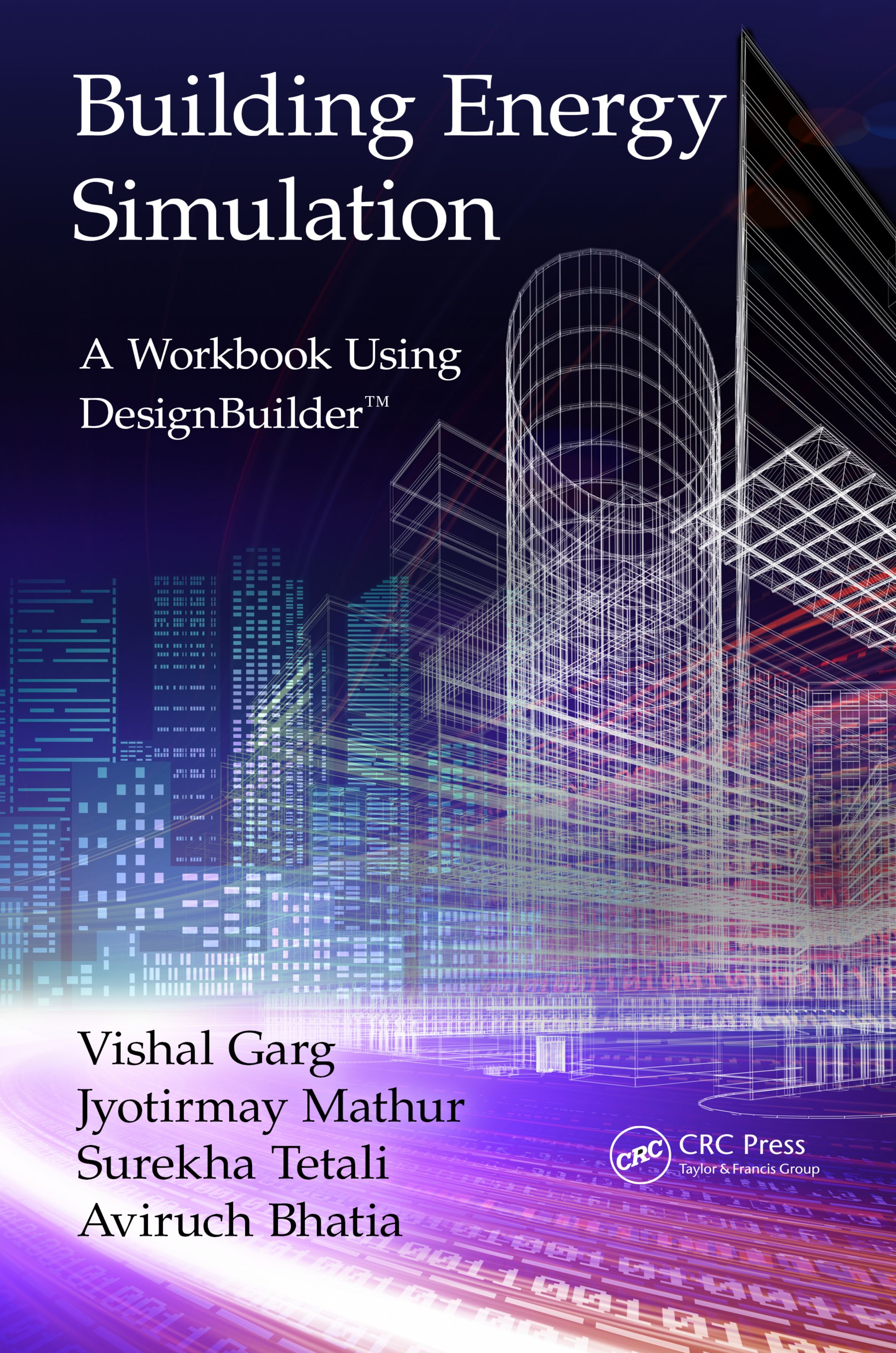
Building Energy Simulation

A Workbook Using DesignBuilder™



Vishal Garg
Jyotirmay Mathur
Surekha Tetali
Aviruch Bhatia

CRC Press
Taylor & Francis Group

Building Energy Simulation

Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

Building Energy Simulation

A Workbook Using DesignBuilder™

Vishal Garg

Jyotirmay Mathur

Surekha Tetali

Aviruch Bhatia

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed on acid-free paper

International Standard Book Number-13: 978-1-138-09323-2 (Hardback)
International Standard Book Number-13: 978-1-4987-4451-5 (Paperback)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Contents

Preface

The *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.

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 participants 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 ten chapters of this workbook cover various aspects of simulation, such as creating the building geometry, assigning material and equipment and analysing the results.

- Chapter 11 explains simulation for the whole building performance method of the ASHRAE 90.1 standard.
- Chapters 12 through 14 provide exercises to simulate three different building projects.

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

Acknowledgements

The authors thank all those who helped during the research, writing, review and editing process, which immensely contributed in making this workbook a reality.

We would like to start by thanking all professionals, researchers and students from all over the globe for providing their feedback during the various building simulation training programs that were conducted in the past few years. This feedback helped us improve the building simulation teaching methodology and motivated us to create this workbook.

We thank Prof. 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, UK for allowing us to develop this book and answering our queries during the writing process.

This workbook would not have been possible without all those reviewers who took time out to patiently go through the content and provide their valuable feedback. The authors would especially appreciate the contribution from Gaurav Choudhary, Hema Rallapalli, Ishita Sharma, Kopal Nihar, Sraavani Gundepudi, Shivraj Dhaka and all the students from International Institute of Information Technology (IIIT), Hyderabad, India and Malaviya National Institute of Technology (MNIT), Jaipur, India who reviewed this workbook and provided feedback on the technical content and its accuracy.

Our special thanks 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 Suchandra Dutta Roy for helping us with the technical editing of the document.

Our sincere gratitude to the team at CRC Press/Taylor & Francis Group, especially Dr. Gagandeep Singh for his trust in us and the numerous extensions to the timelines for delivering this workbook.

Authors

Dr. Vishal Garg is Associate Professor and head of the Center for IT in Building Science, International Institute of Information Technology (IIIT), Hyderabad, India. His current research interests are in the areas of energy simulation and cool roofs. He teaches building automation and controls, energy simulation and lighting design and technology. He has conducted several national and international workshops on intelligent buildings, green buildings and energy simulation. He holds a BTech (Hons.) degree in civil engineering from MBM Engineering College, Jodhpur and a PhD from the Indian Institute of Technology, Delhi, India. Dr. Garg is actively involved in the green building movement, development of eTools and educational platforms for advancing energy efficiency in buildings and energy efficiency building code and its implementation. He was the founding President of the Indian chapter of International Building Performance Simulation Association and chaired the organizing committee of the international conference - Building Simulation 2015.

Dr.-Ing. Jyotirmay Mathur is a Professor of Mechanical Engineering and the founding Head of the Centre for Energy and Environment at Malaviya National Institute of Technology, Jaipur, India. He has done postgraduation in energy studies from the Indian Institute of Technology, Delhi, India, and doctorate in energy systems from University of Essen, Germany. Dr. Mathur has published 65 research papers in refereed international journals and has presented more than 100 papers and talks at international seminars and conference, besides writing five books. Dr. Mathur works in the field of energy modelling, codes and standards, energy conservation in buildings, passive cooling, adaptive thermal comfort and building integrated photovoltaic systems.

Surekha Tetali is an architect. She is currently pursuing her PhD in building performance and diagnostics from Carnegie Mellon University (CMU), Pittsburgh. She holds MS degree in IT in Building Science from IIIT, Hyderabad, India. Her current research involves modelling and simulations to analyse the impact of systems integration in buildings and built environment on microclimate, especially in urban areas. She has been working on a number of research and consulting projects involving building performance simulations and building retrofit design and analysis in the United States and India. Prior to joining CMU, she worked for five years as a building energy analyst in the Center for IT in Building Science at IIIT, Hyderabad, India.

Aviruch Bhatia is an energy engineer. He is currently pursuing his PhD from IIIT, Hyderabad, India. He holds MTech in Energy Engineering from Malaviya National Institute of Technology, Jaipur, India, and MSc and MPhil in physics from University of Rajasthan, Jaipur, India. His areas of interest include building physics, calibrated energy simulation and fault detection and diagnostics in HVAC systems. Prior to joining IIIT, Hyderabad, he worked for three years as an assistant manager at Sustainability Group of Spectral Consultant Pvt. Ltd. (an AECOM company).

CHAPTER ONE

Getting Started with Energy Simulation

This chapter is to acquaint you with 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 get familiarized with key input parameters, output visualization, and 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 along with 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 utilized for estimating the utility bills, for evaluating cost–benefit analysis of various design strategies.

Some of the uses for energy simulation tools are:

Early design decisions: In early design stage, decisions such as 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 while selecting individual components of building envelop or systems. It is quite commonly used to carry out cost–benefit analysis of various designs and components. Therefore, modelling at this stage needs to be performed with greater accuracy as compared to modelling for early design decisions.

Retrofitting decisions: For retrofit of existing buildings, energy simulation can help in selecting cost effective solutions. For an accurate analysis, 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 ambient conditions (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.

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 thickness and thermophysical properties of materials used in each layer of building envelope. Besides the opaque components, it is very important to have properties of window glass, frame and shading devices.

Building services: Information about various services such as HVAC and lighting is required. This includes equipment capacities, energy efficiency, location and controls.

Usage of 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 usage 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 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 calculation has 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 classical method is that various effects of thermophysical properties of materials and the performance of 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, as they can be run on commercially available desktop computers or laptops.

This chapter provides basic tutorials on creating simple geometry, 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. This can be downloaded from: https://www.designbuilder.co.uk/download/software/previous-versions/49-designbuilder-v4-7-0-027-1.

TUTORIAL 1.1 Opening and simulating an example file

GOAL

To evaluate the energy performance of a building provided in an example file in DesignBuilder.

WHAT ARE YOU GOING TO LEARN?

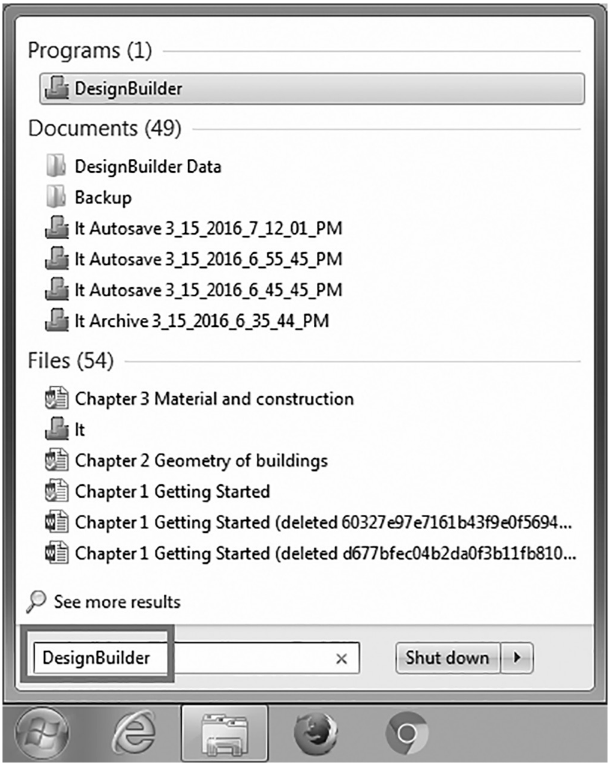
- Simulating an example file
- Viewing energy consumption results based on utility type or fuel, such as electricity and gas
- Viewing the end use energy consumption (lighting, equipment, fan, cooling, heating, pump and domestic hot water)
- Viewing results on a daily, monthly and annual basis
- Switching between Metric (SI) and English (IP) measurement units
- Finding energy use intensity (EUI)

PROBLEM STATEMENT

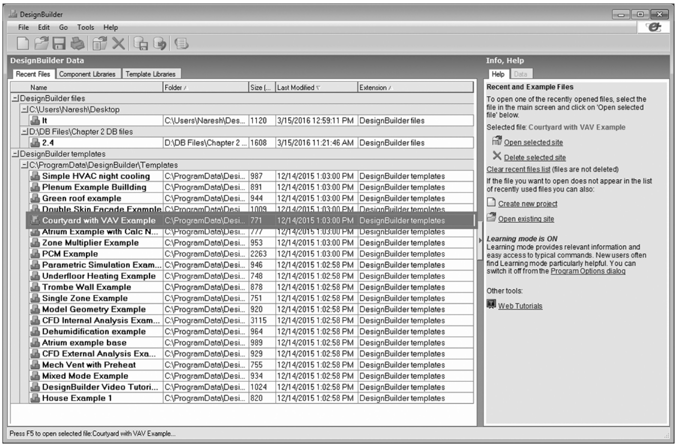
In this tutorial, you are going to simulate an existing template, **Courtyard with VAV Example**, from the DesignBuilder library and simulate it for the climate of London. You will learn how to view the daily, monthly, and annual energy consumptions in a graphical form. You will also learn how to view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

SOLUTION

Step 1: Start **DesignBuilder**. The **DesignBuilder** main screen appears as shown in next step.



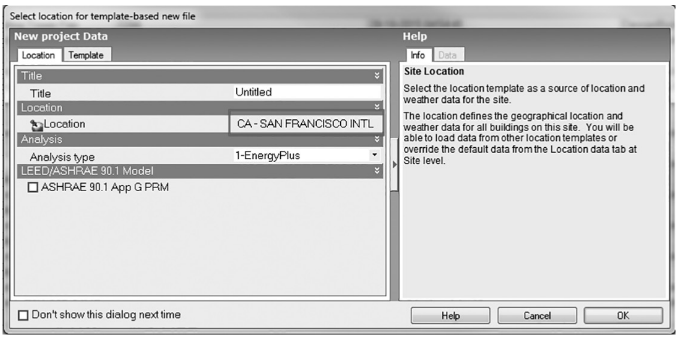
Step 2: Double-click **Courtyard with VAV Example** in the DesignBuilder templates under the Recent Files tab. A **New project Data** screen appears.



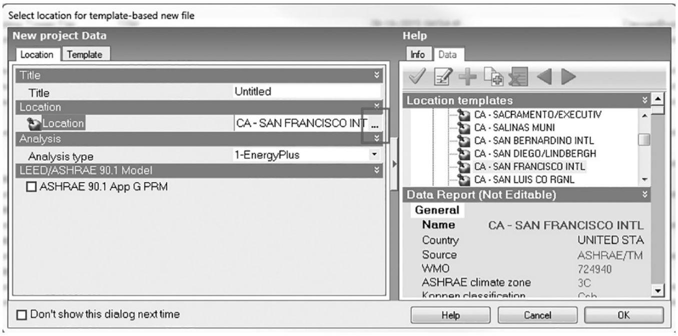
Courtyard with VAV Example is a DesignBuilder template file. A DesignBuilder template file helps in providing examples of various building typologies and systems such as geometry, HVAC system and passive strategies. Relevant data from the example files can be exported and imported into other DesignBuilder 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 location. If you have used DesignBuilder earlier, you may get some other location based on your previous settings.

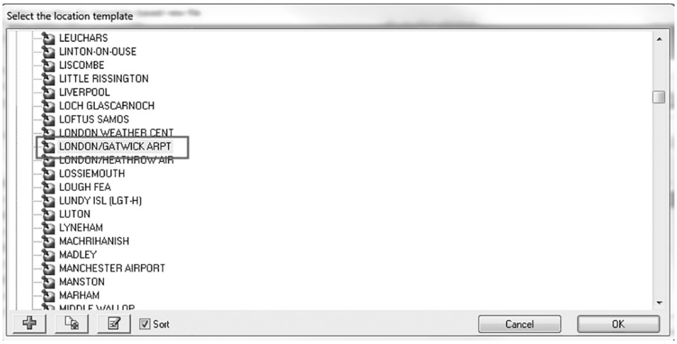


Step 4: Click the three dots (**...**). The **Select the location template** screen appears.

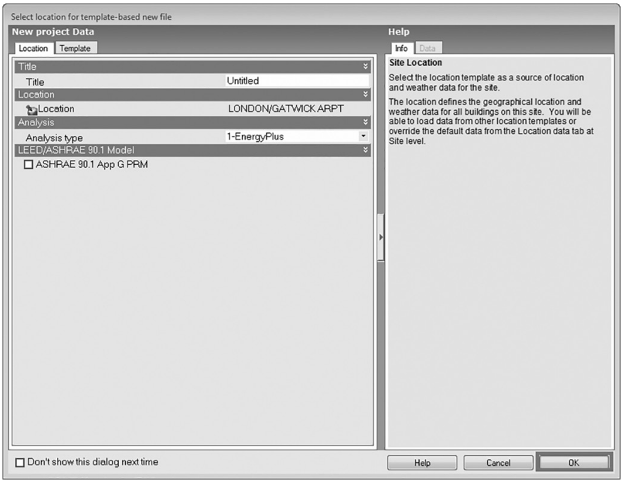


Step 5: Select **LONDON/GATWICK ARPT**. Click **OK**. The **Select location for template-based new file** screen appears.

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



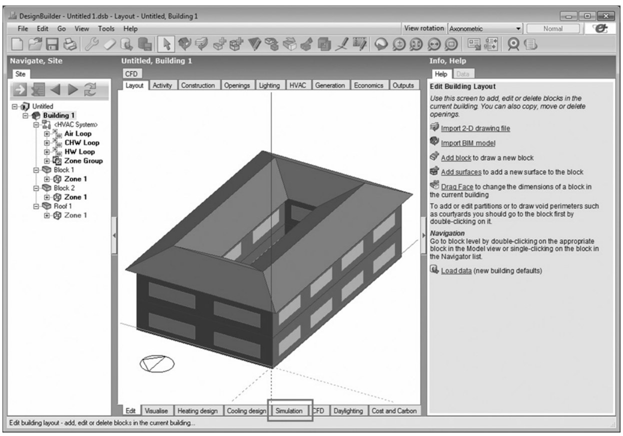
Step 6: Click **OK**.



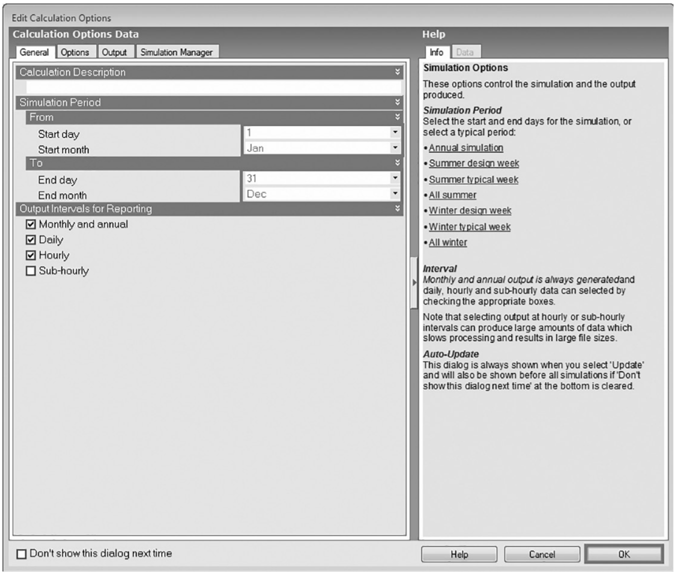
The building layout appears with the following tabs at the bottom of the central display screen:

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

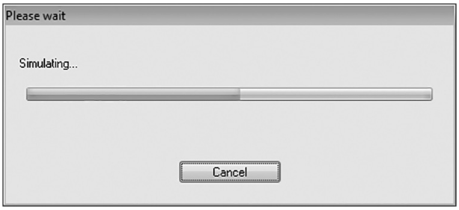
Step 7: Select **Simulation** tab. The **Edit Calculation Options** screen appears.



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



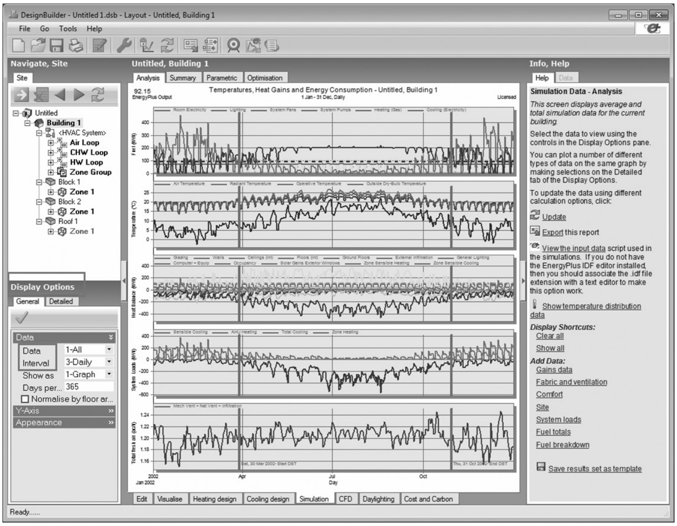
A screen appears showing the simulation progress. Depending on the configuration of the system, it can take several minutes to complete the simulation.

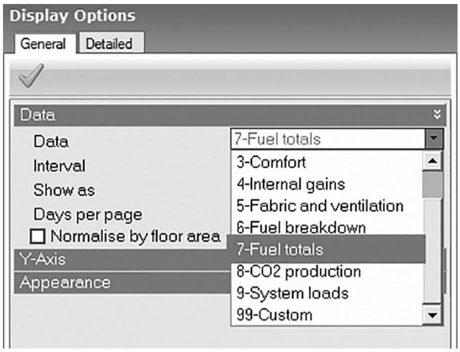


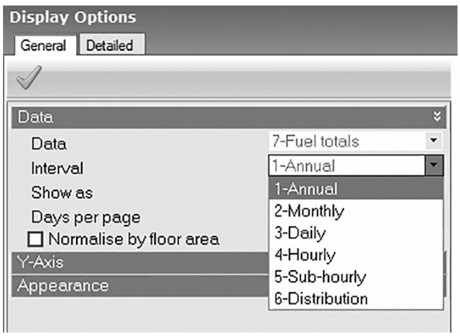
After the simulation is completed, results are displayed in the Analysis subtab of the Simulation tab.

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

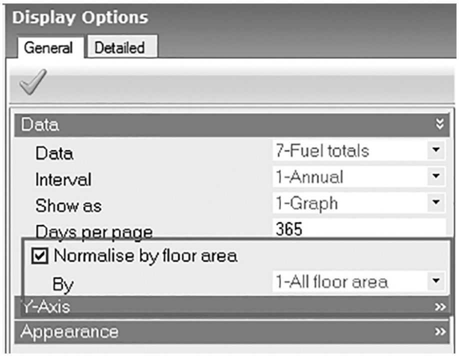
Note: The results are either displayed in IP or SI units based on your configuration of DesignBuilder. The steps involved in switching between SI and IP units are explained in Step 15.

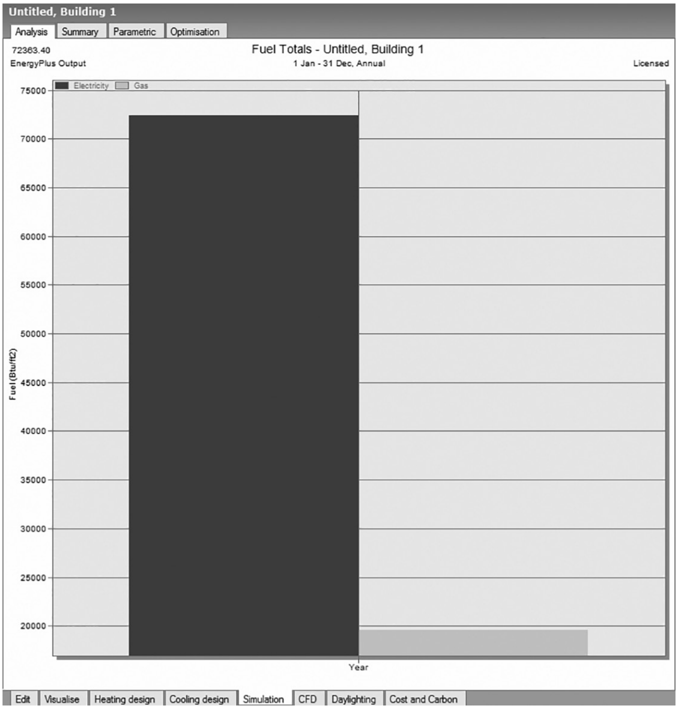

DesignBuilder - Untitled 1.dsb - Layout - Untitled, Building 1
File Go Tools Help
Navigate, Site
Untitled, Building 1
Info, Help
Analysis Summary Parametric Optimisation
Temperatures, Heat Gains and Energy Consumption - Untitled, Building 1
Simulation Data - Analysis
Display Options
General Detailed
Data
Interval
Show as
Days per...
1-All
3-Daily
1-Graph
365
Y-Axis
Appearance
Edit Visualise Heating design Cooling design Simulation CFD Daylighting Cost and Carbon
Ready......


Display Options
General Detailed
Data
Data
Interval
Show as
Days per page
Normalise by floor area
Y-Axis
Appearance
7-Fuel totals
3-Comfort
4-Internal gains
5-Fabric and ventilation
6-Fuel breakdown
7-Fuel totals
8-CO2 production
9-System loads
99-Custom


Display Options
General Detailed
Data
Data
Interval
Show as
Days per page
Normalise by floor area
Y-Axis
Appearance
7-Fuel totals
1-Annual
1-Annual
2-Monthly
3-Daily
4-Hourly
5-Sub-hourly
6-Distribution

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



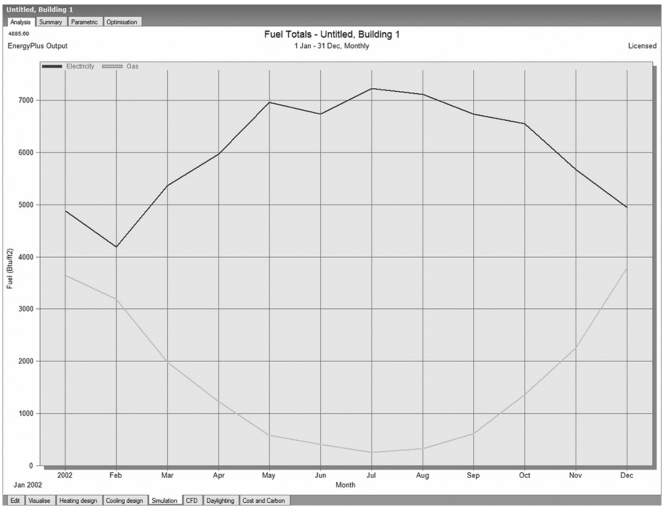


Units for the Fuel totals can be seen on the *y*-axis of the graph.

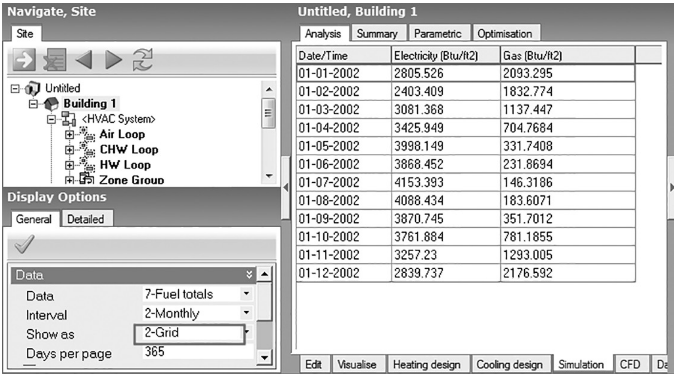
The term EUI refers to the energy consumption of the building per unit area per annum. The same term, in some countries, is also named as Energy Performance Index (EPI). The EUI of a building is calculated by dividing the annual total energy (all fuel types) consumption of the building with its gross floor area. The unit of measurement is kWh/m^2 yr or kWh/ft^2 yr or Btu/ft^2 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 Annual to **Monthly** to view monthly results. Refer to step 9.

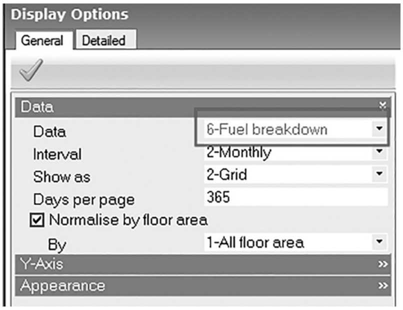


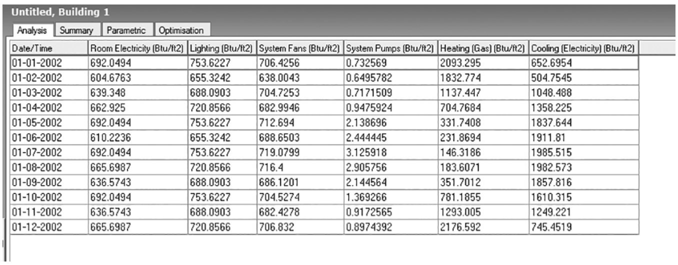
Step 12: Select **Grid** from the **Show as** drop-down list to view results in a grid format.



Date/Time	Electricity (Btu/ft2)	Gas (Btu/ft2)
01-01-2002	2805.526	2093.295
01-02-2002	2403.409	1832.774
01-03-2002	3081.368	1137.447
01-04-2002	3425.949	704.7684
01-05-2002	3998.149	331.7408
01-06-2002	3868.452	231.8694
01-07-2002	4153.393	146.3186
01-08-2002	4088.434	183.6071
01-09-2002	3870.745	351.7012
01-10-2002	3761.884	781.1855
01-11-2002	3257.23	1293.005
01-12-2002	2839.737	2176.592

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

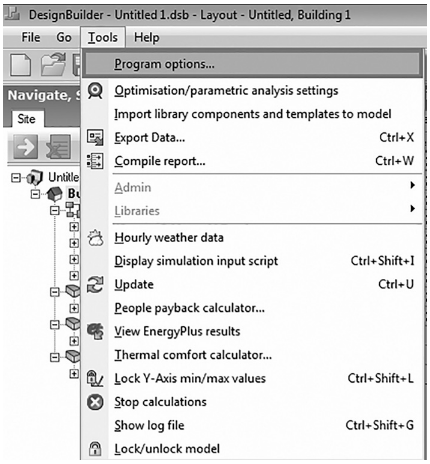




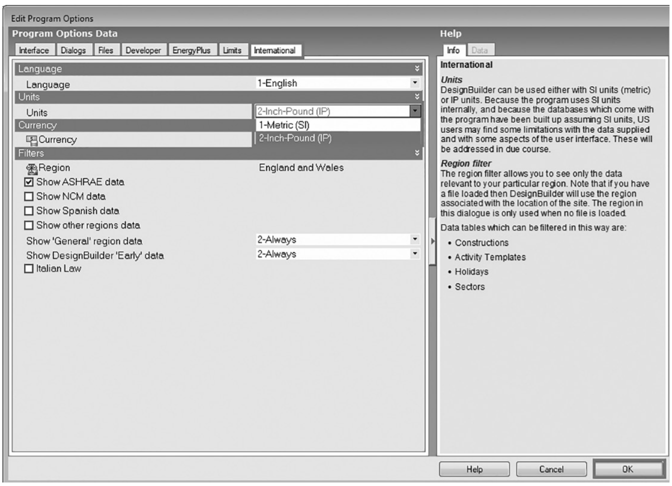
Date/Time	Room Electricity (Btu/ft2)	Lighting (Btu/ft2)	System Fans (Btu/ft2)	System Pumps (Btu/ft2)	Heating (Gas) (Btu/ft2)	Cooling (Electricity) (Btu/ft2)
01-01-2002	692.0494	753.6227	706.4256	0.732569	2093.295	652.6954
01-02-2002	604.6763	655.3242	638.0043	0.6495782	1832.774	504.7545
01-03-2002	639.348	688.0903	704.7253	0.7171509	1137.447	1048.488
01-04-2002	662.925	720.8566	682.9946	0.9475924	704.7684	1358.225
01-05-2002	692.0494	753.6227	712.694	2.138696	331.7408	1837.644
01-06-2002	610.2236	655.3242	688.6503	2.444445	231.8694	1911.81
01-07-2002	692.0494	753.6227	719.0799	3.125918	146.3186	1985.515
01-08-2002	665.6987	720.8566	716.4	2.905756	183.6071	1982.573
01-09-2002	636.5743	688.0903	686.1201	2.144564	351.7012	1857.816
01-10-2002	692.0494	753.6227	704.5274	1.369266	781.1855	1610.315
01-11-2002	636.5743	688.0903	682.4278	0.9172565	1293.005	1249.221
01-12-2002	665.6987	720.8566	706.832	0.8974392	2176.592	745.4519

In all the above 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 step.

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 observe that even with the same location and building envelope, the EUIs of office buildings and residential buildings are different. This is mainly due to the difference in building usage that 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 (Table 1.1).

Table 1.1 Energy use intensities for office and residential buildings

Energy use	Office building EUI (kWh/m^2)	Residential building EUI (kWh/m^2)
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?

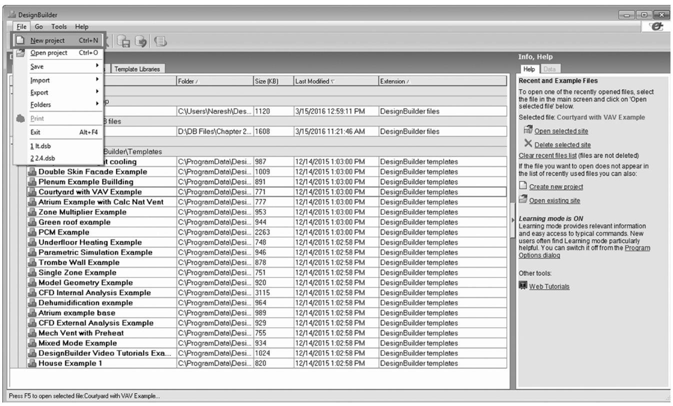
- Creating a new file
- Drawing a rectangular model
- Viewing the building model
- Rendering the building model
- Sizing runs for heating and cooling capacity
- Performing annual energy simulations

PROBLEM STATEMENT

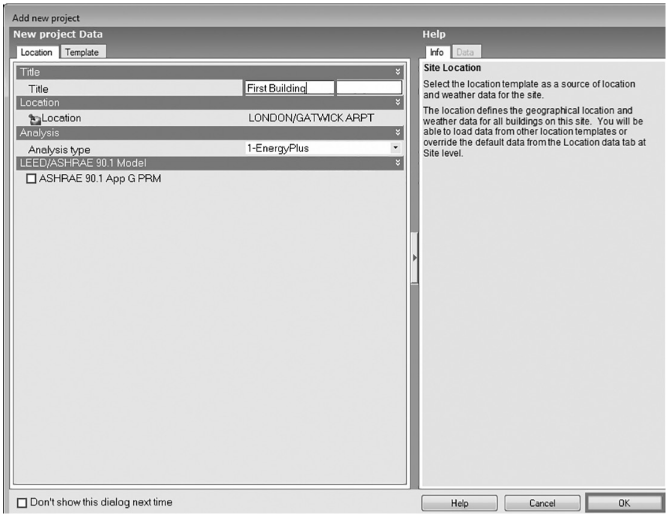
Create a new file and draw a 40 m × 20 m rectangular building of height 3.5 m with location as LONDON/GATWICK ARPT. Perform cooling and heating sizing and annual energy simulation. Use the Dynamic orbit option for different 3D views of the model.

SOLUTION

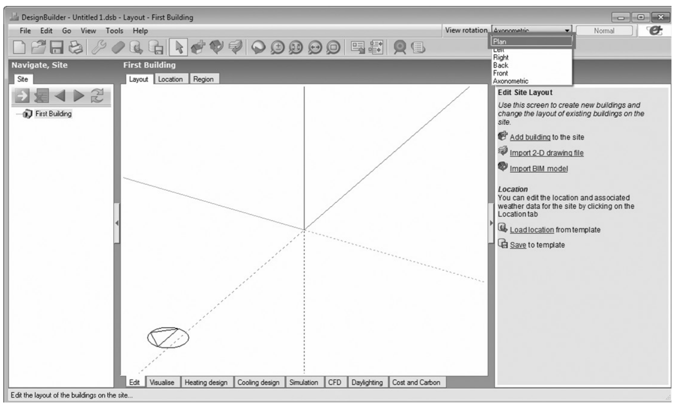
Step 1: Click **File** and select **New Project**. The **Add new project screen** appears.



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

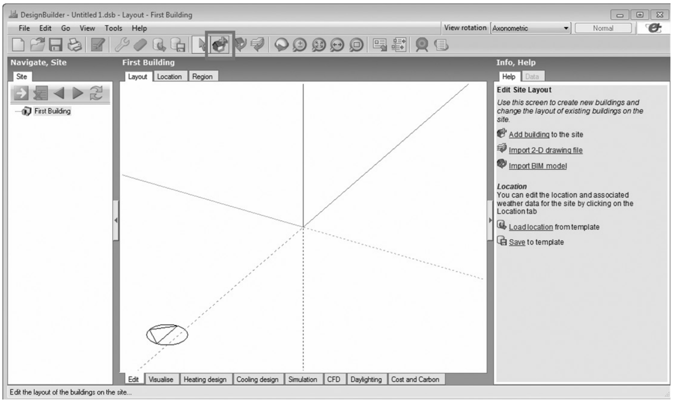


Step 3: Select **Plan** from the **View rotation** drop-down list.

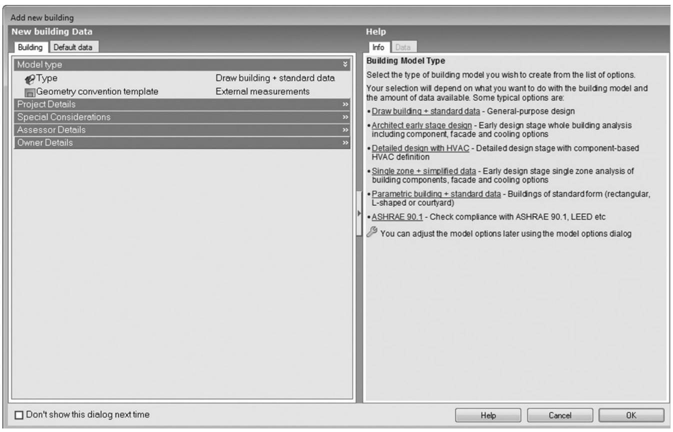


In the DesignBuilder display, the red line represents the *x*-axis, green the *y*-axis, and blue the *z*-axis.

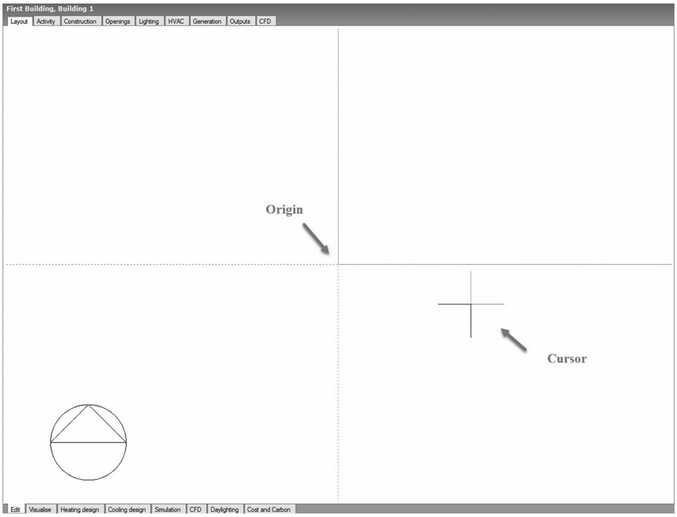
Step 4: Click the **Add new building** button. The **Add new building** screen appears.

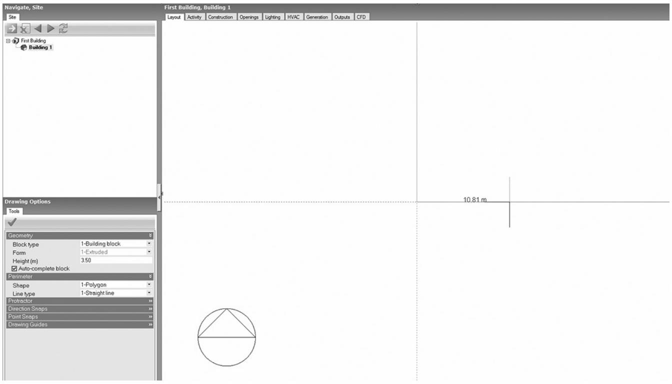


Step 5: Click **OK**. The screen appears with a cursor to draw a building.



Step 6: Move pointer to the **Origin**. Left click, 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).

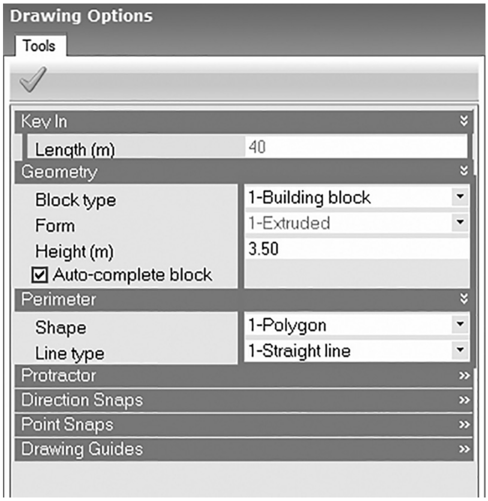




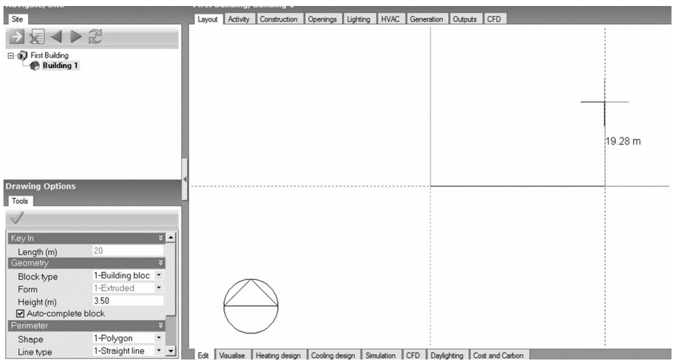
Step 7: Type **40**. The **Length** of the wall is set to **40** m. Ensure that the properties under the Geometry section are as follows:

- Block type – Building Block
- Form – Extruded
- Height – 3.5 m

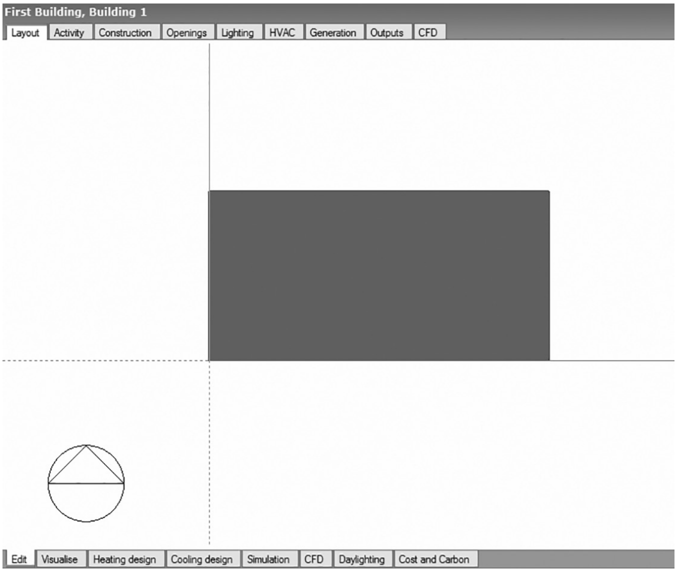
Press **Enter**.



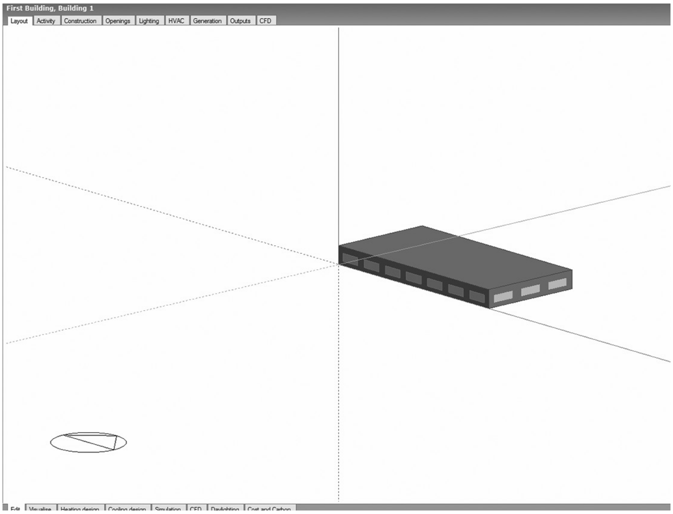
Step 8: Rotate the mouse wheel to zoom in or zoom out. Move the pointer parallel to the positive *y*-axis. It snaps when a dashed vertical line appears. Type **20** to draw the second side of the rectangle. Press **Enter**.



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

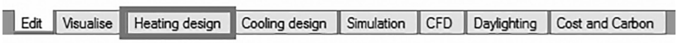


Step 10: Select the **Dynamic orbit** tab on the main menu bar. This shows the block in the orbit mode. Click and drag the mouse in the layout to view the block in the orbit mode.



Now you will learn to run the system sizing.

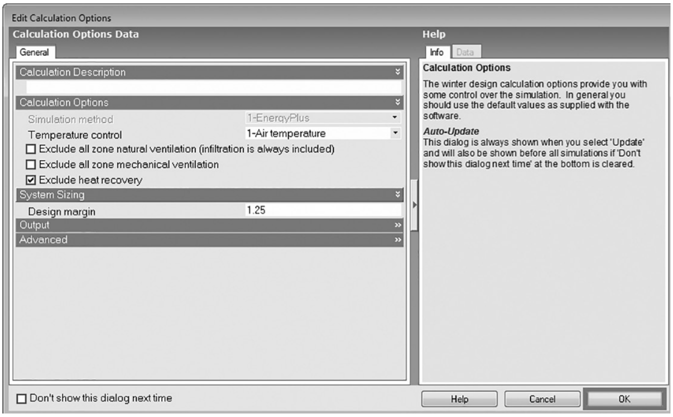
Step 11: Select the **Heating design** tab at the bottom of the screen. The **Edit Calculation Options** screen appears.

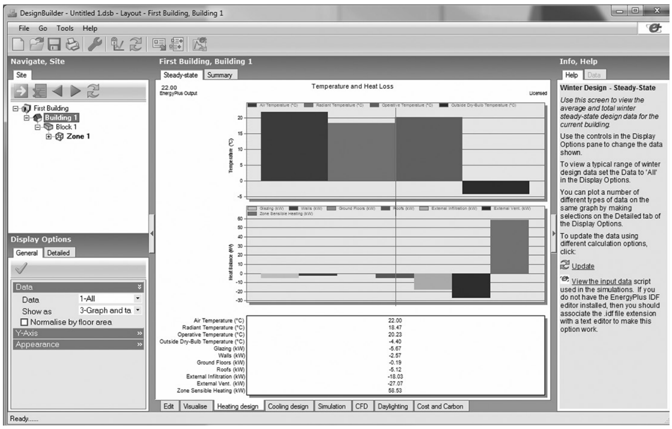


Heating Design calculations show the heating system size in the worst conditions (no internal loads and solar heat gains) for a winter design day.

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.



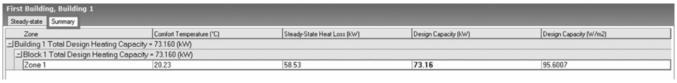


This graph shows the heat balance to maintain the inside temperature of 22°C when the outdoor dry bulb temperature is –4.4°C. You can see that there is a heat flow from the inside to outside (shown as negative numbers; the convention is that a positive value is used for a heat flow from the outside to inside) through the envelop and due to infiltration and ventilation. To balance this heat loss, the required zone sensible heating is 58.53 kW.

The table 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.


First Building, Building 1

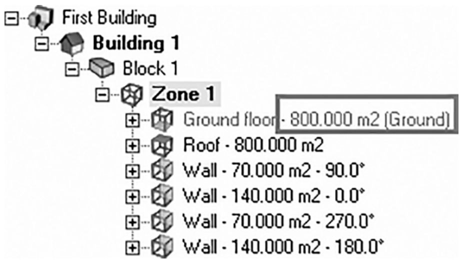
Steady-state | Summary

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 73.160 (kW)				
Block 1 Total Design Heating Capacity = 73.160 (kW)				
Zone 1	20.23	58.53	**73.16**	95.6007

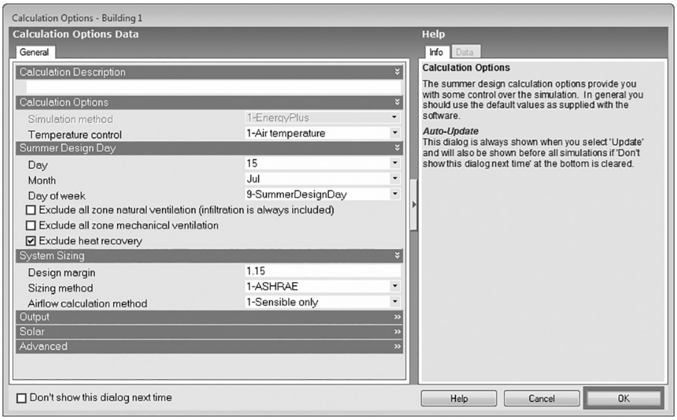
Design capacity is the total heat loss multiplied by the sizing factor.

Sizing factor is the safety factor considered in sizing the HVAC system. For example, the heating system is commonly oversized by 25%.

The design capacity of the building is 73.16 kW, which is calculated considering the sizing factor of 25% over the steady-state heat loss of 58.53 kW. The design capacity normalized by area is 95.60 W/m^2, which is calculated for the building floor area. In this case, the building dimensions are 40 m × 20 m, and the building area is 800 m^2 (Net Floor area is 765.24 m^2).



Step 14: Similarly select the **Cooling design** tab at the bottom of the screen. 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.

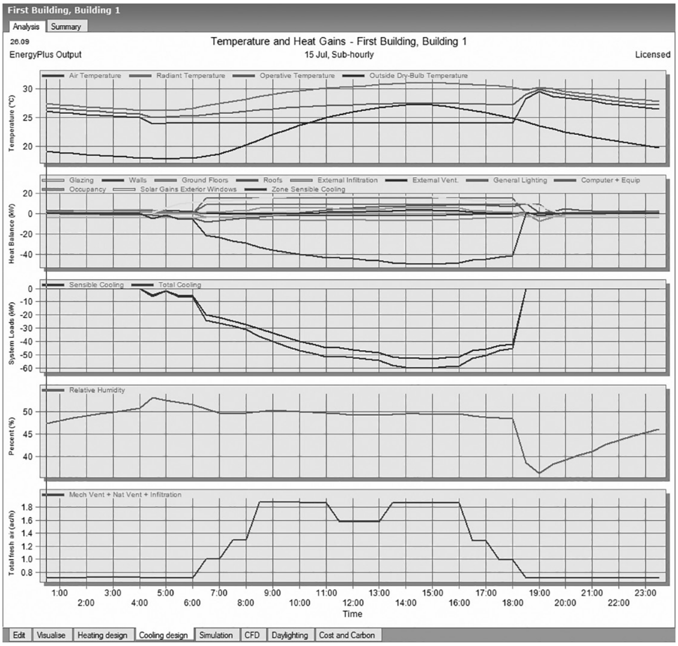


Table 1.2 Data for the single-zone model

Zone	Block 1: Zone 1
Design capacity (kW)	68.9
Design flow rate (m^3/s)	4.2
Total cooling load (kW)	59.9
Sensible (kW)	52.9
Latent (kW)	7.0
Air temperature (°C)	24.0
Humidity (%)	49.5
Time of max cooling	Jul 15:00
Max op temp in day (°C)	29.9
Floor area (m^2)	765.3
Volume (m^3)	2,678.5
Flow/floor area (l/s-m^2)	5.5
Design cooling load per floor area (W/m^2)	90.1
Outside dry bulb temperature at time of peak cooling load (°C)	27.2

First Building, Building 1

Analysis | Summary

Zone	Design Capacity (kW)	Design Flow Rate (m3/s)	Total Cooling Load (kW)	Sensible (kW)	Latent (kW)	Air Temperature (°C)	Humidity (%)	Time of Max Cooli...	Max Op Temp in Day (°C)	Floor Area (m2)	Volume
Building 1											
Block1:Zone1	68.94	4.2185	59.95	52.93	7.01	24.0	49.5	Jul 15:00	29.9	765.3	2678.5
Totals	**68.94**	**4.2185**	**59.95**	**52.93**	**7.01**	**24.0**	**49.5**	**N/A**	**29.9**	**765.3**	**2678.!**

The screen data are provided in table format for a clear view (Table 1.2).

The load calculated in the building is 68.94 kW. Cooling load is also described in tons of refrigeration (TR). For this building, it is 19.64 TR. Enter the cooling and heating capacities in Table 1.4.

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 versus 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.

(*Continued*)

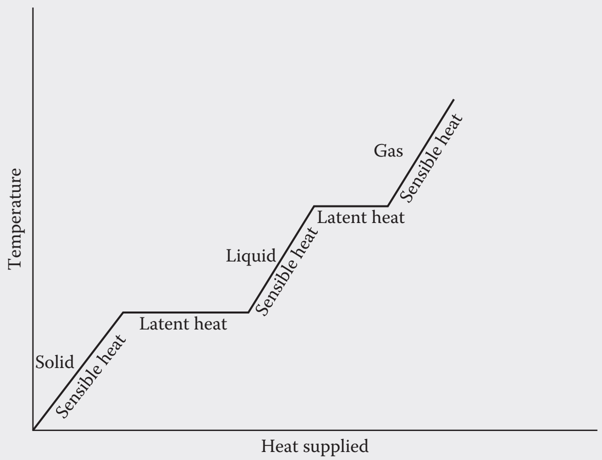
Latent heat, however, does not affect the temperature of a substance. Heat that causes a change of state with no change in temperature is called latent heat.

A cooling system should be capable of removing both the sensible and latent heat from the building. Therefore, the total cooling capacity of a system will be (sensible heat load + latent heat load) × sizing factor.

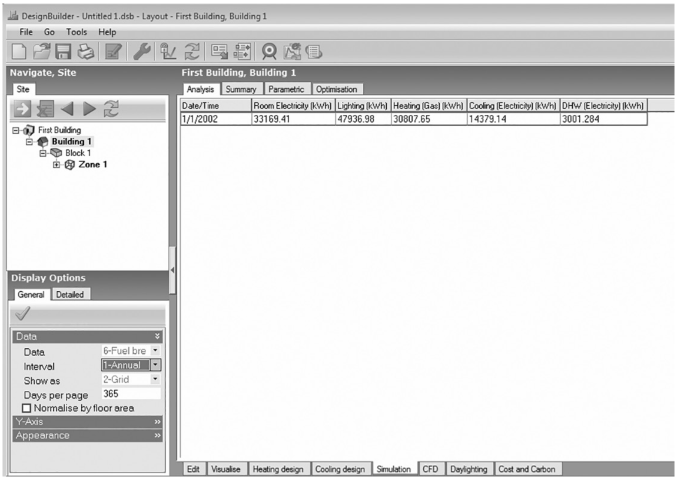
In this tutorial, sensible heat is 52.93 kW and latent heat is 7.01 kW. The addition of both sensible and latent heat is 59.9. Therefore, the design capacity calculated by multiplying 59.9 with sizing factor (1.15) is 68.93.

You can divide this by 3.51 to convert it into the unit of TR.

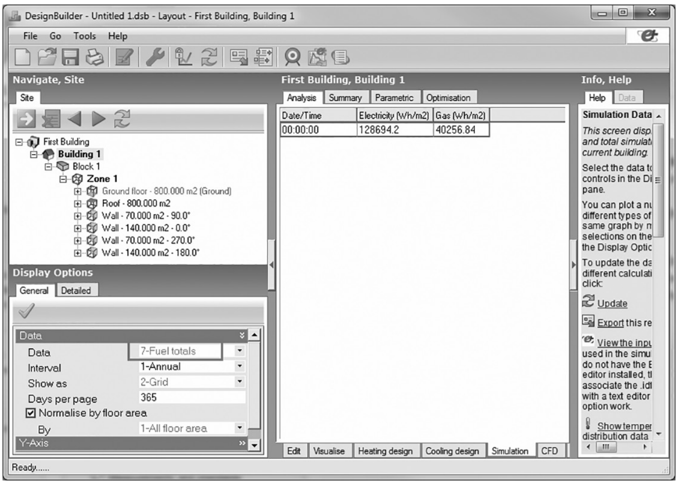
$$\frac{68.93}{3.51} = 19.64 \text{ TR}$$



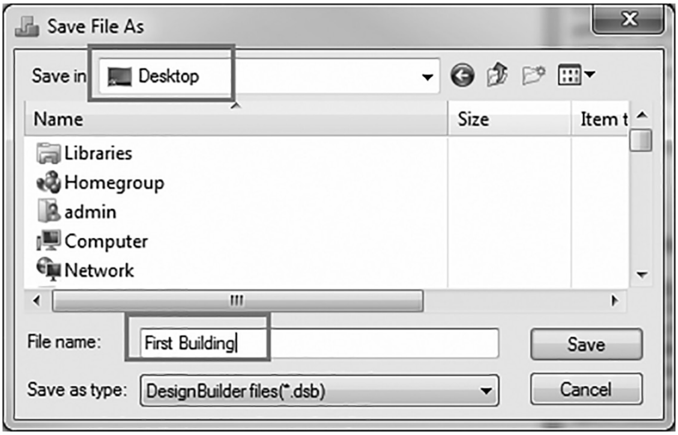
Step 16: Select the **Simulation** tab to perform the annual simulation. Select **Fuel breakdown** from the **Data** drop-down list, **Annual** from the **Interval** drop-down list and **Grid** from the **Show as** drop-down list.



Step 17: Select the **Normalise by floor area** check box 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. Enter the electricity EUI value in Table 1.3.



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



Exercise 1.2

Create a larger building and compare the EUI with a smaller building. Repeat the tutorial to create an 80 m × 40 m rectangular building. Compare the EUI of the larger building with the smaller building (the 40 m × 20 m building created in Tutorial 1.2) and enter it 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 (kWh/m^2 yr) is explained in Tutorial 1.1.

Table 1.3 EUI for a large and small building

	Building with 40 m × 20 m dimension kWh/m^2 yr	Building with 80 m × 40 m dimension kWh/m^2 yr
Electricity		
Gas		

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

	Building with 40 m × 20 m dimensions	Building with 80 m × 40 m dimensions
Capacity of cooling equipment (kW)		
Capacity of heating equipment (kW)		
Cooling capacity (kW/m^2)		
Heating capacity (kW/m^2)		

The following observations can be made through the above exercise:

1. EUIs of both the buildings are different.
2. Cooling and heating equipment capacities are greater for the 80 m × 40 m building compared to the 40 m × 20 m building. Larger buildings require higher capacity equipment due to the greater envelope area, occupancy and internal loads.
3. Cooling/heating equipment capacities per unit area are different. A larger 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 due to a non-linear variation of the exposed surface area with the floor area or carpet area.

TUTORIAL 1.3 Evaluating the impact of building location and orientation

GOAL

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

WHAT ARE YOU GOING TO LEARN?

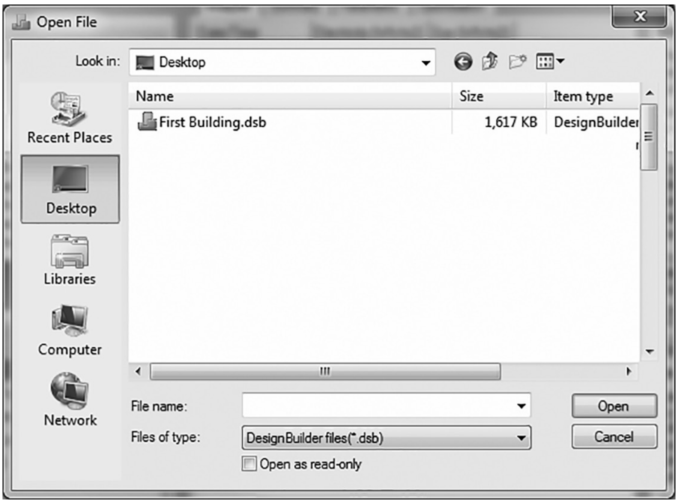
- Changing the location of a building
- Downloading a weather file
- Changing building orientation
- Analysing the impact of weather and orientation on the building's performance

PROBLEM STATEMENTS

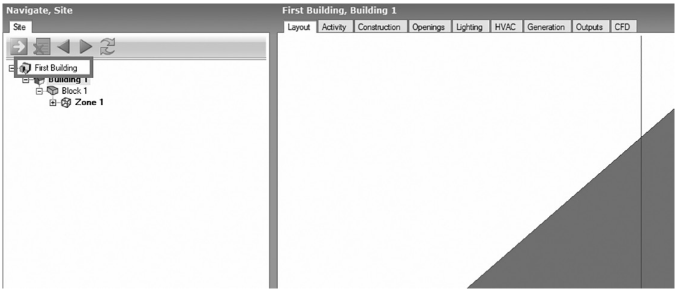
1. In Tutorial 1.2, a 40 m × 20 m rectangular building was simulated for London. Simulate the same building model for New Delhi and compare the HVAC sizing, monthly energy consumption and annual energy consumption.
2. Rotate the building by 90° clockwise and simulate it for New Delhi. Compare the results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

SOLUTION

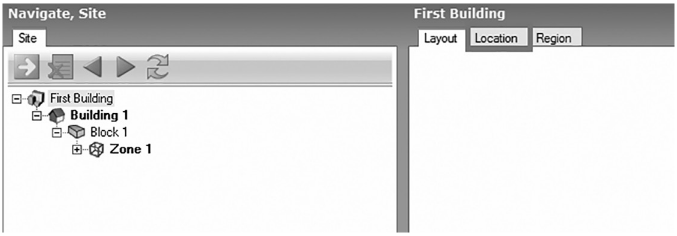
Step 1: Open the model saved in **Tutorial 1.2**.



