Chapter 3
Defining Energy Uses and Spaces

3.1 Energy Uses and Thermal Loads

In Chap. 2 we defined the building envelope, the ambient weather conditions it is exposed to, and the interior Spaces that a building is subdivided into. Of course, the activities that take place in those Spaces are significant drivers for energy consumption as well as the reason buildings exist in the first place. In this Chapter, we will gain a better understanding of how Space occupancy and energy end uses are defined by OpenStudio. As with Constructions, the amount of data required to fully specify Space loads is significant, and we will come to appreciate how OpenStudio Libraries and data inheritance make this process both fast and consistent.

Building end uses may consume energy directly as is the case with lighting, electric, and gas Equipment; however, these end uses may also add heat to the Spaces in which they are contained. This heat may impact the heating or cooling energy, which must be provided by the building's HVAC systems. Modeling these types of interactions is an important feature of whole building energy simulation. Another significant source of thermal loading within Spaces are the occupants themselves; people contribute both sensible and latent heat through physical activity, perspiration, and respiration. Infiltration, unconditioned air that leaks into Space, is also considered a load that will be discussed in this Chapter. Lastly, while they don't generate heat or consume energy explicitly, we will also consider the role that the thermal mass of inanimate objects within Spaces plays in storing and releasing thermal energy.

It is important to note that Space loads are a strong function of occupant behavior. As such, this step in building energy modeling is arguably the most subjective and error prone part of the process. Whereas the thermal properties of

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an insulation material may be well known and accurately modeled, how can one model the actions of building occupant with certainty? Does an occupant show up within a Space for the same period of time each day, and how many are there? Can we predict the level of physical activity an occupant undertakes? How will the occupant operate lights and other equipment? These are only a few factors that drive uncertainty in an analytical process that requires unambiguous numerical input of occupant behavior for 8760 h of each simulated year.

Before you give up and throw this book in the rubbish bin, consider a few key points:

1. As mentioned in Chap. 1, comparative analysis is one of the most important capabilities offered by building energy modeling. As long as occupant behavior is held constant across simulations, uncertainty in occupant behavior will lead to systematic error, which in general, does not invalidate comparisons between multiple energy simulations. The energy impact of changes in occupant behavior can also be modelled as long as the assumptions behind changing the simulation input are well understood.
2. Guidelines like ASHRAE Standard 90.1, ASHRAE Standard 189.1, and California's Title 24 compliance modeling approach are prescriptive about many inputs for energy modeling including Space load assumptions. These guidelines have been informed by surveys like RECS (Residential Energy Consumption Survey), CBECS (Commercial Building Energy Consumption Survey), and CEUS (California End Use Survey) that provide some insight into how different building types are most frequently used. Use of prescriptive input sets is certainly no guarantee that modeled and as-operated energy performance will agree for a specific building, but it does improve consistency in the modeling process.
3. Unlike the previous generation of BEM tools, parametric analysis of multiple OpenStudio simulations (discussed in Chap. 7) enables us to perform Monte Carlo sampling over uncertain inputs. Adopting statistical methods allows the analyst to evaluate distributions of expected performance, which frankly is a more responsible approach than reporting a single, expected savings number to a stakeholder.
4. For existing buildings, calibration (tuning) of building models against measured consumption data is a recommended option to reduce uncertainty in key inputs. OpenStudio makes the calibration process for existing buildings relatively easy.

This Chapter focuses on modeling with standardized inputs (item 2 above) in order to create more consistent modeling outcomes. The approaches suggested in bullet points 3 and 4 will be key topics that we shall revisit in Chap. 7.

3.2 Space Types

Just as Construction Sets are comprised of Constructions, which are in turn comprised of Materials, OpenStudio defines Space Types in terms of smaller building blocks that may be assembled flexibly to describe a variety of programmatic activities. In general, OpenStudio Space Types are defined by a set of thermal loads and

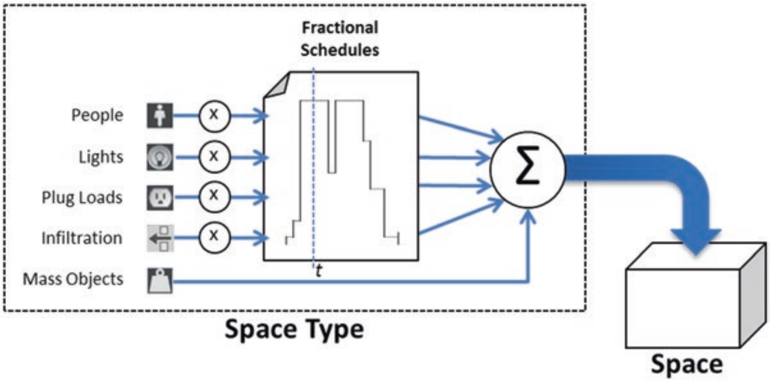


Fig. 3.1 OpenStudio Space Type conceptually applied to a Space

schedules. In aggregate, these loads consume energy and add heat to a Space as a function of time as shown in Fig. 3.1.

Space Types make it easy to define representative loads and schedules once, in order to apply them quickly and consistently across Spaces with similar activities. A Space Type may apply to a single Space within a building, or it may be applied to multiple Spaces if similar activities take place within them. As with Construction Sets, Space Types may also be imported from other OSMs to speed up the modeling process even further.

3.2.1 Schedules

As we have established, individual loads within Spaces are most often a strong function of occupancy, which usually varies with the time of day and day of the week. In terms of modeling approach, this means that we will need to capture occupant, lighting, and equipment schedules if we are to reasonably describe energy uses and their associated thermal loads. The Schedules ( ) Tab in the OpenStudio Application shown in Fig. 3.2 is used for this purpose. New Schedule Sets may be created with the Button, the Button is used to duplicate Sets for editing, and the Button deletes Sets. The Button "purges" unused Schedule Sets from your Model and is useful for tidying up occasionally.

The Schedules ( ) Tab consists of two Sub-Tabs. The Schedule Sets Sub-Tab is used to define collections of Schedules that apply generally to a Space Type. The illustrated example contains Schedule Sets for office break and conference rooms, lobby and open office space. Each Schedule Set may include any or all of the ten categories shown. Individual schedules within a Set may be distinct or duplicative. For example, Occupancy, Lighting, and Electric Equipment Schedules might be the same in an office with staff who diligently turn off lights and equipment whenever they leave a Space. However, different schedules might be used to indicate that occupants leave some lights and equipment on when they leave for lunch.

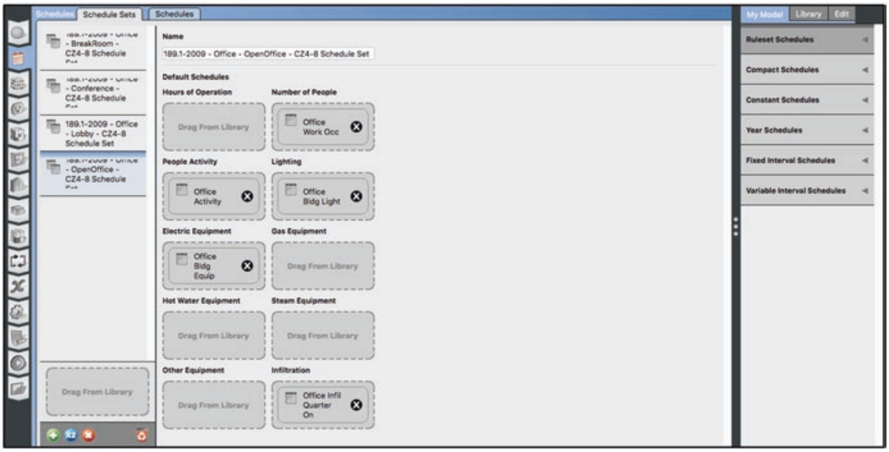


Fig. 3.2 Schedule Set for an Office Break Room

The right-hand pane lists the six types of Schedules that OpenStudio supports. Compact, Constant and Year Schedules are identical to the EnergyPlus objects documented online.[1] Fixed and Variable Interval Schedules are used to capture schedules from actual recorded data, these are similar to the Schedule:File Object in EnergyPlus but the data is contained in the OSM rather than an external Comma Separated Value (CSV) file. The final OpenStudio Schedule is the Ruleset Schedule. This Object is unique to OpenStudio and is automatically converted into a Year Schedule for use by EnergyPlus prior to simulation.

Ruleset Schedules are created and edited in the Sub-Tab as shown in Figs. 3.3 and 3.4. These particular schedules are “fractional,” meaning they vary from 0 to 1 and are used as multipliers on the maximum expected occupancy in a Space to create a time varying number of people. Similar Schedules are used to modulate the total power consumed by lighting, electric Equipment, etc. The Schedule Editor enables visual editing of a variety of schedules and will be discussed in Sect. 3.4.

3.2.2 *Load Definitions*

Space Load definitions are entered using the Loads ( ) Tab, and fall into a number of categories including lighting, miscellaneous electric,[2] gas, steam, and other fuel Equipment, people, and hot water uses. Space load definitions describe a particular type of load. We will use Space load instances in Sects. 3.2.3 and 3.3 to actually assign loads of these types to Space Types and Spaces. Lighting loads may include

[1] http://bigladdersoftware.com/epx/docs/8-7/input-output-reference/group-schedules.html#group-schedules.

[2] Pieces of Miscellaneous Electric Equipment are sometimes referred to as “MELs” or Plug Loads.

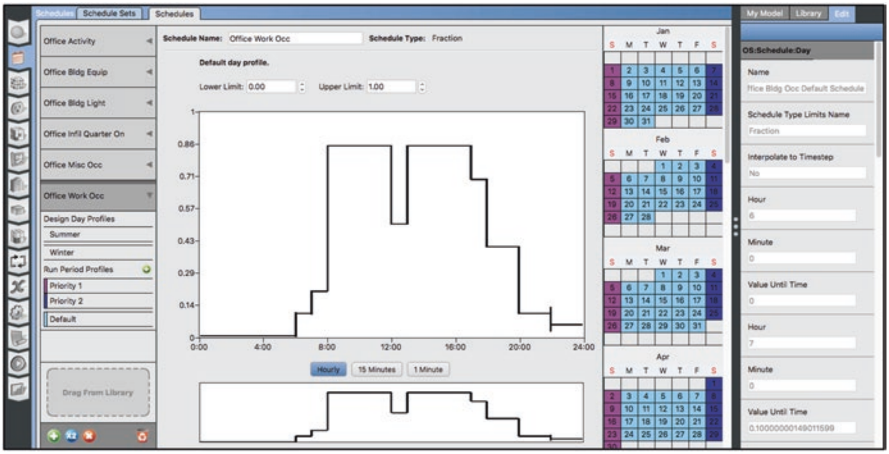


Fig. 3.3 An office Ruleset Schedule defined for workdays

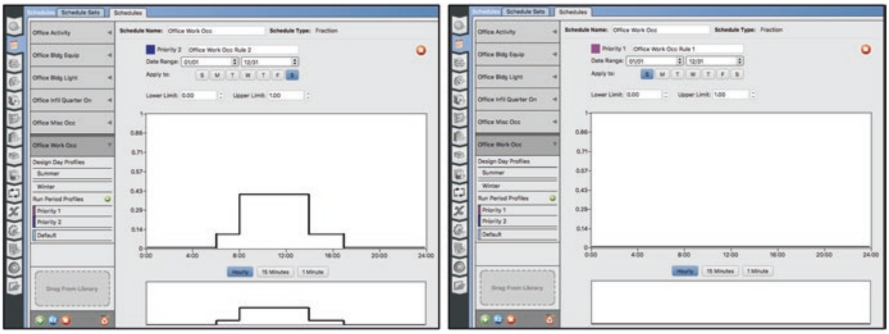


Fig. 3.4 An office Ruleset Schedule defined for Saturdays, and Sundays

individual table or desk lamps, arrays of linear fluorescent tubes, emergency exit lights, high intensity discharge (HID) lamps in high bay installations, and many more. Copy machines, coffee pots, microwave ovens, simple refrigerators, laptops, televisions, video game consoles, hair dryers, etc. are all examples of electric plug loads. Common gas loads include ovens or cook tops. In OpenStudio, occupants, infiltration, and internal mass objects are grouped along with these loads but are special cases and will be discussed in subsequent sections. Like most of the Application Tabs, use the , , , and Buttons to create, duplicate, delete, and purge Loads.

Depending upon use, available data, etc. the power consumed by most loads is typically entered in OpenStudio in one of three ways:

- Rated power consumed by an individual unit (e.g. single laptop or television) within a Space,
- Rated power consumed per unit of floor area in a Space, or
- Rated power consumed per occupant within a Space.

3.2.2.1 Lights and Luminaires

EnergyPlus does not simulate the distribution of electric lights, nor can it be used to verify that a given lighting design provides sufficient illumination. During an EnergyPlus simulation, the electric energy used by lights and luminaires is accounted for as well as the thermal impact of this energy use on the surrounding Space. EnergyPlus does account for the use of daylighting controls to offset energy used by electric lighting, which will be discussed in Chap. 8. Figure 3.5 shows a typical lighting load entered in units of watts per square foot. This is frequently referred to as Lighting Power Density (LPD) and is a common way of characterizing loads such as linear fluorescent lighting that covers a large area; especially when detailed information about the lighting design is not available.

By comparison, individual desk lamps might be best represented in terms of watts per person. If a detailed audit has determined the exact number of lighting fixtures of a particular type, then lighting may be specified in terms of the rated power consumed by an individual unit. In all cases, a multiplier is applied to the space load instance to describe the number of units present in the Space Type or Space. Regardless of how the load is characterized, individual loads are subsequently multiplied by an associated

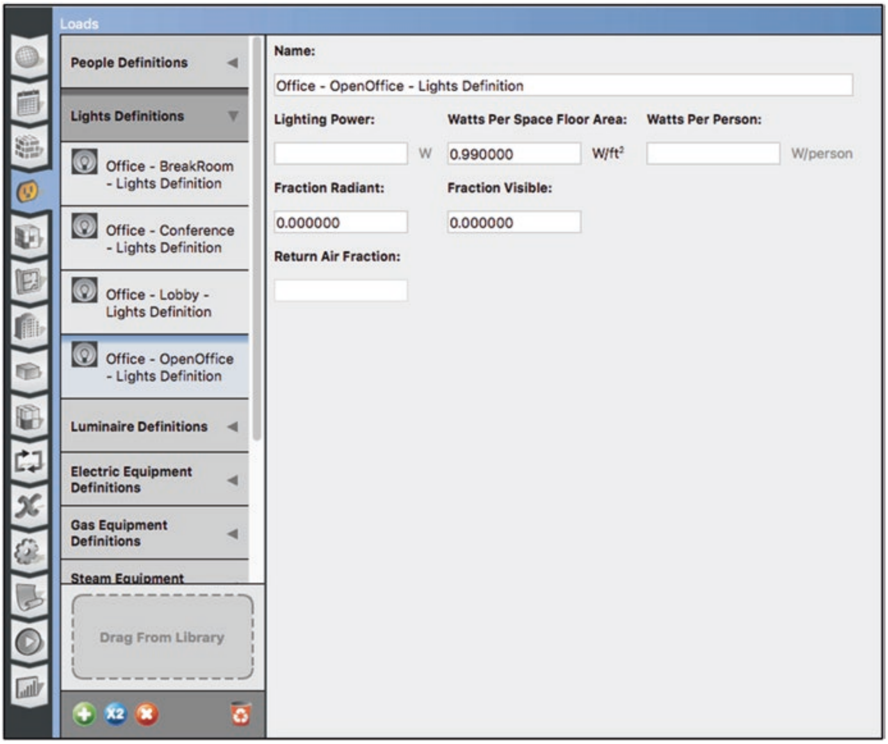


Fig. 3.5 Lighting Power Density defined for an Open Office Space Type

fractional schedule as described in the previous section. This enables us to simulate the time varying nature of power consumption with the added flexibility of separating the magnitude of loads from how frequently they are used. For lighting, all energy used by the fixture is rejected to the environment (there is no useful mechanical work done and very little energy storage). The mechanisms for heat transfer from Lights and Luminaires are:

- **Fraction Radiant** – portion of energy radiated to the Space's Surfaces as long-wave radiation,
- **Fraction Visible** – portion of energy radiated to the Space's Surfaces as short-wave radiation,
- **Return Air Fraction** – portion of energy rejected to air leaving the space to an air handler, and
- **Fraction Convected** – portion of energy rejected to the Space's air volume.

