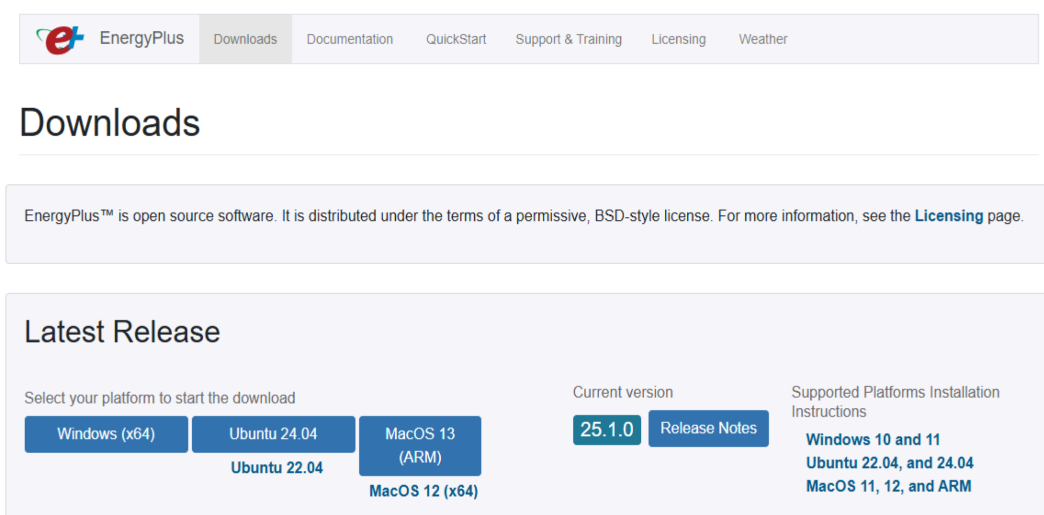
Arch 298 Occupant-Centric Building Energy Modeling with EnergyPlus and Python

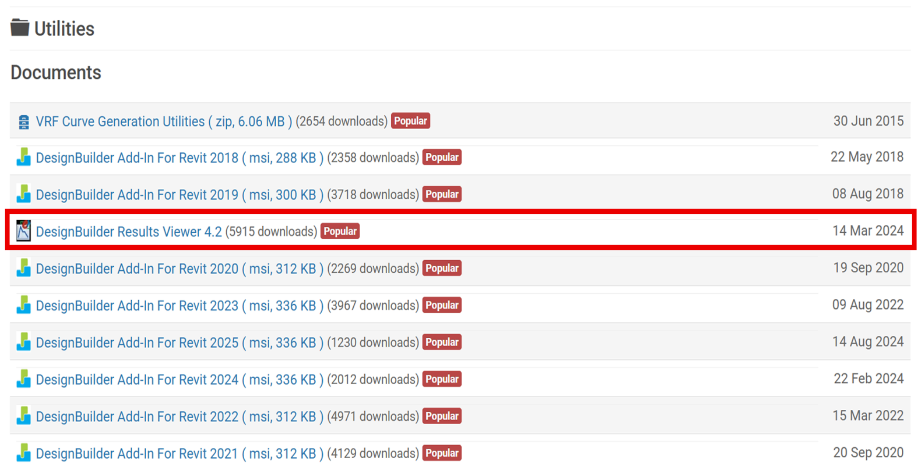
Week 2 – Introduction to Building Energy Simulation

1. Preparation before the class

1.1. Install the Windows version EnergyPlus 25.1 from https://energyplus.net/downloads. While the EnergyPlus engine can run on macOS (see the instruction on how to run EP-Launch.exe on Mac), most graphical user interfaces (GUIs) for EnergyPlus are better supported on Windows PCs. For this reason, we **recommend using a Windows PC** if possible. This is not a strict requirement, but it may improve your overall learning experience. As an alternative, you can also use the Windows operating system on Mac. This is particularly relevant if, as a Mac user, you have faced the struggle of running software available only on Windows before. There are two main approaches to do this: 1. **Boot Camp** – Available on Intel-based Macs, Boot Camp allows you to boot your computer into either macOS or Windows. This is the recommended option, as it typically runs faster and more reliably than virtual machines. You have to create a partition on your hard drive, though. 2. **Virtual Machines** – Software such as Parallels allows you to run Windows within macOS. This is a convenient option if Boot Camp is not available (e.g., on Apple Silicon Macs). Alternatively, you may also choose to **borrow or access a Windows PC** during the course if needed.