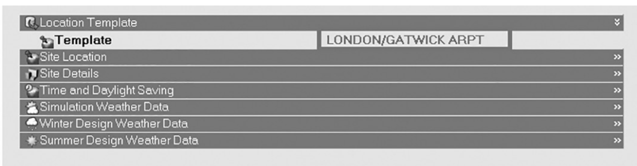
Step 2: Click **First Building**.



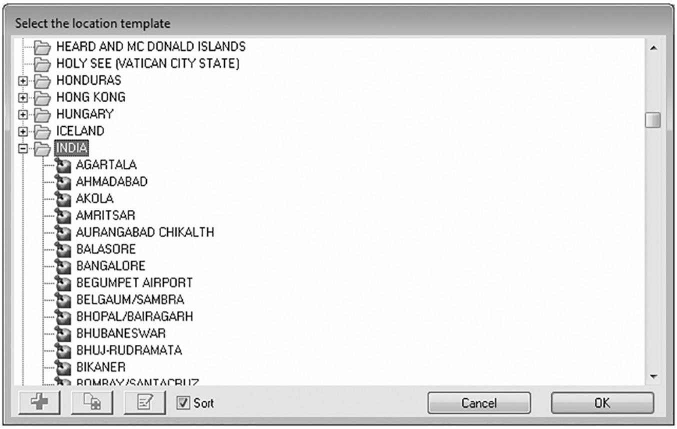
Step 3: Select the **Location** tab. The **Location Template** screen appears.

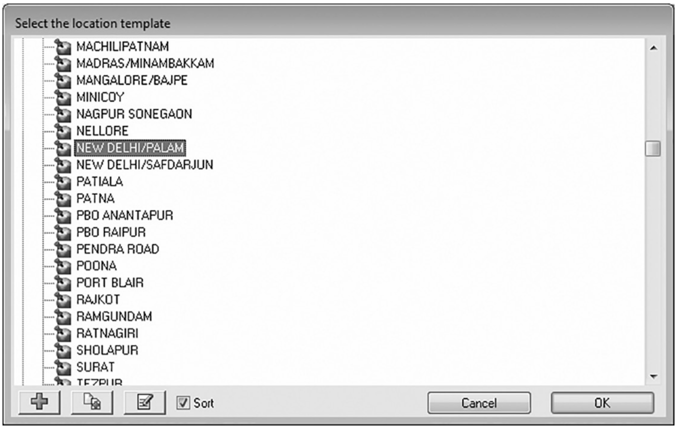


Step 4: Click **LONDON/GATWICK ARPT**. Three dots (…) appear. Click the three dots. The **Select the location template** screen appears.

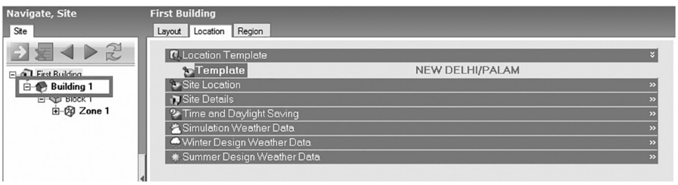


Step 5: Scroll to select **INDIA**. Double click **India** and select **NEW DELHI/PALAM**. Click **OK**.



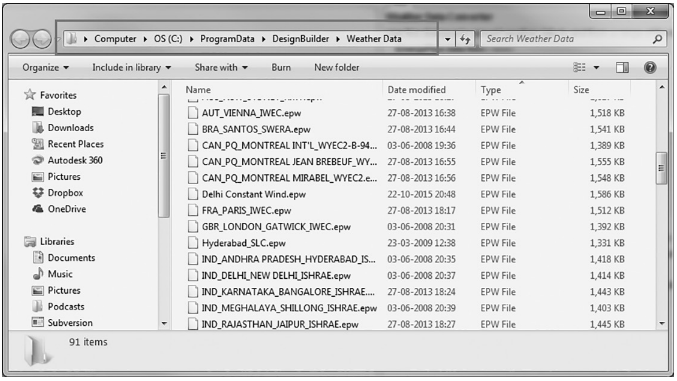


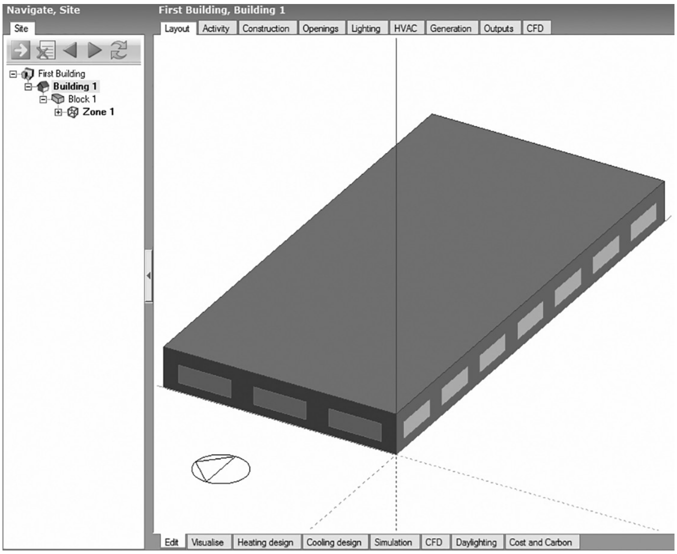
Step 6: Click **Building 1**.



Step 7: Select the **Simulation** tab. 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 .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 London and New Delhi locations. Results for 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 observe that there is no change in room electricity and lighting. This is the result of the same internal loads, and 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 compared to New Delhi.

Table 1.5 Energy consumption with a change in location

Annual fuel breakdown data		
Type	London (kWh)	New Delhi (kWh)
Room electricity	33,169.41	33,169.41
Lighting	47,936.98	47,936.98
Heating (gas)	30,807.65	1,502.32
Cooling	14,379.14	101,945.7
DHW (electricity)	3,001.28	3,001.28

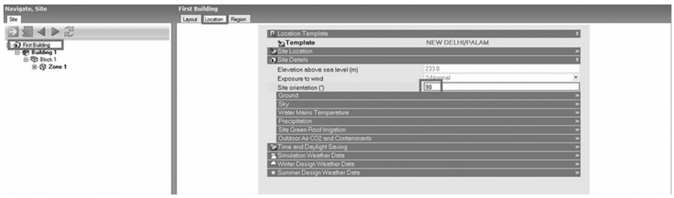
Table 1.6 Heating and cooling equipment capacity with a change in location

	London	New Delhi
Capacity of cooling equipment (kW)	68.94	99.64
Capacity of heating equipment (kW)	73.16	43.56

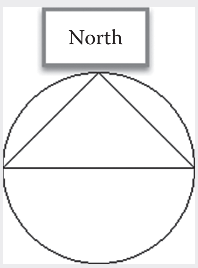
- For the cooling energy consumption, it is the reverse because New Delhi is warmer than London in summers.
- Similarly, there is a significant effect of location on the cooling and heating equipment capacity.

Next steps show how to change the orientation.

Step 9: 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.

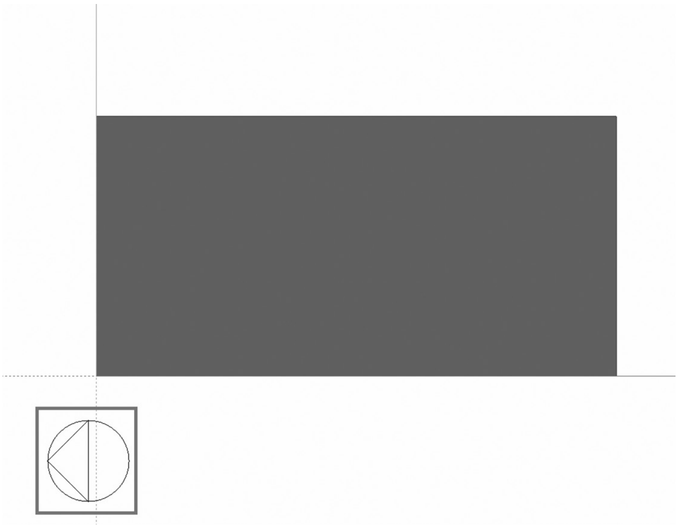


Working at the 'untitled' level (here First Building) of the tree means working at the site level. For example, if there are multiple buildings on a site that are to be modelled in DesignBuilder, after creating one building, return to the site level in the tree to start creating the next building.

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, since there could be multiple buildings on the site, this is called site orientation instead of building orientation.

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



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

Table 1.7 Annual energy consumption with a change in orientation

Type	Orientation 0° (kWh)	Orientation 90° (kWh)
Room electricity	33,169.41	33,169.41
Lighting	47,936.98	47,936.98
Heating (gas)	1,502.32	1,644.22
Cooling (electricity)	101,945.7	103,836.7
DHW (electricity)	3,001.28	3,001.28

Table 1.8 Heating and cooling equipment capacity with change in orientation

Type	Orientation 0° (kW)	Orientation 90° (kW)
Cooling	99.64	105.49
Heating	43.56	43.56

Changing the orientation of the building changes the heating and cooling energy consumption and also the system sizing. You may note that heating capacity does not get affected by the change in orientation due to the fact that peak requirement of heating occurs in non-sunshine hours. Hence, any orientation would require the same amount of heating (Table 1.8).

Exercise 1.3A

For New Delhi, run simulations for three more orientations – 45°, 180° and 270° – and compare the results (Tables 1.9 and 1.10).

Table 1.9 Energy consumption with a change in orientation

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

Table 1.10 Heating and cooling equipment capacity with a change in orientation

Type	0°	45°	90°	180°	270°
Heating capacity (kW)					
Cooling capacity (kW)					

Compare the energy consumption for 0° and 180°; what do you observe?

It can be seen that the results for 0° and 180° are the same, and those of 90° and 270° are the same. This is due to symmetry in the shape and window distribution of the building due to which solar exposure for these two cases becomes similar.

A comparison of the energy consumption for 0° and 90° shows a difference in the cooling capacity as well as energy consumption due to the change in solar exposure.

Exercise 1.3B

Change the weather location of the model with New York and Singapore and enter the values in Tables 1.11 and 1.12.

Table 1.11 Energy consumption with a change in location

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

Table 1.12 Heating and cooling equipment capacity with a change in location

Type	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 orientation as compared to that of the change in location.

The change in energy consumption due to orientation may be more pronounced in buildings having a higher aspect ratio (the ratio of longer and shorter sides) due to 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 harshness of 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 of CDDs and HDDs can be found in weather files, design data books and references such as ASHRAE.

HDDs and CDDs are a common measure 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 temperature and the number of days the outdoor temperature 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 beyond 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 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

The unit of measurement for CDD or HDD is degree days.

TUTORIAL 1.4 Evaluating the impact of opaque envelope components

GOAL

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

WHAT ARE YOU GOING TO LEARN?

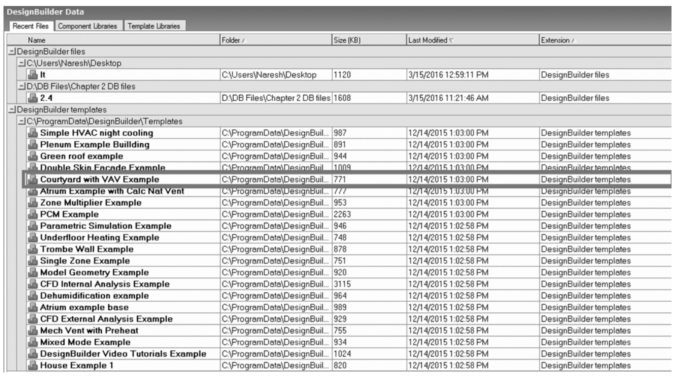
- Changing the wall construction in a building from the library of DesignBuilder
- Changing the roof construction in a building from the library of DesignBuilder

PROBLEM STATEMENT

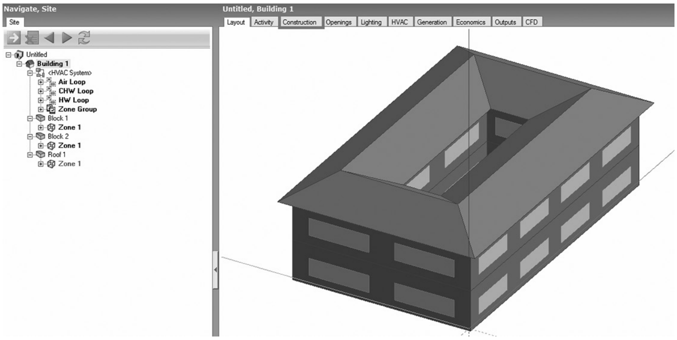
For the Courtyard with VAV Example, change the external wall from 'Best practice wall, Medium weight' to 'Brickwork single leaf construction dense plaster' and record its impact on the building energy performance for the London weather file.

SOLUTION

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



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

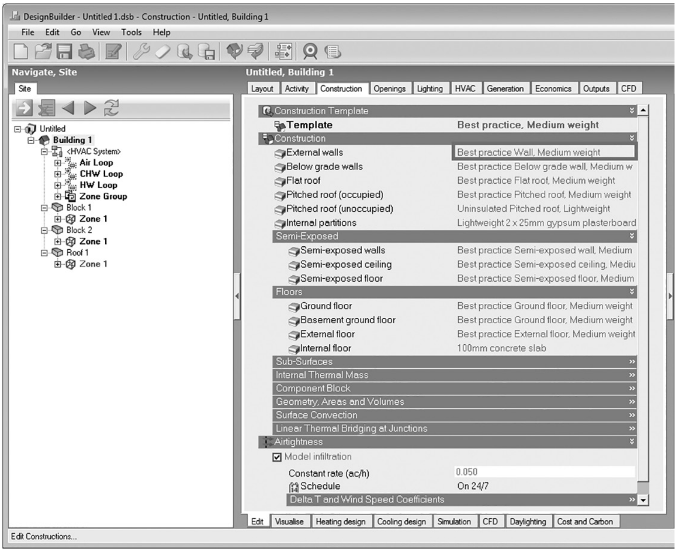


DesignBuilder uses the tree structure for data organization. The 'Template' is the root and all the other fields are the branches. DesignBuilder Templates are databases of typical generic data.

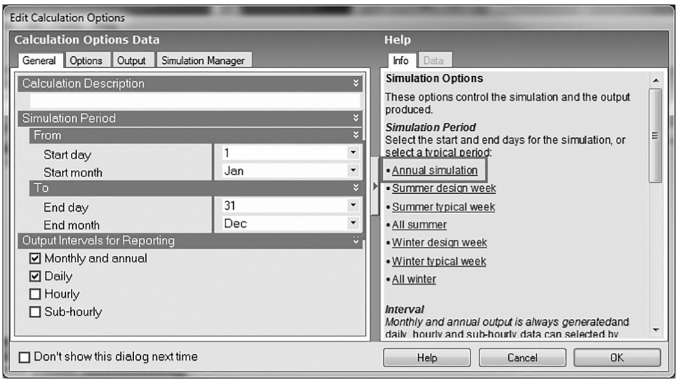
Therefore, when editing the template at the root level, it changes at all branches, but if changes are made at the branch level, root and other branches will not change.

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

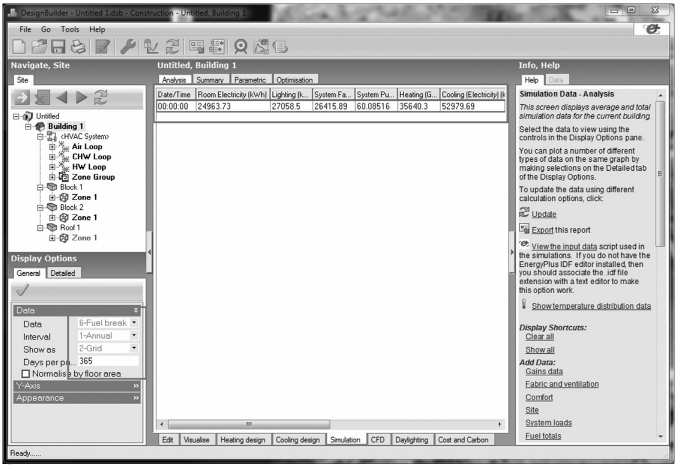
Step 3: Make sure that **Best practice Wall, Medium weight** is selected as **External walls**.



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



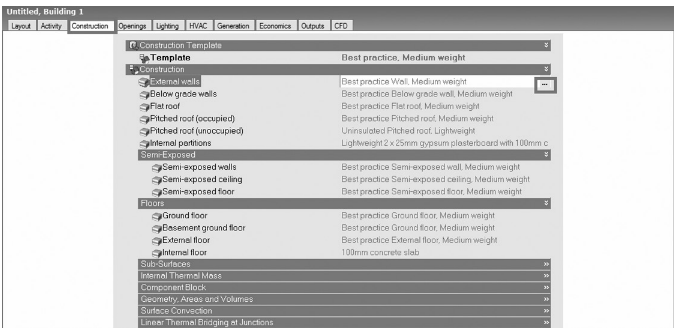
Step 5: Record the energy simulation results.



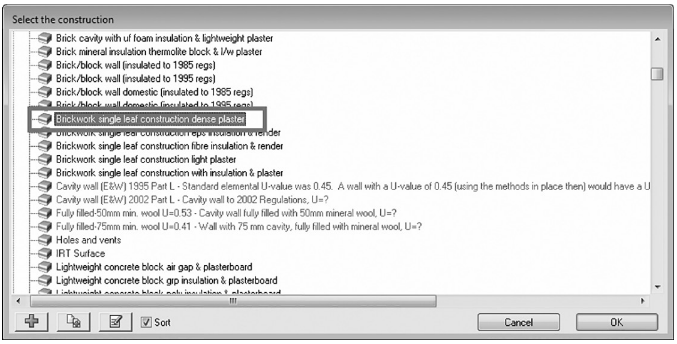
In the next steps, you are going to change the external wall construction.

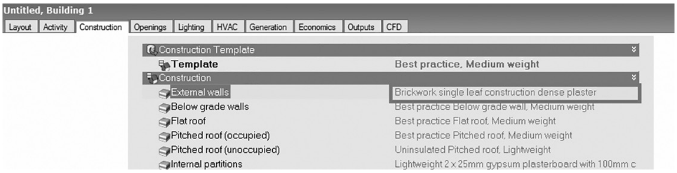
Step 6: Click **Edit**. The **Construction Template** screen appears.

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** tab and perform annual energy simulation. View the energy simulation results in Tables 1.13 and 1.14 and compare.

It can be observed that changing the wall impacts the equipment sizing and energy consumption.

Table 1.13 Energy consumption with a change in the external wall construction

Annual fuel breakdown data		
Type	Best practice wall, medium weight (kWh)	Brickwork single leaf construction dense plaster (kWh)
Room electricity	24,963.73	24,963.73
Lighting	27,058.50	27,058.50
System fans	26,415.89	27,748.42
System pumps	60.09	67.75
Heating (gas)	35,640.30	78,542.51
Cooling (electricity)	52,979.69	53,300.88

Table 1.14 Heating and cooling equipment capacity (kW) with a change in the external wall construction

Type	Best practice wall, medium weight	Brickwork single leaf construction dense plaster
Cooling	73.77	76.55
Heating	56.04	92.32

Exercise 1.4

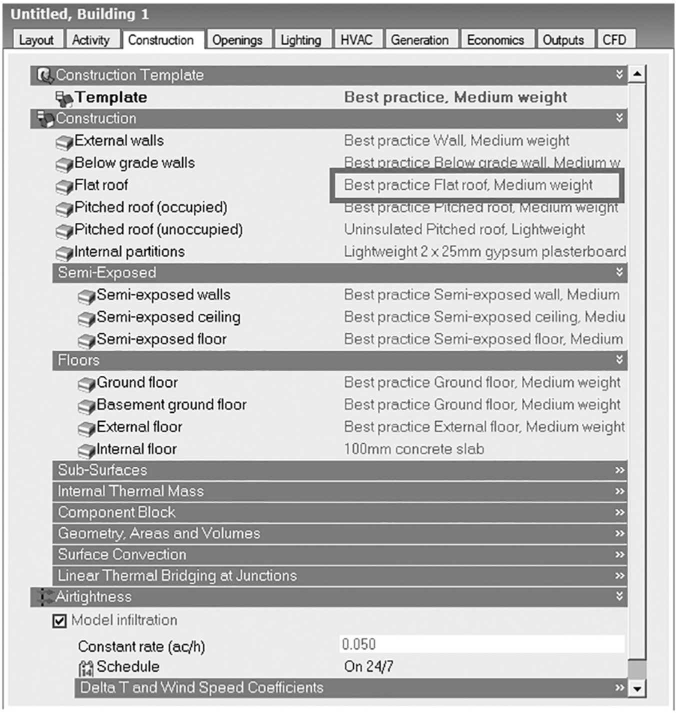
Open the model prepared in Tutorial 1.2. Assign flat roof construction as shown in Tables 1.15 and 1.16. Simulate and compare the results for London.

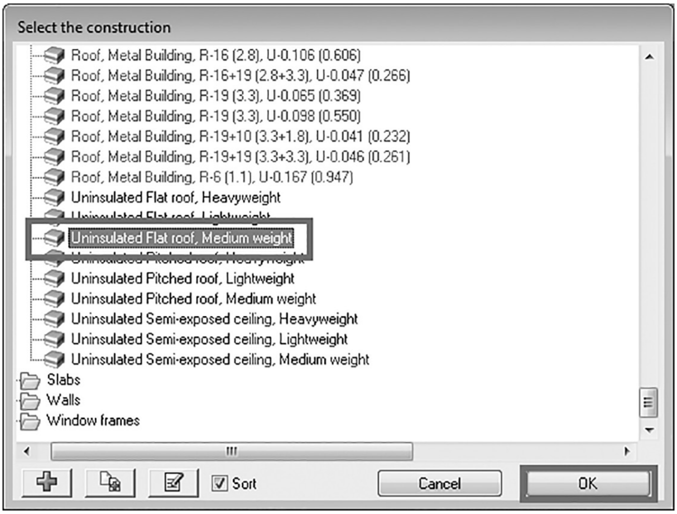
Table 1.15 Energy consumption with a change in roof construction

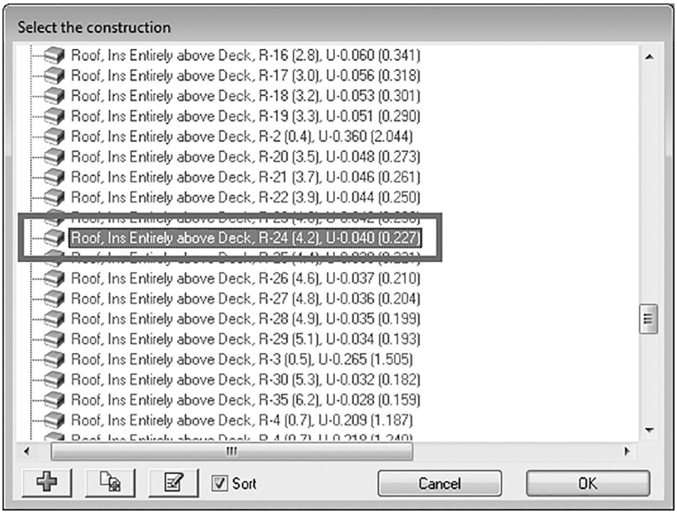
Annual fuel breakdown data		
Type	Roof, ins entirely above deck, R-24 (4.2), U-0.040 (0.227) (kWh)	Uninsulated flat roof, medium weight (kWh)
Room electricity		
Lighting		
System fans		
System pumps		
Heating (electricity)		
Heating (gas)		
Cooling		

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

Heating and cooling sizing (kW)		
Type	Roof, ins entirely above deck, R-24 (4.2), U-0.040 (0.227)	Uninsulated flat roof, medium weight
Heating		
Cooling		


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
Flat roof
Best practice Flat roof, Medium weight
Pitched roof (occupied)
Pitched roof (unoccupied)
Uninsulated Pitched roof, Lightweight
Internal partitions
Lightweight 2 x 25mm gypsum plasterboard
Semi-Exposed
Semi-exposed walls
Best practice Semi-exposed wall, Medium
Semi-exposed ceiling
Semi-exposed floor
Best practice Semi-exposed floor, Medium
Floors
Ground floor
Best practice Ground floor, Medium weight
Basement 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
Model infiltration
Constant rate (ac/h)
0.050
Schedule
On 24/7
Delta T and Wind Speed Coefficients


Select the construction
Roof, Metal Building, R-16 (2.8), U-0.106 (0.606)
Roof, Metal Building, R-16+19 (2.8+3.3), U-0.047 (0.266)
Roof, Metal Building, R-19 (3.3), U-0.065 (0.369)
Roof, Metal Building, R-19 (3.3), U-0.098 (0.550)
Roof, Metal Building, R-19+10 (3.3+1.8), U-0.041 (0.232)
Roof, Metal Building, R-19+19 (3.3+3.3), U-0.046 (0.261)
Roof, Metal Building, R-6 (1.1), U-0.167 (0.947)
Uninsulated Flat roof, Heavyweight
Uninsulated Flat roof, Medium weight
Uninsulated Pitched roof, Lightweight
Uninsulated Pitched roof, Medium weight
Uninsulated Semi-exposed ceiling, Heavyweight
Uninsulated Semi-exposed ceiling, Lightweight
Uninsulated Semi-exposed ceiling, Medium weight
Slabs
Walls
Window frames
Sort
Cancel
OK



You can follow similar steps as you have performed for the external wall.

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 WWR. WWR is the ratio of the total glazing area to the total external wall area in conditioned zones.

WHAT YOU ARE GOING TO LEARN?

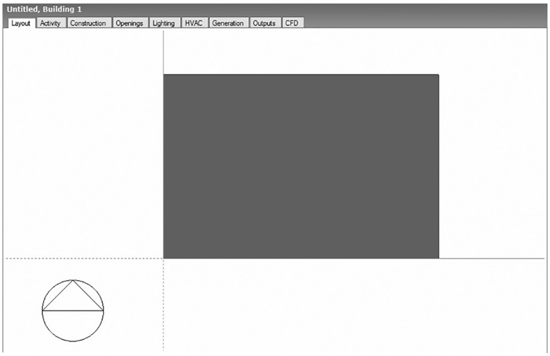
- Creating zones in a building
- Changing WWR
- Changing glazing type

PROBLEM STATEMENT

Create a 60 m × 40 m five-zone, single-story building model for London. Take WWR of 30% and 80% and evaluate the building energy performance. Compare cooling and heating equipment sizing of north and south zones.

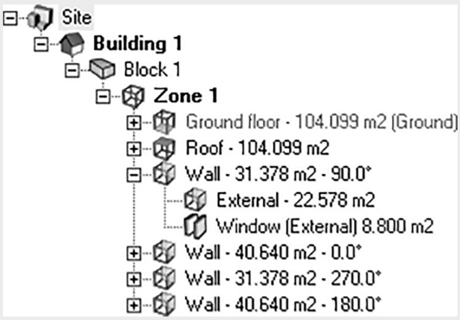
Similarly, compare sizing in east and west zones. Evaluate the impact of glazing by changing the single pane clear glazing (Sgl Clr 3 mm) to high-performance low SHGC dual pane glazing (Dbl Blue 6 mm/13 mm Air).

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



Data structure hierarchy in DesignBuilder:

Site→Building→Floors/Levels→Zones/Rooms→ Opaque Components→Transparent→Components



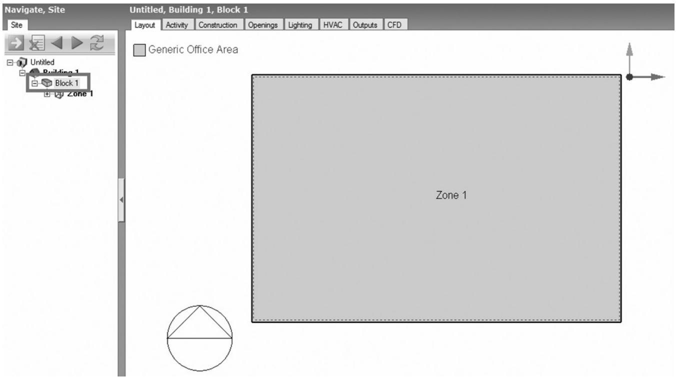
Assigning a template to the upper level branch will result in the same template for all the sub-branches. For example, if a construction template named ‘Framed Construction’ is assigned to the building, all floors and zones will have the same template – ‘Framed Construction’.

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.

(*Continued*)

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’, construction template of zone 1 still retains ‘Mass Construction’.

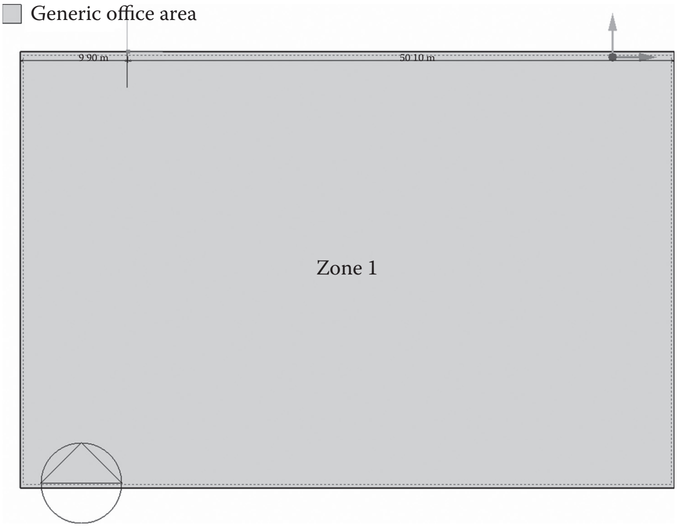
Step 2: Click **Block 1** in navigation tree. The display changes to **Zone 1**.



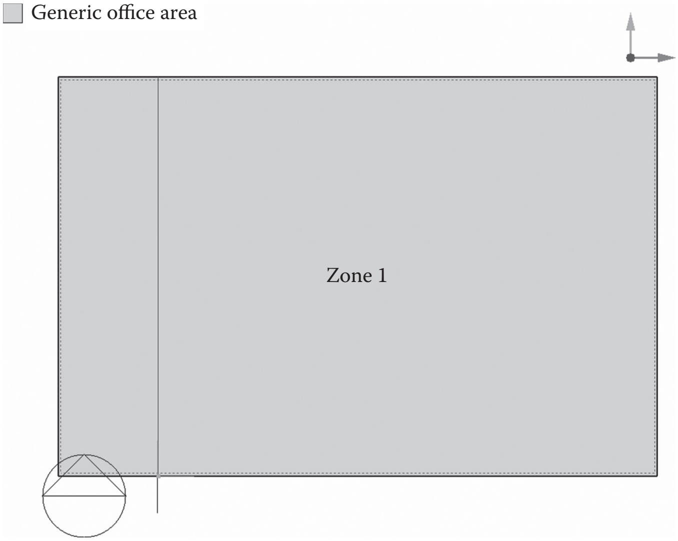
Step 3: Click the **draw construction line** button to mark lines on the zone. You need to draw an internal partition of 10 m offset.

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.

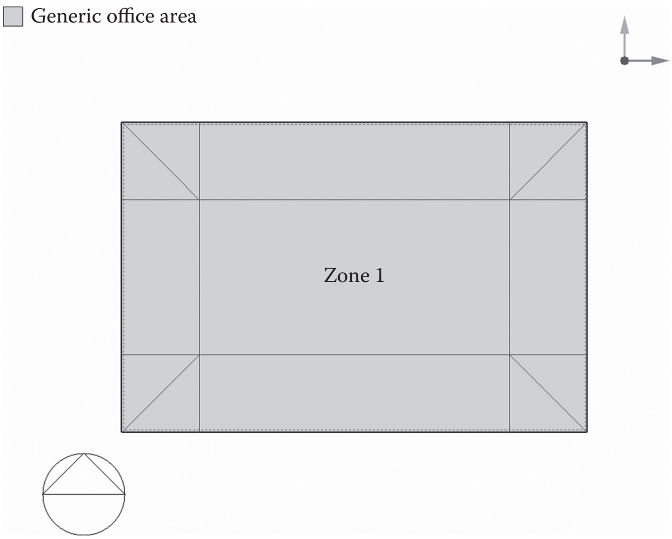
Step 4: Place the pointer near the top-left corner. The pointer snaps to the corner (green square appears at the centre of the cross hair). Left click once the pointer has snapped, and then move the mouse in the right direction over the north wall of the building and type **10**. It draws a construction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



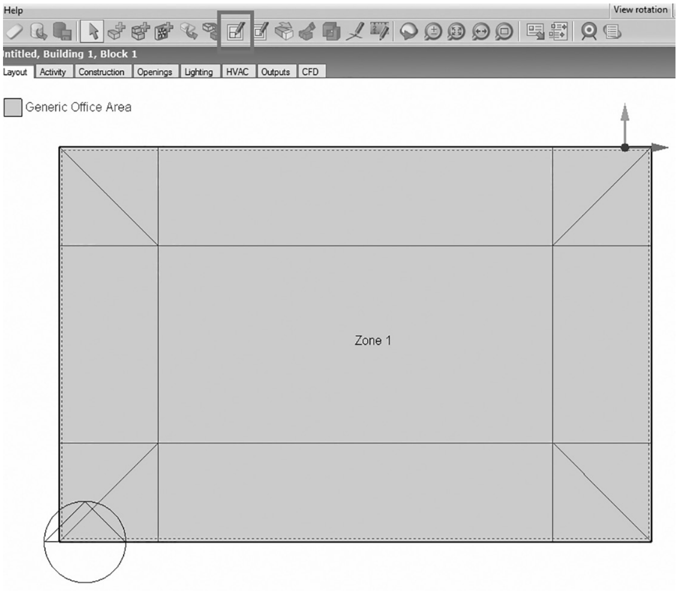
Step 5: Click the right end of the construction line. Now move the mouse vertically down parallel to the west wall of the building with an offset of 10 m (as achieved in the previous step) and snap to the south wall (this time cross hair will change to the red square because it will be edge snapping)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



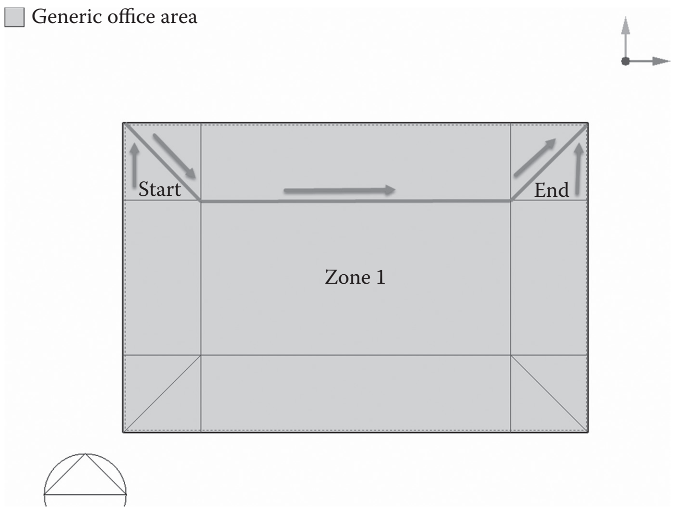
Step 6: Continue drawing all construction lines to mark core and perimeter zones.



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

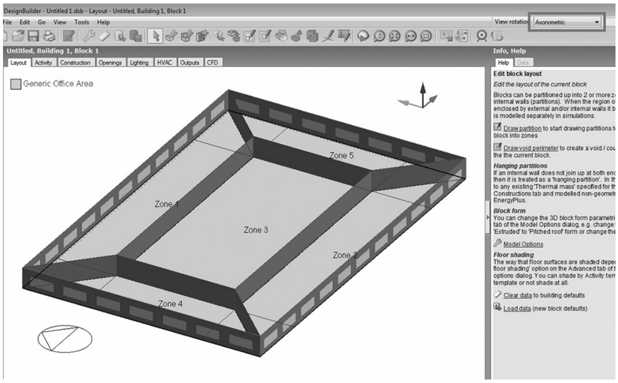


Step 8: Trace the construction line to draw a perimeter zone on the north.

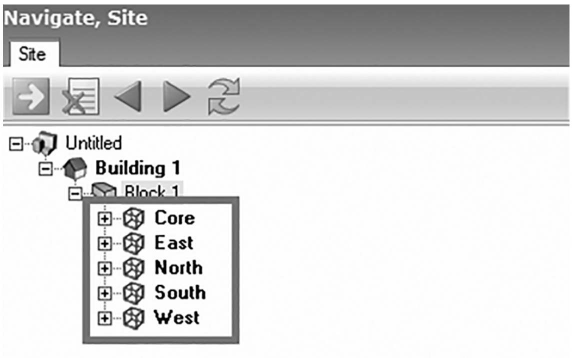


Step 9: Repeat Step 8 to draw other three zones. This step results in a total of five zones, four perimeters and one core as shown below with Axonometric View. (Note: No need to redraw the partition drawn in the previous steps.)

Perimeter and Core zoning is common in building energy simulations, especially when the internal layout of the building that is being modelled is not designed. The Perimeter and Core zoning is also practiced while modelling large open floor plans.

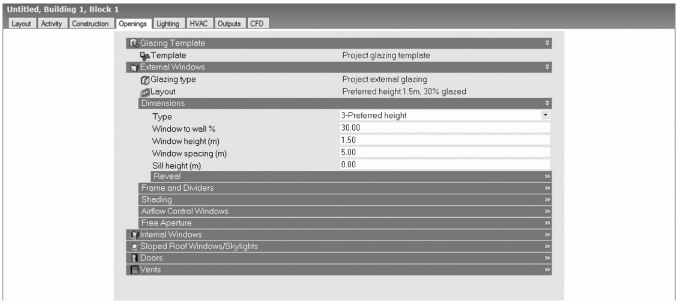


Step 10: Select and rename each zone based on its orientation. (For renaming you need to single click the zone name and wait for about 1 second, and then click again. A text box appears to enter a new name.)



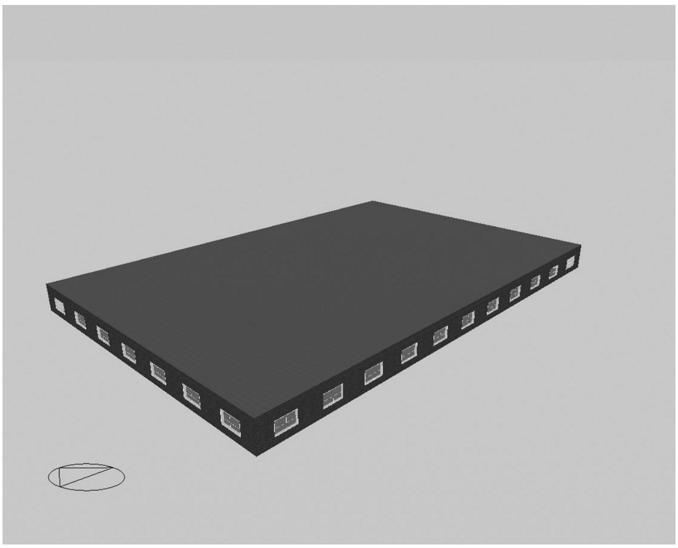
Step 11: Click **Building 1** in the navigation tree. Now you are going to set WWR for the whole building.

Step 12: Select the **Openings** tab. The **Glazing Template** screen appears.

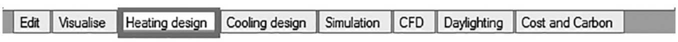


Step 13: Make sure that window to wall percentage is **30**.

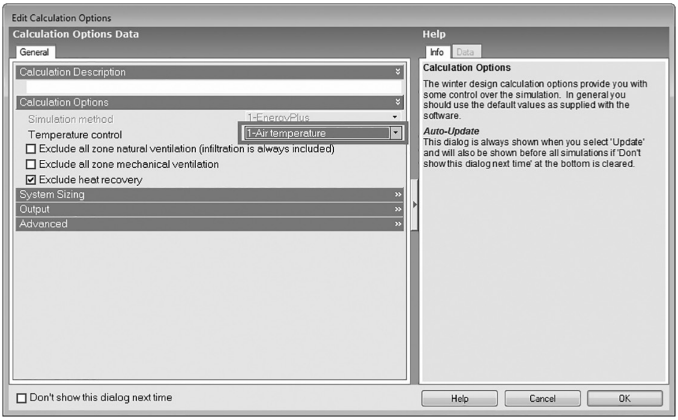
Step 14: Select the **Visualise** tab. Use the orbit tool for 3D visuals.



Step 15: Select the **Heating design** tab.



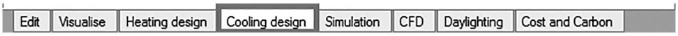
Step 16: Ensure **Air temperature** is selected in the **Temperature control** drop-down list. Click **OK**.

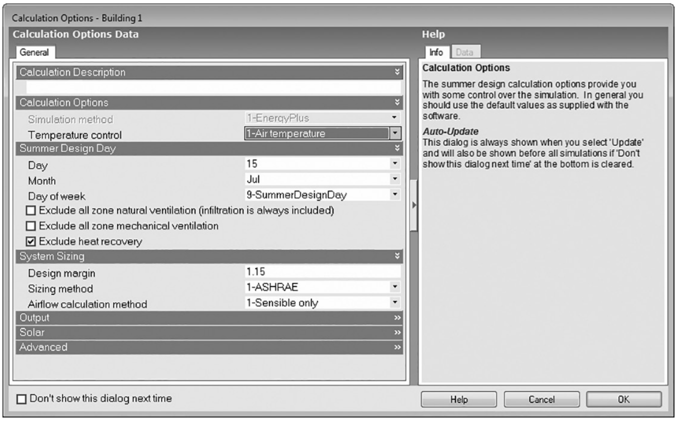


Air temperature control means controlling the mean air temperature of the zone to the assigned setpoint temperatures. Other control types mainly include operative temperature and adjusting zone radiant temperature control fraction. These control types are mainly used in advanced research and comfort analysis studies.

Step 17: Select the **Summary** tab. The results are displayed in a grid view. For each zone, the heating capacity is shown in the table.

Step 18: Select the **Cooling design** tab. Ensure **Air temperature** is selected as temperature control. Click **OK**.



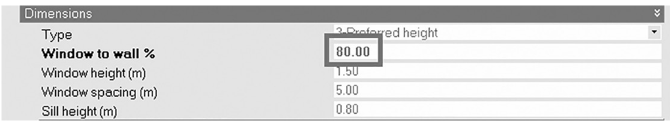


Step 19: Select the **Summary** tab to view the cooling system sizing results of each zone (Table 1.17).

It can be seen that the peak cooling for the east zone is at 10:00 and for the west zone at 16:00. Further, note that the cooling capacity for the west zone is more than the east zone. Also, the design capacity for the south zone is more than the north zone. This is because London is located at 51.5° north latitude, resulting in more solar radiation on the south façade.

Step 20: Run energy simulation and record the results for fuel breakdown. Save the model to use in forthcoming tutorials.

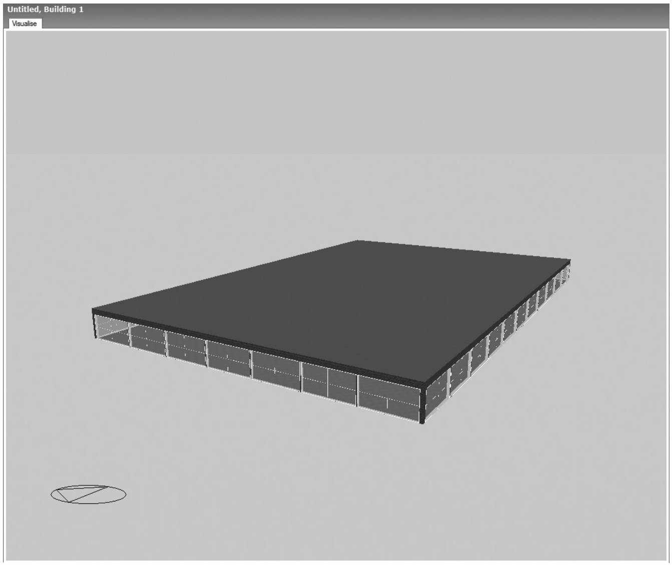
Step 21: Repeat previous steps and set WWR to **80**.



Step 22: Select the **Visualise** tab. Use the orbit tool for 3D visuals.

Table 1.17 Cooling design data for 30% WWR

Zone	Design capacity (kW)	Design flow rate (m^3/s)	Total cooling load (kW)	Sensible (kW)	Latent (kW)	Air temperature (°C)	Humidity (%)	Time of max cooling	Max op temperature in day (°C)
West	31.97	1.99	27.8	24.99	2.81	24	49	Jul 16:00	31.5
North	35.92	2.16	31.23	27.11	4.13	24	50	Jul 15:00	28.6
East	26.18	1.60	22.77	20.1	2.67	24	49.3	Jul 10:00	28.7
South	53.95	3.21	46.92	40.32	6.59	24	50.3	Jul 15:00	28.1
Core	45.37	2.80	39.45	35.17	4.28	24	49.3	Jul 14:00	28.7
Total	193.39	11.77	168.17	147.69	20.48	24	49.7	N/A	31.5



Step 23: Record the heating and cooling design data and fuel breakdown (Tables 1.18 and 1.20).

Now compare the results for each zone to gain a better understanding of the impact of WWR on sizing. The comparison is shown in Table 1.19.

Also compare the energy consumption of the two models (Table 1.20).

In the tutorial so far, you have learned to change WWR and its impact on sizing and energy consumption. Now you will see the impact of glazing by changing from a single pane clear glazing ('Sgl Clr 3mm') to a dual pane low SHGC high-performance glazing ('Dbl Blue 6mm/13mm Air') with 30% WWR. Before going to the next step, make sure that the WWR is 30% and you are at the building level in the navigation tree.

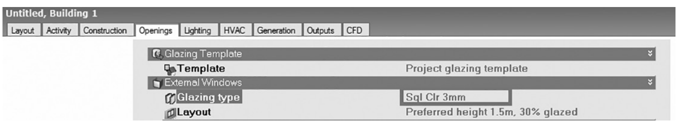


Table 1.18 Cooling design data for 80% WWR

Zone	Design capacity (kW)	Design flow rate (m^3/s)	Total cooling load (kW)	Sensible (kW)	Latent (kW)	Air temperature (°C)	Humidity (%)	Time of max cooling	Max op temperature in day (°C)
West	56.34	3.7411	48.99	46.94	2.05	24	47.7	Jul 17:00	37.8
North	42.65	2.6089	37.08	32.74	4.35	24	49.5	Jul 15:00	30.2
East	49.01	3.1683	42.62	39.75	2.87	24	48.2	Jul 09:00	30.8
South	70.14	4.5091	60.99	56.58	4.41	24	48.4	Jul 13:30	30.1
Core	56.21	3.3603	48.87	42.16	6.71	24	50.2	Jul 15:00	28.4
Total	274.34	17.3878	238.56	218.17	20.38	24	49.1	N/A	37.8

Table 1.19 Heating and cooling sizing for 30% and 80% WWR

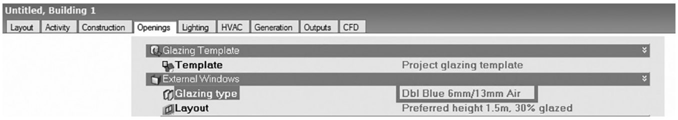
	Heating sizing (kW)		Cooling sizing (kW)	
	WWR 30%	WWR 80%	WWR 30%	WWR 80%
North	43.37	48.36	35.92	42.65
South	43.32	48.21	45.37	70.14
East	26.82	29.44	26.18	49.01
West	26.82	29.44	31.97	56.34
Core	52.6	66.41	53.95	56.21

Table 1.20 Energy consumption with 30% and 80% WWR

Annual fuel breakdown data		
Type	WWR 30% (kWh)	WWR 80% (kWh)
Room electricity	99,994	99,993
Lighting	1,44,513	1,44,512
Heating	90,292	91,614
Cooling	36,454	63,526
DHW	9,048	9,048

Step 24: Select the **Openings** tab and select the **Sgl Clr 3mm** from the library and run the annual simulation.

Step 25: Now select the **Dbl Blue 6mm/13mm Air** from the library and run the annual simulation.



When you compare the results by changing the glazing from single glazing to double glazing, notice that there is a change in the consumption of electricity for cooling and gas for heating (Table 1.21).

Table 1.21 Annual energy consumption with a change in glass type

	Annual fuel breakdown data	
Type	Single glazing (Sgl Clr 3mm) kWh	Double glazing (Dbl Blue 6mm/13mm Air) kWh
Room electricity	99,994	99,994
Lighting	1,44,513	1,44,513
Heating (gas)	1,10,841	1,00,895
Cooling	35,809	30,798
DHW	9,048	9,048

Exercise 1.5

Repeat the above tutorial for Sydney, Australia.

a. Observe the effect when WWR is changed from 30% to 80% (Tables 1.22 and 1.23).

Table 1.22 Energy consumption with 30% and 80% WWR

	Annual fuel breakdown data	
Type	WWR (30%) (kWh)	WWR (80%) (kWh)
Room electricity		
Lighting		
Heating (electricity)		
Heating (gas)		
Cooling (electricity)		

Table 1.23 Heating and cooling sizing capacity with 30% and 80% WWR

	Heating sizing (kW)		Cooling sizing (kW)	
	WWR 30%	WWR 80%	WWR 30%	WWR 80%
North				
South				
East				
West				
Core				

It can be seen that cooling sizing, and cooling energy consumption increases with increase in WWR. This is because larger glass area results in larger solar gain. Further, as the U-value of the window is inferior to the U-value of the wall, larger window results in larger heat gain in summers. It is interesting to note that heating sizing and heating energy consumption also increases with the increase in WWR. Though an increased solar heat gain through the glass tends to reduce the requirement of heating during daytime, the heat loss through the glass due to conduction offsets this effect. At any given time, glass of only one or two orientations would allow solar radiation to enter, whereas glass of other orientations would lose more heat through conduction as compared to a façade with a smaller WWR, assuming that the walls are more insulated than the glass. Further, during off-sunshine hours, the entire glazed area results in more heat loss if the U-value of the glass is inferior to that of the wall.

However, in subsequent chapters, it will be seen that this effect is combined with a reduction in lighting energy consumption if artificial light is simulated with a dimming feature.

b. Observe the effect with the change in glass type for 30% WWR (Tables 1.24 and 1.25).

Table 1.24 Energy consumption with a change in glass type

Annual fuel breakdown data		
Type	Single glazing (Sgl Clr 3mm) kWh	Double glazing (Dbl Blue 6mm/13mm Air) kWh
Room electricity		
Lighting		
Heating (electricity)		
Heating (gas)		
Cooling (electricity)		

Table 1.25 Heating and cooling sizing capacity with the change in glass type

	Cooling and heating system sizing	
Type	Single glazing (Sgl Clr 3mm) kW	Double glazing (Dbl Blue 6mm/13mm Air) kW
Heating		
Cooling		

TUTORIAL 1.6 Evaluating the impact of occupancy density

GOAL

To evaluate the impact of occupancy density on cooling and heating loads, and the whole building energy consumption.

WHAT ARE YOU GOING TO LEARN?

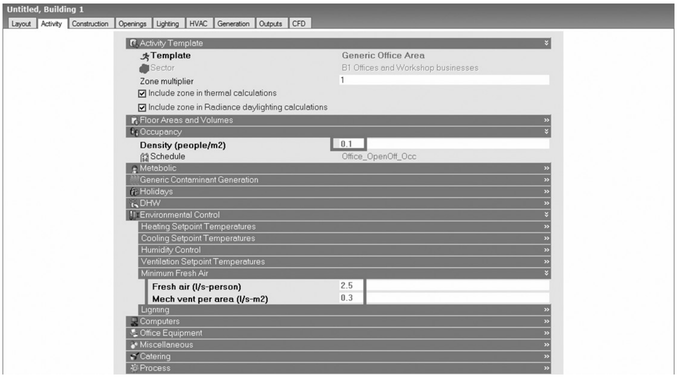
- Changing occupancy density

PROBLEM STATEMENT

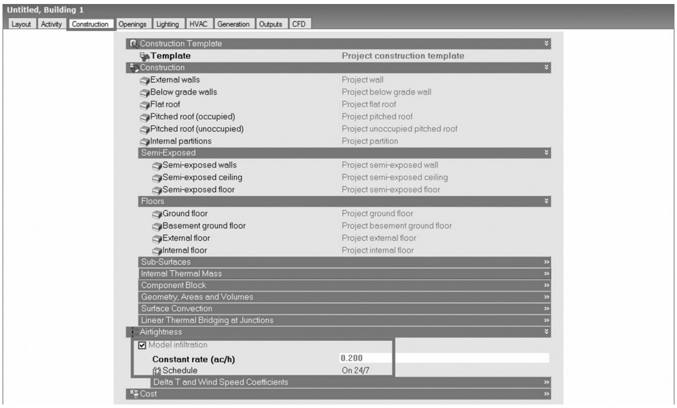
Use the model created in Tutorial 1.5 (60 m × 40 m with five zones). Set WWR to 30%, minimum fresh air (l/s-person) to 2.5, Mech vent per area (l/s-m^2) to 0.3, and model infiltration (ac/h) to 0.20. Run simulations with occupancy density (people/m^2) set to 0.07 and 0.10. Analyse the change in energy consumption. Use the **AZ-PHOENIX/SKY HARBOR**, **USA** weather file.

SOLUTION

Step 1: Select the **Activity** tab, and under the **Occupancy** section, set the occupancy density (people/m^2) to **0.1**. Under the **Minimum Fresh Air** section, set Fresh air (l/s-person) to **2.5** and Mech vent per area (l/sm^2) to **0.3**.



Step 2: Select the **Construction** tab. Under the Airtightness section, set Model Infiltration Constant rate as 0.200 ac/h.



Step 3: Perform the annual simulation and record the results.

Step 4: Set the occupancy density to **0.07** people/m^2. Perform the annual simulation and record the results (Table 1.26).

Here if you observe the results, they clearly show that a change in occupancy density has an impact on the total energy consumption.

The impact of occupancy density on energy consumption can be explained as follows:

- An increase in occupancy density increases cooling energy consumption due to the increased load (addition of sensible and latent loads from the occupants) in the zone air.

Table 1.26 Annual energy consumption with the change in occupancy density

Type	0.1 people/m^2	0.07 people/m^2
Room electricity	99,994	99,994
Lighting	1,44,513	1,44,513
Heating (gas)	1,045	1,096
Cooling (electricity)	2,02,307	1,92,100
DHW (electricity)	9,048	9,048

- An increase in occupancy density decreases the heating energy consumption since the heat added by the occupants to the indoor air helps in reducing the heating loads. However, this effect is not straightforward since a higher occupancy would require a higher fresh air intake that would in turn increase heating energy consumption. Further, for blowing more air into the space, the increase in fan power is also a factor that cannot be neglected.
- Occupancy density has no impact on lighting or equipment energy consumption unless these are directly related to the occupancy.

Two important parameters are used to show the occupancy of a zone:

1. Occupancy density and schedule: As seen in the tutorial, occupancy density is the maximum number of people in a zone. Schedule of occupancy defines when a zone is occupied or unoccupied and by how many people.
2. Metabolic activity: The amount of heat given out by people depends on the activity they perform. For example, a person who is exercising gives out more heat as compared to a person who is sleeping.

Exercise 1.6

For the same tutorial, observe the effect on cooling and heating equipment sizing (Table 1.27).

It can be seen from the results that change in occupancy alters heating and cooling sizing as well.

Table 1.27 Heating and cooling sizing capacity with a change in occupancy density

Type	0.1 people/m^2	0.07 people/m^2
Cooling		
Heating		

Increasing occupancy density results in additional sensible and latent heat into the space leading to higher cooling capacity and higher energy consumption.

Higher occupancy density leads to higher fresh air and supply air requirements. Hence, system capacity needs to be increased.

TUTORIAL 1.7 Evaluating the impact of space activity

GOAL

To understand the impact of space activity on cooling and heating loads, and energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Changing space activity
- Understanding various activity types
- Understanding the impact of activity type on sizing and energy consumption

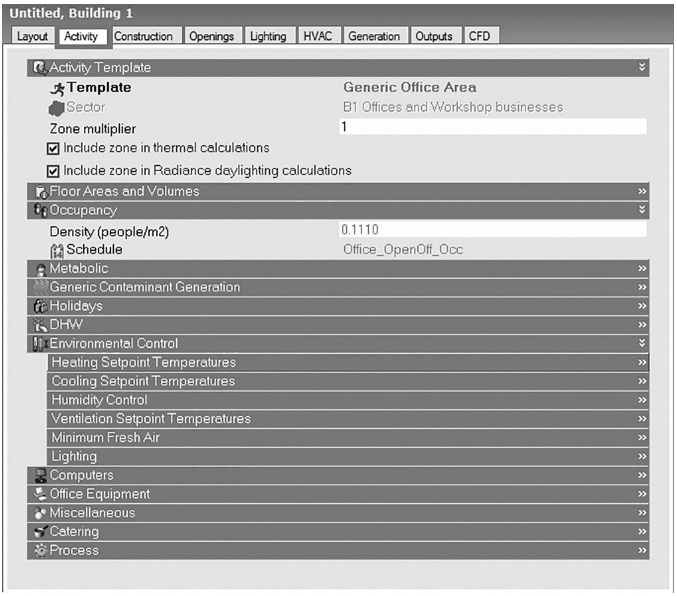
PROBLEM STATEMENT

Create a 20 m × 15 m single-zone model. Set the activity template to Office and Restaurant and compare. Study the effect on sizing and energy consumption for London.

SOLUTION

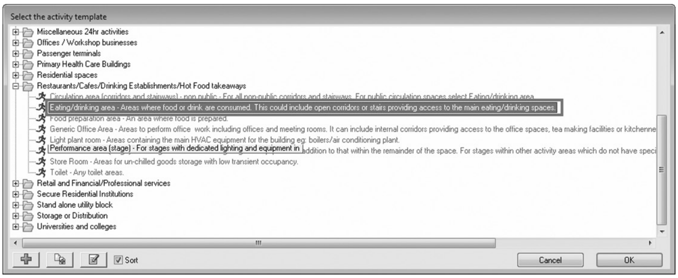
Step 1: Create a 20 m × 15 m single-zone model. You can refer to Tutorial 1.2 to create a single-zone model.

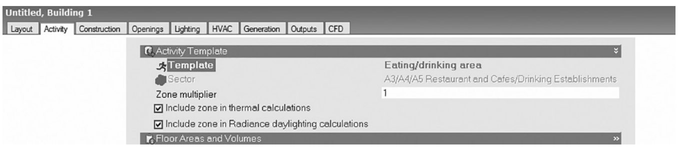
Step 2: Select the **Activity** tab. The **Activity Template** appears.



Step 3: Simulate the model and record the results.

Step 4: Select the **Activity Template** as **Eating/drinking area**. It changes internal gains and schedules of the space.





Step 5: Double click on **RestPub_EatDrink_Occ** schedule under the **Occupancy** tab. The **Edit schedule-RestPub_EatDrink_Occ** screen appears. (You can note the occupancy schedule for comparison with the other activity template as shown in Table 1.28.)

Schedules are used in DesignBuilder to define with respect to time the following:

- Occupancy
- Equipment, lighting HVAC operation
- Heating and cooling temperature setpoints
- Transparency of component blocks (usually seasonal)

Occupancy, equipment and lighting schedule are defined by a fraction (0–1). The maximum gain values (e.g. people/m^2) are multiplied by the values in the schedule to obtain the actual value to use at each time step in the simulation.

