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Building Performance Education with Maedeh Mohit

WBEM COHORT 2026

OpenStudio / EnergyPlus
Workflow Guide

Methodology-First. Performance-Driven. Professionally Applied.

JUN 21
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BUILDING MODELING	SOLAR & PASSIVE DESIGN	HVAC & SYSTEM MODELING	ENERGY SIMULATION & ANALYSIS	WORKFLOW & COMMUNICATION

OpenStudio®

EnergyPlus®

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MAEDX ACADEMY
Building Performance Education

Contents

Session 01:
Fundamentals of Solar Geometry
& Passive Shading Design

1. The Core Philosophy of Shading Design

To design an optimized, performance-based shading device, we must move away from generic assumptions and rely on dynamic climate data. A fixed shading element cannot be ideal for all seasons; therefore, our goal is to mitigate cooling loads during overheated periods without compromising useful solar gains during underheated periods.

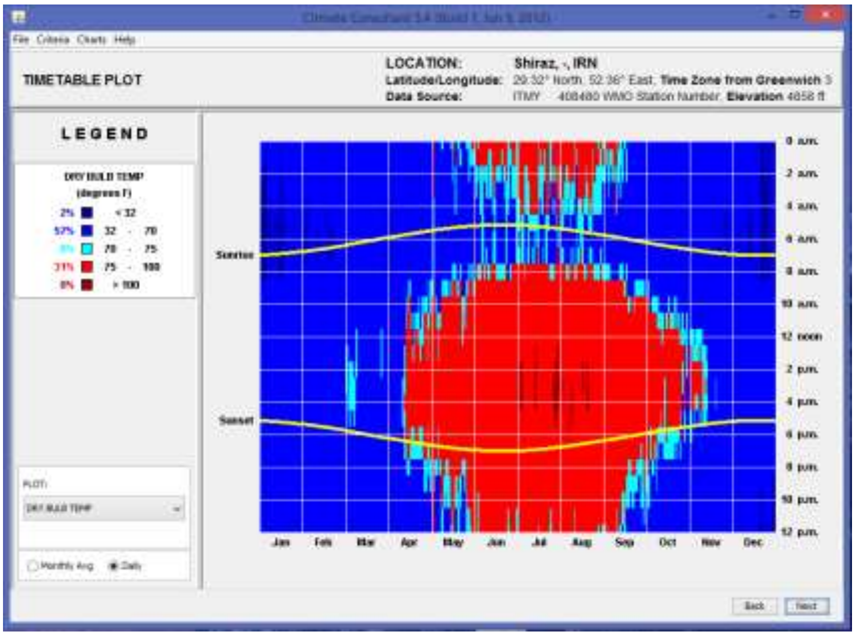
> **Critical Simulation Insight: Energy simulation engines (like EnergyPlus) do not operate on calendar-based seasons (e.g., 'Summer'). Instead, they operate on Overheated Periods derived from hourly thermal comfort boundaries.**

To design an effective shading system, two fundamental pillars are required:

- **1. The Overheated Period:** Identifying the exact hours when ambient conditions fall outside the human thermal comfort zone.
- **2. Solar Position:** Determining the precise coordinates of the sun (**Altitude and Azimuth**) for those specific hours.

2. Defining the Overheated Period

We utilize **Climate Consultant** to analyze the local weather file (EPW). The software visualizes temperature distribution charts and calculates the average hourly temperatures against thermal comfort models (e.g., ASHRAE Standard 55 Adaptive Comfort). This allows us to map the precise timeline of the overheated period. In regions with extreme climates like the **United Arab Emirates (UAE)**, this period spans a significant portion of the year, demanding highly optimized shading solutions.



3. Mathematical Foundations of Solar Position

To map the sun's trajectory relative to a building surface, we must compute key angular parameters. *To calculate the solar position, three primary parameters are required:*

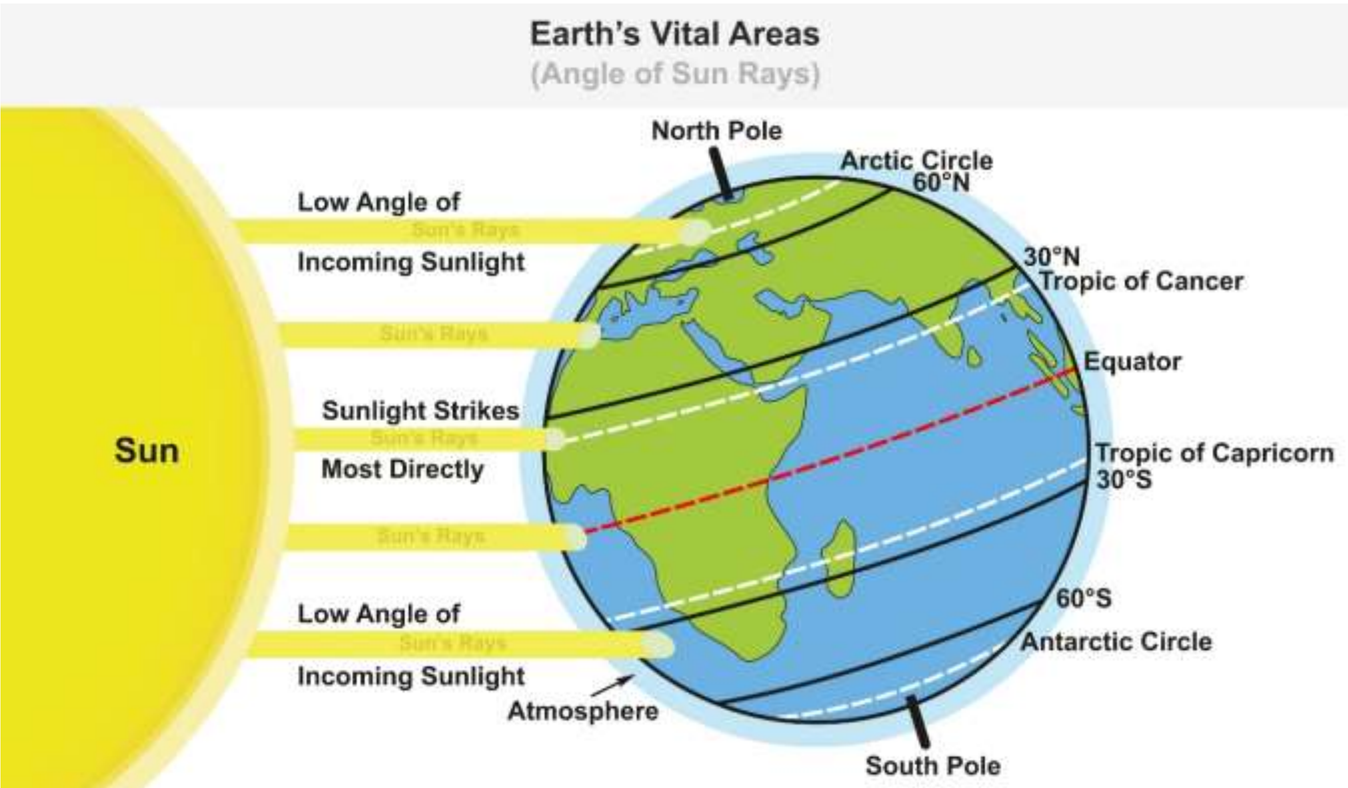
- *the local **latitude** (φ),*
- *the specific **day of the year** (n),*
- *and the **hour angle** (ω) which represents the solar time discrepancy from solar noon.*

1. A. Solar Declination Angle (δ)

The angle between the earth-sun line and the equatorial plane, varying throughout the year due to the earth's tilt (23.45°).

Gregorian Calendar (Counted from January 1st):

- ***δ = Solar declination angle** for any given day of the year*
- ***N = Day number of the year,** counted from the beginning of the Gregorian calendar (January 1st)*



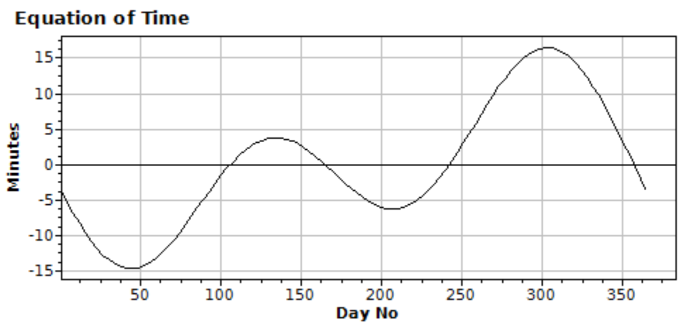
2. B. Apparent Solar Time (AST) vs. Local Clock Time (LCT)

Simulation engines require solar time rather than standard legal time to calculate solar angles accurately:

$$AST = LCT + TZ + \frac{L}{15} + \frac{EQT}{60}$$

- **AST (Apparent Solar Time):**The actual solar time based on the sun's position, varying from city to city.
- **LCT (Local Clock Time):**The standard official time of the country.
- **TZ (Time Zone adjustment):**The offset relative to Greenwich Mean Time (GMT).
- **L (Longitude):** Local Longitude of the specific project site.
- **EQT (Equation of Time):** The necessary correction factor for the Earth's non-circular orbital velocity (in minutes).

Why do we need EQT? The Earth's orbit is elliptical, not perfectly circular, and its orbital speed varies. If you photograph the sun at the exact same clock hour throughout the year, it traces a figure-eight pattern called an Analemma. The EQT corrects this discrepancy.

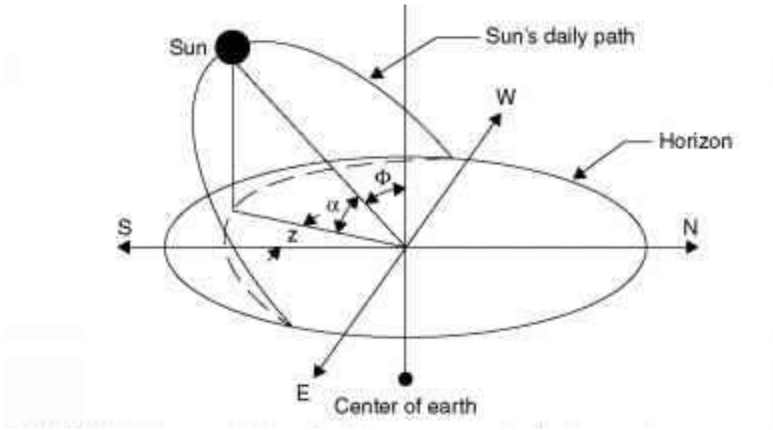


Determining the EQT Correction Factor via Empirical Diagrams

The exact value of EQT varies cyclically and can be extracted using standard empirical curves or data tables mapped across the months of the year.

3. C. Solar Coordinate Angles

The final position of the sun is defined by the Zenith Angle (θ_z), Altitude Angle (α_s), and Azimuth Angle (γ).



Solar Altitude and Azimuth Coordinate System

- **Zenith Angle (θz):** The angle between the sun and the vertical zenith line. It is the complement of the altitude angle ($\theta z = 90° - \alpha s$).

$$cos\,\Theta = \cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta$$

- **Solar Azimuth Angle (γ):** The lateral angular position relative to the reference system.

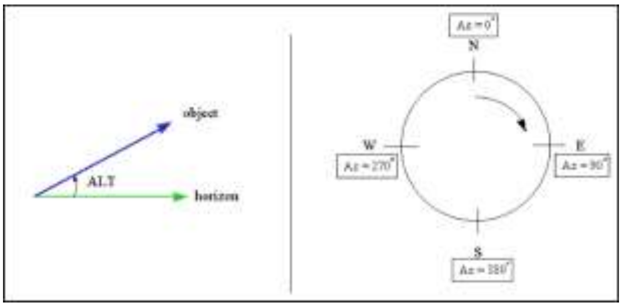
$$\cos\gamma = \frac{\cos\varphi\cos\delta\cos\omega - \sin\varphi\sin\delta}{\sin\alpha}$$

  - ϴ = **Zenith Angle**: The angle between the sun's rays and the vertical line.
  - ϕ = **Latitude**: The geographic coordinate of the project site.
  - δ = **Solar Declination Angle**: The tilt of the Earth relative to the sun.
  - ω = **Hour Angle**: The angular displacement of the sun east or west of the local meridian.
  - γ = **Solar Azimuth Angle**: The horizontal angle of the sun relative to the reference coordinate system.
  - α = **Solar Altitude Angle**: The vertical angle of the sun above the horizontal plane.