1.2. Install ResultsViewer from https://designbuilder.co.uk/download/utilities-1

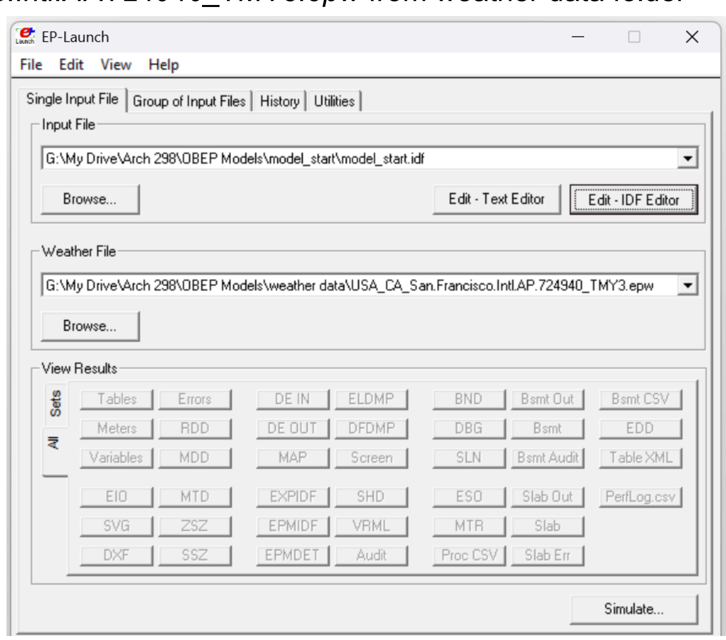


2. Run the baseline model

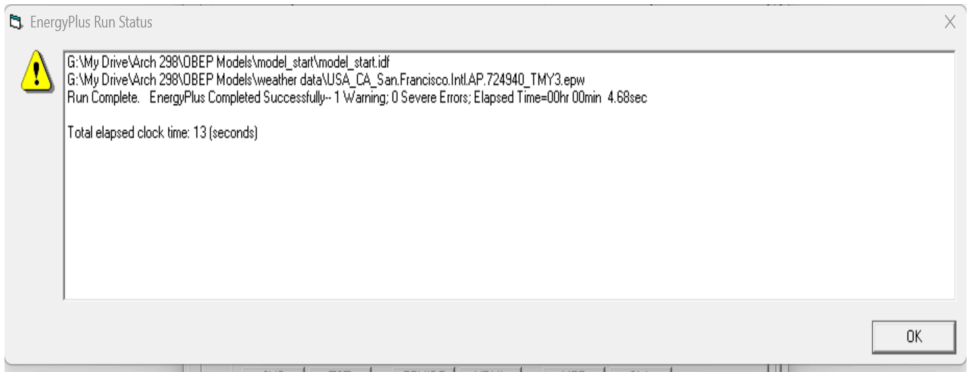
2.1. Find and review the *model_start.idf*:

- Window kept closed
- Mechanical ventilation to provide the minimal required ventilation rate
- Ideal load HVAC system (as opposed to detailed HVAC system modelling)
- Simplified natural ventilation and infiltration models with assumed ACH rates (as opposed to AirFlow Network)
- Fixed/repeated schedules for occupant behavior