Source: http://www.designbuilder.co.uk/helpv4.7/#Schedules_-_EnergyPlus_Compact_Schedules.htm

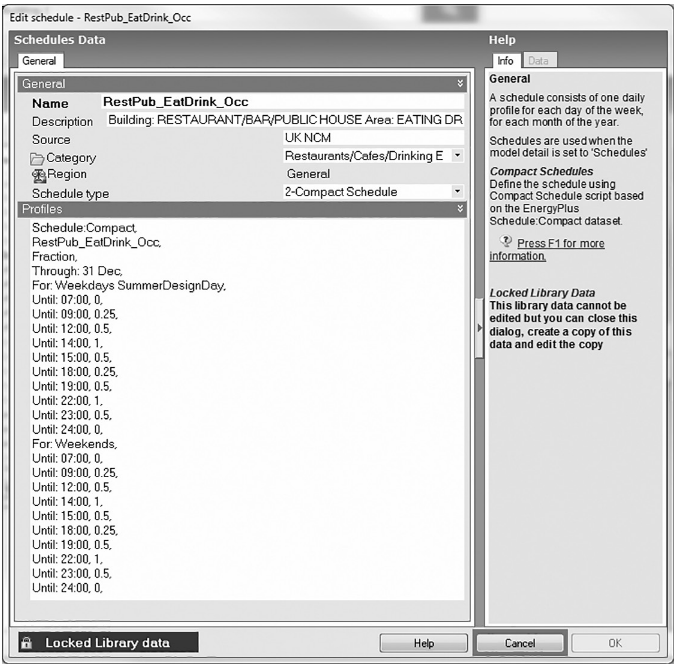


Table 1.28 Workday schedules for a generic office and eating/drinking area

Generic office area Office_OpenOff_Occ	Eating/drinking area RestPub_EatDrink_Occ
Schedule: Compact,	Schedule: Compact,
Office_OpenOff_Occ,	RestPub_FoodPrep_Occ,
Fraction,	Fraction,
Through: 31 Dec,	Through: 31 Dec,
For: Weekdays SummerDesignDay,	For: Weekdays SummerDesignDay,
Until: 07:00, 0,	Until: 06:00, 0,
Until: 08:00, 0.25,	Until: 07:00, 0.25,
Until: 09:00, 0.5,	Until: 08:00, 0.75,
Until: 12:00, 1,	Until: 14:00, 1,
Until: 14:00, 0.75,	Until: 15:00, 0.75,
Until: 17:00, 1,	Until: 17:00, 0.25,
Until: 18:00, 0.5,	Until: 18:00, 0.75,
Until: 19:00, 0.25,	Until: 22:00, 1,
Until: 24:00, 0,	Until: 23:00, 0.75,
For: Weekends,	Until: 24:00, 0.25,
Until: 24:00, 0,	For: Weekends,
For: Holidays,	Until: 06:00, 0,
Until: 24:00, 0,	Until: 07:00, 0.25,
For: WinterDesignDay AllOtherDays,	Until: 08:00, 0.75,
Until: 24:00, 0;	Until: 14:00, 1,
	Until: 15:00, 0.75,
	Until: 17:00, 0.25,
	Until: 18:00, 0.75,
	Until: 22:00, 1,
	Until: 23:00, 0.75,
	Until: 24:00, 0.25,
	For: Holidays,
	Until: 06:00, 0,
	Until: 07:00, 0.25,
	Until: 08:00, 0.75,
	Until: 14:00, 1,
	Until: 15:00, 0.75,
	Until: 17:00, 0.25,
	Until: 18:00, 0.75,
	Until: 22:00, 1,
	Until: 23:00, 0.75,
	Until: 24:00, 0.25,
	For: WinterDesignDay AllOtherDays,
	Until: 24:00, 0;

Step 6: Click **Cancel**. The screen closes.

Step 7: Select the **Simulation** tab to get energy consumption results.

Compare both cases (Table 1.29).

The results show the impact of Activity type on energy consumption.

From the model, you can find out the interior load parameters (Table 1.30). You can get this data from the Activity and Lighting tabs. You can co-relate the change in energy consumption with the change in interior loads.

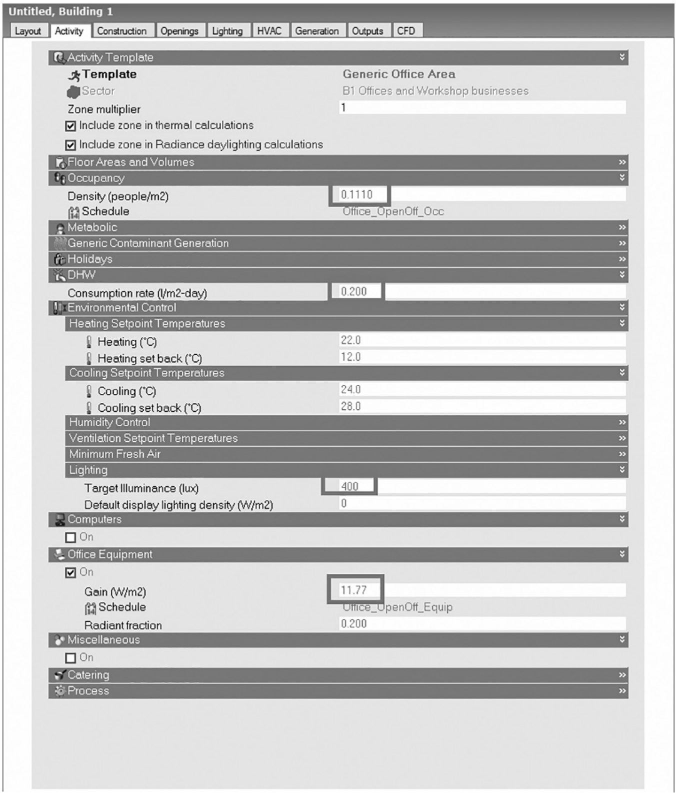


Table 1.29 Annual energy consumption with a change in space activity

Type	Generic office area (kWh)	Eating/drinking area (kWh)
Room electricity	12,131.16	32,225.33
Lighting	17,532.15	12,259.07
Heating (gas)	12,729.33	24,047.98
Cooling (electricity)	6,529.12	8,596.75
DHW (electricity)	1,097.67	43,672.32

Table 1.30 Internal load data for generic office and eating/drinking area

Interior load	Unit	Generic office area	Eating/drinking area
Occupancy	People/m^2	0.111	0.2
Target illuminance	Lux	400	150
Interior light	W/m^2 per - 100 lux	5	5
Equipment	W/m^2	11.77	18.88
DHW	l/s-day	0.2	5.69

Exercise 1.7

Compare the cooling and heating energy consumption for a generic office area and classroom (Table 1.31).

> Activity type: Classroom can be found under 'Universities and college' category.

From the model, you can find out the change in the internal load parameter (Table 1.32).

Table 1.31 Annual energy consumption for a generic office and eating/drinking area

Type	Generic office area (kWh)	Class room area (kWh)
Room electricity		
Lighting		
Heating (Gas)		
Cooling (Electricity)		
DHW (Electricity)		

Table 1.32 Internal load for a generic office and eating/drinking area

Interior load	Unit	Generic office area	Classroom area
Occupancy	People/m^2		
Target illuminance	lux		
Interior light	W/m^2 100 lux		
Equipment	W/m^2		
DHW	l/s-day		

Compare office and class room schedules in Table 1.33.

Table 1.33 Workday schedules for a generic office and class room area

Generic office area Office_OpenOff_Occ	Classroom area

TUTORIAL 1.8 Evaluating the impact of lighting and equipment power

GOAL

To understand the impact of lighting and equipment power density on HVAC system sizing and energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Changing lighting power density (LPD)
- Changing equipment power density (EPD)

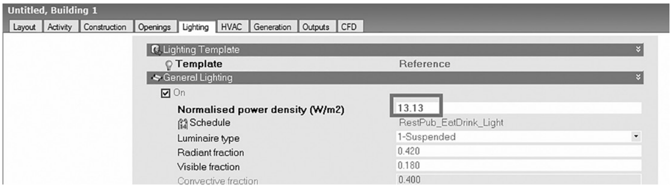
PROBLEM STATEMENT

Compare the energy consumption when you set the LPD as 13.13 and as 10.0 W/m^2. Use the **Courtyard with VAV Example** template for London.

SOLUTION

Step 1: Select the **Lighting** tab, and under the **General Lighting** section, set the LPD shown as Lighting energy (W/m^2) to 13.13.

Lighting power density represents the load of any lighting equipment in any defined area or the watts per square meter of the lighting equipment. It can be obtained by dividing the total lighting load by the area.

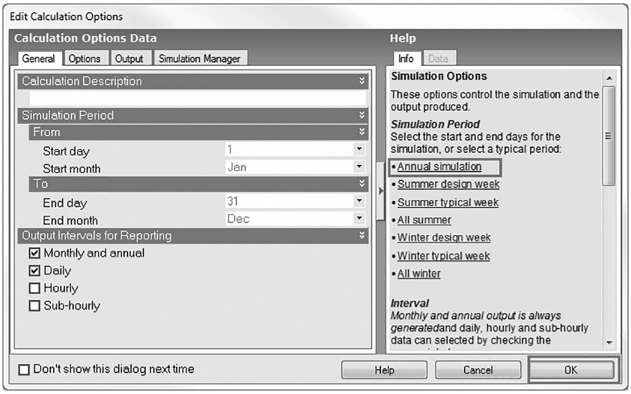


Tip: Does your Lighting energy have units as W/m^2 - 100 lux rather than W/m^2?

If yes, change this to W/m^2 in the following way:

Go to: Edit→Model Options Data→Data→Gain Data→Lighting Gains Units, and change the lighting gain units to W/m^2.

Step 2: Click **Simulate** and click the **Annual simulation** link to perform annual simulation.



Step 3: Repeat the steps to set the LPD to 10.00. Perform annual energy simulation. Compare the end use energy consumption for both cases (Table 1.34).

From the end use energy consumption shown in Table 1.34, it is clear that a reduction in LPD decreases the lighting energy consumption. Also, note the decrease in cooling and fans and pump energy consumption.

Table 1.34 Annual fuel breakdown with a change in LPD

Type	LPD – 13.13 W/m^2 (kWh)	LPD – 10.0 W/m^2 (kWh)
Room electricity	24,963.73	24,963.73
Lighting	23,685.21	18,039.00
System fans	25,854.88	24,916.21
System pumps	57.99	54.61
Heating (gas)	36,880.63	39,053.90
Cooling (electricity)	51,073.34	48,160.19

Exercise 1.8

Set the equipment power density to 20 and 10 W/m^2 and study the impact on building energy consumption and sizing (Tables 1.35 and 1.36).

It can be clearly seen from the results that reducing the LPD and EPD not only results in the reduction of energy consumption for lighting, but it also helps reduce the cooling energy. This is because the energy consumed in lighting or operating equipment such as computers finally gets converted into heat and usually gets added into the space. This additional heat increases the energy consumption of the fans and pumps and also increases the system sizing. In cases of heating energy consumption, the reverse effect is observed since lighting and equipment add additional heat to the space, thereby reducing energy requirement for heating.

Table 1.35 Energy consumption with a change in equipment power density

Annual fuel breakdown data		
Type	EPD (20 W/m^2) (kWh)	EPD (10 W/m^2) (kWh)
Room electricity		
Lighting		
System fans		
System pumps		
Heating (electricity)		
Heating (gas)		
Cooling (electricity)		

Table 1.36 Heating and cooling sizing capacity with a change in equipment power density

Type	EPD (20 W/m^2) (kW)	EPD (10 W/m^2) (kW)
Heating		
Cooling		

TUTORIAL 1.9 Evaluating the impact of daylight controls

GOAL

To evaluate the impact of daylight controls on energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Specifying daylight controls in a building model
- Evaluating the impact of daylight controls on energy consumption

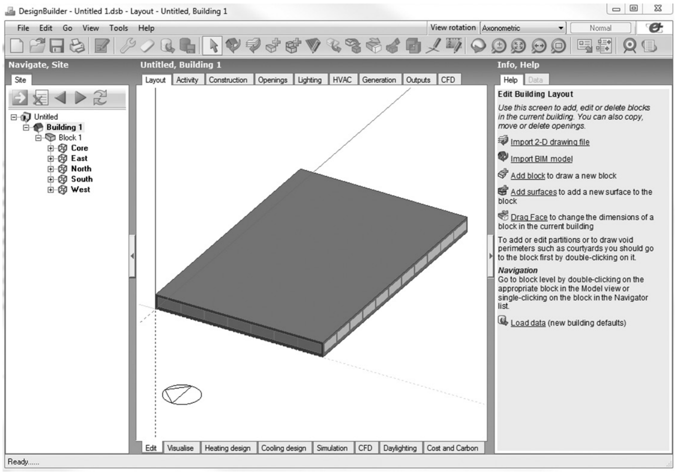
PROBLEM STATEMENT

Create a 60 m × 40 m model with a core and four perimeter zones. Consider a perimeter depth of 5 m. (Refer Tutorial 1.5 for steps to create the model.) Set WWR to 60% and use 'Sgl Grey 3mm' glass (VLT ~ 60%). Perform annual energy simulation without daylight sensors, then install daylight control in the north zone. Compare the lighting energy consumption with and without daylight control for **London Gatwick location, United Kingdom**.

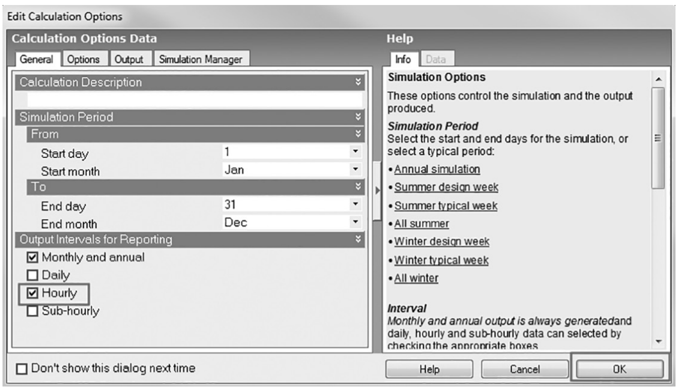
Tip: For single pane glass with 60% visible light transmittance, select 'Sgl Grey 3mm' with a light transmission value of 0.611 under the Single category of the glazing library.

SOLUTION

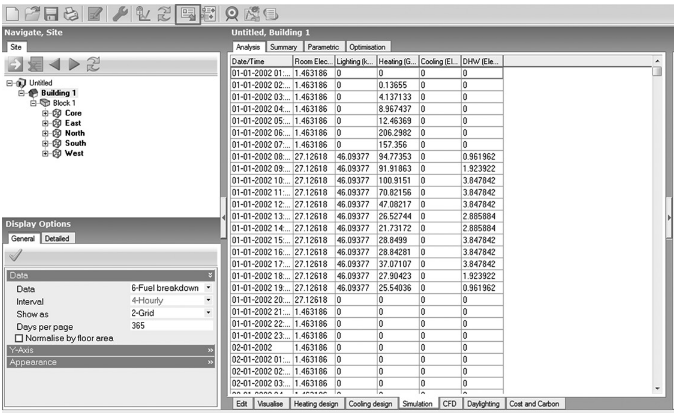
Step 1: Create a five-zone core and perimeter model of size 60 m × 40 m. Set WWR to 60% and select Sgl Grey 3mm glass.



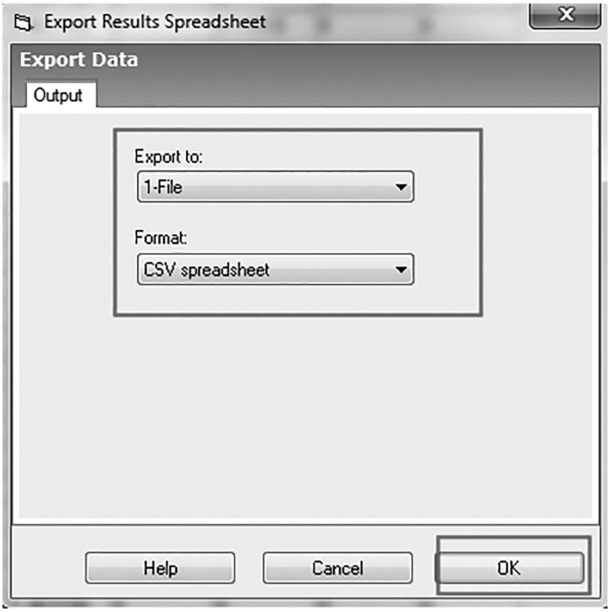
Step 2: Select the **Simulation** tab. The **Edit Calculation Options** screen appears. Select the **Hourly** checkbox under Output Intervals for Reporting and then click **OK**. After simulation, hourly results appear under the Analysis tab.



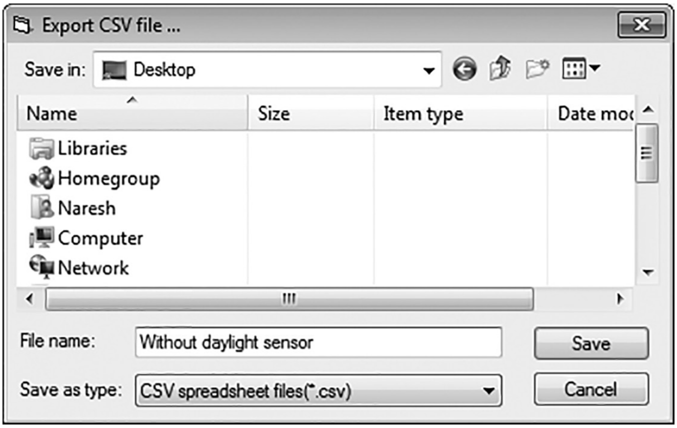
Step 3: Click the **Export data** icon to export the hourly energy consumption in the spreadsheet. (Ensure that Fuel breakdown, Hourly interval and Grid options are selected.)



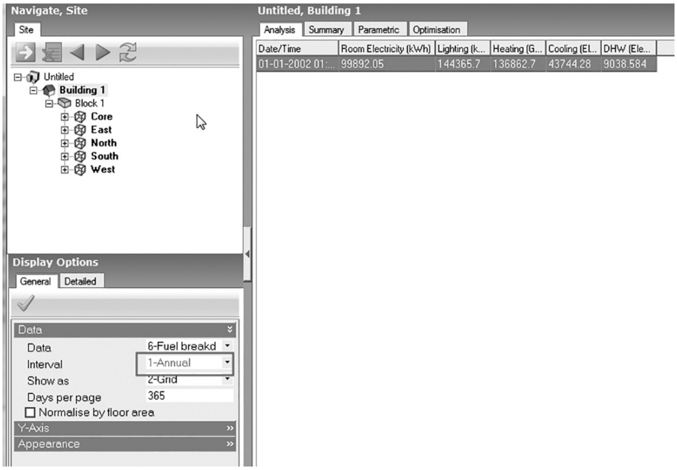
Step 4: Select **File** from the **Export to** drop-down list. Select **CSV spreadsheet** from the **Format** drop-down list. Click **OK**. The **Export CSV file** screen appears.



Step 5: Enter the File name **Without daylight sensor** and save the file on Desktop.



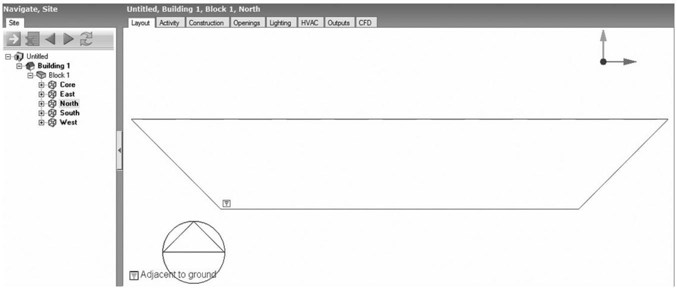
Step 6: Select **Annual** from the **Interval** drop-down list.



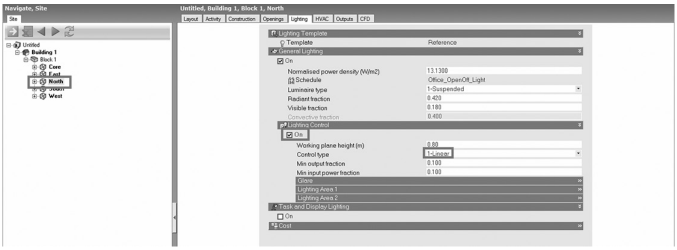
Record the simulation results.

In the next step, you are going to install the daylight sensor in the north zone.

Step 7: Select the **Edit** tab. Click the **North** zone in the navigation tree. It shows the north zone in the Layout tab. Select the **Lighting** tab. The Lighting properties are displayed.



Step 8: Expand the **Lighting control** section. Select the **On** check box. Select **Linear** from the **Control type** drop-down list.

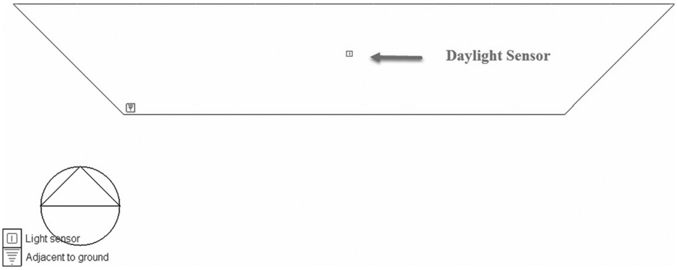


Different types of lighting control options that exist in DesignBuilder are as follows:

1. Linear
2. Linear/off
3. Stepped

Linear control, also called as continuous control, reduces the power input of the luminaire continuously, thereby decreasing the output light from the lamp till it reaches the minimum input and output fraction provided as a user input. this is possible with continuously dimmable fixture and lamps. the decrease in the input power (proportionally the lighting output) depends on the daylight illuminance requirement in the space. as the daylight illuminance increases, the input power reduces till it reaches the minimum input power and light output fraction and remains at the minimum specified ratio with a further increase in daylight illuminance.

Step 9: Select the **Layout** tab. The daylight sensor is displayed.



Step 10: Perform the simulation and record the annual and hourly results of the lighting energy consumption.

Step 11: Compare the results with and without lighting controls (Table 1.37).

Step 12: Draw the graph for hourly lighting energy consumption for 1 January with and without a daylight sensor by using the data exported using a spreadsheet program.

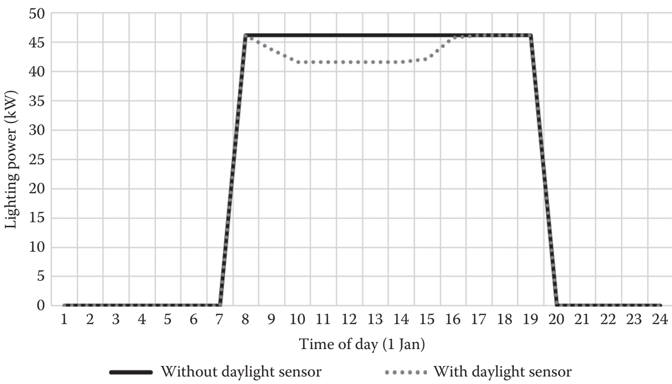


Table 1.37 Annual energy consumption with or without lighting control for the north zone

Type	Without lighting controls (kWh)	With lighting controls (kWh)
Room electricity	99,892	99,892
Lighting	1,44,366	1,32,533
Heating (gas)	1,36,863	1,42,500
Cooling (electricity)	43,744	41,748
DHW (electricity)	9,039	9,039

The above figure shows the hourly lighting energy consumption for 1 January. It can be observed that there is a reduction in the energy consumption with the use of daylight sensor and dimmable luminaire.

The effect of daylight control is similar to that of reducing LPD as discussed in the previous exercise.

The daylight control reduces the artificial lighting load whenever daylight is available in the space. The lighting loads are reduced to the extent that the combined lux levels of artificial light and daylight equals the setpoint lux level.

This reduction in LPD reduces the lighting energy consumption. For example, east and south zones would have different extent and timing of availability of daylight, and hence these would have different energy savings too.

Exercise 1.9

Add daylight control in the south zone of the model and study the effect on the energy consumption (Table 1.38).

It can be observed that the deployment of lighting control increases the heating energy consumption and decreases the cooling energy consumption.

Table 1.38 Annual energy consumption with or without lighting control for the south zone

Type	Without daylight controls (kWh)	With daylight control (kWh)
Room electricity		
Lighting		
System fans		
System pumps		
Heating (electricity)		
Heating (gas)		
Cooling (electricity)		

TUTORIAL 1.10 Evaluating the impact of setpoint temperature

GOAL

To evaluate the impact of setpoint temperature on sizing and energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Changing the setpoint for heating
- Changing the setpoint for cooling

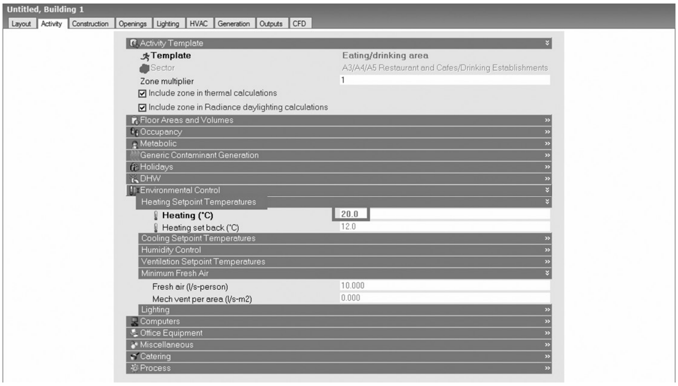
PROBLEM STATEMENT

Create a 60 m × 40 m model with a core and four perimeter zones. Consider a perimeter depth of 5 m. (Refer to Tutorial 1.5 for steps to create the model.) Set the heating setpoint to 20°C and 22°C. Simulate the model with the **PARIS-AEROPORT CHAR** weather file. Analyse the effect of setpoint on the energy consumption and HVAC system sizing.

SOLUTION

Step 1: Create a five-zone core and perimeter model of size 60 m × 40 m.

Step 2: Select the **Activity** tab and go to **Heating Setpoint Temperatures**. Enter **20.0** in Heating (°C) box.



Step 3: Perform the annual simulation and record all end use energy consumption.

Step 4: Repeat steps to set the heating temperature at 22°C. Simulate the model.

Table 1.39 Energy consumption with a change in heating setpoint temperature

Annual fuel breakdown data		
	Heating temperature 20°C (kWh)	Heating temperature 22°C (kWh)
Room electricity	99,895	99,895
Lighting	1,44,369	1,44,369
Heating (gas)	61,076	92,223
Cooling (electricity)	51,646	52,776
DHW (electricity)	9,039	9,039

Table 1.40 Heating sizing capacity with a change in heating setpoint temperature

Heating sizing		
Type	With heating setpoint temperature 20°C (kW)	With heating setpoint temperature 22°C (kW)
Heating	161.45	175.05

Step 5: Compare result for both cases (Tables 1.39 and 1.40).

You can observe that increasing the heating setpoints increases the heating energy consumption and heating sizing (Table 1.40).

Exercise 1.10

Repeat the tutorial for the change in the cooling setpoint from 24°C to 25°C. Compare the results for cooling sizing and energy consumption. Set the weather location as Brisbane, Australia (Tables 1.41 and 1.42).

Table 1.41 Energy consumption with a change in cooling setpoint temperature

Annual fuel breakdown data		
Type	With cooling setpoint 24°C (kWh)	With cooling setpoint 25°C (kWh)
Room electricity		
Lighting		
System fans		
System pumps		
Heating (electricity)		
Heating (gas)		
Cooling (electricity)		

Table 1.42 Cooling sizing capacity with change in cooling setpoint temperature

Type	With cooling setpoint 24°C (kW)	With cooling setpoint 25°C (kW)
Cooling		

The following can be observed:

- Increasing the heating setpoint results in an increase in energy consumption since more heat is to be added to the space for keeping a higher temperature. This also results in a higher system capacity since the rate of heat addition at an elevated temperature is to be matched with the higher rate of heat loss. In case of gas heaters using hot water panels, the energy consumption of the pump also increases with the increase in the setpoint.
- Similarly, a lower cooling setpoint demands the removal of more heat, thereby causing more energy consumption. This also results in a higher capacity of the cooling equipment and more pump and fan energy consumption.

TUTORIAL 1.11 Evaluating the impact of fresh air supply

GOAL

To evaluate the impact of the fresh air supply quantity on energy consumption.

WHAT ARE YOU GOING TO LEARN?

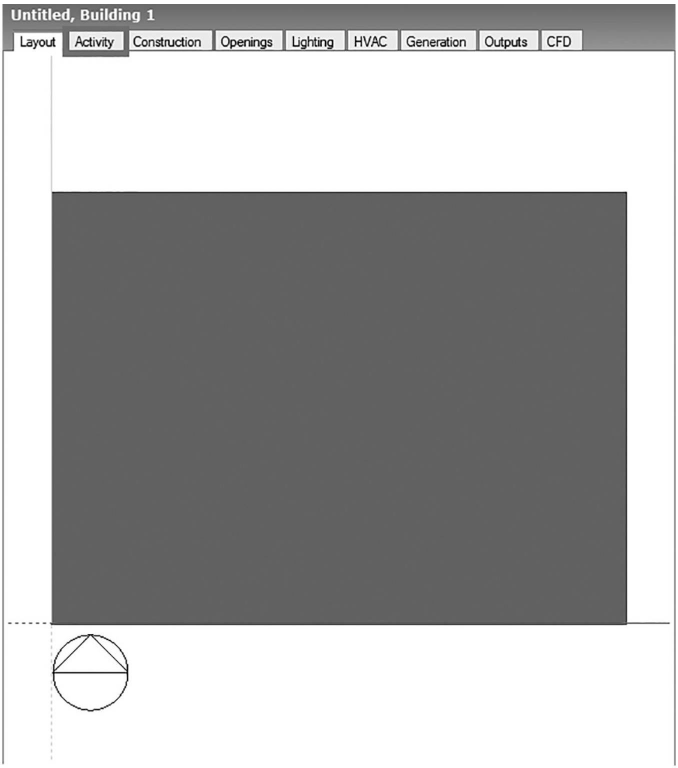
- Changing the fresh air flow rate

PROBLEM STATEMENT

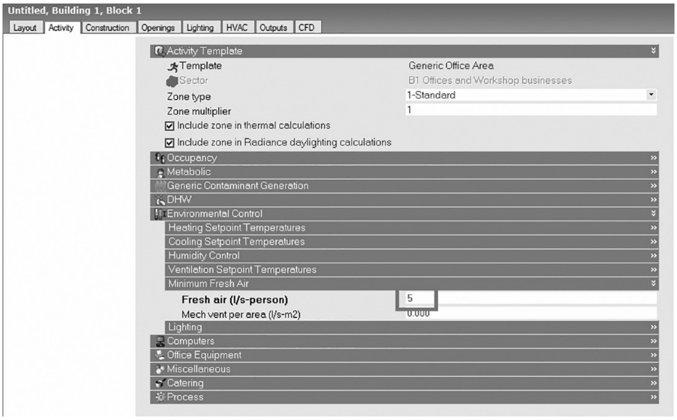
Create a single-zone 20 m × 15 m model. Set the fresh air supply rate (l/s-person) to 5 and 7.5 and compare. Study the effect on energy consumption for the **AZ-PHOENIX DEER VALLEY, USA** location.

SOLUTION

Step 1: Create a single-zone 20 m × 15 m model. Select the **Activity** tab.



Step 2: Expand the **Minimum Fresh Air** section and enter **5** in the Fresh air (l/s-person).



Step 3: Simulate the model and record the results.

Compare the end use energy consumption results for the fresh air supply of 5 and 7.5 l/s-person (Table 1.43).

It can be seen from the above table that with the increase in the fresh air rate, there is an increase in the cooling/heating energy consumption.

Table 1.43 Energy consumption with a change in fresh air supply quantity

Annual fuel breakdown data		
Type	Fresh air supply of 5 l/s-person (kWh)	Fresh air supply of 7.5 l/s-person (kWh)
Room electricity	12,131	12,131
Lighting	17,532	17,532
Heating (gas)	800	812
Cooling (electricity)	31,124	31,442
DHW (electricity)	1,098	1,098

Exercise 1.11

Compare cooling and heating energy consumption for the change of fresh air supply volume from 5 to 9 l/s-person (Table 1.44).

An increase in the fresh air supply rate increases the energy consumption due to several factors:

- More fresh air brings in more sensible as well as latent load from outside. This in turn increases the load on the equipment, which increases the cooling/heating energy consumption.
- The energy consumption of the fan is proportional to the volumetric flow rate. With the increase in the flow rate because of the additional energy required to blow more supply air (for heating/cooling), the fan energy consumption increases.
- More heating/cooling load and higher air flow rate result in the requirement of more water flow as heat adding/removal medium for a fixed change in temperature across the air handling unit since more heat is to be taken away per unit time. This requirement of a higher flow rate increases the pump rating and results in a higher energy consumption by the pump.

Table 1.44 Heating and cooling energy consumption by changing the fresh air supply quantity

	Cooling energy consumption electricity (kWh)		Heating energy consumption gas (kWh)	
	5 l/s-person	9 l/s-person	5 l/s-person	9 l/s-person
Jan				
Feb				
Mar				
Apr				
May				
Jun				
Jul				
Aug				
Sept				
Oct				
Nov				
Dec				

CHAPTER TWO

Geometry of Buildings

In this chapter, we discuss the geometrical aspects, such as thermal zoning, aspect ratio, floor multiplier, and surface adjacency.

Usually buildings have several rooms; however, from modelling perspective, there may not be a requirement to model each room separately. If adjacent spaces have the same specifications, such as schedule, occupancy, and cooling and heating temperature setpoint, you can combine these spaces and model it as a single zone. By doing this, the complexity of the model and its simulation run time can be reduced without affecting the energy simulation results. Similarly, in cases of multi-storied buildings, with typical floors, the model can be simplified by modelling only three floors: ground, mid and top.

One of the important parameters that need to be considered while designing the building is aspect ratio, which is the ratio of the length to width of a building. The aspect ratio affects the envelope area. Increase in the envelope area leads to a higher heat gain/loss from the building. However, higher aspect ratio helps in better distribution of daylight and more access to windows for the occupants.

The impact of these aspects on building performance is explained through four tutorials in this chapter.

TUTORIAL 2.1 Defining thermal zoning for a building

GOAL

To evaluate the effect of architectural and thermal zoning on the end use energy consumption and simulation run time.

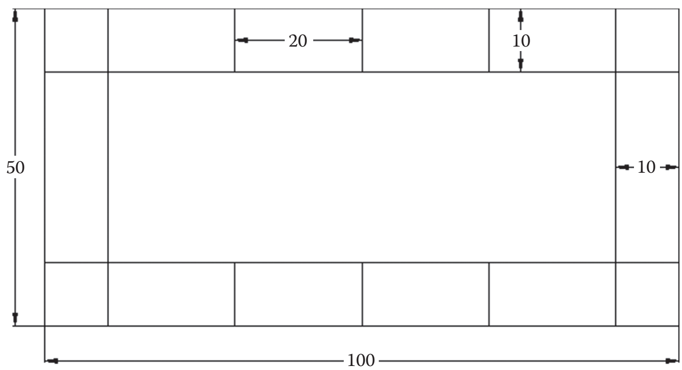
WHAT ARE YOU GOING TO LEARN?

- Defining thermal zoning
- Adding internal mass

PROBLEM STATEMENT

Create a multi-zone (15 zones as shown in the following figure) building with a rectangular footprint of 100 m × 50 m. Find its energy performance and simulation run time. Create another model by combining similar spaces into thermal zones and compare the energy performance and run time duration with the previous model.

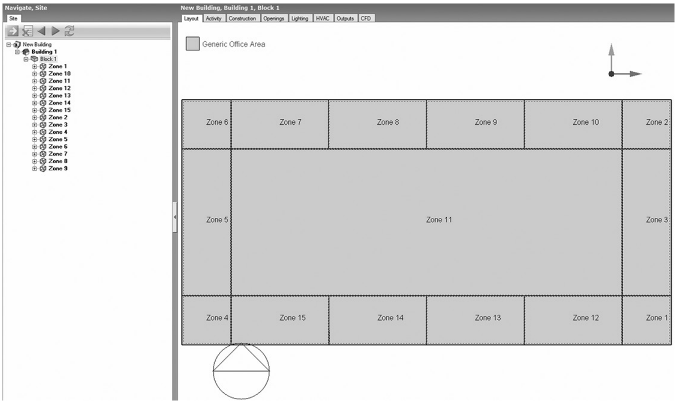
Use the **FRANKFURT MAIN ARPT, Germany** weather file.



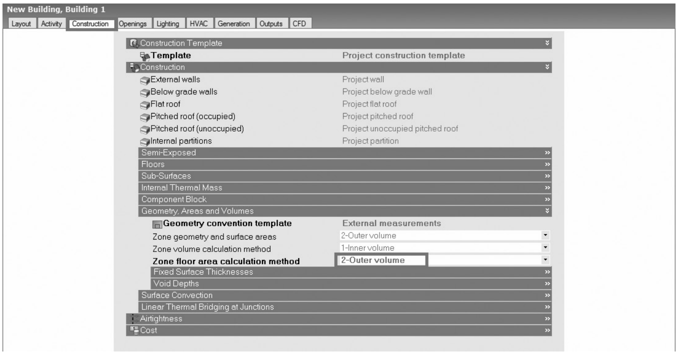
All dimensions are in metre.

SOLUTION

Step 1: Open a **New Project** and create a **100 m × 50 m** block with internal partitions. (Use construction lines to facilitate easy snapping while creating the partitions.)



Step 2: Select the **Construction** tab and select **Outer volume** in the **Zone floor area calculation method** drop-down list.



Zone floor area calculation method

This setting dictates whether internal or external measurements (include external wall thickness inside the zone boundary or not) are used to calculate the zone floor area. This is required to calculate per m^2 values such as occupancy and other internal gains as well as floor area values for general reporting.

Inner – where the zone volume used in thermal calculations is derived from the zone inner geometry.

Outer – where the zone volume used in thermal calculations is derived from the zone outer geometry.

http://www.designbuilder.co.uk/helpv4.7/Content/GeometryAreasAndVolumes.htm

Step 3: Perform hourly simulation for the whole year and record the energy consumption and the run time.

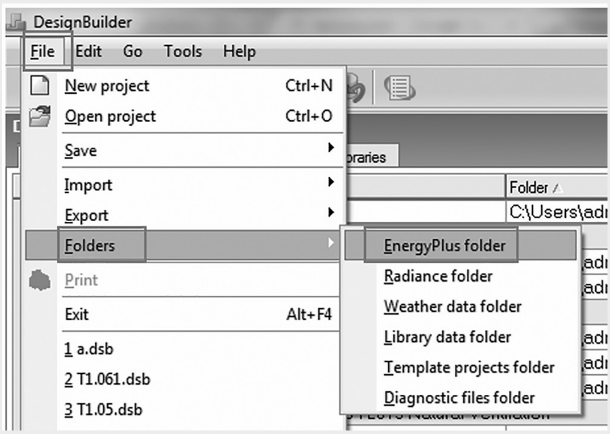
Recording a run time:

After the simulation is complete, type the following path to open the eplusout.err file. You can use any text editor to open this file.

C:\Users\User\AppData\Local\DesignBuilder\EnergyPlus\eplusout.err

The actual folder name on a computer depends on the language setting and your Windows user name. In the path given above, the Windows user name is 'User'.

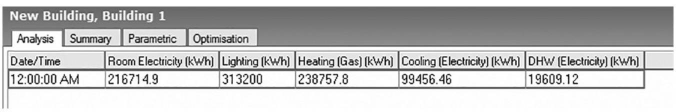
Alternatively, you can open the EnergyPlus folder from the DesignBuilder file option.



At the end of the file, you can find Elapsed Time.

You need to record the elapsed time.

Source: http://www.designbuilder.co.uk/helpv4.7/Content/_DesignBuilder_files_location_and_extensions.htm

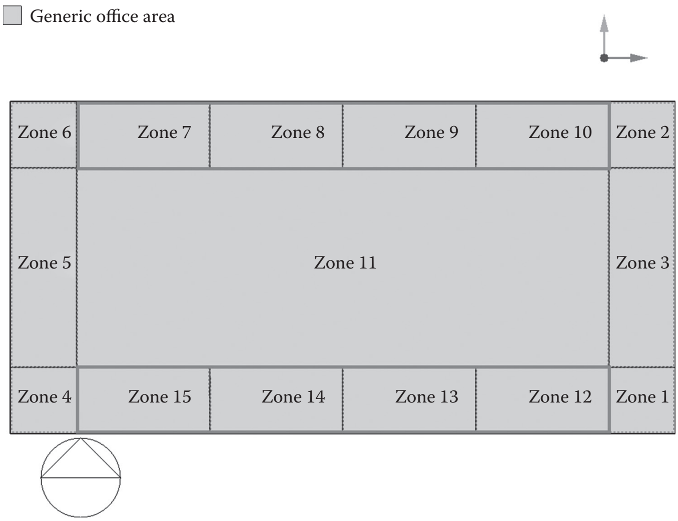


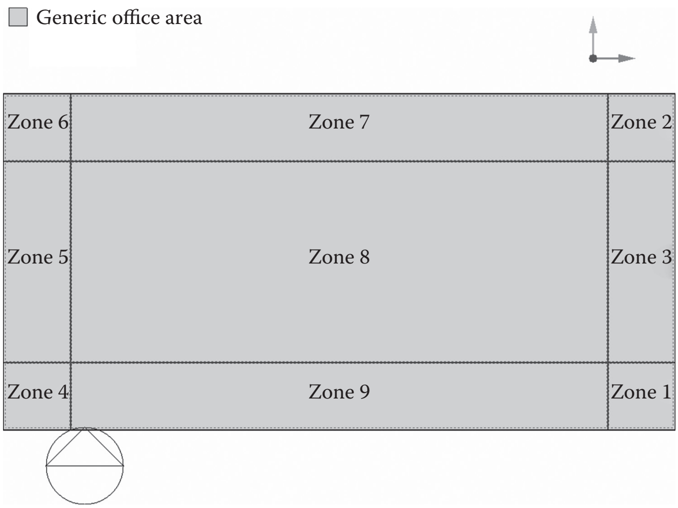
Date/Time	Room Electricity (kWh)	Lighting (kWh)	Heating (Gas) (kWh)	Cooling (Electricity) (kWh)	DHW (Electricity) (kWh)
12:00:00 AM	216714.9	313200	238757.8	99456.46	19609.12

Step 4: Repeat step 1 while combining zones for spaces with similar activity, schedule and setpoints. In this example, let us assume that the north zones (zones 7, 8, 9

and 10), as shown in the following figure, are similar and can be combined into a single thermal zone. Similarly, the south zones (12, 13, 14 and 15) can be combined into a single thermal zone. Do note that zone numbers in your model might differ as zones are numbered in the sequence they are created.

You can select the internal partition and delete the internal partition by pressing the delete key. (Please ensure that you are at the block level.)





A 'thermal zone', usually termed simply 'zone', is a virtual or real segment of a building that has a homogeneous, enclosed volume of air. In a simple approach, each physical space can be treated as one zone. However, to simplify the modeller's work, and to reduce the calculation time, areas having similar thermal and usage conditions such as occupancy, setpoint, and solar exposure, and those that are serviced by common mechanical equipment, can be clubbed to create one zone. Temperatures, supply units, and layout.

Step 5: Perform annual simulation and record the energy consumption and the run time.

Compare the energy simulation results and the simulation run time (Tables 2.1 and 2.2).

Table 2.1 Annual fuel breakdown energy with architectural zoning and lumped thermal zones

Type	With architectural zoning (kWh)	With lumped thermal zones (kWh)
Room electricity	216,715	216,715
Lighting	313,200	313,200
Heating (gas)	238,755	238,281
Cooling (electricity)	99,454	99,166
DHW (electricity)	19,609	19,609

Table 2.2 Simulation run time with architectural zoning and lumped thermal zones

	With architectural zoning	With lumped thermal zones
Simulation run time	48.04 seconds	31.03 seconds

As seen in the results, combining architectural zones to form thermal zones reduces the simulation run time. In this case, there is an approximately 37% decrease in the simulation run time. Note that because there is a difference in the models, there is a slight difference in the energy simulation results.

Exercise 2.1

Create thermal zoning for the plan shown in the following figure. Compare the simulation run time and energy consumption for the models with architectural and thermal zoning (Tables 2.3 and 2.4).

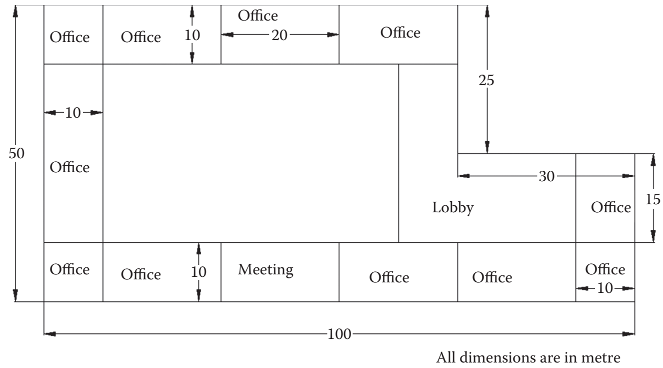


Table 2.3 Annual fuel breakdown energy with architectural zoning and lumped thermal zones

Type	With architectural zoning (kWh)	With lumped thermal zones (kWh)
Room electricity		
Lighting		
Heating (gas)		
Cooling (electricity)		
DHW (electricity)		

Table 2.4 Simulation run time with architectural zoning and lumped thermal zones

	With architectural zoning (kWh)	With lumped thermal zones (kWh)
Run time		

TUTORIAL 2.2 Evaluating the effect of a zone multiplier

GOAL

To evaluate the effect of a zone multiplier on the energy consumption and simulation run time.

WHAT ARE YOU GOING TO LEARN?

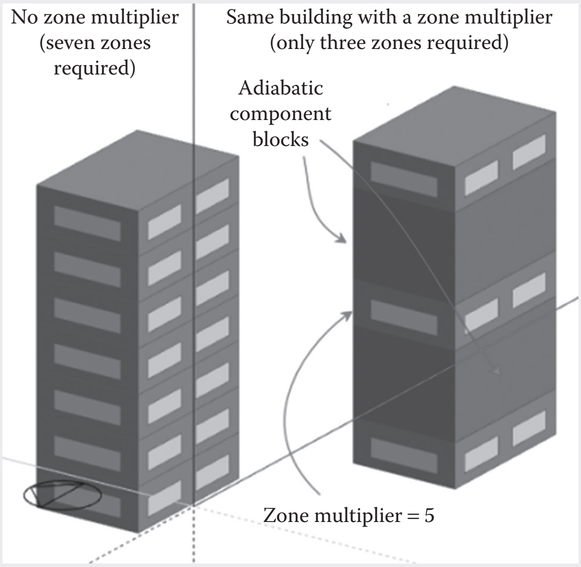
- Using zone multiplier

PROBLEM STATEMENT

Use the **Zone Multiplier Example** template file to evaluate the impact of a floor multiplier on the building energy consumption and simulation run time. This file contains two buildings with and without the floor multiplier. You need to select one building at a time and simulate for London Gatwick Airport, United Kingdom.

DesignBuilder has the concept of zone multiplier. The zone multiplier data allow you to reduce the size of your model in cases where there are similar zones by specifying that certain zones are repeated and so only need to be simulated once. A typical use is for multi-storey buildings with identical (or very similar) floors. The concept of zone multiplier when applied at the floor level multiplies all the zones on the given floor, effectively working as floor multiplier. Hence, in a building where there are several identical floors, you can model one floor and use a zone multiplier on that floor.

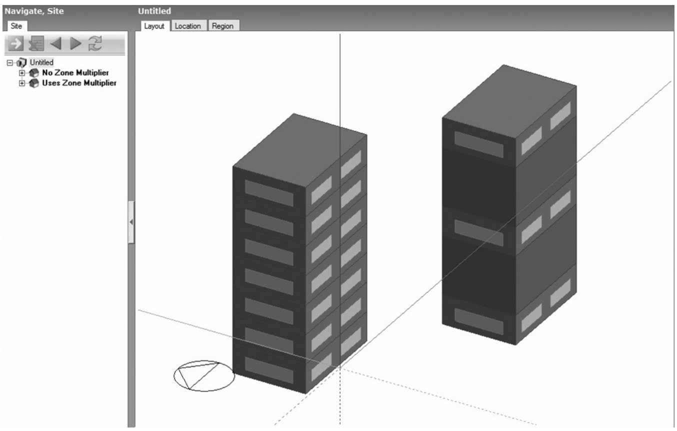
(*Continued*)



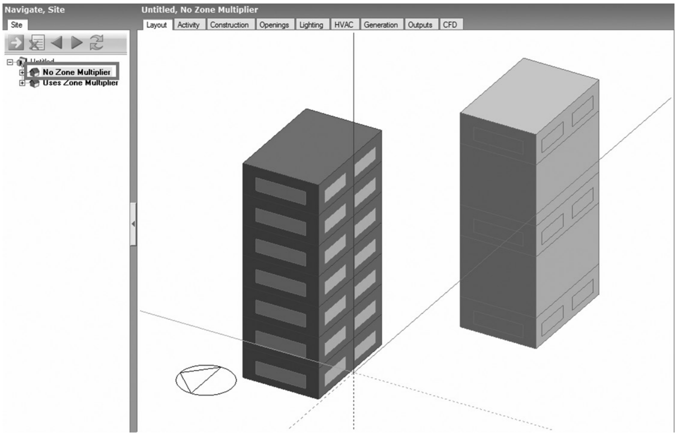
Source: http://www.designbuilder.co.uk/helpv4.7/#Zone_Multiplier.htm

SOLUTION

Step 1: Open the **Zone Multiplier Example** template from DesignBuilder templates. The layout appears with two buildings.



Step 2: Click the **No Zone Multiplier** building in the navigation tree. It selects the building that does not use a floor multiplier.



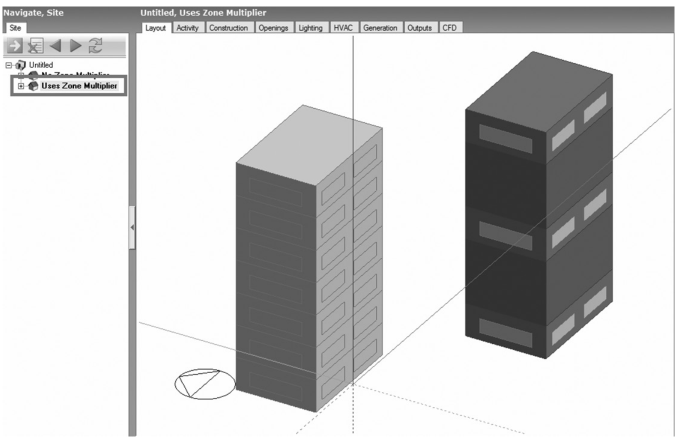
Step 3: Perform annual simulation. Record simulation run time. The results appear. Record the energy simulation results.

Untitled, No Zone Multiplier

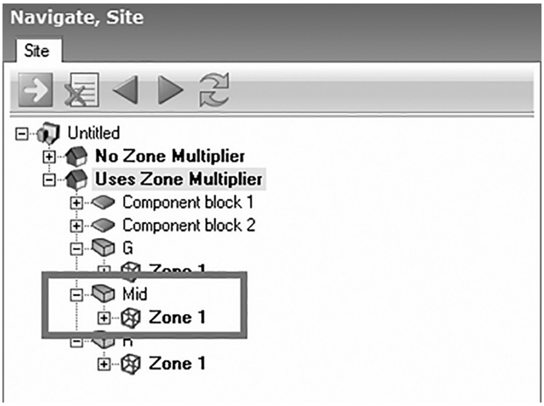
Analysis | Summary | Parametric | Optimisation

Date/Time	Room Electricity (kWh)	Lighting (kWh)	Heating (Gas) (kWh)	Cooling (Electricity) (kWh)	DHW (Gas) (kWh)
12:00:00 AM	29238.68	52820.29	33237.48	22250.89	2998.367

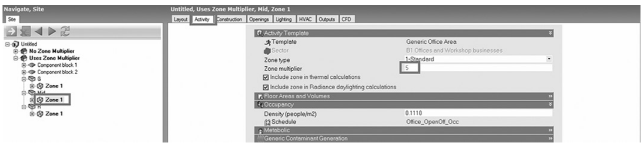
Step 4: Select the **Edit** tab. Click the **Uses Zone Multiplier** building in the navigation tree. Expand the **Uses Zone Multiplier**.



Step 5: Under **Mid**, click **Zone 1**.



Step 6: Select the **Activity** tab. Since the mid five floors are typical floors, the **Zone multiplier** for the whole floor is set to **5**.



When using a floor multiplier, calculations are performed only for one floor and multiplied by the zone multiplier. This helps in reducing the simulation run time.

Compare the results for the models with and without the zone multiplier (Table 2.5).

Table 2.5 Impact of a zone multiplier

	Annual fuel breakdown data	
Type	Without floor multiplier (kWh)	With floor multiplier (kWh)
Room electricity	29,238.68	29,238.68
Lighting	52,820.29	52,820.29
Heating (gas)	33,237.48	33,203.70
Cooling (electricity)	22,250.89	21,744.07
DHW (gas)	2998.37	2998.37
Simulation time	25.13 seconds	13.67 seconds

The results show that using a zone multiplier reduces the simulation run time. However, it has a slight impact on the energy consumption.

Exercise 2.2

Create a building with a total of 20 floors. First 10 floors have a floor plate of dimensions 50 m × 50 m. Floors 11 to 20 have a floor plate of dimensions 25 m × 25 m. Each floor has a height of 3 m. All floors are centrally aligned. Perform annual energy simulation of the building with and without floor multiplier. Compare energy and runtime of the simulation.

TUTORIAL 2.3 Evaluating the impact of the aspect ratio

GOAL

To evaluate the impact of building aspect ratio on energy performance.

WHAT ARE YOU GOING TO LEARN?

- Modelling building with different aspect ratio but same floor area

PROBLEM STATEMENT

In this tutorial, you are going to analyse the impact of the aspect ratio of the building on the energy performance. You need to create models with different aspect ratios for a floor plate of areas 64 m^2 and 625 m^2. Simulate various cases as given below and compare their energy consumption for the London Gatwick weather location. Make sure that WWR is 30%.

> For a rectangular building, aspect ratio is the ratio of the longest dimension of the building footprint to the narrowest dimension. An aspect ratio of 1.0 represents a square building footprint.

a. **For a floor area of 64 m^2, Table 2.6 gives the length and breadth values for various aspect ratios**

Table 2.6 Different aspect ratios for a 64 m^2 floor area

S. No.	Length l (m)	Breadth b (m)	Aspect ratio l/b	Floor area $l \times b$ (m^2)	Façade area (window + wall) (m^2)	Façade area/floor area
1	8.00	8.00	1	64	112.00	1.75
2	11.31	5.65	2	64	118.79	1.86
3	13.85	4.62	3	64	129.33	2.02
4	16.00	4.00	4	64	140.00	2.19

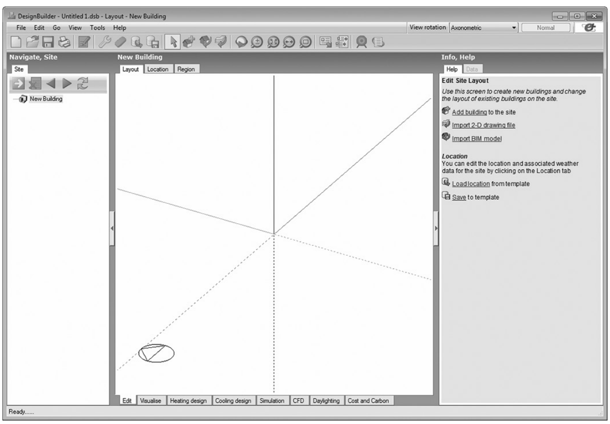
b. **For a floor area of 625 m^2, Table 2.7 gives the length and breadth values for various aspect ratios**

Table 2.7 Different aspect ratios for a 625 m^2 floor area

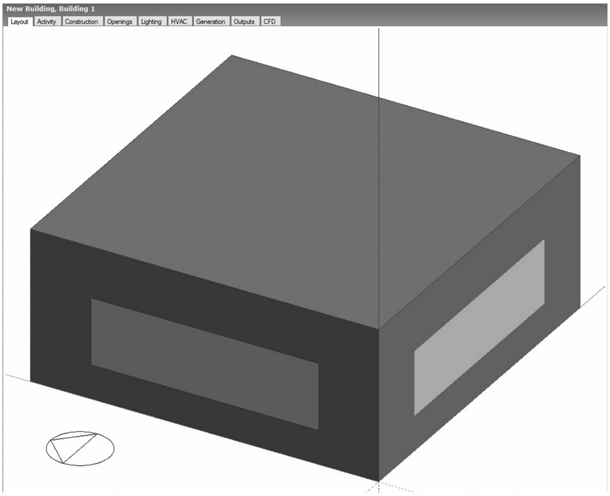
S. No.	Length l (m)	Breadth b (m)	Aspect ratio l/b	Area $l \times b$ (m^2)	Façade area (window + wall area) (m^2)	Façade area/floor area
1	25.0	25.0	1	625	350.00	0.56
3	43.3	14.4	3	625	404.15	0.646
5	55.9	11.2	5	625	469.57	0.75
7	66.1	9.4	7	625	529.15	0.846

SOLUTION

Step 1: Open a new project file.



Step 2: Create an **8 m × 8 m** building (aspect ratio 1).



Step 3: Simulate the model and store the results (Table 2.8).

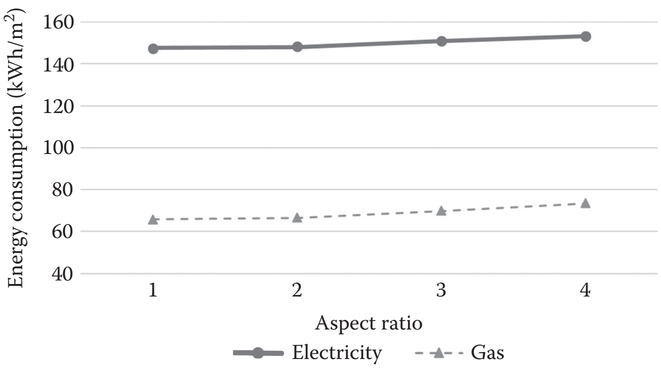
Table 2.8 Energy simulation results for an 8 m × 8 m model

Room electricity	Lighting	Heating (gas)	Cooling (electricity)	DHW (electricity)
Wh/m^2	Wh/m^2	Wh/m^2	Wh/m^2	Wh/m^2
43,342.96	62,639.97	65,691.39	37,698.21	3921.82

Step 4: Repeat steps 1 to 3 for aspect ratios 2, 3 and 4, respectively. Compare the energy simulation results for all cases (Table 2.9).

Table 2.9 Energy consumption with different aspect ratios (without daylight sensor)

Aspect ratio	1	2	3	4
	(8 m × 8 m)	(11.3 m × 5.7 m)	(13.9 m × 4.6 m)	(16 m × 4 m)
Room electricity (Wh/m²)	43,342.96	43,342.96	43,342.96	43,342.96
Lighting (Wh/m²)	62,639.97	62,639.97	62,639.97	62,639.97
Heating (gas) (Wh/m²)	65,691.39	66,469.18	69,815.29	73,499.85
Cooling (electricity) (Wh/m2)	37,698.21	38,203.12	40,965.80	43,371.99
DHW (electricity) (Wh/m2)	3,921.82	3,921.82	3,921.82	3,921.82

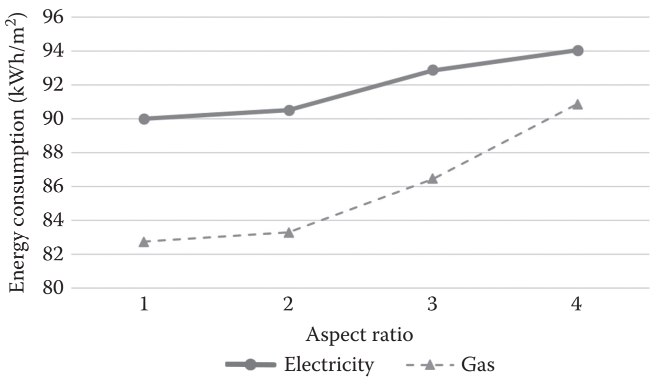


Energy consumption with varying aspect ratios when daylight sensors are not modelled

Step 5: Repeat all the above steps with daylight sensor (Table 2.10).