4. Azimuth Conventions: ASHRAE vs. DOE

ASHRAE Standard: South = 0° | East = Positive (+) up to +180° | West = Negative (-) up to -180°

DOE standard

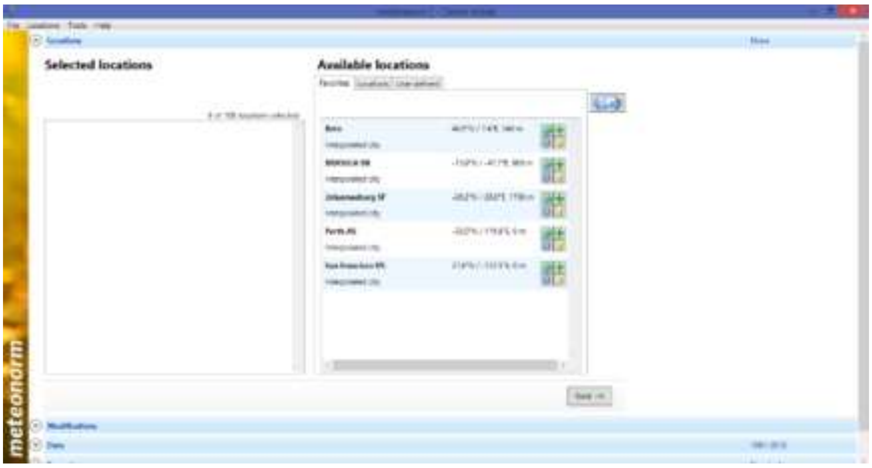


DOE Standard (Simulation): North = 0° | Clockwise rotation up to 360°

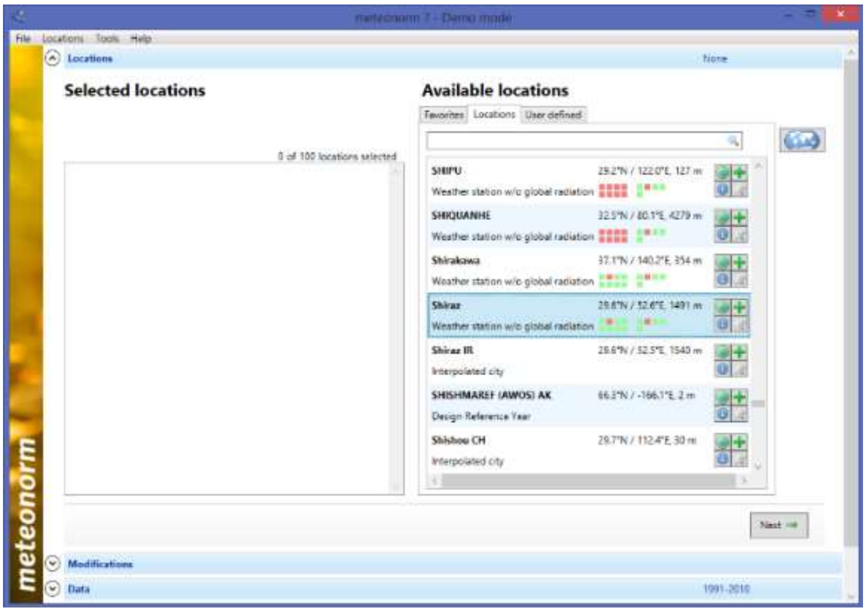
> **Simulation Warning: In engines like EnergyPlus/OpenStudio, the DOE standard is the default. Architects must accurately convert their CAD/Rhino orientation angles to the clockwise North-based system to prevent inverted solar exposure in simulations.**

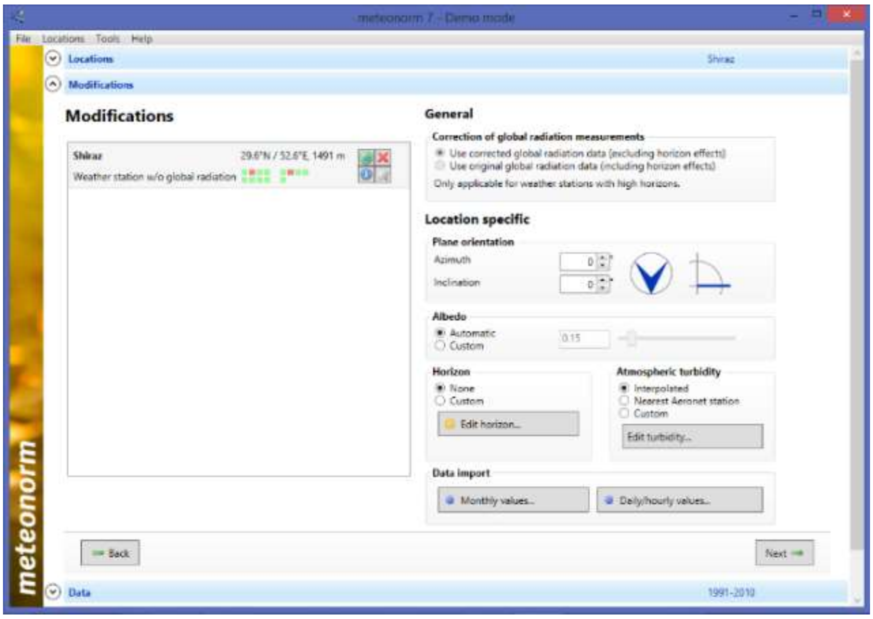
5. Climate Data Generation Workflow (Meteonorm)

- **1. Location Selection:** Identify the target city in the United Arab Emirates (e.g., Dubai) via coordinates or the global map.

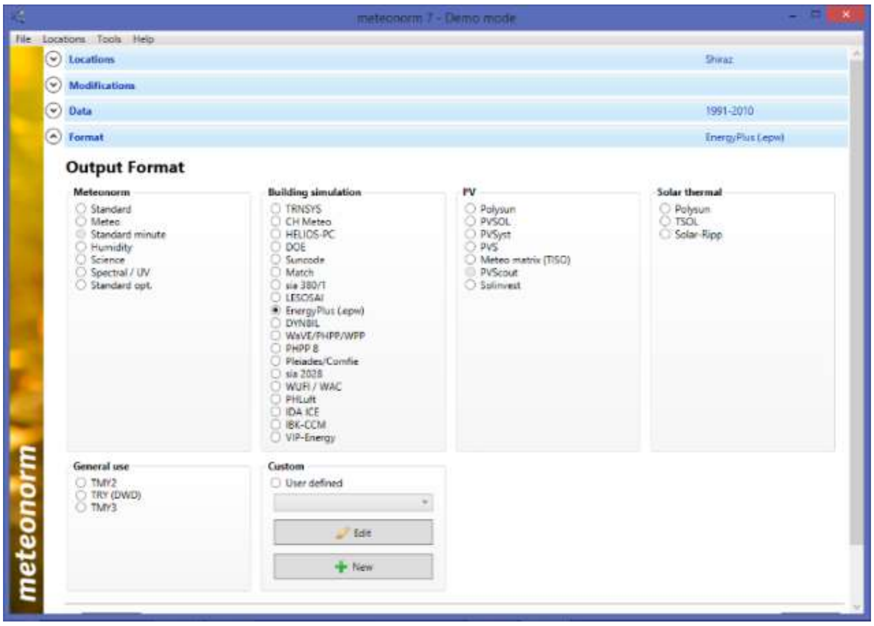


- **2. Data Setting:** Choose the standard historical period and set the output frequency to Hourly Data.





- **3. Format Export:** Select EPW (EnergyPlus Weather) format as the core deliverable.



Hands-on Exercise

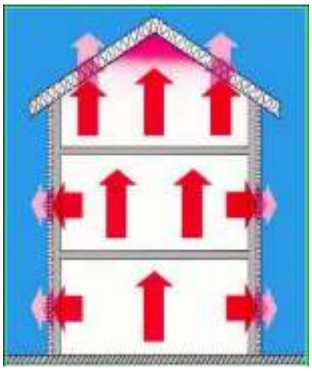
Task: Generate the EPW weather data for Dubai, UAE (Latitude: 25.20° N). Using Climate Consultant, extract the extreme overheated period. Calculate the solar altitude (αs) and DOE-based azimuth (γ) for the hottest day of August at 13:00 AST to manually sketch the required profile angle for an optimized southern overhang.

Session 02: Fundamentals of Heat Transfer & Geometry Modeling in OpenStudio

Before operating any simulation engine, we must understand the fundamental physical principles that govern real-world building performance. Heat exchange between a building and its microclimate occurs via three primary mechanisms:

- **Conduction:** Heat transfer through solid components of the building envelope (walls, roofs, floors).
- **Convection:** Heat transfer between a solid surface and a moving fluid (air tracking along interior or exterior surfaces).
- **Radiation:** Electromagnetic energy exchange between surfaces (solar radiation or long-wave thermal radiation between internal objects).

> **Core Simulation Fact:** In the vast majority of building envelopes, **conduction** is the dominant heat transfer mechanism responsible for raw thermal transmission and peak heating/cooling loads.



1. Mathematical Modeling of Envelope Conduction

Fourier's law dictates that heat transfer through conduction is directly proportional to the surface area and temperature gradient, and inversely proportional to material thickness:

$$\boldsymbol{Q \sim A \frac{\Delta t}{\Delta x} \quad \rightarrow \quad Q = k\,A \frac{\Delta t}{\Delta x} \quad \rightarrow \quad Q = k\,A \frac{T2 - T1}{L}}$$

Nomenclature:

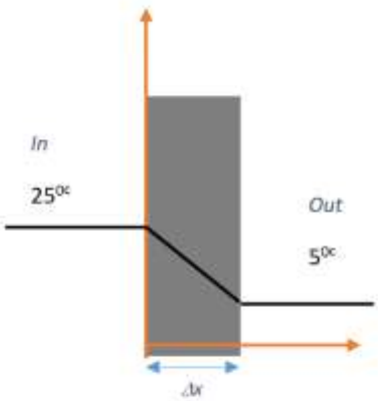
Q = Rate of conduction heat transfer (W)

k = Thermal conductivity coefficient of the material (W/m·K)

A = Surface area of the element (m²)

L = Physical thickness of the layer (m)

ΔT = Temperature difference across the material (T_2 - T_1) (°C)

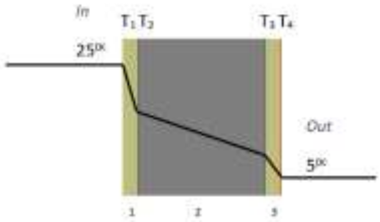


Thermal Resistance (R-Value)

Analogous to electrical resistance, we define the conductive thermal resistance ($\boldsymbol{R}$) of a single material layer as independent of its surface area:

$$I = \frac{\Delta V}{R} \quad , \quad Q = k\,A\,\frac{(T2 - T1)}{L} \quad \rightarrow \quad \frac{\Delta t}{R} = k\,A\,\frac{\Delta t}{L} \quad \rightarrow \quad R^{/} = \frac{L}{kA}$$

