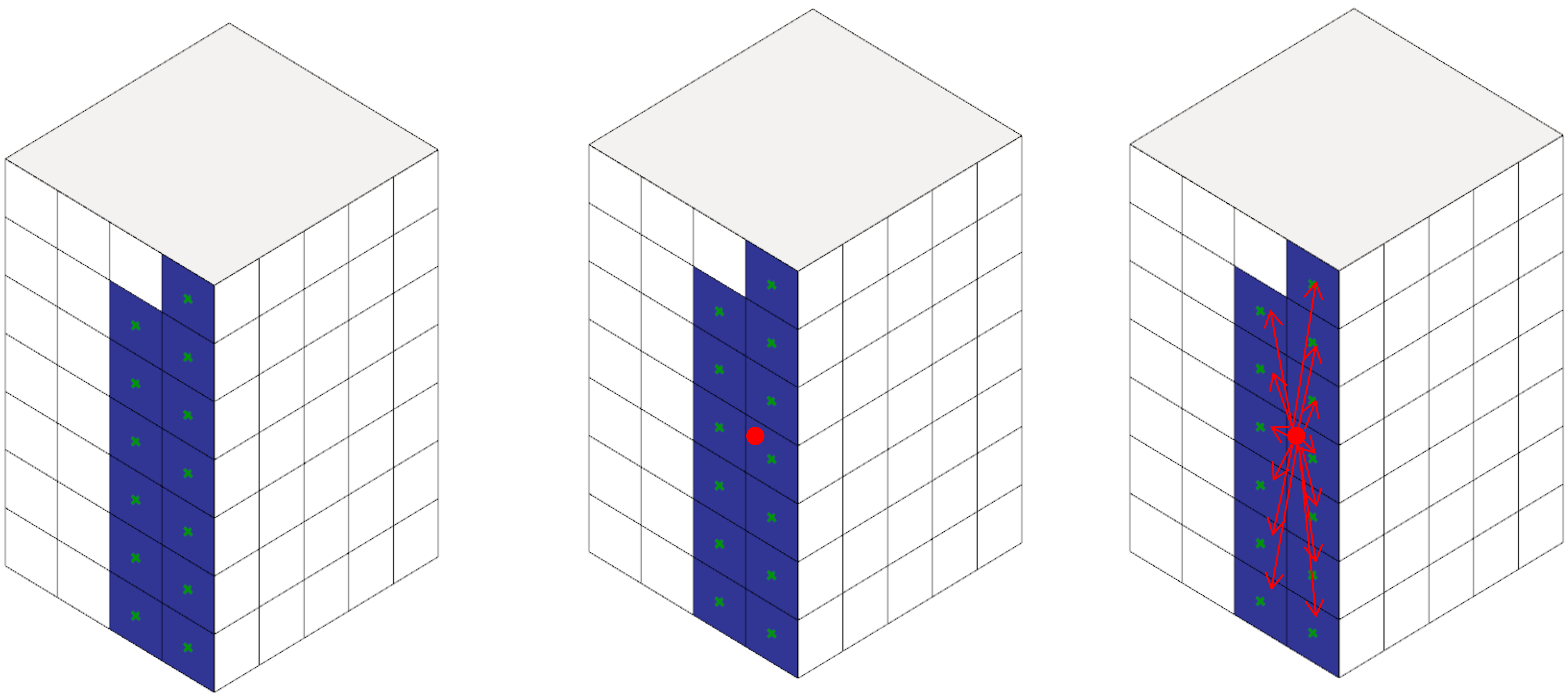
Advantage of Splitting





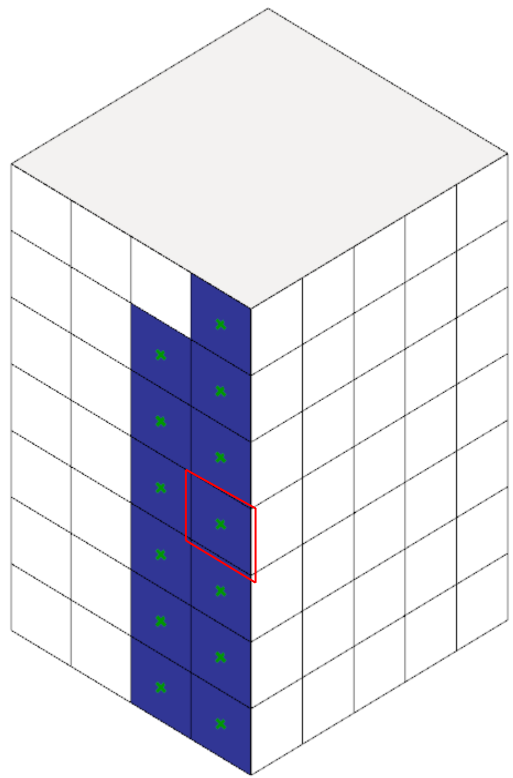
Since the building has already been sorted into top, middle & ground floors, so even if 3 facade patches receive similar radiation but have different boundary conditions of the roof, the ground or the interemediate floors or even a corner zone with 2 facades, they will be identified and marked as such by the algorithm.