Table 2.10 Energy consumption with varying aspect ratios (with daylight sensor)

Aspect ratio	1	2	3	4
	(8 m × 8 m)	(11.3 m × 5.7 m)	(13.9 m × 4.6 m)	(16 m × 4 m)
Room electricity (Wh/m^2)	43,342.96	43,342.96	43,342.96	43,342.96
Lighting (Wh/m^2)	15,987.71	15,997.28	15,752.72	14,627.30
Heating (gas) (Wh/m^2)	82,736.33	83,288.69	86,451.32	90,868.41
Cooling (electricity) (Wh/m^2)	26,754.61	27,236.63	29,863.74	32,160.17
DHW (electricity) (Wh/m^2)	3,921.82	3,921.82	3,921.82	3,921.82

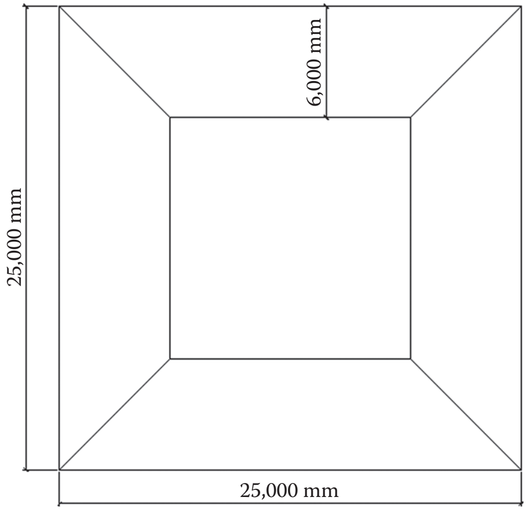


Energy consumption with varying aspect ratios when daylight sensor is modelled

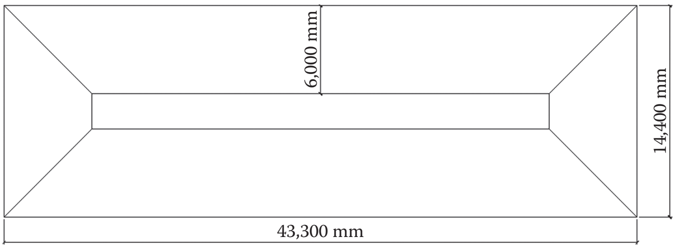
Step 6: Repeat all the above steps for the floor area of 625 m^2 (Tables 2.11 and 2.12).

You need to draw the model with the help of plans as shown in the following figures with aspect ratios 1, 3, 5 and 7.

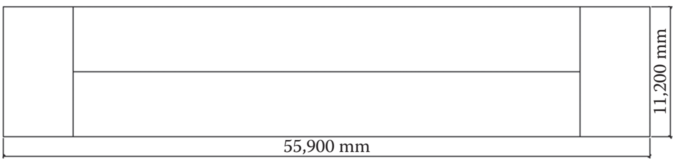
Aspect ratio 1



Aspect ratio 3



Aspect ratio 5



Aspect ratio 7

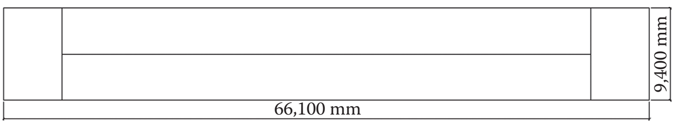
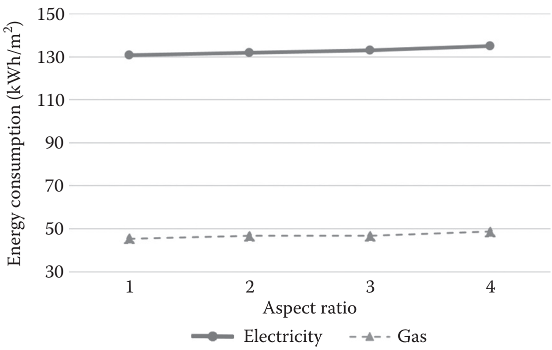


Table 2.11 Energy consumption for different aspect ratios (without daylight sensor)

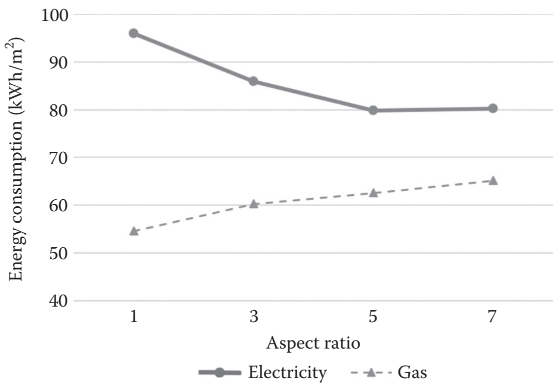
Aspect ratio	1	3	5	7
	(25 m × 25 m)	(43.3 m × 14.4 m)	(55.9 m × 11.2 m)	(66.1 m × 9.4 m)
Room electricity (Wh/m^2)	43,342	43,342	43,342	43,342
Lighting (Wh/m^2)	62,640	62,639	62,639	62,640
Heating (gas) (Wh/m^2)	45,401	46,695	46,654	48,641
Cooling (electricity) (Wh/m^2)	20,772	22,038	23,289	25,238
DHW (electricity) (Wh/m^2)	3,921	3,921	3,921	3,921

Table 2.12 Energy consumption for different aspect ratios (with daylight sensor)

Aspect ratio	1	3	5	7
	(25 m × 25 m)	(43.3 m × 14.4 m)	(55.9 m × 11.2 m)	(66.1 m × 9.4 m)
Room electricity (Wh/m^2)	43,342	43,342	43,342	43,342
Lighting (Wh/m^2)	35,176	25,783	19,702	18,443
Heating (gas) (Wh/m^2)	54,576	60,245	62,566	65,177
Cooling (electricity) (Wh/m^2)	13,529	12,912	12,876	14,513
DHW (electricity) (Wh/m^2)	3,921	3,921	3,921	3,921



Energy consumption with varying aspect ratios when daylight sensors are not modelled



Energy consumption with varying aspect ratios with daylight sensors

---

Exercise 2.3

a. Analyse the effect of the aspect ratio for all cases described in the tutorial for the 90° orientation.
b. Repeat the tutorial for the hot and dry climate (UAE) and observe the energy simulation results.

TUTORIAL 2.4 Evaluating the impact of adjacency of the surface

GOAL

To evaluate the impact of the ground surface on the energy performance.

WHAT ARE YOU GOING TO LEARN?

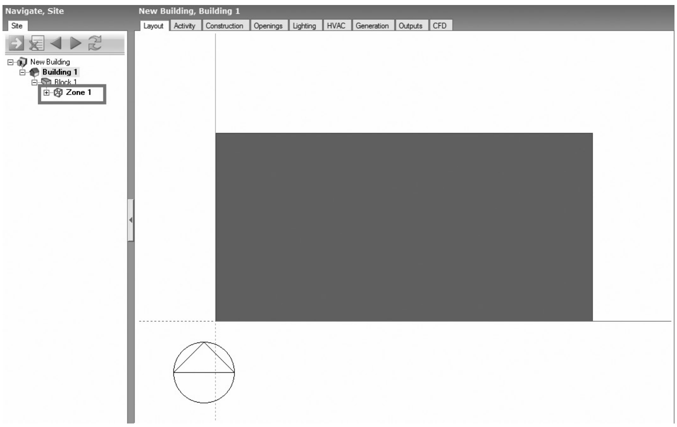
- Assigning surface adjacency
- Making surface adiabatic

PROBLEM STATEMENT

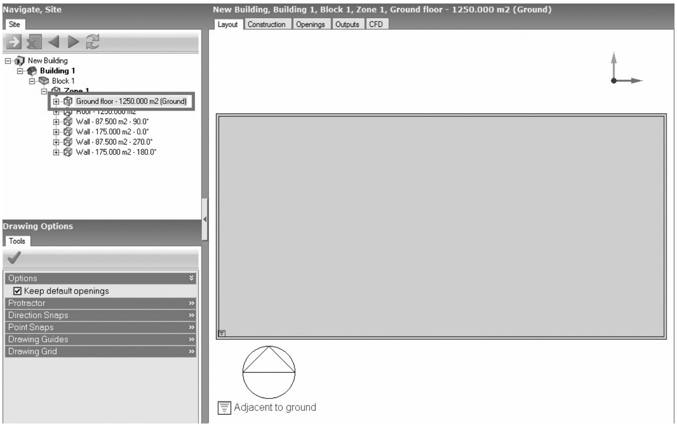
In this tutorial, you are going to create a 50 m × 25 m single-zone model. Assign ground floor construction to a 200 mm aerated concrete slab. Set the ground floor surface adjacency to **Auto** and as **Adiabatic**. Compare the effect of the surface adjacency on the energy consumption for **QC – Montreal/Mirabel INT'L A, Canada**.

SOLUTION

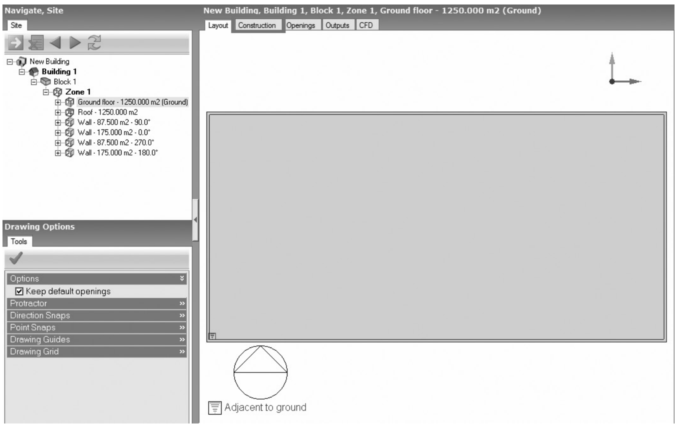
Step 1: Create a **50 m × 25 m single zone** model. Expand **Zone 1** in the navigation tree.



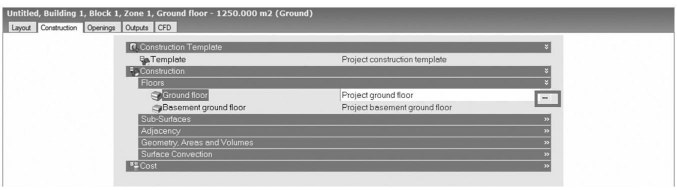
Step 2: Click **Ground Floor**.



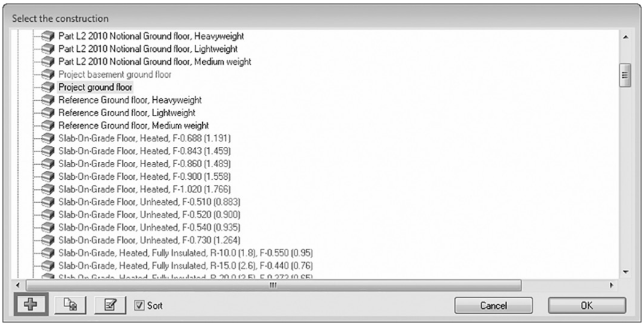
Step 3: Select the **Construction** tab.



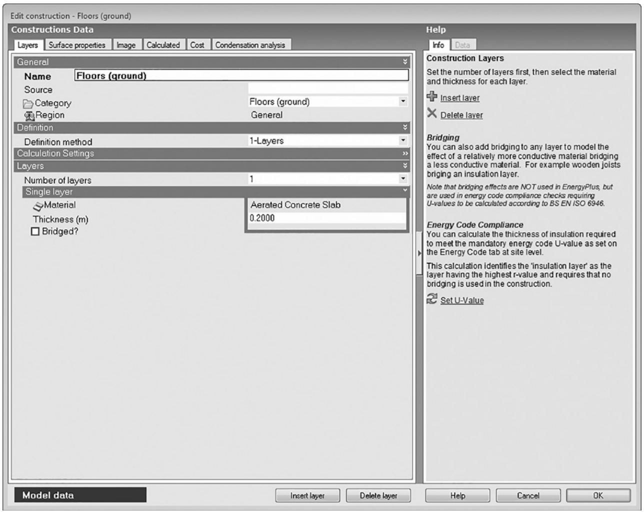
Step 4: Under the Floors section, click **Ground floor**. Three dots (…) appear. Click the **dots**. The **Select the construction** screen appears.



Step 5: Click the **Add new data** button to create a new construction.

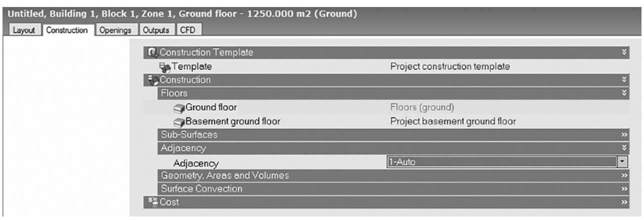


Step 6: Go to the **Layers** section and make sure that **Areated Concrete Slab** is the material and the thickness is **0.2000** m. Click **OK**.

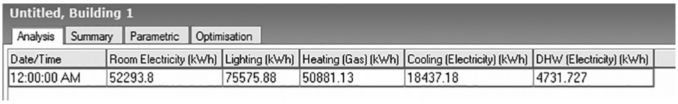


Step 7: Click the **Adjacency** section. It displays the Adjacency property of the selected surface.

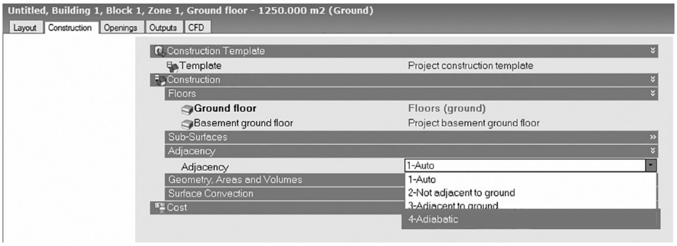
Ensure **Auto** is selected in the adjacency drop-down list.



Step 8: Perform annual energy simulation. Record the results for the end use energy consumption.



Step 9: Repeat step 6 to select **Adiabatic** from the **Adjacency** drop-down list.



Step 10: Run simulation to view the results.

Compare the end use energy consumption breakdown (Table 2.13).

You can observe that there is a change in the cooling and heating energy consumption when the ground floor surface property is set to adiabatic.

Table 2.13 Annual fuel breakdown data for building with ground floor adjacency set to adjacent to ground and adiabatic

Type	Adjacent to the ground (kWh)	Adiabatic (kWh)
Room electricity	52,293.80	52,293.80
Lighting	75,575.88	75,575.88
Heating (gas)	159,140.60	160,616.20
Cooling (electricity)	23,653.23	26,540.71
DHW (electricity)	4,731.72	4,731.72

The EnergyPlus weather file provides ground temperatures for undisturbed sites. However, you should not use the ground temperatures in the EnergyPlus weather file header because these are for undisturbed sites.

The temperature beneath a building is significantly affected by the building itself – the EnergyPlus documentation recommends using a ground temperature of 2°C below average internal temperatures for large commercial buildings (where the perimeter heat loss is relatively less important). Note that this temperature should be applied directly below the slab and should not include ground material; so if you use this approach to ground temperature definition, you should switch off the use of the ground construction at the site level.

EnergyPlus cannot model very thick constructions, so it is necessary to use less thick constructions (2 m or smaller) combined with some assumptions about temperatures at about half a meter below the floor.

Source: http://www.designbuilder.co.uk/helpv4.7/Content/Ground_Modelling.htm

Many modellers prefer to define the ground temperature just below the slab and exclude the earth layers from the model. This has the advantage of simplicity and clarity and the approach recommended by EnergyPlus developers.

Note: The default ground temperatures provided in DesignBuilder assume that an earth layer is included in the constructions adjacent to the ground. If an earth layer is not included, then you should increase the default site ground temperatures to values closer to those typically found just below the ground slab.

Source: http://www.designbuilder.co.uk/helpv4.7/Content/Ground_Modelling.htm

CHAPTER THREE

Material and Construction

The aim of this chapter is to explain how to create a model while defining materials and constructions and to evaluate their impact on the energy consumption of buildings. The chapter starts with a tutorial on evaluating the impact of thermal mass in the envelope by comparing the performance of lightweight and heavyweight external wall construction. Learners can also find a method for calculating the thickness of insulation on the roof or external walls. The tutorials cover analysis of roof insulation location (overdeck or underdeck), use of a cool roof and radiant barrier.

TUTORIAL 3.1 Evaluating the effect of lightweight and heavyweight construction

GOAL

To evaluate the effect of thermal mass – the lightweight and heavyweight external wall construction in a building with night purge – on the thermal performance of the building.

WHAT ARE YOU GOING TO LEARN?

- Assigning lightweight and heavyweight construction
- Getting zone temperatures

PROBLEM STATEMENT

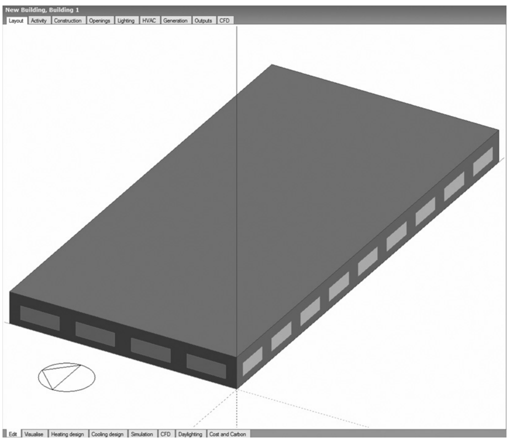
In this tutorial, you are going to use a 50 m × 25 m model and set external wall construction to lightweight and heavyweight. Find out the air temperatures inside the zone for both the cases. You need to analyse it for the **DUBAI INTERNATIONAL, United Arab Emirates** weather location.

You are going to use the following construction for external walls:

- Uninsulated wall, lightweight (wood derivative – plywood 15 mm)
- Uninsulated wall, heavyweight (stone – granite, 450 mm)

SOLUTION

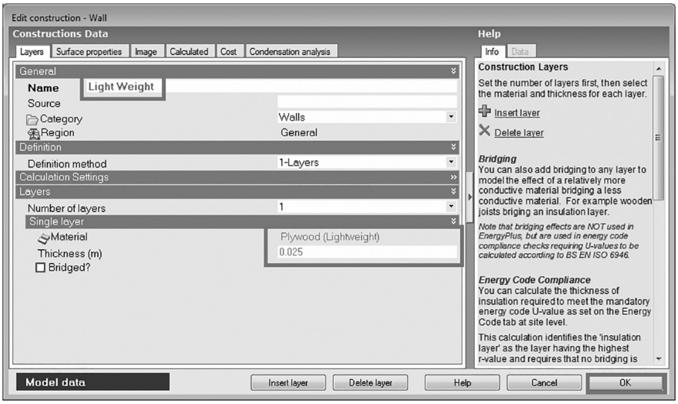
Step 1: Open a new project file. Create a **50 m × 25 m** building.



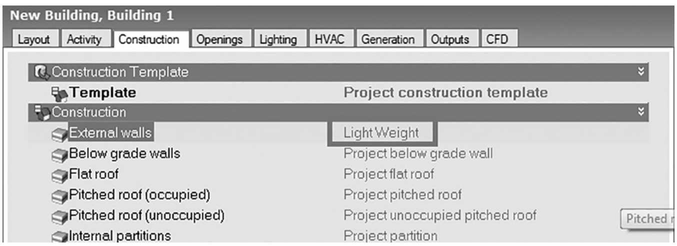
Step 2: Select the **Construction** tab.

Step 3: In the Construction section, click **Project wall. External walls** gets highlighted. Click the **Add new item** icon. The **Edit construction-Wall** screen appears.

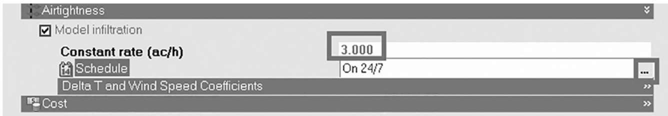
Step 4: Enter **Light weight** as the Name. Go to the Layers section and select **Plywood** as material (you can find it under the **Wood** branch), and set the thickness to **0.025**. Click **OK**. A message box appears.



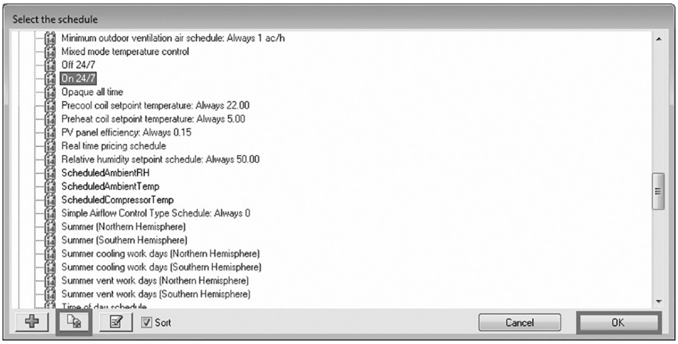
Step 5: Select **Light Weight** as the external wall.



Step 6: Go to the Airtightness section and enter **3.000** in the **Constant rate (ac/h)** box. Click **On 24/7** in the **Schedule** field. Three dots appear. Click the **dots**. The **Select the Schedule** screen appears.

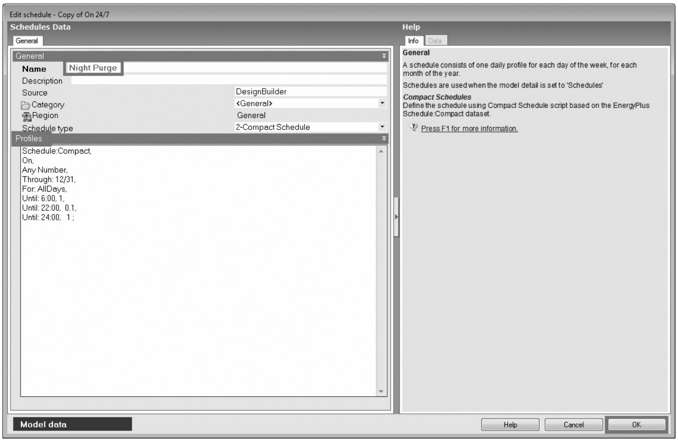


Step 7: Click the **Create copy of highlighted item** icon. Make sure that the copy of the item is highlighted.

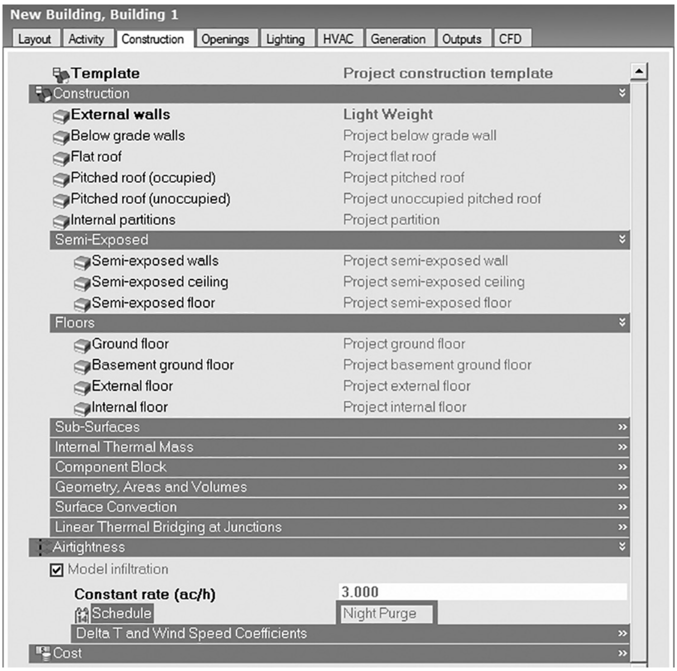


Step 8: Click the **Edit selected data** icon. The **Edit Schedule** screen appears.

Step 9: In the **General** section, enter **Night Purge** in the **Name** box. Under the **Profiles** section, edit the schedule as shown below. Click **OK**.

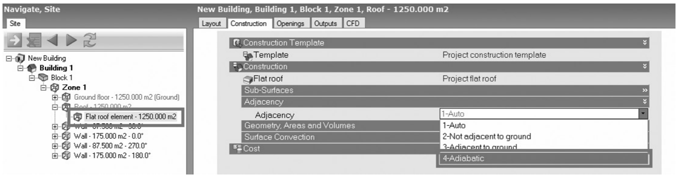


Step 10: Make sure that the **Night Purge** schedule is set.



Night purge is a technique used in conditioned buildings in which during unoccupied night hours, cool ambient air is passed through the building to flush out the heat released/accumulated in the building.

Step 11: Click **Flat roof element - 1250.000 m²** in the navigation tree and select **Adiabatic** from the **Adjacency** drop-down list. Click **Building 1** in the navigation tree.

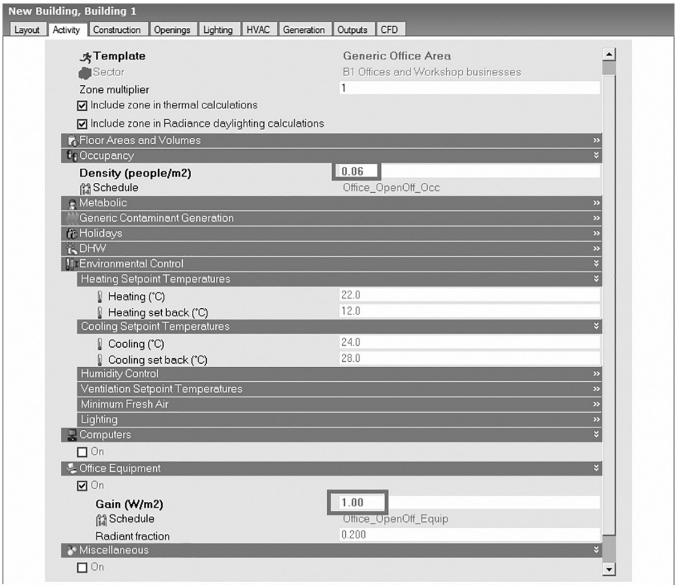


To understand the effect of the thermal mass of the external wall, we want to remove the heat gains and losses from the roof. To achieve this, the roof has been made adiabatic.

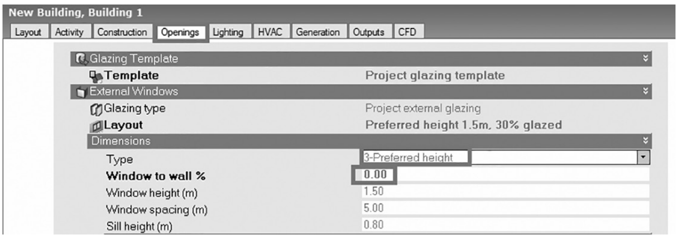
Adiabatic surface means that heat is not transferred across its external surface.

Source: http://www.designbuilder.co.uk/helpv4.7/#Adjacency.htm

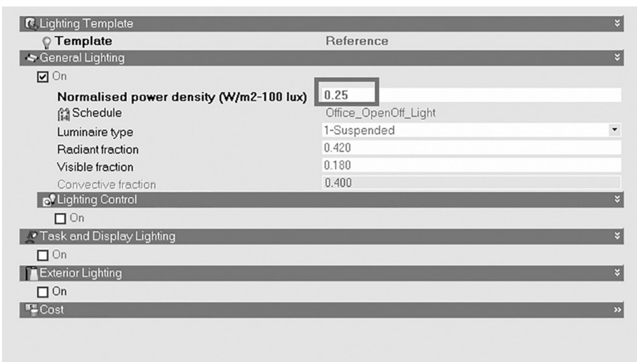
Step 12: Go to the **Building 1** level. Select the **Activity** tab and select **Density (people/m²)** as **0.06** and **Office Equipment Gain (W/m²)** as **1.00**. (The internal load has been reduced so that the effect of the thermal mass is clearly visible. If the internal loads are higher, then the inside zone temperature is dominated by the internal load and you cannot observe the effect of the thermal mass from the envelope.)



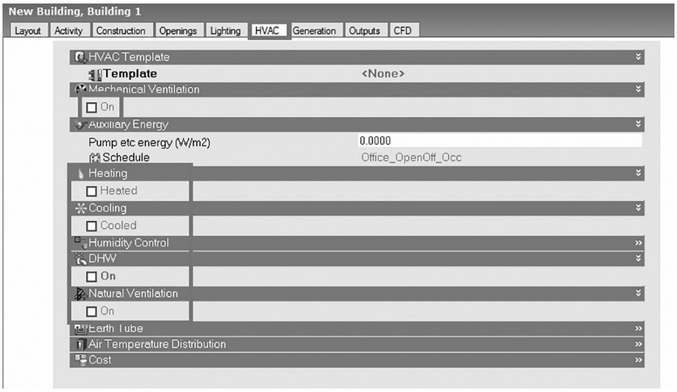
Step 13: Select the **Openings** tab and ensure that **Preferred height** is selected and **window-to-wall percentage** is set as **0.00**.



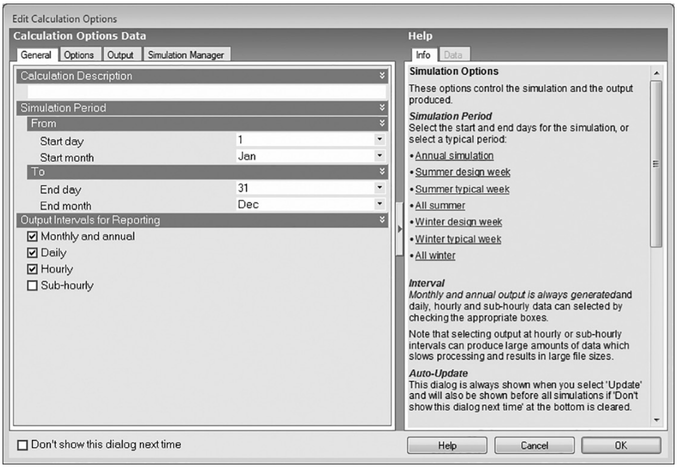
Step 14: Select the **Lighting** tab and select the Lighting energy (**W/m²-100 lux**) as **0.25**.



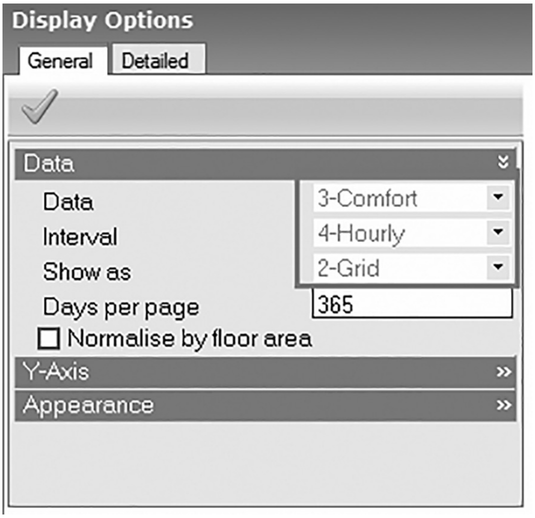
Step 15: Select the **HVAC** tab and select the **template** as **<None>** and clear **Mechanical Ventilation, Heating, Cooling, DHW** and **Natural Ventilation** check boxes.

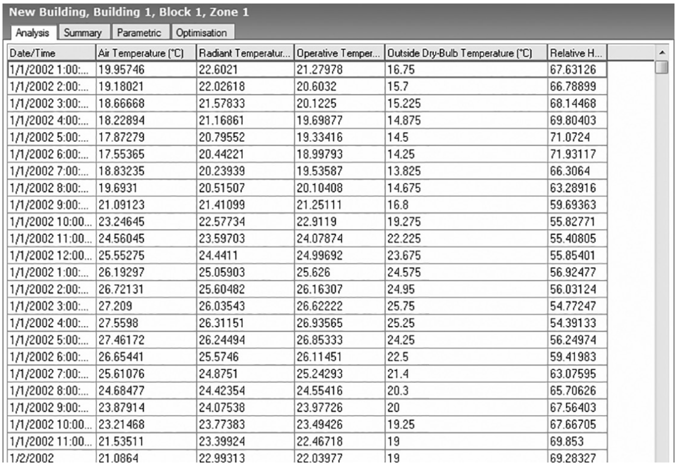


Step 16: Simulate the model for hourly interval reporting.



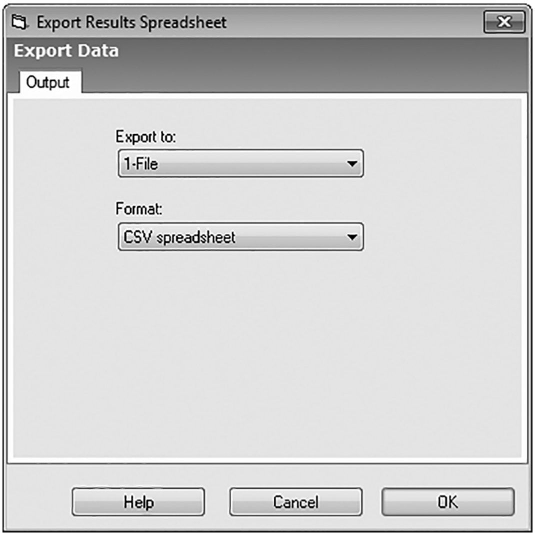
Step 17: Click **OK**. The results are displayed in the grid. You need to click on **Zone 1** to get the results at the zone level.



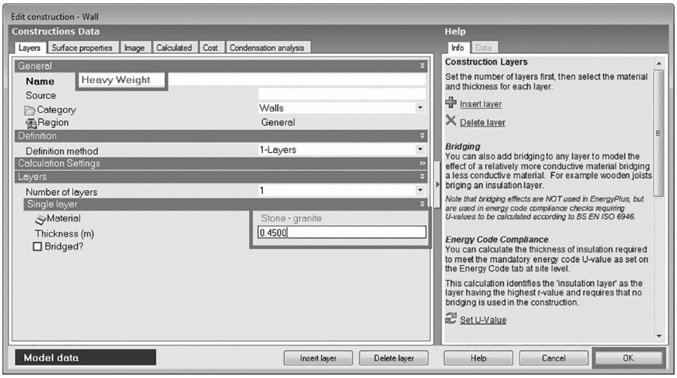


Date/Time	Air Temperature (°C)	Radiant Temperatur...	Operative Temper...	Outside Dry-Bulb Temperature (°C)	Relative H...
1/1/2002 1:00:...	19.95746	22.6021	21.27978	16.75	67.63126
1/1/2002 2:00:...	19.18021	22.02618	20.6032	15.7	66.78899
1/1/2002 3:00:...	18.66668	21.57833	20.1225	15.225	68.14468
1/1/2002 4:00:...	18.22894	21.16861	19.69877	14.875	69.80403
1/1/2002 5:00:...	17.87279	20.79552	19.33416	14.5	71.0724
1/1/2002 6:00:...	17.55365	20.44221	18.99793	14.25	71.93117
1/1/2002 7:00:...	18.83235	20.23939	19.53587	13.825	66.3064
1/1/2002 8:00:...	19.6931	20.51507	20.10408	14.675	63.28916
1/1/2002 9:00:...	21.09123	21.41099	21.25111	16.8	59.69363
1/1/2002 10:00...	23.24645	22.57734	22.9119	19.275	55.82771
1/1/2002 11:00...	24.56045	23.59703	24.07874	22.225	55.40805
1/1/2002 12:00...	25.55275	24.4411	24.99692	23.675	55.85401
1/1/2002 1:00:...	26.19297	25.05903	25.626	24.575	56.92477
1/1/2002 2:00:...	26.72131	25.60482	26.16307	24.95	56.03124
1/1/2002 3:00:...	27.209	26.03543	26.62222	25.75	54.77247
1/1/2002 4:00:...	27.5598	26.31151	26.93565	25.25	54.39133
1/1/2002 5:00:...	27.46172	26.24494	26.85333	24.25	56.24974
1/1/2002 6:00:...	26.65441	25.5746	26.11451	22.5	59.41983
1/1/2002 7:00:...	25.61076	24.8751	25.24293	21.4	63.07595
1/1/2002 8:00:...	24.68477	24.42354	24.55416	20.3	65.70626
1/1/2002 9:00:...	23.87914	24.07538	23.97726	20	67.56403
1/1/2002 10:00...	23.21468	23.77383	23.49426	19.25	67.66705
1/1/2002 11:00...	21.53511	23.39924	22.46718	19	69.853
1/2/2002	21.0864	22.99313	22.03977	19	69.28327

Step 18: Click the **Export Data** icon. The **Export Results Spreadsheet** dialog box appears. You can save this results file on your desktop to retrieve it easily.

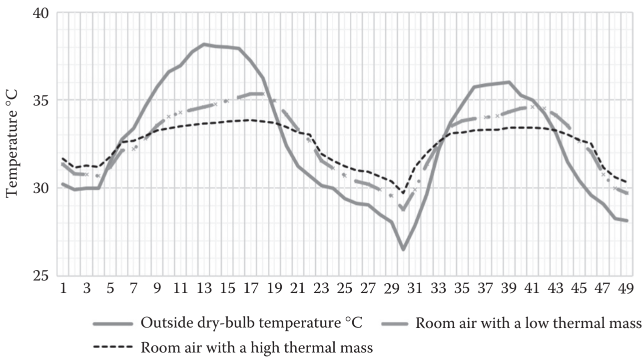


Step 19: Repeat the previous steps to create a high thermal mass external wall.



Step 20: Perform hourly simulation and record the results.

Compare the indoor air temperature for both cases with the outside dry-bulb temperature.



- As shown in the above figure, the temperature difference between the indoor air and outside air is higher for high thermal mass buildings. This is because building walls with a high thermal mass tend to store and increase the time taken for the heat to transfer from the outside to inside.
- The room air temperature in a high thermal mass building has less swing as compared to the room air temperature of a low thermal mass building that follows the outside temperature pattern.
- The occurrence of the highest room air temperature in a high thermal mass building is not at the same time when the outside air temperature peaks. Rather, it is shifted to a later time of the day. This difference in time when the peaks are observed in room temperature and the outside air temperature is defined as the thermal lag.

Exercise 3.1

Repeat the tutorial with insulation on the lightweight external wall. Compare the results with and without insulation on the lightweight wall.

TUTORIAL 3.2 Evaluating the impact of roof insulation

GOAL

To study the effect of roof insulation on the building energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Creating roof construction
- Setting the U-value of the roof

PROBLEM STATEMENT

In this tutorial, you are going to use a 50 m × 25 m model. Construct a roof with a 100 mm Aerated concrete slab and glass fibre slab insulation of varying thicknesses. Achieve the U-values given in Table 3.1 by varying the insulation thickness. Find out the energy consumption for each variation. Use the weather file of **WIEN/SCHWECHAT-FLUG, AUSTRIA**.

Table 3.1 U-values and *R*-values of the roof

S. No.	U-value (W/m² K)	*R*-value (m² K/W)	S. No.	U-value (W/m² K)	*R*-value (m² K/W)
1	1	1	10	0.31	3.25
2	0.8	1.25	11	0.29	3.5
3	0.67	1.5	12	0.27	3.75
4	0.57	1.75	13	0.25	4
5	0.5	2	14	0.24	4.25
6	0.44	2.25	15	0.22	4.5
7	0.4	2.5	16	0.21	4.75
8	0.36	2.75	17	0.2	5
9	0.33	3			

***R*-value or thermal resistance (*R*) –** The *R*-value of any section having one or more layers with parallel surfaces is an indication of the resistance offered by the section to the heat flow. It is the reciprocal of thermal conductance. For a structure having plane parallel faces, the thermal resistance is equal to the thickness (L) of the structure divided by the thermal conductivity (k).

$$R = \frac{L}{k} \tag{3.1}$$

The *R*-value of individual payers can be added to arrive at the total *R*-value of the section.

It is also expressed as the ratio of the temperature difference across an insulator and the heat flux (the heat transfer per unit area per unit time).

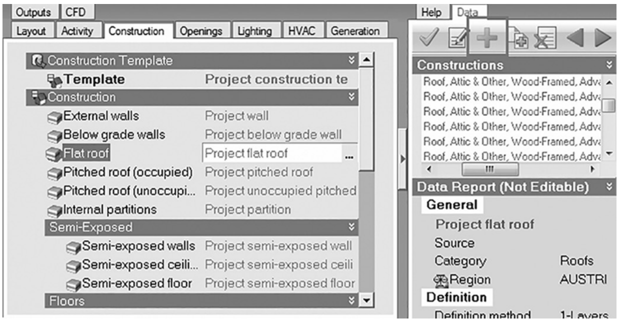
Thermal transmittance (*U-factor*) – thermal transmittance (*U*) – The thermal transmission in the unit time through the unit area of the given section divided by the temperature difference between the fluid on either side of the building unit in steady-state conditions. It is also called the U-value. Its unit is W/m^2 K. It can be treated as a measure of the heat loss through the unit area of a building section such as a wall, floor or roof. A low U-value generally indicates high levels of insulation.

SOLUTION

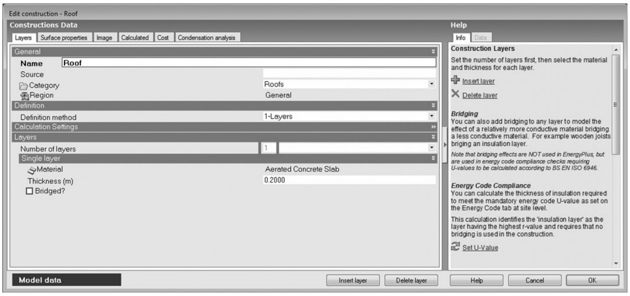
Step 1: Open a new project and create a **50 m × 25 m** building.

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

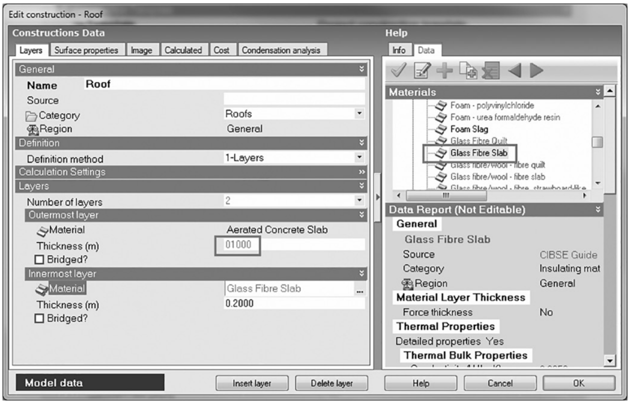
Step 3: Go to the Construction section, click **Flat roof**, and then click the **Add new item** icon. The **Edit construction – Roof** screen appears.



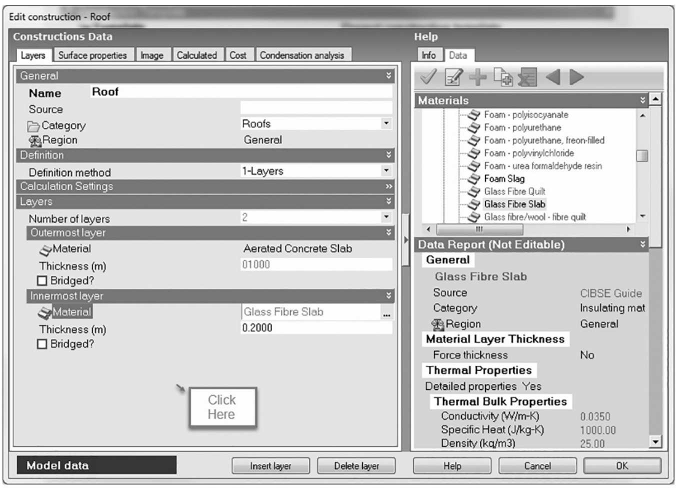
Step 4: Select **2** from the **Number of layers** drop-down list.



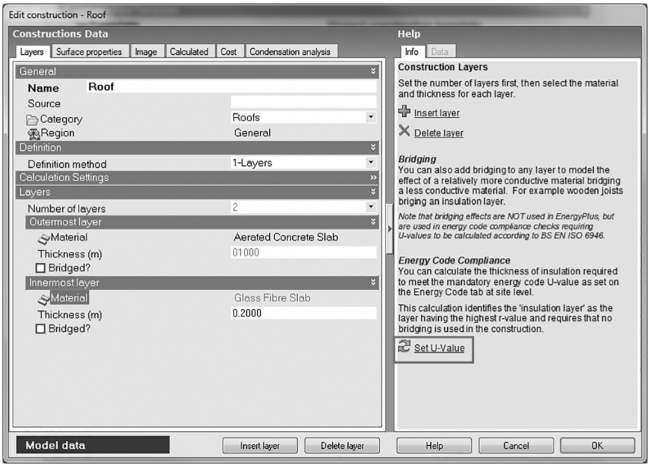
Step 5: Enter **0.1000** as the **Thickness (m)** in the Outermost layer section. Select **Glass Fibre Slab** from Insulating materials for the innermost layer.



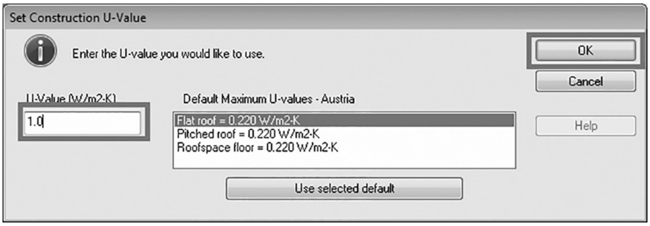
Step 6: Click anywhere in the blank space under the Innermost layer section to update the help section.



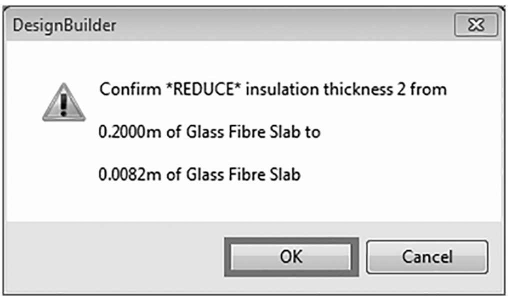
Step 7: Click the **Set U-value** link. The **Set Construction U-value** screen appears.



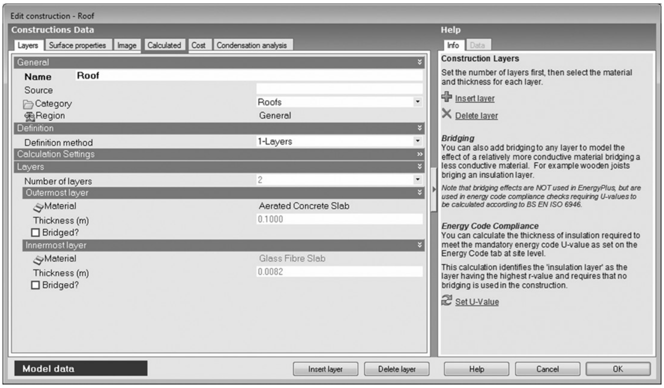
Step 8: Enter the **U-value (W/m² K)** as **1.0**. Click **OK**. A confirmation message appears with the updated insulation thickness.



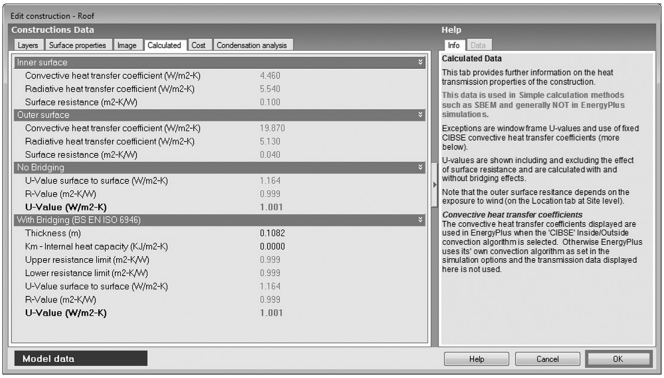
Step 9: Click **OK**. The insulation thickness is updated.



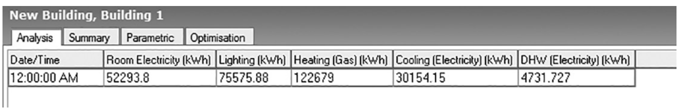
Step 10: Select the **Calculated** tab. The updated **U-Value** of the construction appears.



Step 11: Click **OK**.



Step 12: Perform annual energy simulation and record the results.

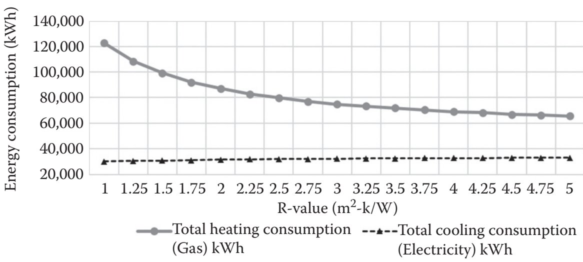


Step 13: Repeat the previous steps to set the U-values as given in Table 3.1. For each U-value, simulate and record the results.

Compare the results for all simulations (Table 3.2).

Table 3.2 Heating and cooling energy consumption for different U-values

S. No.	U-value (W/m^2 K)	*R*-value (m^2 K/W)	Total heating consumption (gas) (kWh)	Total cooling consumption (electricity) kWh
1	1	1	122,679.00	30,154.15
2	0.8	1.25	108,379.80	30,443.14
3	0.67	1.5	99,166.45	30,778.71
4	0.57	1.75	92,090.48	31,118.85
5	0.5	2	87,049.97	31,404.42
6	0.44	2.25	82,713.34	31,677.60
7	0.4	2.5	79,882.75	31,879.73
8	0.36	2.75	77,004.63	32,093.25
9	0.33	3	74,849.12	32,266.08
10	0.31	3.25	73,423.50	32,383.91
11	0.29	3.5	71,980.63	32,507.87
12	0.27	3.75	70,537.98	32,630.72
13	0.25	4	69,108.34	32,756.97
14	0.24	4.25	68,383.09	32,823.62
15	0.22	4.5	66,954.23	32,955.86
16	0.21	4.75	66,236.32	33,021.09
17	0.2	5	65,521.70	33,087.50



- In this scenario, the impact of insulation on the heating energy consumption is more than that on the cooling energy consumption.
- The law of diminishing returns can be seen here, as the heating energy consumption does not proportionally decrease with the increase in the insulation thickness.

Exercise 3.2

Repeat the above with the Miami, Florida location.

TUTORIAL 3.3 Evaluating the impact of the position of roof insulation

GOAL

To evaluate the impact of the position of roof insulation (overdeck and underdeck).

WHAT ARE YOU GOING TO LEARN?

- Editing roof construction

PROBLEM STATEMENT

In this tutorial, you are going to use a 50 m × 25 m model. Use the construction layers as given in the following table. Find out the energy consumption for each variation. Use the weather data for **FRANKFURT MAIN ARPT, Germany** and **DUBAI INTERNATIONAL, United Arab Emirates** (Table 3.3).

Table 3.3 Construction layers

	Case I	Case II
Outermost layer	Concrete, medium density, 0.15 m	XPS extruded polystyrene - HFC blowing, 0.05 m
Innermost layer	XPS extruded polystyrene - HFC blowing, 0.05 m	Concrete, medium density, 0.15 m

In most of the locations, except for very high latitudes, the external surface of the roof is directly exposed to solar radiation for the longest duration as compared to other surfaces of the building. The solar radiation upon being absorbed by the external surface of the roof turns into heat, which subsequently gets transmitted into the rooms below through the roof slab. The slab, due to its thermal mass, also accumulates heat while transmitting it beneath, which continues to be transmitted even after sunset due to the temperature difference between the slab and room interiors. To avoid this transmission and

(*Continued*)

accumulation of heat, insulation on the top surface is required in the form of overdeck insulation. A reduction in heat transmission by using insulation results in low energy consumption for operating cooling devices.

If insulation is provided on the inner surface of the roof, it is termed as underdeck insulation. It results in decreasing energy consumption for cooling devices since it reduces the radiant heat from entering the rooms.

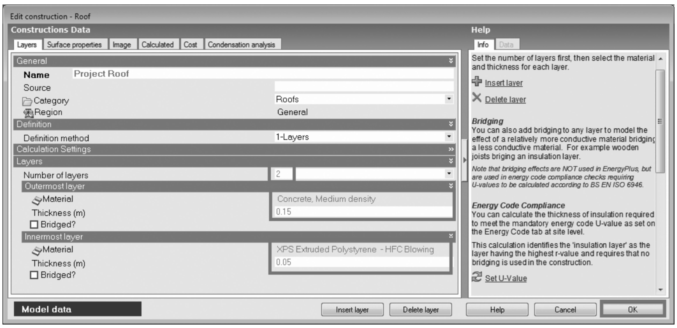
In locations requiring heating of buildings, the reverse is the approach. Insulation is provided on the inner side for reducing the heat flow from the inside to outside. As a concept insulation should be put as early as possible in the path of a heat flow, whether from outside to inside or from inside to outside.

SOLUTION

Step 1: Open a new project. Create a **50 m × 25 m** building. Change the weather location to Frankfurt, Germany.

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

Step 3: Add a roof with underdeck insulation **– 0.15 m** of **Concrete, Medium density** (from Concretes materials), and **0.05 m** of **XPS Extruded Polystyrene - HFC Blowing** (from Insulating materials).



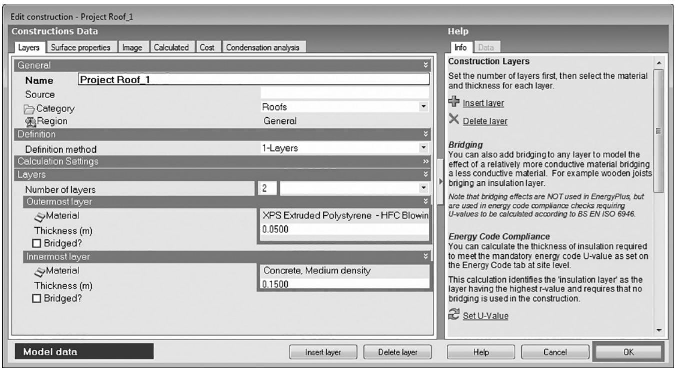
Step 4: Perform the annual simulation and record the results.

Site, Building 1

Analysis | Summary | Parametric | Optimisation

Date/Time	Room Electricity (kWh)	Lighting (kWh)	Heating (Gas) (kWh)	Cooling (Electricity) (kWh)	DHW (Electricity) (kWh)
12:00:00 AM	52293.8	75575.88	78150.55	25341.23	4731.727

Step 5: Repeat the tutorial for overdeck insulation.



Step 6: Simulate the model and compare the results for the two cases (Table 3.4).

Frankfurt requires predominantly heating and underdeck insulation, preventing the internal heat from being absorbed by the slab mass, thereby reducing the heating energy consumption.

Step 7: Change the weather location to **DUBAI INTERNATIONAL, United Arab Emirates** and compare the energy consumption for overdeck and underdeck insulation (Table 3.5).

Cooling is the predominant requirement in Dubai. Overdeck insulation prevents the external heat from being absorbed by the slab mass, thereby reducing cooling energy consumption.

Table 3.4 Annual fuel breakdown for underdeck and overdeck roof insulation for Frankfurt location

	With underdeck roof insulation (kWh)	With overdeck roof insulation (kWh)
Room electricity	52,293.8	52,293.8
Lighting	75,575.8	75,575.8
Heating (gas)	78,150.5	83,534.8
Cooling (electricity)	25,341.2	21,440.5
DHW (electricity)	4,731.7	4,731.7

Table 3.5 Annual fuel breakdown for underdeck and overdeck roof insulation for Dubai location

	With underdeck roof insulation (kWh)	With overdeck roof insulation (kWh)
Room electricity	52,293.8	52,293.8
Lighting	75,575.8	75,575.8
Heating (gas)	659.4	71.2
Cooling (electricity)	171,781.6	169,637.4
DHW (electricity)	4,731.7	4,731.7

Exercise 3.3

Repeat the above tutorial for the external wall. Use the weather data for **FRANKFURT MAIN ARPT, Germany** and **DUBAI INTERNATIONAL, United Arab Emirates** (Table 3.6).

Table 3.6 Construction layers for external walls

	Case I	Case II
Outermost layer	Brickwork 230 mm	XPS extruded polystyrene - HFC blowing, 0.05 m
Innermost layer	XPS extruded polystyrene - HFC blowing, 0.05 m	Brickwork 230 mm

TUTORIAL 3.4 Evaluating the impact of the air gap between roof layers

GOAL

To evaluate the effect of the air gap thickness in roof construction on the energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Adding the air gap between the roof layers
- Changing the air gap thickness

PROBLEM STATEMENT

In this tutorial, you are going to use a 50 m × 25 m model with a roof consisting of the following layers (starting with the outermost layer):

1. 0.01 m of cement/plaster/mortar-plaster
2. 0.15 m concrete, medium density
3. Air gap with varying thicknesses (as given below)
4. 0.01 m gypsum plasterboard

Thickness of the air gap:

1. No air gap
2. Air gap 15 mm (downwards)
3. Air gap 17 mm (downwards)
4. Air gap 25 mm (downwards)
5. Air gap 50 mm (downwards)
6. Air gap 100 mm (downwards)
7. Air gap 300 mm (downwards)

Find out the energy consumption for **LONDON/GATWICK ARPT, United Kingdom**.

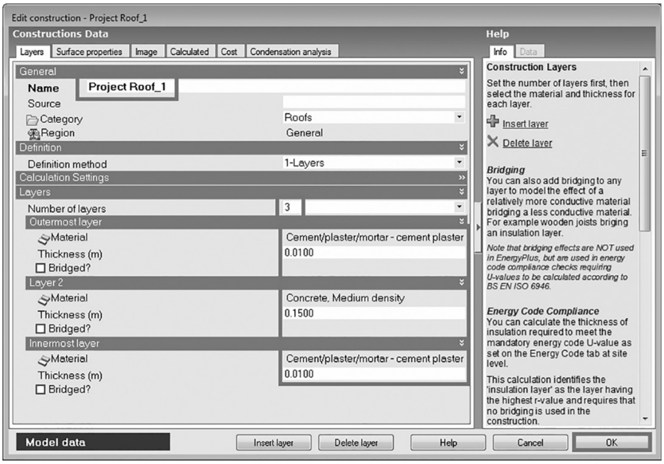
> An air gap is different from the air space layer. An air gap is enclosed on either side, whereas an air space is a gap left between exterior finish layers and interior insulation layers – as commonly practiced in the lightweight construction. The main role of the air space layer is to act as vapour and water drain/barrier, as compared to an air gap that improves the overall insulation properties of the wall/roof section.

SOLUTION

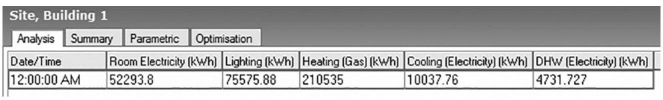
Step 1: Open a new project. Create a **50 m × 25 m** building.

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

Step 3: Add a new roof with three layers. Select **Cement/plaster/mortar- cement plaster** from Plaster materials with thickness (m) as **0.0100, Concrete, Medium density** from Concretes materials with thickness (m) as **0.1500 m**, and select **Gypsum plasterboard** from Plaster materials with thickness (m) as **0.0100 m**.

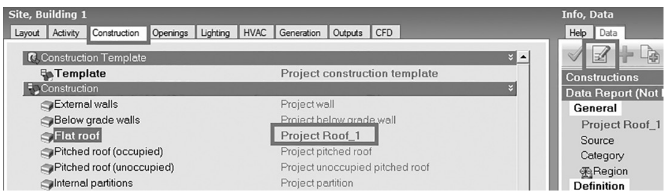


Step 4: Simulate the model and record the results.

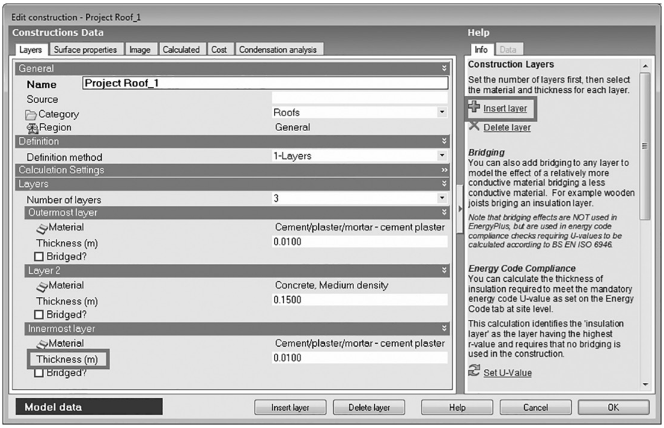


Date/Time	Room Electricity (kWh)	Lighting (kWh)	Heating (Gas) (kWh)	Cooling (Electricity) (kWh)	DHW (Electricity) (kWh)
12:00:00 AM	52293.8	75575.88	210535	10037.76	4731.727

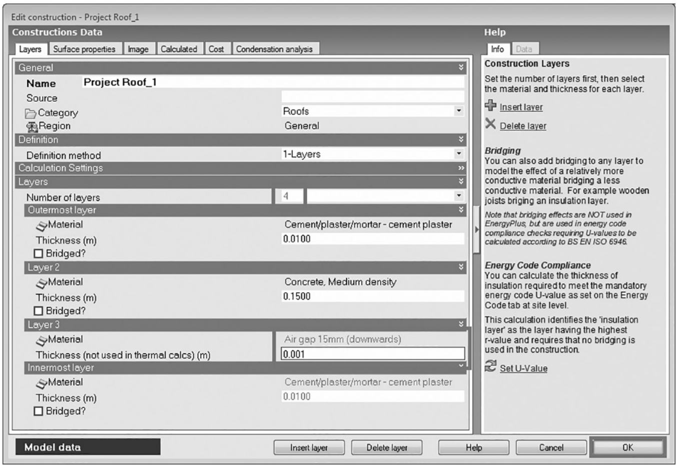
Step 5: Again select the **Construction** tab. Edit the roof construction.



