

Building Energy Simulation

A Workbook Using
DesignBuilder™

Second Edition

Vishal Garg
Jyotirmay Mathur
Aviruch Bhatia



CRC Press
Taylor & Francis Group

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Dedication

This book is dedicated to our beloved teacher, the late Professor N. K. Bansal, who introduced the use of building energy simulation in India for energy-efficient building design.



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Preface

Building Energy Simulation: A Workbook Using DesignBuilder is an outcome of a series of training programs conducted for participants with varied backgrounds. The authors experimented with various teaching techniques and arrived at the conclusion that the most effective method of imparting these training programs is through tutorials and step-by-step instructions along with graphical illustrations. This book is an updation of its first edition, released in 2017. Several new tutorials have been added, as was suggested to the authors through feedback received from book users across the world. The authors thankfully acknowledge these inputs.

The simulations in this workbook are performed using the DesignBuilder software for illustration purpose to help explain the aspects of a whole-building energy simulation process. This workbook adopts the ‘learning by doing’ principle to explain the fundamentals of building physics and building services and, in turn, help readers understand the concept of building energy performance. Based on participant feedback during the training programs, the authors decided to use EnergyPlus with DesignBuilder as the front end to explain the simulation process.

The book has been organized as follows:

- The first 11 chapters of this workbook cover various aspects of simulation, such as creating the building geometry, assigning material and equipment and analysing the results.
- Chapter 12 is new in this edition and explains the method of simulating renewable-energy systems fitted on buildings.
- Chapter 13 is also a new one that explains the method of carrying out life-cycle cost analysis of various design options, including sensitivity and uncertainty analysis.
- Chapter 14 explains simulation for the whole-building performance method of the ASHRAE 90.1 standard.
- Chapters 15 through 17, which are available online, provide exercises to simulate three different building projects.

The authors would highly appreciate any feedback or suggestions for further improving this workbook.



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We thank late Professor N. K. Bansal, who not only introduced us to this subject of building science but also served as our role model in learning the art and science of the teaching process. We are also grateful to DesignBuilder Software, Ltd., Stroud, United Kingdom, for their technical support in developing this book and answering our queries during the writing process.

This workbook would not have been possible without all those reviewers who took the time to patiently go through the contents and provide their valuable feedback. We especially appreciate the contributions from Gaurav Chaudhary, Hema Rallapalli, Kopal Nihar, Nishesh Jain, Sraavani Gundepudi, Shivraj Dhaka and all the students from the International Institute of Information Technology (IIIT), Hyderabad, India, and the Malaviya National Institute of Technology (MNIT), Jaipur, India, who reviewed this workbook and provided feedback on the technical contents and accuracy.

Our special thanks go to Naresh Arthem for running the simulations for all the tutorials, capturing screen shots and closing the technical and editorial comments provided by various reviewers. We also thank Vijay Singh, Sahil Chilana, and Kuntal Chattopadhyay for rerunning all the simulations and for their thorough review of the manuscript.

Our thanks to all friends and family members for their support, and encouragement. Without their support this book would have not been possible.

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1 Getting Started with Energy Simulation

This chapter is designed to acquaint you with building energy simulation. It starts with the introduction of various components and requirements for simulation and then gradually progresses to the concept of simulation using a ready example file. It establishes the impact of key simulation inputs such as lighting power density (LPD), activity, setpoint, window-to-wall ratio (WWR), orientation and fresh air intake on energy consumption. There are 11 tutorials to help you navigate through the chapter. By the end of this chapter, you will be familiar with key input parameters, output visualization and the overall simulation process.

BUILDING ENERGY SIMULATION

Building energy simulation is performed using a computer to virtually represent a building design and perform physics-based calculations. The simulations can range from a building component to a cluster of buildings. For energy simulation, the building model, the usage pattern and the weather of the location are required to determine various outputs, such as peak loads, system sizing and energy consumption for any given period. This information can be used for estimating the utility bills and for evaluating cost-benefit analyses of various design strategies.

Some of the uses for energy simulation tools include the following:

Early design decisions. In the early design stage, decisions such as the orientation and layout of the building are taken. Energy simulation can help in evaluating various design strategies. However, a detailed simulation may not be possible because of the limited information available at this stage.

Component or material selection. Simulation helps in the decision-making process when selecting individual components of the building envelope or systems. It is quite commonly used to carry out cost-benefit analyses of various designs and components. Therefore, modelling at this stage needs to be performed with greater accuracy than the modelling for early design decisions.

Retrofitting decisions. For retrofits of existing buildings, energy simulation can help in selecting cost-effective solutions. For an accurate analysis, the simulation model should be calibrated using the measured performance data of the building.

WHAT IS NEEDED FOR ENERGY SIMULATION

Energy simulation of buildings can be performed using a systematic approach. A lot of data is required. It is recommended that you collect the required data before you start the modelling. The following basic information is required:

Location and weather file. Energy simulation tools need hourly data on ambient conditions (i.e. temperature, humidity, wind velocity, solar radiation, etc.) at the building location. This information is available in weather files. Simulation tools use these weather files to extract the hourly ambient conditions while carrying out the

simulation. However, for some locations, the weather file may not be available. In such cases, the weather file of some other location with similar weather conditions can be used. In addition, weather files are available in different formats. Different simulation tools use different formats of weather files. Utilities are available on the web for converting a weather file from one format to another.

Building geometry. Building elevation and floor plans are required to create the geometric model of a building. Architectural drawings may have many details that might not be directly useful for energy simulation. It is useful to simplify the drawings based on thermal zoning into a single line drawing by removing unnecessary details.

Envelope components. It is necessary to have construction details, such as the thickness and thermophysical properties of materials used in each layer of the building envelope. Besides the opaque components, it is very important to know the properties of the window glass, frames and shading devices.

Building services. Information on various services such as heating, ventilation and air conditioning (HVAC) and lighting is required. This includes equipment capacities, energy efficiency, location and controls.

Use of the building. The hourly values of the following are required:

- Occupancy
- Lighting
- Equipment
- Thermostat setpoint
- HVAC operation

HOW SIMULATION SOFTWARE WORKS

The simulation program enables simultaneous interaction of the geometric model with outdoor conditions, occupancy and use of building systems to predict various loads arising in the building on an hourly basis. Basic laws of physics and energy balance equations are used for calculations. The energy consumption for the operation of systems corresponding to the heat and other loads is also calculated on the same time scale. Results of the processing are passed to the calculations of the next time slice and are also supplied to the output file. This process continues for the entire duration of the simulation, and the final output is seen as aggregated or on the same time slice for which calculations have been carried out. Most simulation tools are capable of simulating the energy flows through different building components on an hourly basis, including the transient effects of the envelope and systems.

The advantage of energy simulation over the classical method is that various effects of the thermophysical properties of the materials and the performance of the various systems under varying external and internal environmental conditions are considered in energy calculations. Most energy simulation tools do not require any special computing power because they can be run on commercially available desktop computers or laptops.

This chapter provides basic tutorials on creating simple geometry and analysing the impact of building orientation, WWR, internal loads and fresh air delivery, with a special focus on analysing building energy performance and system sizing. The tutorials are followed by exercises. There are many energy simulation tools available. For this book, we will be using DesignBuilder v6.1. The latest version of DesignBuilder can be downloaded from <https://designbuilder.co.uk/download>. Please note that there can be minor differences in the user interface and simulation results between the latest version of DesignBuilder and the version used for this book.

Tutorial 1.1

Opening and Simulating an Example File

GOAL

To evaluate the energy performance of a building model provided in an example file with DesignBuilder installation

WHAT ARE YOU GOING TO LEARN?

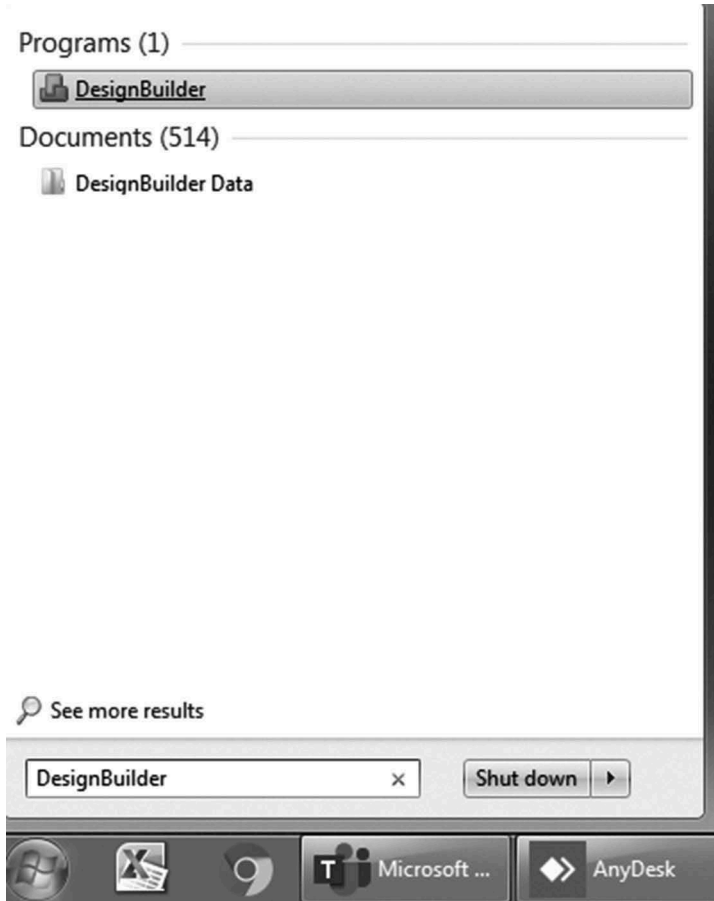
- How to simulate an example file
- How to view energy consumption results based on utility type or fuel, such as electricity or gas
- How to view the end-use energy consumption (i.e. lighting, equipment, fan, cooling, heating, pump and domestic hot water)
- How to view results on a daily, monthly and annual basis
- How to switch between metric (*Système international* [SI]) and English (inch-pound [IP]) measurement units
- How to calculate energy use intensity (EUI)

PROBLEM STATEMENT

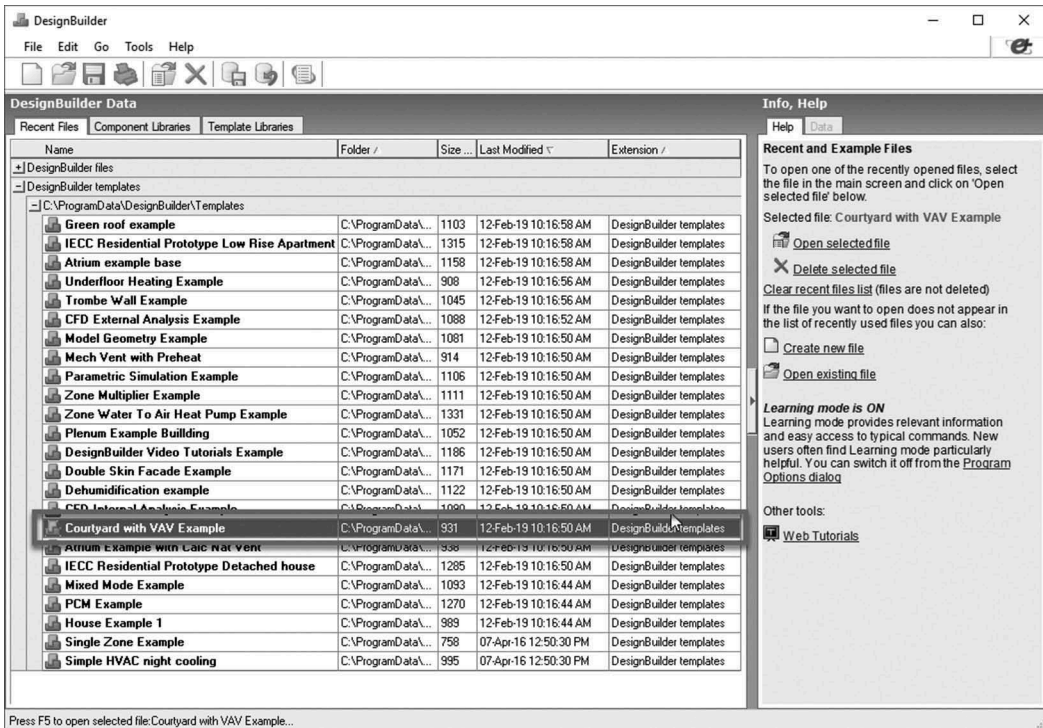
In this tutorial, you are going to simulate an existing template, **Courtyard with VAV Example**, from the DesignBuilder library and simulate it for the climate of London. You will learn how to view the daily, monthly and annual energy consumptions in a graphical format. You will also learn how to view the annual fuel breakdown and fuel total.

SOLUTION

Step 1: Start DesignBuilder. The DesignBuilder main screen appears.



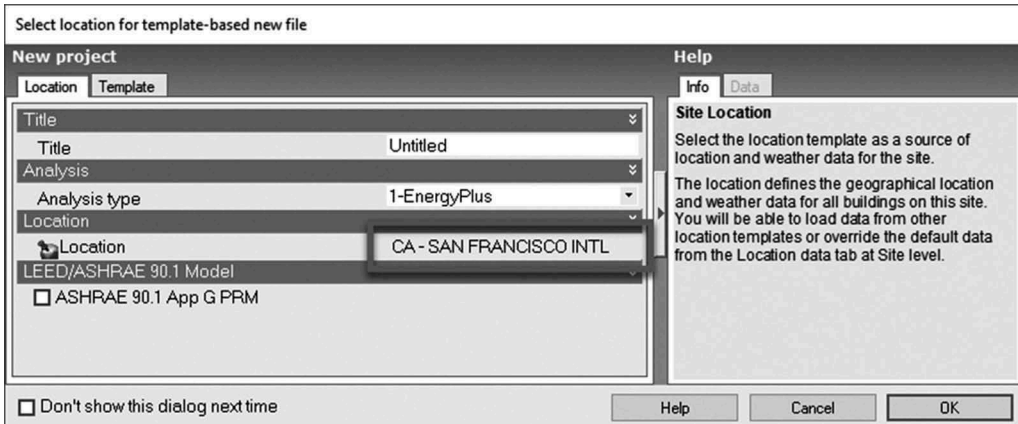
Step 2: Double-click Courtyard with VAV Example in the DesignBuilder templates under the **Recent Files** tab. A **New project** screen appears.



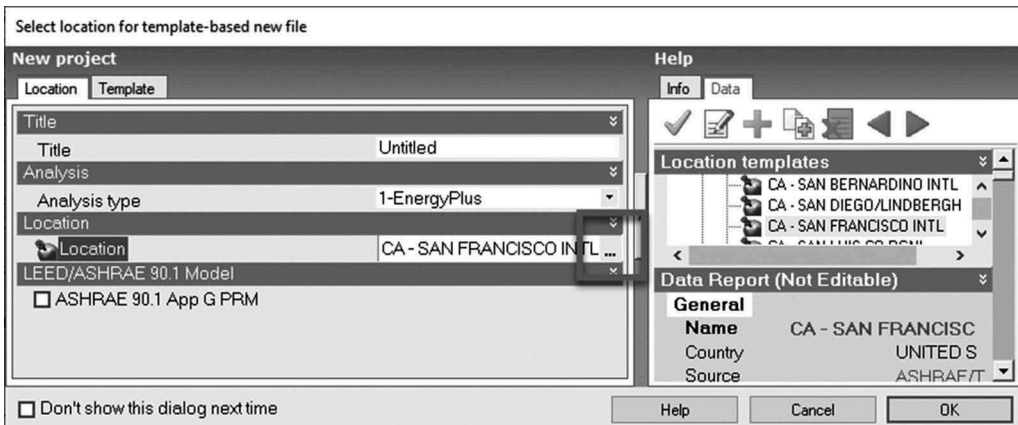
Courtyard with VAV Example is a DesignBuilder template file. A DesignBuilder template file helps to provide examples of various building typologies and systems such as geometry, HVAC system and passive strategies. Relevant data from the example files can be exported and imported into other DesignBuilder models.

Step 3: Click CA-SAN FRANCISCO INTL. Three dots (...) appear.

If you have installed DesignBuilder for the first time on your system, **CA-SAN FRANCISCO INTL** may appear as your location. If you have used DesignBuilder previously, you may get some other location based on your previous settings.

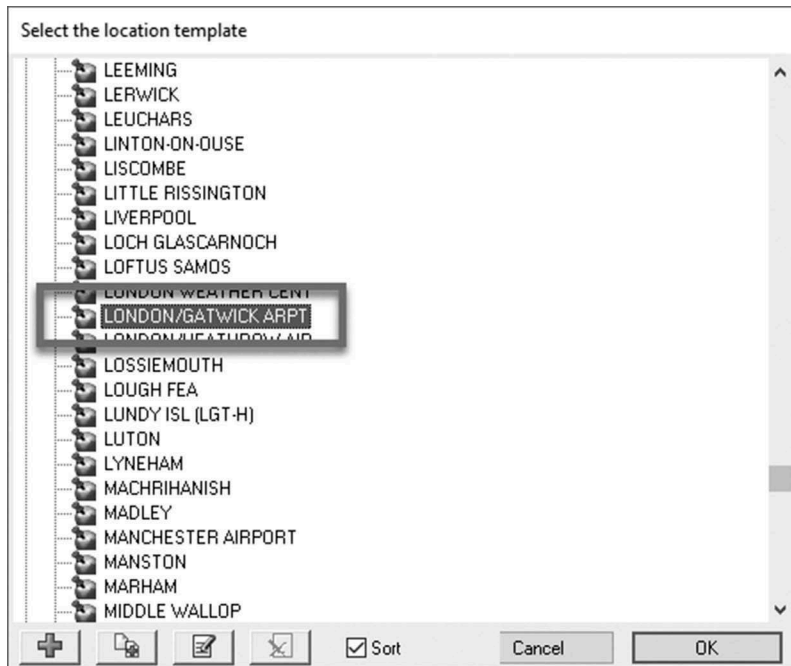


Step 4: Click the three dots (...). The **Select the location template** screen appears.

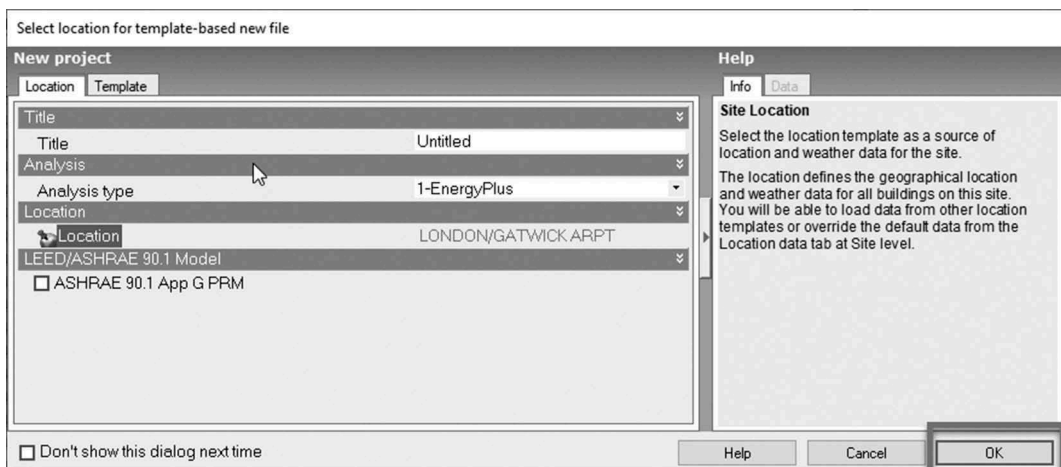


Step 5: **Select LONDON/GATWICK ARPT**. Click **OK**. The **Select location for template-based new file** screen appears.