The fraction convected is not entered directly, rather it is calculated from:

$$f_{convected} = 1 - f_{radiant} - f_{visible} - f_{return\,air}$$

The EnergyPlus Input Output Reference has typical values for these fractional energy factors for different lighting categories under the section for Lights.

Luminaires do not exist as EnergyPlus Objects, and they are a unique to OpenStudio's Object Model. Luminaires are meant to represent individual lighting fixtures and are specified in terms of lighting power per unit. Luminaires also have the ability to be positioned within a Space. This is meant to support simulation of the distribution of electric lighting via Radiance in future versions of OpenStudio.

Like Materials, Constructions, and Construction Sets; Light and Luminaire definitions may also be imported to the current Model from an external Library. Load definitions obtained via Library import contain pre-populated power and heat rejection values, however the modeler should always consider the appropriateness of these values for the specific application. The reader is referred to sources such as the ASHRAE Fundamentals Handbook[3] or The Lighting Handbook published by the Illuminating Engineering Society (IES), as well as manufacturer data sheets for input values DiLaura et al. (2011).

3.2.2.2 Electric, Gas, Steam, and Other Equipment Loads

Similar to lighting, EnergyPlus does not represent individual electric, gas, steam, or other Equipment within Spaces. Most people would be concerned if their favorite video game console was replaced by a toaster. However, to EnergyPlus, these are simply devices that consume electricity and reject heat into the Space. The only way that EnergyPlus differentiates between a blender and an electric kettle is by the maximum power draw, schedule of operation, and the mechanisms of heat transfer

[3] ASHRAE (2013).

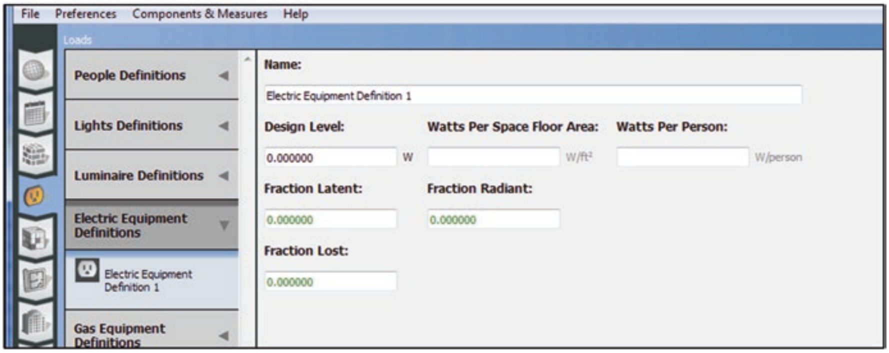


Fig. 3.6 Example of an Electric Equipment Load

into the Space. Like Lights, Equipment may be quantified by power per unit, floor area, or person (Fig. 3.6). However, unlike Lights, Equipment may consume different types of fuel (e.g. electricity, gas, steam, or other). Each fuel type is accounted for separately in the simulation results.

Note that EnergyPlus allows for a Hot Water Equipment Object. This Object is included in the OpenStudio SDK but has been deprecated from the OpenStudio Application in preference to the more flexible Water Use Equipment Object discussed later. Gas Equipment allows the user to specify a carbon dioxide generation rate for air contaminant studies, this is an advanced topic beyond the scope of this text. Other Equipment allows the user to select from less common fuel types – e.g. propane, fuel oil, etc. The mechanisms of heat transfer allowed for Equipment objects are:

- **Fraction Latent** – portion of energy added to the Space's air volume as moisture;
- **Fraction Radiant** – portion of energy radiated to the Space's Surfaces as long-wave radiation;
- **Fraction Lost** – portion of energy that does not impact the Space's heat balance, by performing useful mechanical work or via rejection outside of the Space; and
- **Fraction Convected** – portion of energy rejected to the Space's air volume.

Fraction Convected is not entered directly and is calculated according to:

$$f_{convected} = 1 - f_{latent} - f_{radiant} - f_{lost}$$

3.2.2.3 People

People represent very significant thermal loads in Spaces but are treated a bit differently than lights or Equipment. Like other Loads, occupancy may be characterized by the number of people present within a Space, or in terms of occupant density as

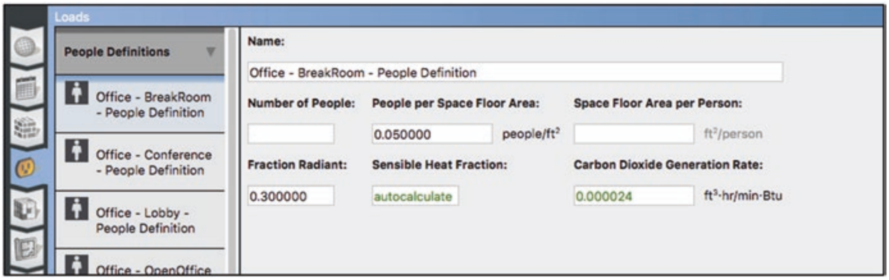


Fig. 3.7 People definition for an Office Break Room Space Type

shown in Fig. 3.7. People are also described by a fraction of radiant energy they contribute to a space. The remainder of the heat they reject is split between sensible and latent heat addition. EnergyPlus is able to automatically calculate the split between sensible and latent heat gain from occupants based on typical metabolic rates given the level of heat rejection. Astute readers may note that there is no field to enter the "rated" power of a human in this window, so how does EnergyPlus know how much heat each person is rejecting to use along with the fractional occupancy Schedules?

Human power consumption is represented by an additional activity Schedule to better reflect the time varying nature of human activity. Figure 3.8 illustrates a typical activity Schedule for a medium office in the Schedules ( ) Tab. In practice, activity Schedules are often entered as constant values, as shown in this example, to reflect that the type of activity in the space is constant while the number of occupants vary according to the occupancy schedule. However, the software allows for the Modeler to capture a half-hour of calisthenics or naptime, depending upon the culture prevalent in a building, independent of the occupancy schedule. Table 3.1 contains typical power consumption estimates for a range of adult activity.

Additional activity values may be found in the Energy Plus Input Output guide.[4]

3.2.2.4 Water Use Equipment

Water Use Equipment represents uses of water within a Space used for showers, cooking, washing, etc. Water Use Equipment is defined in terms of a peak flow rate, which is modulated by a fractional schedule. A Temperature Schedule dictates the temperature of the water. The data entry form for a piece of Water Use Equipment is shown in Fig. 3.9.

The method of accounting for water heating energy depends upon whether or not heating Equipment has been installed elsewhere in the building Model, as will be discussed in Chaps. 4 and 5. If heating Equipment has been specified, then the target

[4] http://bigladdersoftware.com/epx/docs/8-7/input-output-reference/group-internal-gains-people-lights-other.html#field-activity-level-schedule-name.

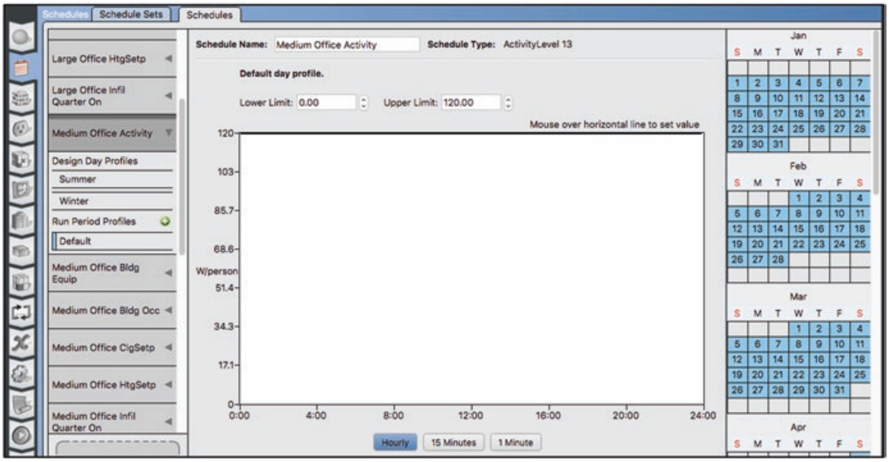


Fig. 3.8 Occupant activity Schedule for an office

Table 3.1 Typical power consumption associated with various activities (ASHRAE 2013, Table 1, p. 18.4.)

Activity	Average Power Consumption (W)
Sitting	97
Moderate office work	130
Light factory work	220
Heavy factory work	425
Exercise	586

temperature is achieved by mixing hot and cold water at the fixture. If the Water Use Equipment has not been connected to a heating system in the simulation, then it is simply provided at the requested temperature and the energy required to heat mains water to the given temperature is not tracked.

In either case, the water consumption is accounted for in the simulation along with any heat rejected to the Space. The mechanisms for heat transfer to the Space are sensible heat addition as well as latent moisture addition, any remaining heat is assumed to be convected out of the space down the drain. For maximum flexibility, the fraction of energy rejected to the Space in sensible and latent form are specified by a schedule rather than a fixed value. Water use Equipment will be discussed further in Chap. 5.

3.2.2.5 Infiltration

Infiltration is unconditioned outdoor air that enters a space from the outside through gaps in the envelope, doors or windows that are periodically opened. Design Specification Outdoor Air is unconditioned, fresh outdoor air intentionally brought into the building for occupant health. Because infiltration and design specification

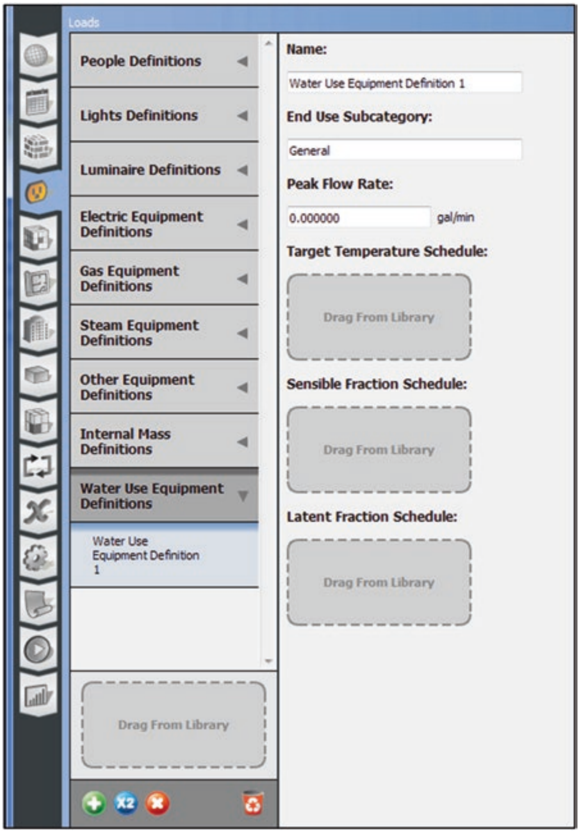


Fig. 3.9 Example water use equipment definition

outdoor air increase or decrease heat and humidity in a Space, they are considered a thermal Load that must be actively managed by HVAC systems. Unlike other Loads, infiltration is defined directly in the Space Types (▣) Tab as shown in Fig. 3.10.

Note that in each of the four Space Types shown in the above example that three types of infiltration Objects may be included:

- Design Specification Outdoor Air,
- Space Infiltration Design Flow Rates, and
- Space Infiltration Effective Leakage Area.

The first is associated with ASHRAE Standards 62.1 and 62.2, which prescribes minimum outdoor ventilation rates for occupant health and comfort and will be discussed further in Chaps. 4 and 5. The latter two Objects represent different models for unintended air infiltration. Modelers will most often select only one of these last two Objects to represent Space infiltration. Figure 3.11 shows some of the input arguments for the Design Flow Rate method of calculation.

Figure 3.12 illustrates selection of the Effective Leakage Area Object from the Library after dragging and dropping it onto a Space Type. Note that dragging infiltration

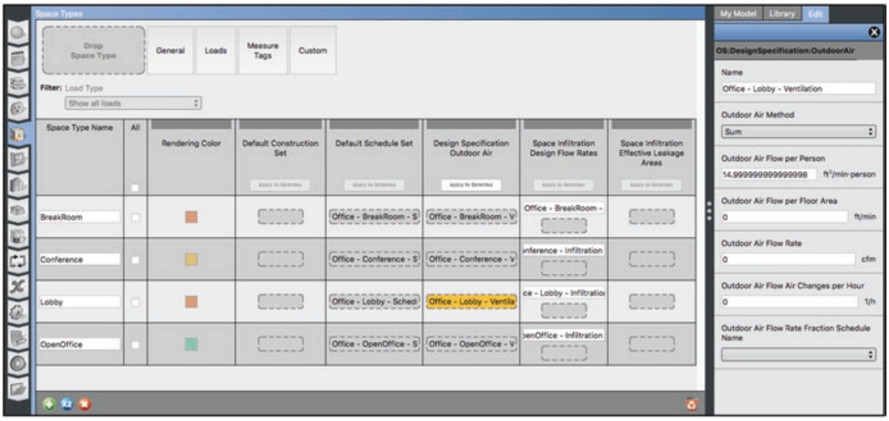


Fig. 3.10 Outdoor air ventilation for an Office Lobby Space Type

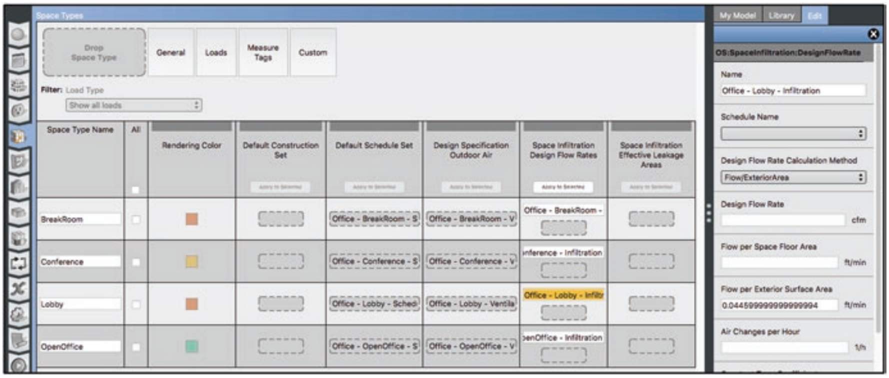


Fig. 3.11 Infiltration Flow Rate for an Office Lobby Space Type

objects in from the library is the only way to create infiltration and design application outdoor air objects in the OpenStudio Application. The reader is directed to the EnergyPlus Input Output Reference Guide for more information on these Objects[5] and appropriate selection of input parameters.

3.2.3 Building a Space Type

The previous three Figures were our first introduction to OpenStudio's Space Type ( ) Tab. The "General" view allows the user to drag Space Types in from a Library, as well as to create, duplicate, delete, or purge Space Types with the appropriate

[5] http://bigladdersoftware.com/epx/docs/8-0/input-output-reference/page-018.html#group-airflow.