2.2. Run *model_start.idf* with the San Francisco weather data using EP launch. (*USA_CA_San.Francisco.Intl.AP.724940_TMY3.epw* from weather data folder



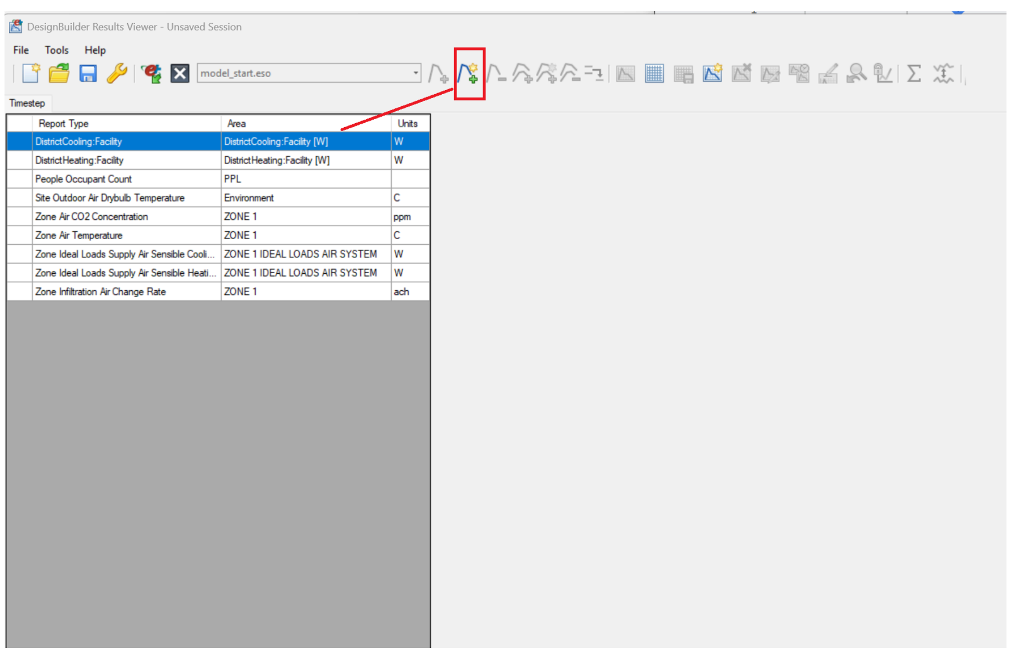
2.3. You should only have 1 warning and 0 severe errors after the simulation finishes. If that's not the case, look into the.err file inside the simulation folder.



2.4. Analyse the time-series simulation results

2.5. Open the *.eso* file and review these variables (see how to pick a variable to plot below)

- Zone air temperature & outdoor air temperature
- Zone CO_2 concentration
- Zone heating/cooling rate
- The number of people



2.6. Review the energy performance metrics (tips: Review the energy performance metrics by opening the file model_0Table.html in any web browser. In the **End Uses** section, look specifically at heating, cooling, and lighting energy consumption)

