Project 1: EnergyPlus/OpenStudio Modeling of Crocker Science Center

1. Project Description

The goal of Project 1 is to create a Building Energy Model (BEM) of Crocker Science Center (CSC) for **building energy efficiency** and **retrofit analysis** by using EnergyPlus/Openstudio. EnergyPlus, developed by the US department of energy (DOE), is one of the most widely used software in the field of building simulation. OpenStudio is the developed graphical user interface (GUI) for EnergyPlus simulation engine. It can invoke EnergyPlus by using interfaces.

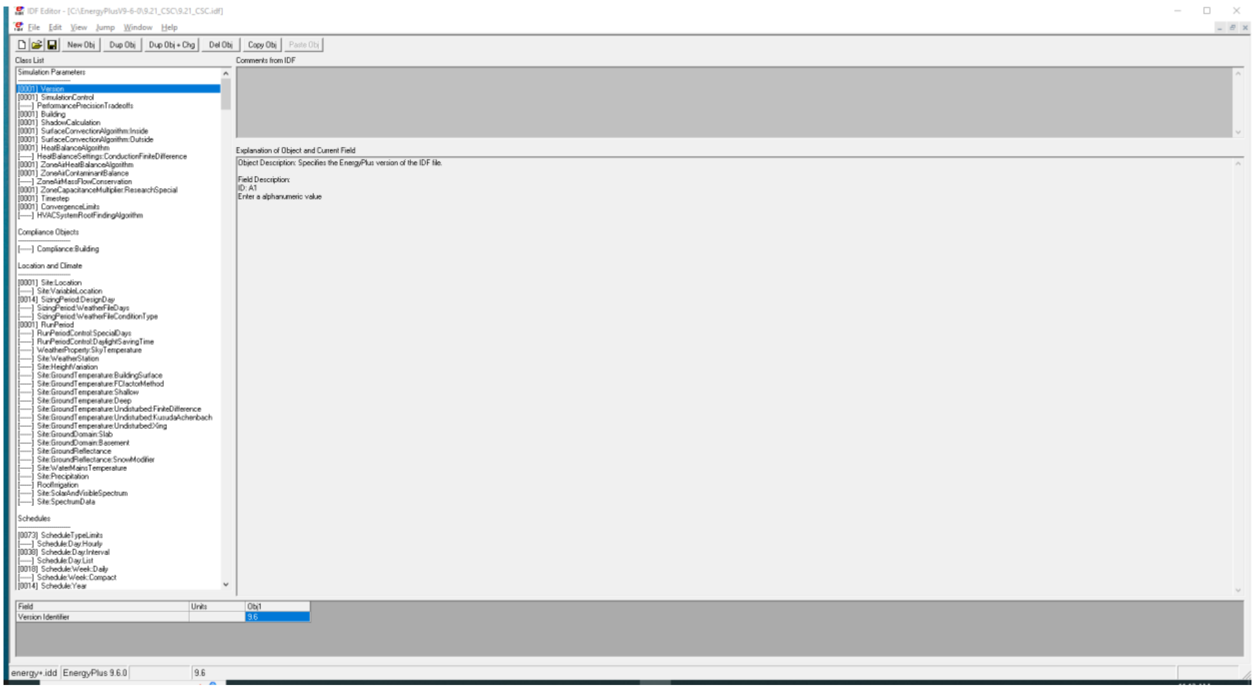

Fig. 1. EnergyPlus simulation interface

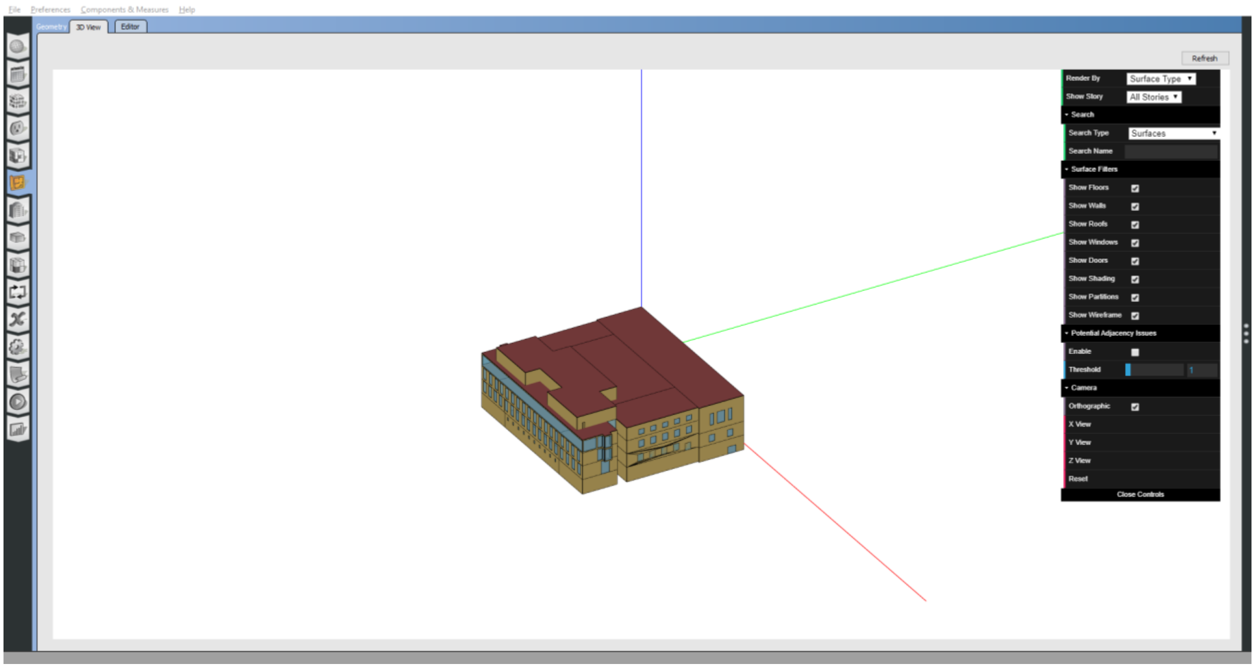

Fig. 2. OpenStudio simulation interface

2. CSC Details

As depicted in Fig. 3, the case project focuses on the Crocker Science Center (CSC) building, located in the main campus of the University of Utah. This four-story building spans a total area of 11437.29 square meters. It encompasses various spaces, including offices, conference rooms, mechanical rooms, an auditorium, and laboratories. The building employs a variable air volume (VAV) system for air conditioning, comprising two air handling units (AHUs). The cooling is supplied by two electrical chillers within the building, while the heating is generated by four boilers within the building.