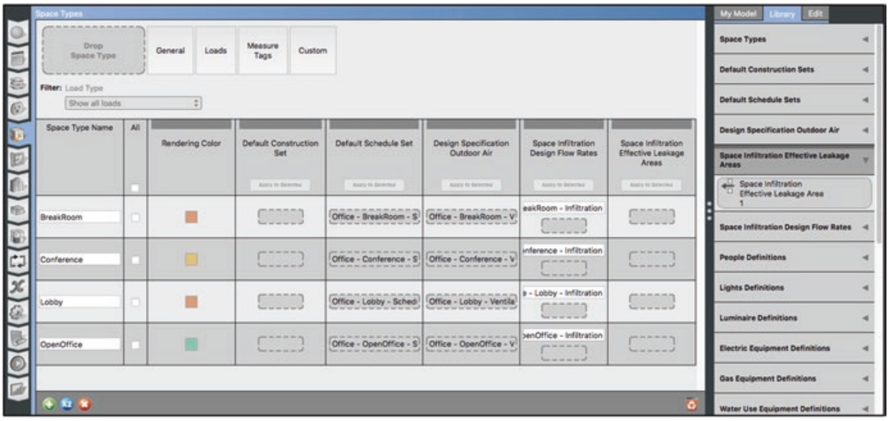


Fig. 3.12 Adding an Infiltration Effective Leakage Area Object

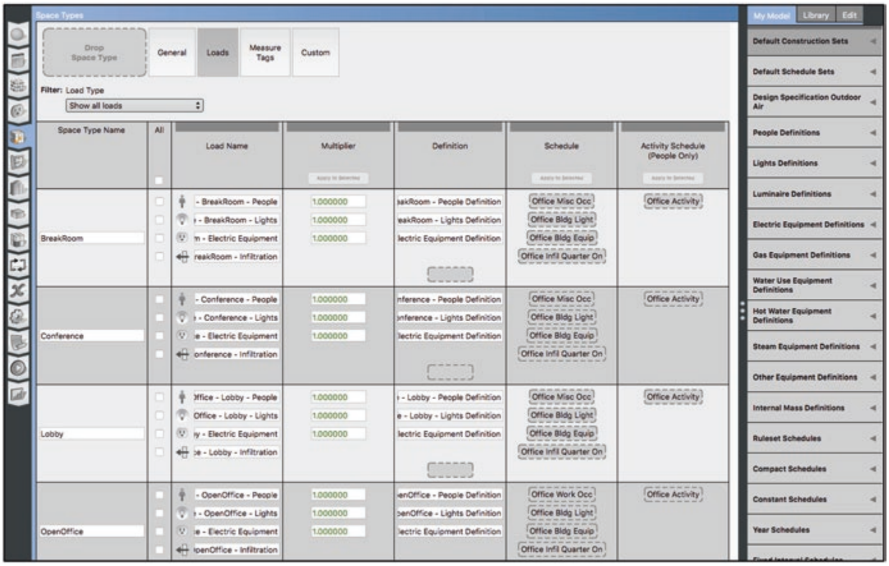


Fig. 3.13 Adding loads to define four office Space Types

Button. This first view allows the user to assign custom colors, Construction Sets, Schedule Sets, and infiltration Objects that will be used whenever the Space Type is assigned to a Space. Note that in Fig. 3.12 no Construction Set has been assigned to any of the Space Types. Recall from the previous Chapter that in the absence of a specific Construction Set definition, OpenStudio will look to the Object's parent (in this case the Building Story) for guidance.

Clicking on the Loads Button at the top of the window switches to a breakdown of Loads within each Space Type as shown in Fig. 3.13. Infiltration will show up automatically, and additional Load Instances may be added by dragging Load Definitions from the right hand into the "Definition" column. Schedules are automatically assigned based on the Schedule Set but can be overridden if needed. Space Type and Load Names may be customized based on the modeler's preference. Lastly, Load Multipliers may be specified for Objects that were defined using individual rated power values (e.g. a multiplier of 10 might apply to the number of computers in a Space).

3.3 Spaces

With Schedules, Loads, and Space Types defined, it's time to assign Space Types to specific activity areas within the building. In the previous Chapter, we used the floor plan editor in the Geometry ( ) Tab to create Spaces. As we with Thermal Zones in Sect. 2.8.7, the Assignments Sub-Tab of the floor plan editor may be used to assign Space Types to Spaces within a model as shown in Fig. 3.14.

The Spaces ( ) Tab shown in Fig. 3.15 may also be used to assign Space Types. At first glance, this Tab may seem superfluous given that the floor plan editor provides similar functionality along with the convenience of being able to visualize the Space locations within the floor plan. However, the Spaces Sub-Tabs allows us to edit multiple Spaces on each Floor simultaneously, while providing added functionality and a greater level of control in defining Space contents.

Figure 3.16 shows the Loads Sub-Tab being used to inspect the Loads within each Space. A quick comparison with the original Space Type definitions in Fig. 3.13

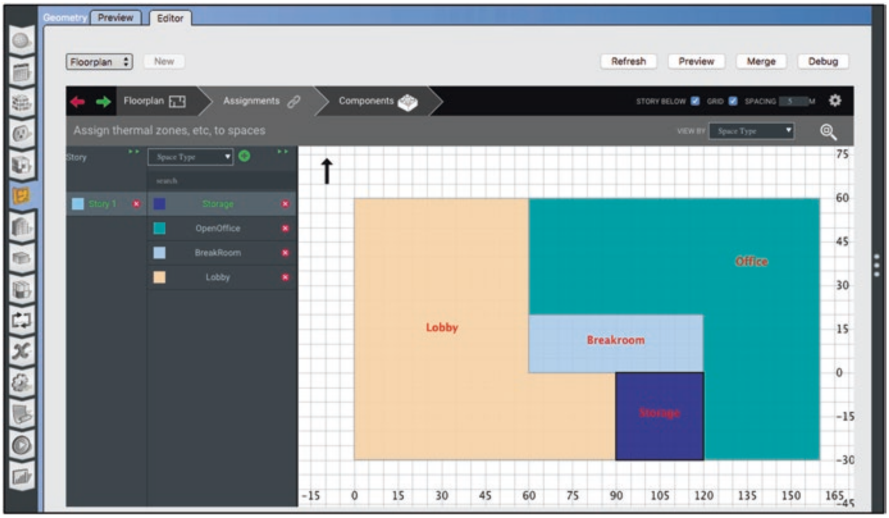


Fig. 3.14 Assigning Space Types using the Geometry editor

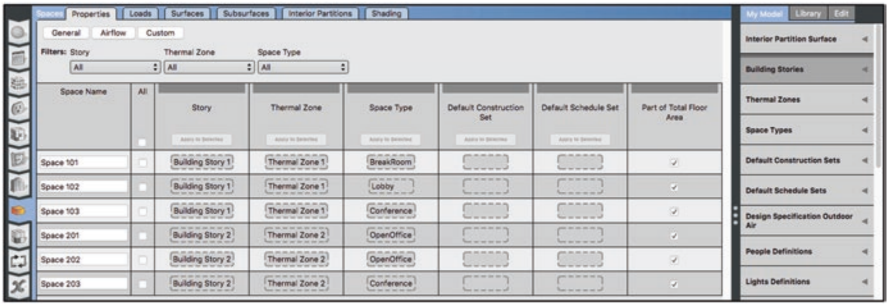


Fig. 3.15 Space assignment Sub-Tab

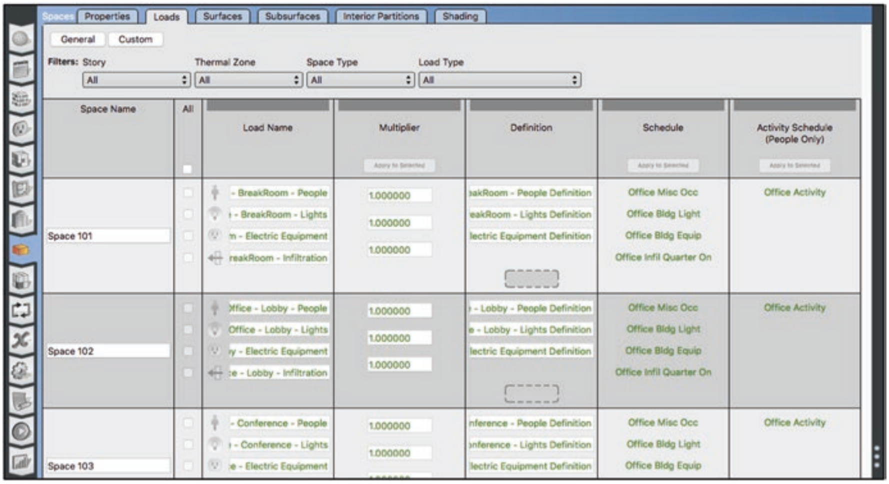


Fig. 3.16 Space load assignments defaulted from Space Type definition

confirms that the loads prescribed by each Space Type were applied correctly. One subtle distinction between these two views is the text color. The text in the Space Type definitions is black, whereas the text in the actual Spaces is green. This is OpenStudio's visual cue that data is being inherited and is used throughout the Application. This particular Sub-Tab allows the user to drag in additional loads that will show up in black text, which may be unique to an individual Space that is otherwise well described by a Space Type. By the same token, checkboxes next to inherited rows may be used to select individual Loads for deletion with the Button. Like Construction Sets, Space Types allow the user to quickly assign activities and loads from manually assembled definitions or Libraries, but they are not restrictive, and Spaces may be customized when necessary.

The Surfaces and Subsurfaces Sub-Tabs shown in Figs. 3.17 and 3.18 also illustrate the data inheritance concept with Construction Sets. In this case, appropriate Constructions have been applied to each Surface and Sub-Surface based on the

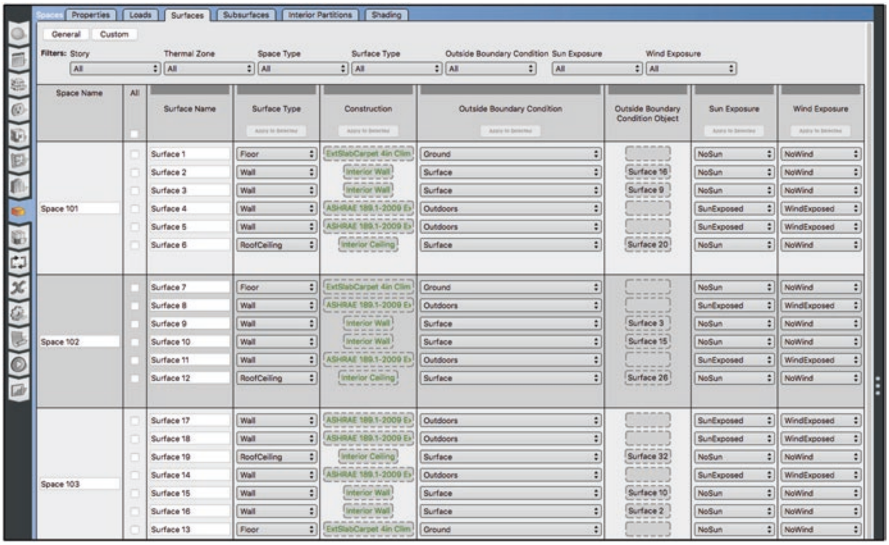


Fig. 3.17 Space Surfaces Sub-Tab with defaulted Construction Set

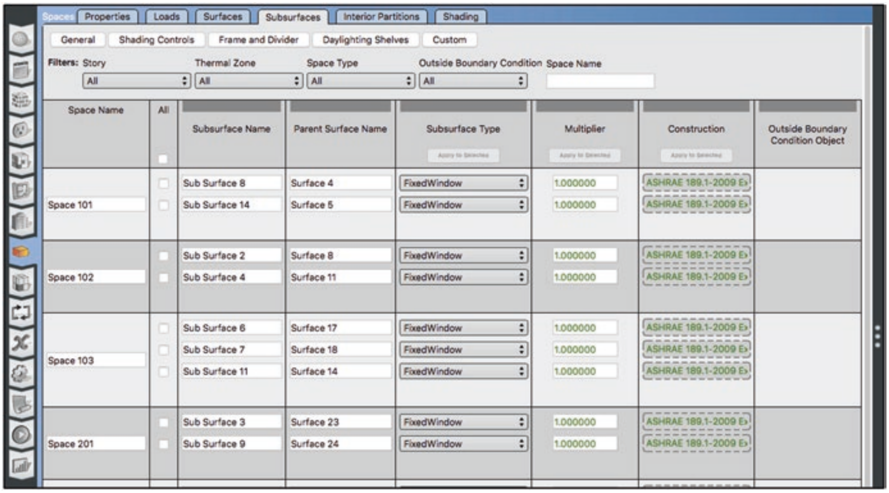


Fig. 3.18 Space Sub-Surfaces Sub-Tab

Surface Type. Unique Constructions may be dragged in to replace inherited Constructions when required.

One type of Load that was briefly mentioned earlier in the Chapter is an "Internal Mass Object." These Objects may be added to Space Types like other Loads as shown in Fig. 3.19. Internal Mass Objects don't consume energy or radiate heat in the same sense as other Objects like people or Equipment, nor do they have associated Schedules. Instead, the Objects add thermal capacitance to the spaces they

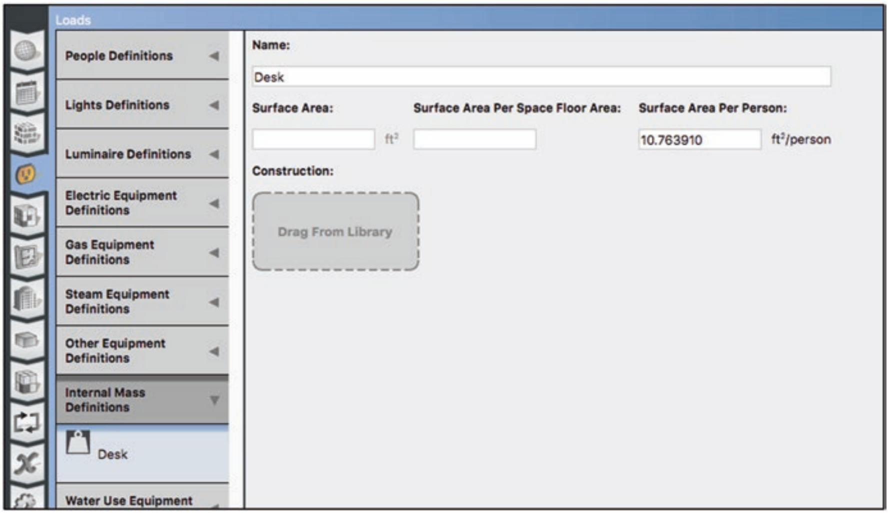


Fig. 3.19 Defining an Internal Mass Object for a Space

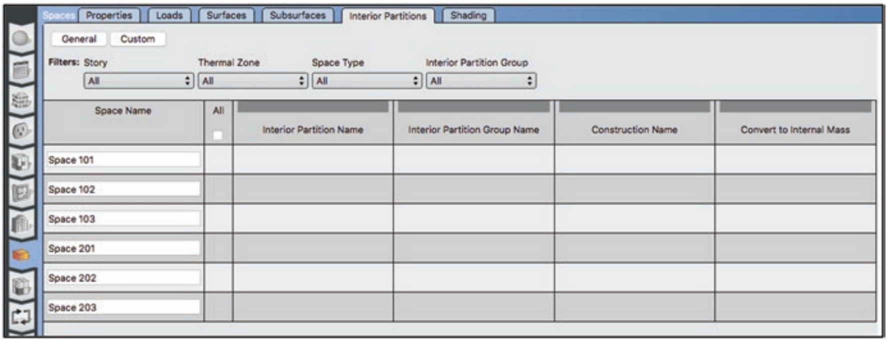


Fig. 3.20 Interior partitions Sub-Tab

occupy; that is, they store and release heat, adding to the dynamic behavior of the Space. The Object's Construction and surface area dictate this behavior. Internal Mass Objects can provide a very significant effect in Spaces used for storage (e.g. warehouses with heavily laden shelves).