Step 6: Select the **Thickness** of the **Innermost layer** (we want to insert a new layer above this layer; hence, we have to select this layer). Click **Insert layer**.



Step 7: Select **Air gap 15mm (downwards)** from Gases materials for the newly inserted layer (Layer 3) and enter **0.001** as thickness (m).



Step 8: Simulate the model and record the results.

Site, Building 1

Analysis | Summary | Parametric | Optimisation

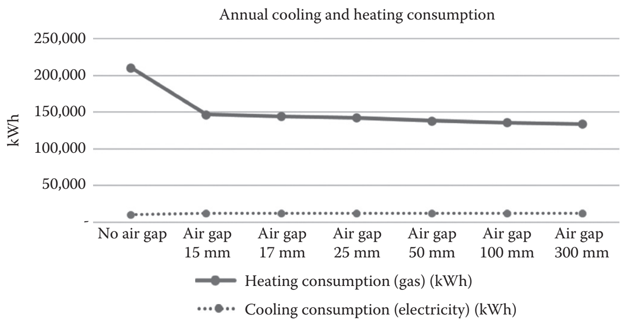
Date/Time	Room Electricity (kWh)	Lighting (kWh)	Heating (Gas) (kWh)	Cooling (Electricity) (kWh)	DHW (Electricity) (kWh)
12:00:00 AM	52293.8	75575.88	146784.7	11597.16	4731.727

Step 9: Repeat the previous steps for all the air gap thicknesses given in the problem statement.

Compare the results for all simulations (Table 3.7).

Table 3.7 Comparison of annual fuel breakdown data for various air gaps

	Annual fuel breakdown data				
	Room electricity (kWh)	Lighting (kWh)	Heating (gas) (kWh)	Cooling (electricity) (kWh)	DHW (electricity) (kWh)
No air gap	52,293.80	75,575.88	210,535.00	10,037.76	4,731.73
Air gap 15 mm	52,293.80	75,575.88	146,784.70	11,597.16	4,731.73
Air gap 17 mm	52,293.80	75,575.88	144,410.50	11,689.15	4,731.73
Air gap 25 mm	52,293.80	75,575.88	142,125.00	11,780.55	4,731.73
Air gap 50 mm	52,293.80	75,575.88	137,828.30	11,954.16	4,731.73
Air gap 100 mm	52,293.80	75,575.88	135,788.40	12,042.50	4,731.73
Air gap 300 mm	52,293.80	75,575.88	133,825.40	12,127.33	4,731.73



TUTORIAL 3.5 Evaluating the impact of surface reflectance

GOAL

To evaluate the effect of surface reflectance on the energy performance of buildings.

WHAT ARE YOU GOING TO LEARN?

- Changing surface reflectivity

PROBLEM STATEMENT

In this tutorial, you are going to use a 50 m × 25 m model with a roof consisting of the following layers (starting with the outermost layer):

- 0.015 m cement/plaster/mortar-plaster
- 0.150 m concrete, medium density
- 0.015 m cement/plaster/mortar-plaster

Vary the roof solar reflectivity on the outermost material from 0.9 to 0.1 in steps of 0.1. Find out the impact of roof solar reflectivity on the energy consumption for **SINGAPORE/PAYA LEBA**.

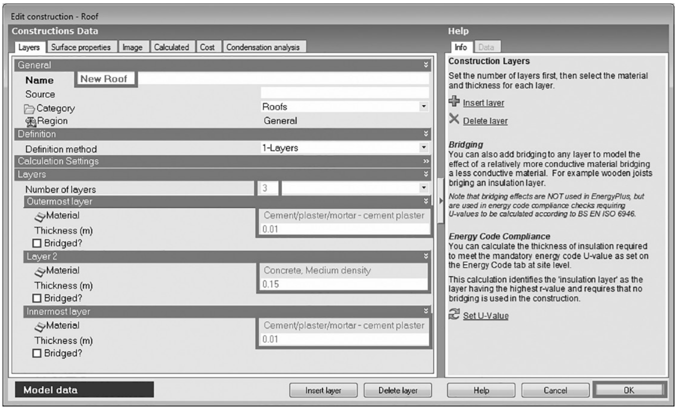
> Surface absorptance is the property of the surface material to absorb radiation, and it is the opposite to surface reflectance, which is the capability to reflect radiation. For opaque surfaces, surface absorptance and surface reflectance values are therefore ratios whose sum is always equal to 1.
>
> Solar reflectivity = Solar absorptance – 1

SOLUTION

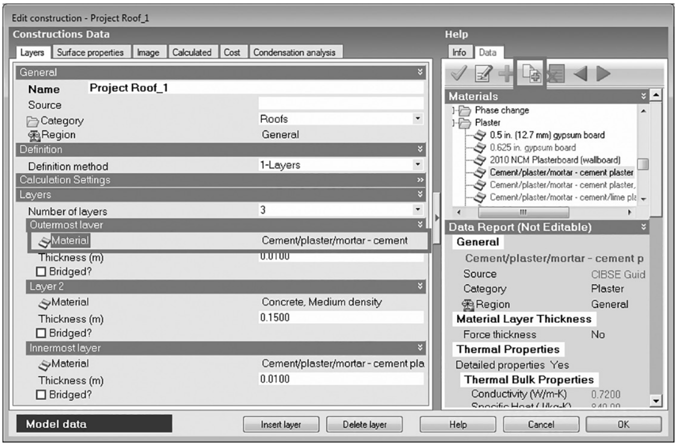
Step 1: Open a new project. Create a **50 m × 25 m** building.

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

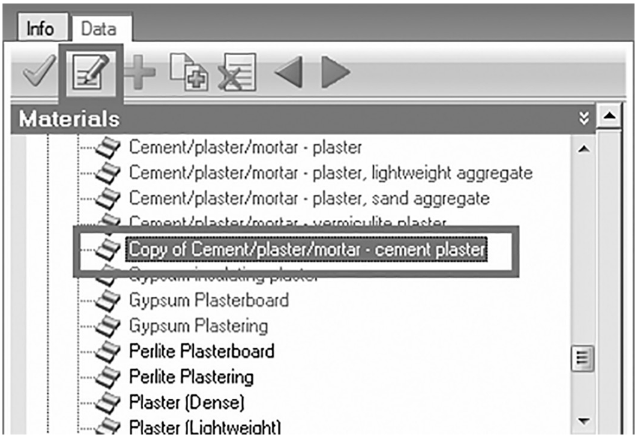
Step 3: Add a new roof with three layers. Select **Cement/plaster/mortar - cement plaster** from Plaster materials with thickness (m) as **0.01**, **Concrete, Medium density** from Concretes materials with thickness (m) as **0.15** and **Cement/plaster/mortar-cement plaster** from Plaster materials with thickness (m) as 0.01.



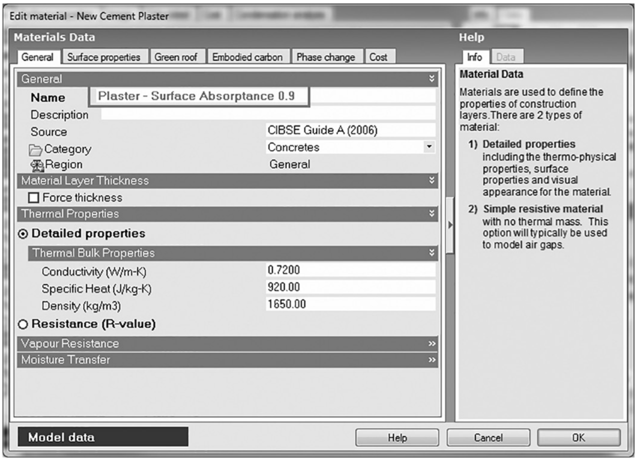
Step 4: Click **Cement/plaster/mortar - cement plaster** in the outermost layer and click the **Create copy of highlighted item** icon.



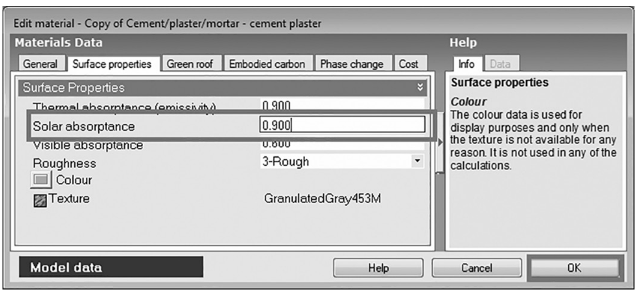
Step 5: Select the **Copy of Cement/plaster/mortar - cement plaster** and click the **Edit highlighted item** icon.



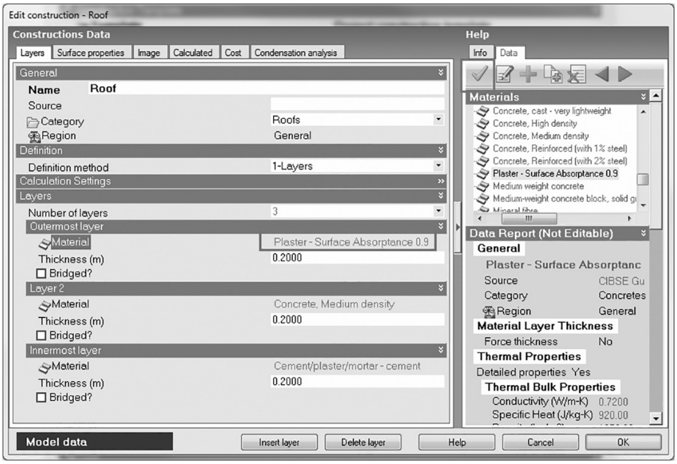
Step 6: Enter **Plaster - Surface Absorptance 0.9** in the Name box.



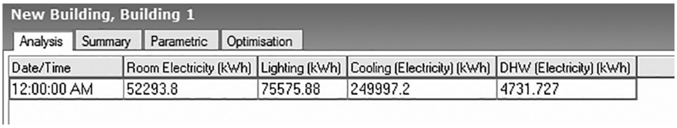
Step 7: Select the **Surface Properties** tab and enter **Solar absorptance** as **0.900**.



Step 8: Click the **Select this data** icon.



Step 9: Perform the annual simulation and record the results.

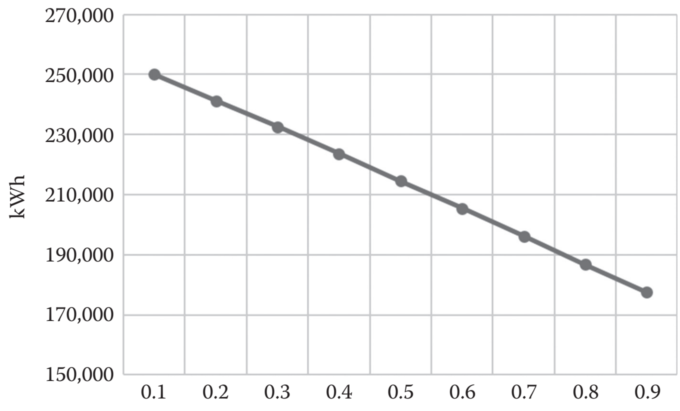


Step 10: Repeat the previous steps for all the values of solar absorptance given in the problem statement.

Compare the results for all simulations (Table 3.8).

Table 3.8 Annual fuel breakdown data for different surface absorptance

Surface absorptance	Surface reflectance	Room electricity (kWh)	Lighting (kWh)	Cooling (electricity) (kWh)	DHW (electricity) (kWh)
0.9	0.1	52,293.80	75,575.88	249,997.20	4,731.73
0.8	0.2	52,293.80	75,575.88	241,298.20	4,731.73
0.7	0.3	52,293.80	75,575.88	232,533.50	4,731.73
0.6	0.4	52,293.80	75,575.88	223,629.40	4,731.73
0.5	0.5	52,293.80	75,575.88	214,548.10	4,731.73
0.4	0.6	52,293.80	75,575.88	205,382.60	4,731.73
0.3	0.7	52,293.80	75,575.88	196,176.00	4,731.73
0.2	0.8	52,293.80	75,575.88	186,744.60	4,731.73
0.1	0.9	52,293.80	75,575.88	177,542.70	4,731.73



Exercise 3.5

Repeat the above tutorial for the **FRANKFURT MAIN ARPT, Germany** weather location (Table 3.9).

Table 3.9 Annual fuel breakdown data for different surface absorptance

Surface absorptance	Surface reflectance	Room electricity (kWh)	Lighting (kWh)	Heating (gas) (kWh)	Cooling (electricity) (kWh)	DHW (electricity) (kWh)
0.9	0.1					
0.8	0.2					
0.7	0.3					
0.6	0.4					
0.5	0.5					
0.4	0.6					
0.3	0.7					
0.2	0.8					
0.1	0.9					

TUTORIAL 3.6 Evaluating the impact of roof underdeck radiant barrier

GOAL

To evaluate the impact of underdeck radiant barrier on the energy performance.

WHAT ARE YOU GOING TO LEARN?

- Changing the emissivity of a material

PROBLEM STATEMENT

In this tutorial, you are going to use a 50 m × 25 m model with a roof consisting of the following layers (starting with the outermost layer).

- 0.01 m cement/plaster/mortar-plaster
- 0.15 m concrete, medium density
- 0.01 m cement/plaster/mortar-plaster

Vary the thermal emittance on the innermost material of the roof (ceiling) from 0.1 to 0.9 in steps of 0.1. Find out the impact of roof thermal emittance on the energy consumption for **CA-SAN FRANCISCO INTL, USA**.

Thermal absorptance (emissivity)
The thermal absorptance represents the fraction of incident long wavelength radiation that is absorbed by the material. This parameter is used when calculating the long wavelength radiant exchange between various surfaces and affects the surface heat balances (both inside and outside as appropriate). Values for this field must be between 0.0 and 1.0 (with 1.0 representing 'black body' conditions).

http://www.designbuilder.co.uk/helpv4.7/Content/SurfaceProperties.htm

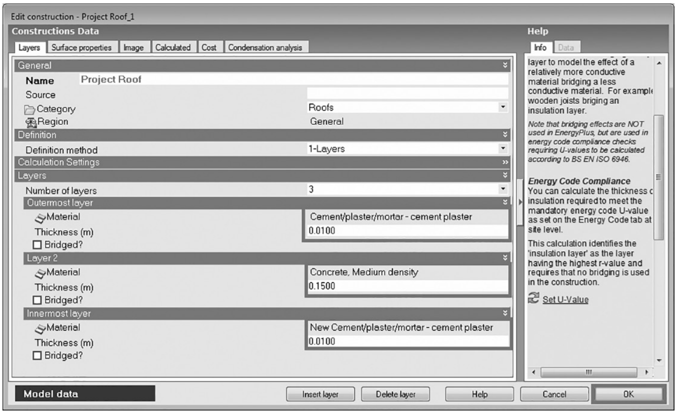
Radiant barrier is the coating used under the roof deck to limit the heat transfer from the inside to outside and the outside to inside.

SOLUTION

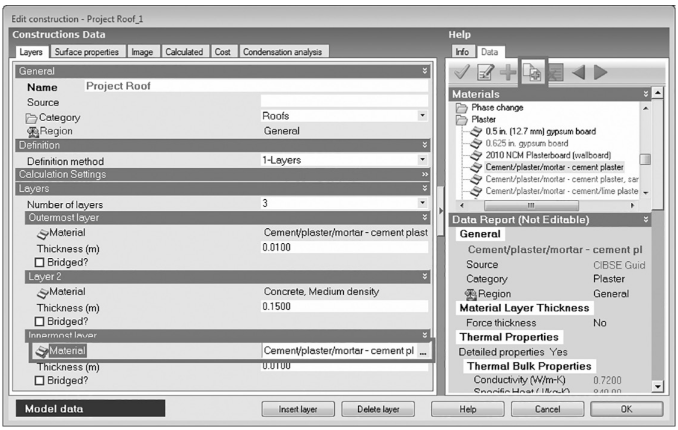
Step 1: Open a new project. Create a **50 m × 25 m** building.

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

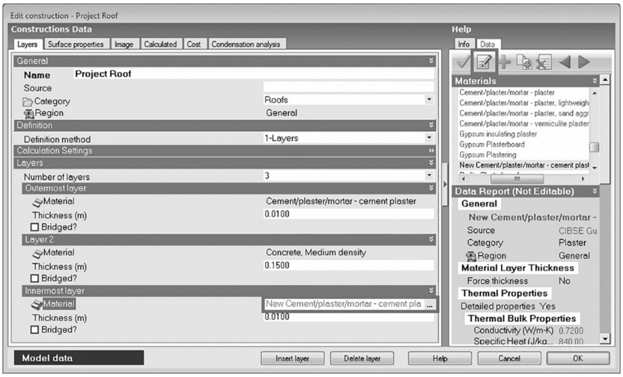
Step 3: Add a new roof with three layers. Select **Cement/plaster/mortar - cement plaster** from Plaster materials with thickness (m) as **0.01, Concrete, Medium density** from Concretes materials with thickness (m) as **0.1500** and select **Cement/plaster/mortar - cement plaster** from Plaster materials with thickness (m) as **0.0100**.



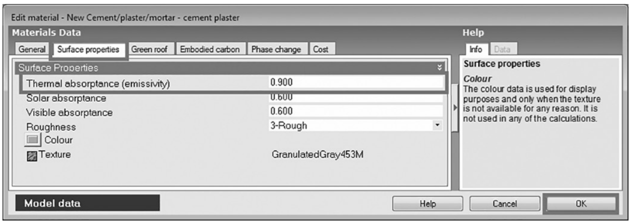
Step 4: Click **Cement/plaster/mortar - cement plaster** in the innermost layer, create a copy and rename it as **New Cement/plaster/mortar - cement plaster**.



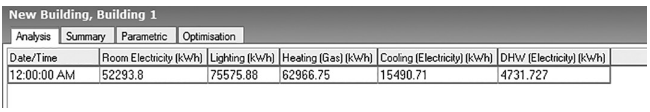
Step 5: Click the **Edit highlighted item** icon.



Step 6: Select the **Surface properties** tab and enter **0.900** as the **Thermal absorptance (emissivity)**.



Step 7: Simulate the model and record the results.

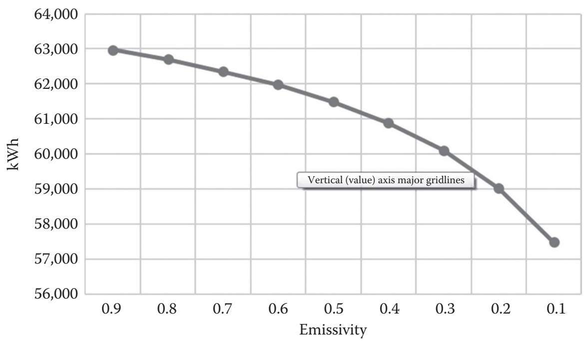


Step 8: Repeat the previous steps for all the values of thermal emissivity given in the problem statement.

Compare the results for all simulations (Table 3.10).

Table 3.10 Comparison of annual fuel breakdown data for thermal absorptance

Thermal absorptance (emissivity)	Room electricity (kWh)	Lighting (kWh)	Heating (gas) (kWh)	Cooling (electricity) (kWh)	DHW (electricity)
0.9	52,293.80	75,575.88	62,966.75	15,490.71	4,731.73
0.8	52,293.80	75,575.88	62,696.43	15,513.52	4,731.73
0.7	52,293.80	75,575.88	62,352.68	15,553.91	4,731.73
0.6	52,293.80	75,575.88	61,982.36	15,619.02	4,731.73
0.5	52,293.80	75,575.88	61,489.79	15,720.82	4,731.73
0.4	52,293.80	75,575.88	60,888.78	15,881.52	4,731.73
0.3	52,293.80	75,575.88	60,104.81	16,128.46	4,731.73
0.2	52,293.80	75,575.88	59,024.70	16,510.27	4,731.73
0.1	52,293.80	75,575.88	57,484.44	17,130.53	4,731.73



Exercise 3.6

Repeat the tutorial for the **DUBAI INTERNATIONAL, United Arab Emirates** weather location (Table 3.11).

Table 3.11 Annual fuel breakdown data

Thermal absorptance (emissivity)	Room electricity (kWh)	Lighting (kWh)	Heating (gas) (kWh)	Cooling (electricity) (kWh)	DHW (electricity)
0.9					
0.8					
0.7					
0.6					
0.5					
0.4					
0.3					
0.2					
0.1					

TUTORIAL 3.7 Evaluating the impact of a green roof

GOAL

To evaluate the impact of a green roof on the energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Creating a green roof

PROBLEM STATEMENT

In this tutorial, you are going to use a 50 m × 25 m model with a roof consisting of the following layers (starting with the outermost layer):

- 0.01 m cement/plaster/mortar-plaster
- 0.15 m concrete, medium density
- 0.01 m cement/plaster/mortar-plaster

Add a green roof to the outermost layer of the roof. Find out the change in energy consumption with and without a green roof for **DUBAI INTERNATIONAL, United Arab Emirates**.

A green roof or living roof is a roof of a building that is partially or completely covered with vegetation and a growing medium planted over a waterproofing membrane.

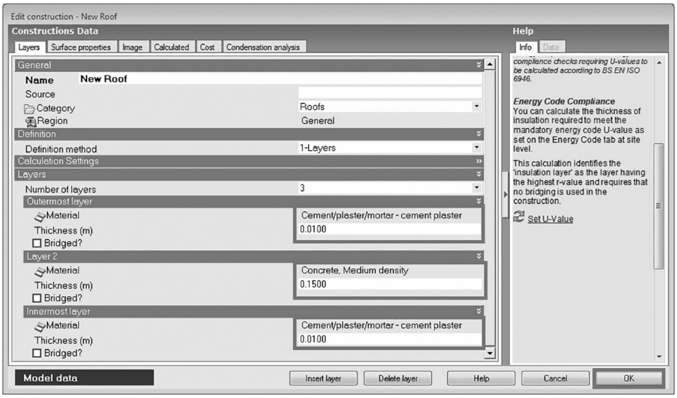
http://www.designbuilder.co.uk/helpv4.7/Content/GreenRoof.htm

SOLUTION

Step 1: Open a new project. Create a **50 m × 25 m** building.

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

Step 3: Add a **New roof** with three layers. Select **Cement/plaster/mortar - cement plaster** from Plaster materials with thickness (m) as **0.0100, Concrete, Medium density** from Concretes materials with thickness (m) as **0.1500**, and **Cement/plaster/mortar - cement plaster** from Plaster materials with thickness (m) as **0.0100**.

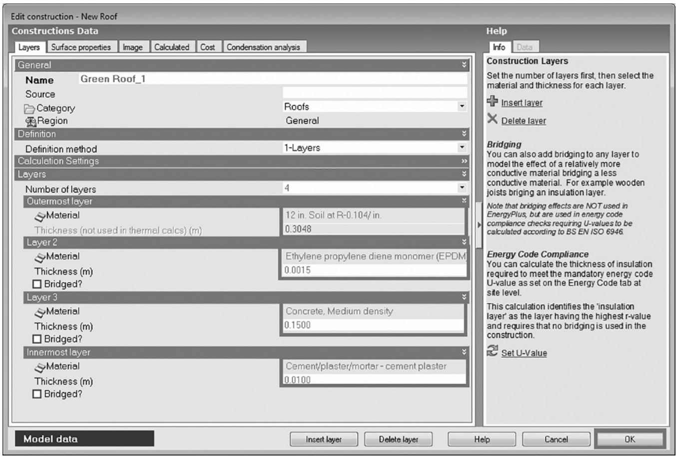


Step 4: Simulate the model and record the results without a green roof.

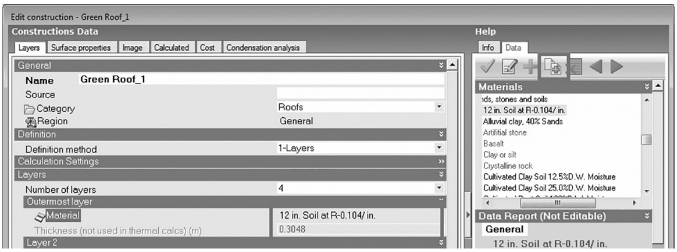
Now you are going to add a green roof.

Step 5: Add a **New roof** with four layers. Select **12 in. Soil at R-0.104/ in.** from sands, stones and soil materials with thickness (m) as **0.305, Ethylene propylene diene monomer (EPDM)** from rubber materials with thickness (m) as **0.0015** and select **Concrete,**

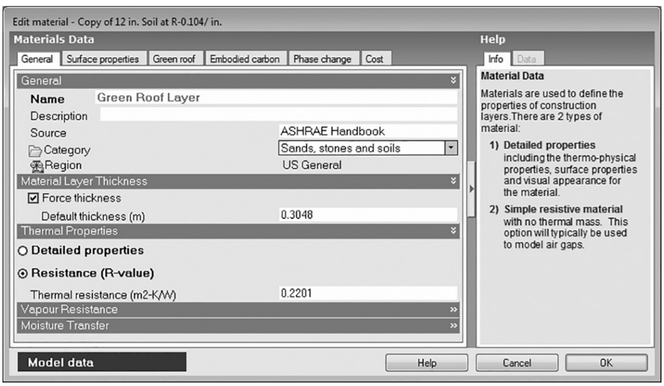
Medium density from concretes materials with thickness (m) as **0.1500**, and **Cement/plaster/mortar - cement plaster** from Plaster materials with thickness (m) as **0.0100**.



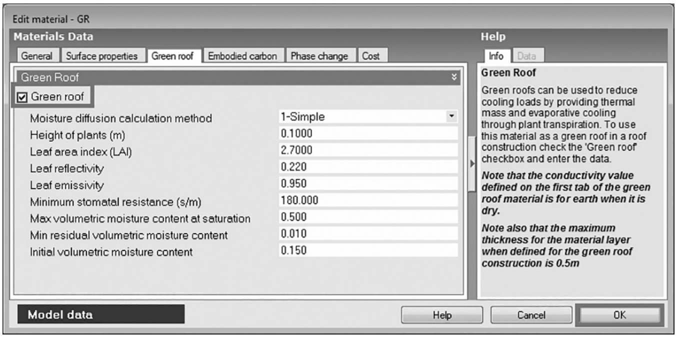
Step 6: Click **12 in. Soil at R-0.104/ in.** In the outermost layer, it highlights and creates a copy.



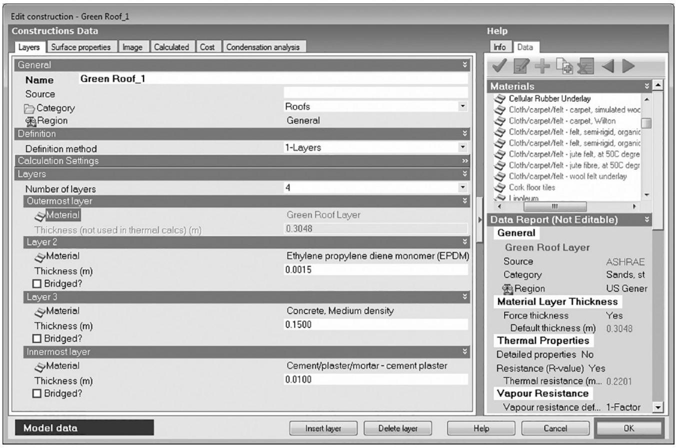
Step 7: Select the **copy of 12 in. Soil at R-0.104/ in.** Rename it Green Roof Layer.



Step 8: Select the **Green roof** tab. Select the **Green roof** check box.



Step 9: Click **OK**. Green Roof Layer appears as the outermost layer.



Step 10: Perform annual simulation and record the results.

Compare the results for both simulations (Table 3.12).

Table 3.12 Annual fuel breakdown with and without a green roof

	Without a green roof (kWh)	With a green roof (kWh)
Room electricity	52,293.80	52,293.80
Lighting	75,575.88	75,575.88
Heating (gas)	2,483.94	470.05
Cooling (electricity)	196,202.30	188,443.40
DHW (electricity)	4,731.73	4,731.73

Exercise 3.7

Repeat the above tutorial for the CA – San Francisco, USA weather file (Table 3.13).

Table 3.13 Annual fuel breakdown consumption with and without a green roof

	Annual fuel breakdown consumption	
	Without a green roof (kWh)	With a green roof (kWh)
Room electricity		
Lighting		
Heating (gas)		
Cooling (electricity)		
DHW (electricity)		

CHAPTER FOUR

Openings and Shading

Openings are required in buildings to bring daylight and fresh air, and provide outdoor views. The energy for artificial electric light can be reduced if there is sufficient daylight in the space. However, daylight increases the heat gain in a space. If the climate is hot/warm, it results in an increase in the air-conditioning energy consumption. Hence, there is a need to optimize the window-to-wall ratio (WWR) to get the minimum energy consumption while getting sufficient daylight.

Choosing glass type is also important for buildings; building glass is specified by some important properties such as *U*-value, solar heat gain coefficient (SHGC) and visible light transmittance (VLT). Generally, VLT to SHGC ratio is taken as an indicator of glass performance in cooling dominated locations. Higher is this ratio, better is the glass. Building shades can be used to cut the direct solar radiation in buildings and get diffused daylight inside the perimeter space. Overhangs and fins are classified as fixed building shades. Operable shades can also be used to cut the direct radiation from windows.

In this chapter, through the three tutorials, you are going to learn how to analyse the impact of different glazing types, fixed shades and operable shades for a given climate. This can be useful in the analysis of different designs and approaches for reducing solar heat gains through windows.

TUTORIAL 4.1 Evaluating the impact of window wall ratio and glazing type

GOAL

To evaluate the impact of WWR and glazing type on the energy consumption.

> Window-to-wall ratio (WWR), is the ratio of the total window area to the total gross exterior above grade wall area.

WHAT ARE YOU GOING TO LEARN?

- Setting WWR
- Selecting glazing type

PROBLEM STATEMENT

In this tutorial, you are going to use a 50 m × 25 m five-zone model with a 5 m perimeter depth. You are going to use the following glass types for the simulations (Table 4.1).

Find out energy consumption for all cases for **SINGAPORE/PAYA LEBA**.

> **Light-to-solar gain (L/S)** is the ratio between the VLT and SHGC. It provides a gauge of the relative efficiency of different glass or glazing types in transmitting daylight while blocking heat gains. The higher the number, the more the light transmitted without adding excessive amounts of heat.

SOLUTION

Step 1: Create a **50 m × 25 m** five-zone model with a 5 m perimeter depth.

PART I: With **Dbl Green 6mm/6mm Air** glass.

Step 2: Select the O**penings** tab and select **Glazing type** as **Dbl Green 6mm/6mm Air.** Set **WWR** to **0.00%**.

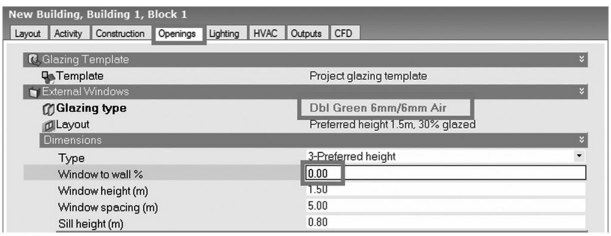


Table 4.1 Glass types and their properties

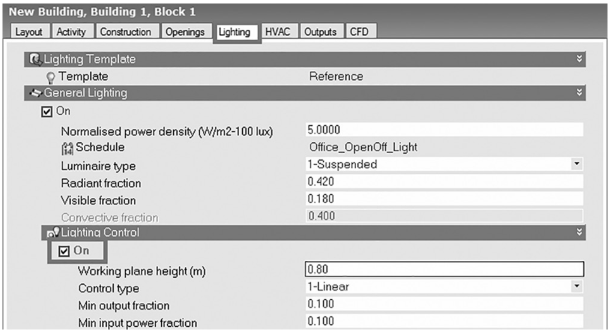
PART	Glass	Properties	Light-to-solar gain ratio (L/S)	WWR	Daylight controls	Shade
I	Double glazing	Green 6mm/6mm Air, SHGC-0.49, VLT-0.66	1.35	0% to 90% in steps of 10%	With and without	None
II	Single glazing	Sgl Clr 6mm, SHGC-0.81 and VLT-0.88	1.09	0% to 90% in steps of 10%	With and without	None
III	ASHRAE 90.1 equivalent glass	U-6.81 W/m^2 K, SHGC-0.25 and VLT 0.53	2.12	0% to 90% in steps of 10%	With and without	None and with a 0.5 m overhang on all windows

Step 3: Simulate the model and record the results.

Step 4: Repeat the previous steps to set WWR (from 10% to 90% in steps of 10%) as given in the problem statement.

Record the results for all WWRs without lighting control (Table 4.2).

Step 5: Select the **Lighting** tab. In the **Lighting Control** section, select the **ON** check box.



When you select the ON check box, you get the daylight sensor placed in all zones. You can see that the lighting energy consumption for the daylit perimeter zones will decrease.

Table 4.2 Annual energy consumption with a double glazing window without daylight controls

Double glazing without daylight controls (Dbl Green 6mm/6mm Air)					
WWR (%)	Room electricity (kWh)	Lighting (kWh)	Cooling (electricity) (kWh)	DHW (electricity) (kWh)	Annual consumption (electricity) (kWh)
0	51,114.49	73,871.52	188,313.20	4,625.02	317,924.23
10	51,114.49	73,871.52	194,815.30	4,625.02	324,426.33
20	51,114.49	73,871.52	201,498.70	4,625.02	331,109.73
30	51,114.49	73,871.52	207,691.50	4,625.02	337,302.53
40	51,114.49	73,871.52	213,531.40	4,625.02	343,142.43
50	51,114.49	73,871.52	219,081.10	4,625.02	348,692.13
60	51,114.49	73,871.52	224,293.80	4,625.02	353,904.83
70	51,114.49	73,871.52	229,142.60	4,625.02	358,753.63
80	51,114.49	73,871.52	233,851.40	4,625.02	363,462.43
90	51,114.49	73,871.52	238,187.40	4,625.02	367,798.43

Step 6: Simulate the model and record the results.

Record the results for all WWRs with lighting control (Table 4.3).

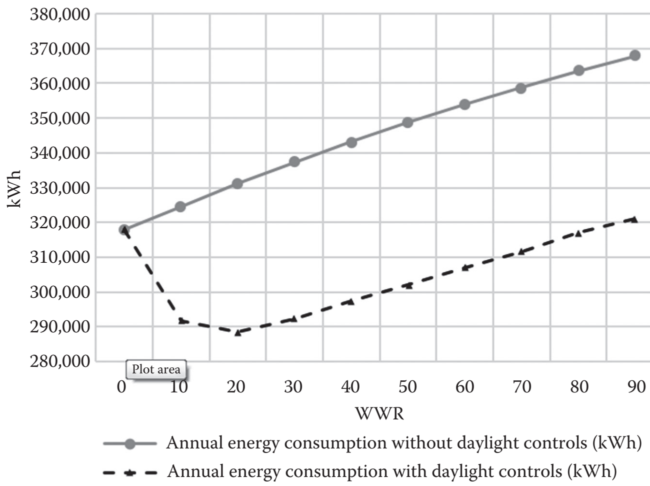
Step 7: Compare the results with and without daylight controls (Table 4.4).

Table 4.3 Annual energy consumption with a double glazing window with daylight controls

Double glazing with daylight controls (Dbl Green 6mm/6mm Air)					
WWR (%)	Room electricity (kWh)	Lighting (kWh)	Cooling (electricity) (kWh)	DHW (electricity) (kWh)	Annual consumption (electricity) (kWh)
0	51,114.49	73,871.52	188,313.20	4,625.02	317,924.23
10	51,114.49	53,353.82	182,543.10	4,625.02	291,636.43
20	51,114.49	46,939.31	185,863.80	4,625.02	288,542.62
30	51,114.49	45,119.64	191,441.50	4,625.02	292,300.65
40	51,114.49	44,352.53	197,248.60	4,625.02	297,340.64
50	51,114.49	43,660.43	202,749.90	4,625.02	302,149.84
60	51,114.49	43,205.62	208,067.20	4,625.02	307,012.33
70	51,114.49	42,831.40	213,031.60	4,625.02	311,602.51
80	51,114.49	43,154.81	218,172.20	4,625.02	317,066.52
90	51,114.49	42,800.91	222,551.70	4,625.02	321,092.12

Table 4.4 Comparison of the total annual energy consumption for a double glazed window with and without daylight sensors

WWR (%)	Annual energy consumption without daylight controls (kWh)	Annual energy consumption with day light controls (kWh)
0	317,924.23	317,924.23
10	324,426.33	291,636.43
20	331,109.73	288,542.62
30	337,302.53	292,300.65
40	343,142.43	297,340.64
50	348,692.13	302,149.84
60	353,904.83	307,012.33
70	358,753.63	311,602.51
80	363,462.43	317,066.52
90	367,798.43	321,092.12



The results show that with double glazed glass, a building consumes the minimum energy at 20% WWR, when daylight controls are installed in the building in all its daylit perimeter spaces.

PART II: With **Sgl Clr 6mm** glass.

Step 8: Repeat the previous steps to get simulation results with **Sgl Clr 6mm** glass (Tables 4.5 through 4.7).

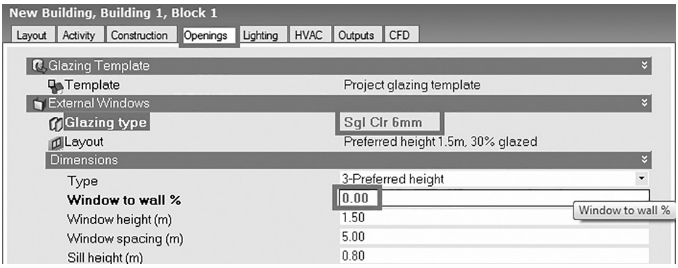


Table 4.5 Annual energy consumption for a single glazed window without daylight controls

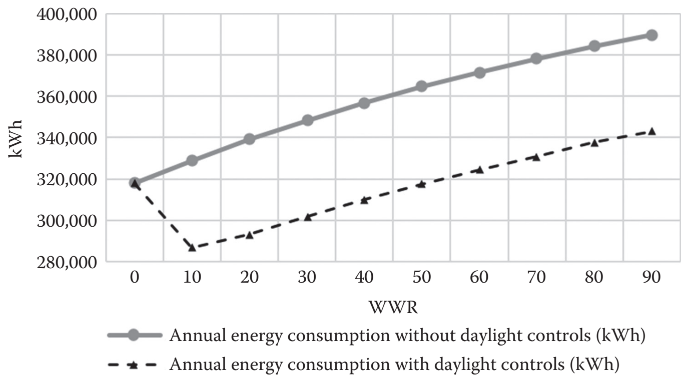
Single glazing without daylight controls (Sgl Clr 6mm)					
WWR (%)	Room electricity (kWh)	Lighting (kWh)	Cooling (electricity) (kWh)	DHW (electricity) (kWh)	Annual consumption (electricity) (kWh)
0	51,114.49	73,871.52	188,313.20	4,625.02	317,924.23
10	51,114.49	73,871.52	199,104.20	4,625.02	328,715.23
20	51,114.49	73,871.52	209,534.90	4,625.02	339,145.93
30	51,114.49	73,871.52	218,763.50	4,625.02	348,374.53
40	51,114.49	73,871.52	227,147.50	4,625.02	356,758.53
50	51,114.49	73,871.52	234,957.70	4,625.02	364,568.73
60	51,114.49	73,871.52	242,125.10	4,625.02	371,736.13
70	51,114.49	73,871.52	248,650.70	4,625.02	378,261.73
80	51,114.49	73,871.52	254,622.30	4,625.02	384,233.33
90	51,114.49	73,871.52	260,126.20	4,625.02	389,737.23

Table 4.6 Annual energy consumption for a single glazed window with daylight controls

Single glazing with daylight controls (Sgl Clr 6mm)					
WWR (%)	Room electricity (kWh)	Lighting (kWh)	Cooling (electricity) (kWh)	DHW (electricity) (kWh)	Annual consumption (electricity) (kWh)
0	51,114.49	73,871.52	188,313.20	4,625.02	317,924.23
10	51,114.49	47,477.93	183,586.70	4,625.02	286,804.14
20	51,114.49	44,369.11	192,984.40	4,625.02	293,093.02
30	51,114.49	43,484.96	202,437.50	4,625.02	301,661.97
40	51,114.49	43,065.26	211,079.50	4,625.02	309,884.27
50	51,114.49	42,599.63	219,113.30	4,625.02	317,452.44
60	51,114.49	42,272.71	226,499.70	4,625.02	324,511.92
70	51,114.49	42,010.69	233,254.80	4,625.02	331,005.00
80	51,114.49	42,242.57	239,633.50	4,625.02	337,615.58
90	51,114.49	41,992.99	245,322.10	4,625.02	343,054.60

Table 4.7 Comparison of the total annual energy consumption for a single glazed window with and without daylight sensors

WWR (%)	Annual energy consumption without daylight controls (kWh)	Annual energy consumption with daylight controls (kWh)
0	317,924.23	317,924.23
10	328,715.23	286,804.14
20	339,145.93	293,093.02
30	348,374.53	301,661.97
40	356,758.53	309,884.27
50	364,568.73	317,452.44
60	371,736.13	324,511.92
70	378,261.73	331,005.00
80	384,233.33	337,615.58
90	389,737.23	343,054.60



The results show that with single glazed glass, a building consumes the minimum energy at 10% WWR when daylight controls are installed in the building in all its daylit perimeter spaces.

PART III A: With **ASHRAE 90.1-2007** equivalent glass (U-1.20 (6.81), SHGC-0.25 and VLT 53%).

Step 9: Now refer to the previous steps and get simulation results with **ASHRAE 90.1** equivalent glass. **Vertical glazing, 0%–40% of wall, U-1.20 (6.81) and SHGC-0.25** (Tables 4.8 and 4.9).

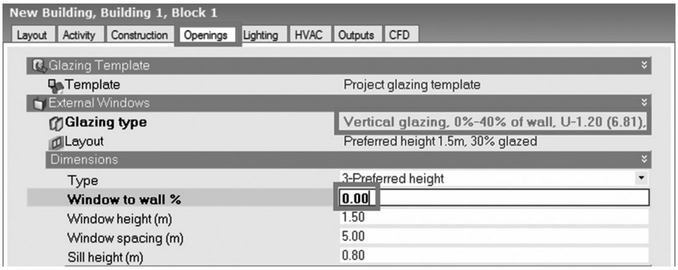


Table 4.8 Annual energy consumption with ASHRAE 90.1 equivalent glass without daylight controls

ASHRAE 90.1 Glass without daylight controls (vertical glazing, 0%-40% of wall, U-1.20 (6.81) and SHGC-0.25)					
WWR (%)	Room electricity (kWh)	Lighting (kWh)	Cooling (electricity) (kWh)	DHW (electricity) (kWh)	Annual consumption (electricity) (kWh)
0	51,114.49	73,871.52	188,313.20	4,625.02	317,924.23
10	51,114.49	73,871.52	191,587.80	4,625.02	321,198.83
20	51,114.49	73,871.52	194,916.30	4,625.02	324,527.33
30	51,114.49	73,871.52	198,107.40	4,625.02	327,718.43
40	51,114.49	73,871.52	201,055.30	4,625.02	330,666.33
50	51,114.49	73,871.52	203,782.00	4,625.02	333,393.03
60	51,114.49	73,871.52	206,272.20	4,625.02	335,883.23
70	51,114.49	73,871.52	208,605.50	4,625.02	338,216.53
80	51,114.49	73,871.52	210,932.40	4,625.02	340,543.43
90	51,114.49	73,871.52	212,968.10	4,625.02	342,579.13

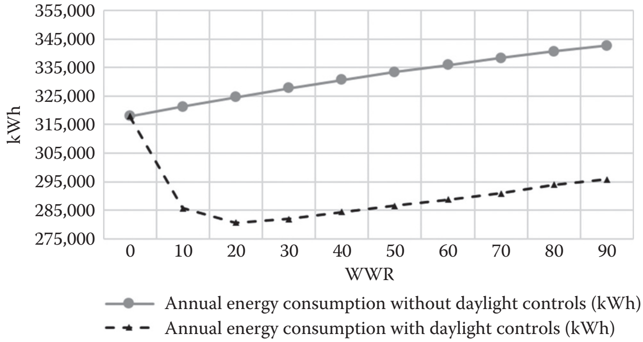
Table 4.9 Annual energy consumption with ASHRAE 90.1 equivalent glass with daylight controls

Good glazing with daylight controls (vertical glazing, 0%–40% of wall, U-1.20 (6.81) and SHGC-0.25)					
WWR (%)	Room electricity (kWh)	Lighting (kWh)	Cooling (electricity) (kWh)	DHW (electricity) (kWh)	Annual consumption (electricity) (kWh)
0	51,114.49	73,871.52	188,313.20	4,625.02	317,924.23
10	51,114.49	51,701.49	178,250.50	4,625.02	285,691.50
20	51,114.49	46,126.67	178,795.00	4,625.02	280,661.18
30	51,114.49	44,625.61	181,601.70	4,625.02	281,966.82
40	51,114.49	43,983.63	184,642.30	4,625.02	284,365.44
50	51,114.49	43,373.37	187,426.20	4,625.02	286,539.08
60	51,114.49	42,948.02	190,069.90	4,625.02	288,757.43
70	51,114.49	42,597.32	192,549.70	4,625.02	290,886.53
80	51,114.49	42,902.14	195,325.90	4,625.02	293,967.55
90	51,114.49	42,571.14	197,496.00	4,625.02	295,806.65

Step 10: Compare the results with and without daylight sensors (Table 4.10).

Table 4.10 Comparison of simulation results of glass with and without daylight sensors

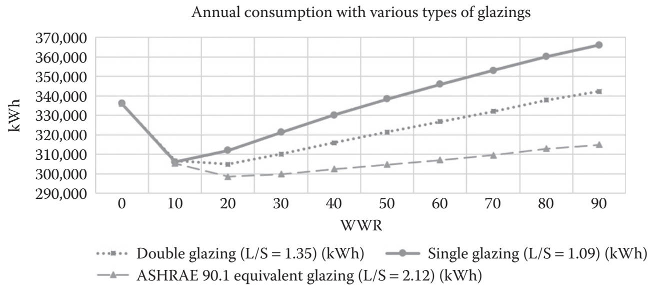
WWR (%)	Annual energy consumption without daylight controls (kWh)	Annual energy consumption with daylight controls (kWh)
0	317,924.23	317,924.23
10	321,198.83	285,691.50
20	324,527.33	280,661.18
30	327,718.43	281,966.82
40	330,666.33	284,365.44
50	333,393.03	286,539.08
60	335,883.23	288,757.43
70	338,216.53	290,886.53
80	340,543.43	293,967.55
90	342,579.13	295,806.65



Step 11: Now compare the results for all simulations of double glazing glass, single glazing glass and ASHRAE 90.1 equivalent glass with lighting controls (Table 4.11).

Table 4.11 Comparison of the total annual energy consumption for all glass types with daylight controls

WWR (%)	Double glazing (L/S = 1.35) (kWh)	Single glazing (L/S = 1.09) (kWh)	ASHRAE 90.1 equivalent glazing (L/S = 2.12) (kWh)
0	336,004.18	336,004.18	336,004.18
10	306,612.44	306,036.66	305,364.20
20	304,903.64	311,950.44	298,535.13
30	310,044.69	321,242.29	299,836.25
40	315,943.50	330,149.92	302,380.69
50	321,484.33	338,323.96	304,731.91
60	326,813.57	345,953.19	307,113.99
70	331,942.46	353,023.54	309,480.51
80	337,800.03	360,149.95	312,833.83
90	342,264.91	366,045.43	314,854.56



PART III B: With **ASHRAE 90.1-2007** equivalent glass (U-1.20 [6.81], SHGC-0.25 and VLT 53%) with the shading of a 0.5 m overhang.

Step 12: Select the **Openings** tab, select the **Local shading** check box under the Shading section and select **0.5m Overhang** from the **Type** (Table 4.12).

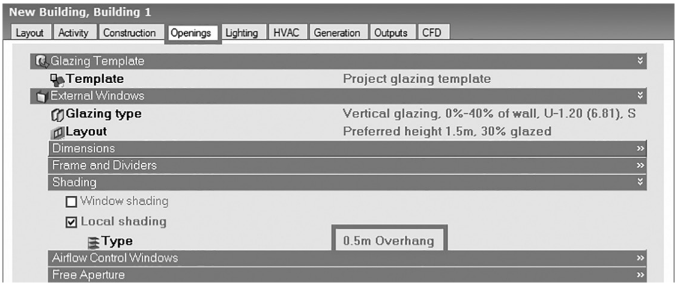


Table 4.12 Annual energy consumption with ASHRAE 90.1 equivalent glass, with fixed shade and daylight controls

Good glazing with daylight controls (vertical glazing, 0%–40% of wall, U-1.20 (6.81) and SHGC-0.25)					
WWR (%)	Room electricity (kWh)	Lighting (kWh)	Cooling (electricity) (kWh)	DHW (electricity) (kWh)	Annual consumption (electricity) (kWh)
0	51,114.49	73,871.52	188,313.20	4,625.02	317,924.23
10	51,114.49	53,819.91	178,846.40	4,625.02	288,405.82
20	51,114.49	47,004.59	177,688.30	4,625.02	280,432.40
30	51,114.49	45,294.22	179,536.80	4,625.02	280,570.53
40	51,114.49	44,561.03	181,742.40	4,625.02	282,042.94
50	51,114.49	43,683.38	184,197.20	4,625.02	283,620.09
60	51,114.49	43,139.11	186,824.00	4,625.02	285,702.62
70	51,114.49	43,017.17	189,495.10	4,625.02	288,251.78
80	51,114.49	43,106.45	192,231.50	4,625.02	291,077.46
90	51,114.49	42,705.82	194,444.50	4,625.02	292,889.83

Compare the results for with and without shading controls for ASHRAE 90.1 equivalent glass (Table 4.13).

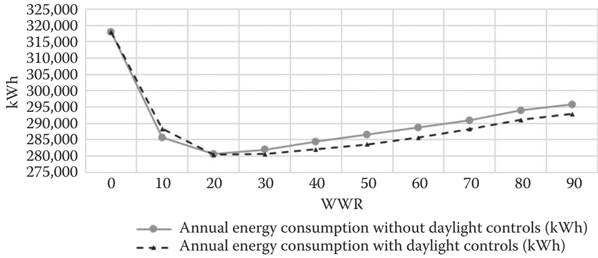


Table 4.13 Annual energy consumption results for ASHRAE 90.1 equivalent glass with and without shading

WWR (%)	Annual energy consumption without daylight controls (kWh)	Annual energy consumption with daylight controls (kWh)
0	317,924.23	317,924.23
10	285,691.50	288,405.82
20	280,661.18	280,432.40
30	281,966.82	280,570.53
40	284,365.44	282,042.94
50	286,539.08	283,620.09
60	288,757.43	285,702.62
70	290,886.53	288,251.78
80	293,967.55	291,077.46
90	295,806.65	292,889.83

For warm/hot climates:

1. If a building is without daylight controls, then the energy consumption increases with the increase in WWR. With the increase in WWR, heat gains through glass increase in the building and due to the absence of artificial lights dimming, the energy consumption increases.
2. If a building is having daylight sensors, then artificial lights can be dimmed when sufficient daylight is available. With the increase in WWR, more daylight is available to the perimeter spaces. Daylight sensors help in reducing the artificial lighting load and offset the heat gains through the glass. However, after a point when the perimeter spaces are daylit, an increase in WWR does not save the artificial lighting energy as the lamps are fully dimmed. After this point with the increase in WWR, the heat ingress increases, thereby increasing the overall energy consumption.
3. Glass with a higher visible light to solar gain (L/S) needs to be selected to get the maximum benefit from daylight.

Exercise 4.1

Repeat the above tutorial for **WIEN/HOHE VARTE, Austria.**

TUTORIAL 4.2 Evaluating the impact of overhangs and fins

GOAL

To evaluate the impact of window overhangs and fins on the energy performance.

WHAT ARE YOU GOING TO LEARN?

- Modelling overhangs and fins

PROBLEM STATEMENT

In this tutorial, you are going to use a 30 m × 30 m model with a 5 m perimeter depth. You need to select the **split no fresh air** HVAC system to the simulation model.

You need to simulate the model with the following options:

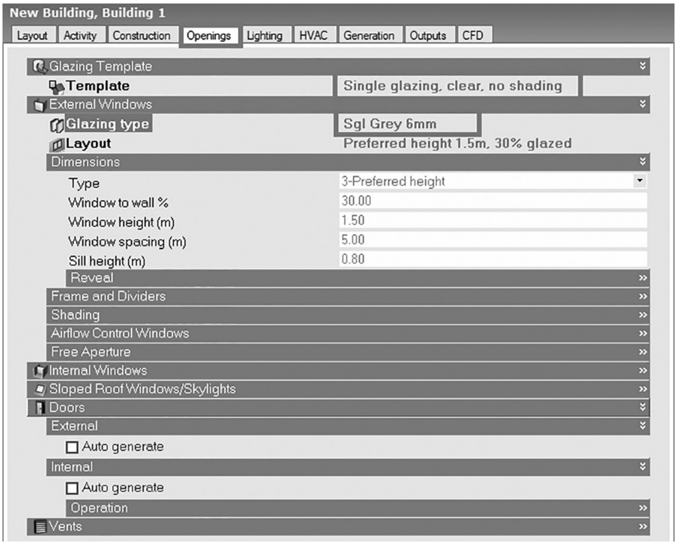
1. No shades
2. Overhangs
3. Vertical fins

Use location **DUBAI INTERNATIONAL, United Arab Emirates**.

SOLUTION

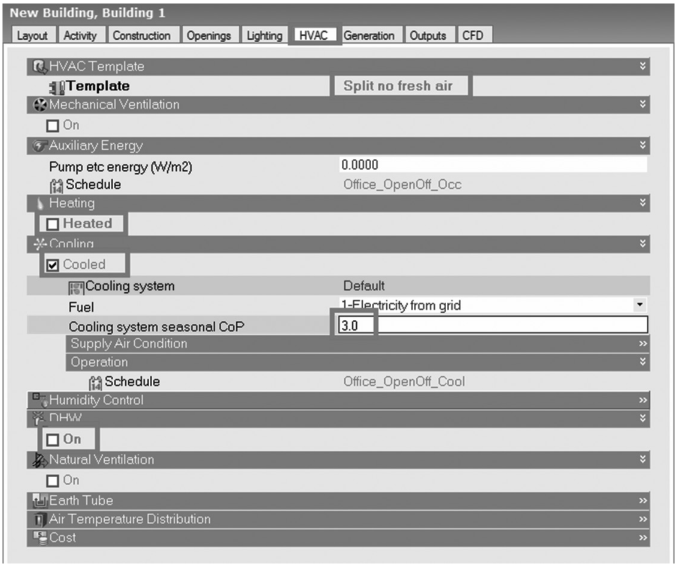
Step 1: Open a new project and create a **30 m × 30 m** building with a 5 m perimeter depth.

Step 2: Select the **Openings** tab. Select the **Single glazing, clear, no shading** template. Select **Sgl Grey 6mm** in **Glazing type**.

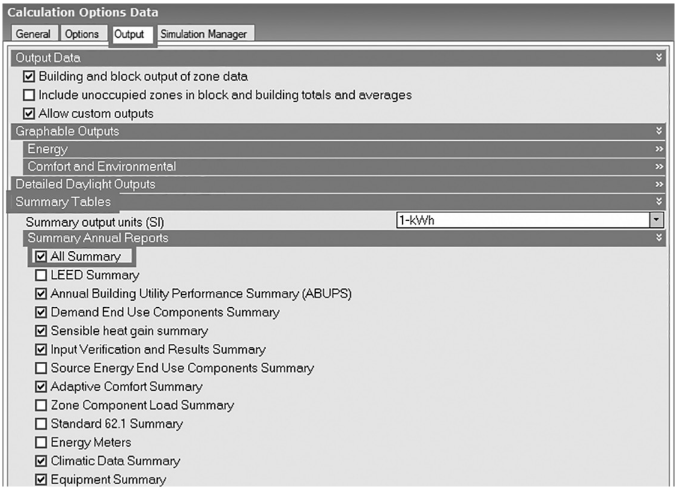


Step 3: Select the **HVAC** tab. Select the **Split no fresh air** template. Clear the **Heated** check box under the **Heating** section and clear the **On** check box under DHW. Select the check box under **Cooling system** and enter **3.0** as **CoP**.

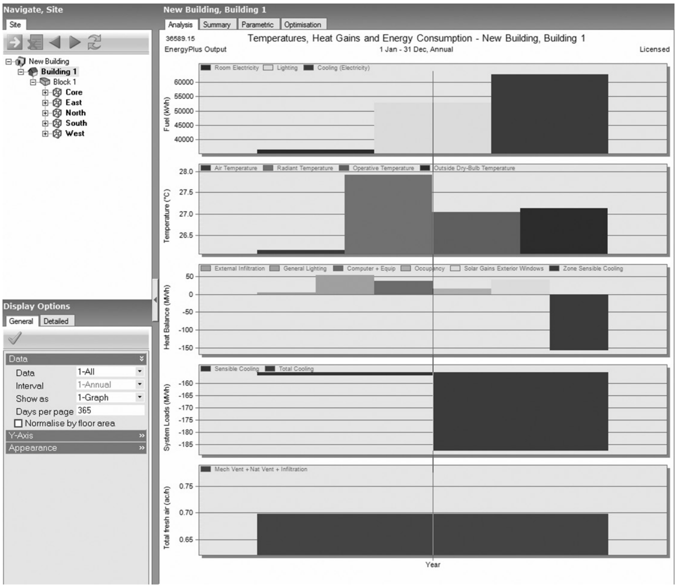
> When you use the Split no fresh air template, you can get the cooling energy consumption for all zones separately.



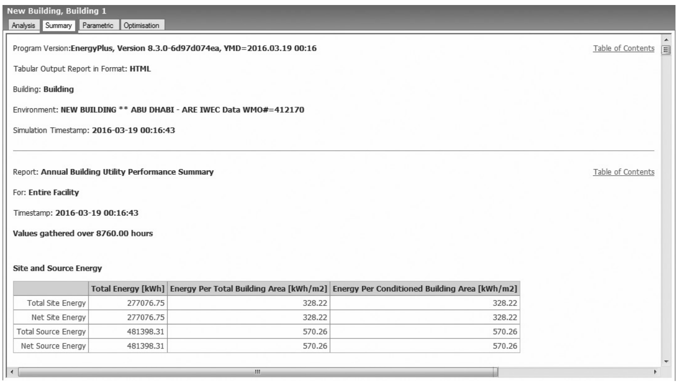
Step 4: Select the **Simulation** tab and select the **Output** tab, expand **Summary Tables** and select the **All Summary** check box under the **Summary Annual Reports** section.



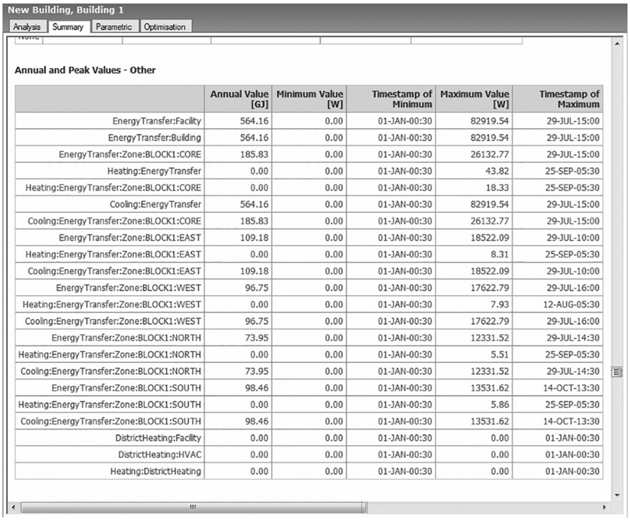
Step 5: Perform annual simulation and view the data in graphical format.



Step 6: Select the **Summary** tab.



Step 7: Scroll down to read **Annual and Peak Values – Other**.