For a multi-layered composite wall assembly, the total thermal resistance is the sum of the individual layer resistances. The steady-state heat flux passing through all layers remains constant, but the temperature profile changes dynamically across each layer based on its material properties:



$$Q_1 = k_1\,A\,\frac{T_2 - T_1}{L_1} \quad , \quad Q_2 = k_2\,A\,\frac{T_3 - T_2}{L_2} \quad , \quad Q_3 = k_3\,A\,\frac{T_4 - T_3}{L_3}$$

$$T_2 - T_1 = \frac{Q\,L_1}{k_1\,A} \quad + \quad T_3 - T_2 = \frac{Q\,L_2}{k_2\,A} \quad + \quad T_4 - T_3 = \frac{Q\,L_3}{k_3\,A}$$

$$T_4 - T_1 = Q\left(\frac{L_1}{k_1\,A} + \frac{L_2}{k_2\,A} + \frac{L_3}{k_3\,A}\right) \quad \rightarrow \quad T_4 - T_1 = Q \sum R^{/}$$

$$\mathbf{Q} = \frac{\boldsymbol{\Delta}\mathbf{t}}{\sum \mathbf{R}^{/}}$$

$$T_4 - T_1 = \frac{Q}{A}\left(\frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{k_3}\right) \quad \rightarrow \quad T_4 - T_1 = Q \sum R$$

$$\mathbf{Q} = \frac{\mathbf{A}\,.\,\boldsymbol{\Delta}\mathbf{t}}{\sum \mathbf{R}}$$

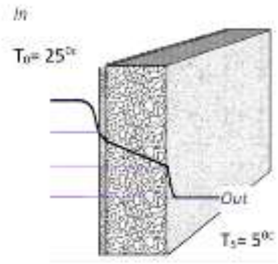
2. Convection and the Total Heat Transfer Coefficient (U-Value)

In real-world scenarios, thin boundary layers of air (air films) exist on both the interior and exterior boundaries of a wall assembly. Heat transfer through these air layers occurs via convection:

$$Q \sim A\,.\,\Delta t \quad \rightarrow \quad Q = h.\,A\,.\,\Delta t$$

$$I = \frac{\Delta V}{R} \quad , \quad Q = h.\,A\,.\,\Delta t \quad \rightarrow \quad \frac{\Delta t}{R} = h.\,A\,.\,\Delta t \quad \rightarrow \quad R = \frac{1}{h\,.\,A}$$

Where h is the convective heat transfer coefficient (W/m²·K), which depends on surface geometry, orientation, and local wind or fluid velocity.



Combining both the conductive material layers and the boundary convective air films yields the complete steady-state heat transfer equation for a multi-layered envelope:

$$Q = \frac{A\,.\,\Delta t}{\sum R} \quad , \quad R = \frac{1}{h\,.\,A} \quad \rightarrow \quad Q = \frac{T_5 - T_0}{\frac{1}{h_1\,.\,A} + \frac{L_1}{k_1\,A} + \frac{L_2}{k_2\,A} + \frac{L_3}{k_3\,A} + \frac{1}{h_2\,.\,A}}$$

This is compressed into the foundational engineering formula used by simulation engines:

$$Q = \frac{A\,(T_5 - T_0)}{\frac{1}{h_1} + \frac{L_1}{k_1} + \frac{L_2}{k_2} + \frac{L_3}{k_3} + \frac{1}{h_2}} \quad \rightarrow \quad Q = \frac{A\,(T_5 - T_0)}{\sum R} \quad \rightarrow \quad Q = U.\,A\,.\,\Delta t$$

Where U represents the overall heat transfer coefficient (U-Value), calculated as the inverse of total thermal resistance ($U = 1 / R_{total}$).

3. Thermal Zoning Strategy

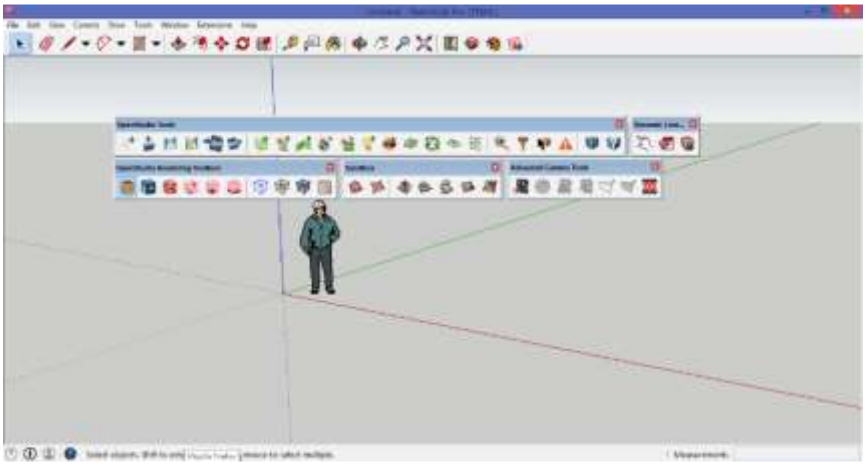
In energy modeling, the golden rule is to **simplify the model geometry as much as possible** while preserving required thermodynamic accuracy.

- An independent **Thermal Zone** should only be created if separate thermal/HVAC diagnostic information is required for that specific space, or if its thermal loading profiles vary significantly.
- If spaces share identical operating schedules, internal loads, and orientations, separating them adds unnecessary computational overhead.

4. OpenStudio Workspace Logic & Save Rules

OpenStudio serves as the core graphical user interface (GUI) to structure geometry and assign thermodynamic attributes before exporting input files to **EnergyPlus** and **Radiance**.

> **Critical Workflow Warning (The No-Undo Rule):** OpenStudio environment nested inside SketchUp does **not** support the standard standard `Undo` (Ctrl+Z) command for thermal objects. You must continuously perform a **"Save As"** routine with sequential filenames (e.g., `model_v1.osm`, `model_v2.osm`) to secure your progress.



4. File Saving and Loading Protocol

- **The Save Disconnect:** Standard SketchUp save commands **do not** preserve OpenStudio objects properly once geometry is converted into OpenStudio spaces.
- **The .osm Format:** You must execute the save command exclusively through the **OpenStudio Toolbar** to generate an OpenStudio Model file (`.osm`).
- **Loading Warning:** If a project is reopened via the standard SketchUp interface, the system will trigger a warning stating that the OpenStudio model was not loaded. To resolve this, always use the **"Open**

OpenStudio Model" button within the plugin to load the `.osm` file.

5. Geometric Modeling Workflow in OpenStudio

5. Space Creation & Object Recognition

1. **Generate a Space:** Click the **"New Space"**  tool on the OpenStudio toolbar and place it in the workspace.
2. **Edit Geometry:** Double-click inside the space bounding box to enter its isolated editing environment. Use SketchUp tools like `Push/Pull` to extrude 2D floor plans into 3D volumes.
3. **Automatic Classification:** OpenStudio instantly interprets surfaces based on their spatial orientation: horizontal top surfaces are classified as roofs/ceilings, vertical surfaces as walls, and rizotl bottom surfaces as floors, assigning distinct technical colors to each.
4. **Surface Normal Orientations (Front vs. Back):** EnergyPlus relies on surface normals to evaluate heat flux. OpenStudio uses color coding to distinguish the front side from the back side of surfaces (the backside appears noticeably lighter, except for ground surfaces).
5. **Sub-Surfaces (Windows and Doors):** Drawing a closed loop surface directly onto an established OpenStudio wall automatically flags it as a **Window**. If that loop touches the floor boundary line, OpenStudio re-classifies it as a **Door**.

6. Surface Thickness & Object Categories

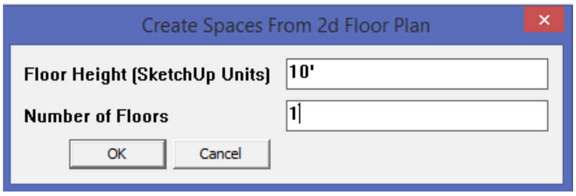
- In thermal simulation, building surfaces are assumed to have **zero physical thickness**; calculations rely strictly on the assigned material property layers.
- **Shading Groups and Interior Partitions:** Shading devices (overhangs, adjacent buildings) and interior partitions are modeled using the same double-click entry logic, but they must be created using their dedicated OpenStudio object category tools to prevent them from acting as conditioned envelope boundaries.

New interior partition surface group  *New shading surface*  *New space* 

6. Core OpenStudio Automation Tools

A. Create Spaces from Diagram

To accelerate large-scale zoning, you can draw a 2D schematic layout using flat lines in SketchUp, select it, and execute the **"Create Spaces from Diagram"** automation. A dialog box will prompt you for the number of floors and floor heights. The tool automatically extrudes every enclosed line boundary into an independent OpenStudio space.

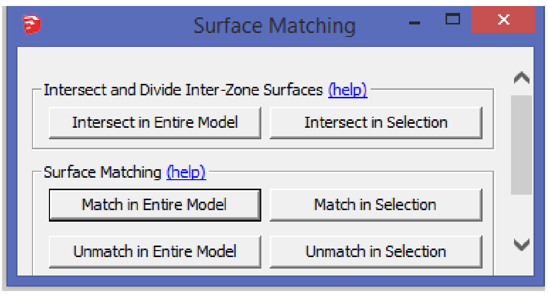


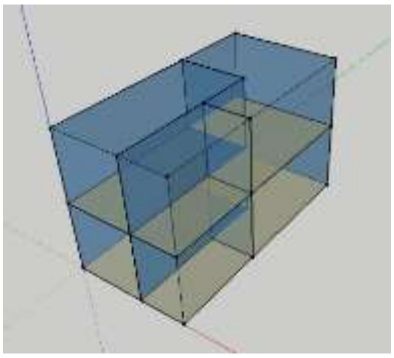
B. Surface Matching Tool (Boundary Conditions)

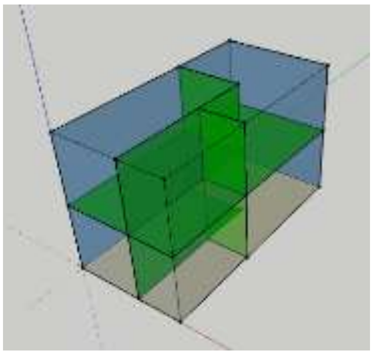
Every envelope surface must have an explicitly defined **Boundary Condition** (e.g., Outdoor, Ground, Zone-to-Zone, Adiabatic) so EnergyPlus can compute surface energy balances.

When multiple spaces are extruded from a diagram, adjacent boundary walls overlap but remain unlinked. To automate this connection:

1. Run **"Intersect in Model"**: This splits overlapping surfaces precisely along their intersecting lines.
2. Run **"Match in Model"**: This links adjacent surfaces together, setting their boundary conditions to `Surface` (Zone-to-Zone).







Visualization Check: Use the **"Render by Boundary Condition"** tool. Exterior walls exposed to wind/ sun will render **Blue**, while successfully matched interior walls shared between conditioned zones will render **Green**. Always audit this visually after every matching routine.

C. Set Attributes for Selected Spaces

To batch-modify spaces, select multiple space objects and open the **"Set Attributes for Selected Spaces"** dialog box to assign parameters like *Space Type*, *Building Story*, or default construction sets. When opening this menu, all dropdown fields default to "No Change," indicating that no overrides will be applied unless you explicitly select a new property.

Session 03:
Thermal Modeling & Advanced Geometry Workflows

Part 1: Physics of Convective Heat Transfer & Boundary Layer Mechanism

1. The Air Film Phenomenon & Thermodynamic Buffer Zone

To comprehend the thermal simulation of a building envelope, fluid behavior (air) must be analyzed at a microscopic scale adjacent to solid boundaries. Consider a vertical wall scenario where an air stream tracks upward along the surface at a constant velocity.

Thermal exchange between this solid boundary and the air particles begins via **pure conduction** at the immediate point of contact. This conductive heat input warms the lower boundary layers of the fluid. As the air particles track further upward, they continuously sweep across these pre-heated solid surfaces, causing their bulk temperature to rise monotonically.

As particles track higher along the vertical boundary, they absorb cumulative thermal energy. This elevated temperature enhances their localized thermal capacity, enabling them to diffuse heat deeper into the free stream, further away from the solid envelope interface.