Locating the Shoebox



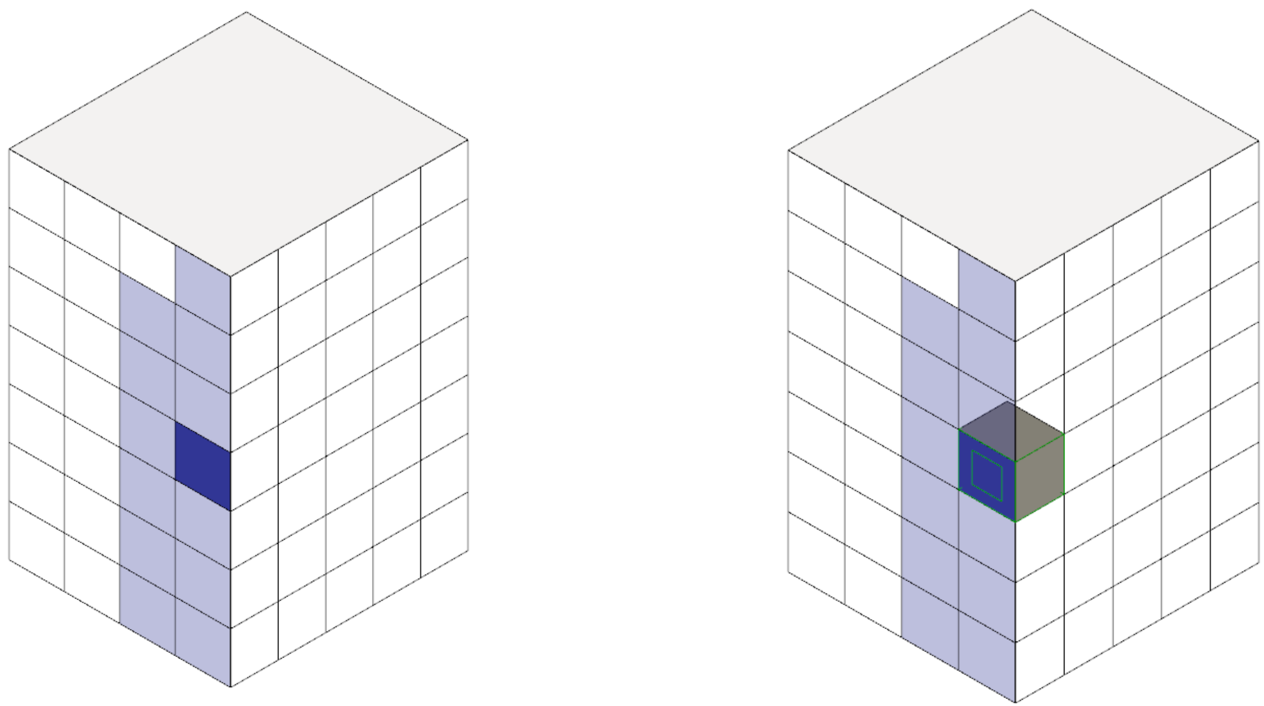
Once we have identified the different micro climatic (radiation) clusters, the next step is to place a representative shoebox energy model. If the similar radiation clusters occur at multiple locations on the facade, we find the centroid of the facade clusters, then identify the facade patch closest to the centroid.

Locating the Shoebox



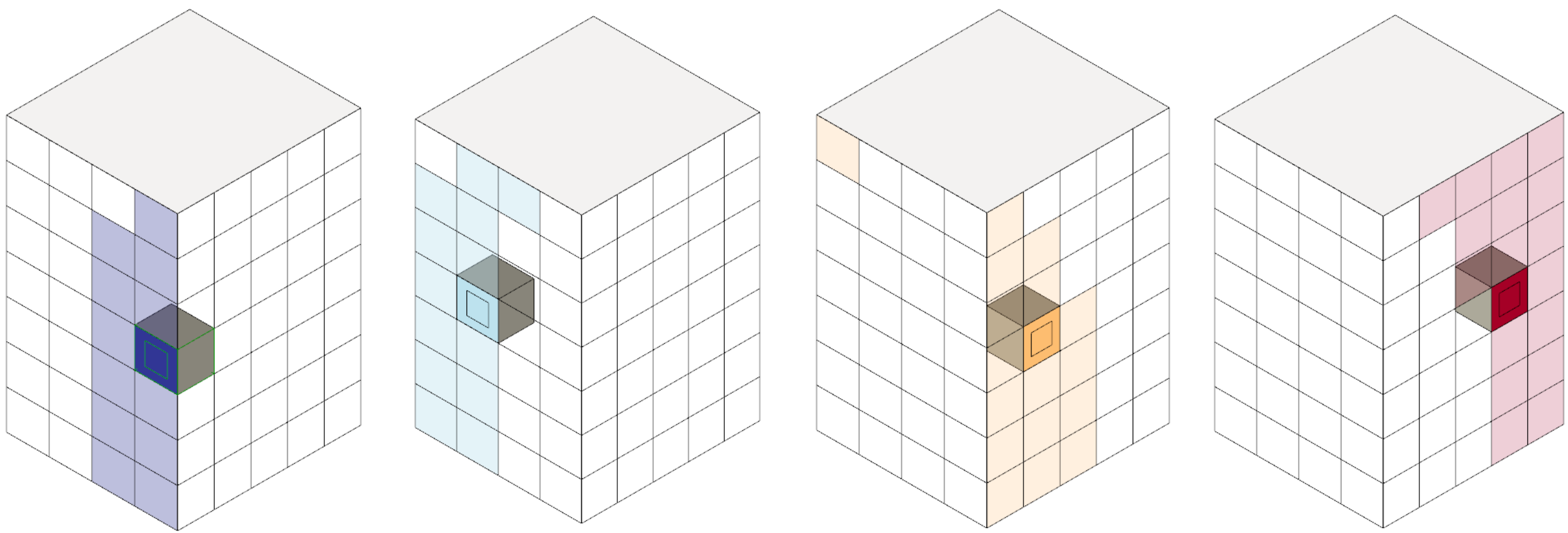
This facade patch is the closest to the centroid.