LONDON/GATWICK ARPT is a weather file that comes along with the Design-Builder installation. For all other locations, an internet connection is needed to download the weather files.



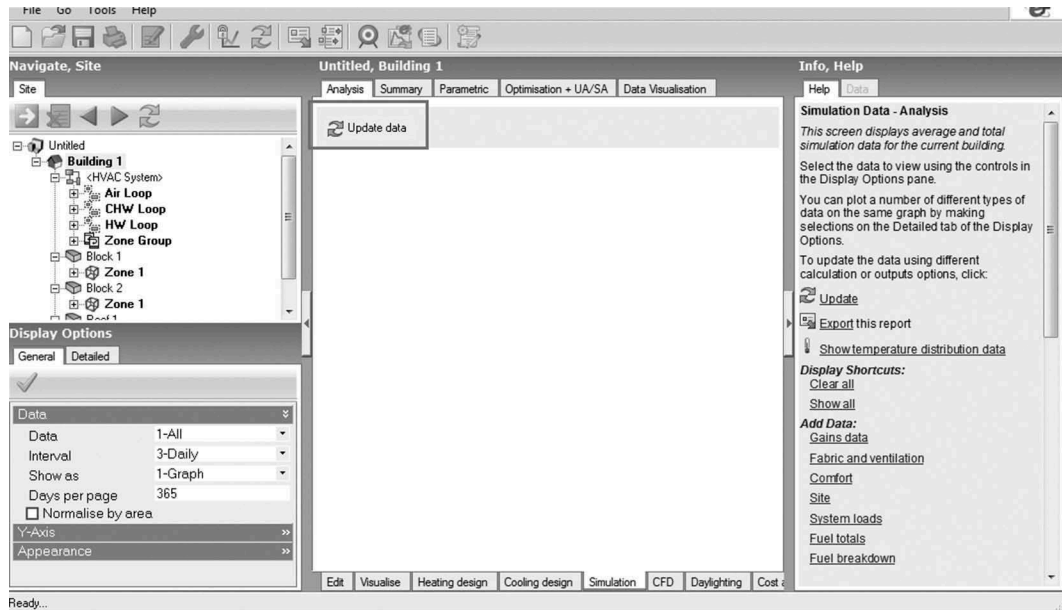
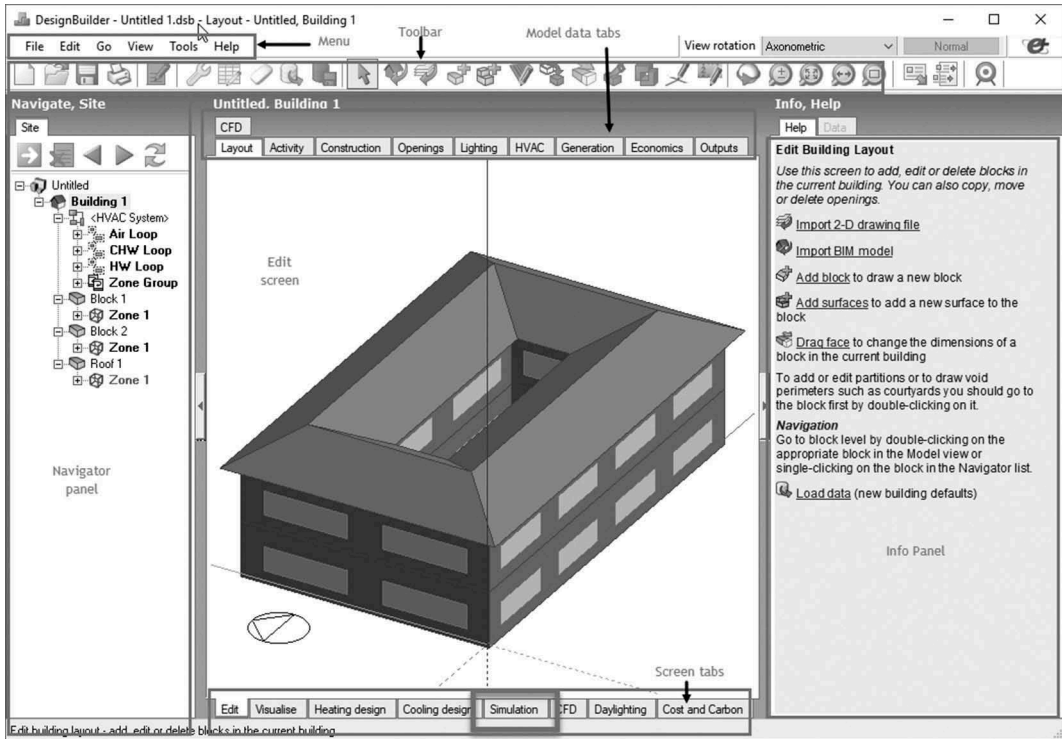
Step 6: Click **OK**.



The building layout appears with the following tabs at the bottom of the central display screen:

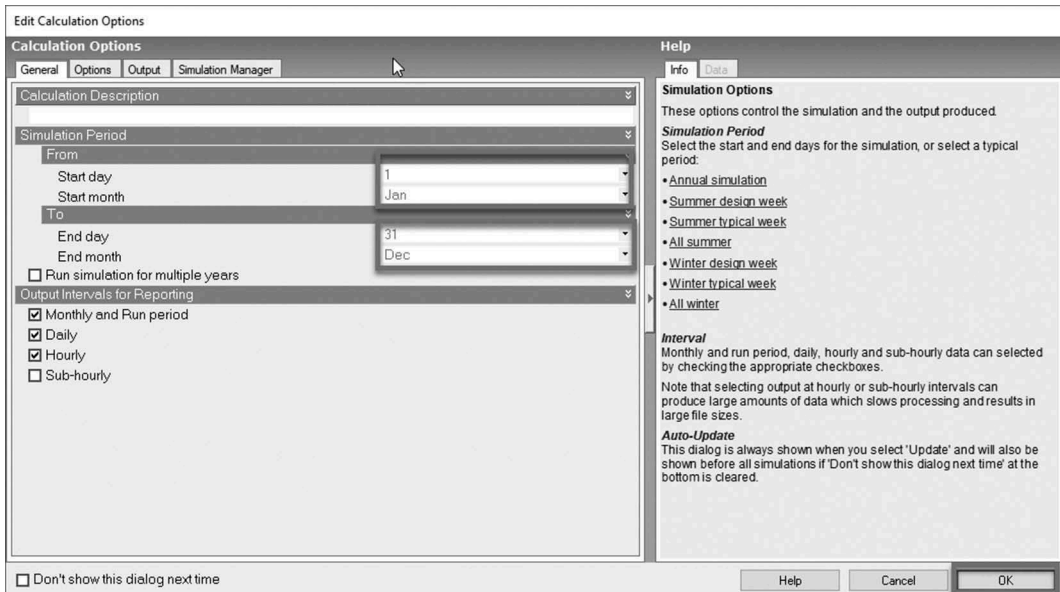
- **Edit**
- **Visualise**
- **Heating design**
- **Cooling design**
- **Simulation**
- **CFD**
- **Daylighting**
- **Cost and carbon**

Step 7: Select the **Simulation** screen tab. Click **Update data**.

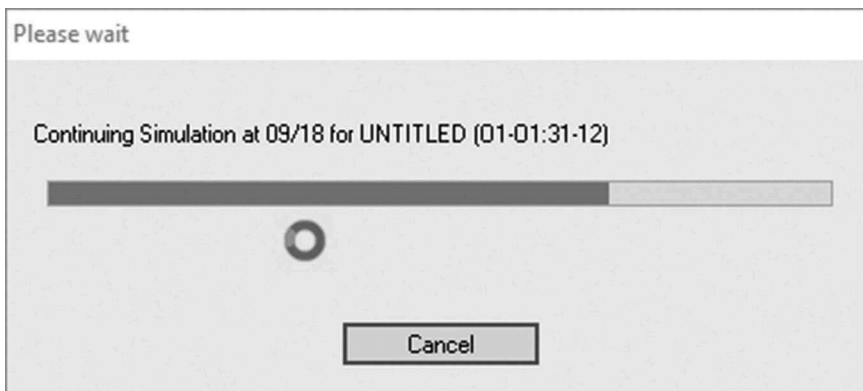


The **Edit Calculation Options** screen appears.

Step 8: Enter the **Simulation Period** start date as **1 Jan** and the end date as **31 Dec**. Click **OK** to start the simulation.



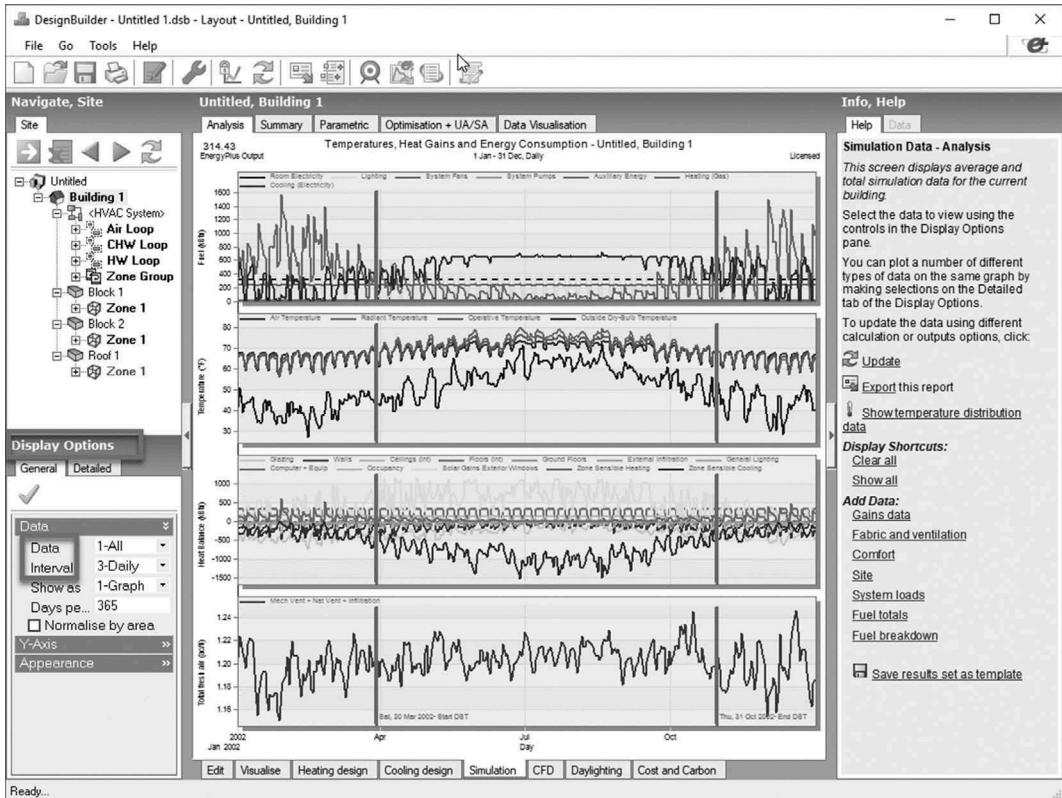
A screen appears showing the simulation progress. Depending on the configuration of the computer, it can take several minutes to complete the simulation.



After the simulation is completed, results are displayed in the **Analysis** subtab of the **Simulation Screen** tab.

Step 9: Under **Display Options**, select **Fuel totals** from the **Data** drop-down list and **Run period** from the **Interval** drop-down list. A screen appears with a bar graph for annual fuel totals for electricity and gas.

Note: The results are either displayed in IP or SI units based on your configuration of DesignBuilder. Switching between SI and IP units is explained in Step 15.



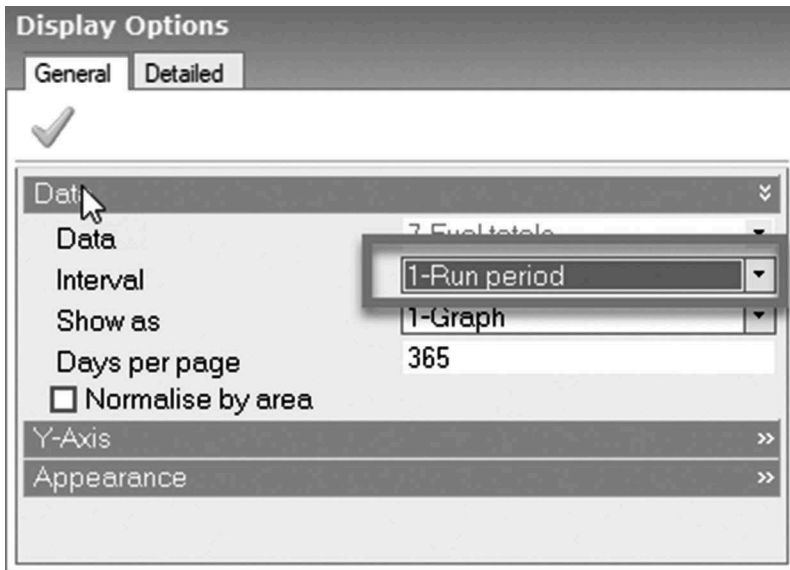
Display Options

General | Detailed

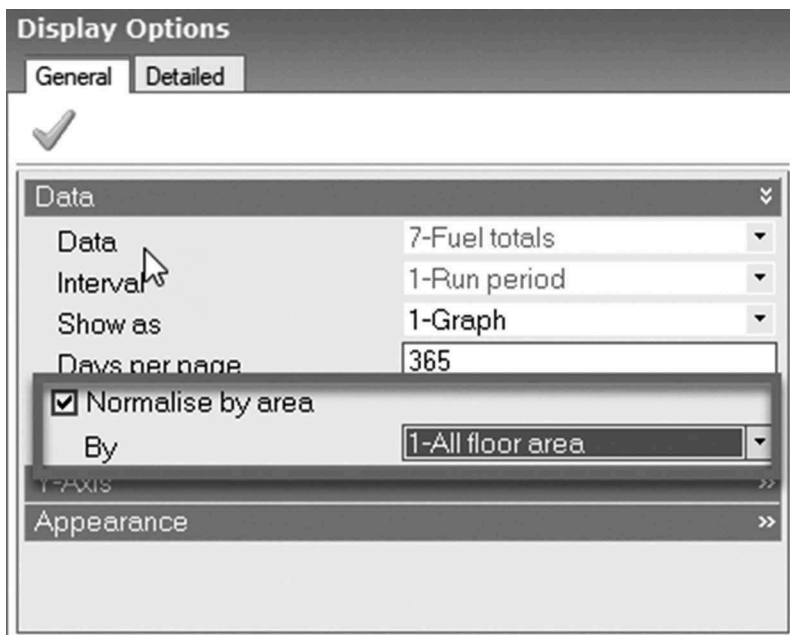
[Checkmark]

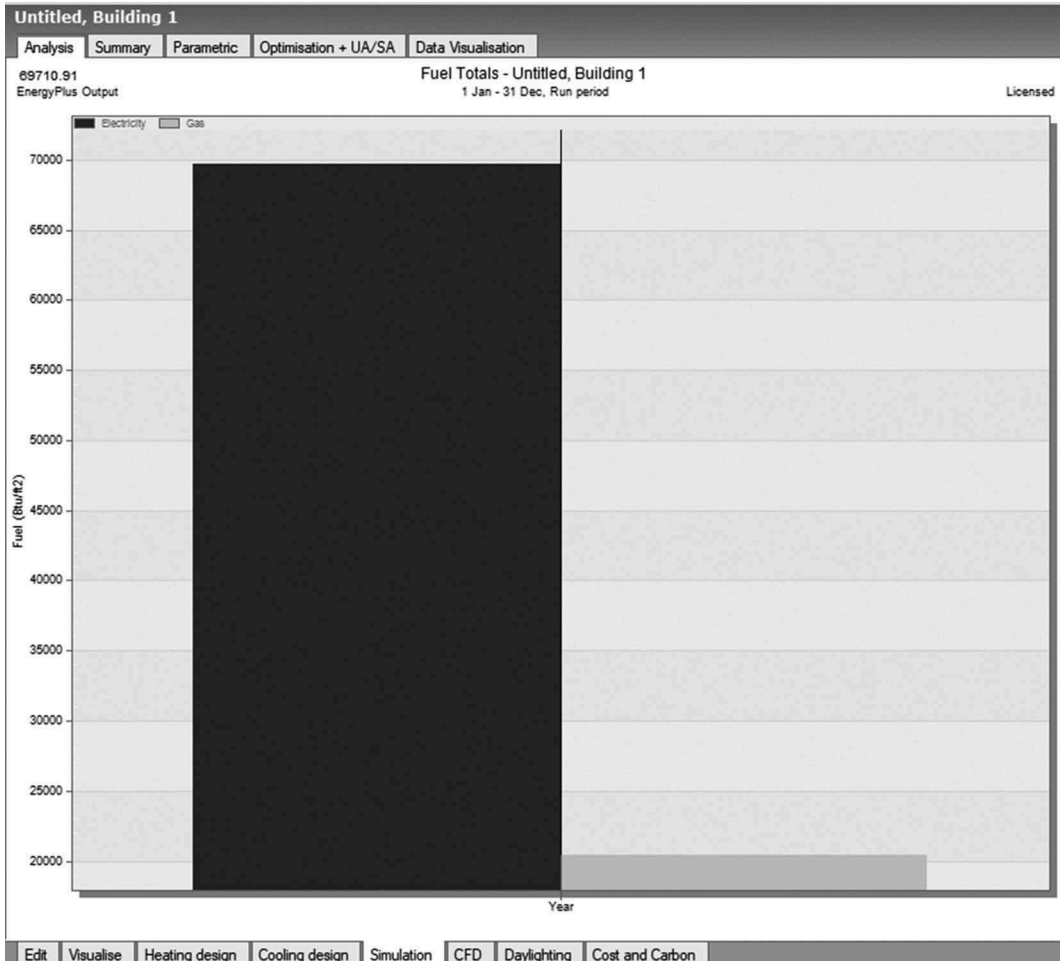
Data

Data	7-Fuel totals
Interval	3-Comfort
Show as	4-Internal gains
Days per page	5-Fabric and ventilation
<input type="checkbox"/> Normalise by floor area	6-Fuel breakdown
Y-Axis	7-Fuel totals
Appearance	8-CO2 production
	9-System loads
	99-Custom



Step 10: Select the **Normalise by floor area** check box and **All floor area** from the **By** drop-down list to view the energy use intensity (EUI) of the building.