2. The Air Film Phenomenon & Thermodynamic Buffer Zone

The critical driver governing this convective heat exchange rate is the temperature gradient, **Δt (the difference between the solid surface temperature and the adjacent fluid temperature).** The concentration and stagnation of these thermally excited air particles near the wall construct a virtual boundary layer, acting as a thermodynamic Buffer Zone between the solid construction and the well-mixed bulk air of the room or the outdoor ambient environment.

In building physics, this localized buffer layer is termed the **Air Film**. The air film establishes a dynamic thermal resistance zone between the physical envelope and the free-flowing air stream. The efficiency and quality of convective heat transfer within this film depend on several key physical parameters:

• **Fluid Thermal Conductivity (k):** Higher intrinsic conductivity of the adjacent gas or air molecule amplifies the rate of heat dissipation between the envelope and the environment.

• **Air Film Thickness (sigma):** Beyond fluid material properties, the spatial thickness of the boundary layer acts as a primary control factor. A thicker air film intensifies the localized buffer effect, thereby increasing localized thermal resistance and mitigating the overall heat transfer rate across the boundary.

3. Discrepancies Between Interior and Exterior Air Films

Airflow velocity shares an inverse relationship with boundary layer thickness. In outdoor microclimates, envelopes are typically exposed to forced convection and higher wind speeds, which strip away and destabilize the stagnant boundary layers. Consequently, the exterior air film maintains a significantly reduced thickness.

Furthermore, the absolute temperature delta (**Δt**) between the exterior environment and the envelope is typically far greater than interior variations. The combination of these two factors–a highly compressed air film thickness and an expanded **Δt** –significantly escalates the convective heat transfer coefficient on the exterior face of the building envelope.

Part 2: Convective Governing Equations & Inert Gas Engineering

1. Convective Governing Equations

The fundamental rate of convective heat transfer is mathematically governed by Newton's Law of Cooling:

$$q = h.A.\Delta$$

Concurrently, the convective heat transfer coefficient (h) is related to the fluid's thermal conductivity (k) and the boundary layer thickness (sigma), expressed via the following proportionality:

$$q \sim \frac{k.\Delta t}{\sigma}.C.A \quad \rightarrow \quad h = \frac{kC}{\sigma} \quad \rightarrow \quad h \sim \frac{k}{\sigma}$$

- q = Convective heat transfer rate (W)
- A = Surface area of the envelope component (m²)
- Δt = Temperature difference between the solid surface and the adjacent fluid (Δt = T_surface - T_fluid) (K or °C)
- h = Convective heat transfer coefficient (W/m²·K), a composite function of fluid properties, boundary thickness, and flow conditions.
- k = Intrinsic thermal conductivity of the fluid/gas medium (W/m·K)
- σ = Physical thickness of the boundary air film layer (m)

2. Microscopic Surface Roughness Effects

An increase in microscopic surface roughness enhances localized frictional shear, thereby retarding the velocity of the air tracking immediately along the wall. This deceleration provides air molecules with extended dwell time to absorb thermal energy from the solid surface. This cumulative absorption expands the boundary zone, increasing the physical film thickness (σ).

Based on the governing equations, an increase in boundary layer thickness (σ) directly yields a reduction in the convective heat transfer coefficient (h). However, it is vital to note that increasing the fluid's bulk thermal conductivity (k) does not scale h linearly. This non-linear behavior occurs because variations in k simultaneously alter the thermodynamic development and thickness profile of the air film itself.

3. Inert Gas Engineering in Multi-Glazed Assemblies

Leveraging the physical principle that heavier gases with lower intrinsic thermal conductivities suppress convective currents, the manufacturing sector utilizes heavy inert gases within multi-glazed fenestration cavities. Heavy noble gases such as Argon (Ar) or Krypton (Kr) introduce formidable thermal insulation barriers. Their elevated molecular weight minimizes their conductivity coefficient (k) and curtails internal cavity buoyancy loops, dramatically depressing overall fenestration U-values and minimizing envelope transmission losses.

Part 3: Double-Skin Façade (DSF) Theory & EnergyPlus Limitations

1. Operational Mechanisms and the Greenhouse Effect

In contemporary architecture, a Double-Skin Façade (DSF) represents an advanced multi-layered envelope system consisting of a primary internal building enclosure shielded externally by a secondary, typically glazed, skin. The operational physics of a DSF is governed by a precise thermodynamic cycle:

1. Incident short-wave solar radiation easily penetrates the high-transmittance outer glazed skin.
2. This short-wave radiation strikes the high-absorptance, opaque primary internal wall, where it is absorbed and re-emitted into the cavity as long-wave thermal radiation.
3. The outer glass skin acts as an opaque barrier to long-wave thermal wavelengths. Consequently, radiant energy is trapped within the intermediate cavity, generating a localized Greenhouse Effect.

This containment causes a rapid temperature spike along the primary internal wall, triggering secondary thermodynamic phenomena: enhanced conductive transmission into the core spaces, an aggressive vertical buoyancy loop (Stack Effect) as low-density air rises, and a severe vertical temperature gradient where upper-level cavity zones experience exponentially higher thermal stress than lower zones.

4. Design Challenges and Seasonal Control Strategies

Engineers encountering DSFs in high-rise constructions must evaluate multi-axis performance criteria and define clear seasonal operational goals. In extreme vertical configurations, buoyancy-driven airflow can generate destructive pressure deltas and high-velocity turbulence.

To mitigate these systemic risks, a rigorous engineering protocol is implemented:

- **Step 1 (Predictive Validation):** Simulating cavity dynamics to evaluate if the intended strategy is fluid-dynamically viable.
- **Step 2 (Corrective Design):** If excessive pressure or thermal stacking threatens structural or HVAC stability, a segmented architectural strategy must be deployed. Segmented DSFs isolate the cavity at specific floor intervals, capping pressure accumulation and localized temperature spikes.

Seasonal Control Conflict: While cavity heat traps are highly advantageous for winter pre-heating strategies, they transform the envelope into a high-load thermal kiln during cooling-dominated summer cycles (e.g., in hot-arid zones like Shiraz). Under summer parameters, the engineering strategy must completely invert to a forced or natural Ventilated Cavity configuration, purging accumulated thermal mass before it conducts into the primary interior core.

5. Computational Limitations of the EnergyPlus Engine vs. CFD Requirements

> *Simulation Warning: If an envelope investigation demands high-fidelity tracking of discrete fluid velocity vectors within the cavity, exact intra-skin temperature profiles, localized dynamic pressure differentials across varying heights, or complex boundary-layer ventilation*

> *interactions, the analyst MUST transition to an advanced Computational Fluid Dynamics (CFD) engine (e.g., Ansys Fluent). The core EnergyPlus engine operates on a macroscopic, well-mixed Bulk thermal nodal network. It lacks the mathematical infrastructure to solve localized Navier-Stokes equations within narrow envelope air cavities; fluid-dynamic boundary layer resolution is fundamentally outside the scope of EnergyPlus.*

Part 4: Geometric Configuration Impacts on Envelope Transmission

1. Continuous vs. Segmented Envelopes

A foundational axiom in envelope thermodynamics dictates that a segmented geometry, maintaining an identical surface area to a continuous benchmark, will exhibit a higher cumulative rate of heat transfer. This inflation stems from multiplied thermal bridging channels and localized perturbations in boundary-layer air films along geometric edges.

• Thermal Load Mitigation Strategy: To achieve maximum thermal resistance and minimum envelope transmission losses (highly critical in extreme heating or cooling-dominated zones), the façade configuration should preserve a continuous, un-interrupted vertical profile.

• Solar Capture Optimization Strategy: Conversely, if the architectural objective demands the maximization of localized solar gain per floor plate, a segmented, terraced façade configuration should be leveraged.

6. Critical Air Cavity Thickness & Internal Convective Onset

Stagnant air gaps enclosed within envelope layers (e.g., within double-glazed windows or insulated spandrel panels) exhibit a dual thermal response. Empirical data indicates that increasing the physical thickness of an unventilated cavity yields a linear expansion in overall thermal resistance (R-Value), up to a highly specific threshold.

If the physical thickness of the cavity surpasses a specific Critical Thickness, the internal buoyancy forces overcome viscous drag. The previously stagnant air layer destabilizes, triggering internal Convective Onset (buoyancy loops). This internal convection acts as an active thermal bridge, rapidly accelerating heat transfer across the cavity. Thus, expanding an air gap beyond this critical limit induces an inverse performance penalty.

Part 5: Geometric Automation Techniques & Advanced Filtering in OpenStudio

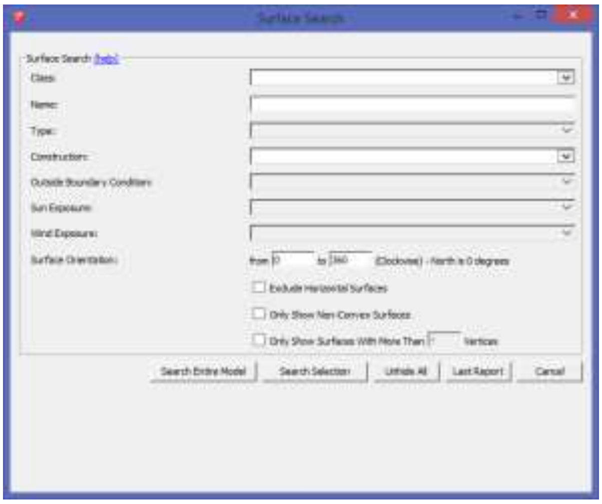
1. Automated Window-to-Wall Ratio (WWR) Methodology

In iterative envelope optimization workflows, evaluating building energy performance across parameterized glazing ratios is mandatory. To execute automated glazing configurations, targeted base walls must be selected. Rather than manually parsing individual spaces–which induces extreme computational overhead and time penalties in commercial-scale models–analysts utilize the advanced **Search Surfaces** filtering tool. This interface allows instantaneous global filtering of surfaces based on Name, Boundary Condition, Construction Type, or Spatial Attributes.

7. The Inspector Interface & Surface Orientation Filtering

The OpenStudio **Inspector** tool provides a unified data grid to batch-assign thermodynamic properties to selected geometric elements. To filter and isolate surfaces occupying a specific cardinal orientation, analysts utilize the **Surface Orientation** filter attributes.

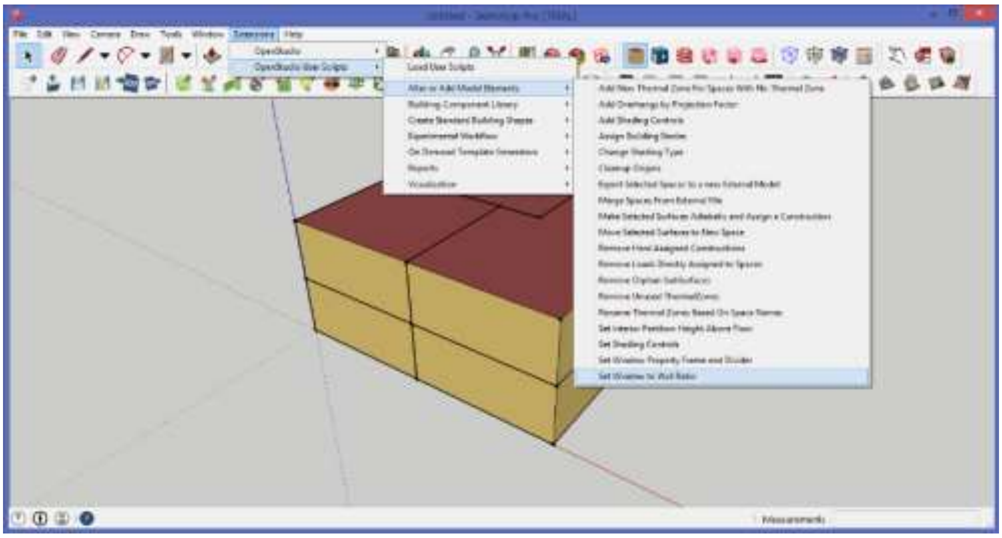
Orientation Coordinate System: In the simulation engine space, the solid green axis natively represents True North (0°). Angular measurement increments strictly clockwise, defining True East as 90°, True South as 180°, and True West as 270°. For instance, to simultaneously capture all primary southern exposures across a multi-zone model, an analyst inputs an orientation value of 180° into both limit fields, instantly selecting the matching façade surfaces.