2.7. See if the roof material in the current model (learn how to navigate the EnergyPlus model structure) is appropriate

3. Change the building construction

3.1. Make a copy of *model_start.idf*, and save it as *model_0.idf* in a new folder (named *model_0*)

3.2. Change the construction material for the roof in *model_0.idf*

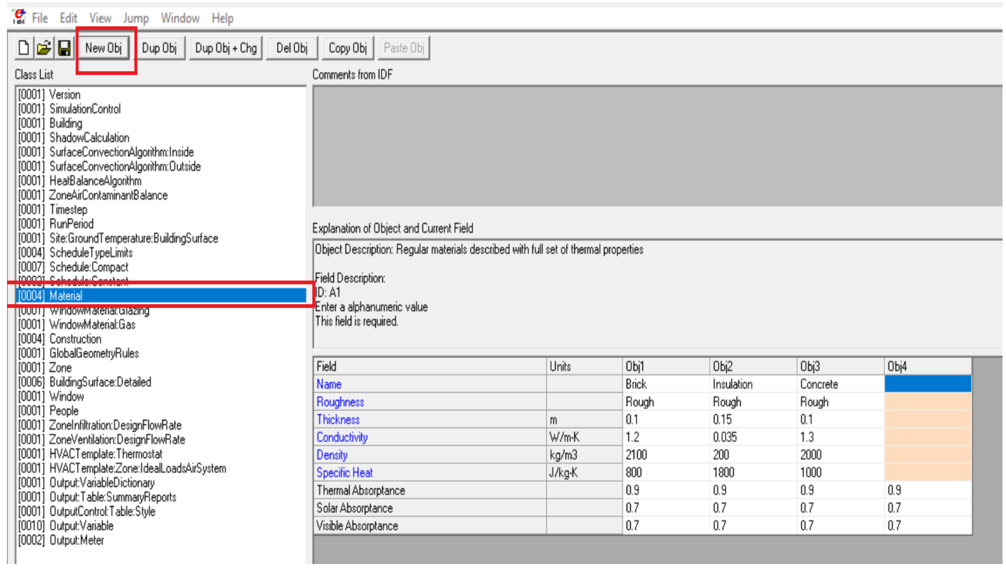
- Create new material in either way:
  - (Recommended) Open the model in any text editor (e.g., NotePad++), and copy & paste the following

```
Material,
  M14a 100mm heavyweight concrete,  !- Name
  MediumRough,             !- Roughness
  0.1016,                  !- Thickness {m}
  1.95,                    !- Conductivity {W/m-K}
  2240,                    !- Density {kg/m3}
  900;                     !- Specific Heat {J/kg-K}

Material:AirGap,
  F05 Ceiling air space resistance,  !- Name
  0.18;                    !- Thermal Resistance {m2-K/W}

Material,
  F16 Acoustic tile,       !- Name
  MediumSmooth,            !- Roughness
  0.0191,                  !- Thickness {m}
  0.06,                    !- Conductivity {W/m-K}
  368,                     !- Density {kg/m3}
  590;                     !- Specific Heat {J/kg-K}
```

  - Alternatively, open the EP-Launch, and manually add those objects (for example, find the Material, click New Obj, and then manually input the parameter values)



■ Create a new construction object (in the same way as adding a new material) named *New Roof*

Construction,
New Roof, !- Name
M14a 100mm heavyweight concrete, !- Outside Layer
F05 Ceiling air space resistance, !- Layer 2
F16 Acoustic tile; !- Layer 3

3.3. Find the Roof surface object and change the Construction Name to *New Roof*

BuildingSurface:Detailed,
roof, !- Name
Roof, !- Surface Type
New Roof, !- Construction Name
zone 1, !- Zone Name
, !- Space Name
Outdoors, !- Outside Boundary Condition
, !- Outside Boundary Condition Object
SunExposed, !- Sun Exposure
WindExposed, !- Wind Exposure
autocalculate, !- View Factor to Ground
4, !- Number of Vertices
0, 0, 3, !- X,Y,Z 1 {m}
10, 0, 3, !- X,Y,Z 2 {m}
10, 5, 3, !- X,Y,Z 3 {m}
0, 5, 3; !- X,Y,Z 4 {m}

3.4. Run the *model_0.idf* with the San Francisco weather data and review the time-series simulation results and energy performance metrics, in comparison with the *model_start* results