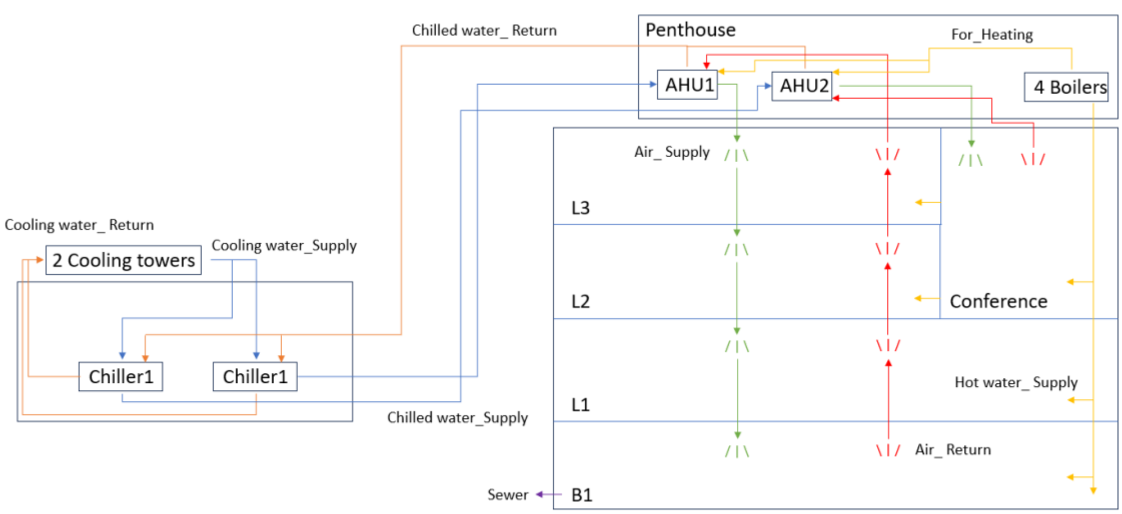

Fig. 3. High-level of CSC building systems

The modeling process includes constructing geometry, construction, and materials, internal loads and schedule, HVAC systems, and running simulation and analysis results.

2.1. Constructing Building Geometry

Fig. 4.a CSC Building.

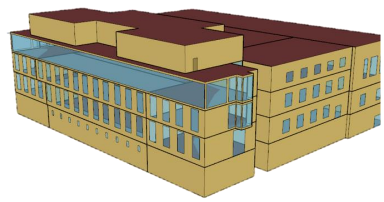

Fig. 4.b Building energy model in EnergyPlus.

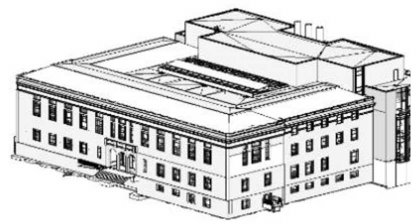

Fig. 4.c Building information model in REVIT.

- Use FloorspaceJS in OpenStudio to create a building geometry model based on the rest of the content. The tutorial on using FloorspaceJS in OpenStudio to create building geometry, thermal zones, and subsurfaces is shown in the following two links.
  - Create Geometry: https://www.youtube.com/watch?v=-5HHfgSlTsc
  - Add Thermal Zones and Subsurfaces: https://www.youtube.com/watch?v=22Lj6kdwWrc
- The floor plan and the matched internal space modeling are shown in **Error! Reference source not found.**. The floor plan drawing can be found in the **Raw drawing folder**. When you use FloorspaceJS you can directly input the **png.** In the **Raw drawing** folder**.**
- To simplify the modeling, all types of rooms are divided into different thermal zones according to orientation. You only need to assign the provided thermal zone and insert components as shown in **Thermal zone and Components** folder. Figure 2 is an example of thermal zones of the basement floor.
- The height of the basement floor is **16.0ft**. The height of the first floor is **15.0ft**. The height of the second and third floor is **14.0ft**. The mechanical room is **8.0ft** height. Orientation: **North Axis=0°**
- For room function: Base1, Lv1-1, Lv2-1, Lv3-1 are the core lobbies. Base 3, Lv1-3, Lv1-4 are the classrooms. Lv2-3 is a conference room. Lv1-2, Lv2-2, Lv3-2 are the Labs. The rest of the rooms are the office. With different room functions, there may be different loads, settings, and controls.
- For more information of CSC building, you can see the **REVIT model** and drawings in the **Raw drawing** folder.