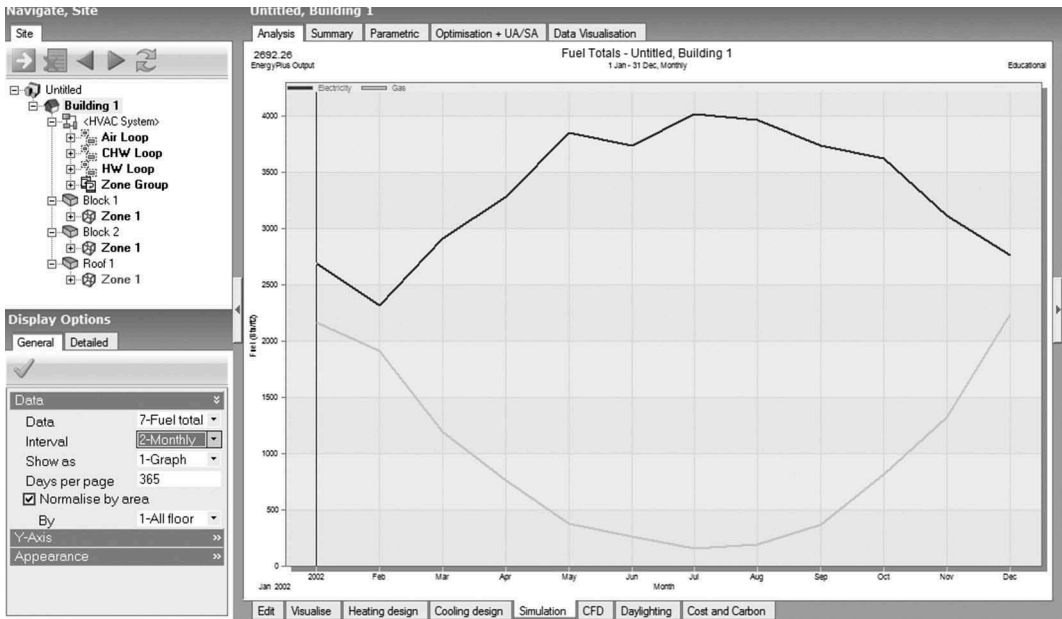
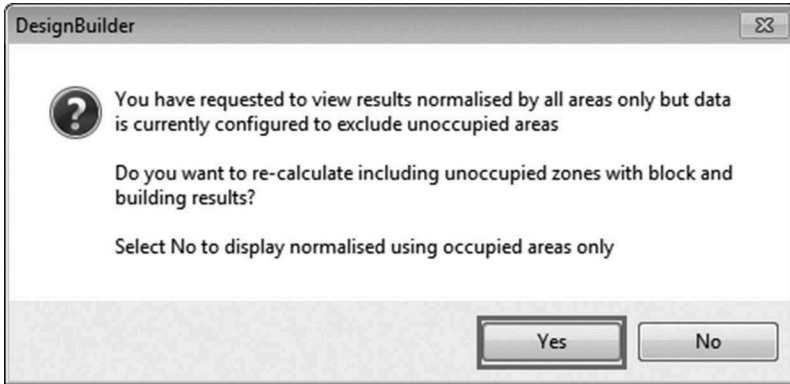
Units for the **Fuel totals** can be seen on the y -axis of the graph.

The term *energy use intensity* (EUI) refers to the energy consumption of the building per unit area per annum. The same term, in some countries, is also called the *energy performance index* (EPI). The EUI of a building is calculated by dividing the annual total energy consumption (all fuel types) of the building by its gross floor area. The unit of measurement is kWh/m² yr or kWh/ft² yr or Btu/ft² yr. A lower EUI means a better energy performance.

The *gross floor area* of a building is the total built-up area, which includes all conditioned and unconditioned enclosed spaces of the building.

Step 11: Change the **Interval from Run** period to **Monthly** to view monthly results. Refer to Step 9.

A DesignBuilder message box appears. Click **Yes**. Click **Update Data**. Click **OK** to perform a simulation to update the results.



Step 12: Select **Grid** from the **Show as** drop-down list to view results in a grid format.

The screenshot shows the software interface for 'Untitled, Building 1'. The 'Data Visualisation' tab is active, displaying a table of energy data. The 'Display Options' panel on the left is set to 'General' and shows 'Show as' set to '2-Grid'.

Date/Time	Electricity (Btu/ft2)	Gas (Btu/ft2)
01/01/2002	2692.263	2164.233
01/02/2002	2318.845	1909.983
01/03/2002	2915.708	1187.944
01/04/2002	3284.352	760.0184
01/05/2002	3850.222	370.7988
01/06/2002	3741.162	255.3987
01/07/2002	4023.724	155.093
01/08/2002	3963.518	190.6269
01/09/2002	3742.542	366.0908
01/10/2002	3620.703	808.7684
01/11/2002	3115.801	1320.318
01/12/2002	2762.257	2236.482

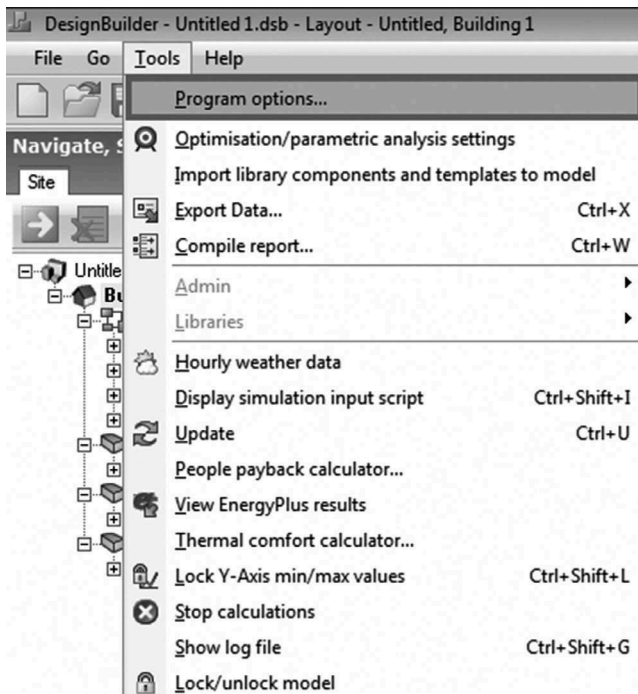
Step 13: Select **Fuel breakdown** from the **Data** drop-down list to view results for fuel breakdown.

This is a close-up of the 'Display Options' panel. The 'Detailed' tab is selected. The 'Data' dropdown menu is open, and '6-Fuel breakdown' is selected. Other settings include 'Interval' set to '2-Monthly', 'Show as' set to '2-Grid', 'Days per page' set to '365', and 'Normalise by area' checked. The 'By' dropdown is set to '2-Occupied floor area'.

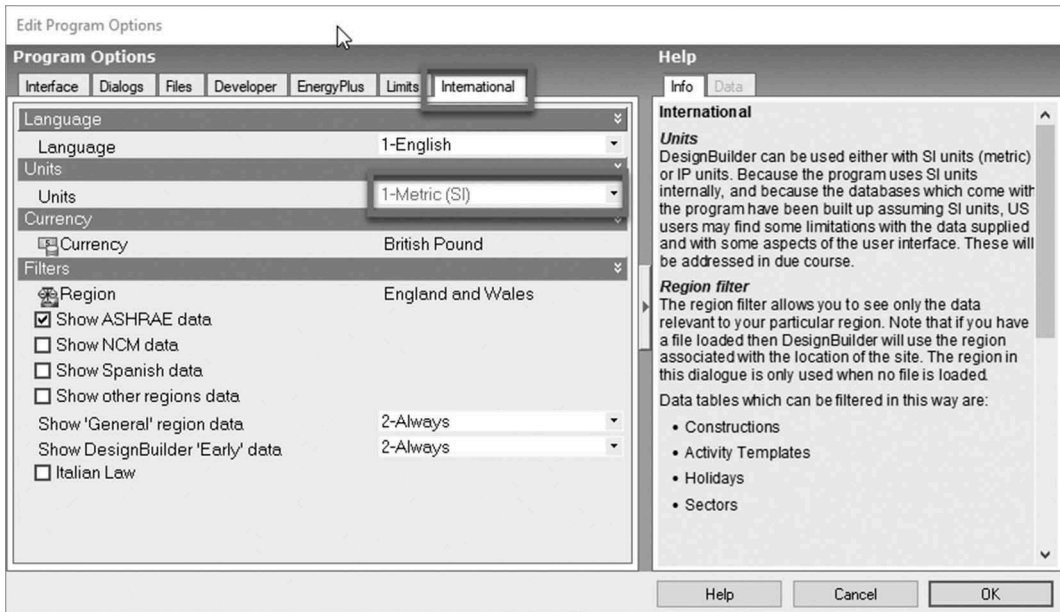
Date/Time	Room Electricity (Btu/It2)	Lighting (Btu/It2)	System Fans (Btu/It2)	System Pumps (Btu/It2)	Auxiliary Energy (Btu/It2)	Heating (Gas) (Btu/It2)	Cooling (Electricity) (Btu/It2)
01/01/2002	692.0494	753.6227	686.3734	0.9800797	1.22131	2164.233	558.0164
01/02/2002	604.6763	655.3242	619.3822	0.8717843	1.076829	1909.983	437.5139
01/03/2002	639.348	688.0903	680.3114	0.824749	0.6714941	1187.944	906.4615
01/04/2002	662.925	720.8566	657.5258	0.9852896	0.4275441	760.0184	1241.631
01/05/2002	692.0494	753.6227	681.5731	2.009294	0.2079078	370.7988	1720.759
01/06/2002	610.2236	655.3242	657.4021	2.297375	0.1430883	255.3987	1815.771
01/07/2002	692.0494	753.6227	683.5579	2.937779	8.807701E-02	155.093	1891.468
01/08/2002	665.6987	720.8566	683.108	2.764592	0.1076462	190.6269	1890.983
01/09/2002	636.5743	688.0903	657.5529	2.087056	0.2052731	366.0908	1758.032
01/10/2002	692.0494	753.6227	678.1192	1.409459	0.454374	808.7684	1494.047
01/11/2002	636.5743	688.0903	659.871	1.037668	0.7438698	1320.318	1123.483
01/12/2002	665.6987	720.8566	687.6447	1.153641	1.256748	2236.482	685.6465

In all the preceding steps, the results are in SI or IP units based on the existing configuration of DesignBuilder in your system. To change the units, perform the following steps.

Step 14: From the **Tools** menu, select **Program options**. The **Edit Program Options** screen appears.



Step 15: Select the **International** tab, and select **Units** as per your requirement. Click **OK**. DesignBuilder updates all the values in the selected units. SI units will be used in this workbook.



Step 16: From the **File** menu, select **Save** to save this model.

EXERCISE 1.1 COMPARE THE EUIS OF RESIDENTIAL AND OFFICE BUILDINGS

Courtyard with VAV Example is for an office space. Simulate a file with residential usage and compare the results.

DesignBuilder can open only one file at a time.

Hint: Open the file **House example 1**. Ensure that the location is London Gatwick. Repeat the steps given in Tutorial 1.1 to find the EUI. Enter the EUI values in the last column of Table 1.1.

You can see that even with the same location, the EUIs of office buildings and residential buildings are different. This is mainly due to the difference in building usage, which includes difference in timing and duration of use, occupancy density, nature of equipment used and other factors. Office buildings usually have a higher EUI, as they have higher internal loads (see Table 1.1).

TABLE 1.1
Energy use intensities for office and residential buildings

Energy use	EUI (kWh/m ²)	
	Office building	Residential building
Electricity		
Gas		

Tutorial 1.2

Creating a Single-Zone Model

GOAL

To create a single-zone model and find heating and cooling capacities

WHAT ARE YOU GOING TO LEARN?

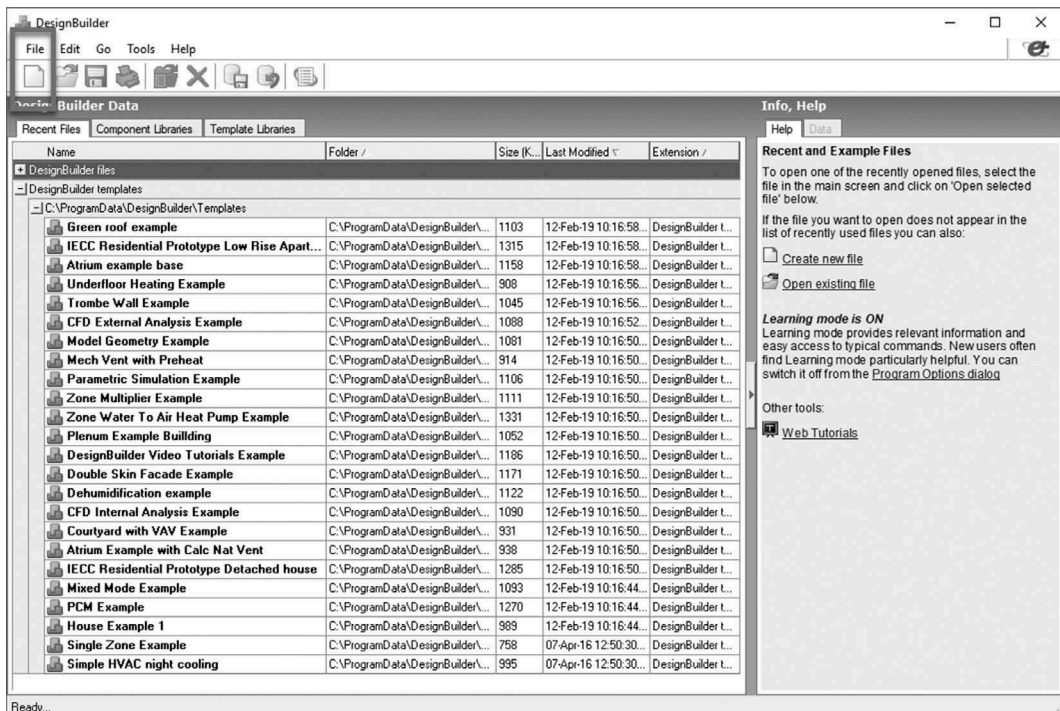
- how to draw, view and render a building model
- How to size runs for heating and cooling capacities
- How to perform an annual energy simulation

PROBLEM STATEMENT

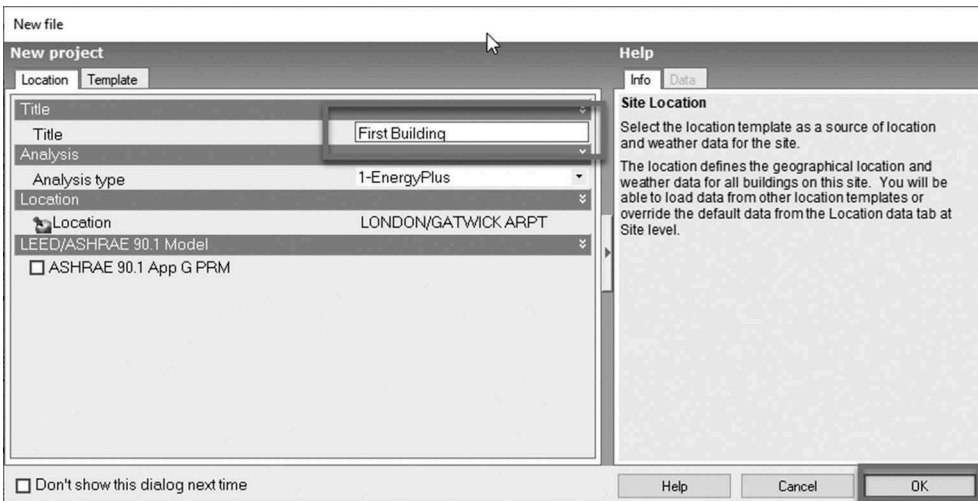
Create a new file and draw a 40- × 20-m rectangular building of height 3.5 m with location as **LONDON/GATWICK ARPT**. Perform a cooling and heating sizing and annual energy simulation.

SOLUTION

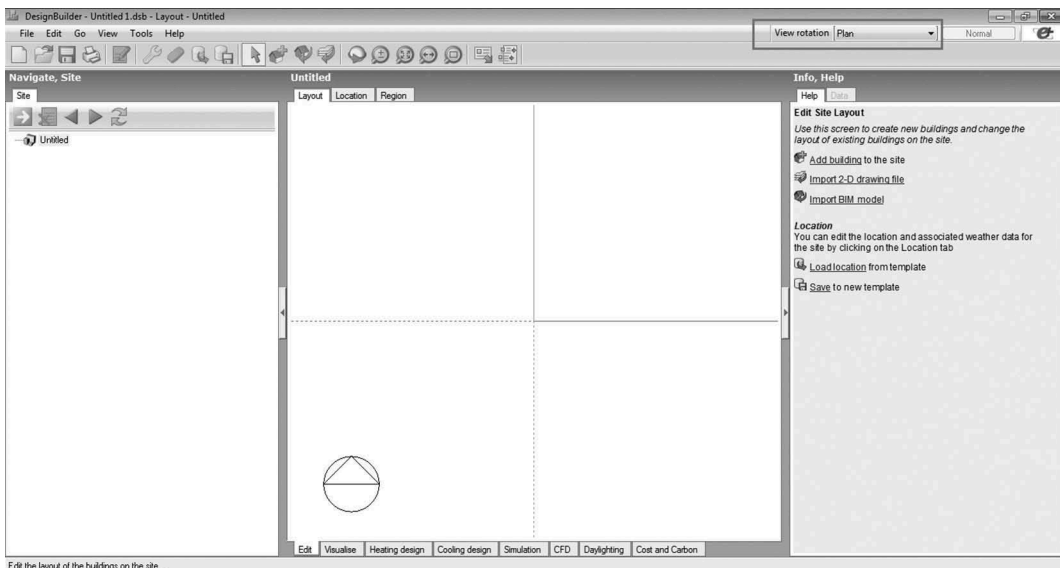
Step 1: Click **File** and select **New file**. The **New file** screen appears.



Step 2: Enter **First Building** in the **Title** text box and click **OK**. A blank building layout appears

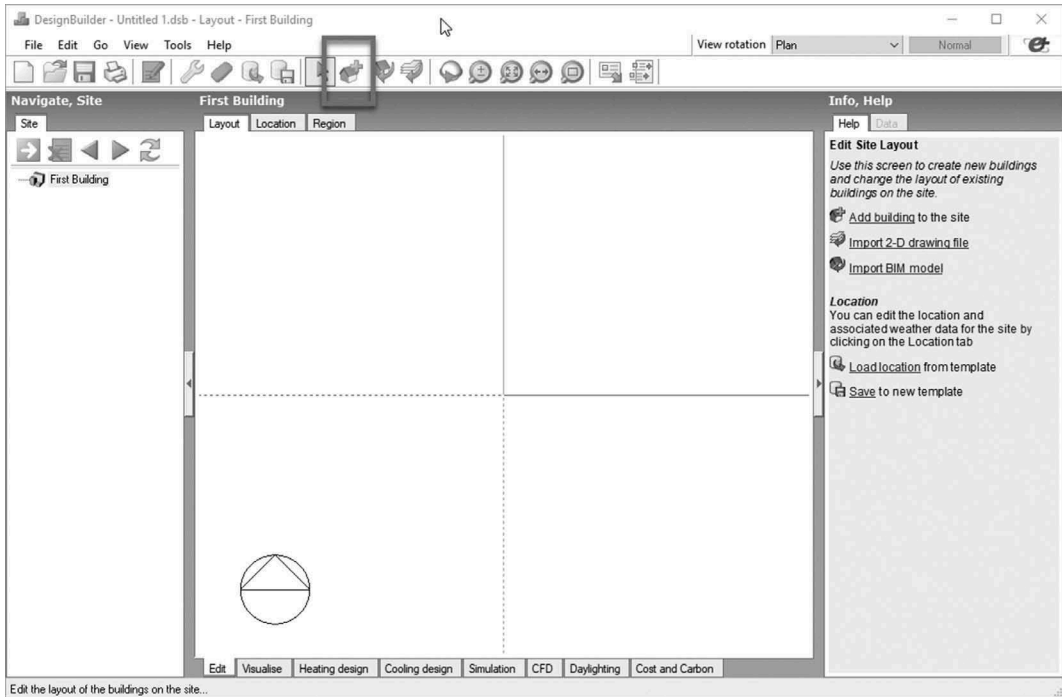


Step 3: Select **Plan** from the **View rotation** drop-down list.