Typical Room Thermal Shoebox



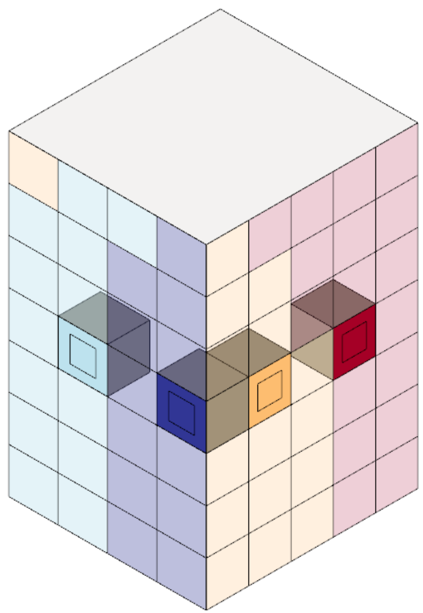
Therefore, for this microclimatic boundary (radiation) cluster, we create our representative shoebox energy model at this location.

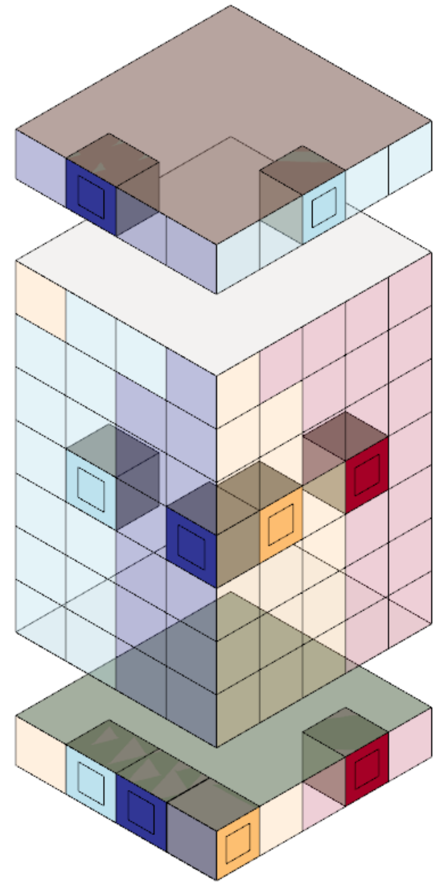
Typical Room Thermal Shoebox



In a similar fashion, we generate all our typical room shoeboxes shoeboxes for each facade insolation cluster.

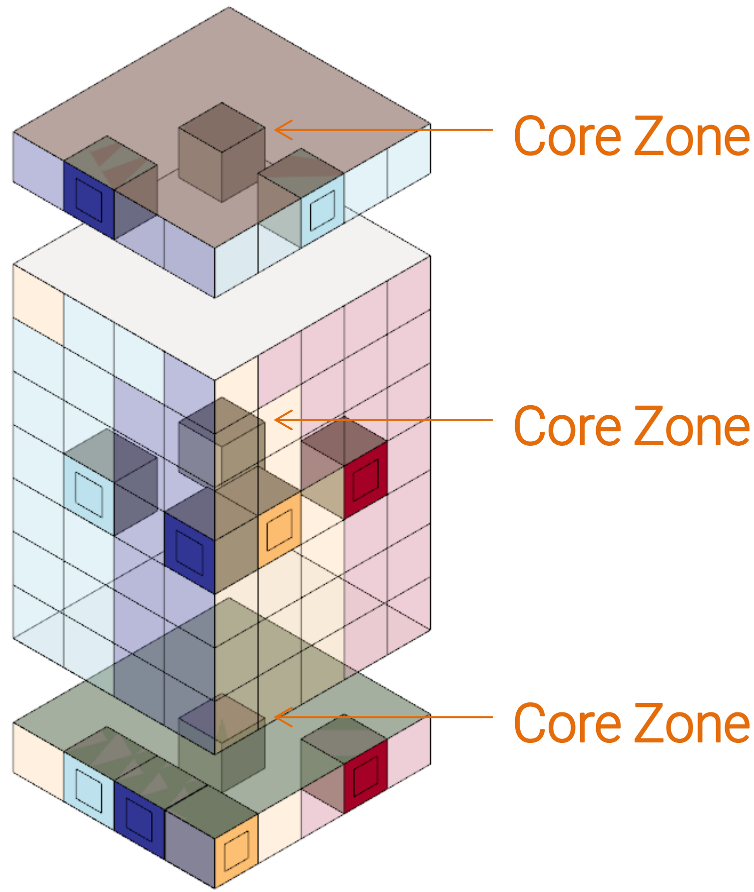
Typical Room Thermal Shoebox





The shoebox models are created for all split parts — roof, ground and floor.