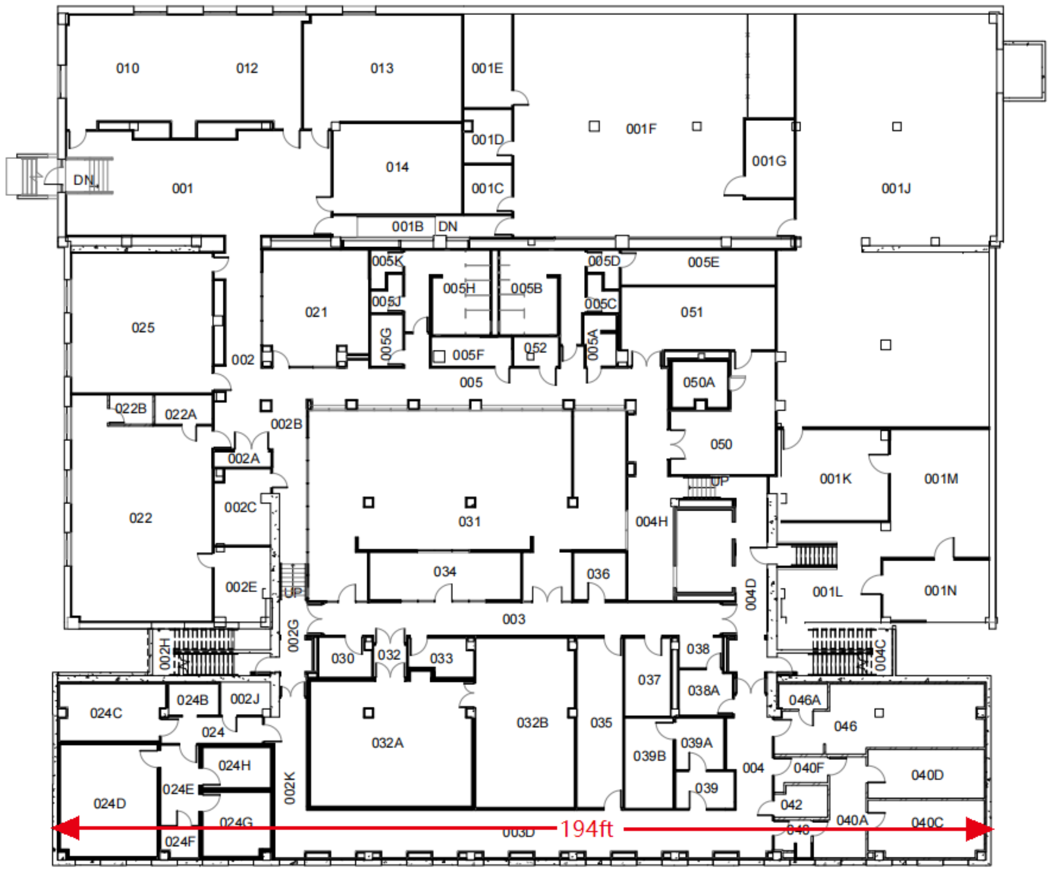

Fig. 5. Use FloorspaceJS to create model geometry.

Fig. 6. Use Thermal zones to simplify building modeling.

- **Door dimension and position**
  - Door dimension:
    - Door 1: Height (ft): 14.0, Width (ft): 8.00
    - Door 2: Height (ft): 6.67, Width (ft): 3.00
  - The door positions are shown in the **Thermal zone and components\Components** folder.
- **Window dimension and position**
  - Window dimension:
    - Window 1: Height (ft): 13.0, Width (ft): 192.0, Sill (ft): 0.5
    - Window 2: Height (ft): 12.0, Width (ft): 6.0, Sill (ft): 1.0
    - Window 3: Height (ft): 7.0, Width (ft): 5.0, Sill (ft): 6.0
    - Window 21: Height (ft): 12.0, Width (ft): 8.0, Sill (ft): 1.0
    - Window 22: Height (ft): 12.0, Width (ft): 2.0, Sill (ft): 1.0
    - Window 23: Height (ft): 12.0, Width (ft): 6.0, Sill (ft): 8.0
  - The Window positions are shown in the **Thermal zone and components\Components** folder.