	Annual Value [GJ]	Minimum Value [W]	Timestamp of Minimum	Maximum Value [W]	Timestamp of Maximum
EnergyTransfer:Facility	564.16	0.00	01-JAN-00:30	82919.54	29-JUL-15:00
EnergyTransfer:Building	564.16	0.00	01-JAN-00:30	82919.54	29-JUL-15:00
EnergyTransfer:Zone:BLOCK1:CORE	185.83	0.00	01-JAN-00:30	26132.77	29-JUL-15:00
Heating:EnergyTransfer	0.00	0.00	01-JAN-00:30	43.82	25-SEP-05:30
Heating:EnergyTransfer:Zone:BLOCK1:CORE	0.00	0.00	01-JAN-00:30	18.33	25-SEP-05:30
Cooling:EnergyTransfer	564.16	0.00	01-JAN-00:30	82919.54	29-JUL-15:00
Cooling:EnergyTransfer:Zone:BLOCK1:CORE	185.83	0.00	01-JAN-00:30	26132.77	29-JUL-15:00
EnergyTransfer:Zone:BLOCK1:EAST	109.18	0.00	01-JAN-00:30	18522.09	29-JUL-10:00
Heating:EnergyTransfer:Zone:BLOCK1:EAST	0.00	0.00	01-JAN-00:30	8.31	25-SEP-05:30
Cooling:EnergyTransfer:Zone:BLOCK1:EAST	109.18	0.00	01-JAN-00:30	18522.09	29-JUL-10:00
EnergyTransfer:Zone:BLOCK1:WEST	96.75	0.00	01-JAN-00:30	17622.79	29-JUL-16:00
Heating:EnergyTransfer:Zone:BLOCK1:WEST	0.00	0.00	01-JAN-00:30	7.93	12-AUG-05:30
Cooling:EnergyTransfer:Zone:BLOCK1:WEST	96.75	0.00	01-JAN-00:30	17622.79	29-JUL-16:00
EnergyTransfer:Zone:BLOCK1:NORTH	73.95	0.00	01-JAN-00:30	12331.52	29-JUL-14:30
Heating:EnergyTransfer:Zone:BLOCK1:NORTH	0.00	0.00	01-JAN-00:30	5.51	25-SEP-05:30
Cooling:EnergyTransfer:Zone:BLOCK1:NORTH	73.95	0.00	01-JAN-00:30	12331.52	29-JUL-14:30
EnergyTransfer:Zone:BLOCK1:SOUTH	98.46	0.00	01-JAN-00:30	13531.62	14-OCT-13:30
Heating:EnergyTransfer:Zone:BLOCK1:SOUTH	0.00	0.00	01-JAN-00:30	5.86	25-SEP-05:30
Cooling:EnergyTransfer:Zone:BLOCK1:SOUTH	98.46	0.00	01-JAN-00:30	13531.62	14-OCT-13:30
DistrictHeating:Facility	0.00	0.00	01-JAN-00:30	0.00	01-JAN-00:30
DistrictHeating:HVAC	0.00	0.00	01-JAN-00:30	0.00	01-JAN-00:30
Heating:DistrictHeating	0.00	0.00	01-JAN-00:30	0.00	01-JAN-00:30

Step 8: Record the annual value for the energy transfer zone (GJ) for all perimeter zones (Table 4.14).

Save the simulation model for the next step.

Now you are going to model window overhangs.

Step 9: Select the **Openings** tab.

Step 10: Click the **Shading** section. Shading options appear.

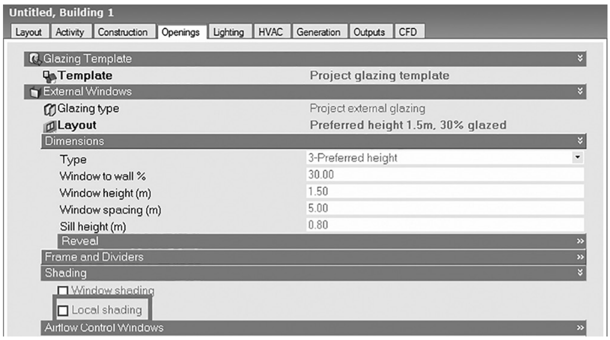
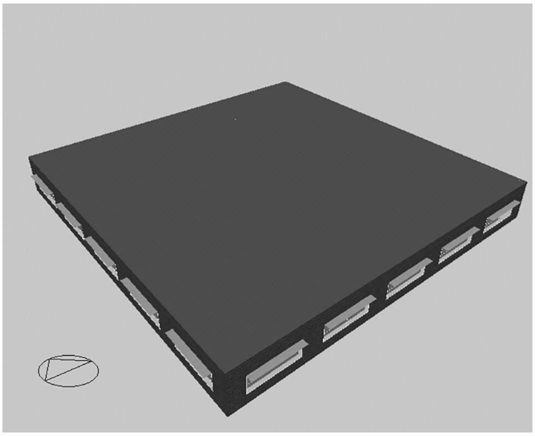


Table 4.14 Annual value for the energy transfer for each zone with no shading

Zone	Annual value for energy transfer (GJ)
North	73.95
East	109.18
West	96.75
South	98.46

Step 11: Select the **Local shading** check box. It displays shading type.

Step 12: Select the **Visualize** tab. It displays the rendering of the building. Make sure that all windows are modelled with an overhang.



Step 13: Repeat the previous steps to get simulation results (Table 4.15).

Save the simulation model with the name **DB_overhang**.

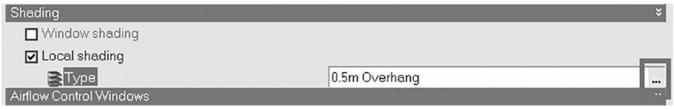
In the next steps you are going to model vertical fins.

Step 14: Open the saved simulation model.

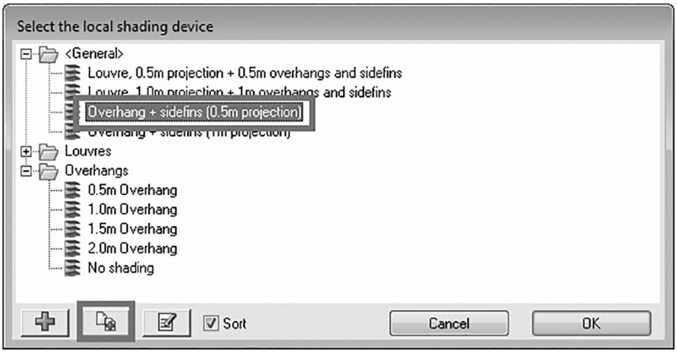
Step 15: Select **Overhang + sidefins (0.5m projection)** and make a copy of the current selection and edit for changes.

Table 4.15 Annual value for energy transfer with overhangs

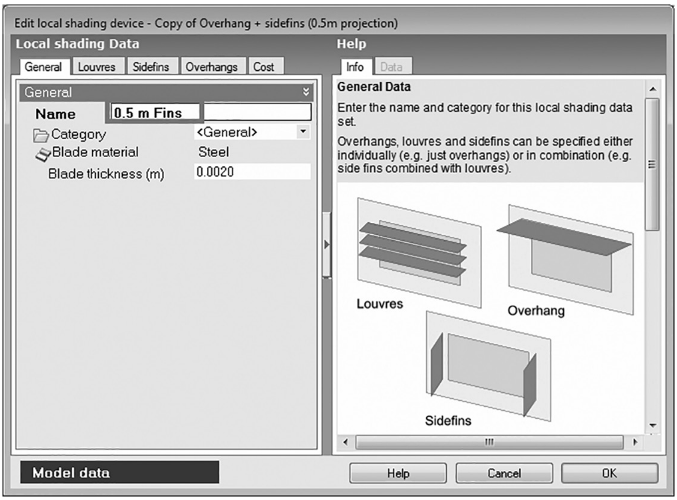
Zone	Annual value (GJ)
North	72.30
East	100.23
West	88.33
South	87.45



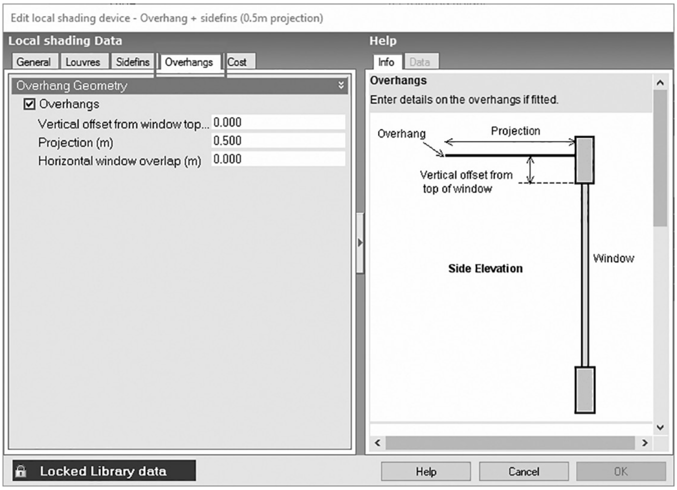
Step 16: Enter **0.5 m Fins** as the name.

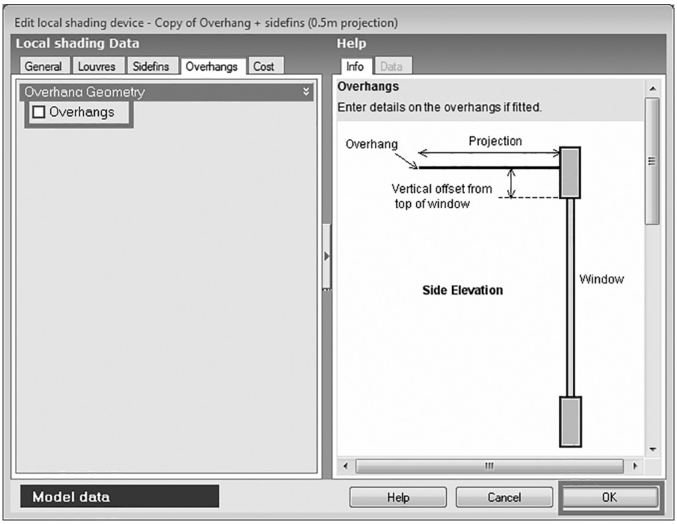


Step 17: Select the **Overhangs** tab.

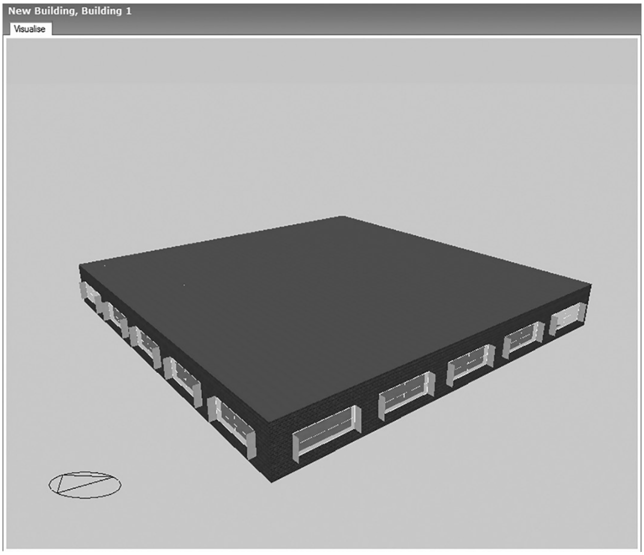


Step 18: Clear the **Overhangs** check box.





Step 19: **Visualize** the model. Make sure that all windows have side fins.



Step 20: Perform annual simulation and record the results (Table 4.16).

Compare the results for all the cases (Table 4.17).

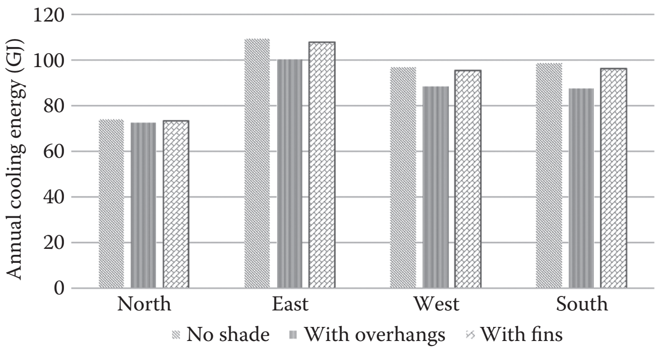
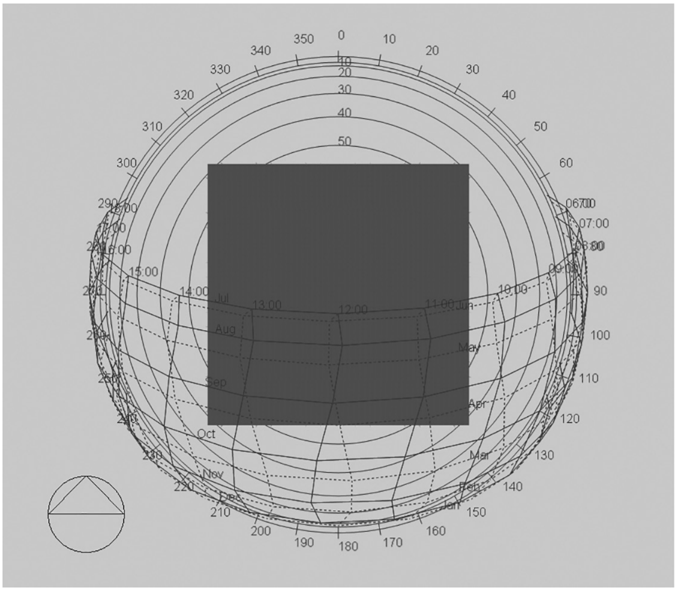


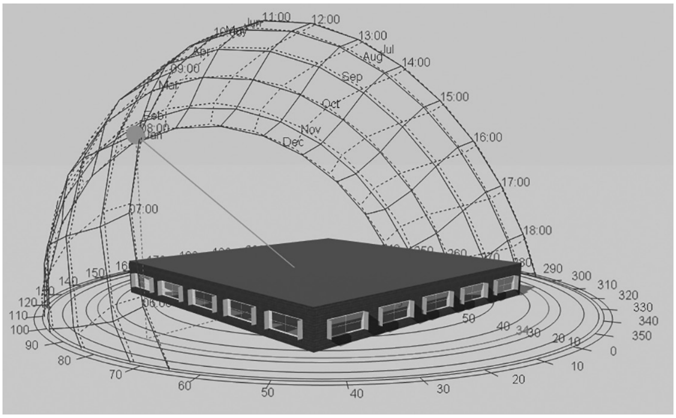
Table 4.16 Annual value of energy transfer for vertical fins

Zone	Annual value (GJ)
North	73.16
East	107.74
West	95.36
South	96.06

Table 4.17 Comparison of the annual cooling energy for all types of shades

	Annual cooling energy (GJ)		
Zone	No shade	With overhangs	With fins
North	73.95	72.30	73.16
East	109.18	100.23	107.74
West	96.75	88.33	95.36
South	98.46	87.45	96.06





The following are the steps to get the sunpath diagram:

Step 1: Select the **Visualize** tab.

Step 2: Under the **Display options**, select the **Show sunpath diagram** check box.

Step 3: Click the **Apply changes** icon.

Exercise 4.2

Repeat the above tutorial for both overhangs and fins to observe the combined effect. Compare the energy consumption for all the perimeter zones.

TUTORIAL 4.3 Evaluating the impact of internal operable shades

GOAL

To evaluate the impact of window internal operable shades on the energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Modelling operable shades

PROBLEM STATEMENT

In this tutorial, you are going to use the model created in Tutorial 4.2 (a 30 m × 30 m model with a 5 m perimeter depth). Find the energy consumption and solar gain for all perimeter zones.

You need to simulate the model with the following options:

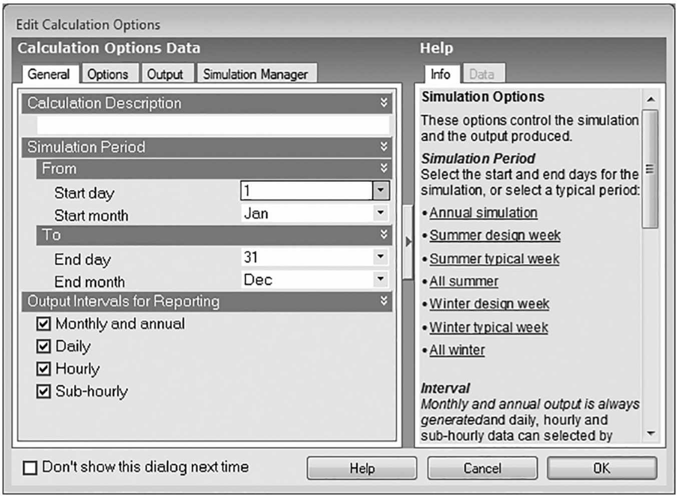
1. Overhang with a 0.5 m depth
2. Internal operable shades with solar control

Use the **New Delhi/Palam, India** weather location.

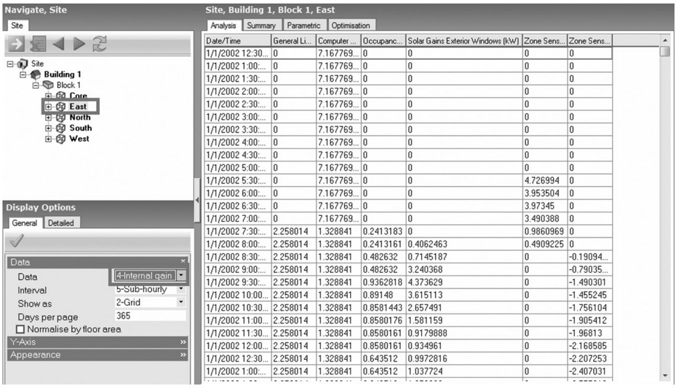
SOLUTION

Step 1: Open the model created in Tutorial 4.2 with a **0.5 m** overhang. Select the **Openings** tab and change window height to 1.00 m. Select the **Simulation** tab. The **Edit Calculation Options** screen appears.

Step 2: Simulate the model and select the **Sub-hourly** check box. Click **OK**. The results are displayed.

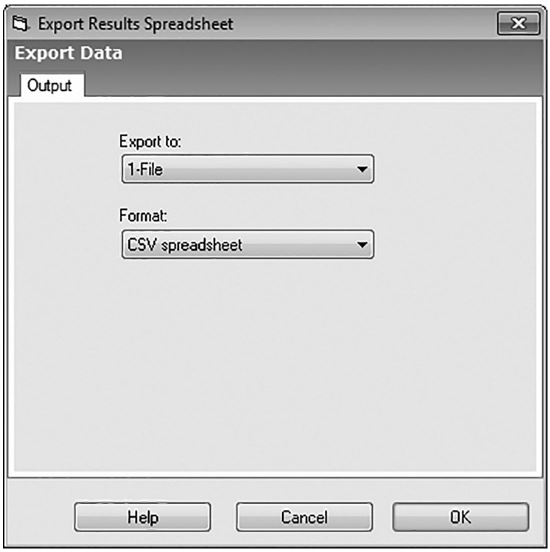


Step 3: Select **Internal gains** from the **Data** drop-down list. Click **East** in the navigation tree. It shows internal gains for the east zone.

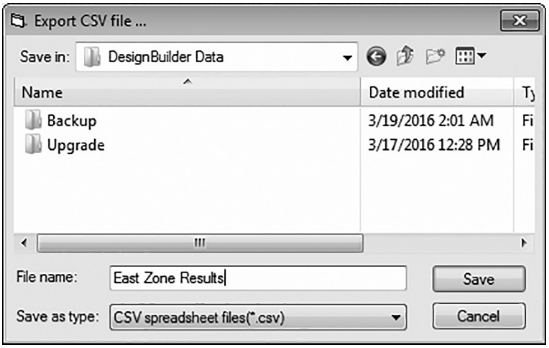


Step 4: Click the **Export data** button. The **Export Results Spreadsheet** screen appears.

Step 5: Select **File** from the **Export to** the drop-down list and **CSV spreadsheet** from the **Format** drop-down list. Click **OK**.



Step 6: Name the file as **East Zone Results** and save this for the comparison of results.

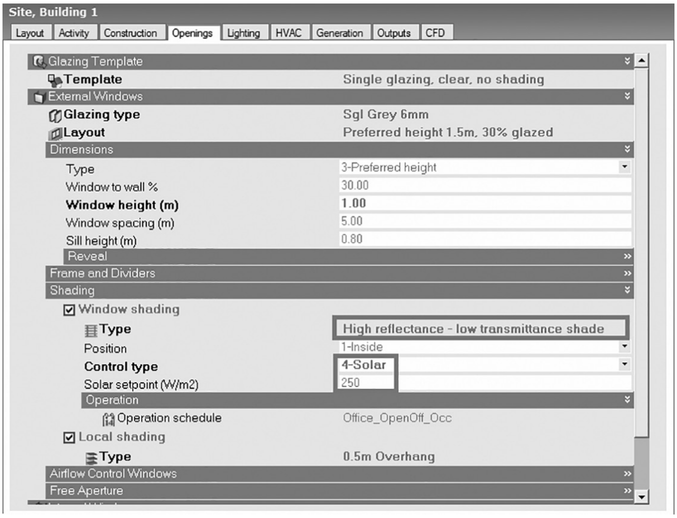


Similarly, repeat the previous step and save the results files for all the perimeter zones.

The next steps show how to model internal shades.

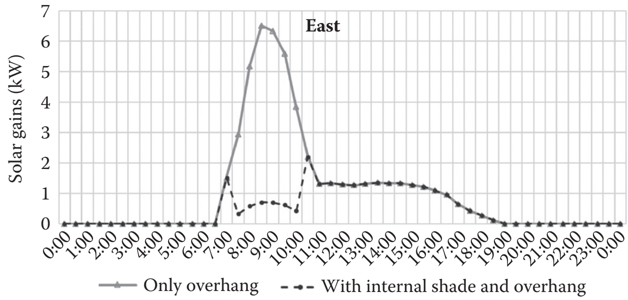
Step 7: Select the **Openings** tab. Select the **Window shading** check box under the **Shading** section. It displays shading type.

Step 8: Select **High reflectance – low transmittance shade** from the **Type**. Select **4-Solar** from the **Control type** drop-down list. Set **250** as **solar setpoint (W/m^2)**.



Step 9: Simulate the model and record the results for all four zones.

Compare the results for two cases in each orientation: only overhang and overhang with internal shade for solar gains (kW) for 4 April.

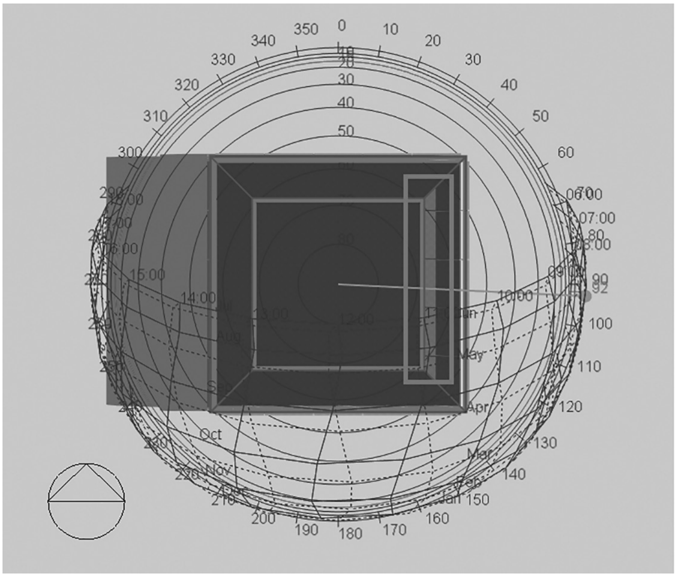


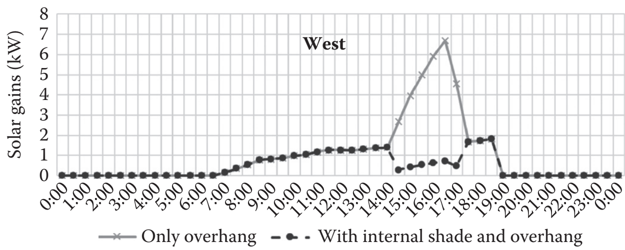
Solar control type operates the indoor shading devices based on the amount of radiation given in W/m^2. In this example, the solar setpoint considered is 250 W/m^2; hence, whenever the solar radiation on the window is above this setpoint, the window shading will be down to reduce the incoming heat through radiation.

Indoor operable shades have other control types such as schedules and illuminance levels.

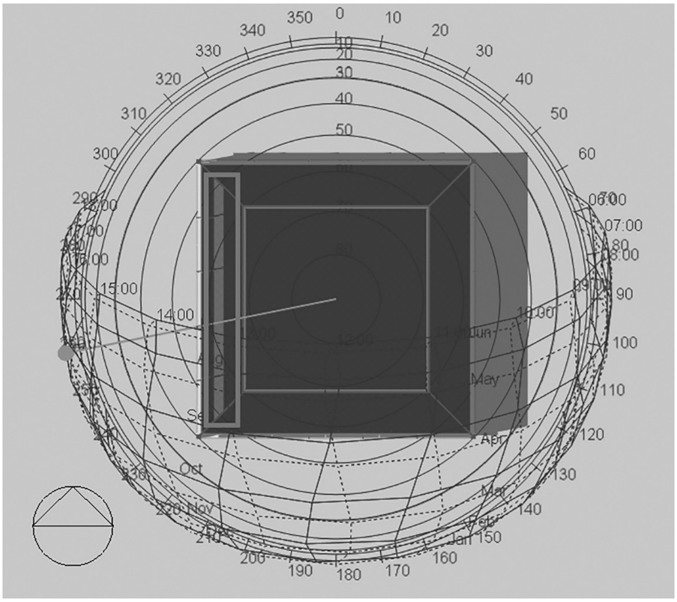
The previous graph shows the profile of solar gains through the window on the east façade with overhang and overhang + internal shades for a day (4 April); you can observe the reduction in solar gains due to internal shades between 7 AM and 10 AM.

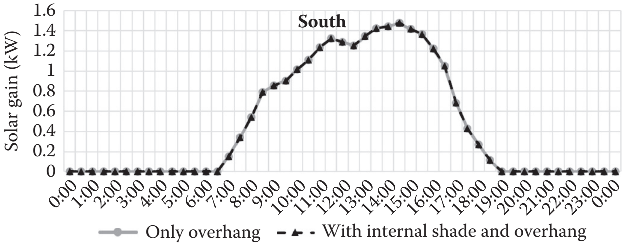
The following sunpath diagram shows direct radiation coming from the east window at 7 AM. Use of the internal shade can cut the direct solar radiation.



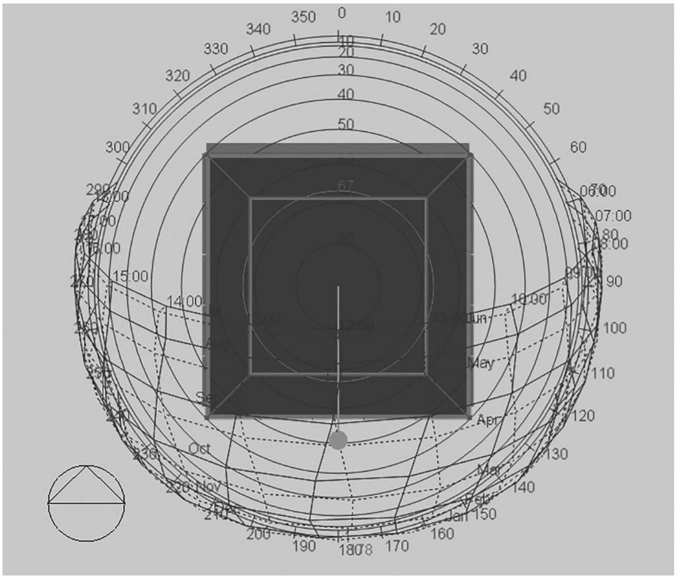


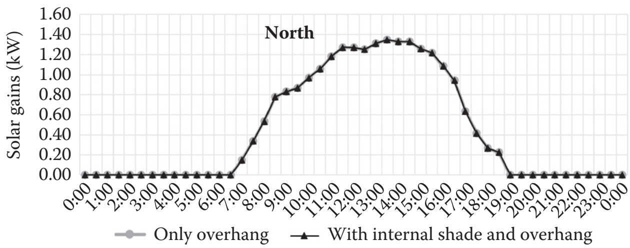
You can observe from the graph plotted above that the internal shade is effective on the west window from 14:00 to 19:00 on 4 April. This can also be seen from the following sunpath diagram that when there are no internal shades, west facing windows get direct solar radiation at 16:00 h.





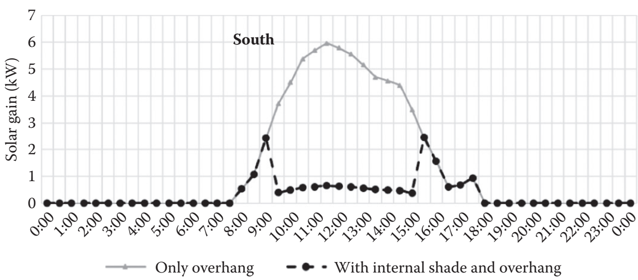
You can observe from the graph above that internal shades are not required on the south window on 4 April for this building. This can also be seen from the following sunpath diagram that the south zone is not getting any direct glare with an overhang of 0.5 m. This is due to the fact that the altitude of the sun in daytime, except for sunrise and sunset hours, is high enough on 4 April to not cause glare through windows.



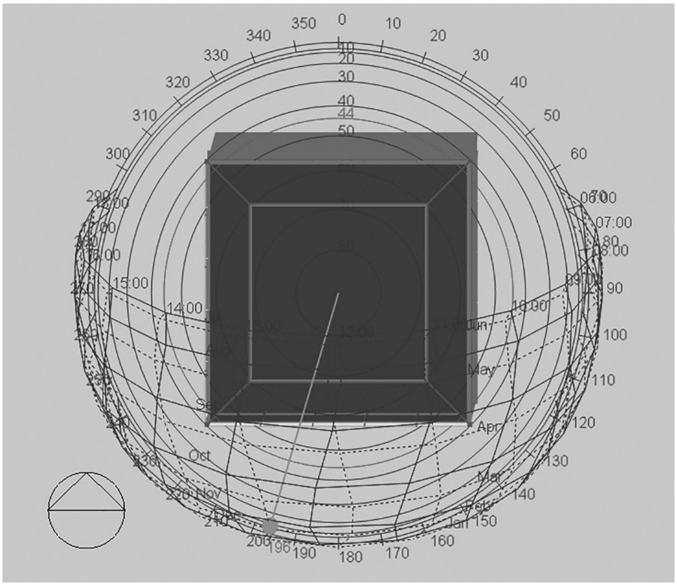


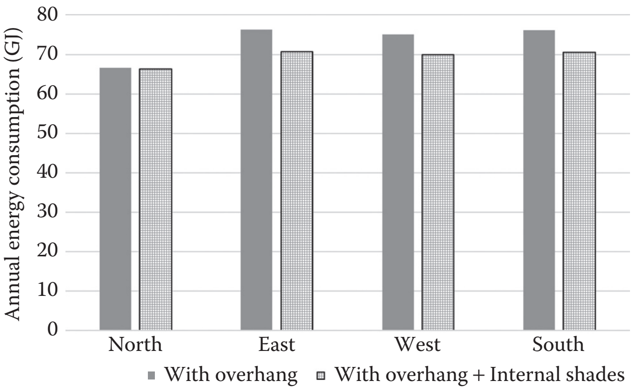
You can observe from the graph above that the internal shade is not required on the north façade on 4 April. This can also be seen from the sunpath diagram that the window in the north direction is shaded on 4 April.

Now plot the solar gains from the south window façade on 6 February when the sun is at a lower altitude.



You can observe that with the internal shades there is a reduction in solar gains from the south window between 12:00 and 16:00 h.

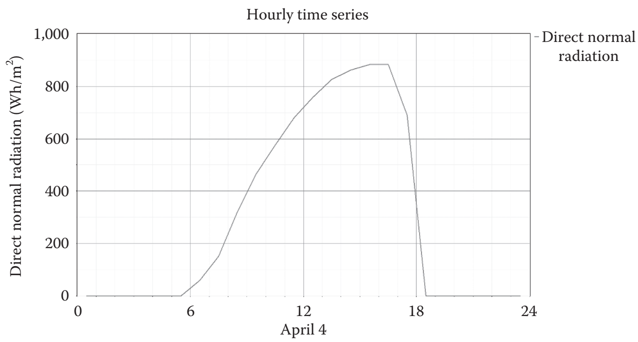


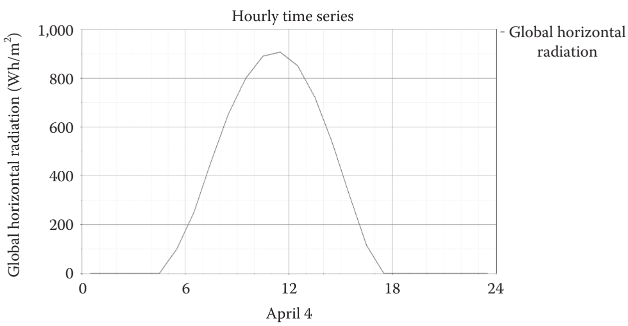


Annual energy consumption with and without overhang in all directions

It is observed from the graph above that internal shades are more effective for the east, west and south zones for the New Delhi climate.

The following two graphs give the direct normal radiation and global horizontal radiation on 4th April. You can see that the solar radiation curve is smooth, implying that the sky is clear.





Exercise 4.3

Repeat the above tutorial for operable shade controlled **Outdoor air temp + Solar on window**. You can consider the outdoor temperature setpoint as 35°C for the **New Delhi/Palam, India** weather location.

Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

CHAPTER FIVE

Lighting and Controls

As daylight varies throughout the day, it cannot provide targeted illuminance levels the whole day. Sensors can be used to measure the deficit in the illuminance levels and can control the artificial lighting to provide the balance lumens. The operating level of artificial lights in daylit areas can be varied to achieve energy savings. Energy simulation tools are capable of handling this phenomenon. This is explained through two tutorials in this chapter.

TUTORIAL 5.1 Evaluating the impact of daylighting-based controls

GOAL

To evaluate the effect of daylighting-based controls on the energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Modelling daylight controls

PROBLEM STATEMENT

In this tutorial, you are going to use a 50 m × 25 m model with a 5 m perimeter depth.

You are going to evaluate the following lighting controls:

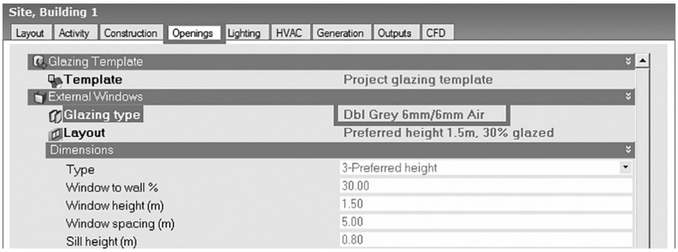
a. No lighting control
b. Linear/off

Use the **WIEN/HOHE WARTE, Austria** weather location.

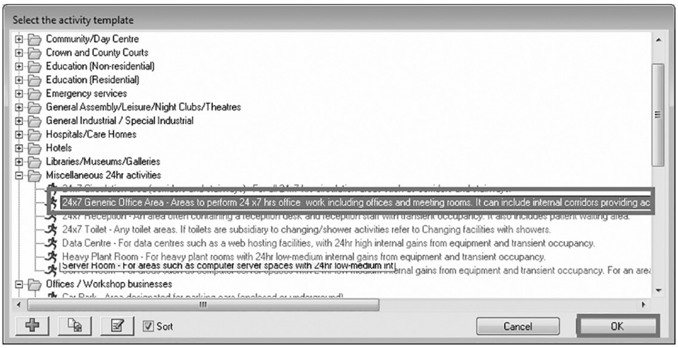
SOLUTION

Step 1: Open a new project and create a **50 m × 25 m** building with a **5 m** perimeter depth.

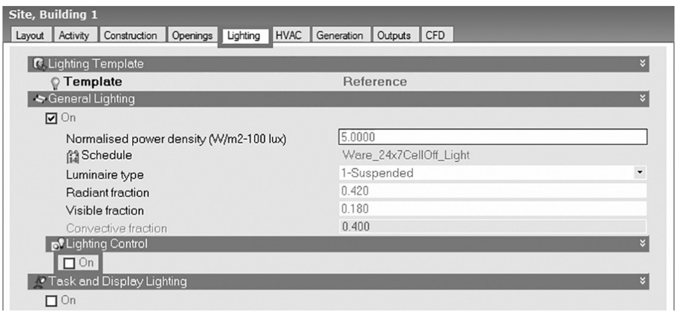
Step 2: Select the **Openings** tab and select **Dbl Grey 6mm/6mm Air** as the **Glazing type** from the drop-down list.



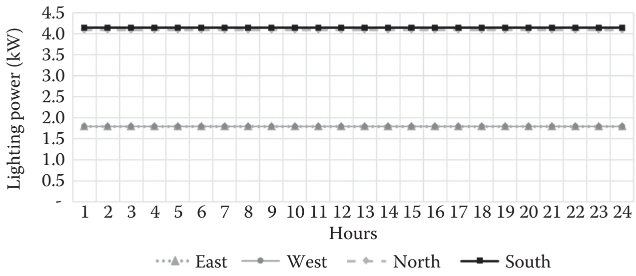
Step 3: Select the **Activity** tab. Select the **24×7 Generic Office Area** template from the **Miscellaneous 24hr activities** folder.



Step 4: Select the **Lighting** tab. Make sure to clear the **On** check box under **Lighting Control**.



Step 5: Perform hourly simulation and record the results. For getting the results of each zone, go to the Navigation Tree on the left, select the zone and select **Internal gains** from the Data drop-down list and **Hourly** from the **Interval** drop-down list.

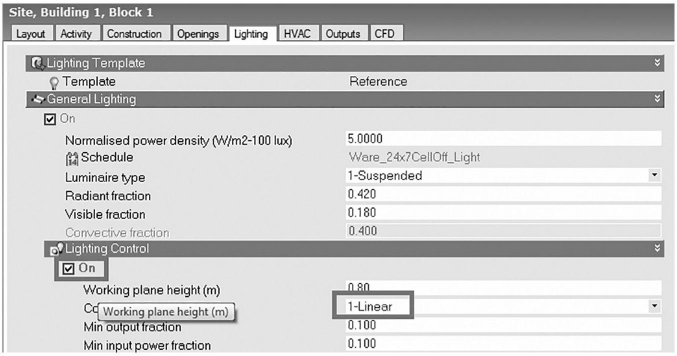


Step 6: Save the model using the **'Save as'** option.

In the next steps, you are going to install daylight controls.

Step 7: Select the **Lighting** tab.

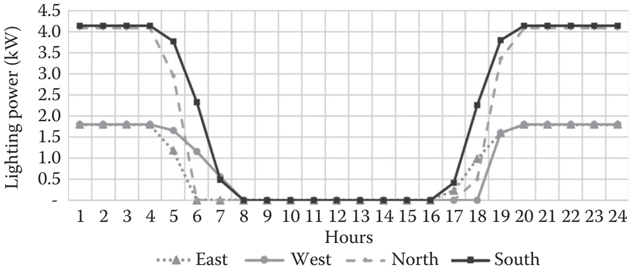
Step 8: Select the **On** check box under the **Lighting Control** section. Select **Linear** from the **Control type** drop-down list.



Based on the control type, lighting controls dim or turn off the internal lighting when the assigned illuminance level is met. This reduces the lighting energy consumption as well as the internal heat gain due to the artificial lighting. This reduction in heat gain decreases the cooling load and hence the cooling energy consumption.

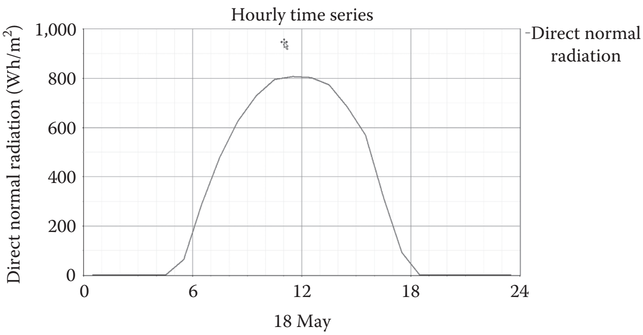
Step 9: Select the **Hourly Simulation** tab and record the results. For getting the results of each zone, go to the Navigation Tree on the left, select the zone and select **Internal gains** from the Data drop-down list and **Hourly** from the **Interval** drop-down list.

Step 10: Compare the hourly comparison of the lighting energy consumption for all options for 18 May. You can use a spreadsheet program to plot the comparative graphs.



From the above graph, it is clear that with the installation of controls, the lighting power consumption has reduced with the the lighting being automatically switched off between 06:00 and 18:00 h in different zones based on the daylight availability.

You can also get the solar radiation profile for 18 May by selecting **Site Data** from the **Data** drop-down list. Export the Direct Normal Solar and plot using a spreadsheet program.



The date of 18 May is selected for the simulation. The solar radiation curve is smooth with no perturbations due to clouds. Hence, it has been selected for the tutorial.

Exercise 5.1

Repeat the above tutorial and compare the energy consumption for stepped lighting controls.

TUTORIAL 5.2 Evaluating the impact of daylight sensor placement

GOAL

To evaluate the impact of daylight sensor positioning on the energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Defining daylight sensors positioning

PROBLEM STATEMENT

In this tutorial, you are going to use a 10 m × 10 m single-zone model with one window only on the south façade. Window area is 40% of gross south facade area. Find out the change in internal lighting gains in the zone with the use of a daylight sensor with linear/off.

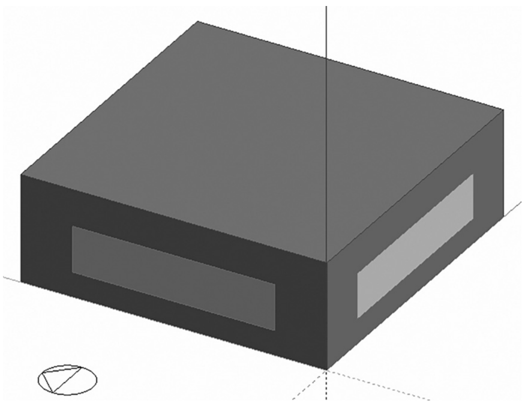
Place daylight sensor(s) at the following locations:

1. 2 m from the window
2. 8 m from the window
3. At 2 and 8 m from the window

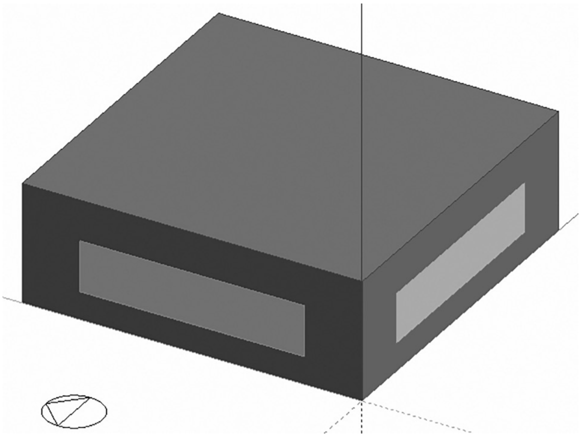
Use the **New Delhi/Palam, India** weather location.

SOLUTION

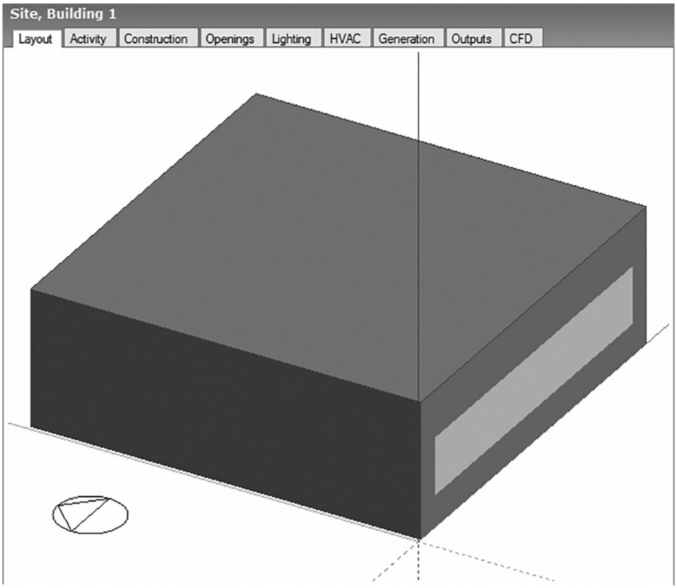
Step 1: Open a new project and create a **10 m × 10 m** single-zone model. Press the **ESC** button to get out from the **Edit mode**.



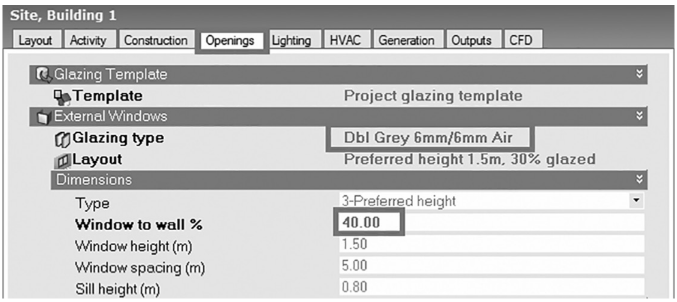
Step 2: Click on the west window; it highlights the window.



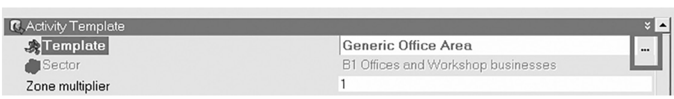
Step 3: Click **Delete selected object(s) (Del)**. Then click **Yes** on the message box. The window disappears. Similarly, you can delete windows on the north and east façade with the help of **Dynamic orbit**.

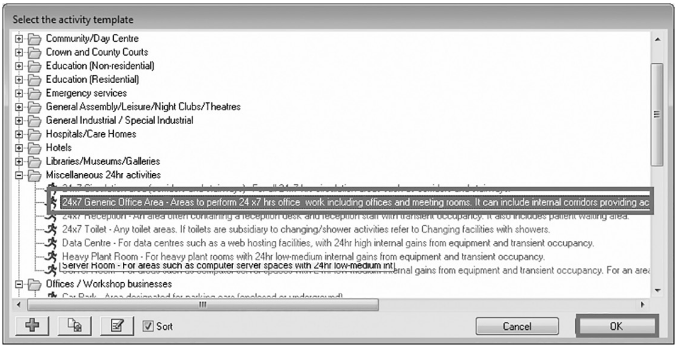


Step 4: Select the **Openings** tab and select **Dbl Grey 6mm/6mm Air** from the glazing type. Set **Window to wall %** as **40.00**.

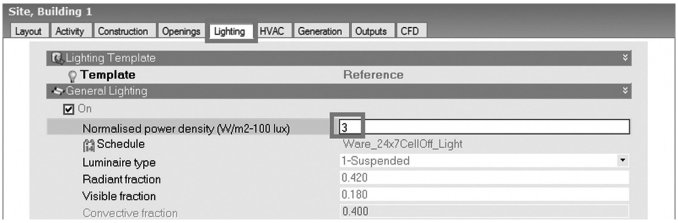


Step 5: Select the **Activity** tab. Select the **24×7 Generic Office Area** template from the **Miscellaneous 24hr activities** branch.

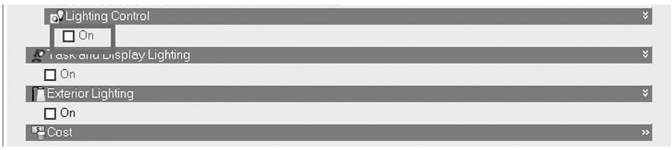




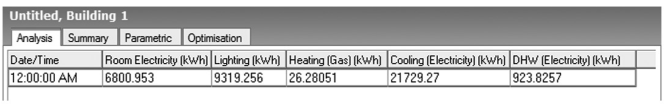
Step 6: Select the **Lighting** tab. Set the **Normalised power density (W/m²-100 lux)** to **3**.



Step 7: Make sure to clear the **ON** check box under the **Lighting Control** section.



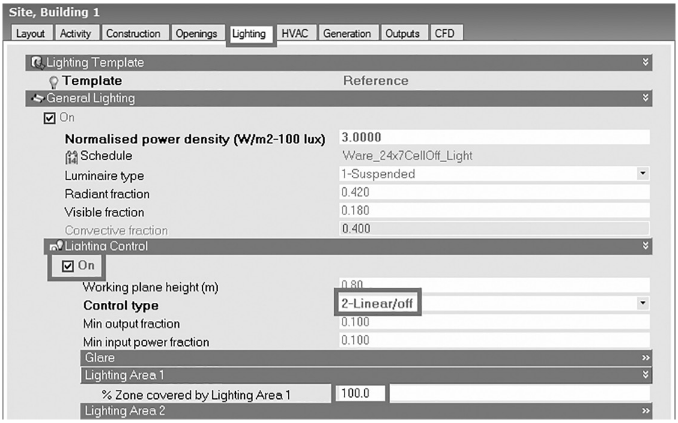
Step 8: Perform hourly simulation and record the results.



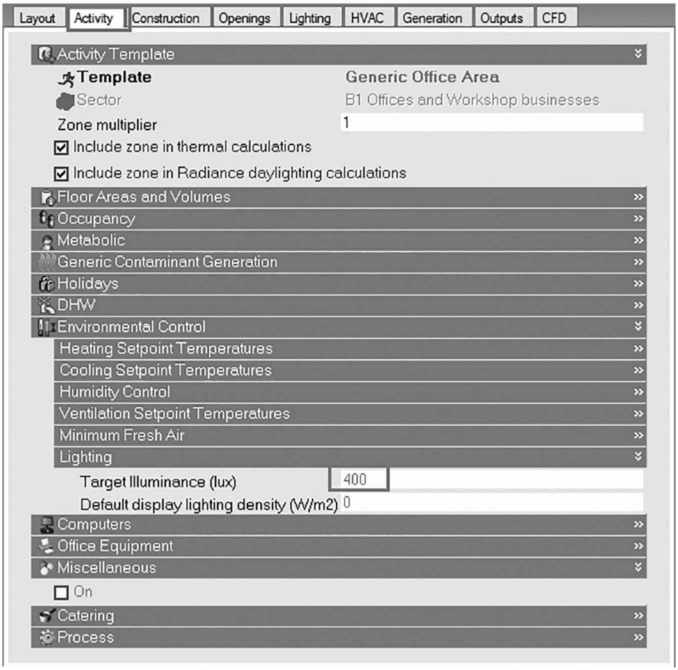
Now you are going to enable the daylight control in the model.

Step 9: Select the **Lighting** tab.

Step 10: Select the **ON** check box under the **Lighting Control** section and select **Linear/off** in the **Control type**. Set **100** for **% Zone covered by Lighting Area 1**. Select the **Layout** tab.

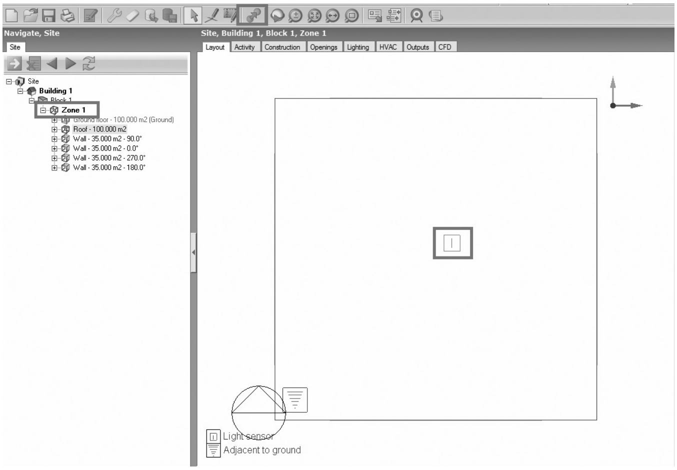


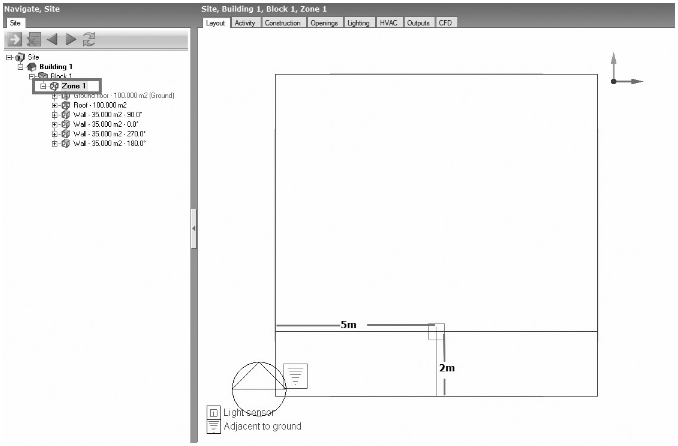
Step 11: Select the **Activity** tab and make sure that the target illuminance (lux) is **400**.



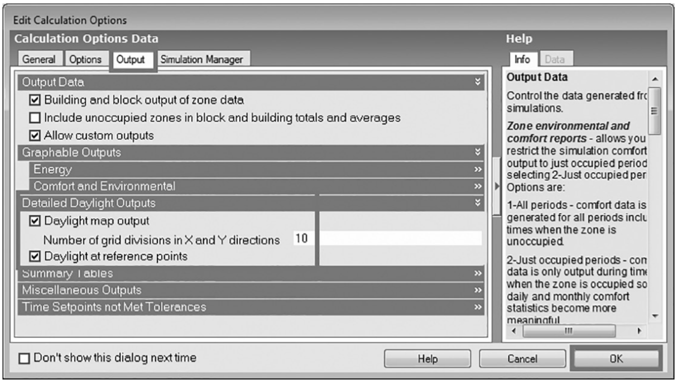
Step 12: Select **Zone 1** from the Navigation Tree. The daylight sensor can be seen in the layout.

Step 13: Select the **Sensor** and click the **Move selected object** icon. Click the daylight sensor and place it 2 m away from the window with the help of construction lines.

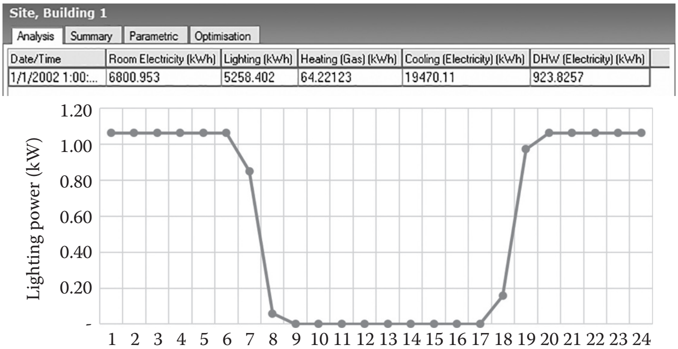




Step 14: Select the **Simulation** tab. The **Edit Calculation Options** screen appears. Select the **Output** tab and click the **Detailed Daylight Outputs** section. Select the **Daylight map output** check box. Click **OK**. Perform hourly simulation.

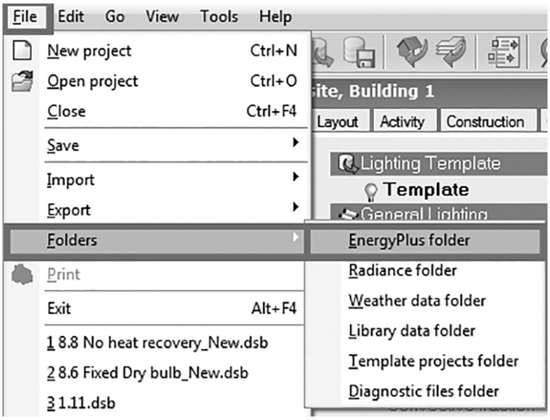


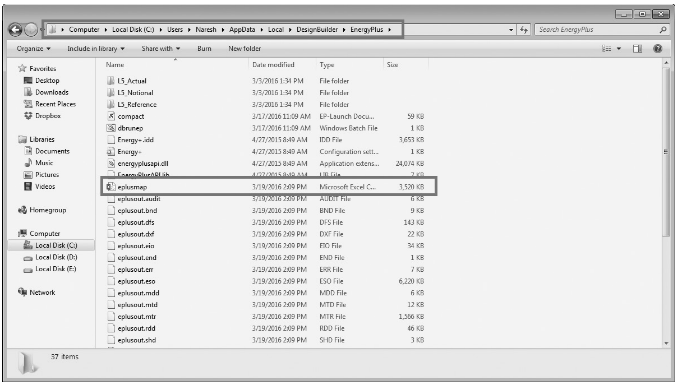
Step 15: Record the results. Plot hourly lighting data for 4 April.



In the above graph, you can observe that the lighting consumption is zero between 09:00 and 17:00 h. To get the lux level at this time, you need to get the illuminance map.

Step 16: Open the **eplusmap** file that exists in the **EnergyPlus** folder.





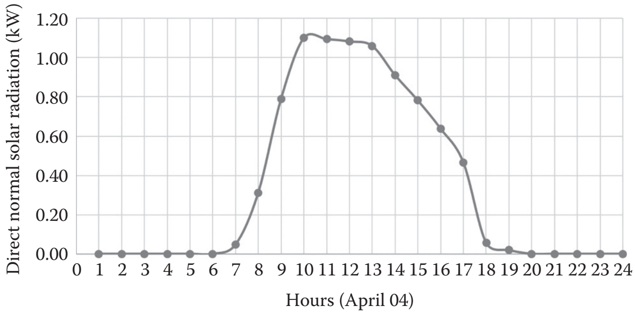
Step 17: Get the data for 11:00 h.

Table 5.1 gives the Illuminance map when the sensor is placed near the window. In the map, each cell reports the illuminance (in lux) at the location specified by the (X;Y) coordinates in the column and row headers. These are XY pairs separated by a semi-colon for ease in importing into the spreadsheet. In **eplusmap** file, the Z coordinate of the map is shown in the title (the illuminance map is set in a plane) and the date and time are indicated in the upper left cell of the map. You can observe that at 09:00 h all artificial lights are off because of sufficient illuminance near the sensor. This leads to low illuminance in the interiors of the space.

Table 5.1 Illuminance map for 4 April

4/4/2016 9:00	(0.32; 0.20)=	(1.38; 0.20)=	(2.45; 0.20)=	(3.52; 0.20)=	(4.58; 0.20)=	(5.65; 0.20)=	(6.72; 0.20)=	(7.78; 0.20)=	(8.85; 0.20)=	(9.92; 0.20)=
(0.32;0.20)=	5073	5940	5948	5948	5949	5951	5952	5951	1069	140
(0.32;1.27)=	462	652	715	730	732	726	704	628	435	226
(0.32;2.33)=	304	367	402	415	417	407	382	333	261	194
(0.32;3.40)=	228	254	272	280	279	271	255	229	198	170
(0.32;4.47)=	187	200	208	212	211	206	196	183	168	153
(0.32;5.53)=	164	171	175	177	176	173	167	160	151	143
(0.32;6.60)=	152	156	158	159	159	156	153	148	143	138
(0.32;7.67)=	142	145	146	146	146	144	142	139	136	133
(0.32;8.73)=	136	138	138	138	138	137	136	134	132	130
(0.32;9.80)=	132	133	133	133	133	132	131	130	129	127

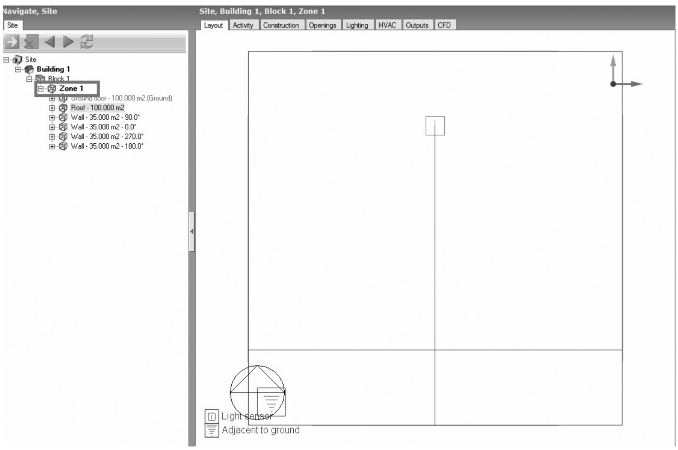
You can also get the solar radiation profile on 4 April by selecting **Site Data** from the **Data** drop-down list. Export the Direct Normal Solar and plot using a spreadsheet program.



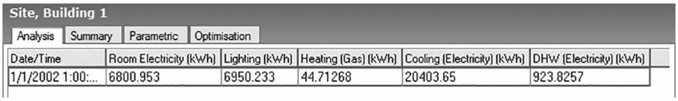
Step 18: Save the model using the **Save as** option.

Now, you are going to change the location of the daylight sensor at 8 m distance from the south window.

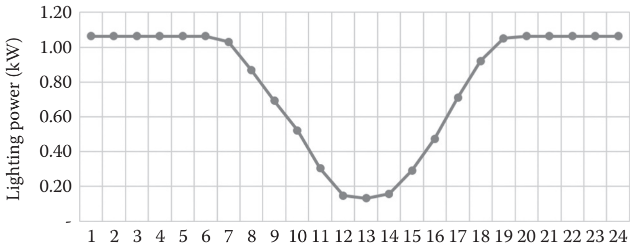
Step 19: Move the daylight sensor 8 m away from the window towards the north (as explained earlier).