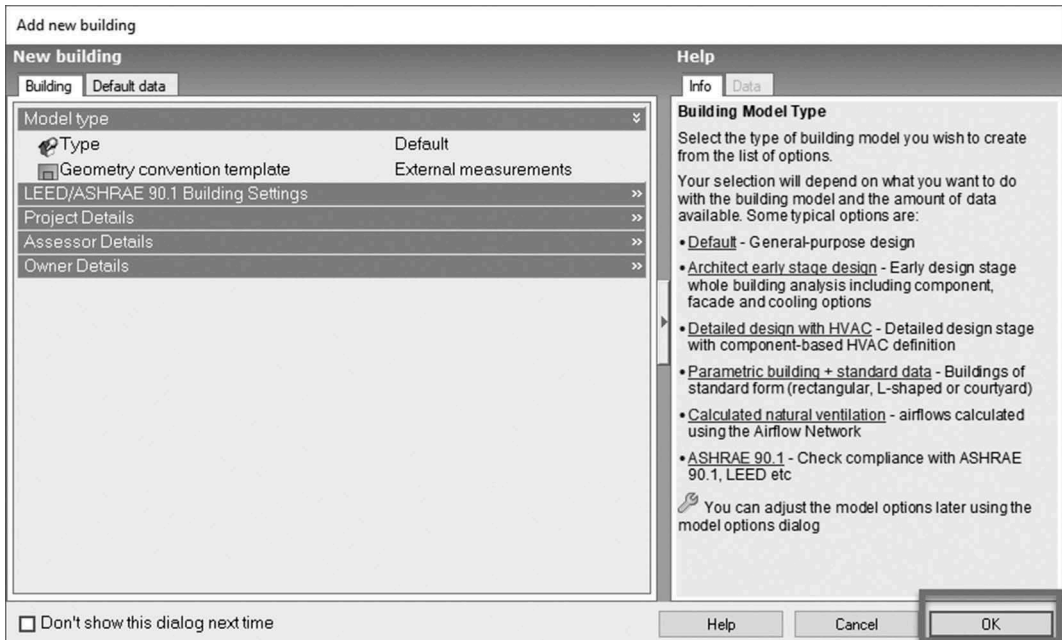


In the DesignBuilder display, the red line represents the x -axis, the green line the y -axis and the blue line the z -axis.

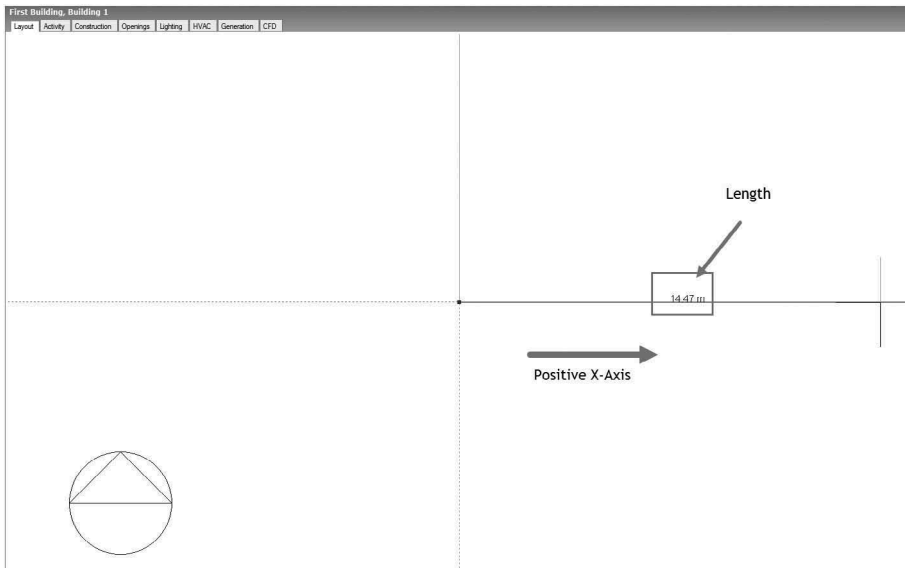
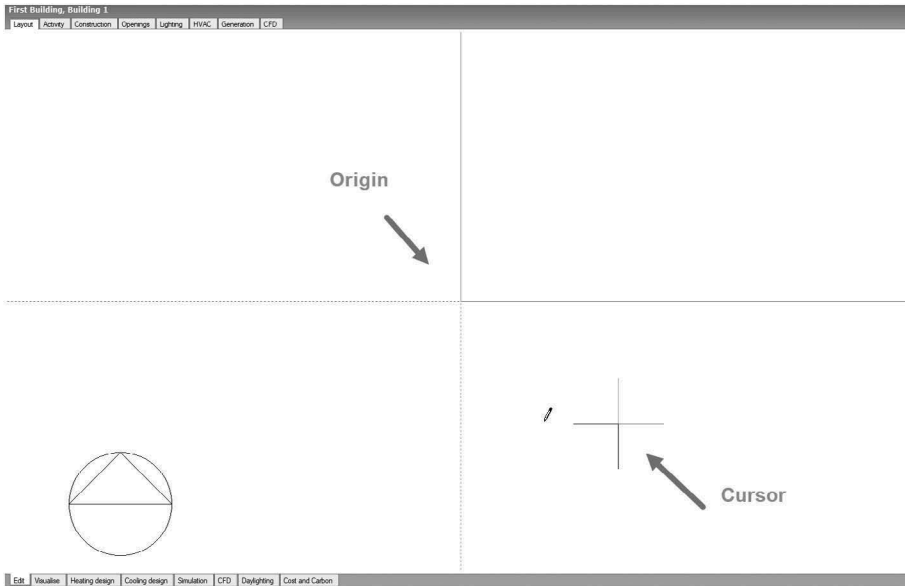
Step 4: Click the **Add new building** button. The **Add new building** screen appears.



Step 5: Click **OK**. The screen appears with a cursor to draw a building.



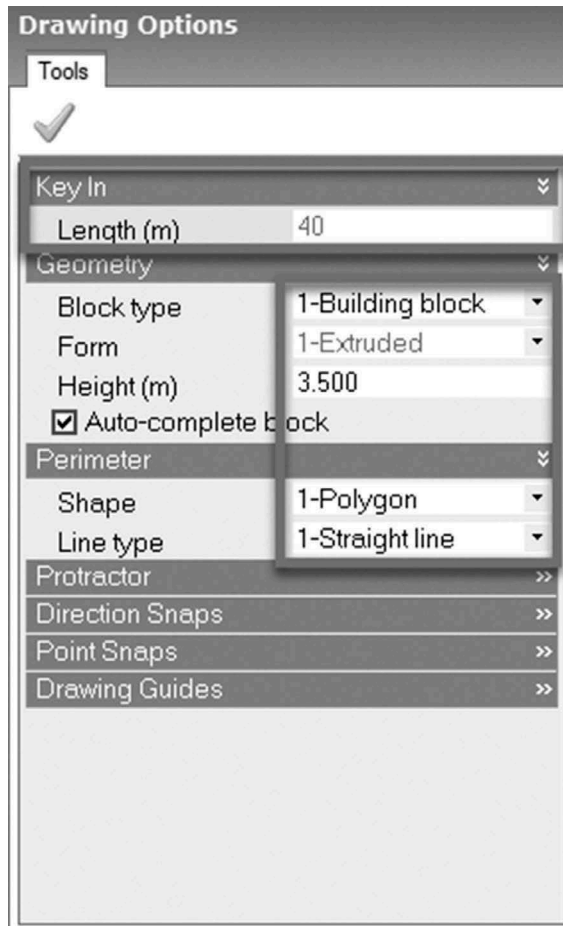
Step 6: Move the pointer to the **Origin**. Left-click, and move on the positive x -axis. The length of the segment is shown. (In case of any mistake, you can choose to cancel the drawn line by pressing the **ESC** key and then try again.)



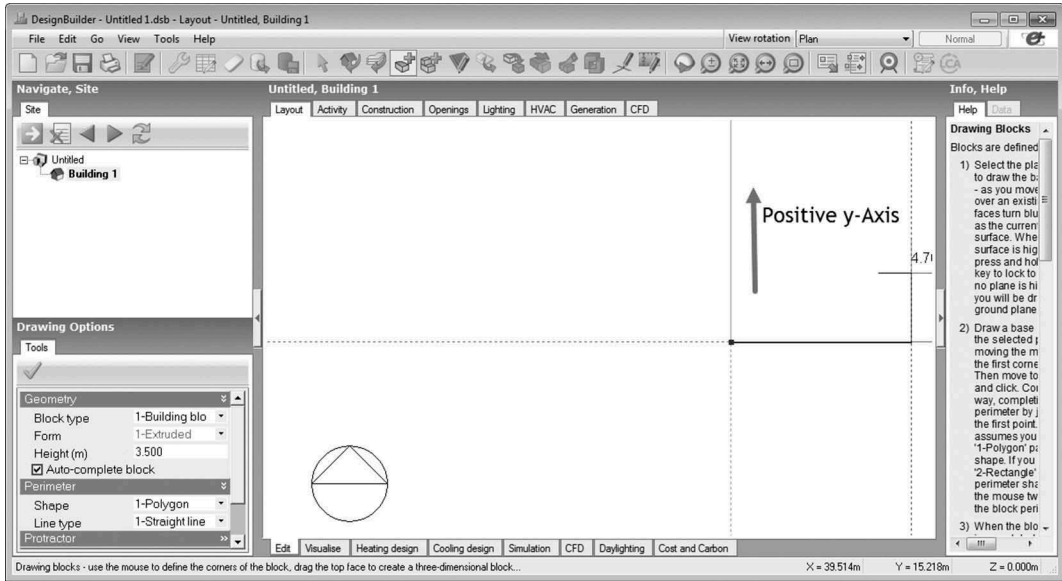
Step 7: Type **40**. You can type directly, and the text box for length will be highlighted. Fill in the value for the length in the **Drawing Options** section. The **Length** of the wall is set to **40** m. Ensure that the properties under the **Geometry** section are as follows:

- Block type: **Building Block**
- Form: **Extruded**
- Height: **3.5 m**

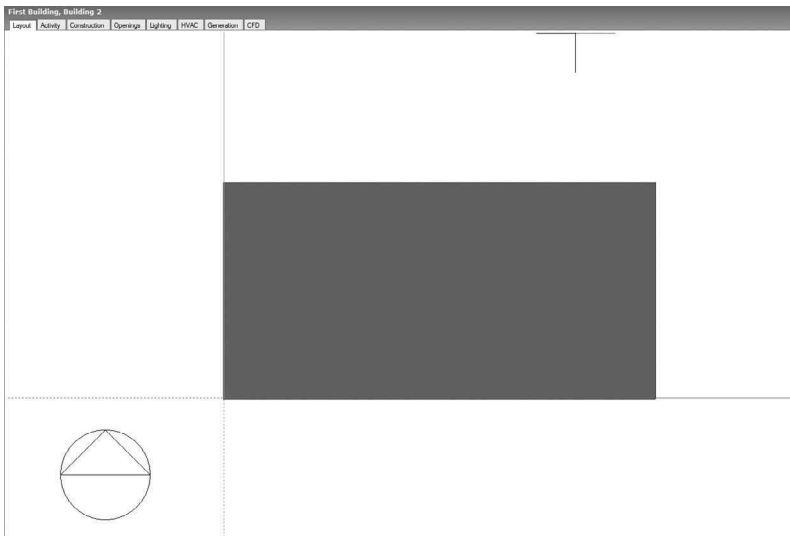
Press **Enter**.



Step 8: Scroll the mouse wheel to zoom in or zoom out until you can see the complete line of 40 m in length. Move the pointer parallel to the positive y-axis. It snaps when a dashed vertical line appears. Type **20** to draw the second side of the rectangle. Press **Enter**.



Step 9: Similarly draw other segments and complete the rectangular building block of dimensions 40 × 20 m. The following screen shows the completed block.



Step 10: Select the **Dynamic orbit** tab on the main menu bar. This shows the block in the orbit mode. Click and drag the mouse in the layout to view the block in the orbit mode.

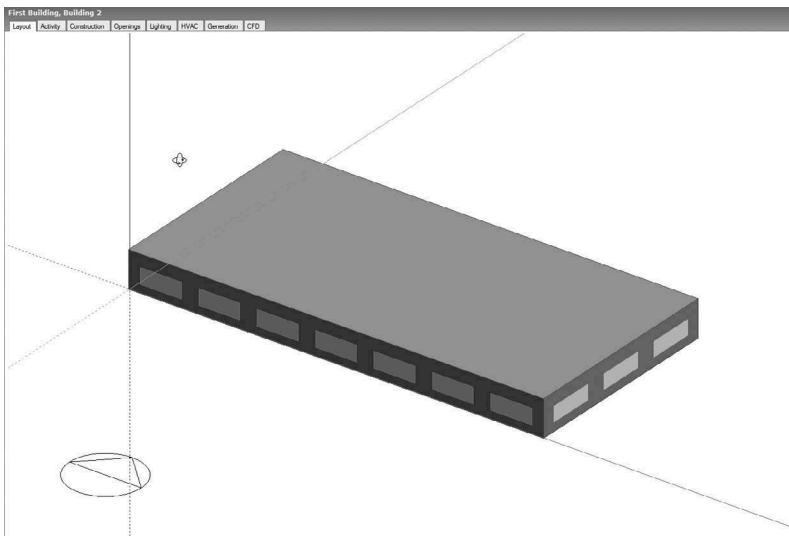


DesignBuilder Snap

When drawing perimeter lines, block partition or surface opening direction snaps can be used to draw lines

- Parallel with the active drawing plane axes (axis snap),
- Parallel with existing elements (parallel snap) or
- Perpendicular to existing elements (normal snap).

Source: https://designbuilder.co.uk/helpv6.0/Content/Direction_snaps1.htm.



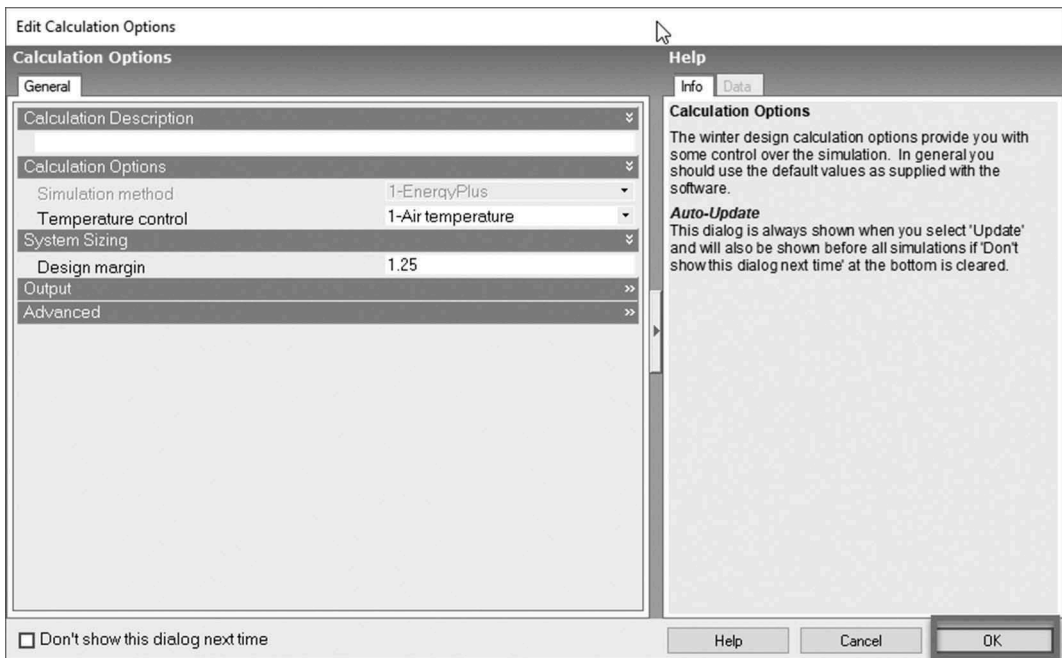
Now you will learn to run the system sizing.

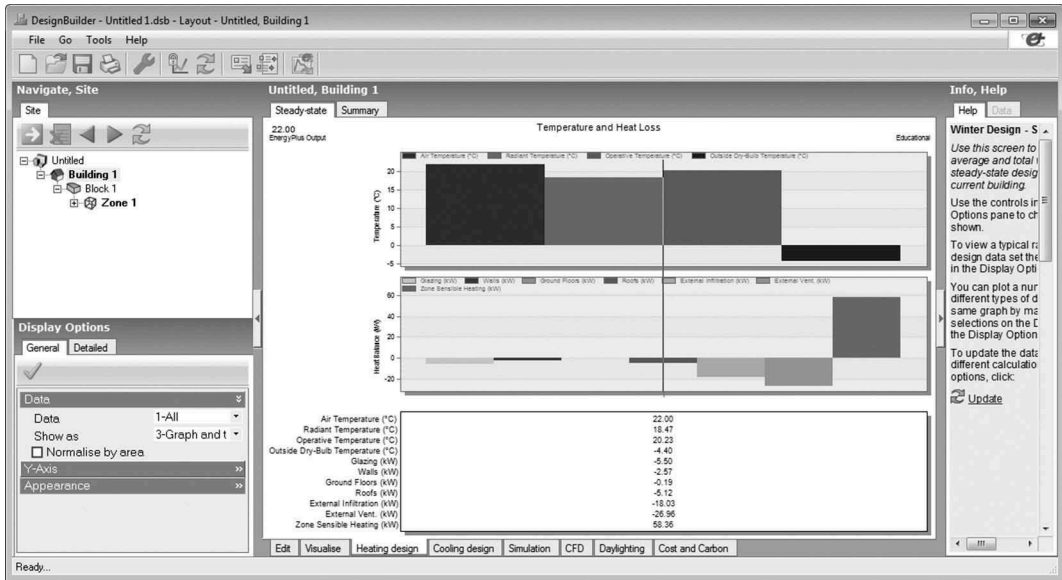
Step 11: Select the **Heating design** screen tab at the bottom. Click **Update data**. The **Edit Calculation Options** screen appears.



Heating design calculations show the heating system size in the worst conditions (no internal loads and solar heat gains) for a winter design day. Steady-state simulations assume that the temperature across the envelope does not vary with time.

Step 12: Select **OK**. The screen appears with the average and total winter steady-state design data for the current building in graphical format.





The graph in the preceding figure shows the heat balance to maintain an inside temperature of 22°C when the outdoor dry bulb temperature is -4.4°C. You can see that there is a heat flow from the inside to the outside (shown as negative numbers; the convention is that a positive value is used for a heat flow from the outside to the inside) through the envelope as a result of infiltration and ventilation. To balance this heat loss, the required zone sensible heating is 58.36 kW. The table in the preceding figure also shows the air temperature, radiant temperature and operative temperature, where the operative temperature is calculated as the average of the radiant and air temperatures.

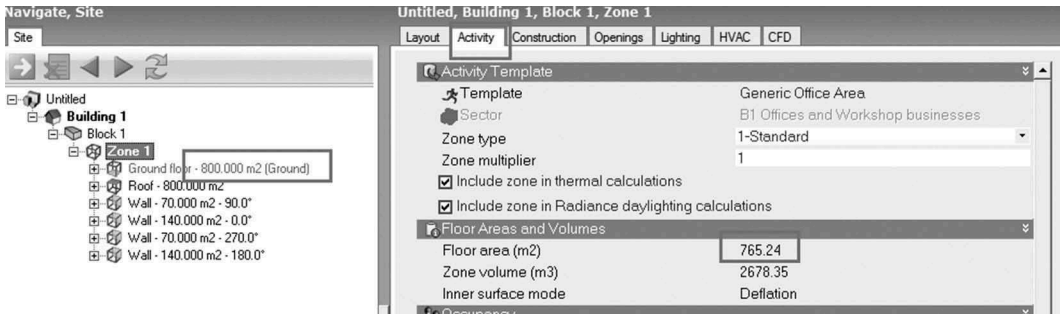
Steady-state heat loss is the total heat loss from the building. In other words, it is the amount of heat needed to maintain the given indoor comfort temperature.

Step 13: Select the **Summary** tab. The heating design data summary appears.