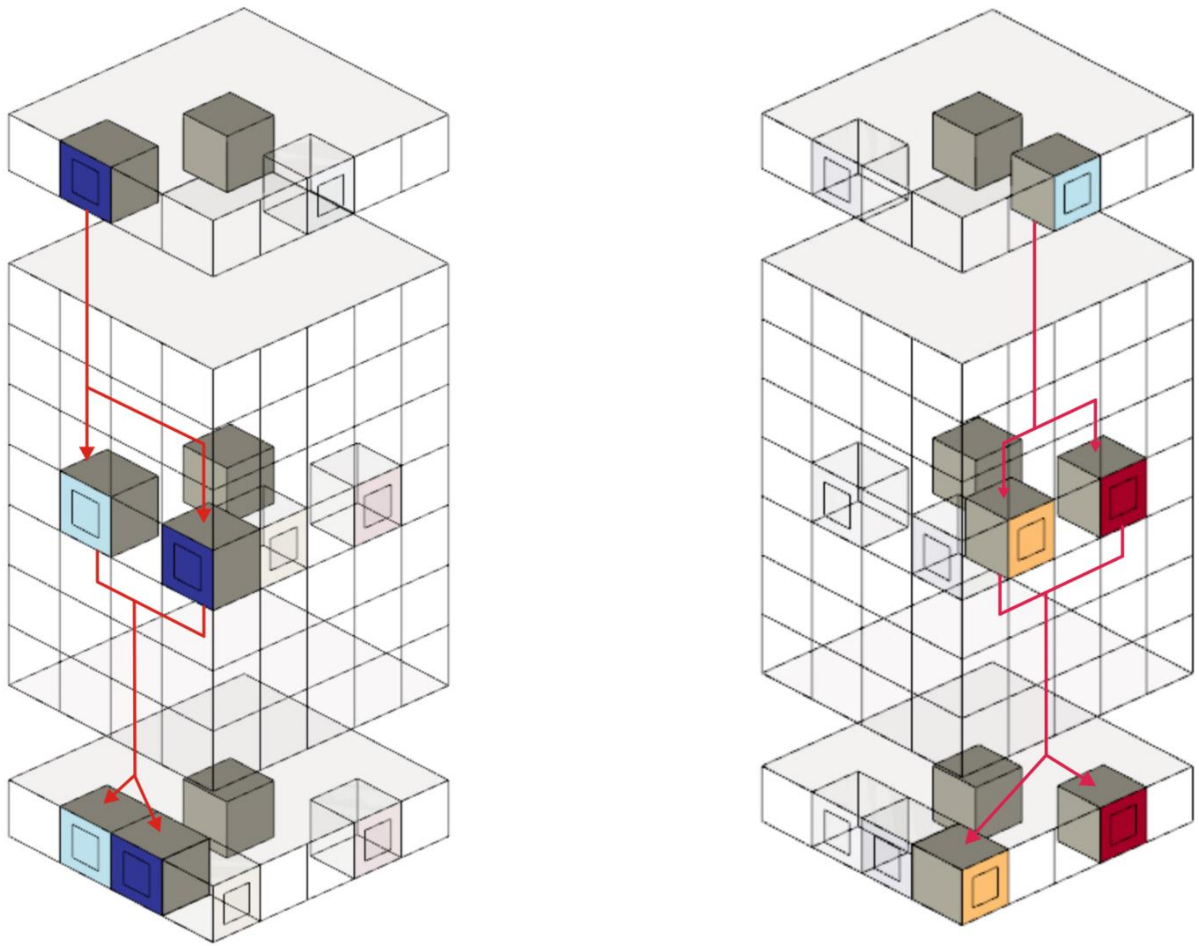
Add Core Zones



In addition to the facade or 'perimeter' shoebox zones, we place additional zones at the core, one each at the top, ground and middle floor.