- To simplify the modeling, the windows above were simplified into six types, and the doors were simplified into two types. The above numbers are all based on estimation. If there are conflicting measurements, the modeler can make assumptions by themselves to allow certain levels of errors. In addition, we encourage you to do modeling based on original drawings and the REVIT model.
- The modeled geometry in OpenStudio should look like the following figures.

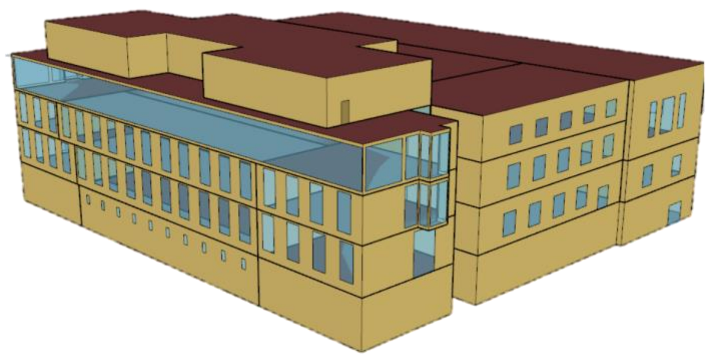

Fig. 7. The appearance of finished geometry model in OpenStudio.

2.2. Constructions and materials

To begin with, it is essential to specify the materials for each construction, encompassing various layers of materials for the construction. Within this project, the building construction comprises elements such as extroof, extwall, ground floor, extwindow, extdoor, intwall, intfloor, and intwindow. Each category of building construction can consist of multiple materials. You have the option to download and consult the reference library (**ASHRAE 189.1-2009 Climate Zone 5**). Choose a reference building construction set from the library and make necessary adjustments, as this approach will significantly streamline the process and save time. In practical application, a **calibration method** will be employed to determine parameter values that closely align with the actual building conditions.

If you are interested, feel free to engage in further discussion with Dr. Chen.

2.2.1. Construction settings of CSC building

Construction	**Layer (outside-inside)**	**Materials**	**Roughness**	**Thickness (m)**	**Conductivity (W/m*k)**	**Density (kg/m3)**	**Specific Heat (J/kg*K)**	**Thermal Absorptance**	**Solar Absorptance**	**Visible Absorptance**
ExWall	Layer1	1IN Stucco	Smooth	0.0253	0.6918	1858.0	837.0	0.9	0.92	0.92
	Layer2	8IN Concrete HW	MediumRough	0.2033	1.7296	2243.0	837.0	0.9	0.65	0.65
	Layer3	Wall Insulation [40]	MediumRough	0.0794	0.036057	91.0	837.0	0.9	0.5	0.5

	Layer4	1/2IN Gypsum	Smooth	0.0127	0.16	784.90	830.0	0.9	0.4	0.4
Roof	Layer1	Roof Membrane	VeryRough	0.0095	0.16	1121.290	1460.0	0.9	0.7	0.7
	Layer2	Roof Insulation [21]	MediumRough	0.2105	0.079325	265.0	836.80	0.9	0.7	0.7
	Layer3	Metal Decking	MediumSmooth	0.0015	45.006	7680.0	418.40	0.9	0.6	0.6
Floor	Layer1	MAT-CC05 4 HW CONCRETE	Rough	0.1016	1.311	2240.0	836.80	0.9	0.85	0.85
	Layer2	CP02 CARPET PAD	Smooth	No thermal mass material Thermal Resistance: 0.1 m2K/W				0.9	0.8	0.8
Glazing window	**Layer (outside-inside)**	**Materials**	**U-Factor (W/m^2*k)**	**Solar Transmittance**						
Win	Layer1	Simple Glazing	5.678263	0.5						

2.3. Internal Loads and schedule

2.3.1. Internal loads

The internal load “people definition” is **13.5 m^2/person.**

The internal load “equipment definition” is 8 **W/m^2.**

The internal load “light definition” is **6 W/m^2 for fluorescent lights. Fraction radiant=0.3, Fraction visible=0.2, Return Air fraction=0.1.**

2.3.2. Schedules

The occupancy of people, lighting, equipment, hot water uses all follow the same schedule. Based on the analysis of historical electricity data, the operational patterns of CSC exhibit two main modes each day: **weekdays** and **weekends**.