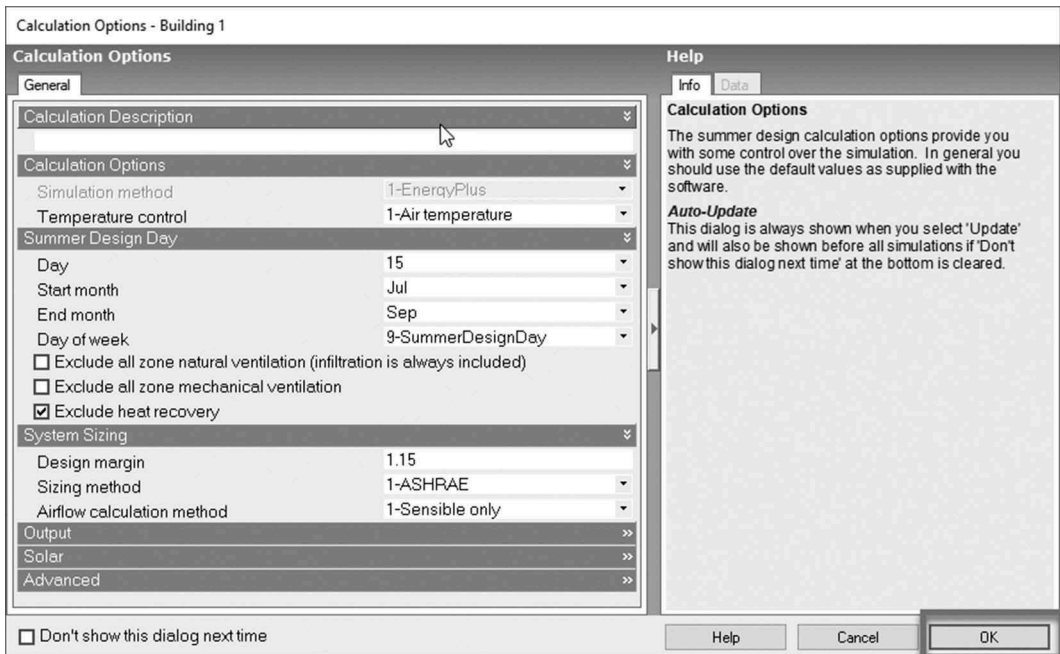
Zone	Comfort Temperature (°C)	Steady-State Heat Loss	Design Capacity (kW)	Design Capacity (kW/m ²)	Glazing Gains (...)	Wall Gains (kW)	Floor Gains (kW)	Roof and Ceilin...	Ventilation Gain...	Infiltration Gain...
[-] Building 1 Total Design Heating Capacity = 72.950 (kW)										
[-] Block 1 Total Design Heating Capacity = 72.950 (kW)										
Zone 1	20.23	58.36	72.95	95.319	-5.501	-2.566	-0.188	-5.118	-26.965	-18.028

Design capacity is the total heat loss multiplied by the sizing factor. Sizing factor is the safety factor considered in sizing an HVAC system. For example, heating systems are commonly oversized by 25%.

The design capacity of the building is 72.950 kW, which is calculated considering the sizing factor of 25% over the steady-state heat loss of 58.36 kW. The design capacity normalized by area is 95.55 W/m², which is calculated for the building floor area. In this case, the building dimensions are 40 × 20 m, and the building area is 800 m² (net floor area is 765.24 m²).

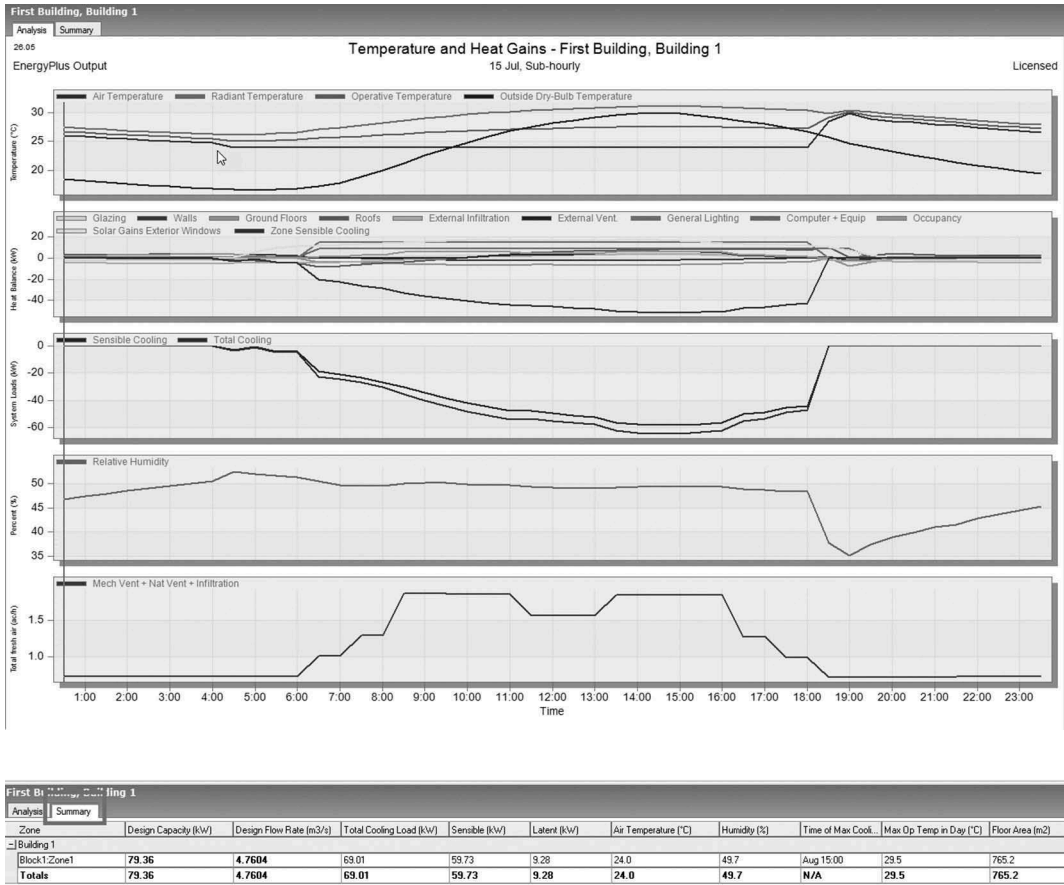


Step 14: Similarly select the **Cooling design** screen tab at the bottom. Click on **Update data**. The **Calculation Options – Building 1** screen appears. Click **OK**. The temperature, heat gains and other parameters appear in graphical format.



A cooling system is commonly oversized by 15%.

Step 15: Select the **Summary** tab. The screen appears with the cooling design data summary.



The screen data are provided in tabular format in Table 1.2. The load calculated in the building is 79.36 kW. The cooling load is also described in tons of refrigeration (TR). For this building, it is 22.6 TR. Enter the cooling and heating capacities in Table 1.4.

TABLE 1.2
Data for the single-zone model

Zone	Block 1: Zone 1
Design capacity (kW)	79.36
Design flow rate (m ³ /s)	4.76
Total cooling load (kW)	69.01
Sensible (kW)	59.73
Latent (kW)	9.28
Air temperature (°C)	24.0
Humidity (%)	49.7
Time of max cooling	August 15:00
Maximum operating temperature in day (°C)	29.5

(Continued)

TABLE 1.2 (Cont.)

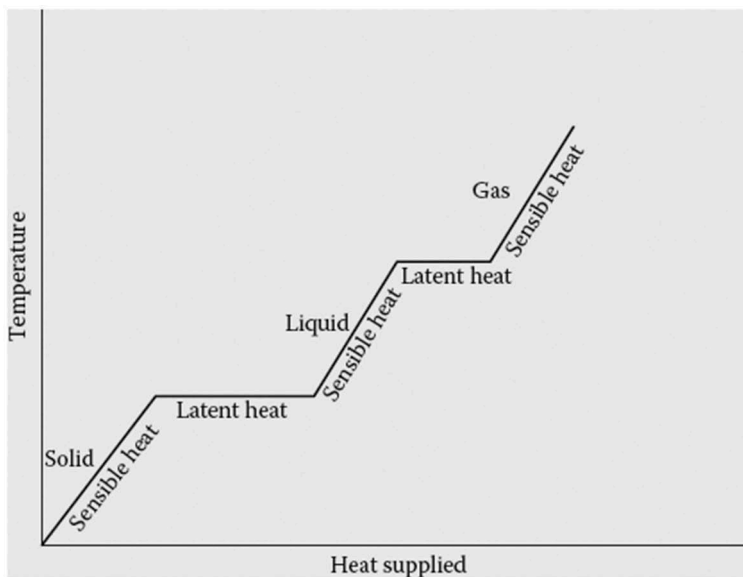
Zone	Block 1: Zone 1
Floor area (m ²)	765.3
Volume (m ³)	2,678.3
Flow/floor area [litres (l)/s-m ²]	6.22
Design cooling load per floor area (W/m ²)	103.7
Outside dry bulb temperature at time of peak cooling load (°C)	30.5

A *ton of refrigeration* (TR) describes the heat-extraction capacity of refrigeration and air-conditioning equipment. It is defined as the rate of heat transfer that results in the melting of 1 short ton (907 kg) of pure ice at 0°C in 24 hours. A refrigeration ton is approximately equivalent to 3.5 kW of cooling effect.

Sensible vs. Latent Heat

Sensible heat is the energy required to change the temperature of a substance with no phase change. Sensible heat represents only the dry bulb temperature change. *Latent heat*, however, does not affect the temperature of a substance. Heat that causes a change of state with no change in temperature is called *latent heat*. A cooling system should be capable of removing both the sensible and latent heats from a building. Therefore, the total cooling capacity of a system will be (sensible heat load + latent heat load) × sizing factor.

In this tutorial, sensible heat is 59.73 kW and latent heat is 9.28 kW. The sum of both sensible and latent heats is 69.01. Therefore, the design capacity calculated by multiplying 69.01 by the sizing factor (1.15) is 79.36. You can divide this by 3.51 to convert it into the unit of tons of refrigeration: $\frac{79.36}{3.51} = 22.6\text{TR}$



Step 16: Select the **Simulation** screen tab to perform the annual simulation. Select **Fuel breakdown** from the **Data** drop-down list, **Run period** from the **Interval** drop-down list and **Grid** from the **Show as** drop-down list.



DesignBuilder - Untitled 1.dsb - Layout - First Building, Building 1

File Go Tools Help

First Building, Building 1

Date/Time	Room Electricity (kWh)	Lighting (kWh)	Heating (Gas) (kWh)	Cooling (Electricity) (kWh)	DHW (Electricity) (kWh)
01-Jan-02	33167.88	47934.77	30669.47	14386.49	3001.146

Display Options

General Detailed

Data: 6-Fuel breakdown

Interval: 1-Run period

Show as: 2-Grid

Days per page: 365

Normalise by area

Y-Axis: >>

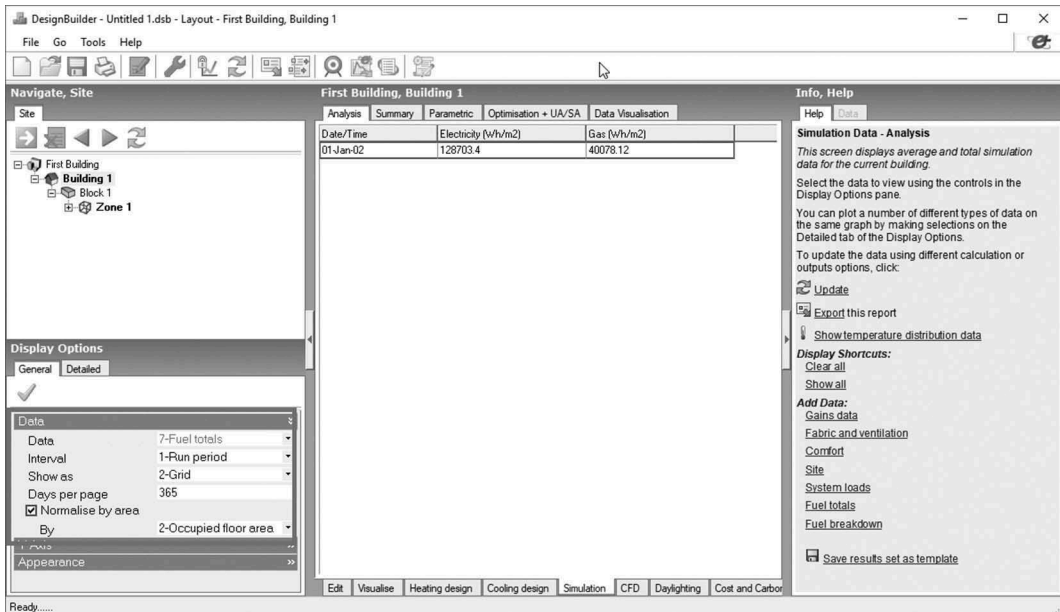
Appearance: >>

Simulation Data

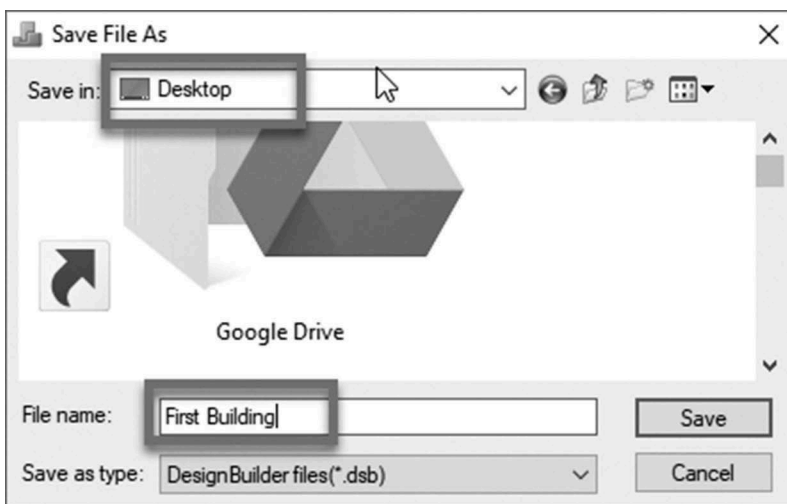
This screen displays and total simulation current building. Select the data controls in the pane. You can plot a different types same graph by selections on the Display Options. To update the different calculation options, click: Update Export this Show temp distribution data Display Short Click all Show all Add Data: Gains data Fabric and v Comfort Site System load

Ready...

Step 17: Select the **Normalise by floor area** checkbox and **All floor area** from the **By** drop-down list to view the EUI of the building. Also select **Fuel totals** from the **Data** drop-down list. The DesignBuilder message screen appears. Click **Yes** to perform simulations for all floor area. Enter the electricity EUI value in Table 1.3.



Step 18: Save the model as **First Building** on your desktop. You are going to use this model in forthcoming tutorials.



EXERCISE 1.2

Compare the EUI of a large building with that of a small building. Repeat the tutorial to create an 80- × 40-m rectangular building. Compare the EUI of the larger building with that of the smaller building (the 40- × 20-m building created in Tutorial 1.2), and enter the result in Table 1.3. Enter and compare the cooling and heating capacities of the larger building in Table 1.4. The method to calculate the EUI ($\text{kWh/m}^2 \text{ yr}$) is explained in Tutorial 1.1.

TABLE 1.3
EUI for a large and small building

Energy use	EUI ($\text{kWh/m}^2 \text{ year}$)	
	Building with 40- × 20-m dimensions	Building with 80- × 40-m dimensions
Electricity		
Gas		

TABLE 1.4
Cooling and heating capacity for a large and small building

Capacity	Building with 40- × 20-m dimensions	Building with 80- × 40- m dimensions
Cooling equipment (kW)		
Heating equipment (kW)		
Cooling per unit area (kW/m^2)		
Heating per unit area (kW/m^2)		

The following observations can be made as a result of Exercise 1.2:

1. The EUIs of both the buildings are different.
2. The cooling and heating equipment capacities are greater for the 80- × 40-m building than for the 40- × 20-m building. Larger buildings require higher-capacity equipment because of their greater envelope area, occupancy and internal loads.
3. Cooling/heating equipment capacities per unit area are also different. A large building has a lower capacity per unit area. The main reason behind such a difference is that although most of the internal loads, such as occupancy, lighting and equipment, vary linearly with area, the heat gain/loss through the building envelope does not follow the same trend because of the nonlinear variation in the exposed surface area versus the floor or carpet area.

Tutorial 1.3

Evaluating the Impact of Building Location and Orientation

GOAL

To evaluate the impact of building location and orientation on HVAC system sizing and building annual energy consumption

WHAT ARE YOU GOING TO LEARN?

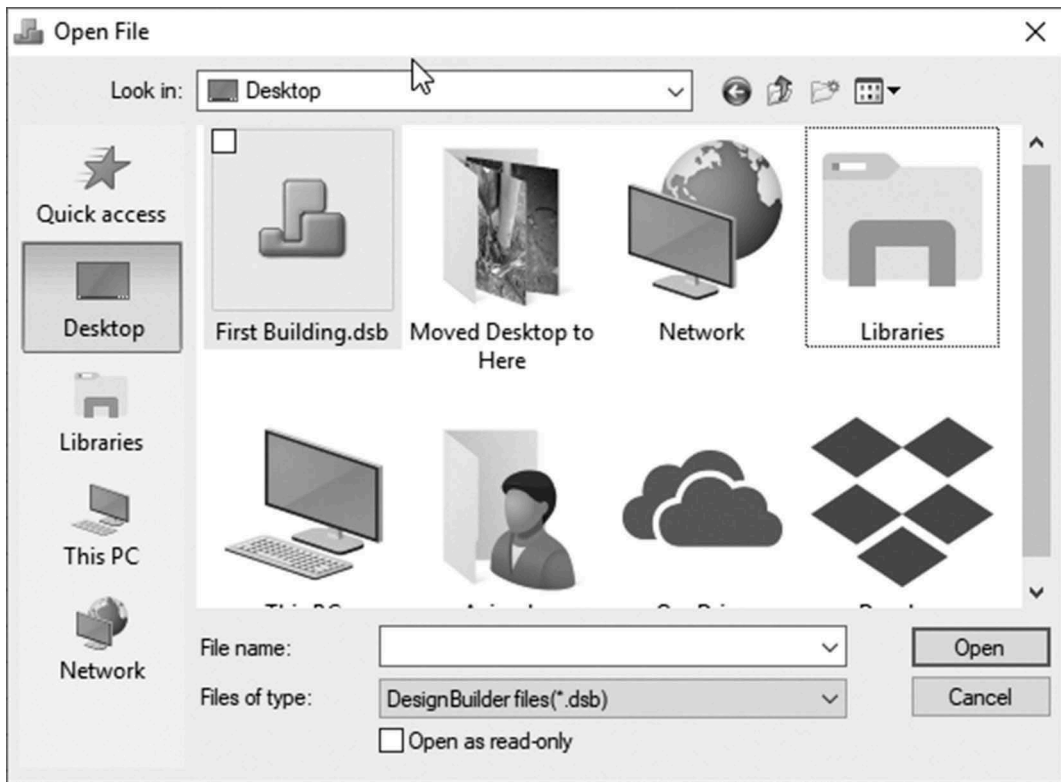
- How to change the location of a building
- How to download a weather file
- How to change the orientation of a building
- How to analyse the impact of weather and orientation on a building's performance

PROBLEM STATEMENTS

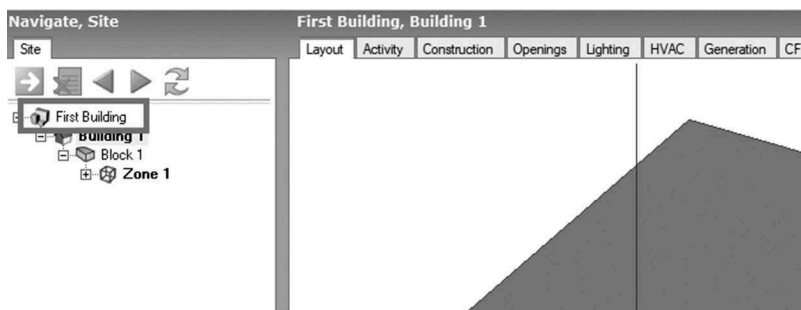
1. In Tutorial 1.2, a 40- × 20-m rectangular building was simulated for London. Simulate the same building model for New Delhi/Palam, and compare the HVAC sizing, monthly energy consumption and annual energy consumption.
2. Rotate the building 90 degrees clockwise, and simulate it for New Delhi. Compare the results of the two models (without rotation and with 90 degrees of rotation).