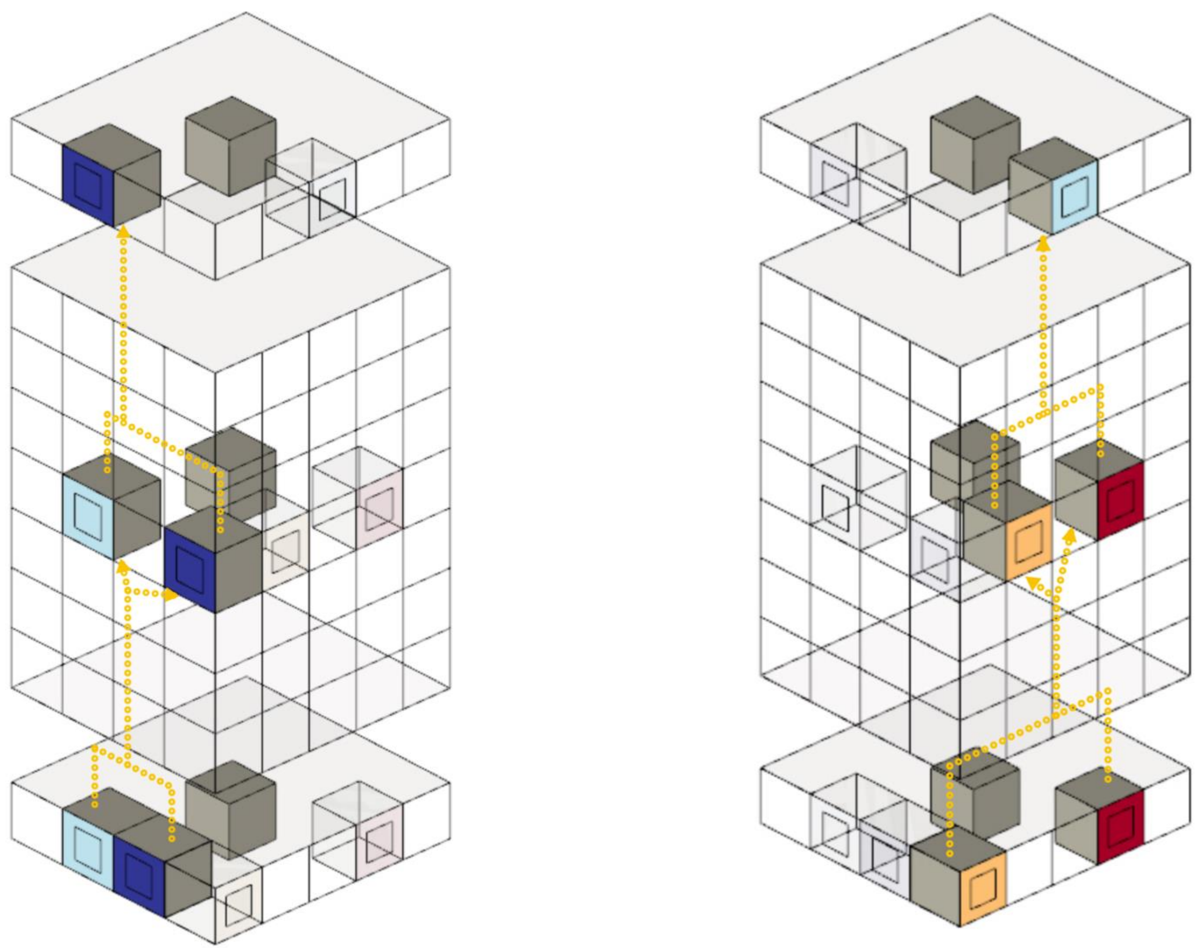
Now once all the thermal shoeboxes are placed, we will begin the next step of connecting the individual zones to set up a multi-zone model.

The Multizone Model



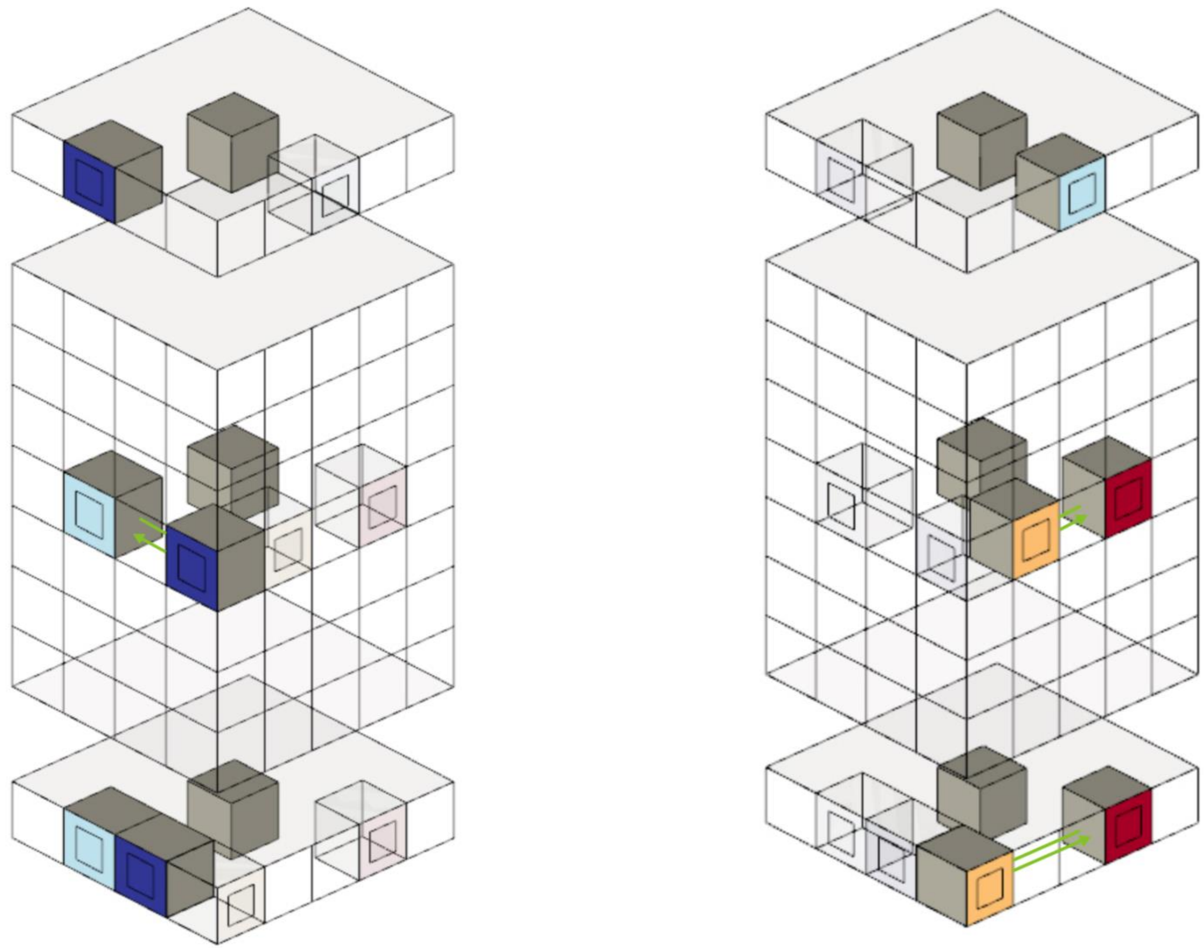
The first boundary condition assumption is that the surface temperature of the ceiling of a shoebox zone is at the same temperature as the average of the surface temperatures of floor of the shoebox zones above it (on the same facade orientation). In the case of zones on the top floor, the ceiling is treated as an external surface exposed to radiation.