We mention Internal Mass Objects here because they are closely connected with the  Sub-Tab shown in Fig. 3.20. Interior Partitions are Surfaces that exist within a Space to represent furniture, or other objects. Interior Partitions are included in detailed renderings using Radiance but do not define boundaries between Spaces or with the exterior environment. However, they may act as Internal Mass Objects, storing and releasing heat within a Space. Interior Partitions will generally be specified along with the Space geometry with an associated Construction. Checking the "Convert to Internal Mass" column tells OpenStudio to include it as part of the overall thermal mass within the Space.

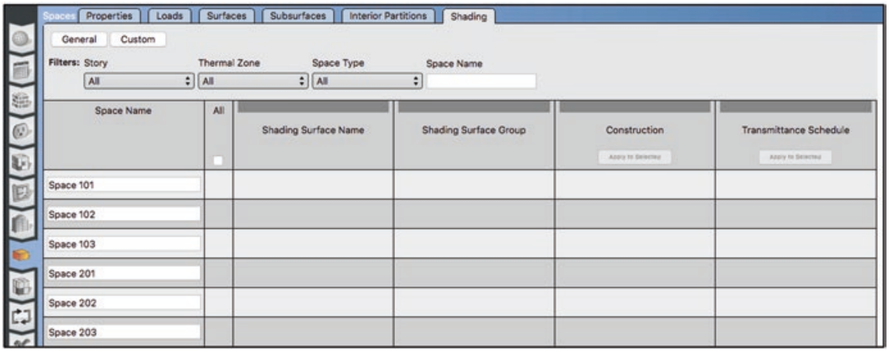


Fig. 3.21 Shading Surfaces Sub-Tab

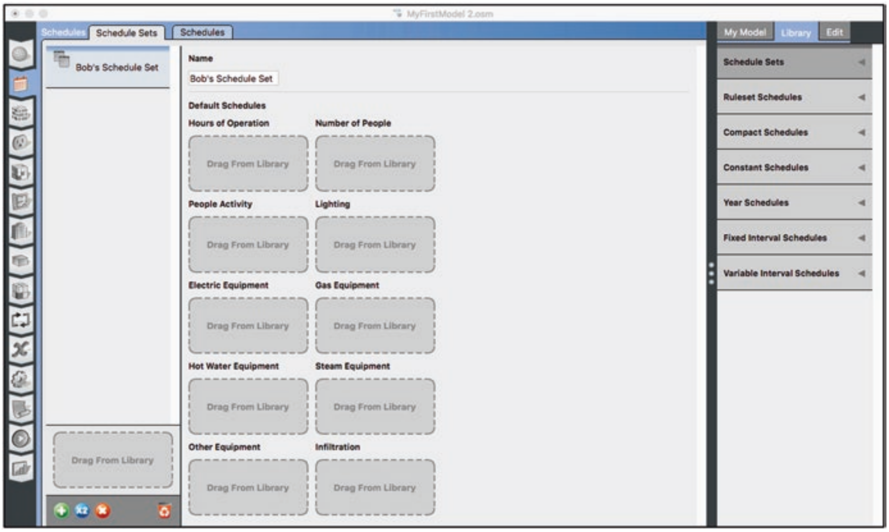


Fig. 3.22 Creating a new Schedule Set

The last Sub-Tab associated with Spaces is Shading, shown in Fig. 3.21. The significance of Shading Surfaces as it relates to solar radiation exposure and daylight availability will be discussed in Chap. 8.

3.4 Checkpoint Three: Ideal Air Load Simulation of a Small Model

Now it's time to revisit the first Model we built in Checkpoint One. Recall when we last worked with that Model; it was a simple box comprised of a single Space and Thermal Zone with no Space Type definition and no HVAC system. The Space temperature was strictly a function of ambient heat transfer through the envelope. In this exercise, we will define a Space Type around a single unfortunate occupant named "Bob" who is forced to use the small, unconditioned building as his office. If we're feeling generous, perhaps we'll try to provide some rudimentary air conditioning for him as well. Open up the last saved version of that Model, and let's get to work.

3.4.1 Creating a Schedule Set

Open the Model and create a new Schedule Set named "Bob's Schedule Set" with the Button in the Schedules () Tab as shown in Fig. 3.22. Leave it blank for the moment and proceed to the Sub-Tab.

Use the Button to create new Ruleset Schedules. A dialog pops up allowing the user to select the type of Schedule as shown in Fig. 3.23. Create the schedules listed in Table 3.2.

Now we need to edit the Schedules themselves. Select one of the Schedule Objects and note that each allows the user to specify Summer and Winter design day profiles and a Default Run Period Profile. Ignore the design day profile options and select the Default Run Period Profile that has a light blue band next to it. This activates a graphical interface for editing our Schedules as shown in Fig. 3.24. Recall from Sect. 3.2.2.3 that Activity Schedules like Bob's are often set as constant values throughout the year, relying on a fractional occupancy Schedule to modulate them. If you would like to make Bob lazier, click on the constant line and drag it down. You may also hover the mouse over the bar, type in a number and press enter to set a specific value. Let's leave Bob's Activity level at 100 W for the purpose of this exercise.

Having set Bob's typical energy consumption, we now need to specify a working schedule for his thermal torture chamber – aka office. Select Bob's Schedule to produce the Default Schedule shown in Fig. 3.25. The "tip list" and Fig. 3.26 will help you understand how the Schedule editor works.

Useful Schedule Editor Tips:

- Double clicking on horizontal lines splits them into multiple segments.
- Horizontal segments may be dragged up and down or set to a specific value by typing a number and pressing enter.
- Double clicking on vertical lines deletes segments.
- Vertical segments may be dragged back and forth.
- The Hourly, 15 min, and 1 min selectors at the bottom of the window allow for finer resolution along the time axis.

Notice that the light blue color band next to Default matches the color of each day on the calendar to the right of the window. This indicates that the Default schedule will be used 365 days of the year. We can allow Bob to take days off by specifying

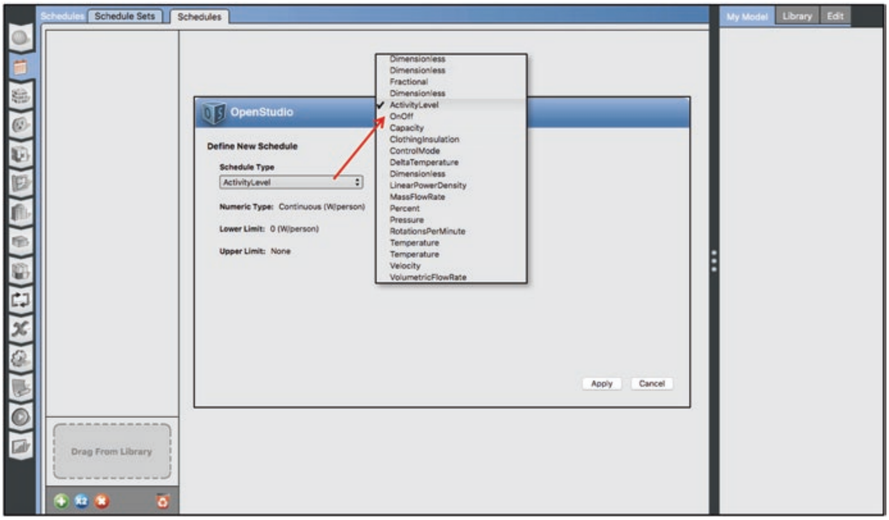


Fig. 3.23 Creating a new Ruleset Schedule

Table 3.2 Schedule Types and names for Checkpoint 3 exercise

Schedule Type	Name
Activity	Bob's activity
Fractional	Bob's schedule
Temperature	Heating thermostat
Temperature	Cooling thermostat

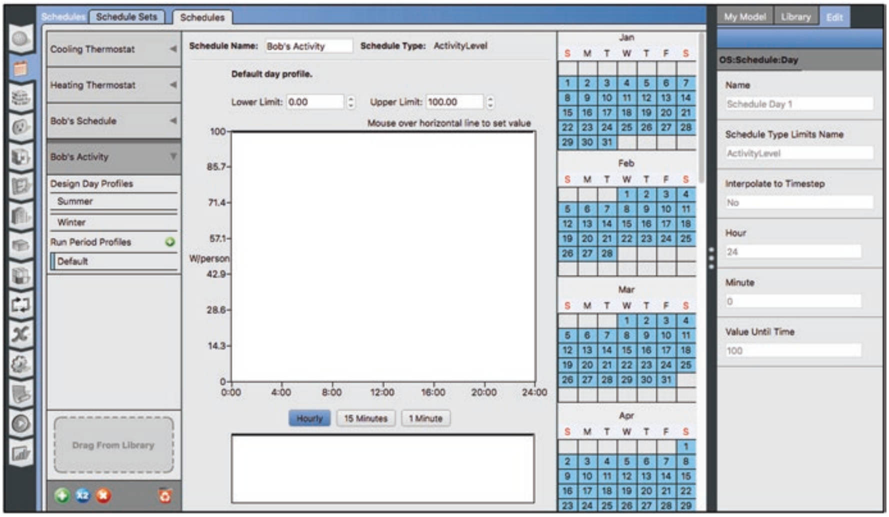


Fig. 3.24 Editing Bob's activity Schedule

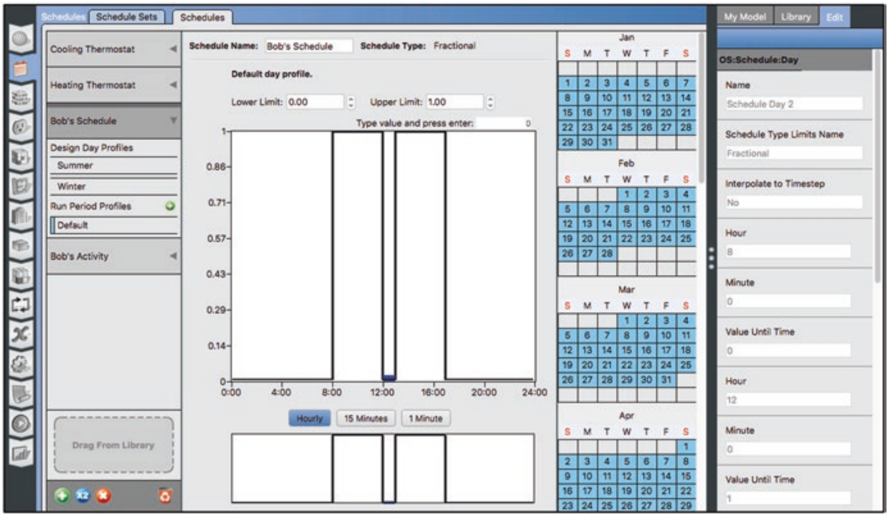


Fig. 3.25 Bob's default Occupancy Schedule

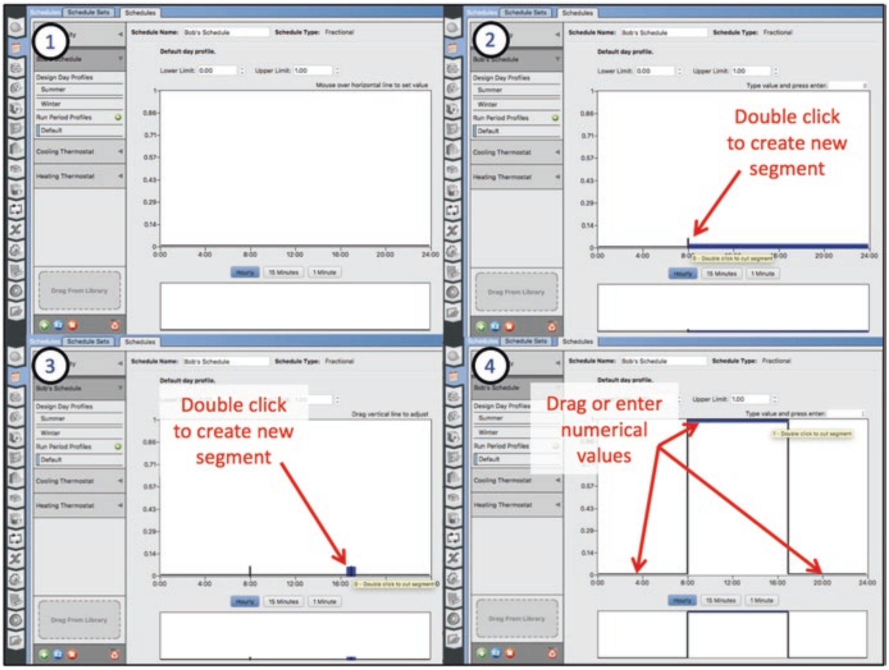


Fig. 3.26 Using the Schedule editor to create a Fractional Occupancy Schedule

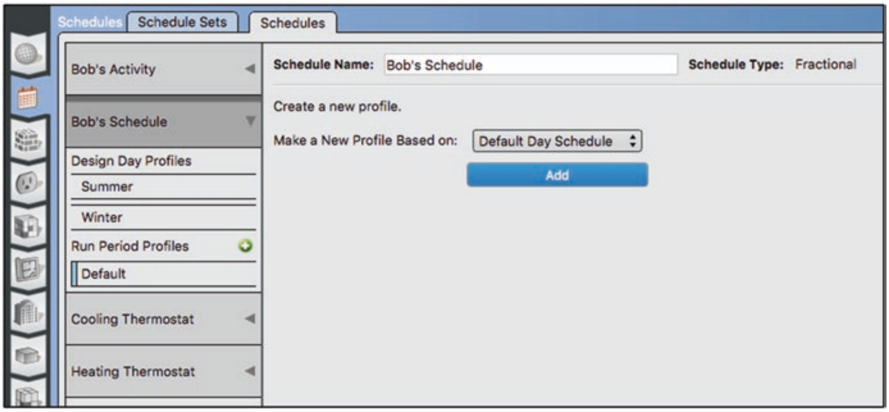


Fig. 3.27 Creating a new Run Period Profile in a Ruleset Schedule

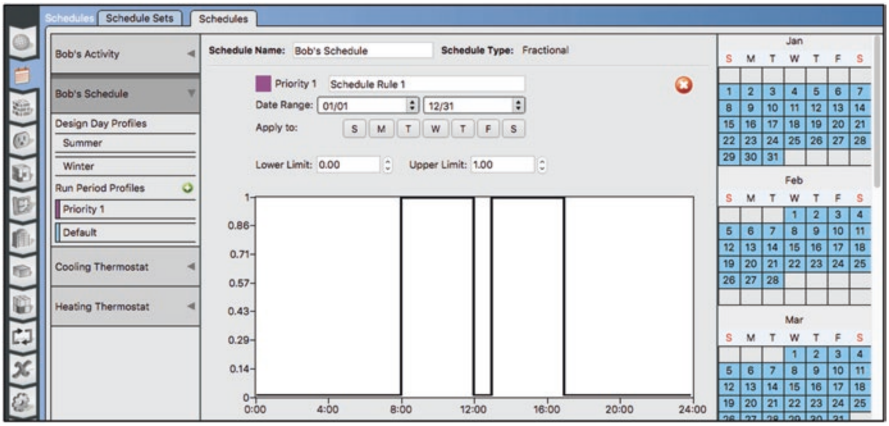


Fig. 3.28 A new profile for Bob's Schedule copied from the default Profile

additional Profiles and selection rules as part of the Ruleset Schedule. Click the small next to "Run Period Profiles" to add an additional Profile. We are given the option to create an entirely new Profile or copy from another Profile in the Ruleset Schedule as shown in Fig. 3.27. Figure 3.28 shows a second Profile that has been copied from the default Profile. Notice that our new Profile is called "Priority 1" and marked with a purple band. This Profile also includes a date range and Buttons corresponding to the days of the week that was not present in the Default Profile. Clicking on the Buttons corresponding to Saturday and Sunday and setting the schedule to a uniform 0 fraction leads to the Profile shown in Fig. 3.29.