8. Automated Glazing Algorithms (Set Window-to-Wall Ratio)

Once the targeted orientation facades are isolated, the parametric glazing layout is generated via the OpenStudio plugin infrastructure:

OpenStudio Plugin -> Script User Scripts -> Alter Geometry -> **Set Window to Wall Ratio**.



The automation script requires three critical inputs:

• **Target WWR:** Glazing ratio expressed as a decimal parameter (e.g., 0.3 for a 30% WWR).

• **Offset Distance:** The structural buffer clearance distance maintained from the bounding floor or ceiling lines.

• **Offset Position:** Determines the geometric anchor point for the offset clearance calculation, tracking from either the Top (Ceiling) or Bottom (Floor) boundary lines.

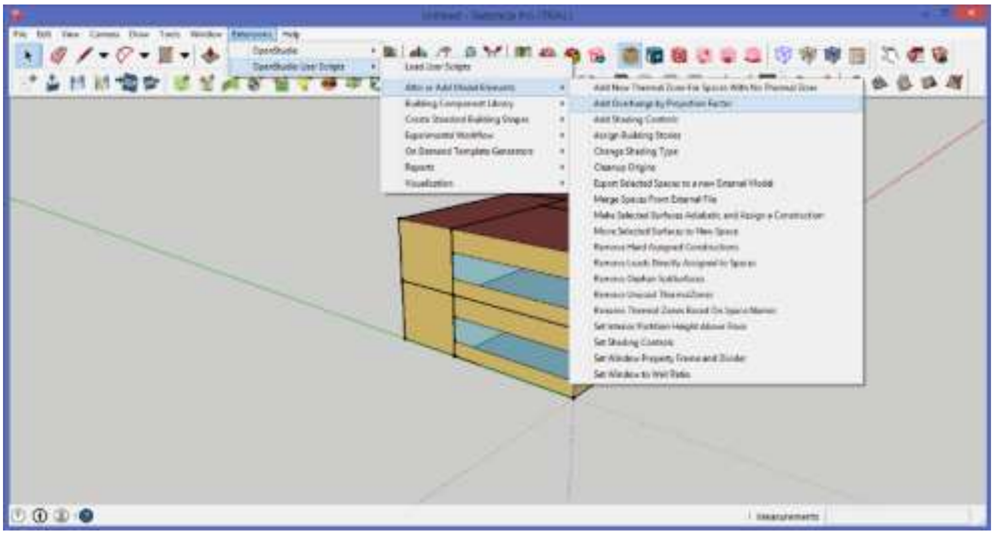
9. Automated Shading Projection Scripts (Add Overhang)

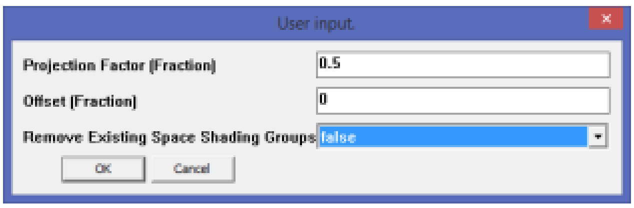
To suppress excessive summer solar gains, horizontal overhangs are programmatically projected above fenestration geometries using the automated script pathway: OpenStudio Plugin -> Script User Scripts -> Alter Geometry -> Add Overhangs by Projection Factor.

The primary geometric variable governing this script is the Projection Factor. The Projection Factor is explicitly defined as the ratio of the physical depth of the overhang to the vertical height of the window glass:

• **Projection Factor =** 1.0: The horizontal overhang depth matches the exact vertical height of the window, providing comprehensive solar cutoff.

• **Projection Factor =** 0.0: The overhang depth is zero, completely purging shading structures from the fenestration sub-surfaces.





Part 6: Internal Partitions Modeling Methodology & Thermal Mass Optimization

1. Geometric Modeling of Interior Partitions

To represent non-bounding internal walls, analysts execute the **New Partition Interior Surface Group**  tool within a designated Space group. Interior partitions are geometrically modeled to fulfill three critical thermodynamic requirements:

1. **Internal Air Barrier Approximations:** Accounting for bulk physical obstructions against convective air movement within macro-zones.
2. **Daylighting Ray-Tracing Resolution:** Providing exact physical geometry for the Radiance engine to compute realistic internal reflections, shadowing, and lux sensor boundaries.
3. **Radiative Thermal Mass Buffering**: Capturing internal radiant exchange and energy storage capacity, which directly influences peak load delay times.

10. Geometric Optimization of Thermal Mass via the InternalMass Attribute

While interior walls can be drawn geometrically and assigned Adiabatic boundary conditions, large-scale commercial models with hundreds of internal subdivisions utilize the more efficient **InternalMass** attribute. The InternalMass field encapsulates the bulk heat capacity of non-structural partitions, furniture, and internal fixtures textually, bypassing the rendering overhead of explicit CAD geometry.
Zone Merging and the Dual-Sided Surface Area Protocol: When multiple physical spaces sharing identical schedules and internal loads are merged into a unified thermal zone to accelerate simulation runtimes, the internal walls are stripped from the CAD canvas. To retain their vital thermal mass signature, their material properties and total areas are mapped into the InternalMass grid.

> ***Critical InternalMass Area Protocol:*** *When converting explicit internal partitions to textual InternalMass data, the analyst MUST compute and input the total dual-sided surface area. Because both faces of an internal wall are concurrently exposed to the zone's air volume, they actively participate in simultaneous convective and radiative heat exchange. Formula: For an internal partition with a baseline geometric area of 12 m^2, the final value declared within the InternalMass attribute must be exactly: 12 m^2 + 12 m^2 = 24 m^2.*

Part 7: Advanced Space Management, Naming Protocols, and Debugging Workflows

1. Automated Glazing Projection (Project Loose Geometry)

Manually entering dozens of localized Space groups to draw individual fenestration boundaries introduces immense workflow inefficiencies. To bypass this, OpenStudio provides the **Project Loose Geometry** automation script:

1. The analyst draws all windows and doors globally as free, un-grouped 'Loose Geometry' directly on

the external facade of the building envelope within the master canvas.

2. The entire loose geometry cluster is selected globally.

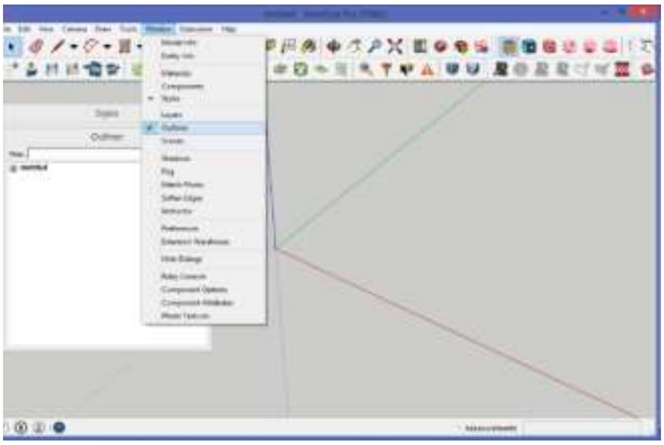
3. The analyst triggers the Project Loose Geometry command from the OpenStudio toolbar.

The script automatically intersects the global loose geometry with the underlying space boundaries, cutting the primary walls and embedding the sub-surfaces into their respective isolated Space structures instantly.

11. Engineering Naming Protocols and Model Navigation

Preserving rigorous, standardized naming conventions across Spaces and Thermal Zones is mandatory. Retaining generic default names (e.g., Space 01, Space 02) creates immense friction during downstream schedule assignments, HVAC loops configuration, and error-log debugging.

To efficiently navigate and audit high-density models, analysts leverage two key interfaces:

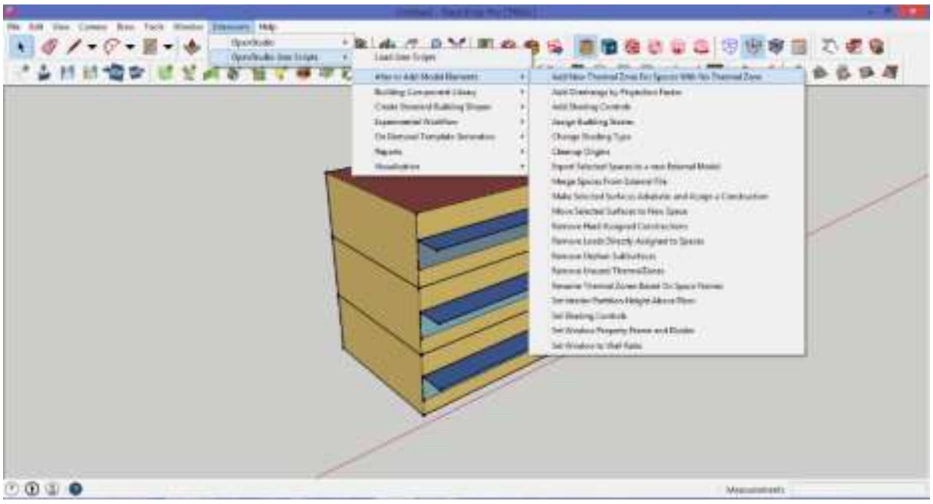


- **The SketchUp Outliner Panel:** Provides a hierarchical tree view of all space groupings, enabling rapid isolation and cross-checking of nested components.
- **Empty Space Auditing:** Accidental generation of empty spaces containing zero geometric surfaces creates an incomplete mathematical node structure.

> *Fatal Error Warning: Prior to exporting the OSM model to the core EnergyPlus simulation engine, all Empty Spaces must be identified via the Outliner and completely purged. Failure to eliminate these empty space nodes will break the thermal matrix calculation, causing the simulation engine to throw a Fatal Error and completely terminate the run.*

12. Batch Thermal Zone Assignment Workflows

To bridge architectural Space entities with thermodynamic Thermal Zone objects, analysts deploy either the **Set Attributes for Selected Spaces** tool for localized batch mapping or execute global synchronization via the multi-zone spreadsheet grid interface in the OpenStudio application main panel.



Session 04:
Energyplus Runtime Environment
& Programming Framework

1. FUNDAMENTALS OF THERMAL MASS PHYSICS

Thermal mass refers to the intrinsic ability of building components and materials to absorb, store, and dynamically release heat over time. In professional workflow modeling, strategically incorporating thermal mass establishes internal thermal equilibrium, dampens peak cooling and heating loads, and shifts the peak demand hour away from extreme external conditions.

> **Core Simulation Fact:** Thermal mass is not equivalent to thermal resistance (R-Value). However, by retarding heat flux via time-dependent storage, it creates a buffering mechanism known as the "insulating effect of mass," effectively expanding and stabilizing the occupants' indoor thermal comfort range.

Material Classifications & Architecture Integration

- **Traditional Mediums:** Water, earth, natural stone, adobe, and high-density clay bricks.
- **Modern Systems (PCM):** Phase Change Materials utilize latent heat capacity storage via phase transitions, keeping high-volume thermal storage within a minimal physical footprint.

In modern architectural simulation, thermal mass properties are deployed across two core strategies:

- **Passive Solar Assemblies:** Trombe walls, attached greenhouses, and direct-gain radiant floor plates designed to absorb solar irradiance during daytime hours and discharge it to the zone at night.
- **Night Purge / Night Cooling:** Mechanically or naturally flushing internal mass with cool night air, drawing out accumulated heat to optimize lower cooling startup loads during the subsequent daytime peak.