The Multizone Model



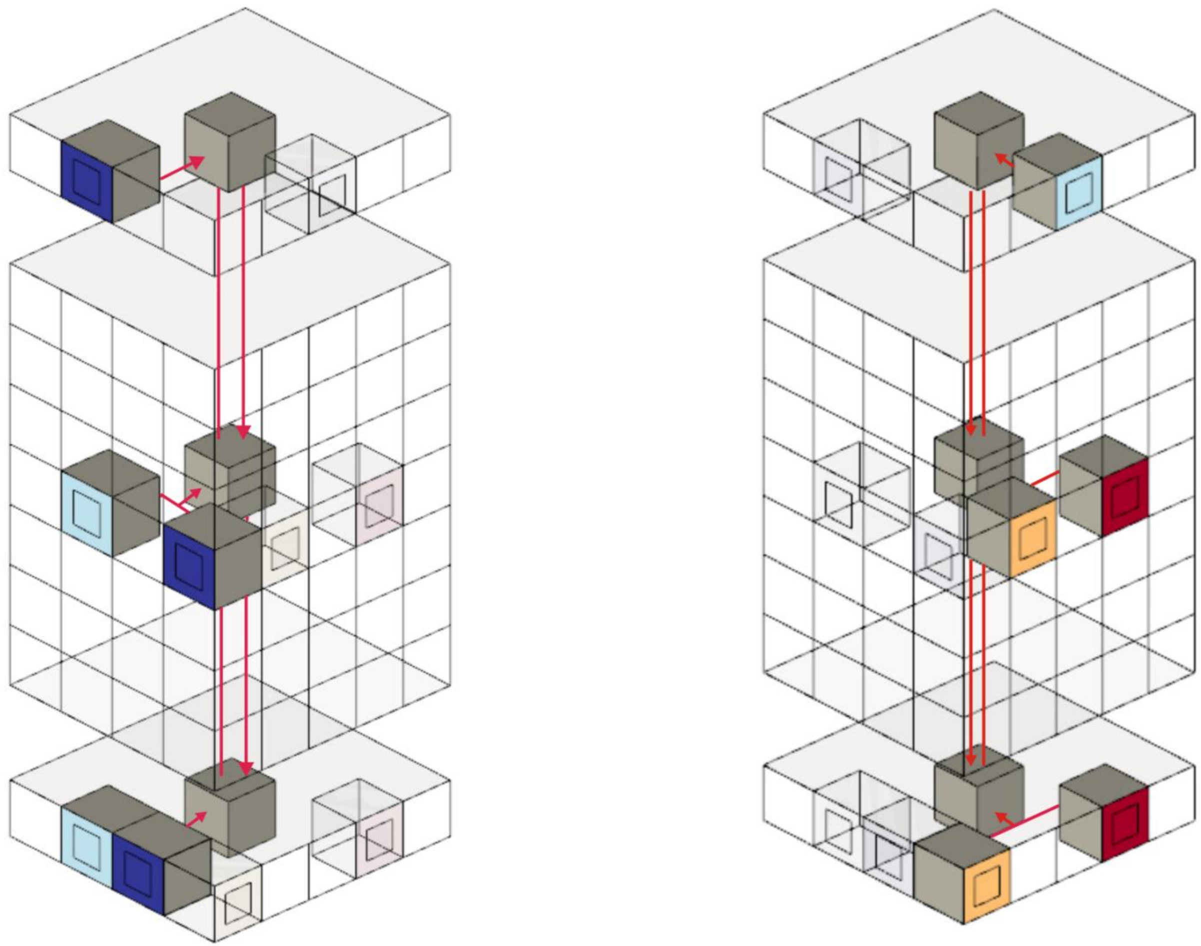
The second boundary condition assumption is that the surface of the floor of a shoebox zone is at the same temperature as the average of the surface temps of ceilings of the shoebox zones below it (on the same facade orientation). In case of ground floor zones, the floor surface temperature is treated the same as Tsoil.

The Multizone Model



The third assumption about boundary conditions is that the side walls of a shoebox that face each other are at the same surface temperature