Additional Profiles may be added with their own date ranges and days of the week to reflect holidays, cleaning crew occupancy, and more. Each new Profile is assigned its own priority number. The highest priority (lowest number) always wins

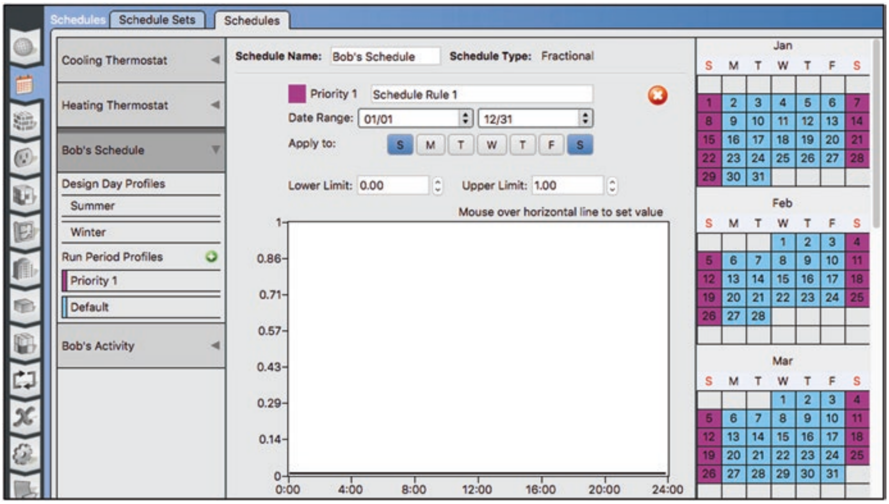


Fig. 3.29 A higher priority Ruleset Schedule profile for weekends

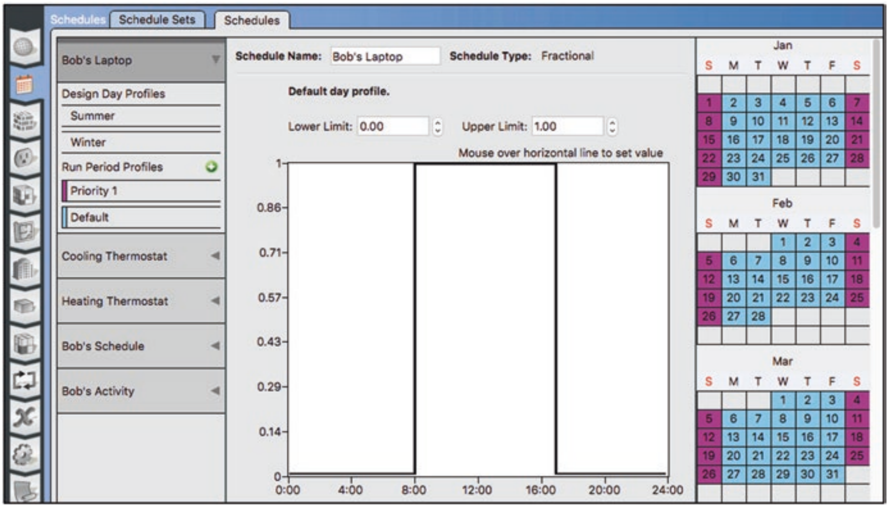


Fig. 3.30 Laptop usage profile derived from Occupancy Schedule

out – another example of data inheritance in OpenStudio. Checking color codes on the calendar is always recommended to ensure that a Ruleset Schedule will be applied as expected.

Now use the Button to duplicate Bob's Schedule. Rename it "Bob's Laptop," and edit the Default Profile so it looks like Fig. 3.30. This reflects the likelihood that Bob leaves his Laptop running in the Space when he slips out during his lunch hour.

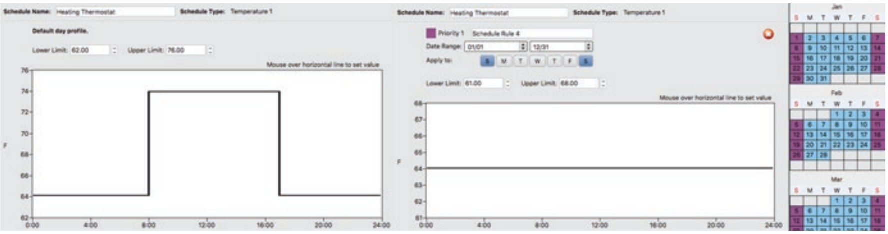


Fig. 3.31 Setting a Heating Thermostat Ruleset Schedule for Bob's Office

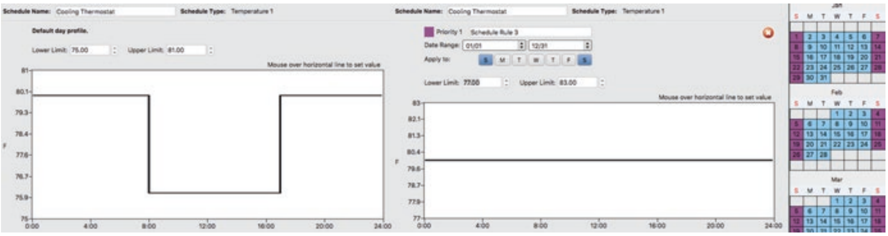


Fig. 3.32 Setting a Cooling Thermostat Ruleset Schedule for Bob's Office

The last two Schedules we need for this exercise are shown in Figs. 3.31 and 3.32. Use the Schedule editor to create both of them and save your work.[6]

With all of our Schedules defined, go back to the Schedule Set editor and drag the individual Ruleset Schedules in as shown in Fig. 3.33. This assignment assumes that Bob turns off the lights whenever he leaves. We will make use of the thermostat Schedules elsewhere.

3.4.2 *Defining Our Loads*

Now navigate to the Loads ( ) Tab to define all of the Loads for our Space Type. Add Loads for Bob, Lights, and his laptop as shown in Fig. 3.34.

3.4.3 *Defining and Assigning Our Space Type*

With Schedules and Loads defined, it's time to assemble them into a Space Type that we can apply to Spaces within our Building. Use the Space Types ( ) Tab to create a new Space Type with the Button. Drag and drop the new Schedule Set into the Default Schedule Set column as shown in Fig. 3.35. Ignore the other

[6] The values shown assume that you have set the Application's units preference to English (I-P).

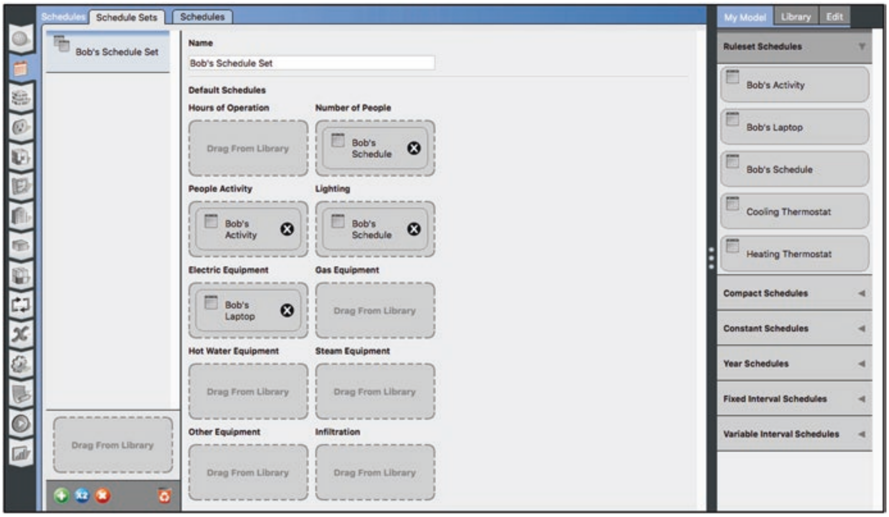


Fig. 3.33 Defining a Schedule Set for Bob's Office

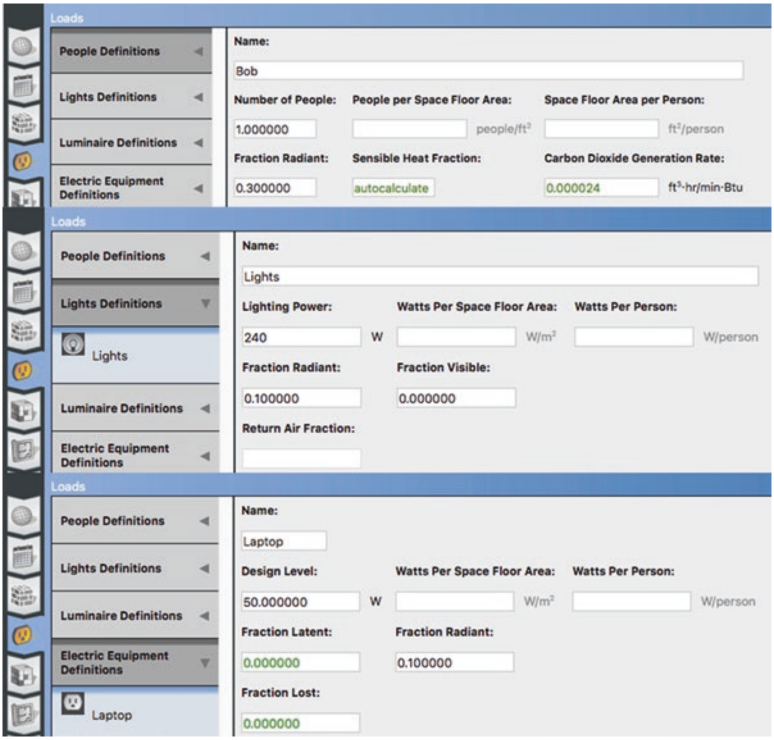


Fig. 3.34 Defining the Loads for Bob's Office

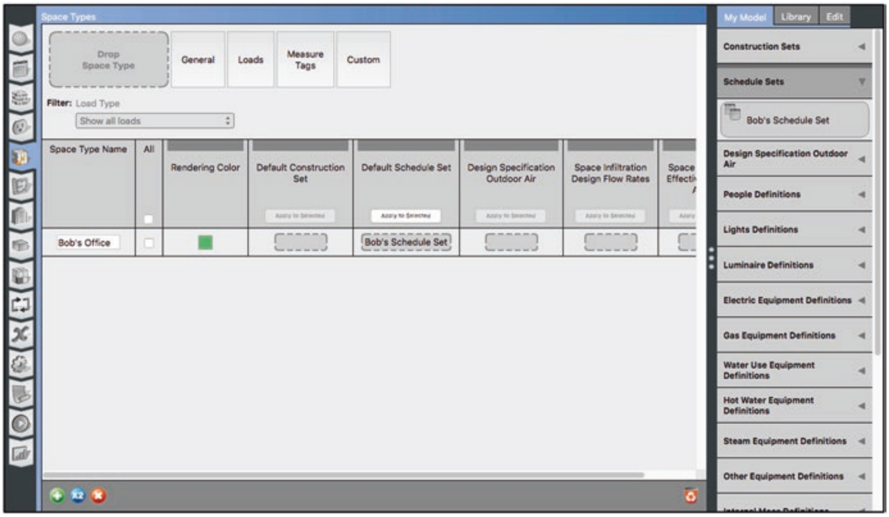


Fig. 3.35 Creating a new Space Type and Adding a Schedule Set

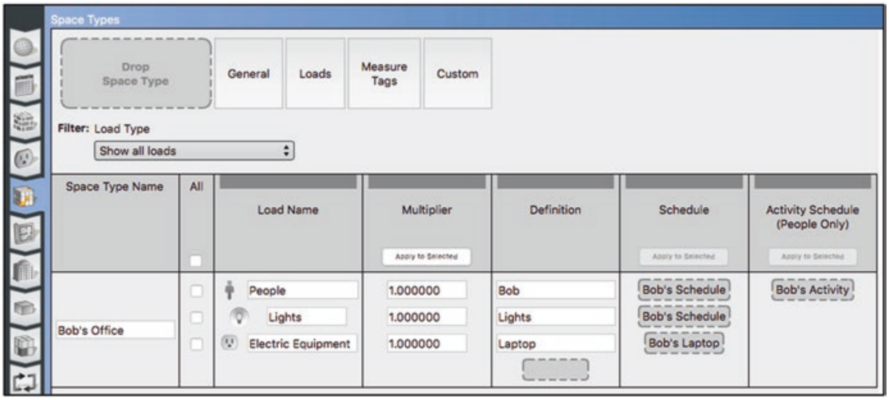


Fig. 3.36 Adding Loads to a Space Type

columns, since we will let the Space Type inherit the Floor's Construction Set and won't include infiltration for this first example.

Next, click on the Loads Button. Use Fig. 3.36 as an example of how to drag and drop people, light, and electric Equipment definitions from "My Model" into the Definitions column for the Bob's Office Space Type. Schedules are automatically assigned based on the Schedule Set.

Now that the Space Type has been defined, we're ready to apply it to the single Space in our Building. Switch to the Spaces ( ) Tab to drag and drop the Bob's Office Space Type onto our Space as shown in Fig. 3.37. Switch to the Loads Sub-Tab to verify that all of our Loads and Schedules were correctly inherited from the

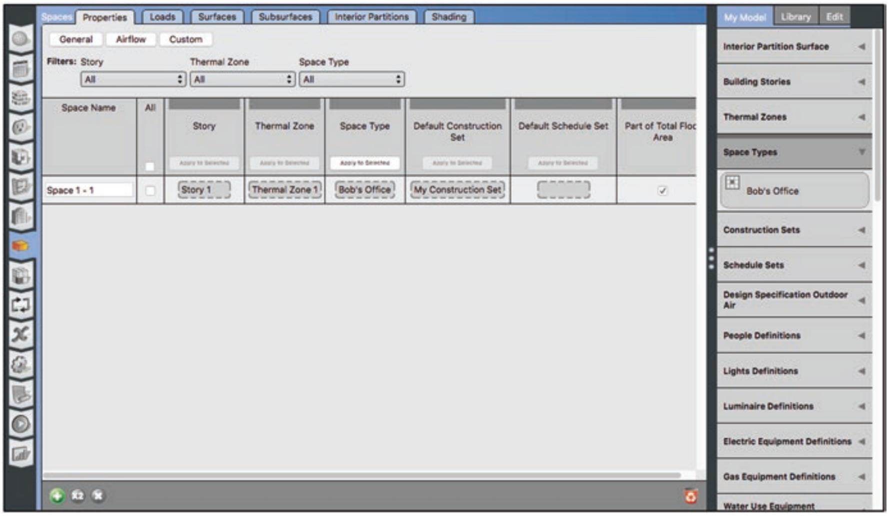


Fig. 3.37 Assigning our New Space Type to Bob's Space

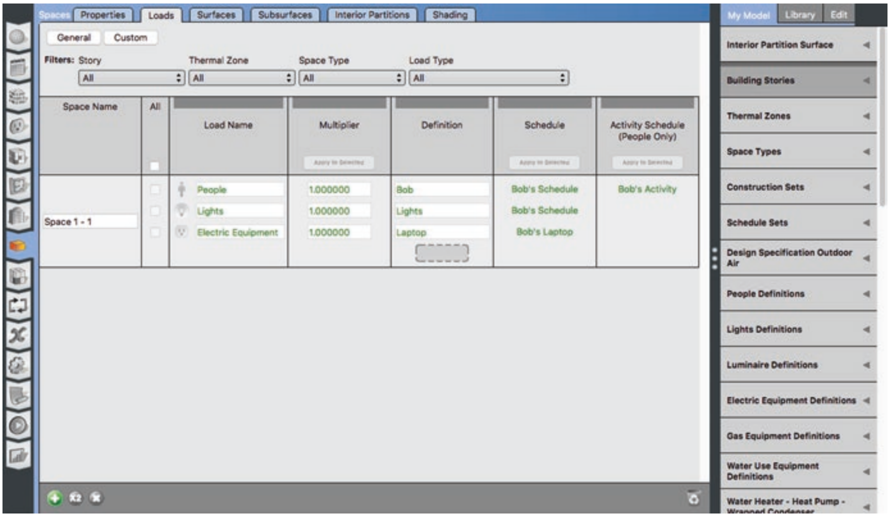


Fig. 3.38 Inspecting the Loads assigned to Bob's Space

Space Type (Fig. 3.38). If you wish, you may check that Surfaces and Sub-Surfaces were inherited from the Floor/Building as well.