SOLUTION

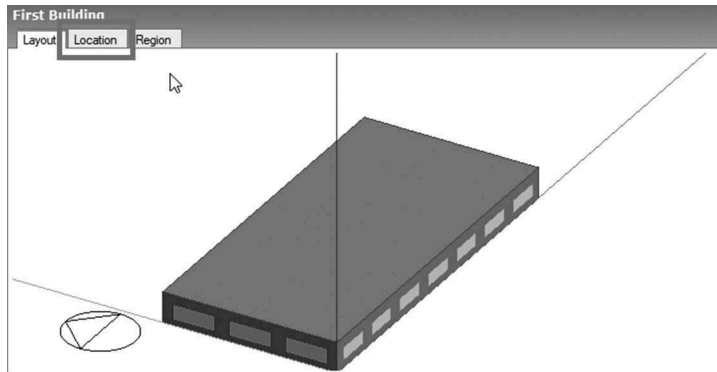
Step 1: Open the model saved in **Tutorial 1.2**.



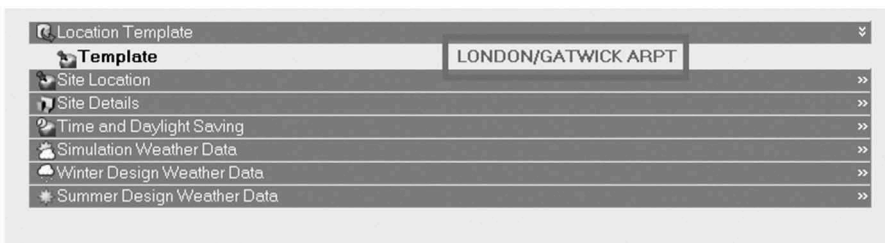
Step 2: Click **First Building**.



Step 3: Select the **Location** tab. The **Location Template** screen appears.

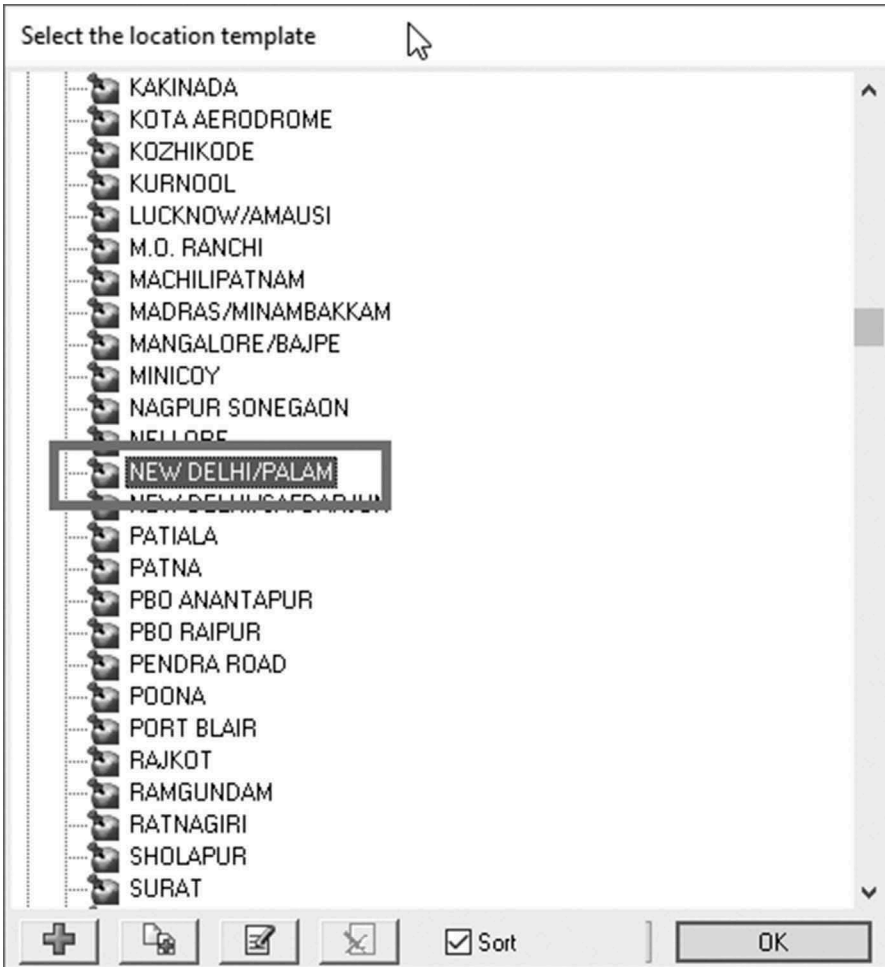


Step 4: Click **LONDON/GATWICK ARPT**. Three dots (...) appear. Click the three dots. The **Select the location template** screen appears.

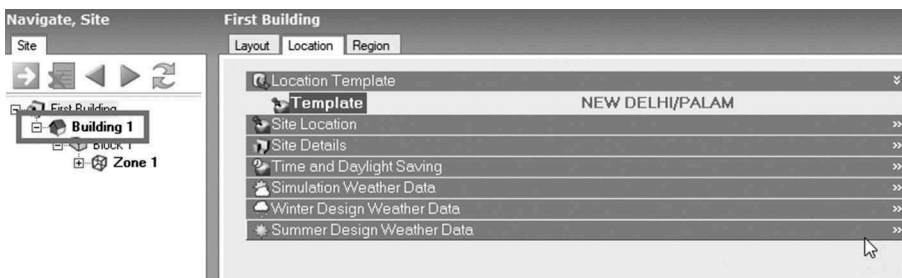


Step 5: Scroll to select **INDIA**. Double-click **INDIA**, and select **NEW DELHI/PALAM**. Click OK.



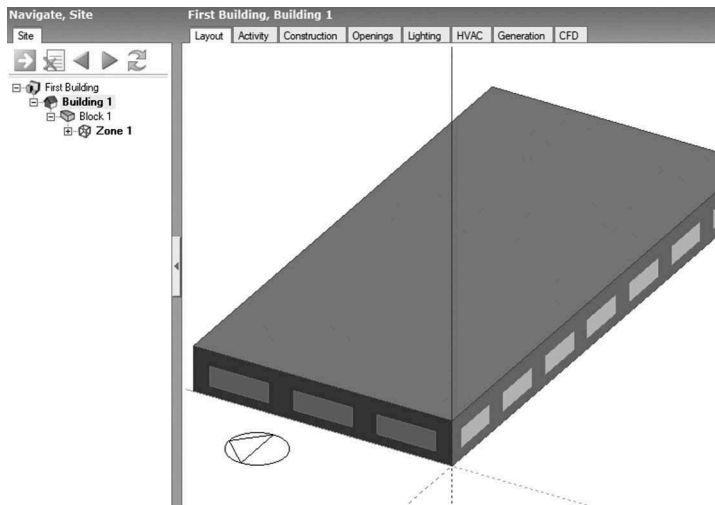
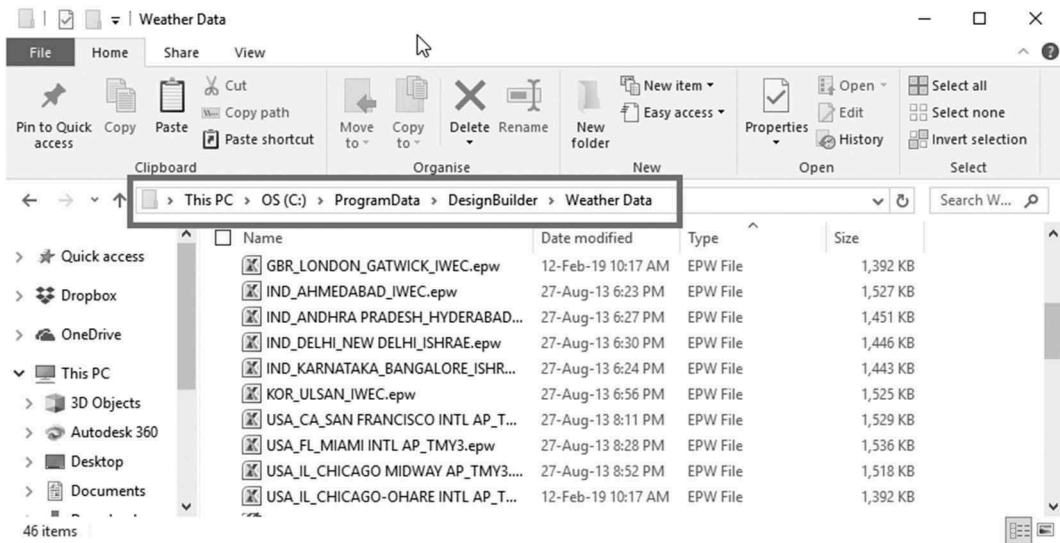


Step 6: Click **Building 1**.



Step 7: Select the **Simulation** tab. Click on **Update data**. The **Edit Calculation Options** screen appears. Click **OK**. If your computer is connected to the internet, DesignBuilder directly downloads the weather file. If, for some reason, DesignBuilder is not able to download the weather file, you can manually download the weather file from <https://energyplus.net/weather>.

Place the downloaded weather file in the folder **C:\ProgramData\DesignBuilder\Weather Data**



DesignBuilder uses hourly weather files with the **.epw** extension. Weather files can be downloaded from the following link: <https://energyplus.net/weather>. Weather files that are downloaded directly from the website should be copied in the DesignBuilder weather data folder located at **C:\ProgramData\DesignBuilder\Weather Data**.

Step 8: Compare the simulation results for the London and New Delhi locations. Results for the London location can be obtained from Tutorial 1.2.

The impact of location on building energy consumption can be seen from the results reported in Table 1.5. You can see that there is no change in room electricity and lighting. This is because there were no change in internal loads; further, as there is no daylight-based control, the change in location does not change these values. From the results in Tables 1.5 and 1.6, the following observations can be made:

- The heating energy consumption is more in London than in New Delhi. This is because London has a colder climate than New Delhi.
- The reverse is true for the cooling energy consumption because New Delhi is warmer than London in summer.
- Similarly, there is a significant effect of location on the cooling and heating equipment capacities.

TABLE 1.5
Energy consumption with a change in building location

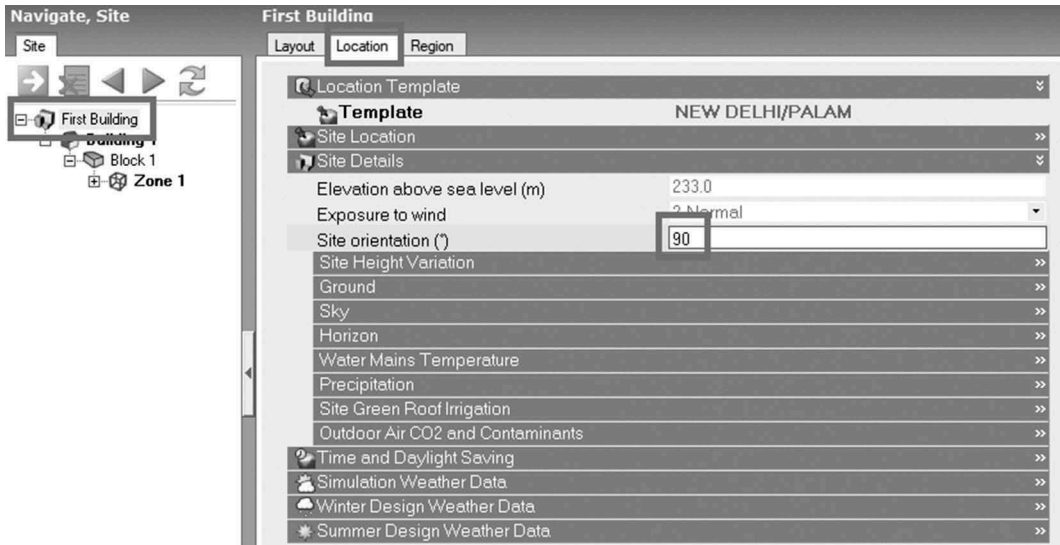
Type of consumption	Annual fuel breakdown data (kWh)	
	London (kWh)	New Delhi (kWh)
Room electricity	33,167.88	33,167.88
Lighting	47,934.77	47,934.77
Heating (gas)	30,669.47	1516.51
Cooling	14,385.49	102,428.10
Domestic hot water (DHW, electricity)	3,001.15	3,001.15

TABLE 1.6
Heating and cooling equipment capacity with a change in location

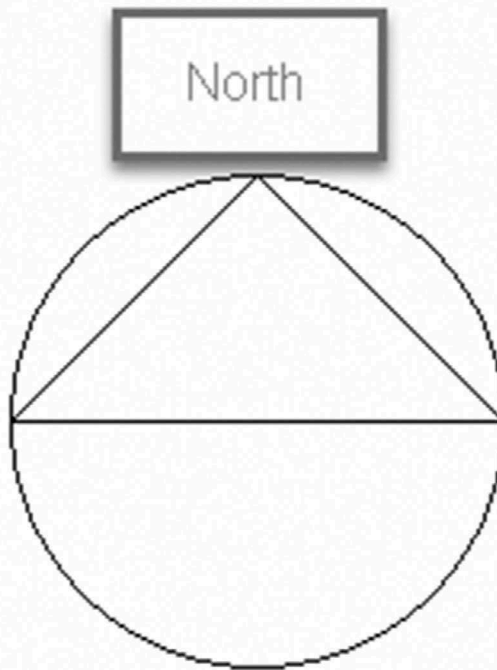
	London	New Delhi
Capacity of cooling equipment (kW)	79.36	119.35
Capacity of heating equipment (kW)	72.95	43.32

The following steps show how to change the orientation.

Step 9: Ensure that you are at the **First Building** level in the **Navigation** panel. Select the **Location** tab (refer to Steps 2 and 3 of this tutorial), and click **Site Details**. Enter **90** in the **Site Orientation** text box. Select the **Layout** tab. You can observe the change in the north arrow direction before and after changing the site orientation.

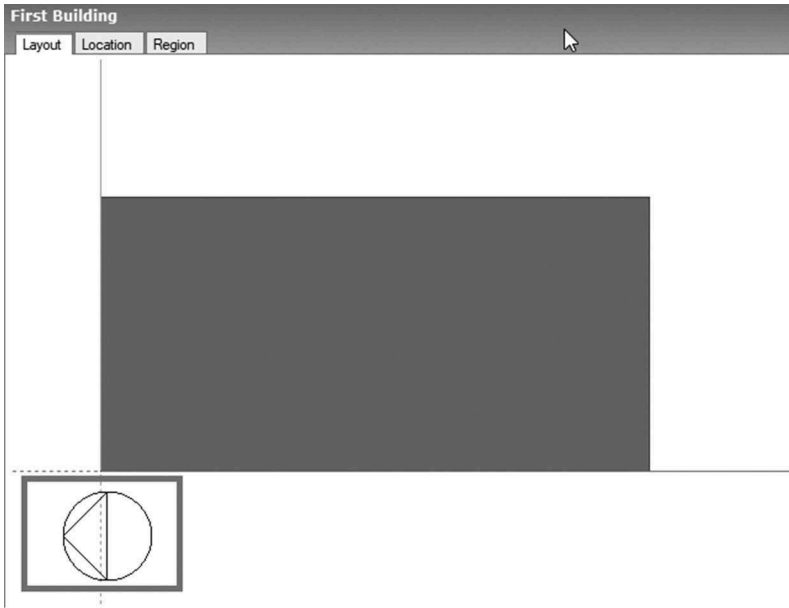


North is indicated by the direction of the north arrow in the sketch plan view. Working at the ‘untitled’ level (here **First Building**) of the tree means working at the site level. For example, if there are multiple buildings on a site that are to be modelled in DesignBuilder, after creating one building, return to the site level in the tree to start creating the next building. Therefore, all site-specific information such as location and orientation can be assigned to the model only when the site level is selected in the navigation tree.



Site orientation (°) in DesignBuilder represents the alignment of the building(s) with respect to true north. However, because there could be multiple buildings on the site, this is called *site orientation* instead of *building orientation*.

Step 10: Select the **Simulation** screen tab to get the results.



The impact of building orientation on building energy consumption is shown in the results recorded in Table 1.7.

Changing the orientation of a building changes the heating and cooling energy consumption as well as the size of the system. You may note that heating capacity is not affected by the change in orientation because of the fact that the peak requirement for heating occurs in non-sunshine hours. Hence, any orientation would require the same amount of heating (Table 1.8).

TABLE 1.7

Annual energy consumption with a change in building orientation

Type of consumption	Orientation 0 degrees (kWh)	Orientation 90 degrees (kWh)
Room electricity	33,167.88	33,167.88
Lighting	47,934.77	47,934.77
Heating (gas)	1,516.51	1,662.15
Cooling (electricity)	102,428.10	104,099.10
DHW (electricity)	3,001.146	3,001.146

TABLE 1.8

Heating and cooling equipment capacity with a change in building orientation

Type of equipment	Orientation 0 degrees (kW)	Orientation 90 degrees (kW)
Cooling	119.35	125.60
Heating	43.32	43.32

EXERCISE 1.3A

For New Delhi, run simulations for three more orientations: 45, 180 and 270 degrees. Compare the results (Tables 1.9 and 1.10).

TABLE 1.9
Energy consumption with a change in building orientation

Type of consumption	Annual fuel breakdown data (kWh)				
	0 Degrees	45 Degrees	90 Degrees	180 Degrees	270 Degrees
Room electricity					
Lighting					
Heating (gas)					
Cooling (electricity)					
DHW (electricity)					

TABLE 1.10
Heating and cooling equipment capacity with a change in building orientation

Type of equipment	0 Degrees	45 Degrees	90 Degrees	180 Degrees	270 Degrees
Heating capacity (kW)					
Cooling capacity (kW)					

Compare the energy consumption for 0 and 180 degrees. What do you observe? It can be seen that the results for 0 and 180 degrees are the same, and those for 90 and 270 degrees are the same. This is due to symmetry in the shape and window distribution of the building such that solar exposure for these two cases becomes similar. A comparison of the energy consumption for 0 and 90 degrees shows a difference in the cooling capacity as well as energy consumption owing to the change in solar exposure.

EXERCISE 1.3B

Change the weather locations of the model to New York and Singapore, and enter the values in Tables 1.11 and 1.12.

TABLE 1.11
Energy consumption with a change in building location

Type of consumption	Annual fuel breakdown data (kWh)	
	New York	Singapore
Room electricity		
Lighting		
Heating (gas)		
Cooling (electricity)		
DHW (electricity)		

TABLE 1.12
Heating and cooling equipment capacity with a change in building location

Type of equipment	New York (kW)	Singapore (kW)
Heating		
Cooling		

Observe and write why energy consumption and system sizing changed? It can be seen that the extent of variation is significantly less for a change in orientation versus a change in location. The change in energy consumption due to orientation may be more pronounced in buildings that have a higher aspect ratio (the ratio of longer and shorter sides) because of the change in solar exposure of the building that influences heat gain.

The change in energy consumption with location is largely due to the change in the harshness of the climatic conditions. This can be proportional to the *cooling degree days* (CDDs) for cooling energy consumption and *heating degree days* (HDDs) for heating energy consumption. Values for CDDs and HDDs can be found in weather files, design data books and references such as American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) handbooks.