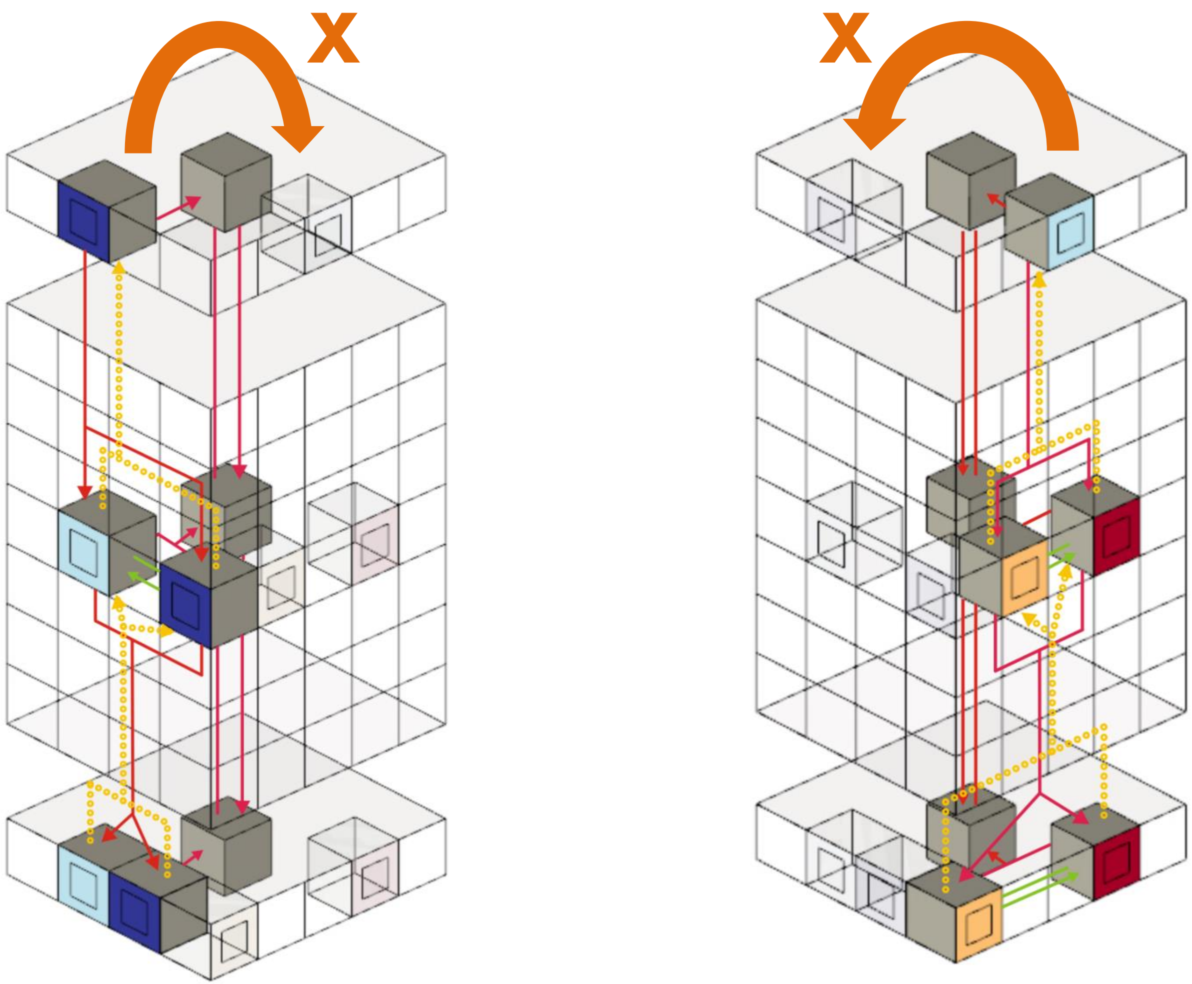
The Multizone Model



The fourth assumption is that the walls of a core shoebox are at the same temperature as back walls (that face the core) of a facade shoebox.

The fifth assumption is that the floors and the ceilings of the core zones exchange surface temperature information between them in the same way as facade zones (assumption 1 + 2)

The Multizone Model



The sixth assumption is that the facade zones at one orientation do not exchange surface temperature information with facade zones at a different orientation. All temperature information exchange between facade zones at different orientations takes place through the core zones.

This completes the Characterization step.

QUANTIFICATION

- Run TRNLizard and get the EUI of each zone
- Multiply EUI with the Area Weight of each zone and Add to get the Total Energy Demand of the Archetype Unit
- Extrapolate and Map the Results on the Urban Level

The 3rd & final step of the archetype approach is Quantification. For this, we identify the % of floor plate area associated with each facade microclimatic boundary cluster. This gives us the area-weight associated with each typical room shoebox. This allows us to extrapolate & map the results for each building in the city.

TRNLIZARD

ZILLA

Thus TRNZilla extends the capabilities of TRNLizard to suit an Urban scale. It allows to determine & analyse the spatio-temporal energy demand with outputs such as Total Energy Demand, Peak Demand & generate Load Profile Curves at a city level.