Step 20: Perform hourly simulation. Record the annual results. Also record hourly lighting data for 4 April.



Date/Time	Room Electricity (kWh)	Lighting (kWh)	Heating (Gas) (kWh)	Cooling (Electricity) (kWh)	DHW (Electricity) (kWh)
1/1/2002 1:00:...	6800.953	6950.233	44.71268	20403.65	923.8257



Hourly lighting load for 4 April (the daylight sensor at 8 m away from the window).

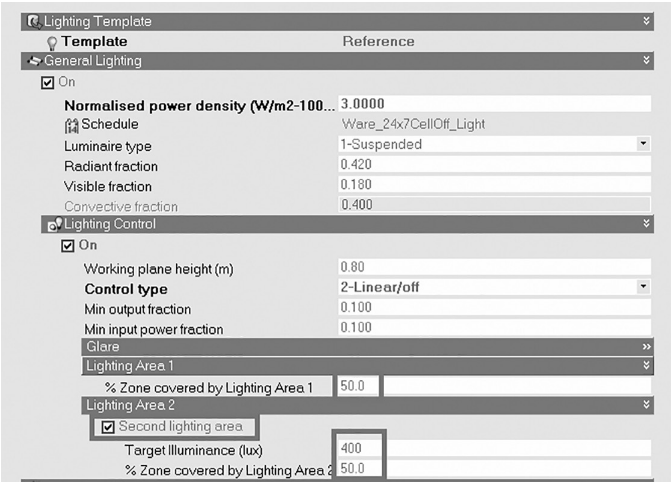
In the above graph, you can observe that lighting energy consumption between 08:00 and 17:30 h is higher compared to when the sensor is placed near the window. When the sensor is moved away from the window it gets into darker portion of the room and is triggered when more daylight enters the room. This increase in daylight might take some time thereby delaying the time when the lights are switched off. This increases the lighting energy consumption but ensures that sufficient light is available even in the interior areas of the room when the lights are switched off. However, this might lead to higher illuminance levels near the window, leading to visual discomfort.

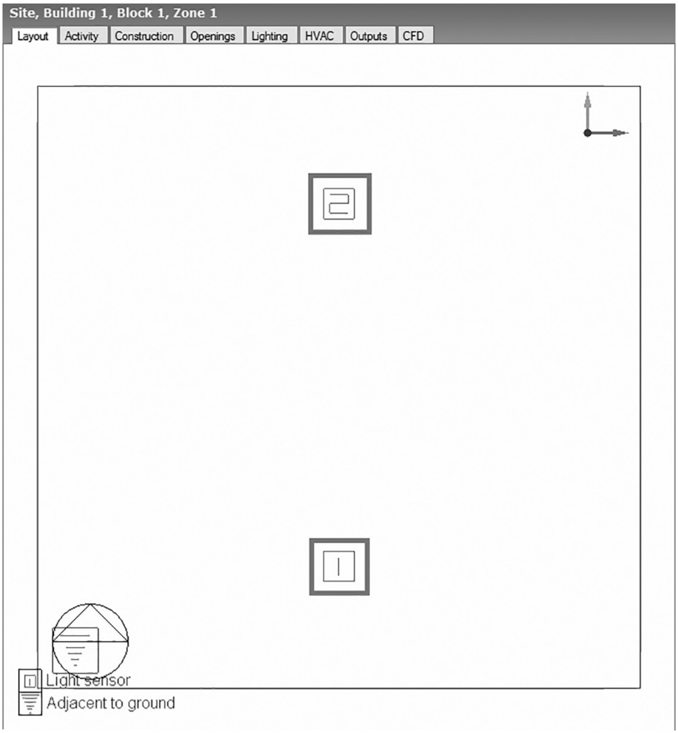
So there is a need to place two sensors at different positions to get energy savings and visual comfort.

Step 21: Save the model using the **Save as** option.

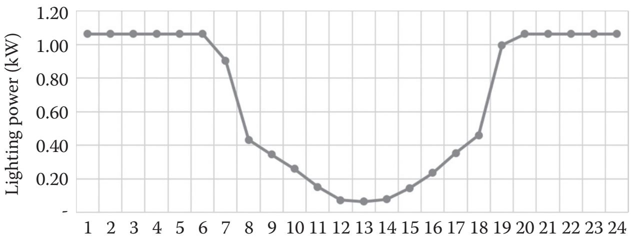
Now, you are going to install one more daylight sensor.

Step 22: Select the **Lighting** tab and select the **Second lighting area** check box. Enter **50.0** as the **% Zone covered by Lighting Area 1** and **% Zone covered by Lighting Area 2**. Make sure the **Target Illuminance (lux)** is **400**.





Step 23: Perform hourly energy simulation and record the results.



In the above graph, we can observe the lighting consumption between 08:00 and 17:30 h. The energy consumption is less compared to the case when the sensor is placed far from the window, as artificial lights are switched off near the window when there is sufficient daylight.

Get the data for 11:00 h for illuminance levels (Table 5.2).

Now compare the annual energy consumption for all three cases (Table 5.3).

Table 5.2 Illuminance map for 4 April

04/04 09:00	(0.32; 0.20)=	(1.38; 0.20)=	(2.45; 0.20)=	(3.52; 0.20)=	(4.58; 0.20)=	(5.65; 0.20)=	(6.72; 0.20)=	(7.78; 0.20)=	(8.85; 0.20)=	(9.92; 0.20)=
(0.32;0.20)=	5073	5940	5948	5948	5949	5951	5952	5951	1069	140
(0.32;1.27)=	462	652	715	730	732	726	704	628	435	226
(0.32;2.33)=	304	367	402	415	417	407	382	333	261	194
(0.32;3.40)=	228	254	272	280	279	271	255	229	198	170
(0.32;4.47)=	187	200	208	212	211	206	196	183	168	153
(0.32;5.53)=	164	171	175	177	176	173	167	160	151	143
(0.32;6.60)=	152	156	158	159	159	156	153	148	143	138
(0.32;7.67)=	142	145	146	146	146	144	142	139	136	133
(0.32;8.73)=	136	138	138	138	138	137	136	134	132	130
(0.32;9.80)=	132	133	133	133	133	132	131	130	129	127

Table 5.3 Annual lighting energy consumption with different sensor placements

Sensor placement	Annual lighting energy consumption (kWh)
No sensor	9,319.25
Near to the window	5,258.40
Far from the window	6,950.23
With two sensors	6,056.55

It can be observed that the placement of the sensor affects the energy consumption. It is due to the fact that while using a single sensor, the controller assumes the same illuminance level in the entire zone as is found on the sensor. With this approach, when the sensor is placed close to the window, the model calculates the requirement of artificial light against a higher daylight level, as compared to the case of a lower daylight level when the sensor is placed far away. With two sensors, the space is divided into two zones independently controlled hence the energy consumption is between the two cases as discussed above. In practice, however, even while using a single sensor, different fixtures can be calibrated to adjust against different daylight levels at various depths.

CHAPTER SIX

Heating and Cooling Design

This chapter explains how to size and model the heating, ventilation and air conditioning (HVAC) systems. Out of the three tutorials, one explains the effect of HVAC operating criteria on energy consumption. Often, thermostats of HVAC are operated by sensing the air temperature, and the same criterion is also used for the evaluation of thermal comfort hours through simulation. This tutorial shows the difference in alternative approaches using the case of 'operative temperature', that is, a combination of air temperature and mean radiant temperature. The second tutorial explains the method of sizing HVAC systems, and the third one covers the effect of using different calculation algorithms for performing HVAC calculations in the simulation.

TUTORIAL 6.1 Evaluating the impact of temperature control types

GOAL

To evaluate the impact of temperature control types – air temperature and operative temperature on HVAC equipment sizing and energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Changing temperature setpoint control types and evaluating its impact

PROBLEM STATEMENT

In this tutorial, you are going to use a 50 m × 25 m model with a 5 m perimeter depth with the following specifications:

- Number of floors: G+1
- Window-to-wall ratio: 40%
- Glass type: Dbl Blue 6mm/13mm Air (U-value-2.70° W/m^2 K, SHGC-0.48, VLT-0.50)
- Roof construction: Roof, Ins Entirely above Deck, R-50(8.8), U-0.020(0.114)
- Activity template: 24×7 Generic Office Area

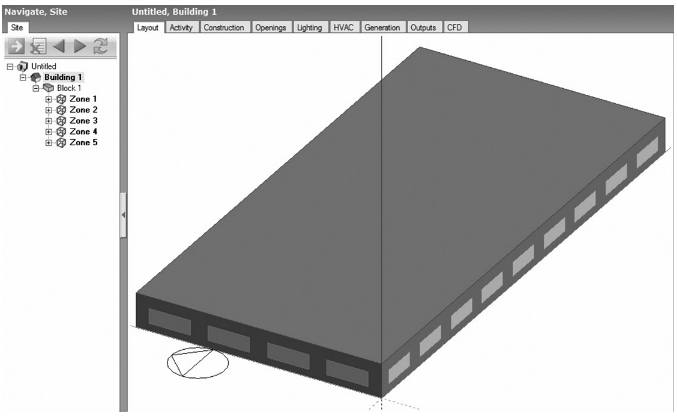
Find the cooling equipment sizing and energy consumption for the ground floor with the following two temperature controls:

1. Air temperature (AT)
2. Operative temperature (OT)

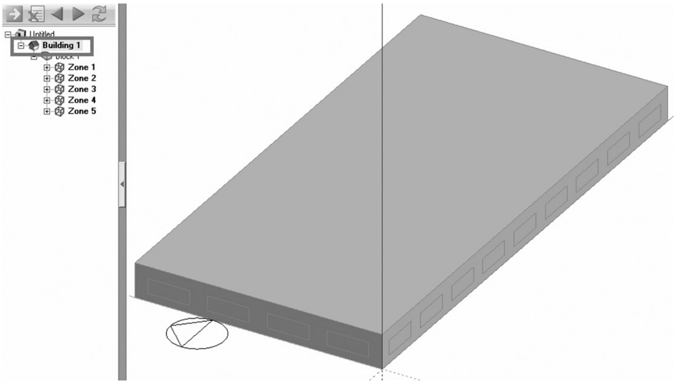
Use the **New Delhi/Palam, India** weather location.

SOLUTION

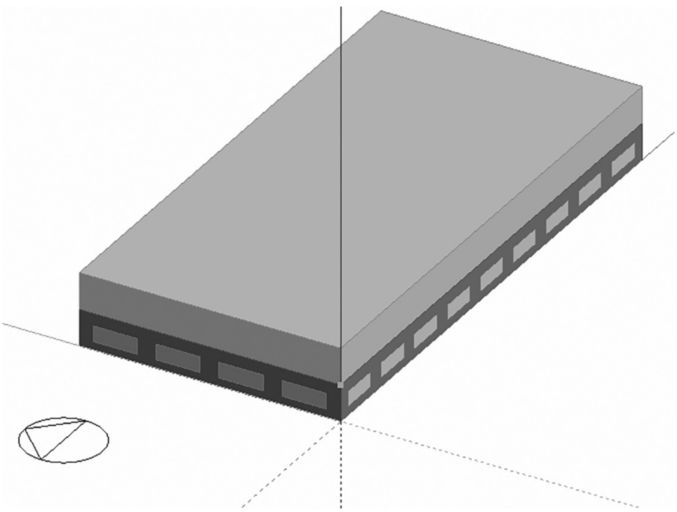
Step 1: Open a new project and create a **50 m × 25 m** building with a **5 m** perimeter depth and select the template as **24×7 Generic Office Area**.

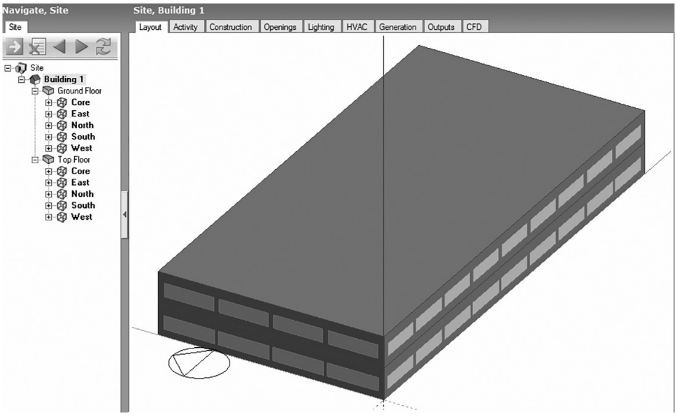


Step 2: Go to the **Building level** and select the **Building** on the edit screen.

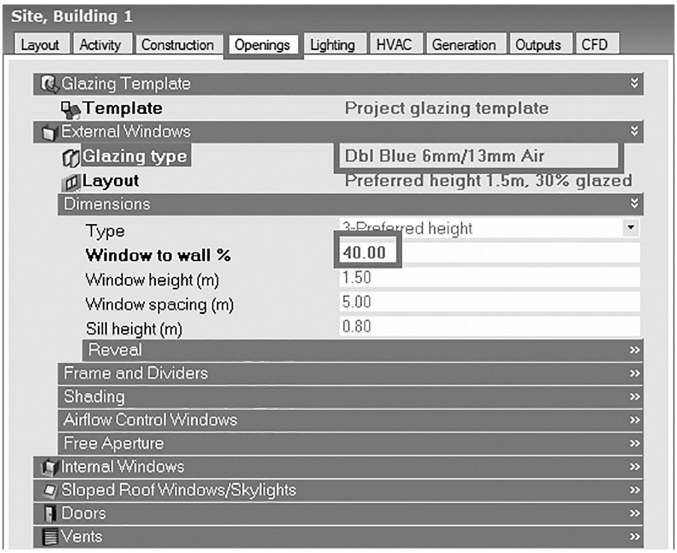


Step 3: Click **Clone selected object(s)**. Click the origin of the floor, move the cursor to the top of the floor to paste the cloned floor.

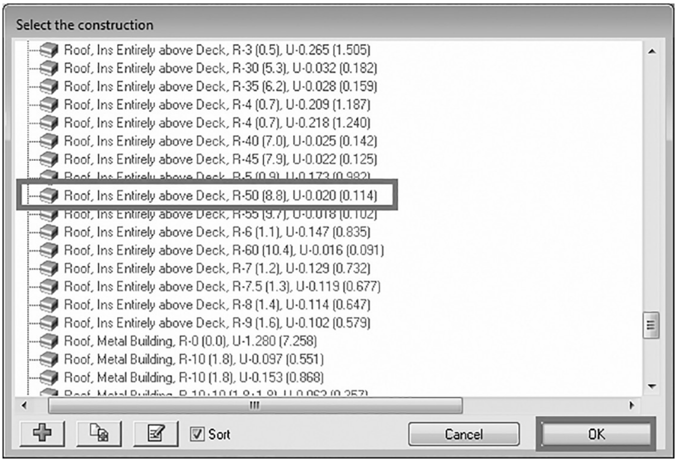




Step 4: Select the **Openings** tab. Select **Dbl Blue 6mm/13mm Air** as **Glazing type** and set the layout as **Preferred height 1.5m, 40% glazed**.

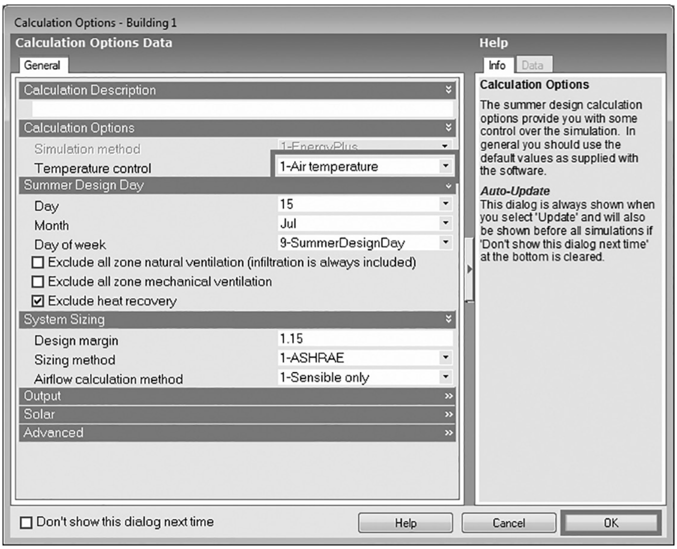


Step 5: Select the **Construction** tab and select **Roof, Ins Entirely above Deck, R-50 (8.8), U-0.020 (0.114)** as the **Flat roof** type.



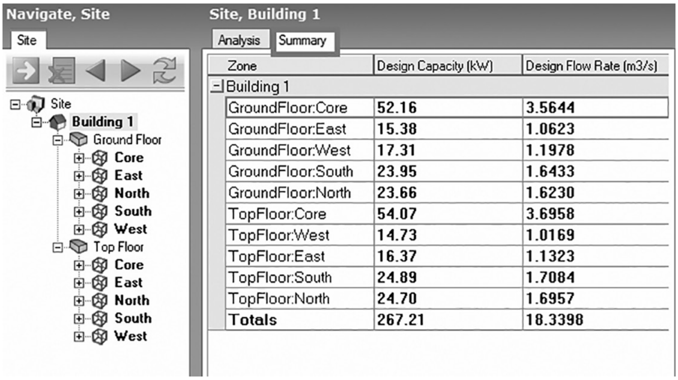
Step 6: Select the **Cooling design** tab. The **Calculation Options** screen appears.

Step 7: Select **Air temperature** from the **Temperature control** drop-down list. Click **OK**. The results are displayed in the Analysis tab.

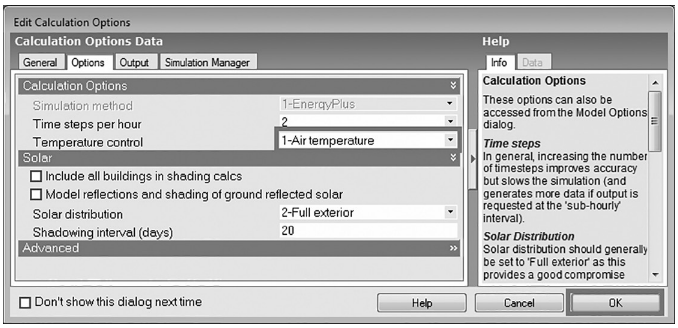


Day of week field is used to identify the appropriate daily profile within the schedules to use for the Cooling design calculations. The day type should be the day when the most extreme conditions and highest cooling loads are expected. You should normally keep the 9-SummerDesignDay default option, while running simulations.

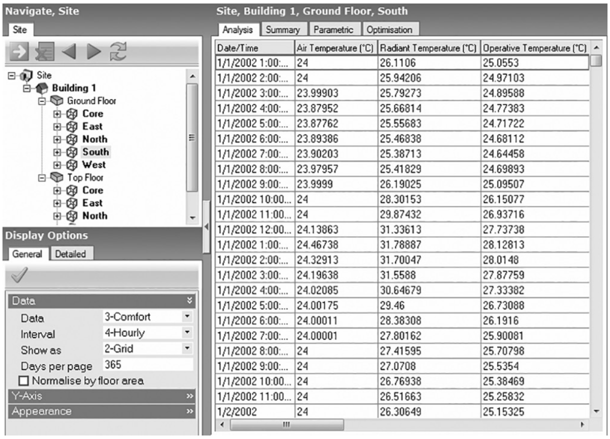
Step 8: Select the **Summary** tab. Record the results.



Step 9: Select the **Simulation** tab. In the **Edit Calculation Options** screen, select the **Options** tab. Ensure that the **Air temperature** is selected. Ensure that Hourly Simulation is selected in General tab. Click **OK**.



Step 10: Click **South** in the Ground Floor in the navigation tree. Record the air temperature and operative temperature for 4 April. (Data displayed on the screen is for the whole year; you can scroll to get the data for 27 March.)



Date/Time	Air Temperature (°C)	Radiant Temperature (°C)	Operative Temperature (°C)
1/1/2002 1:00:...	24	26.1106	25.0553
1/1/2002 2:00:...	24	25.94206	24.97103
1/1/2002 3:00:...	23.99903	25.79273	24.89588
1/1/2002 4:00:...	23.87952	25.66814	24.77383
1/1/2002 5:00:...	23.87762	25.55683	24.71722
1/1/2002 6:00:...	23.89386	25.46838	24.68112
1/1/2002 7:00:...	23.90203	25.38713	24.64458
1/1/2002 8:00:...	23.97957	25.41829	24.69893
1/1/2002 9:00:...	23.9999	26.19025	25.09507
1/1/2002 10:00...	24	28.30153	26.15077
1/1/2002 11:00...	24	29.87432	26.93716
1/1/2002 12:00...	24.13863	31.33613	27.73738
1/1/2002 1:00:...	24.46738	31.78887	28.12813
1/1/2002 2:00:...	24.32913	31.70047	28.0148
1/1/2002 3:00:...	24.19638	31.5588	27.87759
1/1/2002 4:00:...	24.02085	30.64679	27.33382
1/1/2002 5:00:...	24.00175	29.46	26.73088
1/1/2002 6:00:...	24.00011	28.38308	26.1916
1/1/2002 7:00:...	24.00001	27.80162	25.90081
1/1/2002 8:00:...	24	27.41595	25.70798
1/1/2002 9:00:...	24	27.0708	25.5354
1/1/2002 10:00...	24	26.76938	25.38469
1/1/2002 11:00...	24	26.51663	25.25832
1/2/2002	24	26.30649	25.15325

Step 11: Repeat the previous steps (the cooling design and simulation) by selecting the operative temperature control in place of the air temperature control.

Operative temperature is defined as follows:

A uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment. It is the combined effect of the mean radiant temperature and air temperature calculated as the average of the two. It is also known as dry resultant temperature or resultant temperature. It can be calculated as follows:

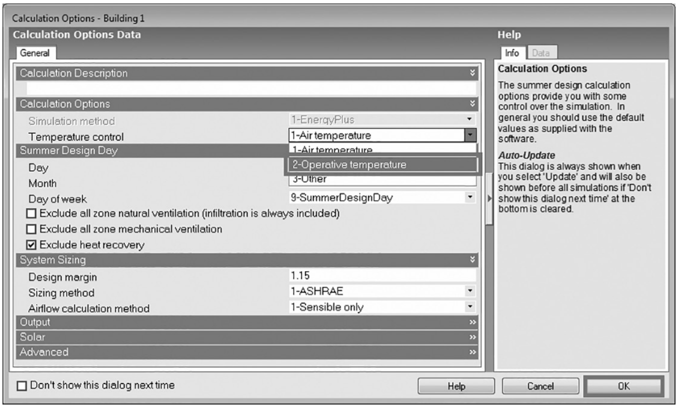
$$t_o = \frac{\left(\left(t_a \times \sqrt{10\vartheta}\right) + t_{\mathrm{mr}}\right)}{1 + \sqrt{10\vartheta}}$$

where:

ϑ = the air velocity
t_a = the air temperature
t_{mr} = the mean radiant temperature

The mean radiant temperature of an environment is defined as the uniform temperature of an imaginary black enclosure that would result in the same heat loss by radiation from the person as the actual enclosure.

Step 12: Select **Operative temperature** from the **Temperature control** drop-down list. Click **OK** and get the summary of analysis.



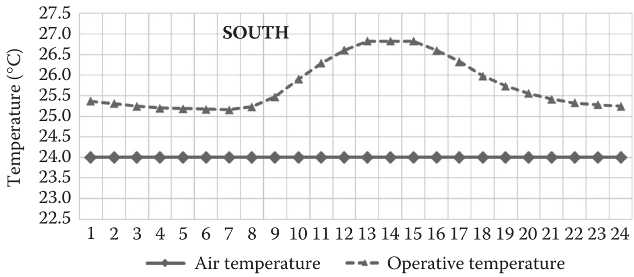
Step 13: Select the **Summary** tab. Record the results in a separate spreadsheet (hourly values for AT, OT on 27 March for all zones on the ground floor, cooling design data and annual energy consumption results).

Now compare the results for both the cases (Table 6.1).

Step 14: Plot AT and OT for the Ground Floor: South zone with the air temperature control for 27 March.

Table 6.1 Design capacity of cooling equipment

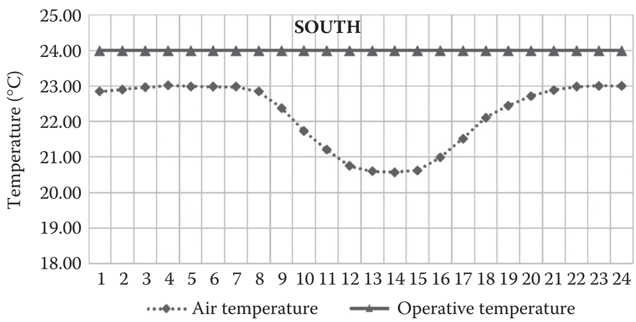
	Design capacity of cooling equipment (kW)	
Zone	Air temperature control	Operative temperature control
Ground: East	15.49	20.19
Ground: West	17.44	22.61
Ground: North	23.71	26.43
Ground: South	23.81	26.75
Ground: Core	51.98	53.76



You can observe that the zone air temperature is maintained at 24°C. However, the operative temperature of the zone is not constant over the day. In this case, the operative temperature of the zone is higher than the zone air temperature due to the higher temperature of the exposed walls and windows. It can also be noted that this difference is highest during afternoon because the exposed surfaces of the south zone absorb solar radiation resulting in a higher surface temperature.

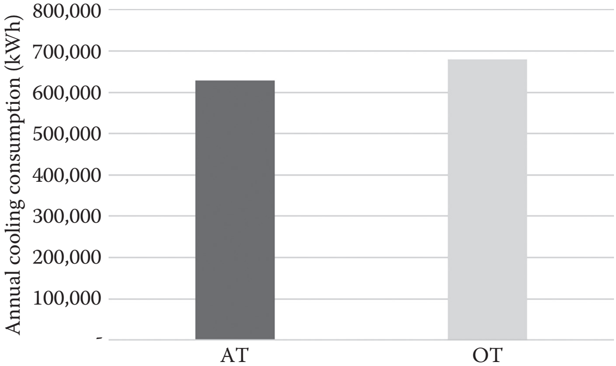
A higher operative temperature can cause discomfort despite the air temperature being maintained at 24°C. Hence, to get comfort in the zone, there is a need to set the thermostat based on the operative temperature.

Step 15: Now plot temperatures (AT and OT) for the Ground Floor: South zone with the operative temperature control.



It can be noted that for maintaining a constant operative temperature during the afternoon, the air temperature was reduced significantly to compensate for the higher surface temperature in the zones.

Step 16: Plot a chart for the annual cooling energy consumption for the air and operative temperature controls.



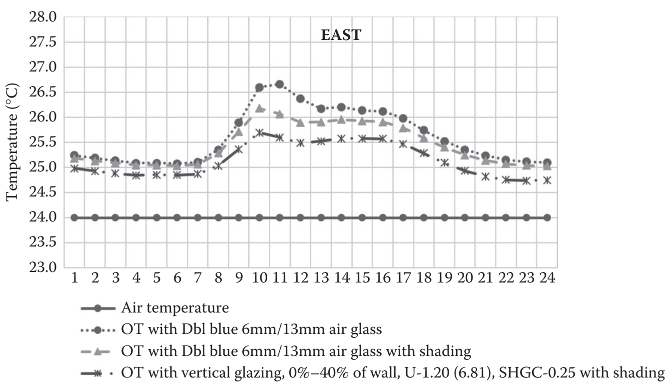
As discussed in the previous step, because the air temperature was reduced below 24°C to compensate for the higher surface temperature, the energy consumption in the operative temperature control mode is higher than that in the air temperature control mode.

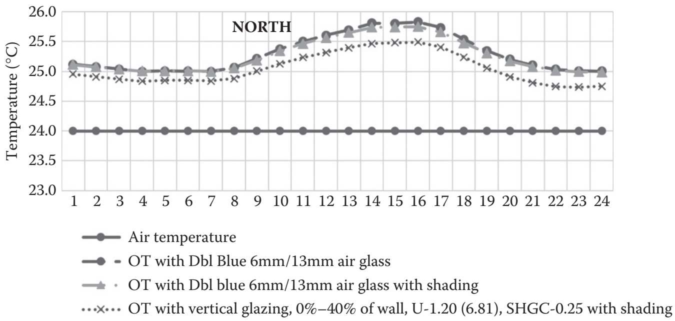
Now repeat the steps for the following two cases:

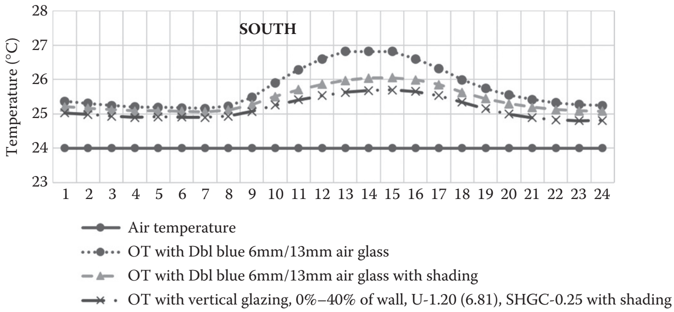
- Add a local shading 0.5 m overhang
- Use **Vertical glazing, 0%–40% of wall, U-1.20 (6.81), SHGC-0.25** glass with local shading as a 0.5 m overhang

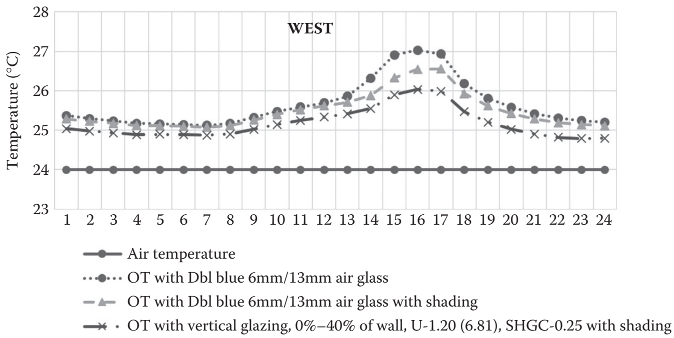
Simulate both the models for the air temperature based thermostat control. Record the results and plot the temperatures for all the zones on the ground floor. Also run annual simulations and observe the energy consumption.

Step 17: Plot the temperatures for all zones on the ground floor with the air temperature for 4 April.



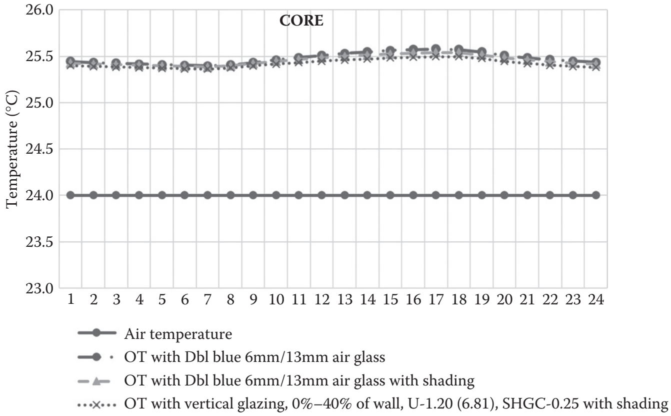






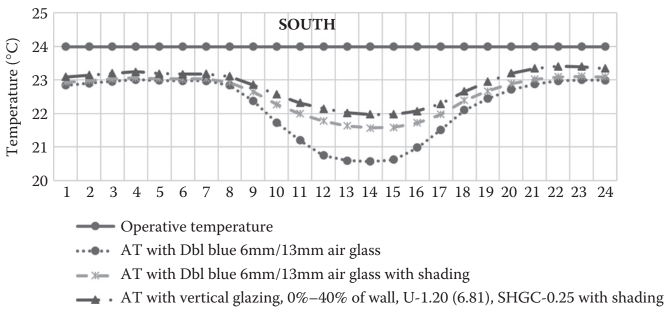
The results display that by putting shade above the opening reduces the operative temperature. Use of high performance glass also reduces the OT as the high performance glass surface tends to remain cooler then low performance glasses.

It can also be seen that the pattern of operative temperature is different for each zone. It is governed by the time of day when the zone receives solar radiation.

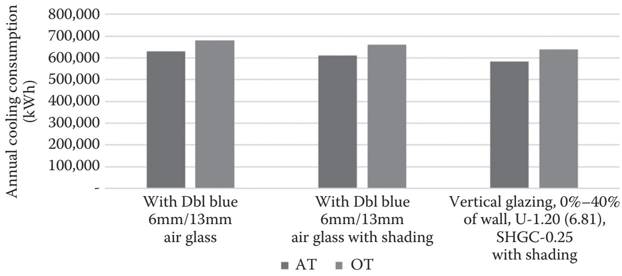


For the core zone it can be observed that the variation in OT is minimal since the walls are not receiving direct solar radiation and thus not getting heated up to the extent of the perimeter zones.

Step 18: Now, plot temperatures for the Ground Floor: South zone with the operative temperature control.



Step 19: Plot a chart for the annual cooling energy consumption for the air and operative temperature controls.



Analysis of results:

The thermostat control in conventional HVAC systems is activated as per the air temperature; however, human comfort is a function of operative temperature. Operative temperatures include the combined effect of air temperature and mean radiant temperature. During summer, perimeter spaces are uncomfortable due to higher operative temperatures. Therefore, there is an increase in the cooling equipment sizing of the system, because the operative temperature setpoint continues to condition the building until comfort conditions are met.

You can observe that the effect of the operative temperature setpoint is more noticeable in perimeter zones of the building compared to the core zone. This can be explained by the fact that the perimeter zones have more surfaces that are connected with the outdoor environment, whereas for the core zone, only the roof is connected to the outdoor environment.

Exercise 6.1

Repeat the above tutorial for 20% WWR (Table 6.2).

Table 6.2 Comparison of the design capacity of cooling equipment for air temperature and operative temperature controls

	Design capacity of cooling equipment (kW)	
Zone	Air temperature control	Operative temperature control
Ground: East		
Ground: West		
Ground: North		
Ground: South		
Ground: Core		

TUTORIAL 6.2 Evaluating the impact of design day selection

GOAL

To find the cooling equipment capacity using the design-day and annual energy simulation approaches.

WHAT ARE YOU GOING TO LEARN?

- Sizing using two methods: design day and annual energy simulation methods

PROBLEM STATEMENT

In this tutorial, you are going to use a **50 m × 25 m** model with a **5 m** perimeter depth.

Find the peak cooling load

a. With the design day 15 July (as explained in Tutorial 6.1)

b. Using annual energy simulations

Use the **New Delhi/Palam, India** weather file. Find the total cooling load for both options. Also note the time of occurrence of the maximum cooling load in each case.

COOLING DESIGN CALCULATION

Cooling design calculations are carried out to determine the capacity of the mechanical cooling equipment required to meet the hottest summer design weather conditions likely to be encountered at the site location.

Cooling design simulations using EnergyPlus have the following characteristics:

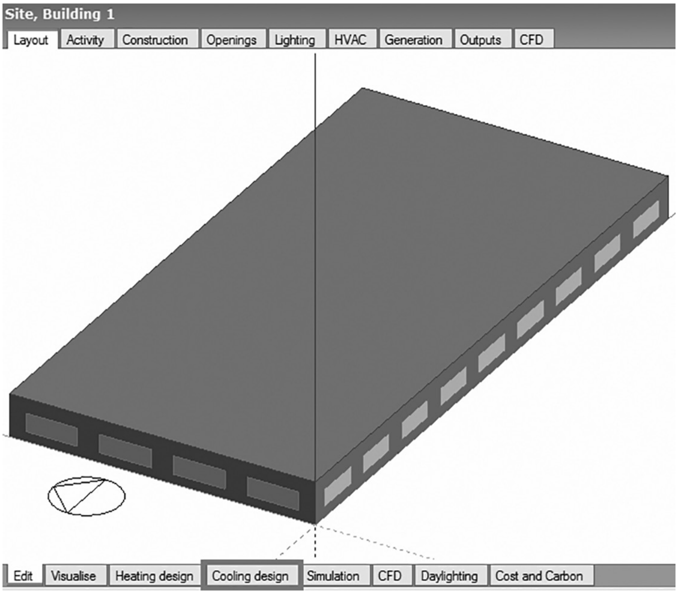
- Periodic steady-state external temperatures calculated using the maximum and minimum design summer weather conditions
- No wind
- Includes solar gains through windows and scheduled natural ventilation
- Includes internal gains from occupants, lighting and other equipment
- Includes consideration of heat conduction and convection between zones of different temperatures

For buildings situated in the Northern Hemisphere, cooling design calculations are made for the month of July, and for buildings in the Southern Hemisphere they are made for the month of January.

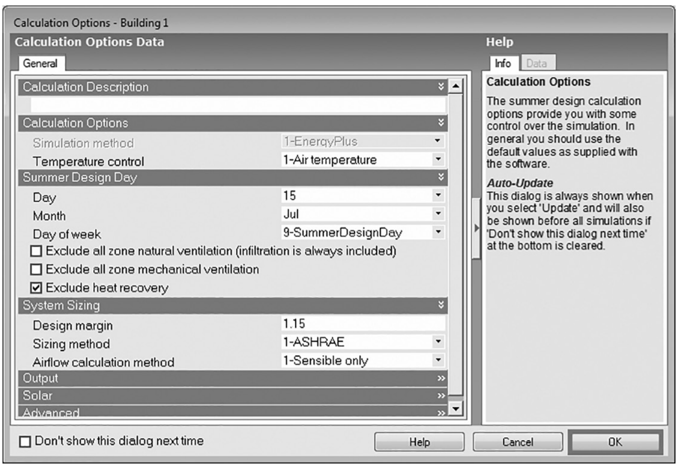
Source: http://www.designbuilder.co.uk/helpv4.7/Content/_Cooling_design_simulation.htm

SOLUTION

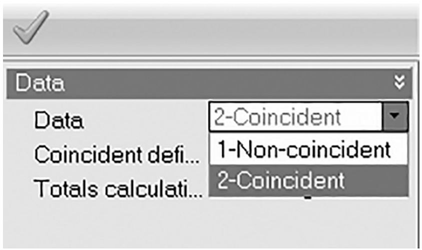
Step 1: Open a new model and create a **50 m × 25 m** building with a **5 m** perimeter depth. Select the **Cooling design** tab. The **Calculation Options** screen appears.

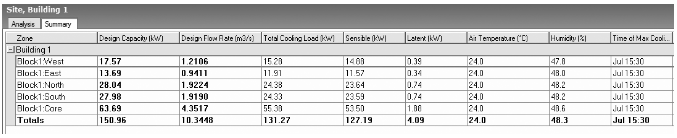


Step 2: Click **OK**. The results are displayed on the Analysis tab.



Step 3: Select the **Summary** tab. It shows the design capacity for 15 July. Select **Coincident** and record the results.




Site, Building 1

Analysis | Summary

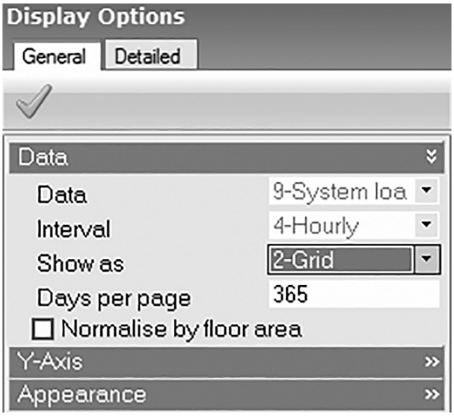
Zone	Design Capacity (kW)	Design Flow Rate (m3/s)	Total Cooling Load (kW)	Sensible (kW)	Latent (kW)	Air Temperature (°C)	Humidity (%)	Time of Max Cooli...
Building 1								
Block1:West	**17.57**	**1.2106**	15.28	14.88	0.39	24.0	47.8	Jul 15:30
Block1:East	**13.69**	**0.9411**	11.91	11.57	0.34	24.0	48.0	Jul 15:30
Block1:North	**28.04**	**1.9224**	24.38	23.64	0.74	24.0	48.2	Jul 15:30
Block1:South	**27.98**	**1.9190**	24.33	23.59	0.74	24.0	48.2	Jul 15:30
Block1:Core	**63.69**	**4.3517**	55.38	53.50	1.88	24.0	48.6	Jul 15:30
Totals	**150.96**	**10.3448**	**131.27**	**127.19**	**4.09**	**24.0**	**48.3**	**Jul 15:30**

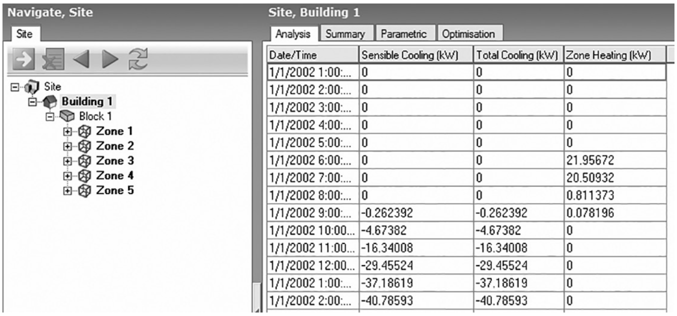
‘Cooling design’ does not require the weather data file for the calculation. DesignBuilder has all the required information in the ‘ASHRAE_ 2005_Yearly_DesignConditions.xls’ file. This file can be accessed at C:\ProgramData\DesignBuilder\Weather Data path.

These details automatically get loaded in the DesignBuilder when the location is selected.

In the next steps, you are going to find out the cooling load using annual energy simulations.

Step 4: Select the **Simulation with Hourly** tab. After completion of the simulation, select **System loads** from the **Data** drop-down list.





Step 5: Click the **Export** icon to export the results to the spreadsheet (Table 6.3).

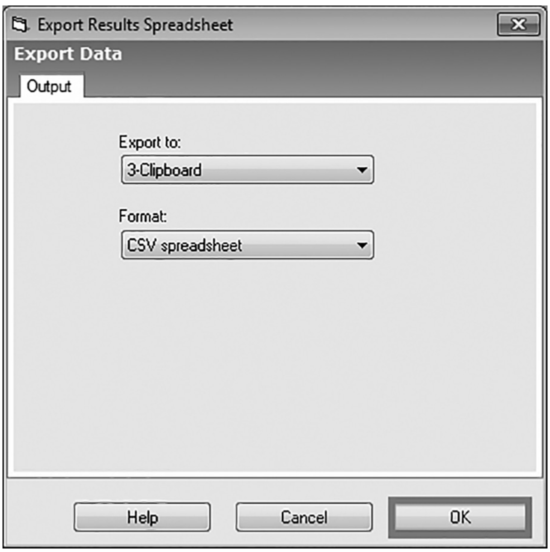


Table 6.3 Total cooling load

Day month	Time	Total cooling (kW)
19 June	4:00:00 PM	–158.2764
17 June	3:00:00 PM	–158.2065
19 June	5:00:00 PM	–158.1657
19 June	3:00:00 PM	–158.0092
17 June	4:00:00 PM	–157.7638
18 June	4:00:00 PM	–156.7041
18 June	3:00:00 PM	–156.598
17 June	12:00:00 PM	–156.2252
18 June	5:00:00 PM	–156.2232
21 June	5:00:00 PM	–156.0791
24 June	4:00:00 PM	–156.0511
17 June	5:00:00 PM	–156.0495
10 June	4:00:00 PM	–156.0368
17 June	11:00:00 AM	–156.0086
24 June	5:00:00 PM	–155.972
17 June	2:00:00 PM	–155.8881
9 July	5:00:00 PM	–155.832
20 June	3:00:00 PM	–155.7305

Step 6: Open the spreadsheet and sort the results for the total cooling (kW) in decreasing order. This provides the peak total cooling (kW) of the building.

Compare the results for the building (Table 6.4).

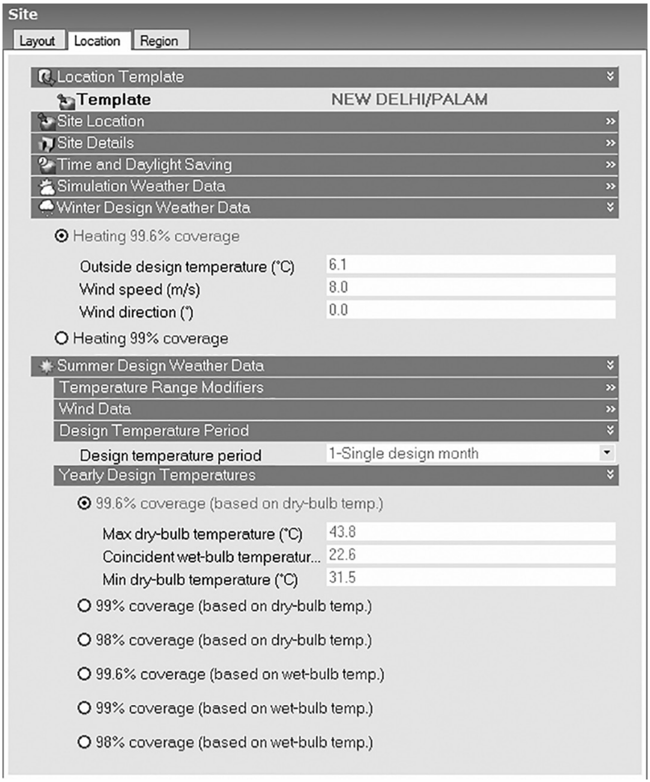
The results show that there is a difference between the peak total cooling load of the building with the design day and without explicitly defining the design day. One should always be cautious while selecting the design day for cooling. Sometimes the design day might not represent the day of the maximum total cooling load.

Save the simulation model for use in next tutorials.

Table 6.4 Total cooling load for design day and annual energy simulation

With design day on 15 July		With annual energy simulation	
Total cooling load (kW)	Date and time of peak	Total cooling load (kW)	Date and time of peak (building)
150.79	15 July at 15:00	158.27	19 June at 14:00

In some cases, design conditions, namely, max dry bulb, concurrent wet bulb and minimum dry bulb temperature are known to HVAC designers. As a third alternate, these conditions can directly be filled in DesignBuilder.



Exercise 6.2

Repeat the same steps as in the tutorial for London to find the heating design capacity.

You can use the heating sizing tab for this (Table 6.5).

Table 6.5 Total heating design capacity for design day and annual energy simulation

With design day on 15 Jan		With annual energy simulation	
Total heating design capacity (kW)	Date and time of peak of heating load	Total heating design capacity (kW)	Date and time of peak heating load (building)

Heating design calculations are carried out to determine the size of the heating equipment required to meet the coldest winter design weather conditions likely to be encountered at the site location.

The simulation calculates the heating capacities required to maintain the temperature setpoints in each zone and displays the total heat loss broken down as follows:

- Glazing
- Walls
- Partitions
- Floors
- Roofs
- External infiltration
- Internal natural ventilation (i.e. the heat lost to other cooler adjacent spaces through windows, vents, doors and holes)

TUTORIAL 6.3 Evaluating the impact of the air flow calculation method

GOAL

To evaluate the impact of the air flow calculation method on HVAC equipment sizing.

WHAT ARE YOU GOING TO LEARN?

- Changing the air flow calculation method and finding the design air flow

PROBLEM STATEMENT

In this tutorial, you are going to use the simulation model used for Tutorial 6.2 (50 m × 25 m model with a 5 m perimeter depth) with building usage as classroom. Find the cooling equipment sizing, and design flow rates, for the following airflow calculation methods:

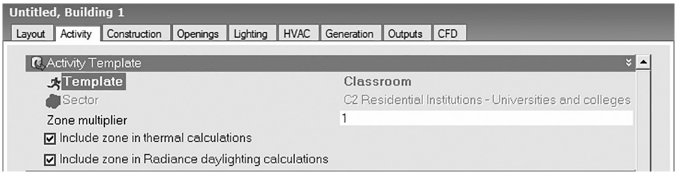
1. Sensible
2. Sensible + latent

Use the **AZ - PHOENIX/SKY HARBOR, USA** weather file.

SOLUTION

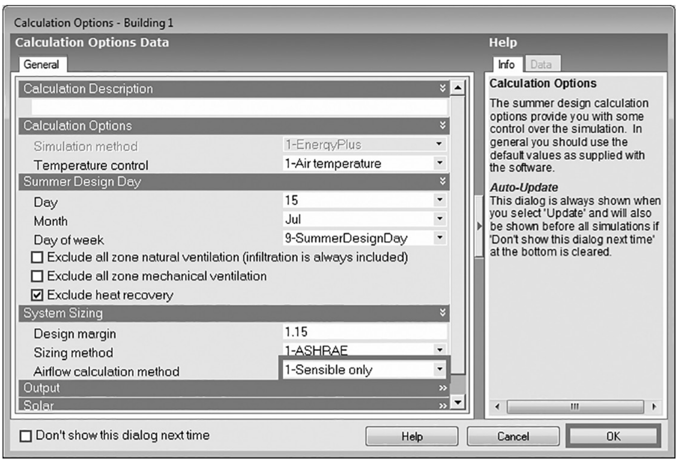
Step 1: Open the model saved in Tutorial 6.2 (a **50 m × 25 m** building with a **5 m** perimeter depth).

Step 2: Select the **Activity** tab. Select **Classroom** in the Universities and colleges section.



Step 3: Select the **Cooling design** tab. The **Calculation Options** screen appears.

Step 4: Select **Sensible only** from the **Airflow calculation method** drop-down list. Click **OK**. The results are displayed in the Analysis tab.



The supply air for cooling

$$Q_s = \frac{q_s}{C_1(t_R - t_s)}$$

The supply air for dehumidification

$$Q_L = \frac{q_L}{C_2(W_R - W_s)}$$

where:

Q_s = supply air volume required to satisfy the peak sensible load
Q_L = supply air volume required to satisfy the peak latent load
q_s = peak sensible load
q_L = peak latent load
t_R = room air temperature
t_s = supply air temperature
W_R = room humidity ratio
W_s = humidity ratio of the dehumidified supply air
C_1 = 1.23 (For calculation in SI units)
C_2 = 3010 (For calculation in SI units)

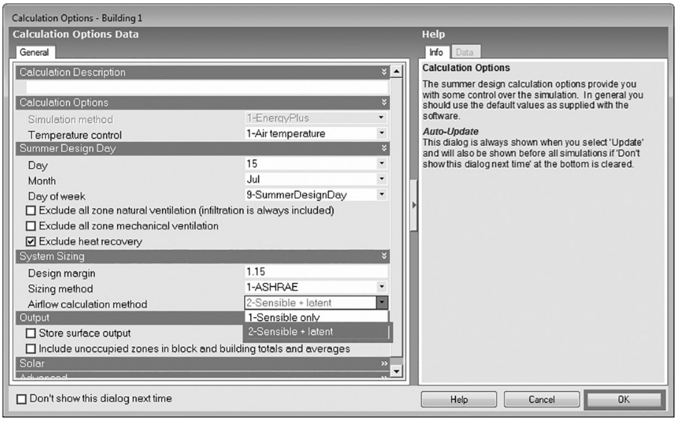
Step 3: Select the **Summary** tab. Record the results.

Untitled, Building 1

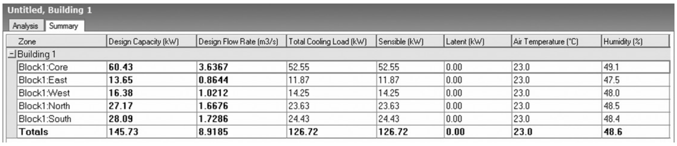
Analysis | Summary

Zone	Design Capacity (kW)	Design Flow Rate (m3/s)	Total Cooling Load (kW)	Sensible (kW)	Latent (kW)	Air Temperature (°C)	Humidity (%)
Building 1							
Block1:Core	**60.43**	**4.7209**	52.55	52.55	0.00	23.0	49.1
Block1:East	**13.65**	**1.0665**	11.87	11.87	0.00	23.0	47.5
Block1:West	**16.38**	**1.2798**	14.25	14.25	0.00	23.0	48.0
Block1:North	**27.17**	**2.1224**	23.63	23.63	0.00	23.0	48.5
Block1:South	**28.09**	**2.1944**	24.43	24.43	0.00	23.0	48.4
Totals	**145.73**	**11.3841**	**126.72**	**126.72**	**0.00**	**23.0**	**48.6**

Step 4: Repeat the previous steps to select **Sensible+latent** from the **Airflow calculation method** drop-down list. Click **OK**.



Step 5: Select the **Summary** tab. Record the results.



Untitled, Building 1

Analysis | Summary

Zone	Design Capacity (kW)	Design Flow Rate (m3/s)	Total Cooling Load (kW)	Sensible (kW)	Latent (kW)	Air Temperature (°C)	Humidity (%)
Building 1							
Block1:Core	60.43	3.6367	52.55	52.55	0.00	23.0	49.1
Block1:East	13.65	0.8644	11.87	11.87	0.00	23.0	47.5
Block1:West	16.38	1.0212	14.25	14.25	0.00	23.0	48.0
Block1:North	27.17	1.6676	23.63	23.63	0.00	23.0	48.5
Block1:South	28.09	1.7286	24.43	24.43	0.00	23.0	48.4
Totals	145.73	8.9185	126.72	126.72	0.00	23.0	48.6

Compare both cases (Table 6.6).

Table 6.6 Design capacity and design flow rate for each zone

Zone	Design capacity (kW)	Design flow rate (m^3/s)	
		Sensible only	Sensible + latent
Core	15.88	4.72	3.64
East	26.94	1.07	0.86
West	13.38	1.28	1.02
North	61.03	2.12	1.67
South	27.94	2.19	1.73
Total	145.16	11.38	8.92

Factors that influence the sensible cooling load	Factors that influence the latent cooling load
Glass, windows or doors • Solar radiation striking windows, skylights or glass doors • Thermal resistance of exterior walls • Partitions (that separate spaces of different temperatures) • Ceilings under an attic • Thermal resistance of roofs and floors • Air infiltration through cracks/ gaps in the building, doors and windows • Building occupants • Equipment and appliances operated in the summer • Light	Moisture is introduced into a structure through: • Building occupants • Equipment and appliances that release vapour in space, such as tea kettle • Air infiltration through cracks/gaps in the building, doors and windows and frequent doors opening to the ambience

Exercise 6.3

Repeat the above tutorial for the London Getwick Airport, UK (Table 6.7).

Table 6.7 Design capacity and design flow rate for each zone

Zone	Design capacity (kW)	Design flow rate (m^3/s)	
		Sensible only	Sensible + latent
Core			
East			
West			
North			
South			
Total			

CHAPTER SEVEN

Unitary HVAC Systems

In most unitary HVAC systems, coefficient of performance (COP) and fan properties are the two key aspects that govern their energy consumption. Higher COP is associated with a reduction in energy consumption. Unitary systems require a fan for blowing air over the condenser as well as evaporator tubes. A fan is characterized by its static pressure and volumetric air flow rate. High static pressure and flow rate help in achieving setpoint faster, however, they are also associated with higher energy consumption. If these parameters are not specified properly, results of the energy model could significantly deviate from the actual performance. This chapter explains the method of modelling unitary systems by specifying COP and fan properties.

TUTORIAL 7.1 Evaluating the impact of unitary air conditioner COP

GOAL

To evaluate the impact of unitary air conditioner COP on building energy performance.

WHAT ARE YOU GOING TO LEARN?

- Modelling the unitary HVAC system
- Changing the cooling system COP

PROBLEM STATEMENT

In this tutorial, you are going to create a 50 m × 25 m 5-zone model with 5 m perimeter depth. You need to model the unitary HVAC system and then change the COP of the system.

You need to change the cooling COP from 1.5 to 3.5 with increments of 0.5.

Use **FL – MIAMI, USA** weather file. Find energy consumption for all COP values.

COP = desired effect/work input

For cooling:

$$COP_{cooling} = \frac{Q_o}{W} \tag{7.1}$$

For heating:

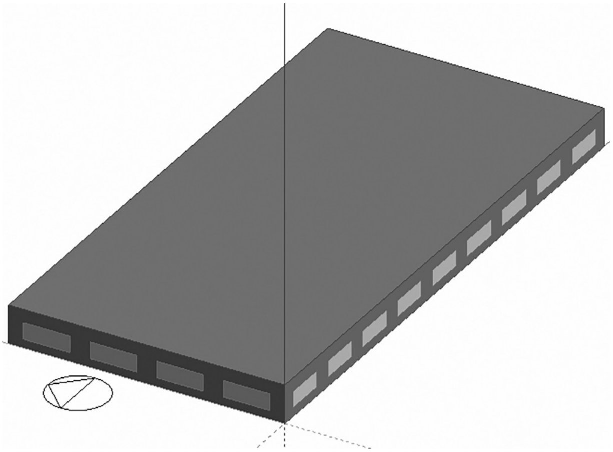
$$COP_{Heating} = \frac{Q_k}{W} \tag{7.2}$$

where:
Q_o = heat absorbed in the evaporator
Q_k = heat rejected in the condenser
W = compressor work

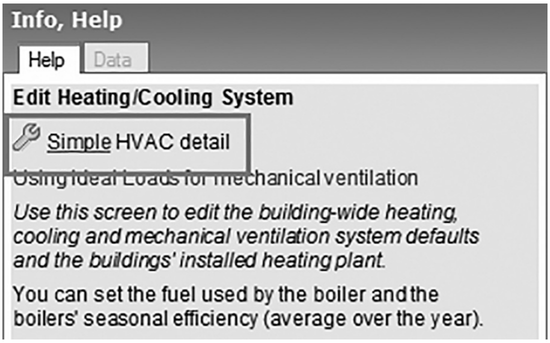
The COP of the refrigeration cycle is a dimensionless index used to indicate the performance of a thermodynamic cycle or the thermal system. The magnitude of COP is usually greater than 1.

SOLUTION

Step 1: Open a new project and create a **50 m × 25 m** building with five zones and consider a **5 m** perimeter depth. Select the **HVAC** tab.



Step 2: Make sure **Simple HVAC detail** is displayed under the **Help** tab.



There are three HVAC model options available in DesignBuilder:

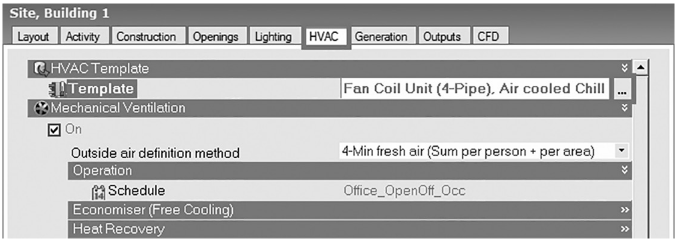
Simple HVAC is suitable for use at early design stages. The heating/cooling system is modelled using basic loads calculation algorithms.

Compact HVAC – the heating/cooling systems are defined in DesignBuilder using moderately basic HVAC descriptions that are expanded into detailed HVAC definitions and modelled in EnergyPlus including boiler, chiller and fan part-load characteristics. Compact HVAC is now a deprecated feature and may not be supported in future releases.

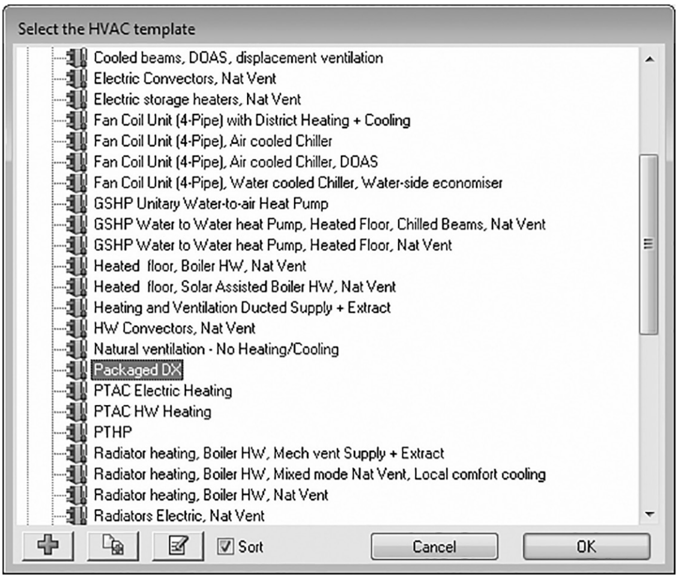
Detailed HVAC – the HVAC system is modelled in full detail using EnergyPlus air and water-side components linked together on a schematic layout drawing. This option will usually involve more work in setting up the setpoints, etc. especially for large models, but there is increased flexibility.

Source: http://www.designbuilder.co.uk/helpv4.7/ Content/_HVAC_model_detail.htm

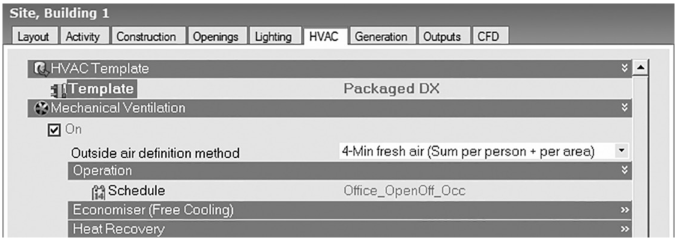
Step 3: Click **Template** under the **HVAC Template** section. It displays three (**…**) dots. Click the three dots. The **Select the HVAC template** screen appears.