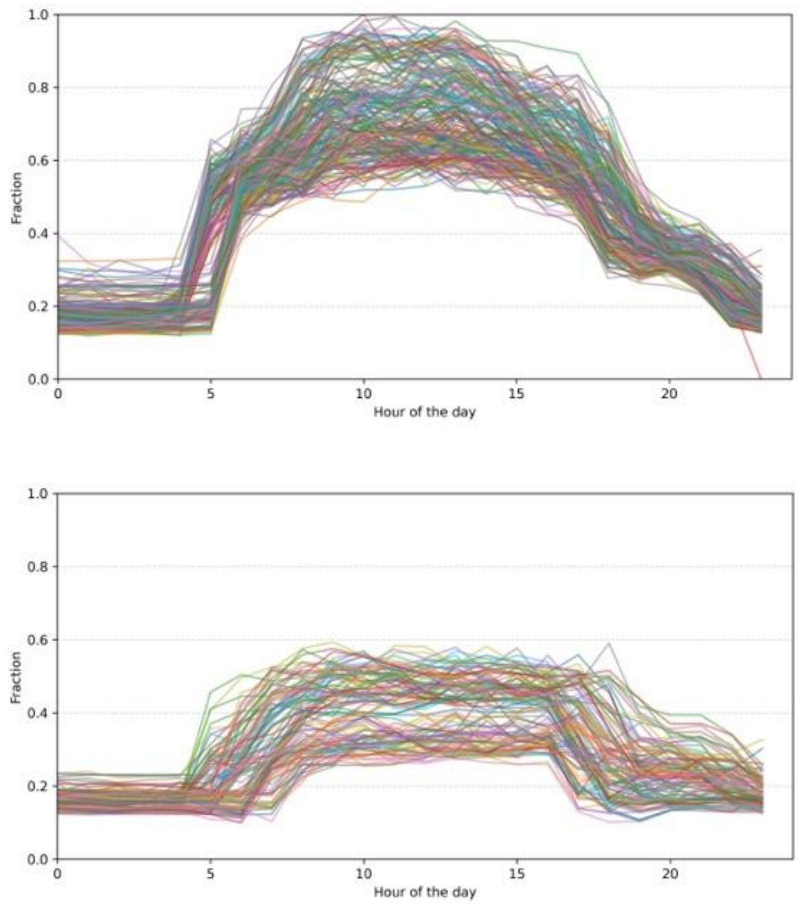

Fig. 8. Clusters of electricity consumption profiles (lift: workdays, right: weekends).

By statistically analyzing the electricity situation for each hour of the day and standardizing the data, can determine the range for the hourly schedule.