4. Add lighting and equipment (internal gain) objects

4.1. Make a copy of *model_0.idf*, and save it as *model_1.idf* in a new folder (named *model_1*)

4.2. Add a Lights object (recommended to use a text editor) and a schedule

```
Lights,
    Lighting1,              !- Name
    zone 1,                 !- Zone or ZoneList or Space or SpaceList Name
    Office Lighting,        !- Schedule Name
    Watts/Area,             !- Design Level Calculation Method
    ,                       !- Lighting Level {W}
    7.5,                    !- Watts per Zone Floor Area {W/m2}
    ,                       !- Watts per Person {W/person}
    0,                      !- Return Air Fraction
    0.37,                   !- Fraction Radiant
    0.18,                   !- Fraction Visible
    1;                      !- Fraction Replaceable

Schedule:Compact,
    Office Lighting,        !- Name
    Fraction,               !- Schedule Type Limits Name
    Through: 12/31,         !- Field 1
    For: Weekdays SummerDesignDay,  !- Field 2
    Until: 05:00, 0.05,     !- Field 4
    Until: 07:00, 0.1,      !- Field 6
    Until: 08:00, 0.3,      !- Field 8
    Until: 17:00, 0.9,      !- Field 10
    Until: 18:00, 0.5,      !- Field 12
    Until: 20:00, 0.3,      !- Field 14
    Until: 22:00, 0.2,      !- Field 16
    Until: 23:00, 0.1,      !- Field 18
    Until: 24:00, 0.05,     !- Field 20
    For: Saturday WinterDesignDay,  !- Field 21
    Until: 06:00, 0.05,     !- Field 23
    Until: 08:00, 0.1,      !- Field 25
    Until: 12:00, 0.3,      !- Field 27
    Until: 17:00, 0.15,     !- Field 29
    Until: 24:00, 0.05,     !- Field 31
    For: Sunday Holidays AllOtherDays,  !- Field 32
    Until: 24:00, 0.05;     !- Field 34
```

4.3. Add Equipment and a schedule (recommended to use a text editor)

```
OtherEquipment,
    Equipment1,             !- Name
    Electricity,            !- Fuel Type
    zone 1,                 !- Zone or ZoneList or Space or SpaceList Name
    Office Equipment,       !- Schedule Name
    Watts/Area,             !- Design Level Calculation Method
    ,                       !- Design Level {W}
    4,                      !- Power per Zone Floor Area {W/m2}
    ,                       !- Power per Person {W/person}
    ,                       !- Fraction Latent
    0.2,                    !- Fraction Radiant
```

```
  ;                       !- Fraction Lost

Schedule:Compact,
  Office Equipment,        !- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Weekdays,           !- Field 2
  Until: 05:00, .05,       !- Field 4
  Until: 07:00, .1,        !- Field 6
  Until: 08:00, .3,        !- Field 8
  Until: 12:00, .9,        !- Field 10
  Until: 13:00, .8,        !- Field 12
  Until: 17:00, .9,        !- Field 14
  Until: 18:00, .5,        !- Field 16
  Until: 20:00, .3,        !- Field 18
  Until: 22:00, .2,        !- Field 20
  Until: 23:00, .1,        !- Field 22
  Until: 24:00, .05,       !- Field 24
  For: Saturday,           !- Field 25
  Until: 06:00, .05,       !- Field 27
  Until: 08:00, .1,        !- Field 29
  Until: 12:00, .3,        !- Field 31
  Until: 17:00, .15,       !- Field 33
  Until: 24:00, .05,       !- Field 35
  For: Allotherdays,       !- Field 36
  Until: 24:00, .05;       !- Field 38
```

4.4. Add related output variables

```
Output:Variable,*,Zone Lights Electricity Rate,Timestep;
```

4.5. Run the *model_1.idf* with the same San Francisco weather data and compare the energy performance metrics with the *model_0* results