HDDs and **CDDs** are common measures used to interpret the heating and cooling needs of a location. Degree days are the summation of the product of the difference in temperature (ΔT) between the average outdoor and the hypothetical average indoor temperatures and the number of days the outdoor temperature is above or below the hypothetical average indoor temperature.

The degree days are calculated in reference to a baseline line temperature that is commonly 18°C. Temperatures above 18°C need to be cooled, and temperatures below 18°C need to be heated.

Example: To calculate CDDs for two consecutive days:

Baseline temperature: 18 °C

Daily average outdoor dry bulb temperature (DBT) on day 1: 20°C

Daily average outdoor DBT on day 2: 17°C

CDD on day 1: $20 - 18 = 2$

CDD on day 2: $17 - 18 = -1$

Total CDD: 2 (sum for days that have positive values only)

The unit of measurement for CDDs and HDDs is degree days.

Tutorial 1.4

Evaluating the Impact of Opaque Envelope Components

GOAL

To understand the impact of the thermal properties of opaque envelope components (the external wall and roof) on HVAC system sizing and energy consumption

WHAT ARE YOU GOING TO LEARN?

- How to change wall and roof construction

PROBLEM STATEMENT

For the **Courtyard with VAV Example**, change the external wall from **Best practice Wall, Medium weight** to **Brickwork single leaf construction dense plaster**, and record its impact on the building energy performance for the London weather file.

SOLUTION

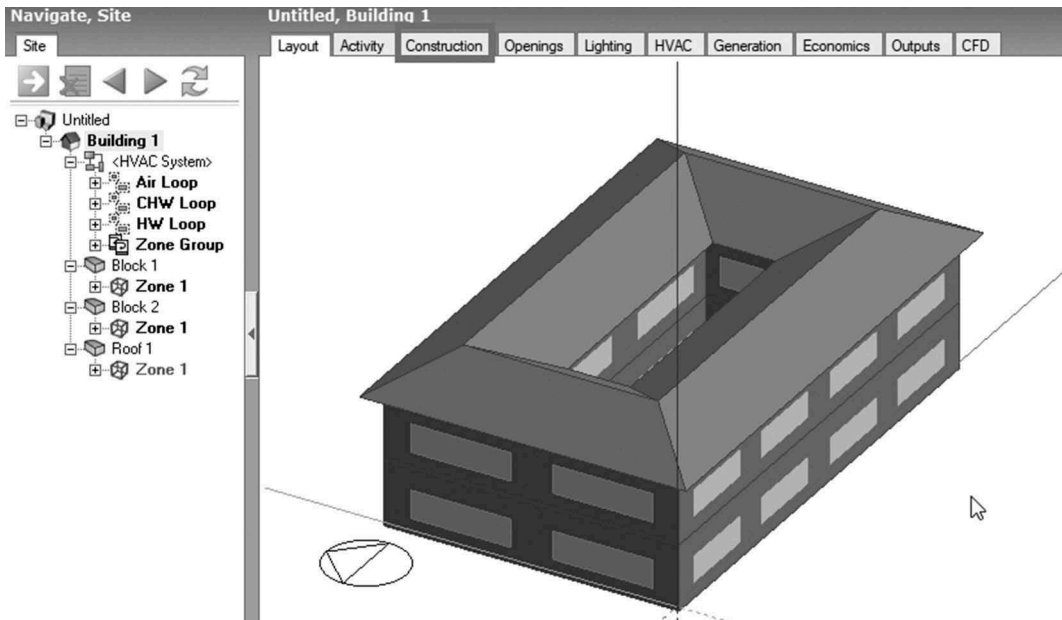
Step 1: Open the **Courtyard with VAV Example** model from the template.

DesignBuilder Data

Recent Files | Component Libraries | Template Libraries

Name	Folder /	Size (KB)	Last Modified	Extension /
IECC Residential Prototype Low Rise Apa...	C:\ProgramData\DesignBuilde...	1315	12-Feb-19 10:16:58 AM	DesignBuilder templates
Atrium example base	C:\ProgramData\DesignBuilde...	1158	12-Feb-19 10:16:58 AM	DesignBuilder templates
Underfloor Heating Example	C:\ProgramData\DesignBuilde...	908	12-Feb-19 10:16:56 AM	DesignBuilder templates
Trombe Wall Example	C:\ProgramData\DesignBuilde...	1045	12-Feb-19 10:16:56 AM	DesignBuilder templates
CFD External Analysis Example	C:\ProgramData\DesignBuilde...	1088	12-Feb-19 10:16:52 AM	DesignBuilder templates
Model Geometry Example	C:\ProgramData\DesignBuilde...	1081	12-Feb-19 10:16:50 AM	DesignBuilder templates
Mech Vent with Preheat	C:\ProgramData\DesignBuilde...	914	12-Feb-19 10:16:50 AM	DesignBuilder templates
Parametric Simulation Example	C:\ProgramData\DesignBuilde...	1106	12-Feb-19 10:16:50 AM	DesignBuilder templates
Zone Multiplier Example	C:\ProgramData\DesignBuilde...	1111	12-Feb-19 10:16:50 AM	DesignBuilder templates
Zone Water To Air Heat Pump Example	C:\ProgramData\DesignBuilde...	1331	12-Feb-19 10:16:50 AM	DesignBuilder templates
Plenum Example Building	C:\ProgramData\DesignBuilde...	1052	12-Feb-19 10:16:50 AM	DesignBuilder templates
DesignBuilder Video Tutorials Example	C:\ProgramData\DesignBuilde...	1186	12-Feb-19 10:16:50 AM	DesignBuilder templates
Double Skin Facade Example	C:\ProgramData\DesignBuilde...	1171	12-Feb-19 10:16:50 AM	DesignBuilder templates
Dehumidification example	C:\ProgramData\DesignBuilde...	1122	12-Feb-19 10:16:50 AM	DesignBuilder templates
CFD Internal Analysis Example	C:\ProgramData\DesignBuilde...	1090	12-Feb-19 10:16:50 AM	DesignBuilder templates
Courtyard with VAV Example	C:\ProgramData\DesignBuilde...	931	12-Feb-19 10:16:50 AM	DesignBuilder templates
Atrium Example with Calc Nat Vent	C:\ProgramData\DesignBuilde...	538	12-Feb-19 10:16:50 AM	DesignBuilder templates
IECC Residential Prototype Detached ho...	C:\ProgramData\DesignBuilde...	1285	12-Feb-19 10:16:50 AM	DesignBuilder templates
Mixed Mode Example	C:\ProgramData\DesignBuilde...	1093	12-Feb-19 10:16:44 AM	DesignBuilder templates
PCM Example	C:\ProgramData\DesignBuilde...	1270	12-Feb-19 10:16:44 AM	DesignBuilder templates
House Example 1	C:\ProgramData\DesignBuilde...	989	12-Feb-19 10:16:44 AM	DesignBuilder templates
Single Zone Example	C:\ProgramData\DesignBuilde...	758	07-Apr-16 12:50:30 PM	DesignBuilder templates
Simple HVAC night cooling	C:\ProgramData\DesignBuilde...	995	07-Apr-16 12:50:30 PM	DesignBuilder templates

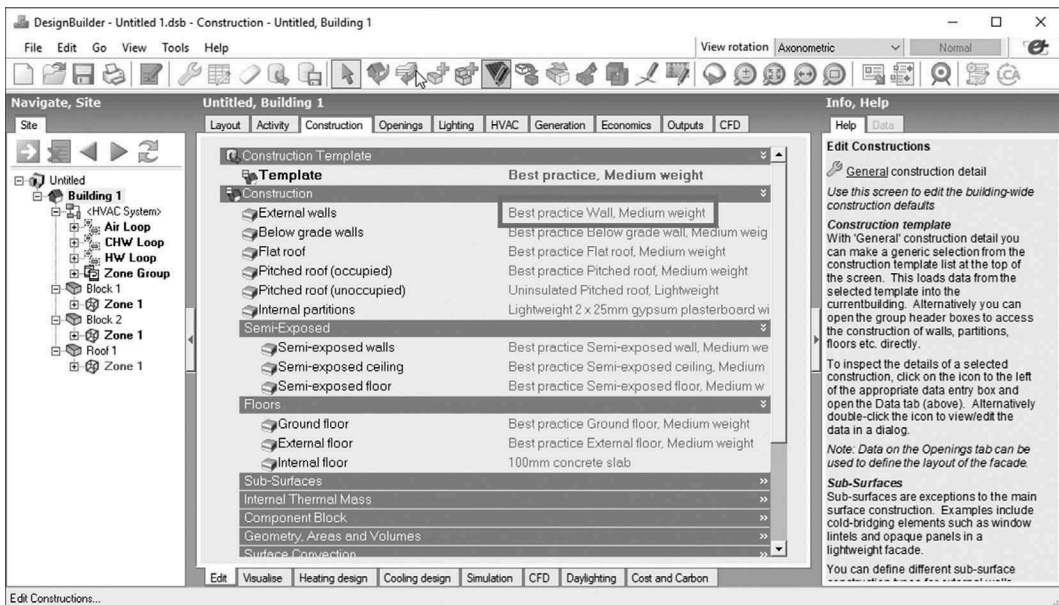
Step 2: Select the **Construction** tab.



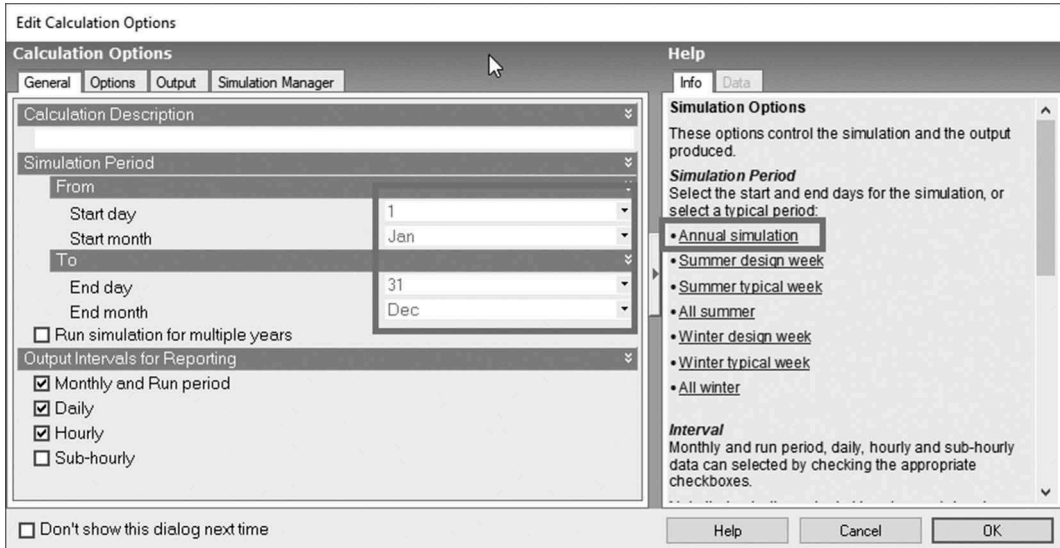
DesignBuilder uses a tree structure for data organization. The template is the *root*, and all the other fields are the *branches*. DesignBuilder templates are databases of typical generic data. Therefore, when editing the template at the root level, it changes at all branches, but if changes are made at the branch level, root and other branches will not change.

Objects such as external walls in the **Construction** template can also be edited individually without changing the complete root template. However, in this case, it is to be noted that this particular object will be decoupled from the root. This means that changing the root object does not impact the value of this object.

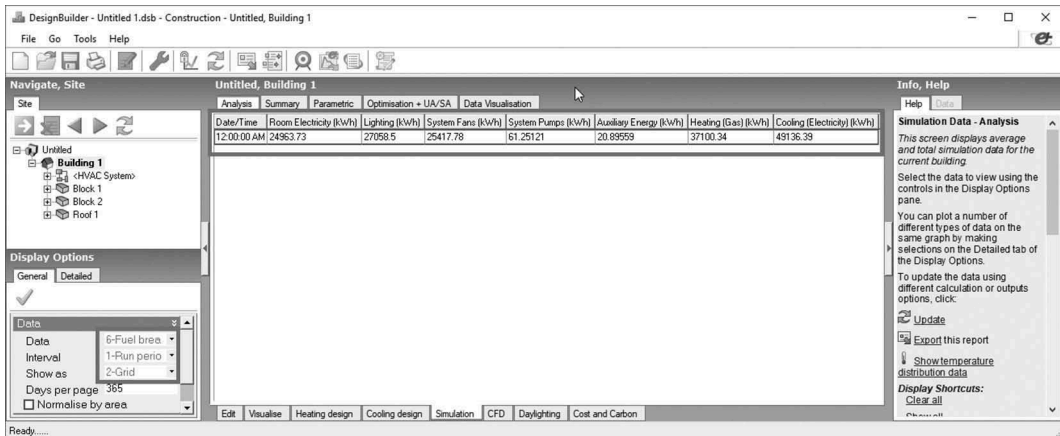
Step 3: Make sure that **Best practice Wall, Medium weight** is selected as External walls.



Step 4: Select the **Simulation** screen tab. Click on **Update data**. The **Edit Calculation Options** screen appears. Click the **Annual simulation** link to set the annual simulation period.



Step 5: Record the energy simulation results.



In the following steps, you are going to change the external wall construction.

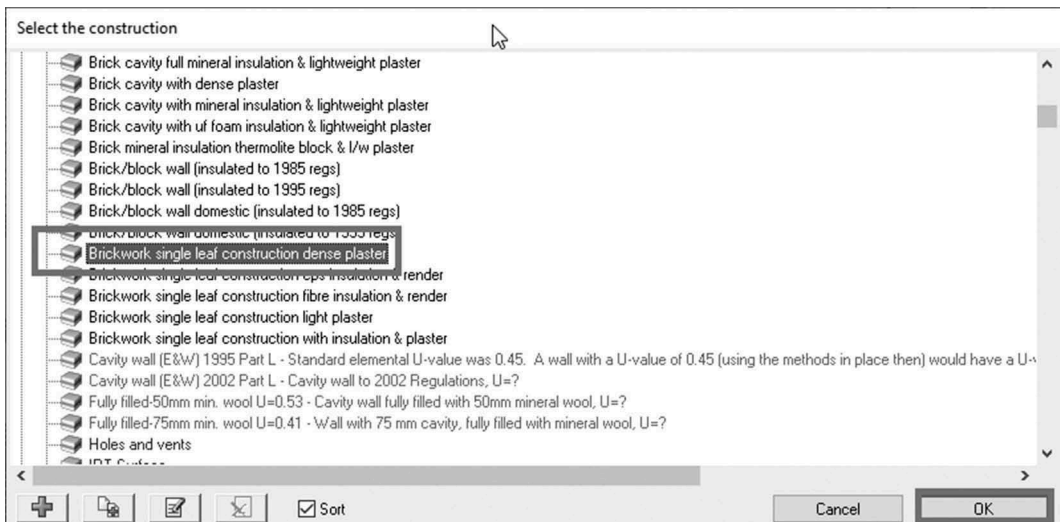
Step 6: Click the **Edit** screen. The **Construction Template** screen appears.

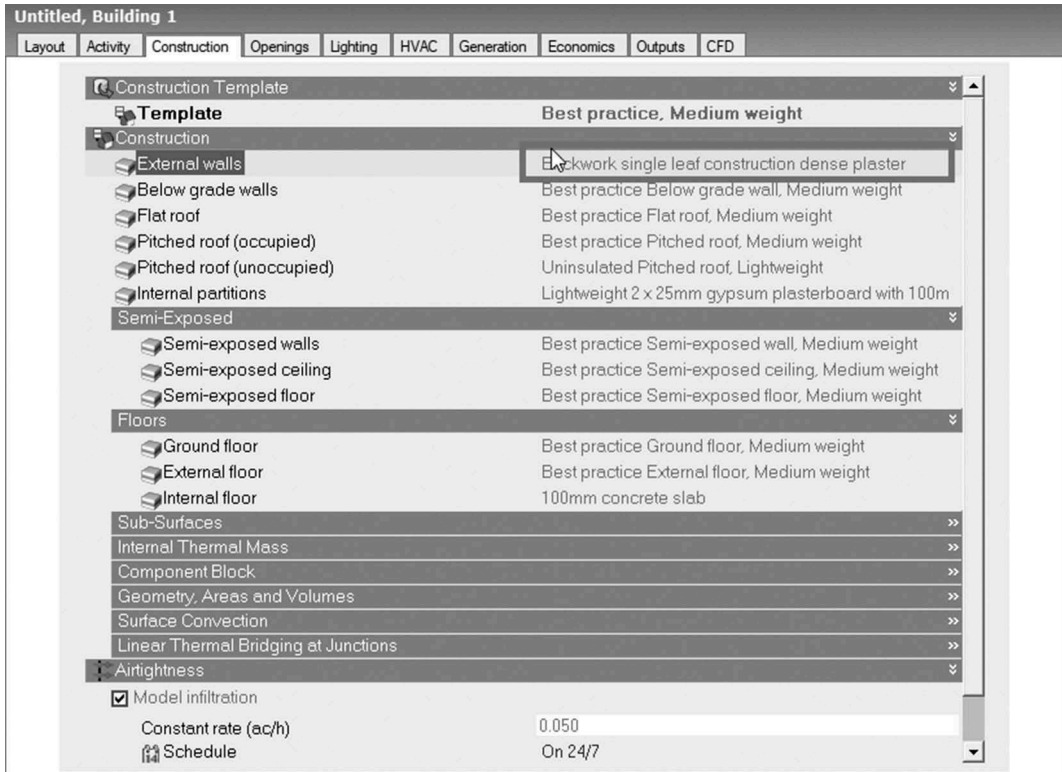


Step 7: Click **External walls** under the **Construction** section. Three dots (...) appear. Click the three dots. The **Select the construction** screen appears.



Step 8: Select **Brickwork single leaf construction dense plaster**.





Step 9: Select the **Simulation** screen tab, and perform the annual energy simulation. View the energy simulation results in Tables 1.13 and 1.14 and compare. It can be seen that changing the wall impacts both equipment sizing and energy consumption.

TABLE 1.13
Energy consumption with a change in external wall construction

Type of consumption	Annual fuel breakdown data (kWh)	
	Best practice Wall, Medium weight	Brickwork single leaf construction dense plaster
Room electricity	24,964	24,964
Lighting	27,059	27,059
System fans	25,418	26,119
System pumps	61	68
Auxiliary energy	21	25
Heating (gas)	37,100	80,716
Cooling (electricity)	49,136	48,741

TABLE 1.14
Heating and cooling equipment capacity with a change in external wall construction

Type of capacity	Best practice Wall, Medium weight (kW)	Brickwork single leaf construction dense plaster (kW)
Cooling	70.37	72.62
Heating	55.87	93.07

EXERCISE 1.4

Open the model prepared in Tutorial 1.2. Assign flat roof construction as shown in Tables 1.15 and 1.16. Simulate and compare the results for London.

TABLE 1.15
Energy consumption with a change in roof construction

Type of consumption	Annual fuel breakdown data (kWh)	
	Roof, insulated entirely above deck, R-24 (4.2), U-0.040 (0.23)	Uninsulated flat roof, medium weight
Room electricity		
Lighting		
System fans		
System pumps		
Heating (electricity)		
Heating (gas)		
Cooling (electricity)		

TABLE 1.16
Heating and cooling sizing with a change in roof construction

Type	Heating and cooling sizing (kW)	
	Roof, insulated entirely above deck, R-24 (4.2), U-0.040 (0.23)	Uninsulated flat roof, medium weight
Heating		
Cooling		

You can follow similar steps for the external wall. Please refer to the following screenshots for help.