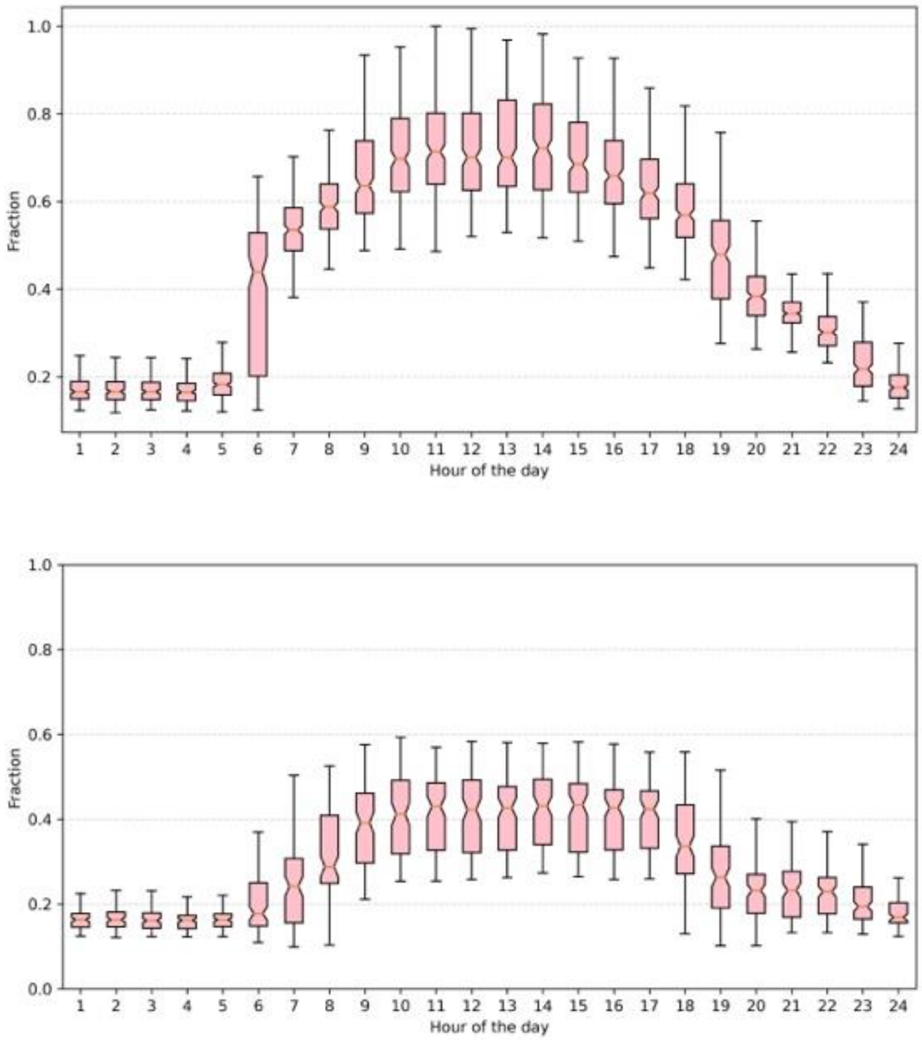

Fig. 9. Daily schedules (lift: workdays, right: weekends).

You can use the schedule settings below.

Workdays schedule	Schedule part	Weekends schedule	Schedule part
0.2	1(1-5AM)	0.2	1(1-6AM)
0.56	2(5-6AM)	0.33	2(6-7AM)
0.59	3(6-7AM)	0.48	3(7-8AM)
0.68	4(7-8AM)	0.49	4(7-8AM)
0.67	5(8-9AM)	0.45	5(9-10AM)
0.75	6(9AM-2PM)	0.58	6(10AM-5PM)
0.52	7(2PM-5PM)	0.49	7(5PM-6PM)
0.42	8(5PM-6PM)	0.39	8(6PM-7PM)

0.5	9(6PM-7PM)	0.14	9(7PM-10PM)
0.45	10(7PM-8PM)	0.2	10(10PM-12PM)
0.34	11(8PM-10PM)		
0.29	12(10PM-12PM)		

2.4 Infiltration and outdoor air flow

The infiltration will be defined using **Space Infiltration Design Flow Rates**. In this object, the main inputs are shown in Eq. 1. According to the engineering experience, Constant Term Coefficient = 0, Temperature Term Coefficient = 0, **Velocity Term Coefficient = 0.224**, Velocity Squared Term Coefficient = 0 (adjusted to SI units). Apply the infiltration to all zones. Infiltration and airflow are very important parameters for high-resolution. Below is the reference.