5. Add daylighting control

5.1. Make a copy of model_1.idf, and save it as model_2.idf in a new folder (e.g., named model_2)

5.2. Add daylighting control

```
Daylighting:Controls,
  daylightcontrol1,        !- Name
  zone 1,                  !- Zone or Space Name
  SplitFlux,               !- Daylighting Method
  Office HVAC,             !- Availability Schedule Name
  Continuous,              !- Lighting Control Type
  0.1,                     !- Minimum Input Power Fraction for Continuous or ContinuousOff Dimming Control
  0.1,                     !- Minimum Light Output Fraction for Continuous or ContinuousOff Dimming Control
  1,                       !- Number of Stepped Control Steps
  1,                       !- Probability Lighting will be Reset When Needed in Manual Stepped Control
  daylightingref1,         !- Glare Calculation Daylighting Reference Point Name
  0,           !- Glare Calculation Azimuth Angle of View Direction Clockwise from Zone y-Axis {deg}
  22,                      !- Maximum Allowable Discomfort Glare Index
```

```
    1,                    !- DElight Gridding Resolution {m2}
    daylightingref1,      !- Daylighting Reference Point 1 Name
    1,                    !- Fraction of Lights Controlled by Reference Point 1
    400;                  !- Illuminance Setpoint at Reference Point 1 {lux}

Daylighting:ReferencePoint,
    daylightingref1,      !- Name
    zone 1,               !- Zone Name
    5,                    !- X-Coordinate of Reference Point {m}
    2.5,                  !- Y-Coordinate of Reference Point {m}
    0.8;                  !- Z-Coordinate of Reference Point {m}
```

5.3. Run the model_2.idf with the San Francisco weather data and compare the energy performance metrics with the model_1 results

6. Add blind control

6.1. Make a copy of model_2.idf, and save it as model_3.idf in a new folder (e.g., named model_3)

6.2. Add a blind material (from EnergyPlus DataSets/WindowBlindMaterials.idf), a new WindowProperty:ShadingControl, a new construction, and an output variable for blind open state.

```
WindowMaterial:Blind,
    High-Reflect Blind,   !- Name
    Horizontal,           !- Slat Orientation
    0.025,                !- Slat Width {m}
    0.01875,              !- Slat Separation {m}
    0.001,                !- Slat Thickness {m}
    45.0,                 !- Slat Angle {deg}
    0.9,                  !- Slat Conductivity {W/m-K}
    0.0,                  !- Slat Beam Solar Transmittance
    0.8,                  !- Front Side Slat Beam Solar Reflectance
    0.8,                  !- Back Side Slat Beam Solar Reflectance
    0.0,                  !- Slat Diffuse Solar Transmittance
    0.8,                  !- Front Side Slat Diffuse Solar Reflectance
    0.8,                  !- Back Side Slat Diffuse Solar Reflectance
    0.0,                  !- Slat Beam Visible Transmittance
    0.8,                  !- Front Side Slat Beam Visible Reflectance
    0.8,                  !- Back Side Slat Beam Visible Reflectance
    0.0,                  !- Slat Diffuse Visible Transmittance
    0.8,                  !- Front Side Slat Diffuse Visible Reflectance
    0.8,                  !- Back Side Slat Diffuse Visible Reflectance
    0.0,                  !- Slat Infrared Hemispherical Transmittance
    0.9,                  !- Front Side Slat Infrared Hemispherical Emissivity
    0.9,                  !- Back Side Slat Infrared Hemispherical Emissivity
    0.050,                !- Blind to Glass Distance {m}
    0.5,                  !- Blind Top Opening Multiplier
    0.5,                  !- Blind Bottom Opening Multiplier
    0.5,                  !- Blind Left Side Opening Multiplier
    0.5,                  !- Blind Right Side Opening Multiplier
    ,                     !- Minimum Slat Angle {deg}
```

```
;                       !- Maximum Slat Angle {deg}

WindowShadingControl,
  ShadeCtrl,              !- Name
  zone 1,                 !- Zone Name
  1,                      !- Shading Control Sequence Number
  ExteriorBlind,          !- Shading Type
  ,                       !- Construction with Shading Name
  OnIfHighSolarOnWindow,  !- Shading Control Type
  ,                       !- Schedule Name
  400,                    !- Setpoint {W/m2, W or deg C}
  No,                     !- Shading Control Is Scheduled
  No,                     !- Glare Control Is Active
  High-Reflect Blind,  !- Shading Device Material Name
  ,                       !- Type of Slat Angle Control for Blinds
  ,                       !- Slat Angle Schedule Name
  ,                       !- Setpoint 2 {W/m2, deg C or cd/m2}
  daylightcontrol1,       !- Daylighting Control Object Name
  Sequential,             !- Multiple Surface Control Type
  south window;           !- Fenestration Surface 1 Name

Output:Variable,*,Surface Shading Device Is On Time Fraction,Timestep;
Output:Variable,*,Surface Outside Face Incident Solar Radiation Rate per Area,Timestep;
```