Since this particular building has only a single Space, the extra effort of defining a Space Type isn't necessarily warranted. As mentioned previously in Sect. 3.3, we could also have dragged loads and schedules directly into our Space without relying on data inheritance. The real value of Space Types will become apparent in the next exercise where many Spaces can benefit from common Space Type definitions.

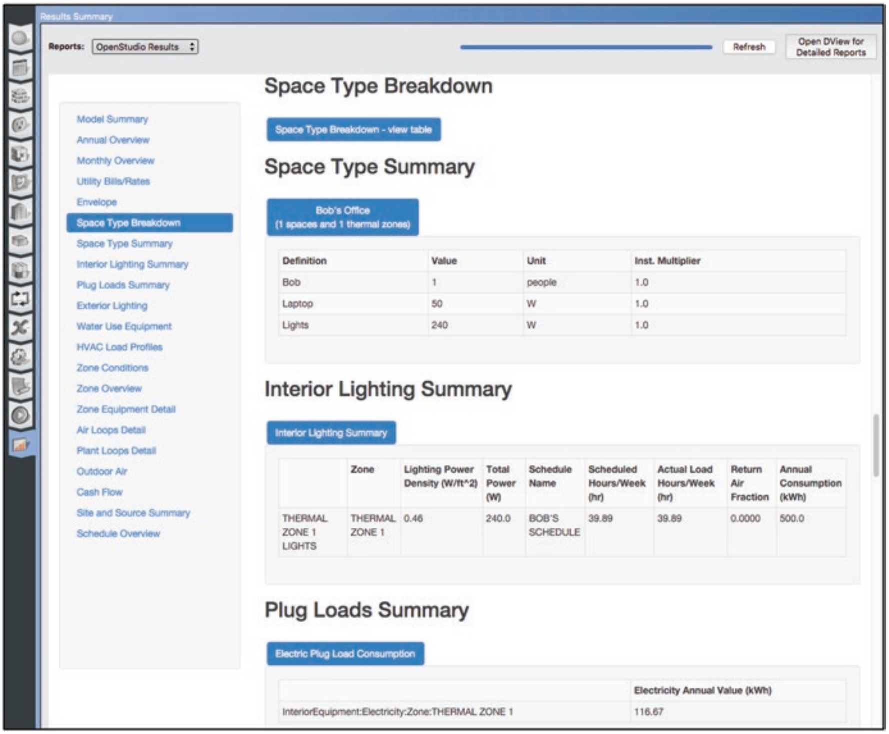


Fig. 3.39 Additional content in the OpenStudio report related to our Space

End Use	Consumption (kBtu)
Heating	0
Cooling	0
Interior Lighting	1,706
Exterior Lighting	0
Interior Equipment	398
Exterior Equipment	0
Fans	0
Pumps	0
Heat Rejection	0
Humidification	0
Heat Recovery	0
Water Systems	0
Refrigeration	0
Generators	0

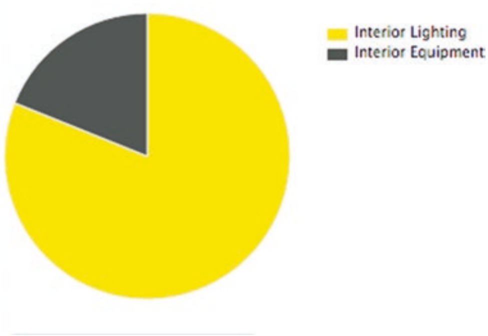


Fig. 3.40 Annual end use breakdown for Bob's Unconditioned Office

3.4.4 Running the Simulation

We are told that Bob is (very reluctantly) prepared to begin his year-long tenure in his unconditioned office. Let's make sure he shows up by adding "People Occupant Count" as a Timestep variable with the Variables (icon) Tab. Use the Run (icon) Tab to run the simulation. When the simulation has completed, switch to the Reports (icon) Tab to view the OpenStudio standard report. Clicking on the Space Type Breakdown link in the report produces Fig. 3.39 allowing us to quickly verify that all of the Loads we prescribed in "Bob's Office" are present and accounted for.

The Annual Overview link (Fig. 3.40) now includes pie charts showing the end use breakdown for lighting and Bob's Laptop across the entire year. Hovering the

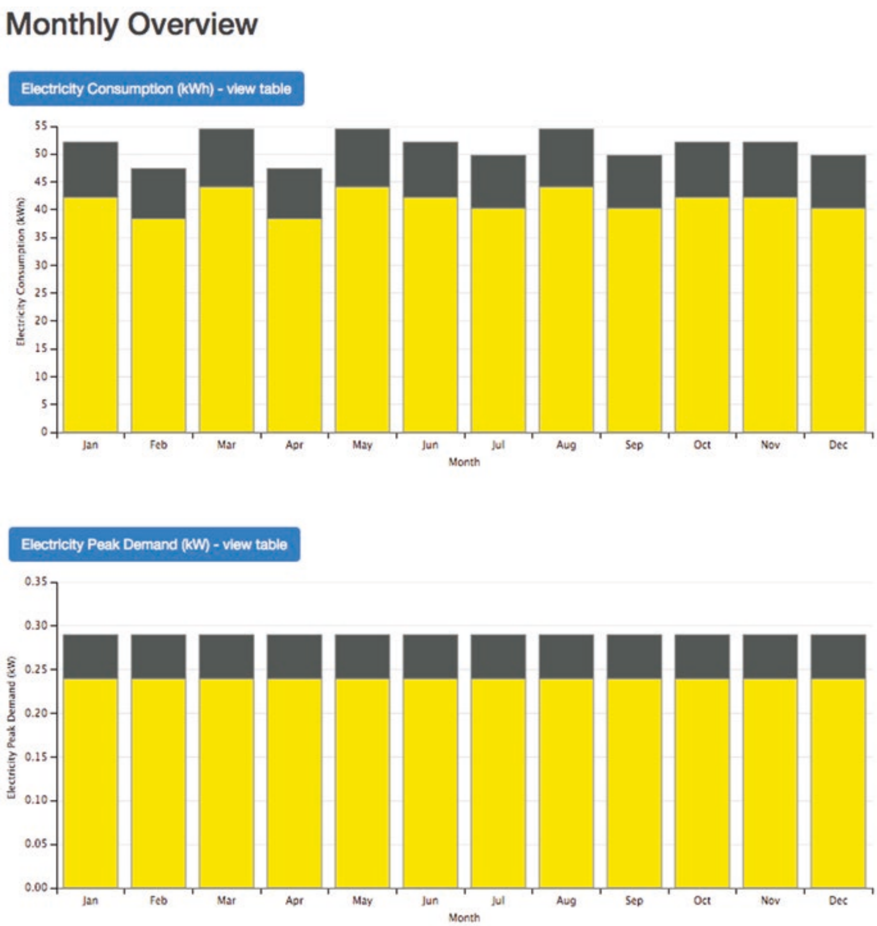


Fig. 3.41 Monthly end use breakdown for Bob's Unconditioned Office

Zone	Unmet Htg (hr)	Unmet Htg - Occ (hr)	< 56 (F)	56-61 (F)	61-66 (F)	66-68 (F)	68-70 (F)	70-72 (F)	72-74 (F)	74-76 (F)	76-78 (F)	78-83 (F)	83-88 (F)	>= 88 (F)	Unmet Clg (hr)	Unmet Clg - Occ (hr)	Mean Temp (F)
THERMAL ZONE 1	0	0	42	169	419	245	342	432	446	420	371	831	708	4335	0	0	93.1 (F)

Zone	< 30 (%)	30-35 (%)	35-40 (%)	40-45 (%)	45-50 (%)	50-55 (%)	55-60 (%)	60-65 (%)	65-70 (%)	70-75 (%)	75-80 (%)	>= 80 (%)	Mean Relative Humidity (%)
THERMAL ZONE 1	1980	560	486	459	371	359	355	372	356	343	328	2791	58.4 (%)

Fig. 3.42 Zone Conditions for Bob's Unconditioned Office

mouse over these plots reveals specific numbers, and the blue "view table" Buttons expand to reveal detailed tabular data underlying the charts.

Also of note is the Monthly Overview (Fig. 3.41). These monthly consumption plots are essentially flat, varying only based on the number of workdays that fall in any given month.

Of greatest interest (at least to Bob) is the Zone Conditions section of the report, as it most concisely reflects the cruelty we have inflicted upon him. As evidenced by Fig. 3.42, adding Bob, his laptop, and lighting to the Space has increased the number of hours spent in excess of 88 degrees Fahrenheit by nearly 300 h! On the bright side, the thermal Loads in Bob's office decreased the number of extremely cold hours a small amount. Also of significance is the dramatic shift in humidity within the Space. Bob's presence now results in nearly 3000 additional hours at 80% relative humidity or higher.

Adding insult to injury is the time series plot produced using DView and the simulations' eplusout.sql file. Figure 3.43 compares ambient and interior temperatures over the same time period we plotted in Chap. 2. This new plot shows that Bob did indeed turn up for work each day, and experienced peak temperatures that were nearly ten degrees higher than if he and his equipment weren't in the Space. The authors feel terrible about Bob's deplorable working conditions. Let's see if we can't do something for him in the next part of this exercise.

3.4.5 Ideal Air Loads

We will begin considering HVAC systems in the next Chapter, but OpenStudio and EnergyPlus provide a "quick and dirty" way of managing interior temperatures called an Ideal Air Load. An Ideal Air Load represents a Zone that is conditioned by an idealized HVAC system to maintain heating and cooling temperatures. Heating or cooling is supplied by a fictitious district[7] heating and cooling system with no significant sizing or dynamic constraints placed upon its performance.

[7] District systems are heating or cooling systems that exist external to the building. Examples include central steam or chiller plants that provide heating and cooling to a campus of buildings.

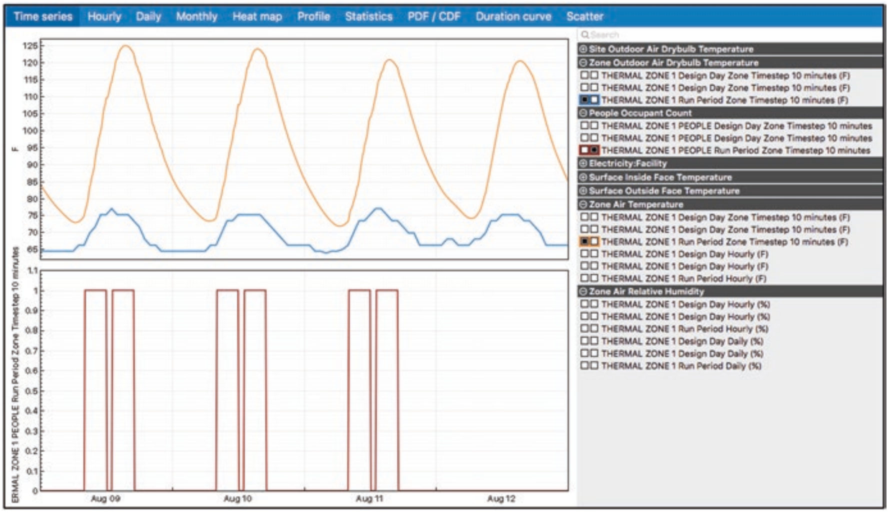


Fig. 3.43 DView time series plots for Bob's Unconditioned Office

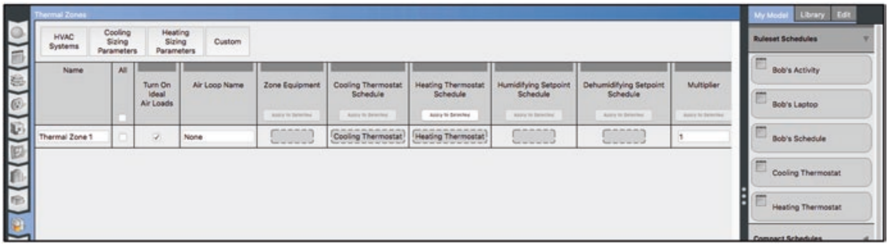


Fig. 3.44 Adding Thermostat Schedules and Ideal Air Loads to our Thermal Zone

Ideal Air Loads are turned on with a simple checkbox on the Zones (🖼) Tab. The Ideal Air Load requires heating and cooling thermostat schedules to function properly. Fortunately, we created them when we built our Space Type definition. Drag the thermostats onto the Zone and check the Ideal Air Loads box as shown in Fig. 3.44. Remember to save your work, and run the updated simulation to see if we've made Bob's life any better.

Jumping straight to the Zone Conditions summary in the OpenStudio report (Fig. 3.45) shows a tremendous change for the better. There are now zero hours in excess of 88 degrees Fahrenheit. The number of chilly hours could be improved by alterations to the heating thermostat schedule, but we don't want Bob to get too complacent. The Annual and Monthly Overview sections of the reports shown in Figs. 3.46 and 3.47 have also changed to reflect the addition of district heating and cooling to condition Bob's Office.

Figure 3.47 represents our closest look yet at end use breakdowns required to heat, cool, and light a building (albeit a simple one) that supports occupant activity. As a building modeler, it is important to inspect these kinds of results to see if they

Zone	Unmet Htg (hr)	Unmet Htg - Occ (hr)	< 56 (F)	56-61 (F)	61-66 (F)	66-68 (F)	68-70 (F)	70-72 (F)	72-74 (F)	74-76 (F)	76-78 (F)	78-83 (F)	83-88 (F)	>= 88 (F)	Unmet Clg (hr)	Unmet Clg - Occ (hr)	Mean Temp (F)
THERMAL ZONE 1	0	0	0	0	2053	665	610	450	420	1363	1659	1540	0	0	0	0	72.3 (F)

Zone	< 30 (%)	30-35 (%)	35-40 (%)	40-45 (%)	45-50 (%)	50-55 (%)	55-60 (%)	60-65 (%)	65-70 (%)	70-75 (%)	75-80 (%)	>= 80 (%)	Mean Relative Humidity (%)
THERMAL ZONE 1	0	10	1770	2912	766	892	777	1595	38	0	0	0	47.2 (%)

Fig. 3.45 Zone Conditions with Ideal Air Loads

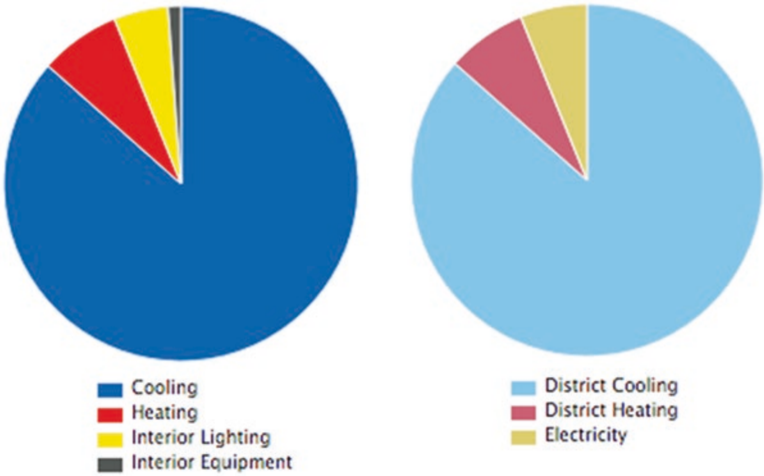


Fig. 3.46 Annual end use breakdown with Ideal Air Loads

make sense. One feature of these monthly bar charts that should give us pause is the need for simultaneous heating and cooling throughout the year, an indicator of an inefficient design. In the case of an Ideal Air Load system, this can be a result of poorly selected heating and cooling thermostat schedules. We can verify that this is the case by looking at time series plots in DView (Fig. 3.48).