The outdoor air flow is by mechanical ventilation. The building average **Design Specification Outdoor Air Flow** is **1.1/hour**.

$$\text{Infiltration} = (I_{design})(F_{schedule})\left[A + B\left|(T_{zone} - T_{odb})\right| + C(\text{WindSpeed}) + D(\text{Windspeed}^2)\right] \quad \text{Eq. 1}$$

Extra information about the infiltration.

https://bigladdersoftware.com/epx/docs/8-0/engineering-reference/page-048.html

https://bigladdersoftware.com/epx/docs/8-0/input-output-reference/page-018.html#zoneinfiltrationdesignflowrate

2.5 HVAC System

Use the Openstudio's HVAC template to design HVAC system for CSC.

- **Four boilers** for space heating and domestic hot water (two variable speed water pumps with two heating coils). The peak flow rate of domestic hot water is **15.7 gal/min**. The boilers' nominal thermal efficiency is **0.65**.
- **Two centrifugal chillers** for space cooling (two variable speed water pumps with two cooling coils) The chillers' reference COP is **4.0**.
- **Two cooling towers** for removing the heat from the chillers (two variable speed water pumps).
- **Two air handling units (AHUs)** with variable air volume systems (VAV) for air conditioning. AHU1 is for cooling the conference room (Lv2-3). AHU2 is for cooling the rest of the rooms.

The thermostat setpoints of each zone are listed as follows. All rooms **unoccupied** cooling setpoints are **80°F**, heating setpoints are **60°F** (during 10PM to 4AM).

- The cores are conditioned with dual cooling and heating setpoint. The cooling setpoint is **74°F** and the heating setpoint is **68°F**.
- The classrooms are conditioned with dual cooling and heating setpoint. The cooling setpoint is **72°F** and the heating setpoint is **70°F**.
- Offices are conditioned with dual cooling and heating setpoint. The cooling setpoint is **72°F** and the heating setpoint is **70°F**.
- Libs are conditioned with dual cooling and heating setpoint. The cooling setpoint is **72°F** and the heating setpoint is **70°F**.
- The conference room is conditioned with dual cooling and heating setpoint. The cooling setpoint is **74°F** and the heating setpoint is **68°F**.
- The plant room doesn't have cooling and heating setpoint.

The setpoints of the control of HVAC system.

- The hot water temperature is **153°F**.
- The cooling water temperature is **44.1°F**.
- The chilled water temperature is **89.6°F**.
- The supplied air temperature is deadband control, **50-80°F**.

Project Instruction:

Follow the instructions in this document and create EnergyPlus/OpenStudio model for CSC. Submit the finalized "IDF" file and "OSM" file.

Question to answer:

The facility managers of the UofU campus is considering retrofitting of this building

1. Propose two solutions to retrofit walls and windows, assess and explain the corresponding performance improvement associated with retrofitting.
2. Propose one solution to retrofit roofs, assess and explain the corresponding performance improvement associated with retrofitting.
3. Propose one solution to retrofit building systems, assess and explain the corresponding performance improvement.
4. Change the settings of HVAC operation, including both temperature setpoint in summer/winter as well as occupied and non-occupied hours with temperature setback, how does the energy consumption of building change?

5. Propose one solution to retrofit lighting systems, assess and explain the corresponding performance improvement. (Note: for LED, you can use Fraction radiant=0.4, Fraction visible=0.3, Return Air fraction=0.1 as model specification)
6. How does a change of window-wall ratio influence the energy performance of the building? Assess and Explain.
7. Under the climate of Utah, which do you think will be the most effective retrofitting strategy you recommend to facility managers? (consider investment return)
8. What if this building is placed in the climate zone of 1A, how would you expect the performance of proposed retrofitting measures to change? What else retrofitting strategy will you propose (mention at least one different strategy compared to what you have proposed)? Explain your answers.

Note: (1) Please differentiate/zoom into heating/cooling seasons for analysis of proposed retrofitting measures, (2) The analysis of retrofitting measures should be divided into building heating load, cooling load, total electricity, and total gas usage, (3) Just presenting the simulation results are not sufficient, please explain your answers/reasonings as well.