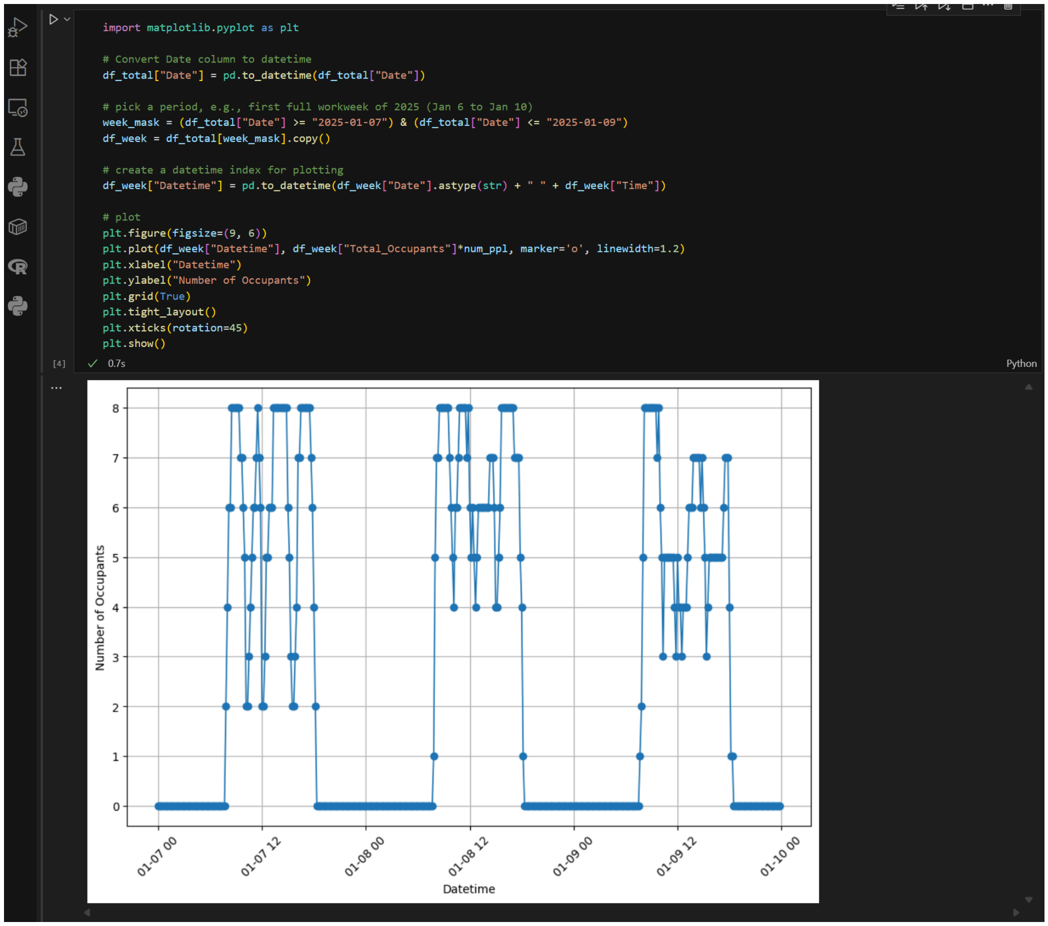
6.3. Run the *model_3.idf* with the San Francisco weather data and compare the energy performance metrics with the *model_1* results.