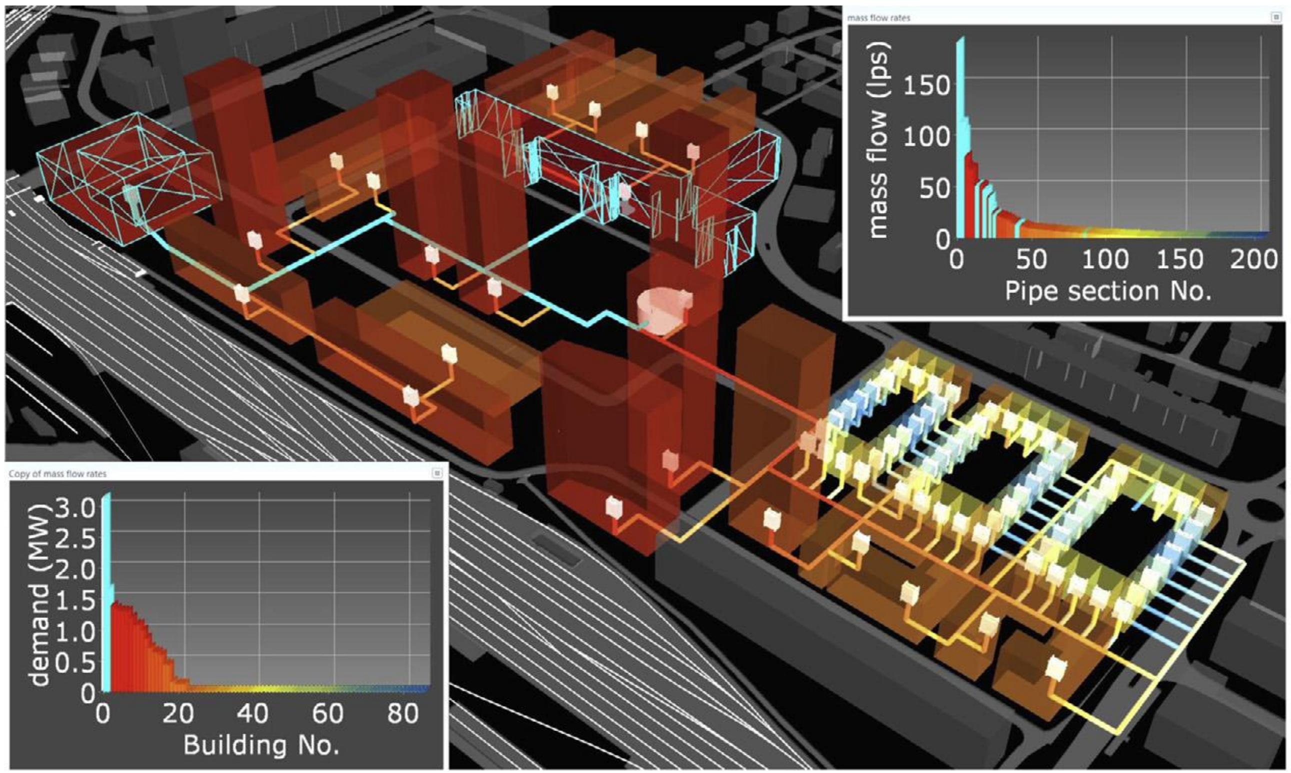
In the Pipeline

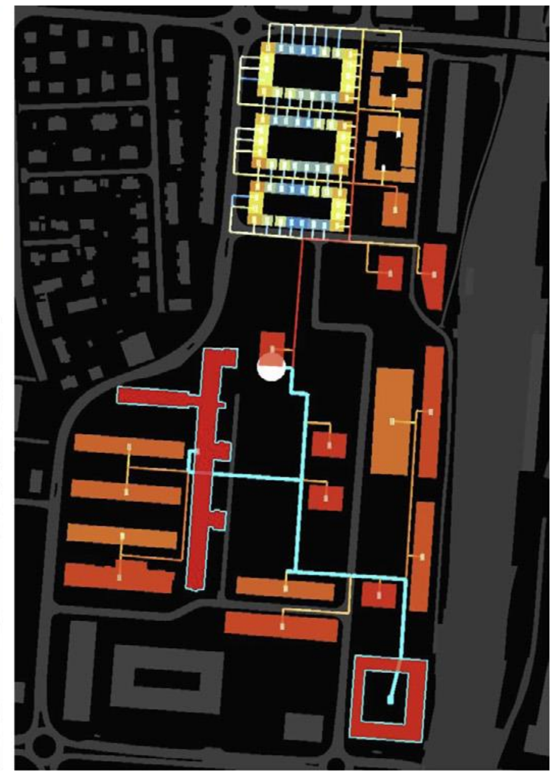
- Refine Segmentation Algorithm and include the capability to model mixed use buildings
- Develop Quantification Algorithm & Visual Aids (Graphs)
- Model Support for Energy Exchange Between Facade Zones at Different Orientations
- Add Support for Pitched Roofs
- Add Support for Basements & Underground Floors
- Validation with use in buildings with courtyards.
- Develop Efficient Looping Algorithm
- Fix Bugs
- Urban Climate (Heat Island) modelling with Dragonfly using UWG Engine developed by MIT

TRNZilla is a Work-in-Progress and requires a large amount of additional research and refinement. It also requires validation of results against some benchmarks. With the right support and opportunities, I hope to continue with its development to make it more robust.

The Vision Ahead

Integration with Tools for District Level Solutions





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Since TRNZilla is developed primarily as a Urban Energy Demand Estimation tool, in the long term vision, I hope to integrate the tool with robust Urban Supply Systems Design tools such as the City Energy Analyst developed by ETH Zurich.

Urban Building Energy Modelling
(Project Summary)

- 100 SMART (Energy Self-Sufficient in our context) Cities to be developed in India
- A workflow for the generation of complete urban building energy demand model
- Use of GIS Datasets for Existing Cities
- Predict Urban Energy Use in Hourly Timesteps
- Simulate (using TRNLizard) combined effect of multiple energy efficiency measures in a city
- Works by Clustering large models (into Archetypes) through a multizone network of single space ‚Typical Room' Models
- Semi-Automated Procedure

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With Special Thanks To:

Monika Lauster
Christian Degengardt
and
Transsolar Academy

That's All I That I Have To Offer !

Thank you for the enriching year at Transsolar Academy !!!