As we add non-idealized HVAC systems to our models, behaviors like simultaneous heating and cooling, unmet hours of operation, and Equipment cycling become more likely. Casting a critical eye at the annual, monthly, and time series data provided by the software is an important role of the energy modeler. Just because the simulation "said so" does not make it correct or optimal. In this case, what would you do to eliminate simultaneous heating and cooling with our Ideal Air Load System? Test your ideas by changing your Model and re-running it.

Fig. 3.47 Monthly end use breakdown with Ideal Air Loads

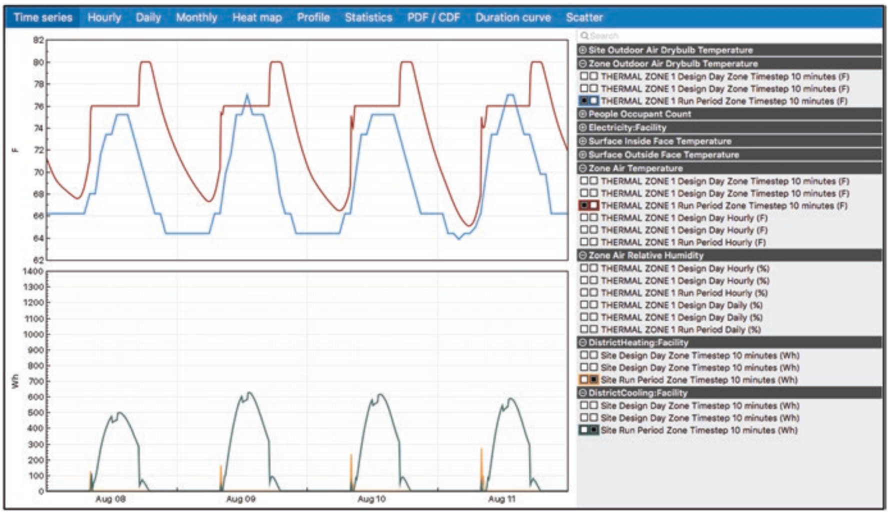


Fig. 3.48 Time series plots of ambient and interior temperatures alongside district heating/cooling load

3.5 Checkpoint Four: Assigning Space Types to a School Model

Let us continue refining our school capstone Model from Checkpoint Two. Instead of going through all the tedious steps of defining Loads and Schedules we used in the previous exercise, we will make use of Libraries to speed up the process. Use the following steps to get started:

1. Open your Primary School Model (or a copy of it) from Checkpoint Two.
   (a) We recommend using "Save As" to preserve your previous work.
2. Pick "Load Library" from the File menu and import *PrimarySchool.osm* to load the Model library with Space Types.
3. Navigate to the Space Type () Tab, select Space Types labeled *90.1–2010 – PriSchl* and drag them into your Model as shown in Fig. 3.49. Rename them if you wish.
4. Navigate to the Building () Tab, select the Classroom Space Type you just added, and drag it to become the Default Building Space Type (Fig. 3.50).
5. Save your Model.

Note that you could have selected any of the Space Types we just added as the default Space Type. In general, you should select the Space Type that is most frequently used in your building – in this case a classroom.

Before proceeding, this is a good opportunity to see how much time we just saved by importing those Space Type Definitions, and also to verify the assumptions we are making with loads, schedules. etc. Use the Loads section of the Space Types () Tab to inspect the definitions for each Space Type as shown in Fig. 3.51. Each definition includes People, Lights, Equipment, Infiltration, and associated Schedules without any significant effort on our part.

We can dig a bit deeper into the underlying definitions using the Schedules () and Loads () Tabs. Take a moment to browse through those sections of the Model

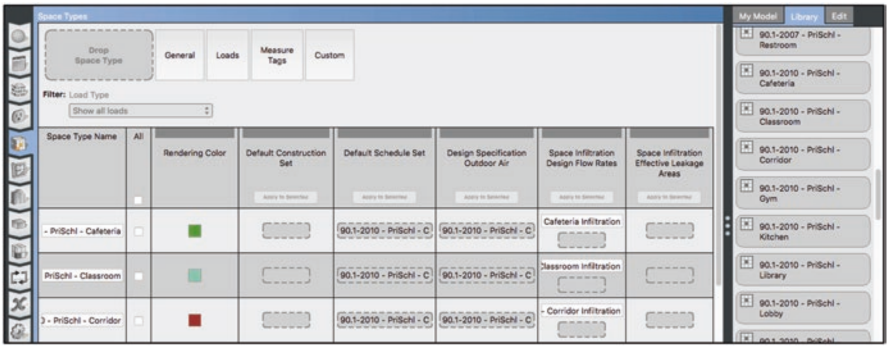


Fig. 3.49 Adding Space Types from the Library

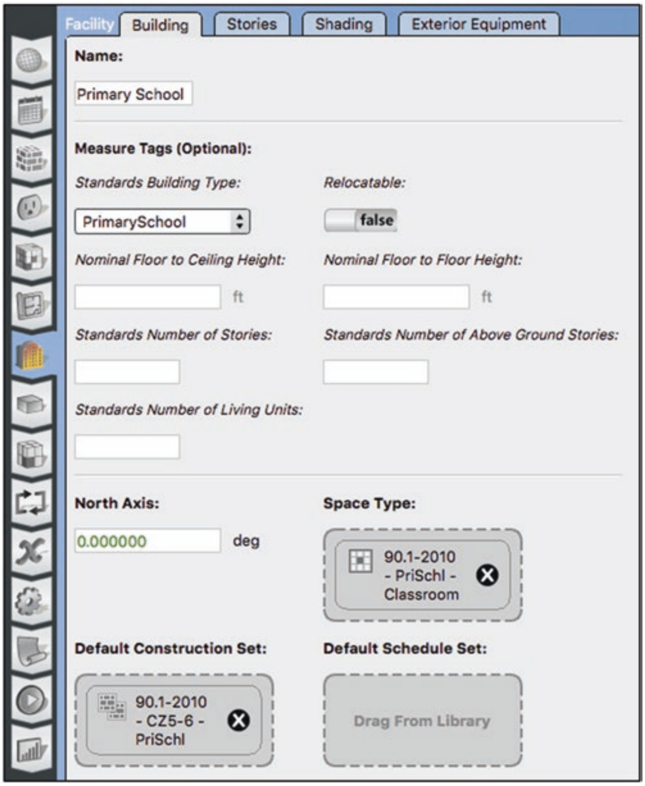


Fig. 3.50 Adding the Classroom Space Type as the building default

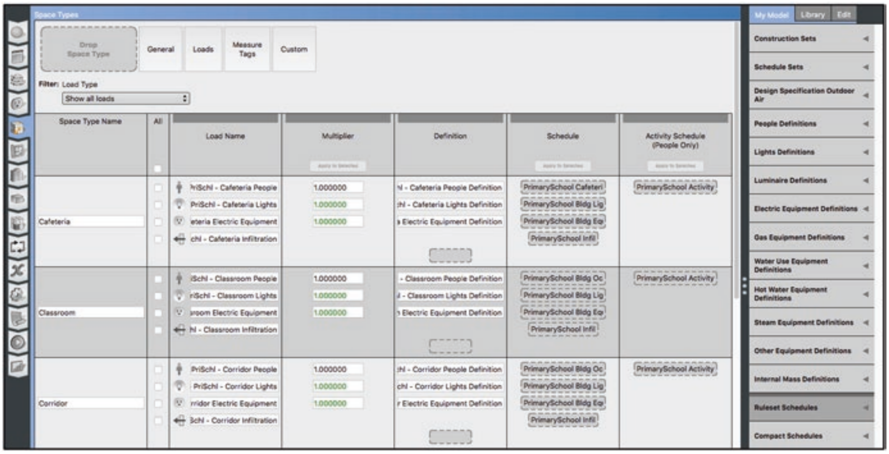


Fig. 3.51 Inspecting load definitions for the new Space Types

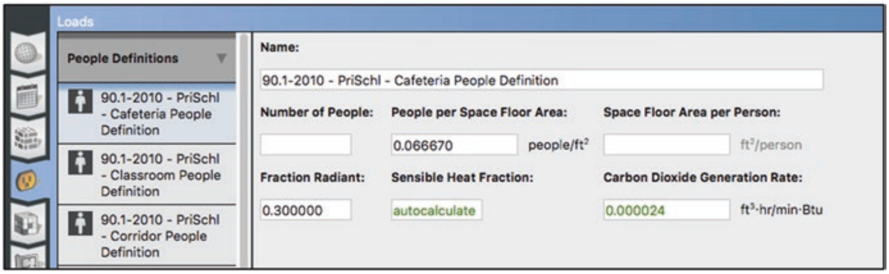


Fig. 3.52 Inspecting the imported people definition for the Cafeteria Space Type

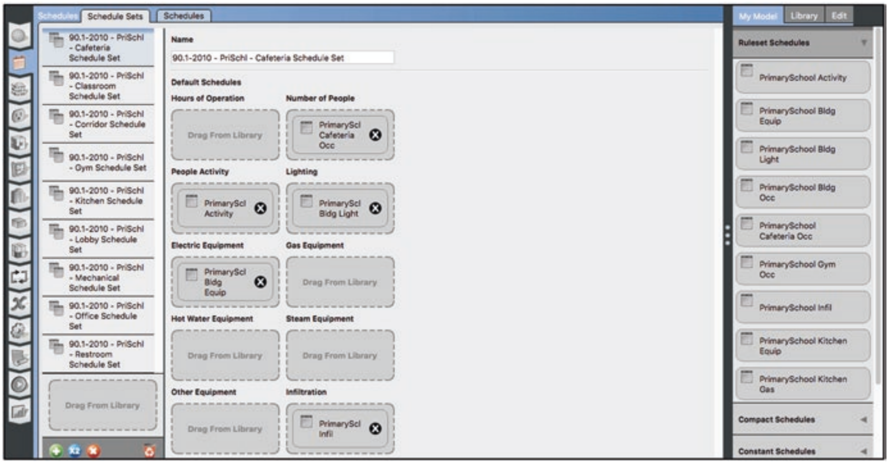


Fig. 3.53 Inspecting the Imported Schedule Set for the Cafeteria Space Type

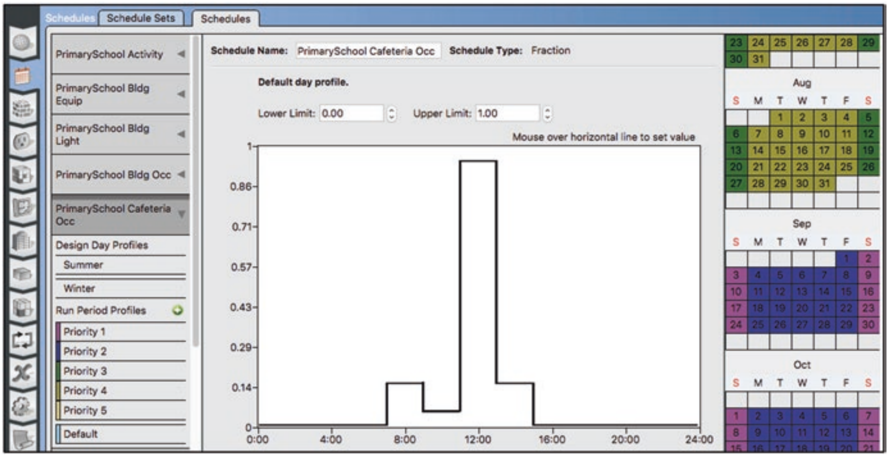


Fig. 3.54 Inspecting an Imported RuleSet Schedule for the Cafeteria Space Type

to see what data has been added. For example, Fig. 3.52 illustrates the definition of a person in our Cafeteria.

Figure 3.53 highlights the Cafeteria Schedule Set, just one of many we imported. Switch to the Schedules Sub-Tab to examine individual Schedules that were added as part of those Sets. For example, Fig. 3.54 illustrates the Cafeteria Occupancy Ruleset Schedule built up from a Default Profile and Five different Priority Profiles representing weekends, the School Year, Holidays, etc. How much time did making use of pre-built schedules save? How many mistakes were potentially avoided?

While we are in this particular Sub-Tab, take a moment to add two additional Ruleset Schedules from the Library you imported. We will make use of: *PrimarySchool HtgSetp* and *PrimaryScool ClgSetp* (Fig. 3.55). As you might guess, these are thermostat schedules that we will use when adding Idea Air Loads to our Thermal Zones.

Having verified the specific Loads and Schedules associated with our new Space Types, it's time to actually apply them to the Spaces in our building. Navigate to the Spaces ( ) Tab. Note in Fig. 3.56 that the Classroom Space Type has been automatically assigned to all Spaces in the building per our default assignment. In general,

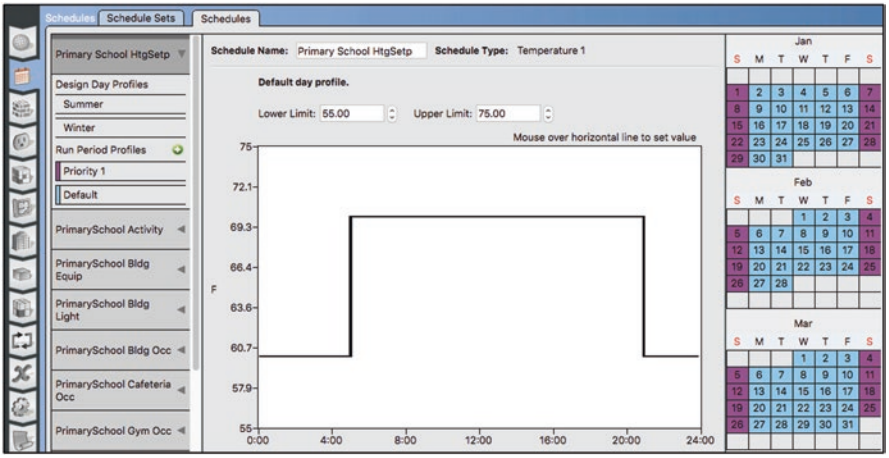


Fig. 3.55 Adding PrimarySchool HtgSetp and ClgSetp from the Library

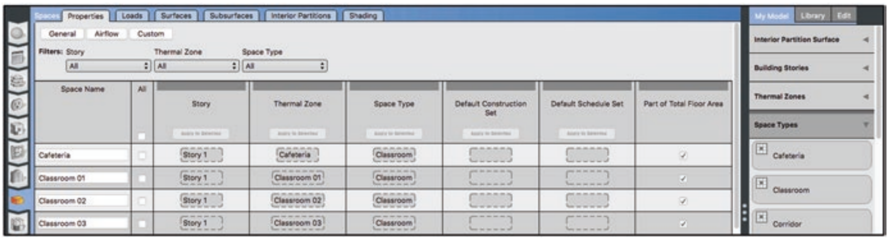


Fig. 3.56 All Spaces defaulted to the Classroom Space Type

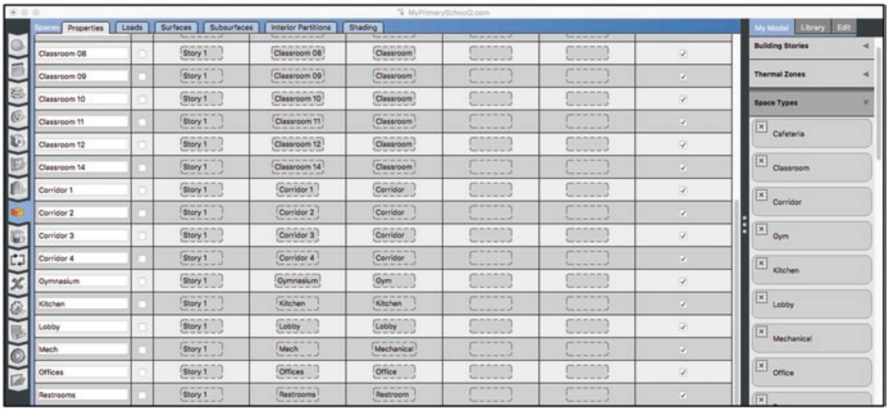


Fig. 3.57 Overriding Space Type defaults for other Spaces

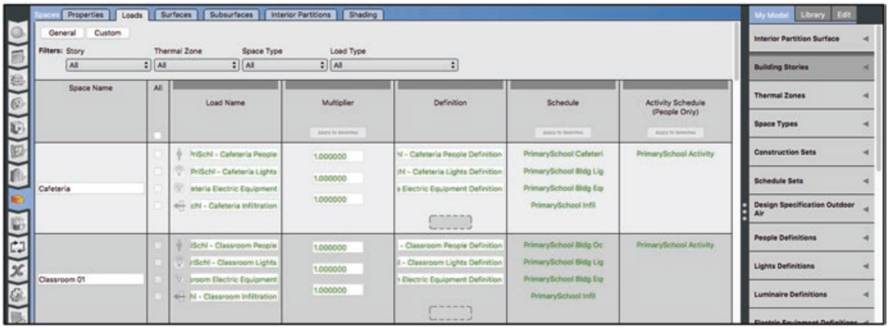


Fig. 3.58 Verifying load definitions for Spaces

that's a good thing, but it did incorrectly assign Spaces like the Cafeteria as a Classroom. Drag and drop the correct Space Types onto the appropriate Spaces as shown in Fig. 3.57.