7. Implement a stochastic occupancy model

7.1. Run the *occ_sch_generator.ipynb* script (in the *py* folder), which generates individual stochastic occupancy schedules for all occupants as well as the total occupancy rate for the entire office.

Name	Date modified	Type	Size
occ_sch_generator.ipynb	8/19/2025 9:40 AM	Jupyter Source File	87 KB
all_ppl_schs.csv	8/14/2025 10:53 PM	Microsoft Excel Com...	1,146 KB
occ_sch_person_1.csv	8/14/2025 10:52 PM	Microsoft Excel Com...	3,276 KB
occ_sch_person_2.csv	8/14/2025 10:52 PM	Microsoft Excel Com...	3,279 KB
occ_sch_person_3.csv	8/14/2025 10:53 PM	Microsoft Excel Com...	3,270 KB
occ_sch_person_4.csv	8/14/2025 10:53 PM	Microsoft Excel Com...	3,280 KB
occ_sch_person_5.csv	8/14/2025 10:53 PM	Microsoft Excel Com...	3,276 KB
occ_sch_person_6.csv	8/14/2025 10:53 PM	Microsoft Excel Com...	3,275 KB
occ_sch_person_7.csv	8/14/2025 10:53 PM	Microsoft Excel Com...	3,277 KB
occ_sch_person_8.csv	8/14/2025 10:53 PM	Microsoft Excel Com...	3,256 KB

7.2. Try plotting the occupancy schedule using the provided Python script for any period of interest; compare the stochastic schedule with the fixed one as defined in the previous models



7.3. Make a copy of *model_3.idf*, and save it as *model_4.idf* in a new folder (named *model_4*)

7.4. Copy and paste the *all_ppl_schs.csv* to the *model_4* folder

7.5. Add a new schedule:file object in *model_4.idf*

```
Schedule:File,
    random_occ,             !- Name
    Any Number,             !- Schedule Type Limits Name
    all_ppl_schs.csv,       !- File Name
    3,                      !- Column Number
    1,                      !- Rows to Skip at Top
    8760,                   !- Number of Hours of Data
    Comma,                  !- Column Separator
    No,                     !- Interpolate to Timestep
    10,                     !- Minutes per Item
    No;                     !- Adjust Schedule for Daylight Savings
```

7.6. Use this random schedule in the People object by referencing the *random_occ*

```
People,
    PPL,                    !- Name
    zone 1,                 !- Zone or ZoneList or Space or SpaceList Name
    random_occ,             !- Number of People Schedule Name
```

```
People,               !- Number of People Calculation Method
8,                    !- Number of People
,                     !- People per Floor Area {person/m2}
,                     !- Floor Area per Person {m2/person}
0.3,                  !- Fraction Radiant
autocalculate,        !- Sensible Heat Fraction
Activity Office,      !- Activity Level Schedule Name
0.0000000382,         !- Carbon Dioxide Generation Rate {m3/s-W}
No,                   !- Enable ASHRAE 55 Comfort Warnings
EnclosureAveraged,    !- Mean Radiant Temperature Calculation Type
,                     !- Surface Name/Angle Factor List Name
,                     !- Work Efficiency Schedule Name
DynamicClothingModelASHRAE55;  !- Clothing Insulation Calculation Method
```

7.7. Run the *model_4.idf* with the San Francisco weather data and compare the energy performance metrics with the *model_3* results

After finishing the previous steps, fill out the following table and briefly analyze the energy performance between different model assumptions in a comparative and critical way

Climate	**Model**	**Total Energy Intensity** [kWh/m^2]	**Heating Intensity** [kWh/m^2]	**Cooling Intensity** [kWh/m^2]	**Lighting Electricity Intensity** [kWh/m^2]
SF	Model 1				
	Model 2				
	Model 3				
	Model 4				