13. THERMOPHYSICAL MATHEMATICAL MODELING

The dynamic heat capacity of an assembly is heavily influenced by three core physical properties: **density** (***ρ***), **specific heat capacity** (***Cp***), and **thermal conductivity** (***k***). Combining density and specific heat capacity defines
the Volumetric Heat Capacity:

$$\textit{Volumetric Heat Capacity} = \rho \times Cp$$

Materials like iron exhibit high heat capacity but fail as effective thermal mass due to an excessive thermal conductivity (***k***). This behavior is modeled via Thermal Diffusivity (***α***), which is directly proportional to conductivity and in

$$\alpha = k/\rho C$$

Thermal Time Constant (TTC) & Insulation Sequencing

The Thermal Time Constant (TTC) governs the transient response and time lag (τ) of a wall envelope. It defines the operational time required for an assembly to reach approximately 62% of a sudden ambient temperature change. Formulations must be sequentially accumulated **from the exterior layer to the interior**

layer:

$$TTC = \rho h C_p$$

Where the total heat quantity (Q) and convective heat transfer rate (q) maintain a derivative relationship (q = dQ/dt):

$$Q = mc\Delta t$$
$$q = hA\Delta t$$

> **Core Simulation Fact:** Two distinct walls can share identical overall R-Values but demonstrate vastly different TTC metrics. Layer sequencing is critical: placing insulation on the **exterior side** shields the heavy thermal mass from outer temperature fluctuations, significantly increasing the time lag (τ) and boosting the aggregate TTC.

14. ENERGYPLUS WORKFLOW & DIRECTORY ARCHITECTURE

The standard simulation pipeline is executed across three discrete architectural stages:

```
Preprocessing (OpenStudio, IDF Editor) –> Processing (EnergyPlus Engine) –> Post-processing (DesignBuilder)
```

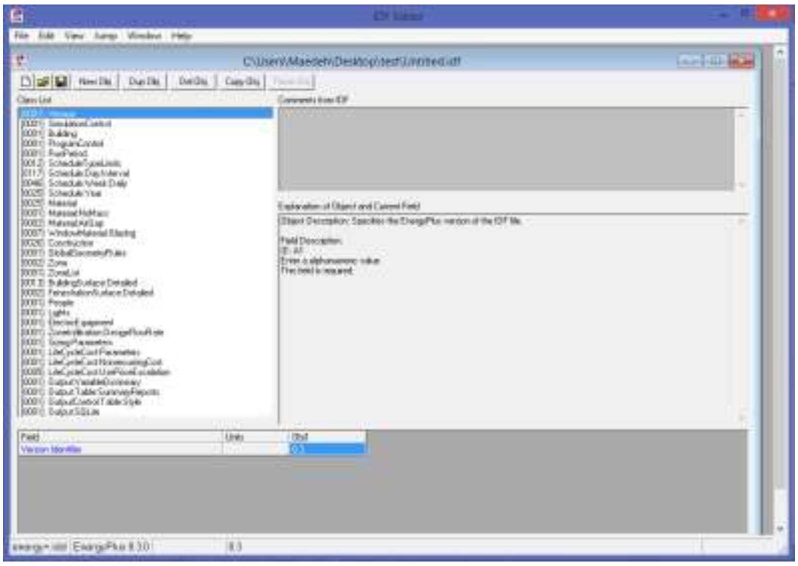
Upon standard installation (typically on the C:\ drive), the key directories include:

- **DataSets:** Standardized libraries containing certified material records, preconfigured construction layers, and default schedule templates.
- **ExampleFiles:** Reference input data files (.idf) illustrating advanced subsystem configurations.
- **PreProcess / PostProcess:** Essential execution scripts including weather file converters and post-simulation data miners.
- **WeatherData:** Storage directory for EPW files. It is recommended to place custom localized climate files directly here.

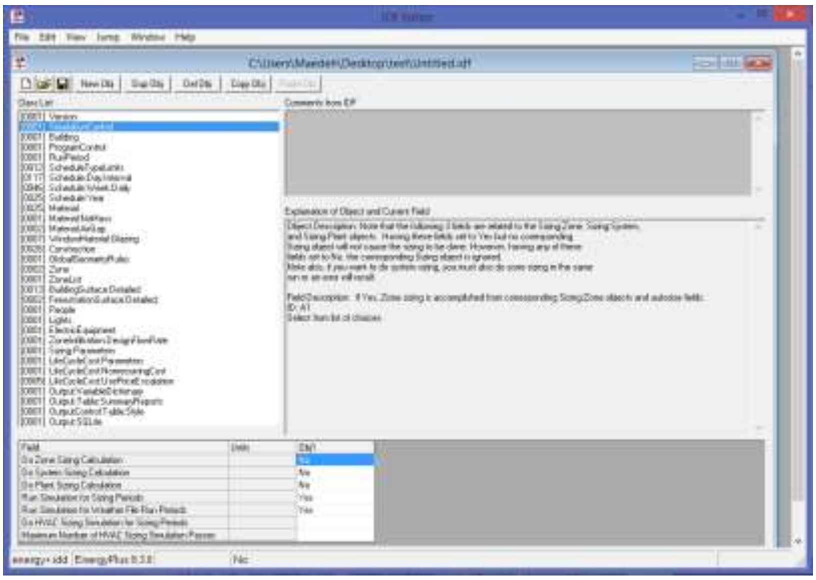
15. CORE IDF CLASS OPERATIONS & BOUNDARY CONFIGURATION

IDF Top-Level Class	Critical Parameters & Simulation Functions
Version	Mandatory field enforcing structural synchronization with the active compiler build.
Simulation Control	Flags execution parameters for plant sizing, zone equipment capacity, and sizing periods.
Building	Defines geometric clockwise orientation, terrain roughness, and matrix convergence tolerances.

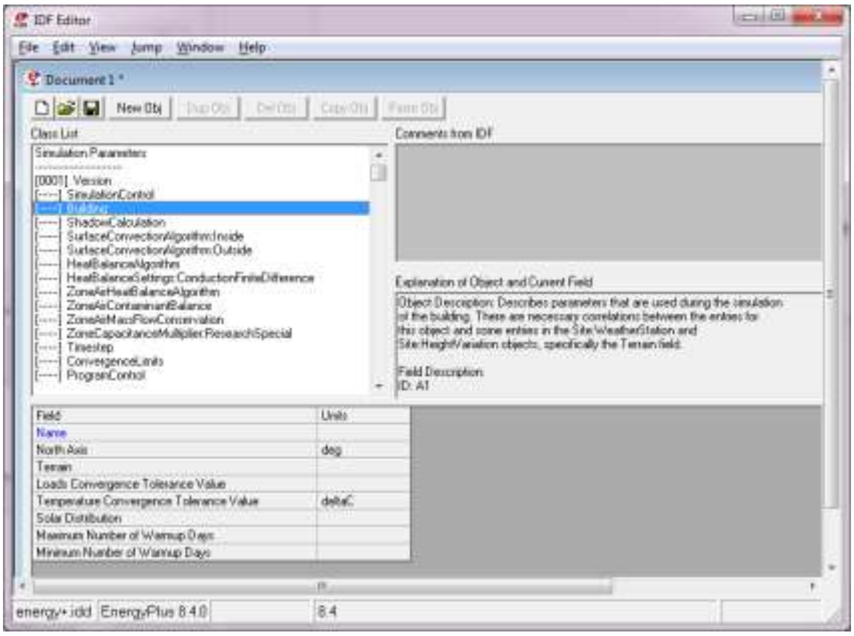
Version



Simulation Control



Building



Solar Distribution Algorithms & Convex Layout Restrictions

- **Full Exterior:** Introduces all external radiation; internal redistribution is handled uniformly without localized ray tracing.
- **Full Interior and Exterior:** Computes ray entry paths, projecting radiation onto the floor and distributing reflections based on localized surface absorptance.
- **Full Exterior/Interior with Reflections:** Tracks complex external reflections from surrounding terrain and structural shading blocks. This requires strict **convex geometry layouts**.

Non-Convex Boundary Mitigation: If the architectural floor plan is concave, it must be split into convex zones separated by a virtual partitioning wall. This virtual boundary is modeled using a Material:NoMass object with near-zero resistance and mass, coupled with a transparent glazing profile. Airflow mixing across the virtual zone boundary is driven by establishing an Airflow Network with defined dual nodes and an unconstrained open aperture window.

16. SCHEDULE OBJECT PROGRAMMING & CONSTRUCTION LAYERING

Schedules govern the time-variant profiles of zone occupancy, lighting power density ($ ext{W/m}^2$), and HVAC operational setpoints. In compact syntax formats, periods must form a continuous chain without overlapping intervals or unassigned time gaps:

```
Schedule:Compact,
  Zone_Lighting_Sched,      !- Name
  Fraction,                 !- Schedule Type Limits Name
  Through: 12/31,           !- Structural temporal boundary
  For: AllDays,             !- Target day grouping
  Until: 08:00, 0.20,       !- Chronological step and fractional multiplier
  Until: 17:00, 1.00,       !- Peak load period
  Until: 24:00, 0.00;       !- Midnight shutdown
```

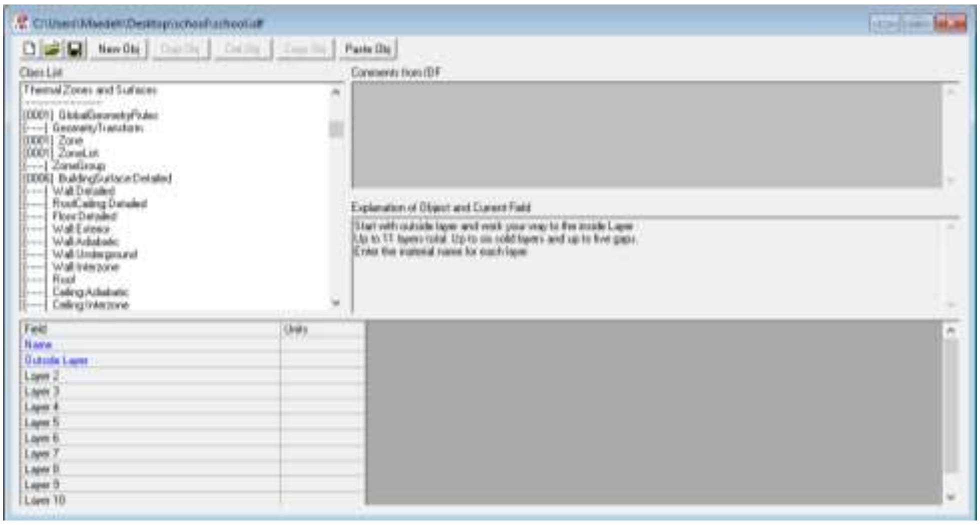
The Boundary Condition Rule for Interior Partitions

When defining an internal common wall partitioning two adjacent thermal zones, the geometric engine utilizes coincident coplanar surfaces. Each surface must explicitly reference the neighboring zone as its boundary condition. Because EnergyPlus strictly evaluates construction layers **“from outside to inside”** relative to the zone's viewpoint, the two coincident surfaces must be assigned **inverted (mirror-image) construction objects** to prevent heat balance matrix errors.

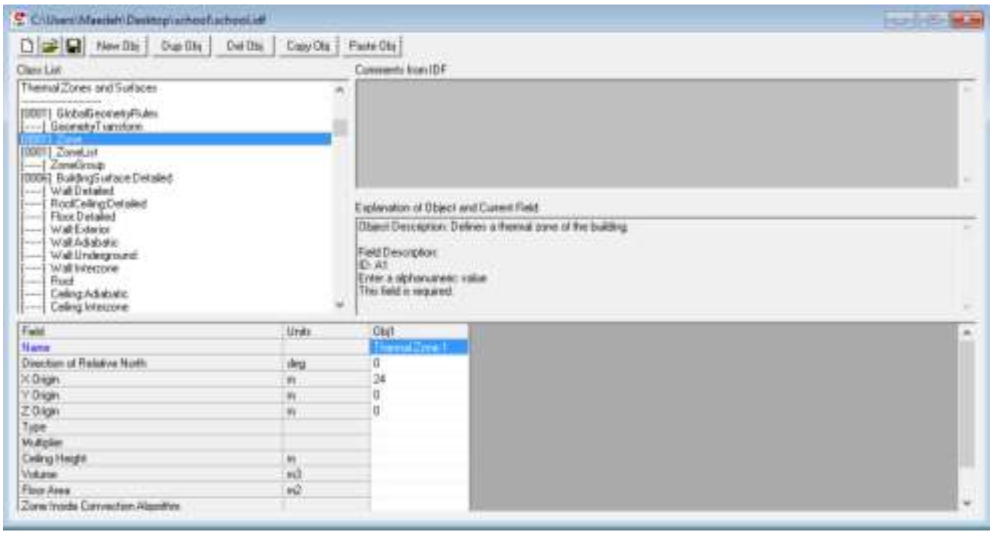
Session 05:
Energyplus Advansed Geometry ,
Internal Gains & HVAC
Templating

1. THERMAL ZONES & BOUNDARY GEOMETRY RULES

The **Thermal Zones and Surfaces** class group governs spatial definitions and boundary logic. The **GlobalGeometryRules** object dictates coordinate layouts, typically mapped automatically during OpenStudio translation workflows.