To reinforce our understanding of data inheritance and verify that the correct Loads and Schedules are applied to our Spaces, switch to the Loads Sub-Tab. The telltale green text in Fig. 3.58 informs us that Loads and Schedules were inherited from either the Building Default Space Type or the Space Types we manually assigned. If we wished to add specific loads to Spaces that aren't pre-defined by the Space Types, we could drag them in here. For our purposes we will stick with the default definitions.

If you didn't check out the Surface and Subsurface assignments during the Checkpoint Two exercise, this is a convenient time to do so. Select the Surfaces or Subsurfaces Sub-Tabs to verify that the building Construction Set was correctly applied to your Spaces. Figure 3.59 is an example illustrating that the Default Constructions that were applied to each surface in every Space. Again, we could choose to replace

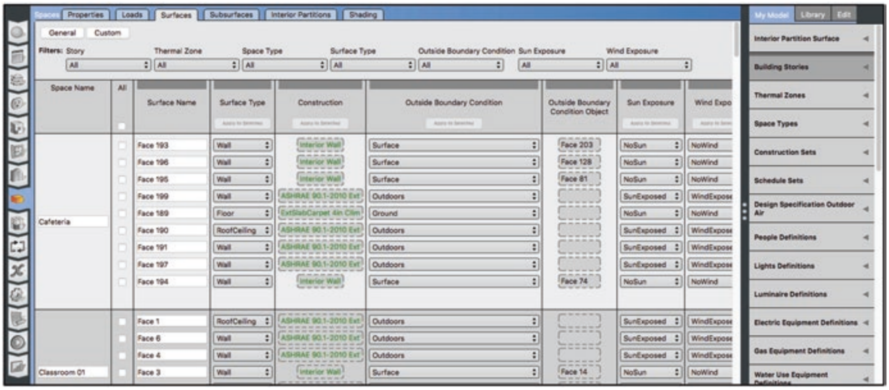


Fig. 3.59 Verifying Surface Constructions for Spaces

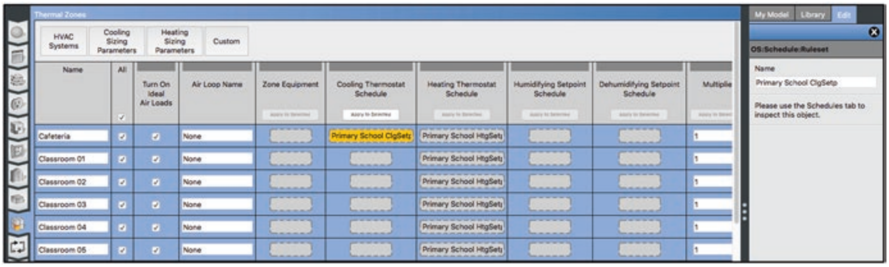
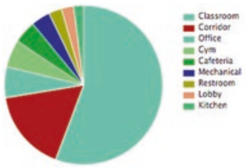


Fig. 3.60 Using multi-select to assign the cooling Thermostat Schedule to all zones

any of these with a custom construction, but there is no need to do so for our exercise.

The last step in preparing our Model for simulation is to assign our heating and cooling thermostats and turn on Idea Air Loads in each Thermal Zone. Switch to the Zones ( ) Tab shown in Fig. 3.60. Dragging and dropping the Heating and Cooling Schedules onto every Zone in our Model is, pardon the pun, a drag. Fortunately, OpenStudio makes this easier. Use the following steps to assign multiple schedules at once:

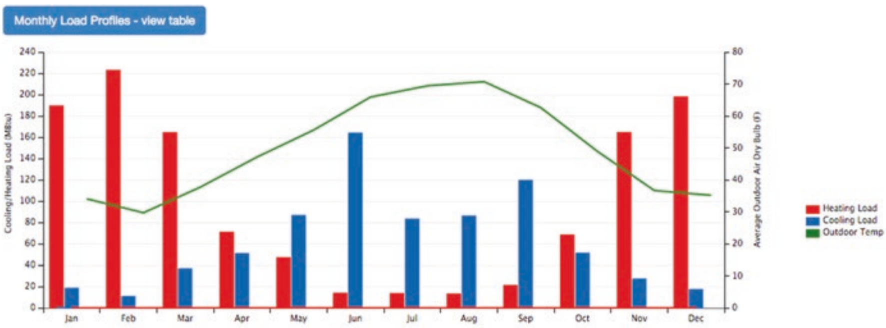
1. Click the checkbox under the “All” column. This selects every Thermal Zone in your Model.
2. Drag your Heating Thermostat Schedule onto the correct column for one of the Zones.
3. Click that Schedule to highlight it.
4. Click the Apply to Selected Button to apply that Schedule to all the selected Thermal Zones.
5. Repeat for the Cooling Thermostat Schedule as shown in Fig. 3.60.
6. Don’t forget to check the Ideal Air Load boxes too!



Classroom
(13 spaces and 13 thermal zones)

Definition	Value	Unit	Inst. Multiplier
90.1-2010 - PriSchl - Classroom People Definition	0.0232	people/ft^2	1.0
90.1-2010 - PriSchl - Classroom Electric Equipment Definition	1.0200	W/ft^2	1.0
90.1-2010 - PriSchl - Classroom Lights Definition	1.2400	W/ft^2	1.0
90.1-2010 - PriSchl - Classroom Infiltration	0.0446	cfm/ext surf area ft^2	
90.1-2010 - PriSchl - Classroom Ventilation (outdoor air method Sum)	10.0000	cfm/person	
90.1-2010 - PriSchl - Classroom Ventilation (outdoor air method Sum)	0.1200	cfm/floor area ft^2	

Fig. 3.61 Space Type breakdown for the Primary School Model



Temperature (Table values represent hours spent in each temperature range)

Zone	Unmet Htg (hr)	Unmet Htg - Occ (hr)	< 56 (F)	56-61 (F)	61-66 (F)	66-68 (F)	68-70 (F)	70-72 (F)	72-74 (F)	74-76 (F)	76-78 (F)	78-83 (F)	83-88 (F)	>= 88 (F)	Unmet Clg (hr)	Unmet Clg - Occ (hr)	Mean Temp (F)
CLASSROOM 01	0	0	0	1912	1059	375	1274	2214	1567	128	231	0	0	0	0	0	67.7 (F)
CLASSROOM 02	0	0	0	1770	1126	421	1356	2125	1689	154	119	0	0	0	0	0	67.8 (F)
CLASSROOM 03	0	0	0	2065	1032	360	1412	2173	1419	129	170	0	0	0	0	0	67.5 (F)
CLASSROOM 04	0	0	0	1952	1094	386	1573	2028	1553	110	64	0	0	0	0	0	67.5 (F)

Fig. 3.62 HVAC Loads and Zone Conditions for the Primary School Model

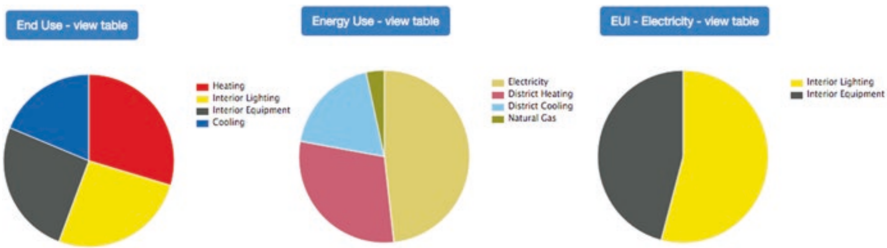


Fig. 3.63 Annual end use breakdowns for the Primary School Model

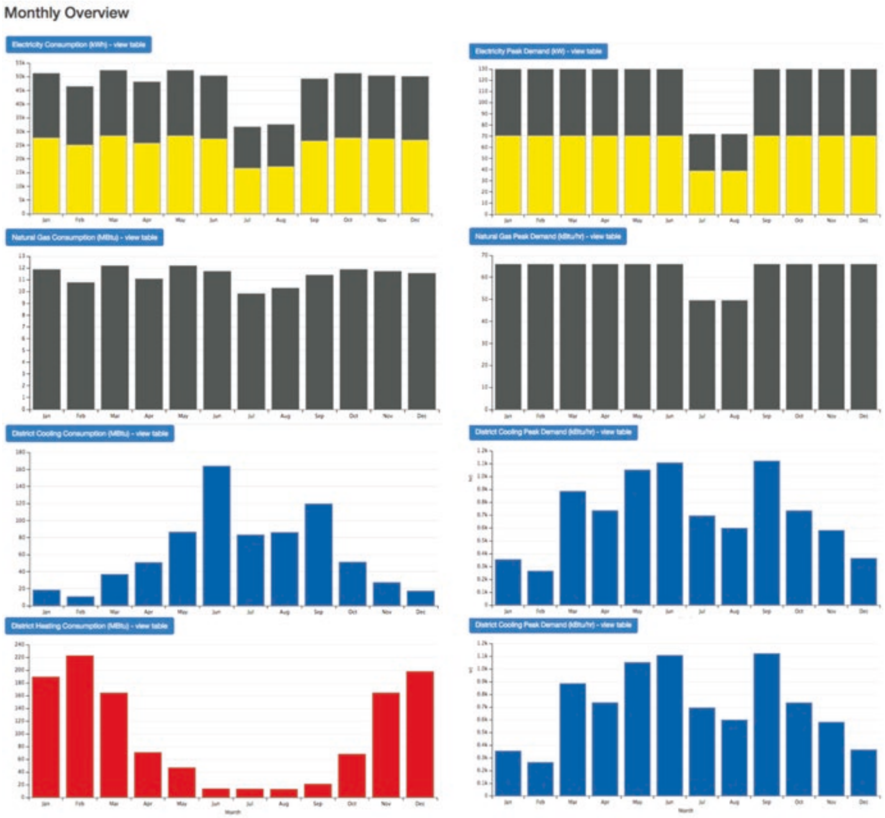


Fig. 3.64 Monthly end use breakdowns for the Primary School Model

Run the simulation and browse the standard reports. Specific areas of interest are the Space Type Breakdown and Summary sections shown in Fig. 3.61, which allow us to spot check the simulation's end use definitions.

The HVAC Load Profile and Zone Condition sections tell us that the Thermostat Schedules and Ideal Air Loads provided Space conditioning via a fictitious district system (Fig. 3.62). Figures 3.63 and 3.64 show the annual and monthly end use breakdowns for the school.

Lastly, take a look at the time series data for your simulation using DView. Figure 3.65 compares outdoor and Zone temperatures for the Lobby (Red) and Mechanical Room (Orange) over the same time period as in the unconditioned response plots we presented in Fig. 2.56. The lower plot shows the heating and cooling loads from the district system required to achieve the Thermostat target temperatures. Unlike our final results in Checkpoint Three, there is far less evidence of simultaneous heating and cooling, suggesting that our Thermostat Schedules are fairly reasonable.

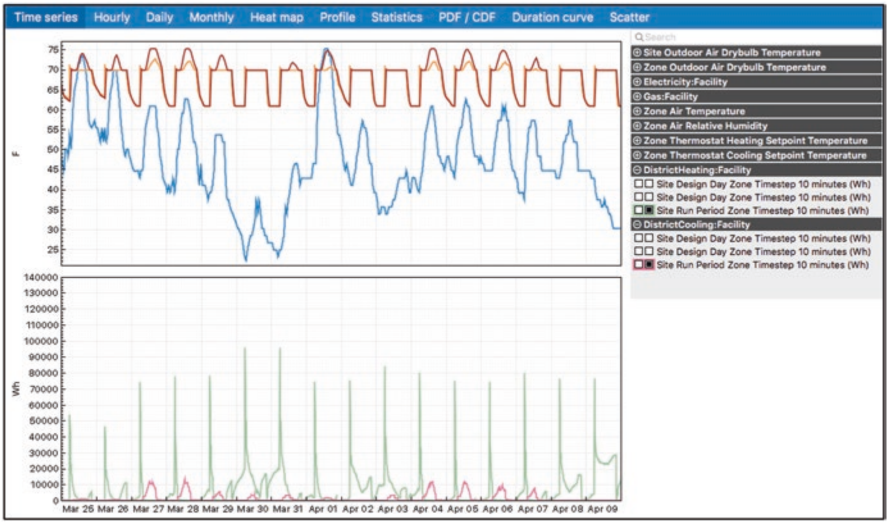


Fig. 3.65 Time series plots for the Primary School Model

We now have a working knowledge of building Constructions, Loads, Schedules, and the Spaces they support using OpenStudio. We have also learned how to crudely condition those Spaces using Ideal Air Loads to evaluate the reasonableness of our Envelope and Space assumptions. It is now time to turn our attention to modeling how buildings are actually conditioned – using HVAC systems.

3.6 Additional Exercises

Use the “Additional Exercises” Model you created in Chap. 2 to continue learning about Space Types:

- Open the Model you created in the Additional Exercises section of Chap. 2,
- Import Space Type definitions into your Library from a similar Model (e.g. School, Office, etc.),
- Assign Space Types to the Spaces in your Model,
- Assign Ideal Air Loads to your Thermal Zones, and
- Run a simulation of your Model.

Review outputs from your model and compare them with results from your previous Checkpoints. Do the end uses in your model make sense? Are the time series plots from your simulations consistent with the Schedules used by your Space Types?

References

ASHRAE (2013) Handbook fundamentals, ASHRAE, pp 18.3–18.12.

DiLaura D, Houser K, Mistrick R, Stetty G (2011) The lighting handbook, 10th edn. Illuminating Engineering Society (IES). https://www.ies.org/store/lighting-handbooks/lighting-handbook-10th-edition/

http://bigladdersoftware.com/epx/docs/8-7/input-output-reference/group-schedules.html#group-schedules

http://bigladdersoftware.com/epx/docs/8-7/input-output-reference/group-internal-gains-people-lights-other.html#field-activity-level-schedule-name

http://bigladdersoftware.com/epx/docs/8-0/input-output-reference/page-018.html#group-airflow