Untitled, Building 1

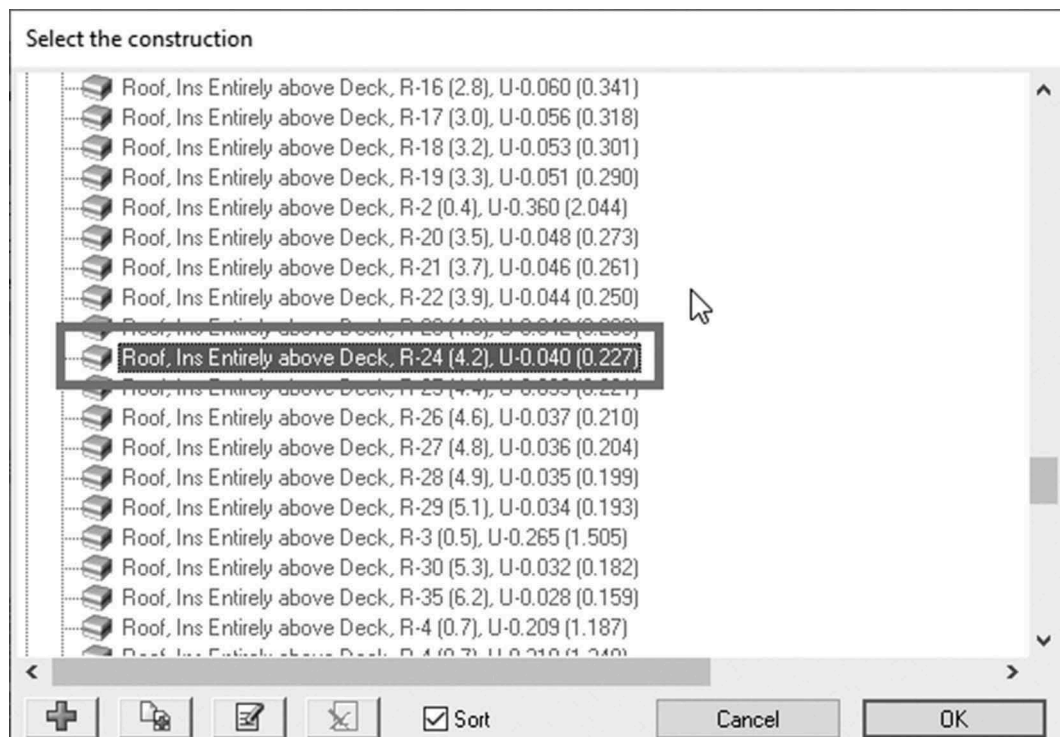
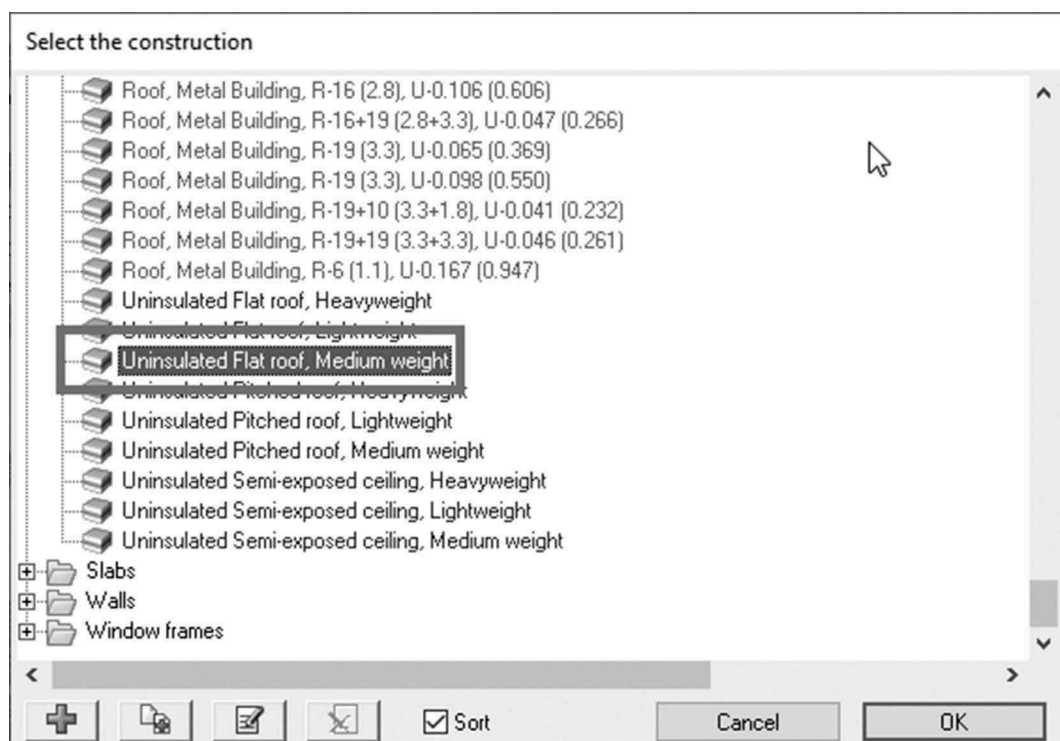
Layout Activity Construction Openings Lighting HVAC Generation Economics Outputs CFD

Construction Template

Template Best practice, Medium weight

Construction

External walls	Best practice Wall, Medium weight
Below grade walls	Best practice Below grade wall, Medium weight
Flat roof	Best practice Flat roof, Medium weight
Pitched roof (occupied)	Best practice Pitched roof, Medium weight
Pitched roof (unoccupied)	Uninsulated Pitched roof, Lightweight
Internal partitions	Lightweight 2 x 25mm gypsum plasterboard with 100m
Semi-Exposed	
Semi-exposed walls	Best practice Semi-exposed wall, Medium weight
Semi-exposed ceiling	Best practice Semi-exposed ceiling, Medium weight
Semi-exposed floor	Best practice Semi-exposed floor, Medium weight
Floors	
Ground floor	Best practice Ground floor, Medium weight
External floor	Best practice External floor, Medium weight
Internal floor	100mm concrete slab
Sub-Surfaces	
Internal Thermal Mass	
Component Block	
Geometry, Areas and Volumes	
Surface Convection	
Linear Thermal Bridging at Junctions	
Airtightness	
<input checked="" type="checkbox"/> Model infiltration	
Constant rate (ac/h)	0.050
Schedule	On 24/7



Tutorial 1.5

Evaluating the Impact of WWR and Glass Type

GOAL

To evaluate the impact of glazing area and glazing properties on the energy performance of a building

In the field of building energy simulations, glazing area is most commonly quantified in terms of *window-wall ratio* (WWR). The WWR is the ratio of the total glazing area to the total external wall area in conditioned zones.

WHAT YOU ARE GOING TO LEARN?

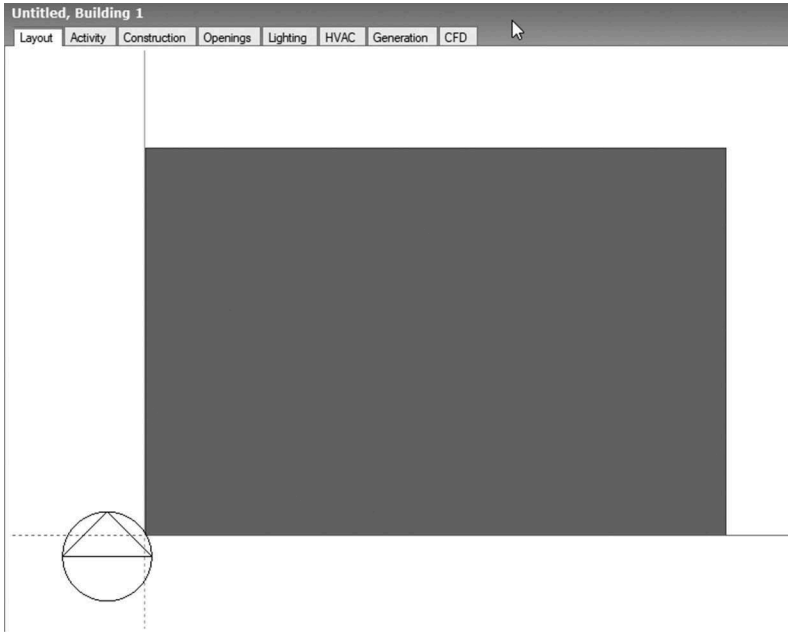
- How to creating zones in a building
- How to change the WWR
- How to change glazing type

PROBLEM STATEMENT

Create a 60- × 40-m five-zone single-story building model for London. Take WWRs of 30% and 80% and evaluate the building energy performance. Compare cooling and heating equipment sizing of the north and south zones. Similarly, compare sizing in east and west zones. Evaluate the impact of glazing by changing the single-pane clear glazing (**Sgl Clr 3mm**) to high-performance, low solar heat gain coefficient (SHGC) dual-pane glazing (**Dbl Blue 6mm/13mm Air**).

SOLUTION

Step 1: Open a new project, and draw a building with a size of **60 × 40 m**.



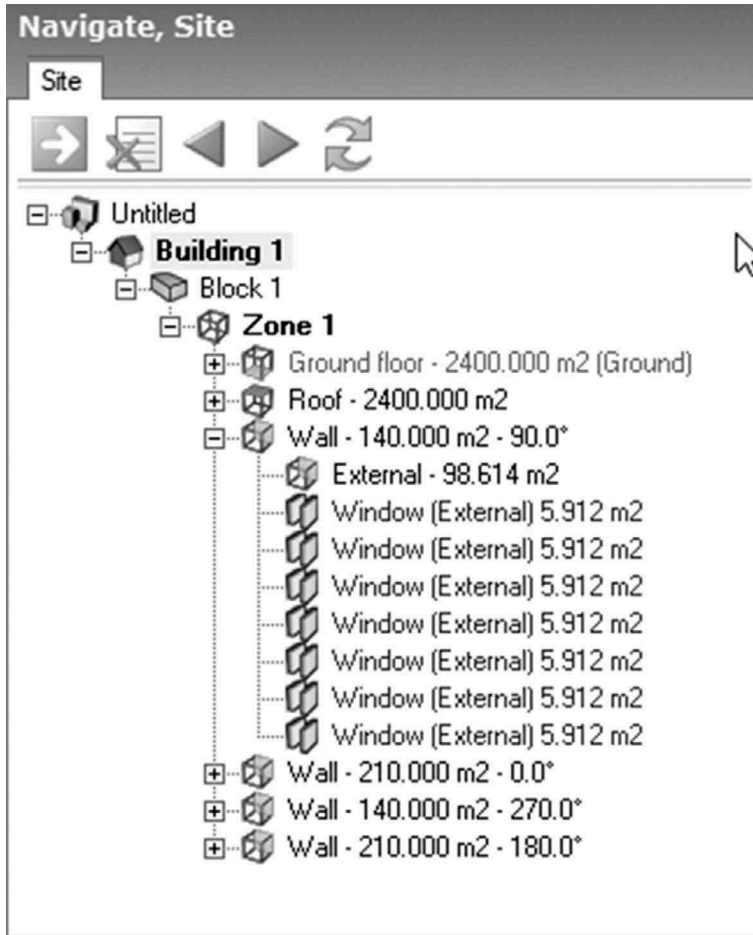
Data Structure Hierarchy in DesignBuilder

Site→Building→Block→Zone→Surface→Opening

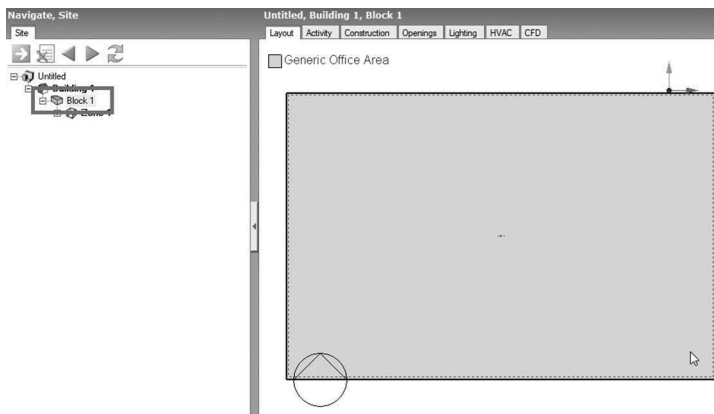
Assigning a template to the upper-level branch will result in the same template for all the sub-branches. For example, if a construction template named ‘Framed Construction’ is assigned to the building, all floors and zones will have the same template: ‘Framed Construction’. When a particular sub-branch is edited, it is separated from the main branch, resulting in a need for a separate edit from the main branch.

For example, if a particular zone (such as zone 1) of the first floor of the building is selected and the construction template is changed from ‘Framed Construction’ to ‘Mass Construction’, and later the whole building is selected and the construction template is changed from ‘Framed Construction’ to ‘Steel Construction’, the construction template of zone 1 still retains ‘Mass Construction’.

Source: https://designbuilder.co.uk/helpv6.0/#_Model_data_hierarchy_and_data_inheritance.htm.



Step 2: Click **Block 1** in navigation tree. The display changes to **Zone 1**.

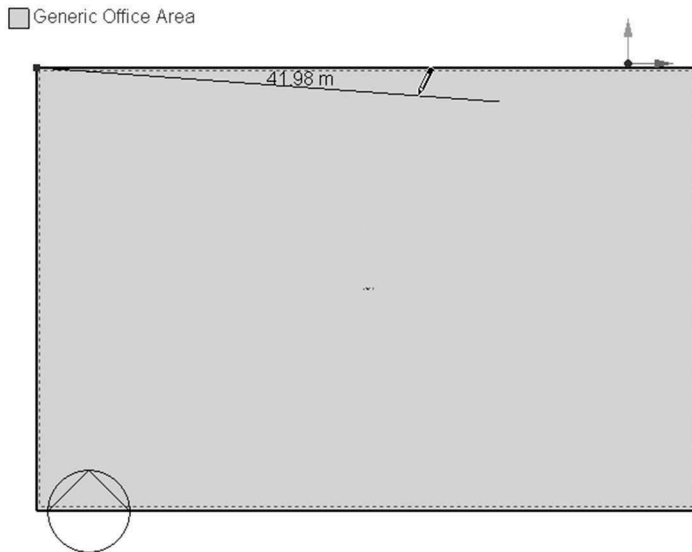


Step 3: Click the **Draw construction line** icon to mark lines on the zone. You need to draw an internal partition with an offset of 10 m.

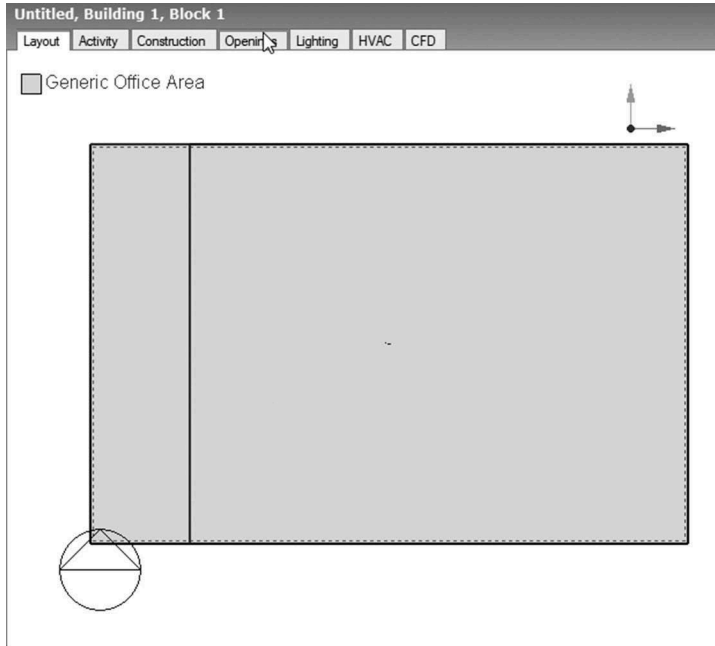


Similar to other drafting programs, DesignBuilder provides some important drafting options such as snap points, gridlines and direction snap. Make sure to select the relevant options while creating the custom geometry.

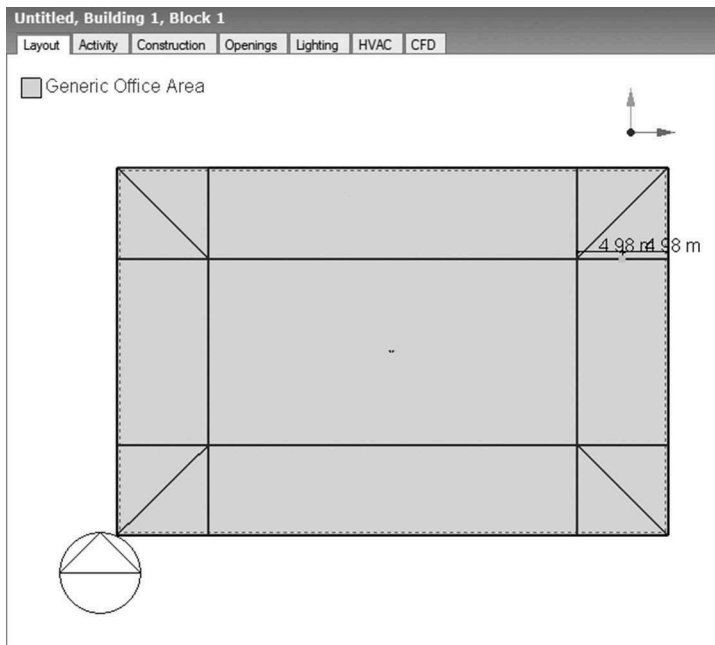
Step 4: Place the pointer near the top-left corner. The pointer snaps to the corner (green square appears at the centre of the crosshairs). Left-click once the pointer has snapped, and then move the mouse in the right direction over the north wall of the building and type **10**. This draws a 10-m construction line from the top-left corner on the north wall.



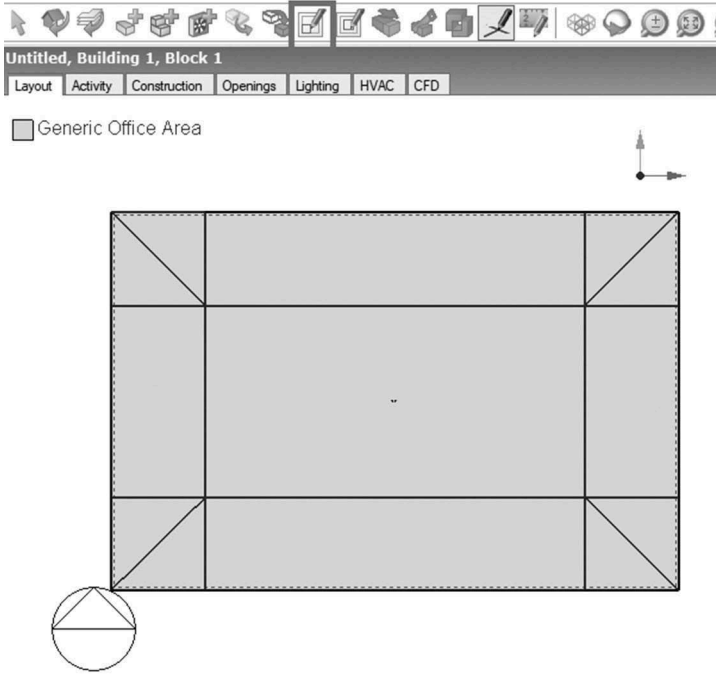
Step 5: Click the right end of the construction line. Now move the mouse vertically down parallel to the west wall of the building with an offset of 10 m (as achieved in the preceding step), and snap to the south wall (this time the crosshairs will change to the red square because it will be edge snapping) and click.



Step 6: Continue drawing all construction lines to mark core and perimeter zones.



Step 7: Click the **Draw partition** icon. The screen appears with a cursor to draw the internal partitions.



Step 8: Trace the construction line to draw a perimeter zone on the north.