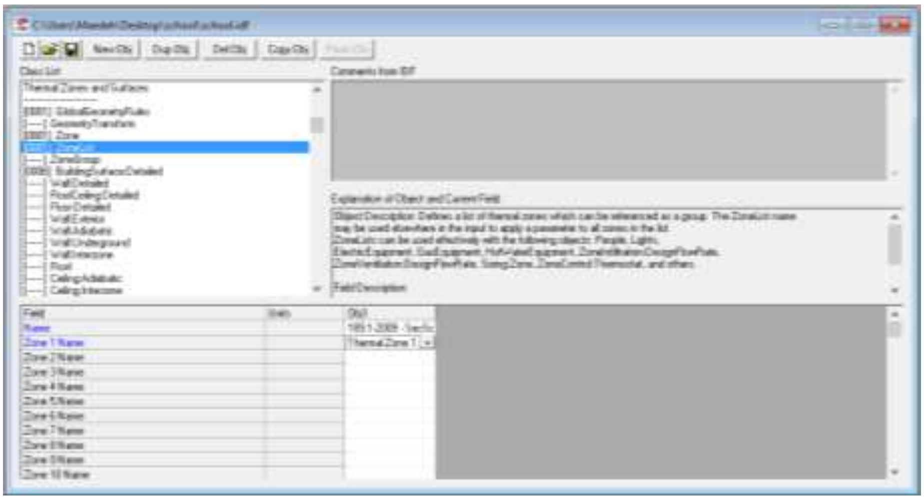


Within the Zone sub-class, each object corresponds to an isolated thermal entity. **Zones** can be rotated relative to true North using clockwise angles. A vital scalability optimization parameter is the **Multiplier**.



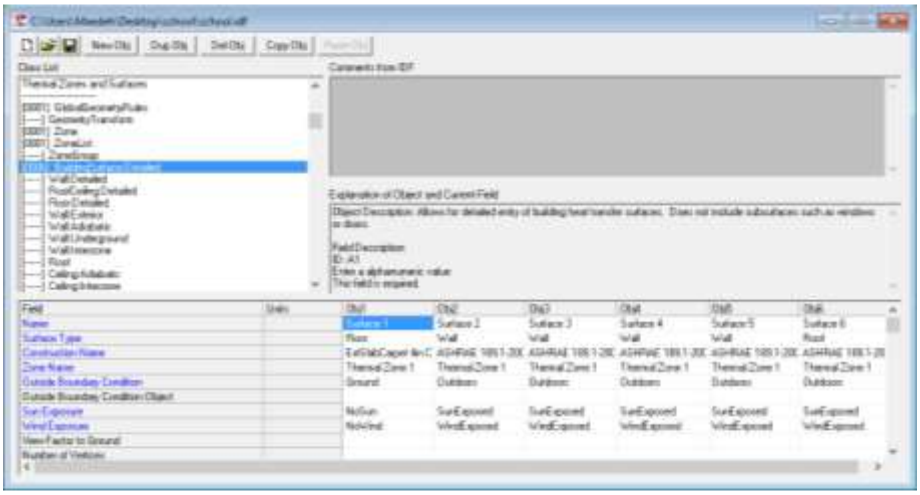
> **Core Simulation Fact:** In a multi-story building (e.g., 20 stories) with uniform boundary metrics, it is geometrically inefficient to model every single floor. The building envelope can be strategically simplified into 3 representative zones: Ground Floor, Top Floor, and a Middle Floor. A **Zone Multiplier** is assigned to the Middle Floor object to scale up its volumetric and energy calculations without increasing runtime overhead.

Furthermore, the ZoneList object allows grouping of separate zones experiencing equivalent thermal exposure, permitting the collective assignment of setpoints or schedules.



17. DETAILED OPAQUE SURFACES & BOUNDARY CONDITIONS

The **BuildingSurface:Detailed** object explicitly handles all opaque structures (walls, roofs, floors). Every single surface requires a unique identifier name and a parent zone assignment.



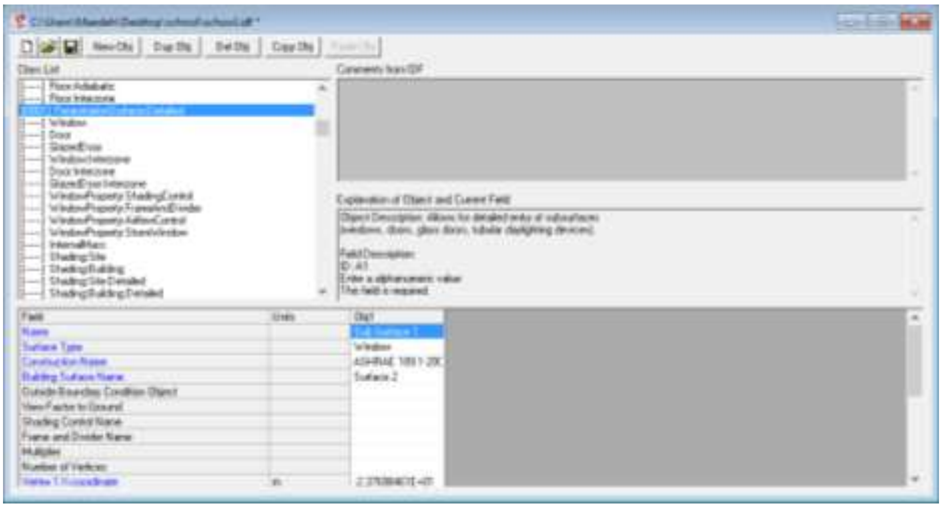
The **Outside Boundary Condition** field maps the ambient thermodynamic state of the outer layer. Selecting **Adiabatic** indicates zero net heat transfer across the surface ($\Delta Q = 0$). This is highly useful when capturing the thermal mass or internal storage capacitance of a partition while completely ignoring raw conductive transmittance to an unconditioned exterior.

> **Core Simulation Fact:** If a wall interfaces with an adjacent zone, its Outside Boundary Condition must point to the neighboring surface. This requires explicit interlocking known as Surface Matching. Alternatively, pointing directly to an adjacent Zone requires erasing the redundant coincident plane in the neighboring geometry list to avoid dual-evaluation in the matrix engine.

18. FENESTRATION HIERARCHIES, GLAZING MATERIALS & SHADING SYSTEMS

Subsurfaces (windows, doors, skylights) are programmed via **FenestrationSurface:Detailed**. EnergyPlus maintains a strict hierarchical **parent-child** object structure where subsurfaces act as child objects mapped onto parent opaque walls.

Specialized fenestration sub-types include **TubularDaylightDome** and **TubularDaylightDiffuser** for pipe daylighting algorithms. When internal windows divide two zones, the child windows must explicitly reference each other as adjacent **subsurfaces** across inverted (mirror-image) constructions.



Dynamic Shading & Glazing Hardware Classifications

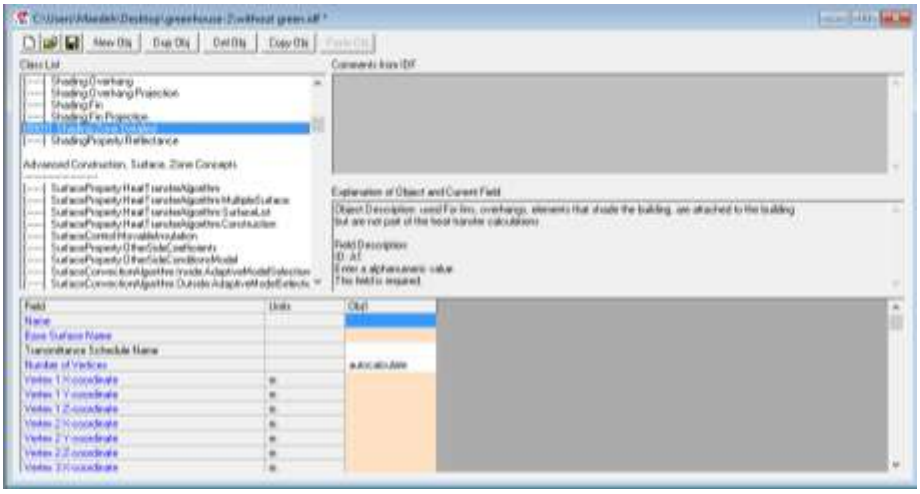
Dynamic or manual curtains and blinds are activated by pointing the window to an active object inside **WindowProperty:ShadingControl**. The physical layers are divided into three core classes:

- **Shade (WindowMaterial:Shade):** Thin, uniform fabric screens or curtains designed to scatter and diffuse incident solar beam radiation. These can be located internally, externally, or between panes.
- **Screen (WindowMaterial:Screen):** Arrays of tightly spaced cylindrical wires. They filter solar energy dynamically based on solar angles, wire thickness, and material geometry.
- **Blind (WindowMaterial:Blind):** Venetian slatted systems with variable or fixed slat tilt angles and curvature spacing rules.

Window frames and thermal thermal bridging dividers are handled in the **WindowProperty:FrameAndDivider** class. Window multipliers are available but must be used cautiously; if shading calculations or solar tracking rely on exact spatial locations, multiplier shortcuts can severely skew zone peak cooling estimates.

19. SHADING GEOMETRY & COMPLEX SHADOWING CALCULATIONS

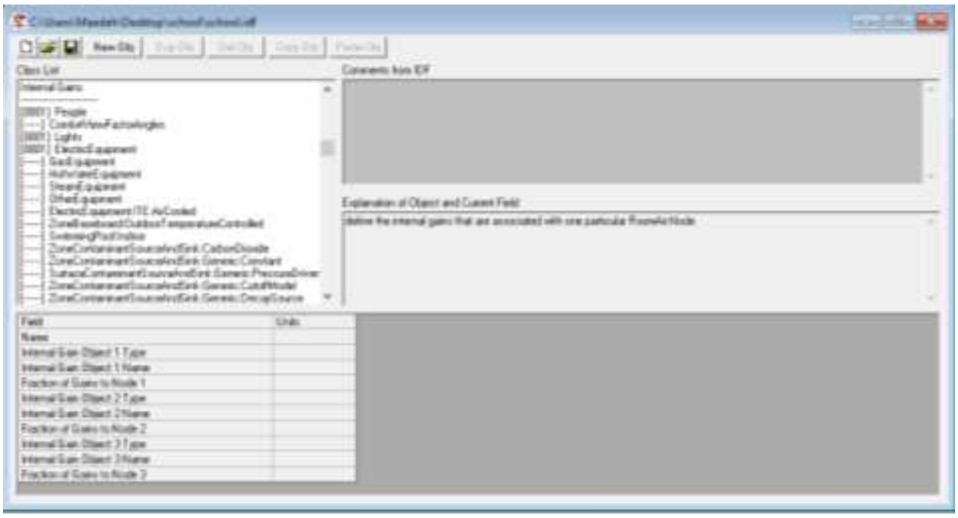
External detached shading objects are declared via **Shading:Zone:Detailed**. By default, EnergyPlus projects shadow arrays using a surface's outward-pointing normal vector. For instance, a flat roof's normal vector points straight toward the sky; hence, any structural roof overhang extending past the wall will not automatically cast a shadow onto the lower wall unless that extension is isolated and re-drawn as an explicit **Shading:Zone:Detailed** object.



> **Core Simulation Fact:** EnergyPlus possesses built-in geometric ray-tracing algorithms that automatically detect self-shading profiles in non-convex structures (such as L-shaped or U-shaped floor plans). However, standalone external shading transparency or foliage variations must be controlled via transmission schedules. Shading transmittance affects visible light spectrum processing, but note that far-infrared longwave blocking remains absolute regardless of schedule variations.

20. INTERNAL HEAT GAINS (PEOPLE, LIGHTS, EQUIPMENT)

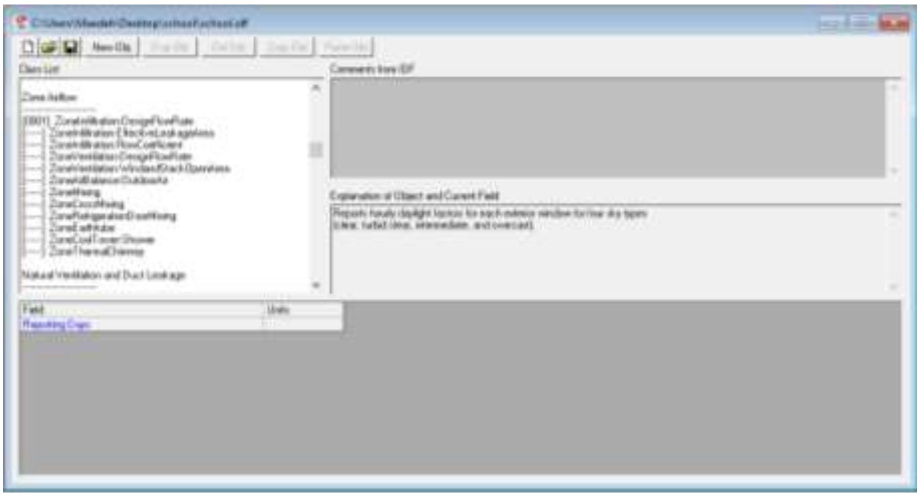
Internal heat gains add sensible and latent heat loads to the zone heat balance. The People class defines human occupancy. The peak maximum density must be declared via absolute counts, absolute areas per person, or people per area, scaled dynamically by fractional Schedule objects. The metabolic work rate is declared via an activity schedule (typically 100 W - 150 W for office domains).



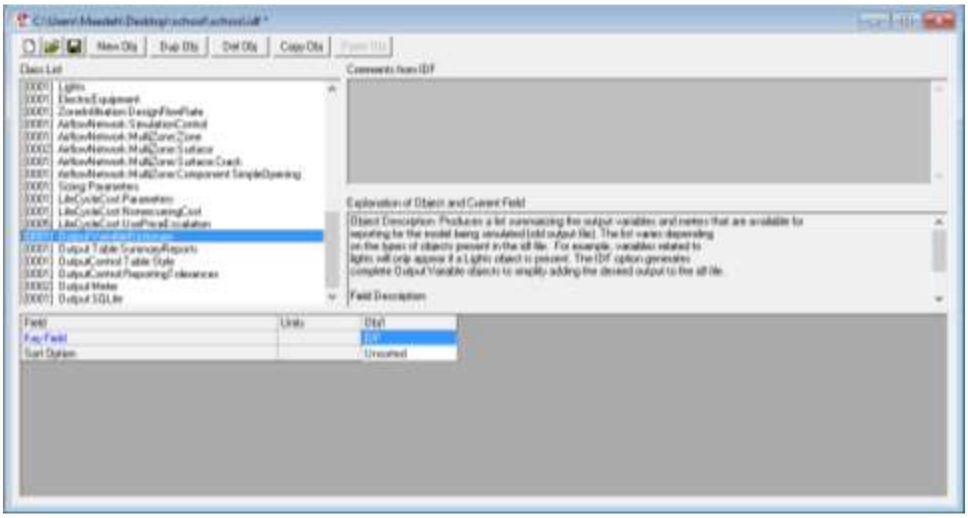
Internal Gain Class	**Critical Parameter Fields & Thermodynamic Splits**
People	Fraction Radiant, Sensible Heat Fraction, Activity Level Schedule (Watts per person). Generates latent moisture.
Lights	Return Air Fraction (heat extracted directly via return ducts), Fraction Radiant, Fraction Visible.
ElectricEquipment	Fraction Latent, Fraction Radiant, Fraction Lost (heat entirely vented outside the zone boundary). No return air extraction field.

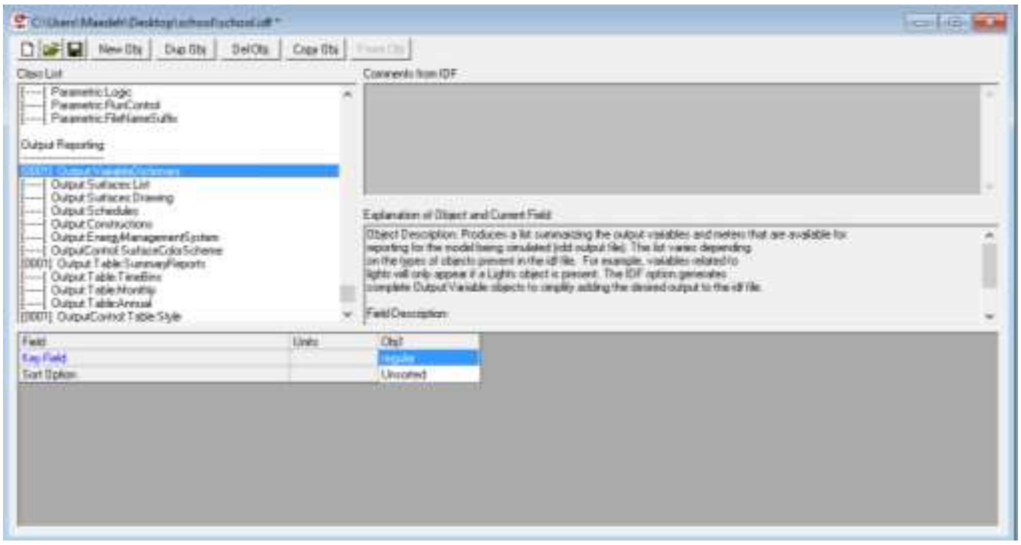
21. AIR INFILTRATION, OUTPUT VARIABLES & HVAC TEMPLATING

Basic uncontrolled air leaking is evaluated using **ZoneInfiltration:DesignFlowRate**, which utilizes static design values irrespective of precise dynamic wind vectoring. To simulate variable opening cracks and pressure-driven leakage, an advanced **AirflowNetwork** must be established.



Simulation diagnostics are configured under **Output:Diagnostics** by enabling **DisplayExtraWarnings** to catch matrix instability. Raw variables cannot be accessed prior to runtime execution. To explore available nodes, use **Output:VariableDictionary** with the key field set to **Regular**, exposing outputs like Zone Mean Air Temperature.

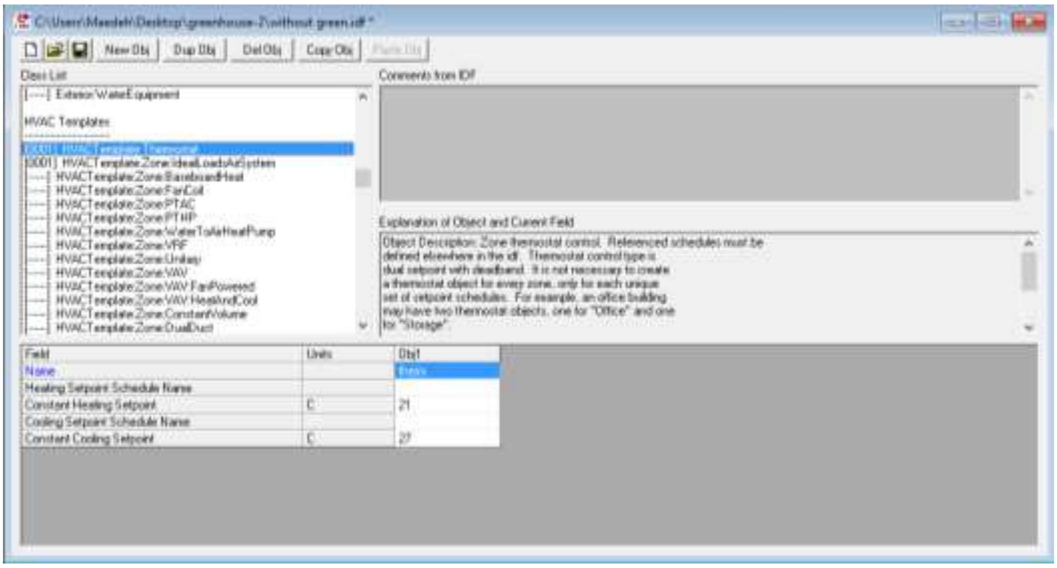




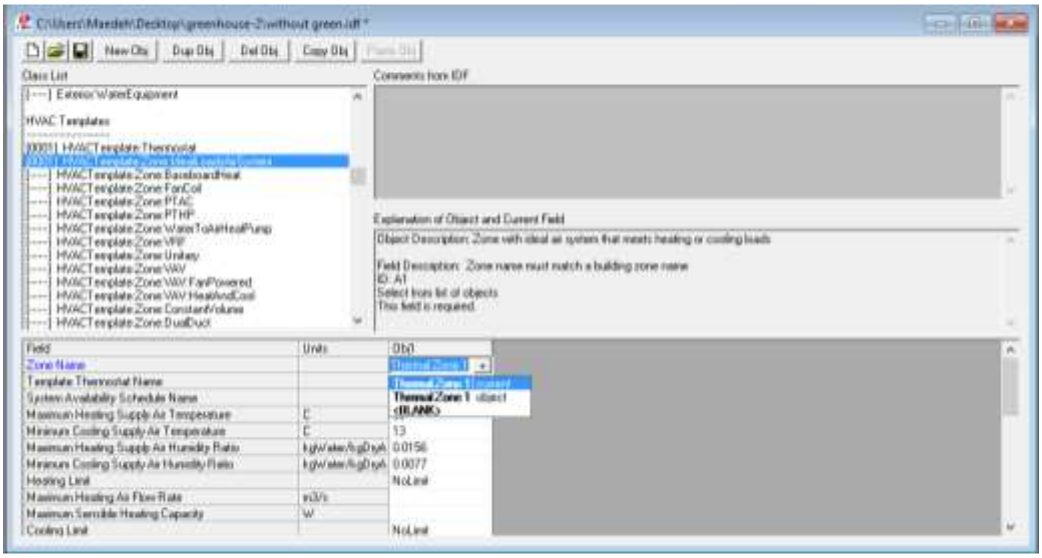
HVAC Simplification via Ideal Loads Air Systems

To bypass complete mechanical plant component modeling during early stage design, templates are deployed. A baseline thermostat schedule is defined in **HVAC-Template:Thermostat**. This is paired with the zone using an **HVAC-Template:Zone:IdealLoadsAirSystem**.

HVAC-Template:Thermostat



HVAC-Template:Zone:IdealLoadsAirSystem



```
HVAC-Template:Zone:IdealLoadsAirSystem,
  Zone_01_Ideal_HVAC,        !- Name
  Office_Thermostat,         !- Thermostat Name
  Allways_On_Sched,          !- System Availability Schedule (Binary 1/0)
  50.0,                      !- Maximum Heating Supply Air Temperature [C]
  13.0,                      !- Minimum Cooling Supply Air Temperature [C]
  NoLimit,                   !- Heating Limit (NoLimit capacity matching vs LimitFlowRate)
  NoLimit;                   !- Cooling Limit
```