Step 4: Select **Packaged DX**. Click **OK**.



The screen appears showing the selected template as Packaged DX:

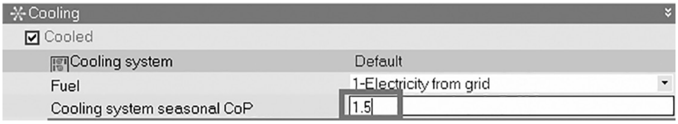


A unitary system combines heating, cooling and fan sections all in one or a few assemblies for simplified application and installation and are used in most classes of buildings, particularly where low initial cost and simplified installation are important.

In DesignBuilder, the Unitary single zone option allows you to model simple single constant volume direct expansion (DX)-based HVAC configurations with several heating options. Direct expansion includes single-packaged rooftop systems commonly seen in commercial buildings and split systems commonly seen in residential buildings.

Source: http://www.designbuilder.co.uk/helpv4.7/#_Unitary_single_zone.htm

Step 5: Enter **1.5** as the **Cooling system seasonal CoP** in the **Cooling** section.



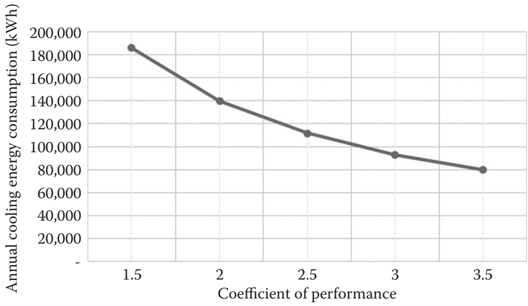
Step 6: Perform annual simulation and record the results.

Step 7: Repeat the previous steps for all other COP values and record the results (Table 7.1).

Compare the results.

Table 7.1 Variation in annual energy consumption (kWh) with COP

End-use category	COP				
	1.5	2	2.5	3	3.5
Room electricity	51,114.94	51,114.94	51,114.94	51,114.94	51,114.94
Lighting	73,872.16	73,872.16	73,872.16	73,872.16	73,872.16
Cooling (electricity)	186,137.60	139,603.20	111,682.60	93,068.80	79,773.26
DHW (electricity)	4,625.06	4,625.06	4,625.06	4,625.06	4,625.06



Results show that there is a decrease in energy consumption with the increase in COP of the system. Systems with higher COP require lesser energy input to remove the same amount of heat from the thermal zone.

Save the model to use in the subsequent tutorial.

Exercise 7.1

Repeat the above tutorial for the heating system COP. Use CA-SAN FRANCISCO INTL, USA weather data.

End-use category	Annual energy consumption (kWh)				
	COP 1.5	COP 2.0	COP 2.5	COP 3.0	COP 3.5
Room electricity					
Lighting					
System fans					
Heating (electricity)					
Cooling (electricity)					
DHW (electricity)					

TUTORIAL 7.2 Evaluating the impact of the fan efficiency of a unitary air conditioning system

GOAL

To evaluate the impact of the fan efficiency of a unitary air conditioning system on energy performance.

WHAT ARE YOU GOING TO LEARN?

- Changing the fan efficiency

PROBLEM STATEMENT

In this tutorial, you are going to use a 50 m × 25 m five-zone model with 5 m perimeter depth.

Model the unitary HVAC system with the following three fan efficiencies:

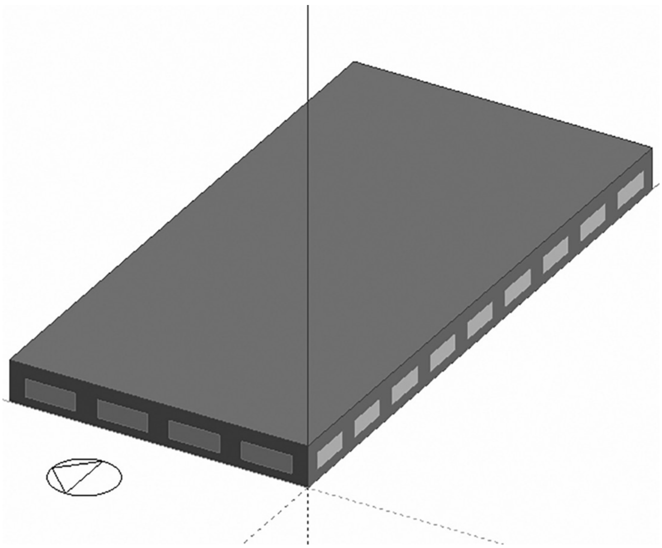
1. 0.600
2. 0.700
3. 0.800

Find change in energy consumption for all the cases.

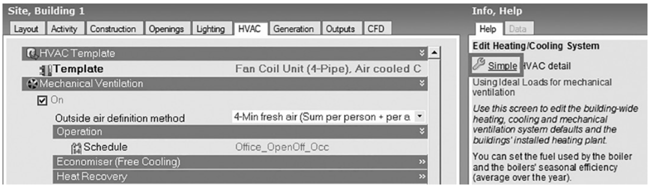
Use **Rio de Janeiro (AERO), Brazil** location.

SOLUTION

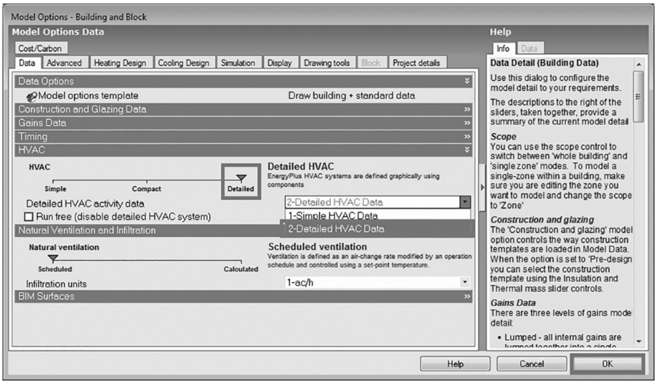
Step 1: Open a new project and create a **50 m × 25 m** building with **5 m** perimeter depth.



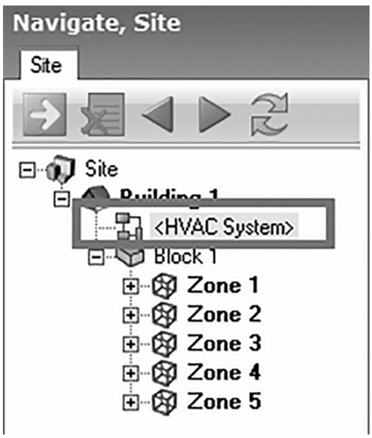
Step 2: Select the **HVAC** tab. Click **Simple** link under the **Help** tab. The **Model Options – Building and Block** screen appears.



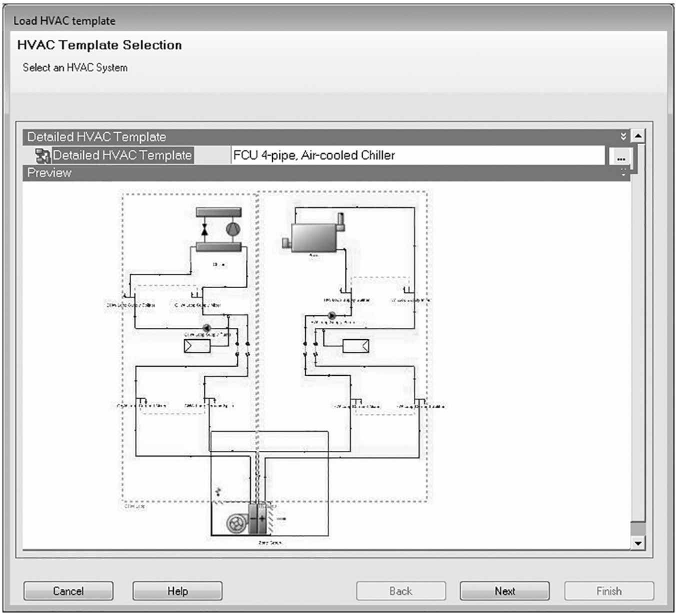
Step 3: Click **Detailed** under the HVAC slider. Select **Detailed HVAC Data** from the Detailed HVAC drop-down list. Click **OK**. It displays the <HVAC system> option under Building 1.



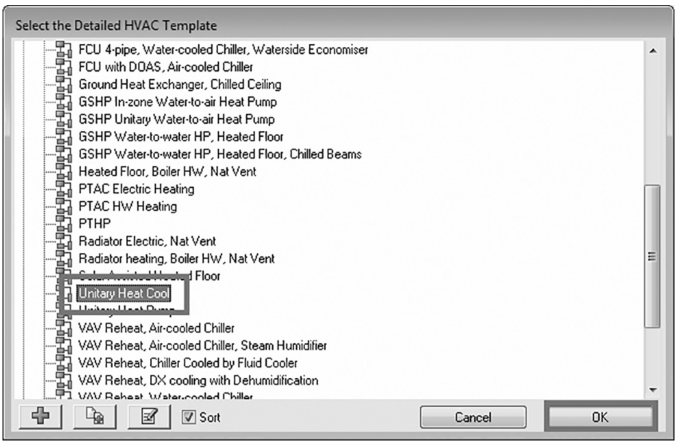
Step 4: Click **<HVAC System>**. It displays initializing HVAC progress bar and subsequently the **Load HVAC template** screen appears.



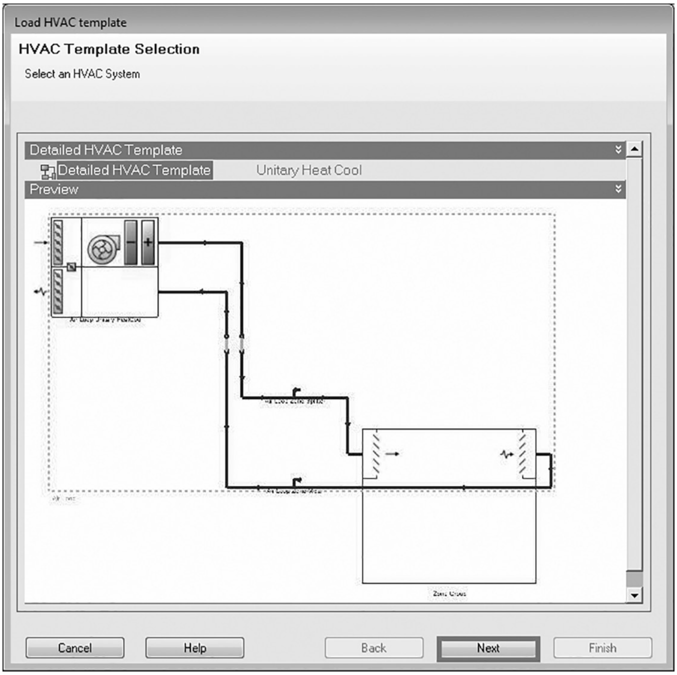
Step 5: Click **Detailed HVAC Template**. It displays three **(…)** dots. Click the three dots. The **Select the Detailed HVAC Template** screen appears.



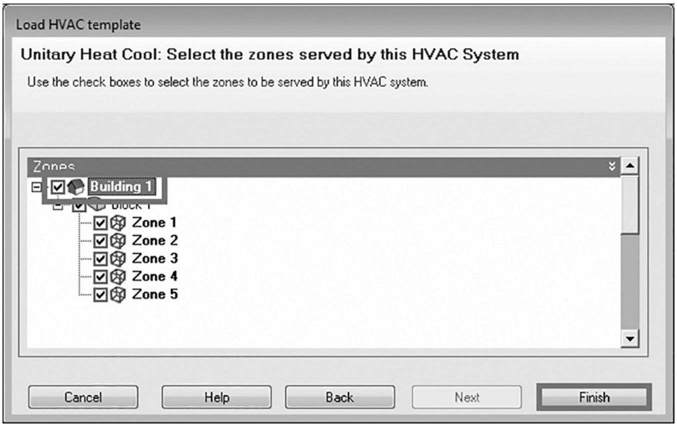
Step 6: Select **Unitary Heat Cool** under Select Detailed HVAC Template. The **Load HVAC template** screen appears.



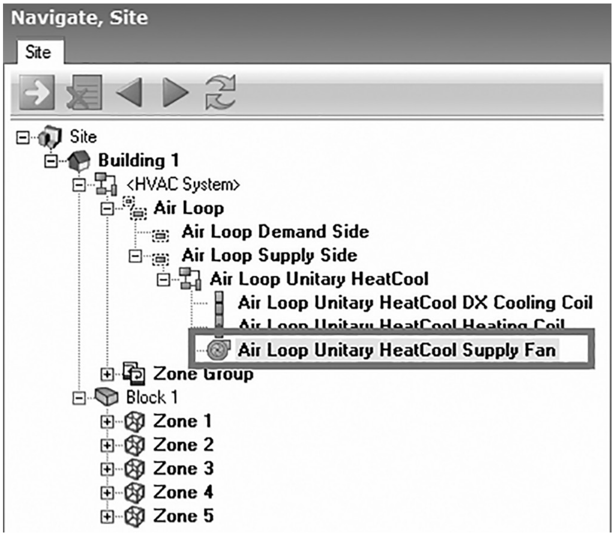
Step 7: Click **Next**. It displays all the zones.



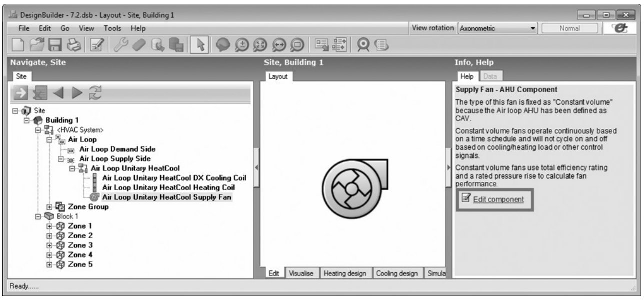
Step 8: Select the **Building 1** check box and click **Finish**.



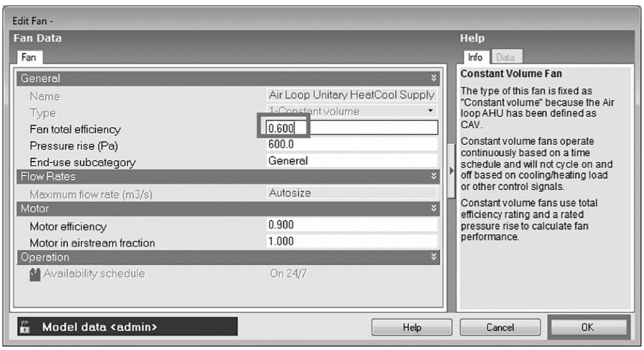
Step 9: In the navigation tree, select **Air Loop Unitary HeatCool Supply Fan** from the <HVAC System> tree. You need to click **+** to expand the tree.



Step 10: Click **Edit component**.



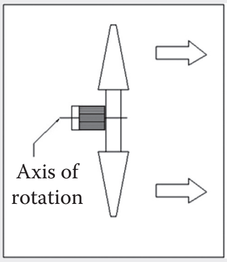
Step 11: Enter **0.600** for **Fan total efficiency** (%). Click **OK**.



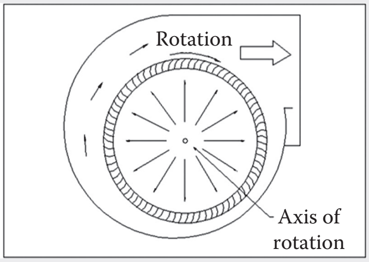
A fan is a power-driven rotary machine that causes a continuous flow of air.

A fan is a machine that causes flow of air.

There are two broad categories of fans – axial and centrifugal.



Axial flow fan



Centrifugal fan

In axial flow fans, air moves parallel to the shaft. This type is used in many applications such as a cooling fan for electronics and wind tunnel.

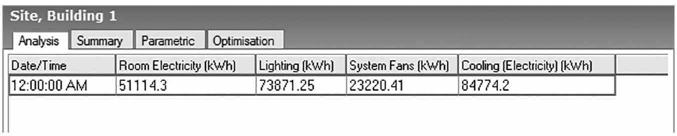
A centrifugal fan blows air at 90° to the intake of the fan. Mostly, it is used for HVAC applications.

Fan Efficiency
The fan efficiency is the ratio between the power transferred to the air flow and the power used by the fan.

$$\eta = \frac{\Delta P . Q}{W_{\text{fan}}} \tag{7.3}$$

where:
η = fan efficiency (values between 0 and 1)
ΔP = total pressure (Pa)
Q = air volume delivered by the fan (m^3/s)
W_{fan} = power used by the fan (Watt)

Step 12: In the navigation tree, click **Building 1**. Perform annual simulation and record the results.



Date/Time	Room Electricity (kWh)	Lighting (kWh)	System Fans (kWh)	Cooling (Electricity) (kWh)
12:00:00 AM	51114.3	73871.25	23220.41	84774.2

Table 7.2 Variation of annual energy consumption with fan efficiency

	Annual energy consumption (kWh)		
End use	0.60	0.70	0.80
Room electricity	51,114.30	51,114.30	51,114.30
Lighting	73,871.25	73,871.25	73,871.25
System fans	23,220.41	19,903.21	17,415.31
Cooling (electricity)	84,774.20	83,792.05	83,051.09

Step 13: Repeat the previous steps for 0.700 and 0.800 fan efficiency.

Compare the results (Table 7.2).

It can be seen that in addition to the reduction in energy consumption under system fans, there is a decrease in cooling (electricity) with the increase in fan efficiency. It is due to the fact that with a high-efficiency fan, lesser heat is added to the air while it passes over the fan motor, thus requiring a lesser cooling effect to be delivered by the system.

Save the simulation model with 0.7 fan efficiency to use in the next tutorial.

Exercise 7.2

Repeat the above tutorial for fan efficiency varying from 0.3 to 0.9 with steps of 0.1 for climate Melbourne, Australia.

TUTORIAL 7.3 Evaluating the impact of fan pressure rise

GOAL

To evaluate the impact of fan pressure on building energy performance.

WHAT ARE YOU GOING TO LEARN?

- Changing fan pressure rise

PROBLEM STATEMENT

In this tutorial, you are going to use the simulation model created in Tutorial 7.2 (50 m × 25 m model with 5 m perimeter depth).

Model the unitary HVAC system with the following two fan pressures:

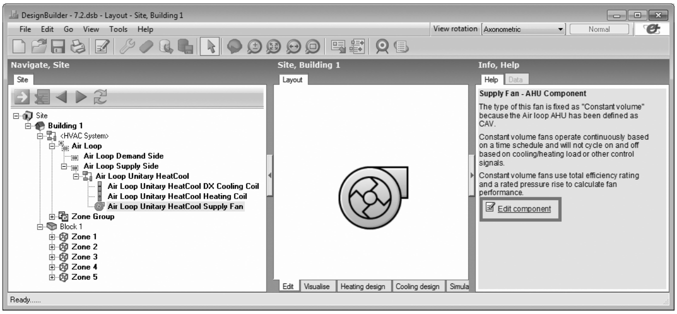
1. 500 Pa
2. 750 Pa

Find the change in energy consumption for both cases.

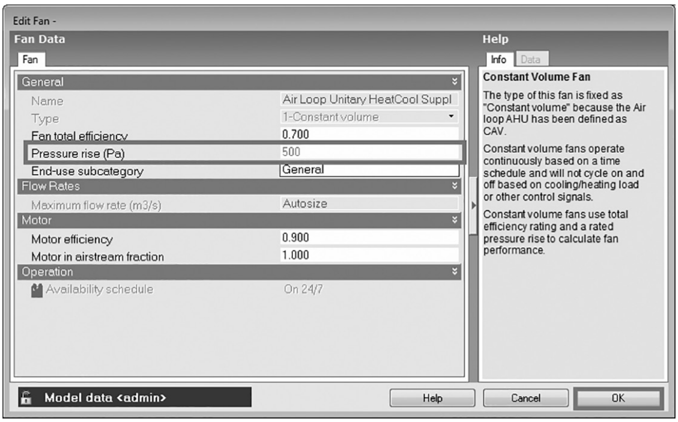
Use **Rio de Janeiro (AERO), Brazil** weather location.

SOLUTION

Step 1: Open the project file used in Tutorial 7.2. In the navigation tree select **Air Loop Unitary HeatCool Supply Fan**. Click **Edit component**.



Step 2: Enter **500** for Pressure rise (Pa). Click **OK**.



Fans provide energy to air that helps the air to move through the ducts and other parts of the air side of an HVAC system, such as grills, diffusers, air filters, humidifiers and dampers.

All these components impose resistance to the flow of air. To overcome such resistance, an increase in pressure is required.

As seen in Tutorial 7.2, fan power is inversely proportional to pressure rise:

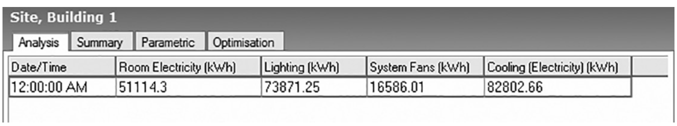
- A typical fan running at a fixed speed can provide a greater volumetric flow rate for systems with smaller total pressure drops (if we are to the right of the peak in the fan curve).

Static pressure is used to overcome the pressure drop due to various ventilation system components on the airflow path within a given system. For mechanical ventilation systems, the fans create positive static pressure to move air through a given system.

The positive static pressure created by the fans equals the negative static pressure created by resistance as air navigates obstacles in the ventilation path plus the head required to impart sufficient kinetic energy to air for getting spread into the space.

Proper air filtration results in better conditions and air quality for occupants of the building as well as increases the longevity of the HVAC system. However, due to high negative pressure or resistance to flow with filtration devices, their use results in the rise in the static pressure requirement of the fan for maintaining the same flow rate.

Step 3: In the navigation tree, click **Building 1**. Perform annual simulation and record the results.



Date/Time	Room Electricity (kWh)	Lighting (kWh)	System Fans (kWh)	Cooling (Electricity) (kWh)
12:00:00 AM	51114.3	73871.25	16586.01	82802.66

Table 7.3 Variation of annual energy consumption with fan pressure rise

	Annual energy consumption (kWh)	
End-use categories	500 Pa	750 Pa
Room electricity	51,114.30	51,114.30
Lighting	73,871.25	73,871.25
System fans	16,586.01	24,879.01
Cooling (electricity)	82,802.66	85,262.43

Step 4: Repeat the previous steps for **750 Pa** fan pressure.

Compare the results (Table 7.3).

From the results, you can observe that there is an increase in fan energy consumption due to the rise in fan pressure. Also you can observe that there is an increase in cooling energy consumption with the increase in pressure rise due to the addition of more heat to the air passing over a fan motor of higher power rating.

Exercise 7.3

In the tutorial, make Motor in airstream fraction as 0 and observe the effect on the cooling and fan energy consumption. Use the same Rio de Janeiro (AERO), Brazil weather file (Table 7.4).

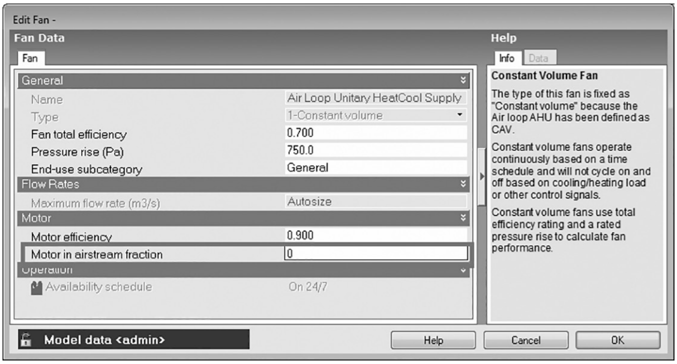


Table 7.4 Variation of annual energy consumption with fan efficiency

	Annual energy consumption (kWh)	
End-use categories	500 Pa	750 Pa
Room electricity		
Lighting		
System fans		
Cooling (electricity)		

CHAPTER EIGHT

Central HVAC System

Energy consumption of the centralized HVAC (Heating, Ventilating and Air Conditioning) system depends on the selection of individual components and their integration in the entire system. Major variations include the type of condenser for heat rejection, chilled water-pumping scheme, efficiency of the air distribution system, waste heat recovery and efficiency of the chiller and boiler. This chapter, through its tutorials, explains the method of modelling central HVAC systems. Different variations of systems are explained, such as types of chillers, cooling towers and the use of variable speed drives in HVAC components. The impact of each variation on energy consumption is also explained.

TUTORIAL 8.1 Evaluating the impact of air-cooled and water-cooled chillers

GOAL

To evaluate the impact of air-cooled and water-cooled chillers on the building energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Modelling the central HVAC system
- Modelling the air-cooled chiller
- Modelling the water-cooled chiller

PROBLEM STATEMENT

In this tutorial, you are going to use a G+5 floor building model. Each floor has a 50 m × 25 m area and five zones with 5 m perimeter depth. You need to make use of the floor/zone multiplier option to model the building. Model HVAC systems having **VAV with reheat**.

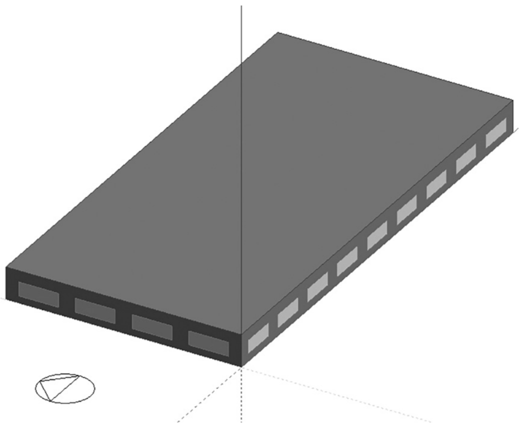
Use the following two options for a chiller in the HVAC system:

1. Air cooled
2. Water cooled

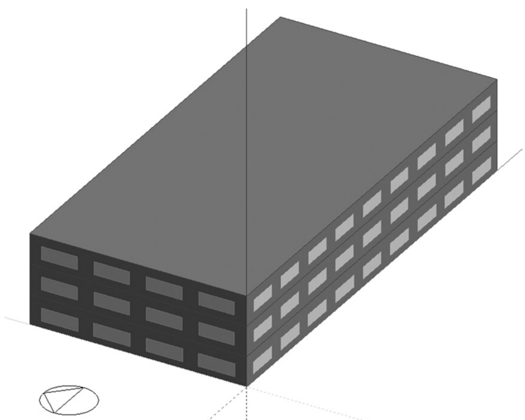
Compare the energy consumption of the two chillers for **AZ-PHOENIX/SKY HARBOR, USA** weather location. Phoenix has long, very hot summers and short, mild winters. The climate is arid, with plenty of sunshine and clear skies.

SOLUTION

Step 1: Open a new project and create a building with ground floor having a **50 m × 25 m** area and five zones with **5 m** perimeter depth.

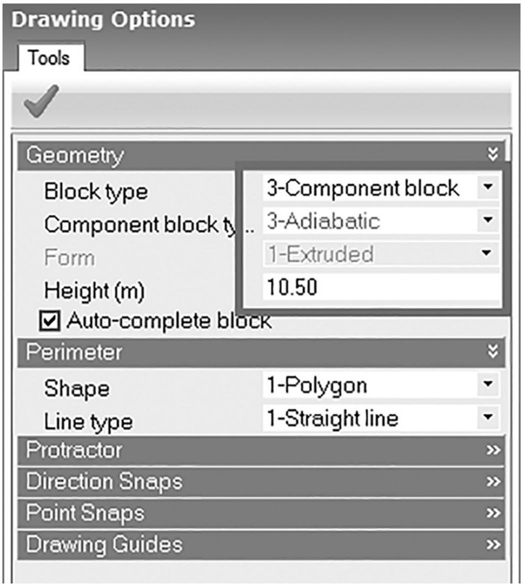


Step 2: Copy ground floor and create two other floors. (You can refer to Tutorial 6.1 to copy/clone floors.)

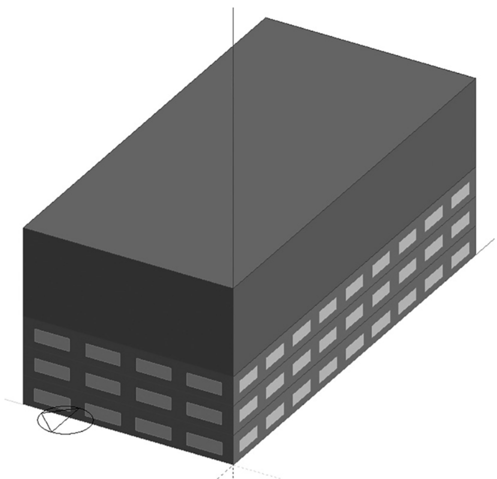


Step 3: Select **Plan** from View rotation drop-down. Click the **add block** icon.

Before drafting, select Block type as **Component block** and **Adiabatic** in the Component block type and enter **10.50** in Height (m).

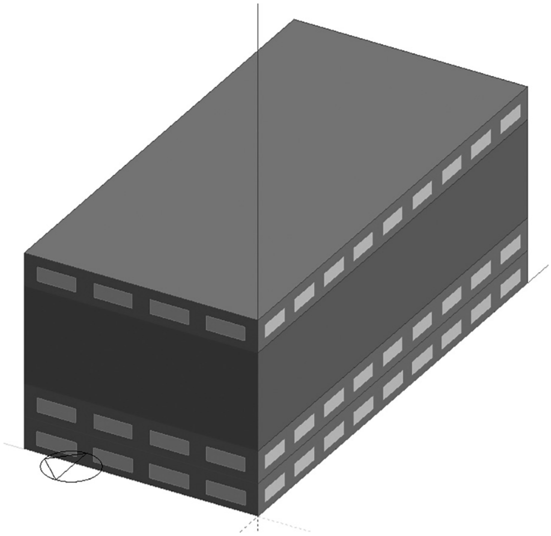


Go to Axonometric view, click in the corner and make sure that the roof is selected, when you click the point.

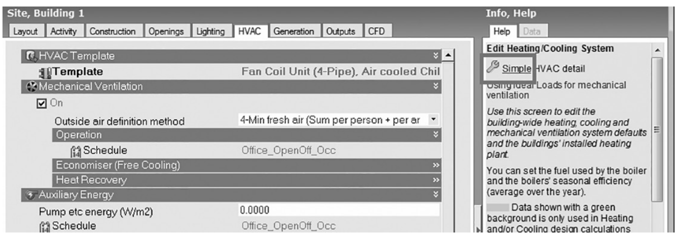


With the help of **Move Selected Object** icon, it can be adjusted.

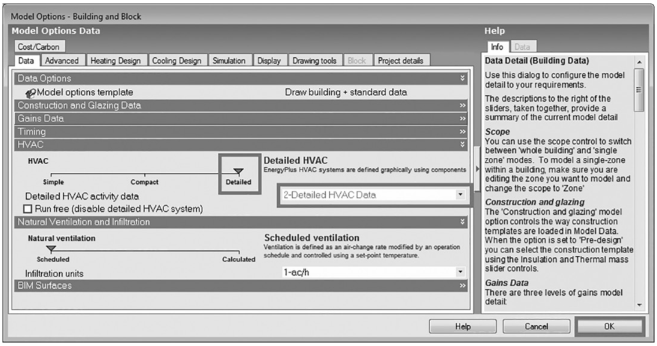
(You can also refer to Chapter 2 for floor/zone multiplier.)



Step 4: Select the **HVAC** tab. Click **Simple** link under **Help** tab. The **Model Options – Building and Block** screen appears.

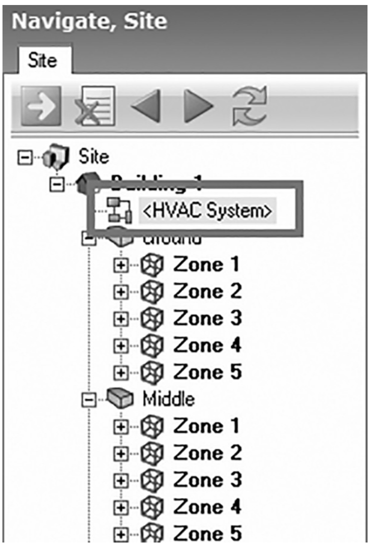


Step 5: Click **Detailed** under HVAC slider. Select **Detailed HVAC Data** from the Detailed HVAC drop-down list. Click **OK**. It displays <HVAC system> option under Building 1.

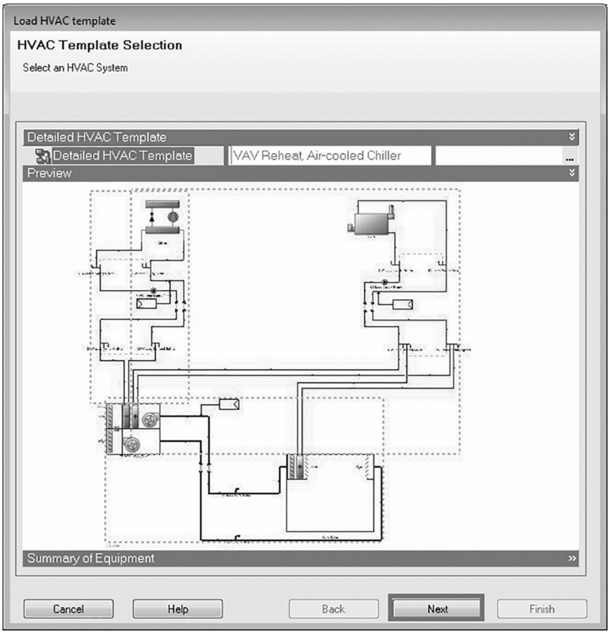


Detailed HVAC – The HVAC system is modelled in detail using EnergyPlus air- and water-side components linked together on a schematic layout drawing. In this case, HVAC data is accessed by clicking on the <HVAC System> navigator node.

Step 6: Click <**HVAC System**>. It displays the initializing HVAC progress bar and subsequently the **Load HVAC template** screen appears.



Step 7: Select **VAV Reheat, Air-cooled Chiller** from **Detailed HVAC Template**. Click **Next**.



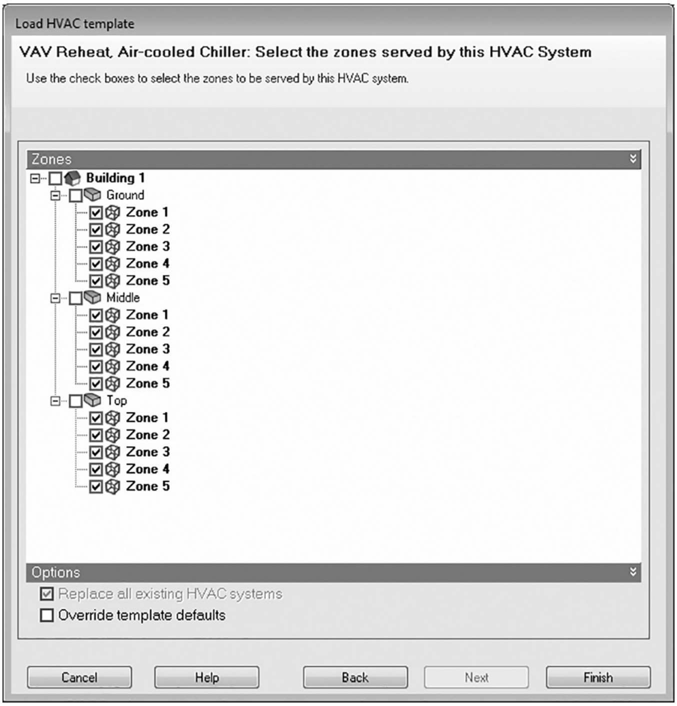
In medium to large air conditioning systems, chilled water from the central plant is used to cool the air at the coils in an air handling unit (AHU).

Based on the condenser cooling, chillers are of two types:

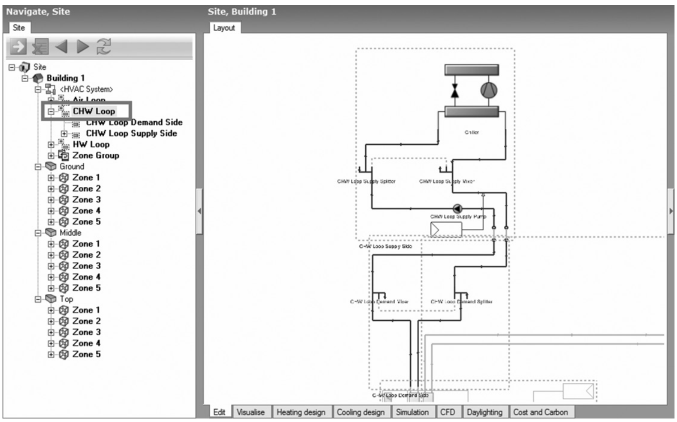
- An air-cooled chiller has a condenser that is cooled by ambient air. Air-cooled chillers are preferred for small or medium installations and are preferred in cases where there is not enough water.
- A water-cooled chiller has a condenser connected with a cooling tower. Cold water is obtained through partial evaporation of water through ambient air that is used to facilitate heat rejection from the condenser. The use of a cooling tower to cool the condenser increases the efficiency of water-cooled chillers over air-cooled systems in which ambient air cools the condenser.

	Air cooled	Water cooled
Efficiency	Less	High
Cost	Less	High
Maintenance	Less	High

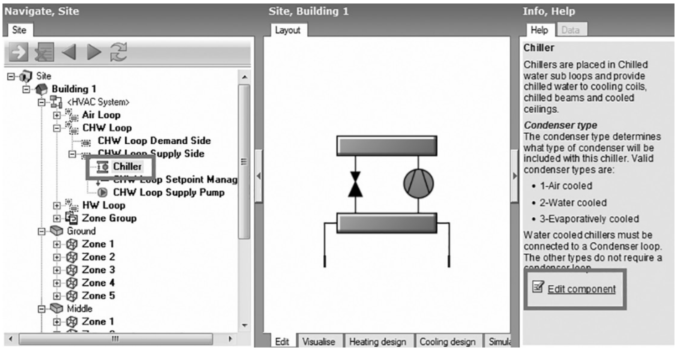
Step 8: Select all the check boxes from the **Zones** section. Click **Finish**. It displays the system layout.



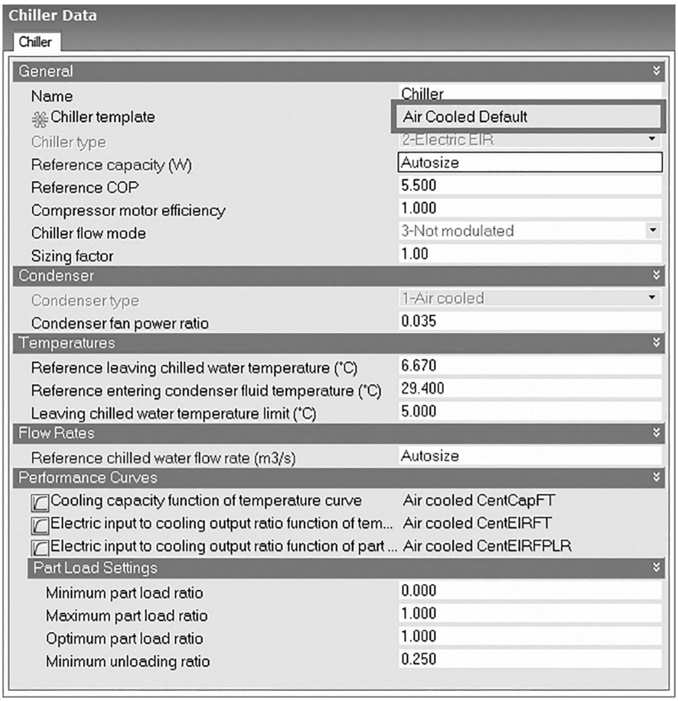
Step 9: In the navigation bar, expand **CHW Loop**.



Step 10: Expand **CHW Loop Supply Side** and click **Chiller**. The Chiller layout appears. Click **Edit component** under the **Help** tab. The Chiller data appears.

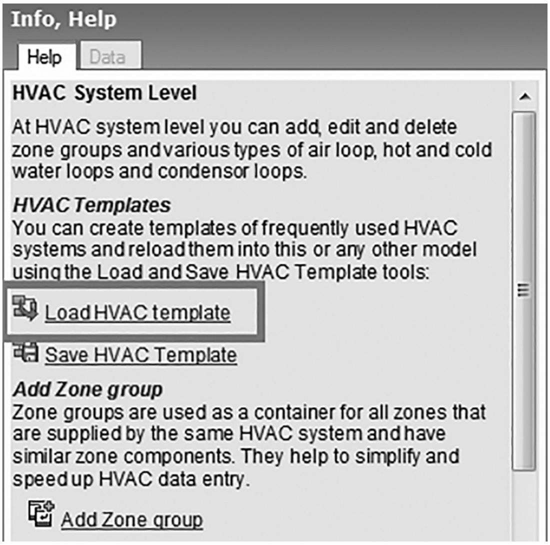


Step 11: Make sure that **Air Cooled Default** is selected for **Chiller template**.

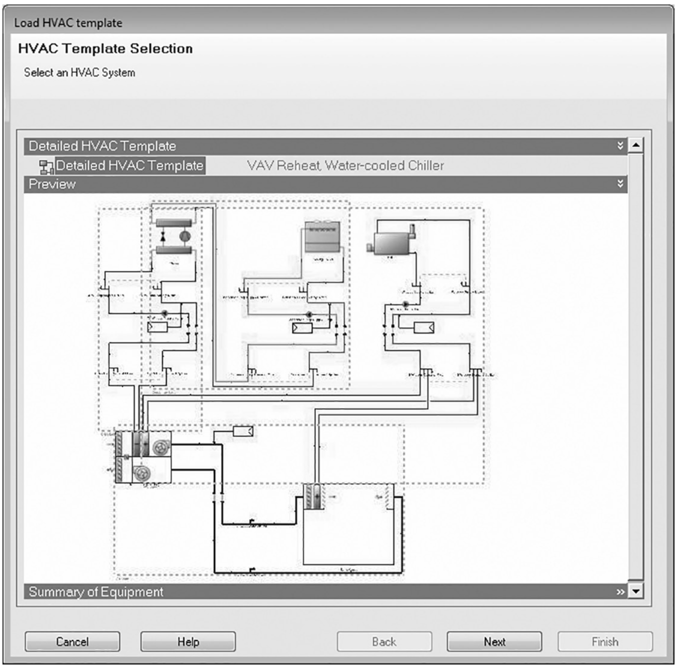


Step 12: Simulate the model and record Annual Fuel Breakdown results.

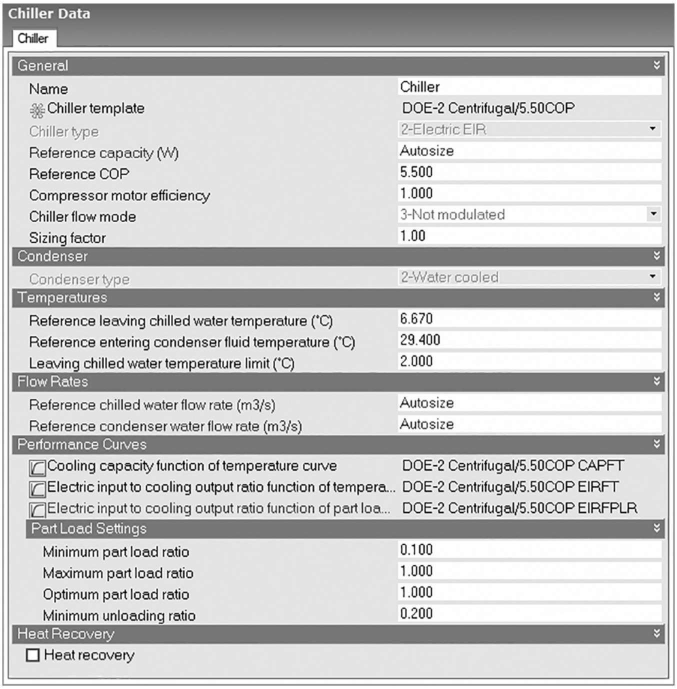
Step 13: Select the **Edit** tab. In the navigation tree click **<HVAC System>** and select **Load HVAC Template**.



Step 14: Repeat the previous steps to select **VAV Reheat, Water-cooled Chiller** from **Select the Detailed HVAC Template**.



Step 15: Select **DOE-2 Centrifugal/5.50COP** in the chiller template field.



Step 16: Perform annual energy simulation and compare results for both cases (Table 8.1).

Table 8.1 Energy consumption for air- and water-cooled chillers

	Annual energy consumption (kWh)	
End-use categories	Air-cooled chiller	Water-cooled chiller
Room electricity	153,342.90	153,342.90
Lighting	221,613.80	221,613.80
System fans	168,257.40	168,257.40
System pumps	1,275.77	8,569.14
Heating (gas)	100,853.20	100,853.20
Cooling (electricity)	494,753.60	253,026.60
Heat rejection	Not applicable	55,257.56

Air-cooled chillers do not have a cooling tower for condenser cooling. In DesignBuilder, a heat rejection term is used for reporting cooling tower energy consumption. Hence, for the air-cooled chiller in the end-use category – heat rejection – there is no value.

You can also observe that the cooling energy consumption with the water-cooled chiller is less compared with the air-cooled chiller. The use of water instead of air increases the efficiency of heat transfer from the condenser, thereby increasing the efficiency of the chiller.

However, due to the addition of a water loop, a circulation pump called condenser water pump is required, which increases the energy consumption under system pumps.

Save the simulation model with the water-cooled chiller to use in subsequent tutorials.

TUTORIAL 8.2 Evaluating the impact of variable speed drive (VSD) on a chiller

GOAL

To evaluate the impact of VSD on a centrifugal chiller on building energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Modelling the chiller with VSD

PROBLEM STATEMENT

In this tutorial, you are going to use the water-cooled chiller model saved in Tutorial 8.1 (50 m × 25 m model with 5 m perimeter depth, six floors).

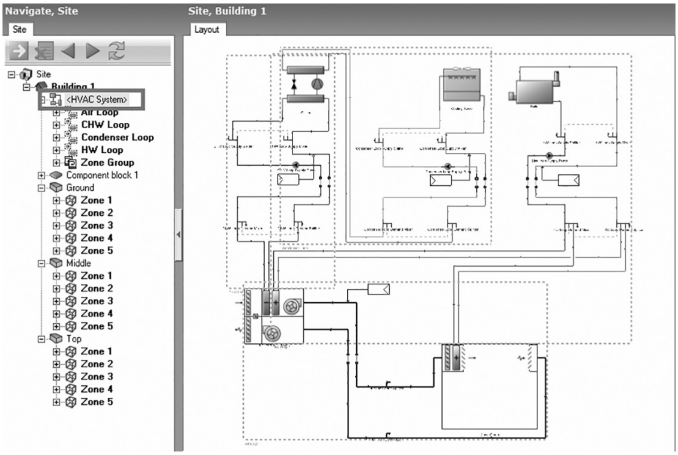
You need to select the following two chillers and find out energy consumption in both cases:

1. EIRchiller Centrifugal Carrier 19XR 1213kW/7.78COP/Vanes
2. EIRchiller Centrifugal Carrier 19XR 1143kW/6.57COP/VSD

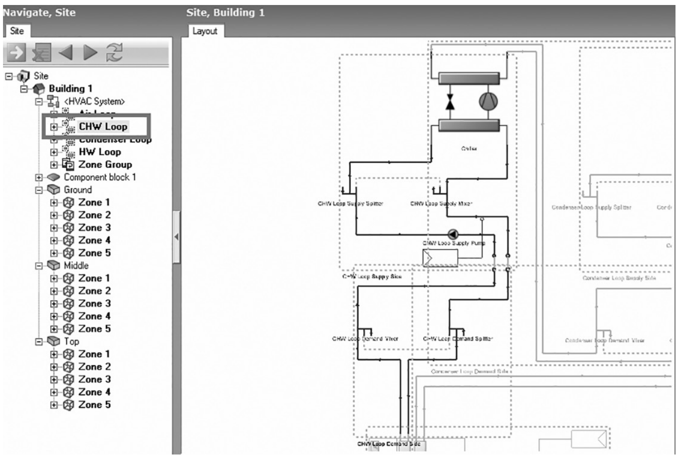
Use **AZ-PHOENIX/SKY HARBOR, USA** weather location.

SOLUTION

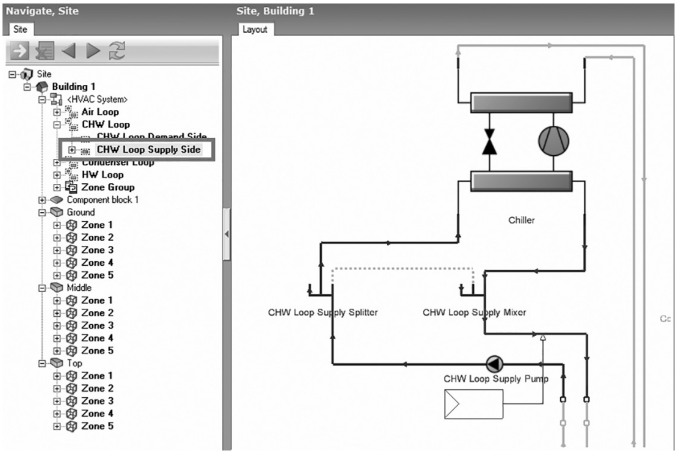
Step 1: Open the simulation model saved in Tutorial 8.1. Click <**HVAC System**> in the navigation pane.



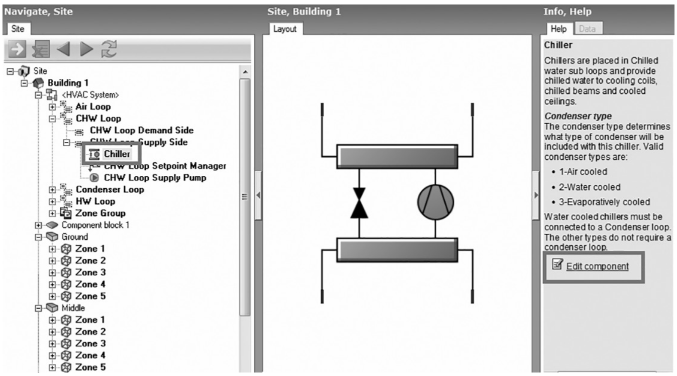
Step 2: Click **CHW Loop**. The components under the CHW loop appear.



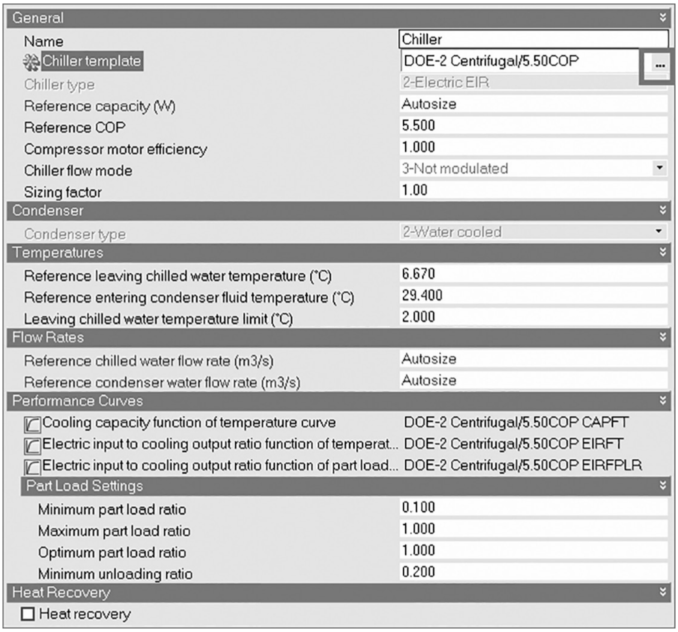
Step 3: Click **CHW Loop Supply Side**.



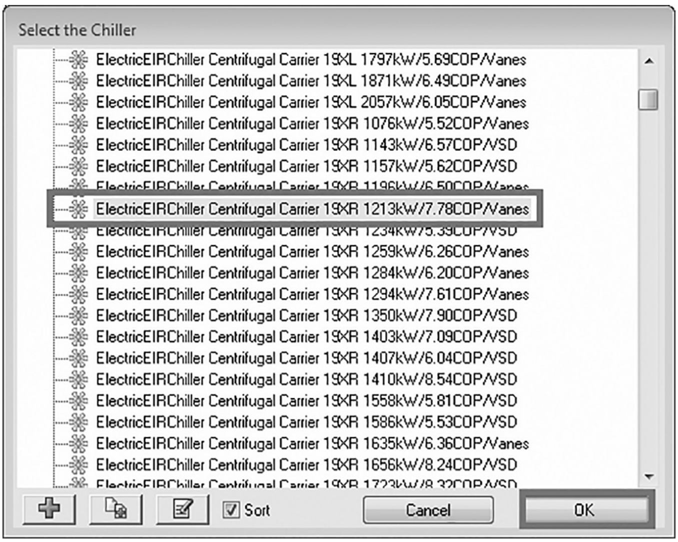
Step 4: Click **Chiller**. The chiller layout appears on the **Layout** tab. Click **Edit component** under the **Help** tab. The **Edit Chiller** screen appears.



Step 5: Click **DOE-2 Centrifugal/5.5COP**. Three dots (**…**) appear. Click the three dots. The **Select the Chiller** screen appears.

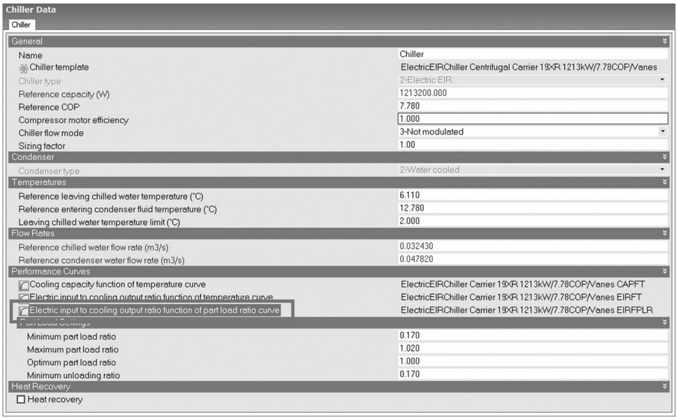


Step 6: Click **ElectricEIRChiller Centrifugal Carrier 19XR 1213kW/7.78COP/Vanes**.

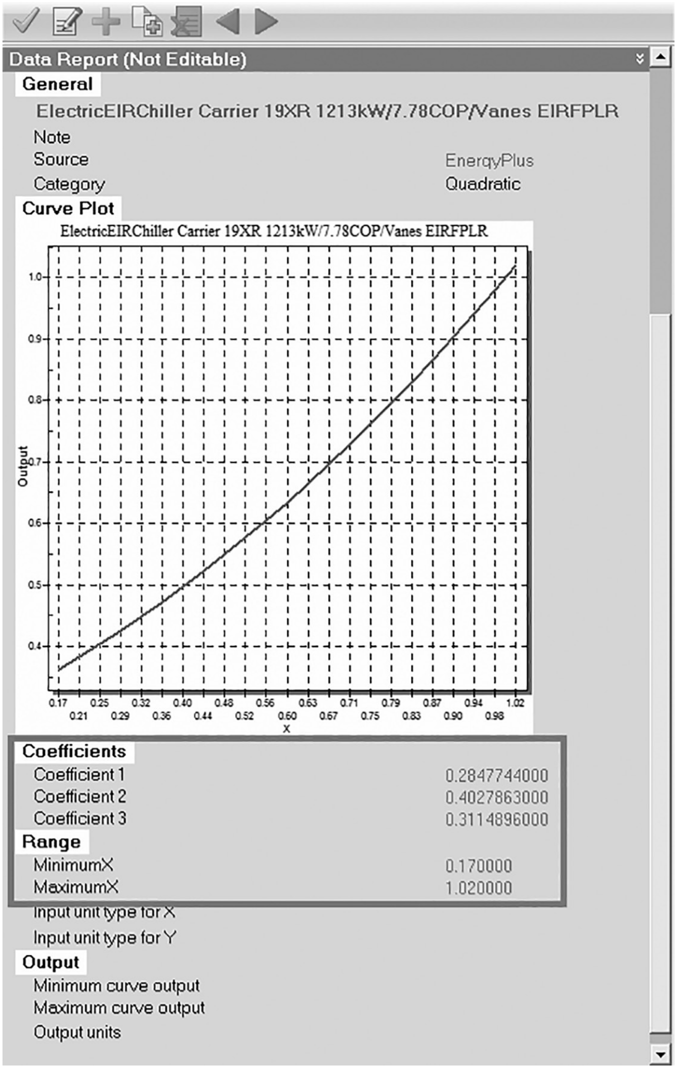


Step 7: Click **Electric input to cooling output ratio function of part load ratio curve**. EIR vs part load curve is displayed on the right side.

> Numerically, EIR (energy input ratio) is the inverse of COP. The part-load ratio is the ratio of actual cooling load delivered at any point of time compared to the chiller's cooling capacity.



You can also view the curve coefficients.



Performance Curves

Cooling capacity function of temperature curve
The biquadratic performance curve parameterizes the variation of the cooling capacity as a function of the leaving chilled water temperature and the entering condenser fluid temperature. The output of this curve is multiplied by the reference capacity to give the cooling capacity at specific temperature operating conditions (i.e. at temperatures different from the reference temperatures). The curve should have a value of 1.0 at the reference temperatures and flow rates specified above. The biquadratic curve should be valid for the range of water temperatures anticipated for the simulation.

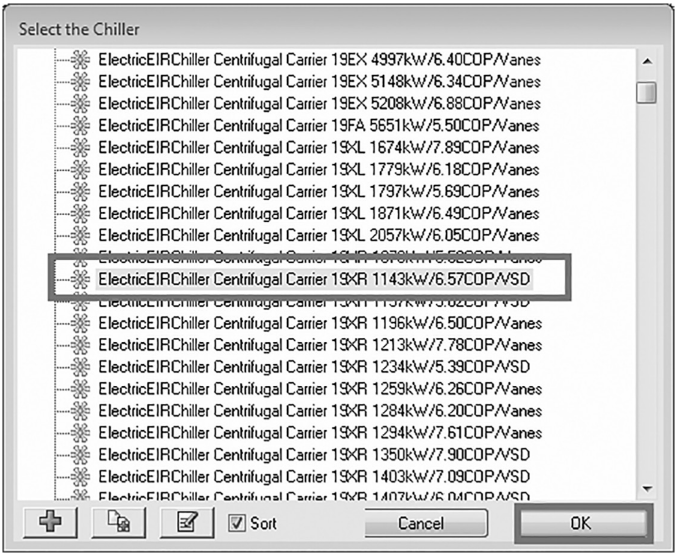
Electric input to cooling output ratio function of temperature curve
The biquadratic performance curve parameterizes the variation of the energy input to cooling output ratio (EIR) as a function of the leaving chilled water temperature and the entering condenser fluid temperature. The output of this curve is multiplied by the reference EIR (inverse of the reference COP) to give the EIR at specific temperature operating conditions (i.e. at temperatures different from the reference temperatures). The curve should have a value of 1.0 at the reference temperatures and flow rates specified above. The biquadratic curve should be valid for the range of water temperatures anticipated for the simulation.

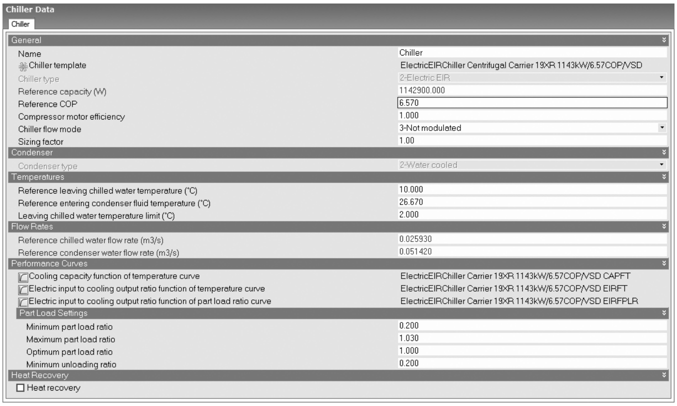
Electric input to cooling output ratio function of part load ratio curve
The quadratic performance curve parameterizes the variation of the EIR as a function of the part load ratio. The output of this curve is multiplied by the reference EIR (inverse of the reference COP) and the energy input to cooling output ratio function of temperature curve to give the EIR at the specific temperatures and part load ratio at which the chiller is operating. This curve should have a value of 1.0 when the part load ratio equals 1.0. The quadratic curve should be valid for the range of part load ratios anticipated for the simulation.

Source: http://www.designbuilder.co.uk/helpv4.7/Content/Performance_Curves.htm

Step 8: Perform annual simulation and record the results.

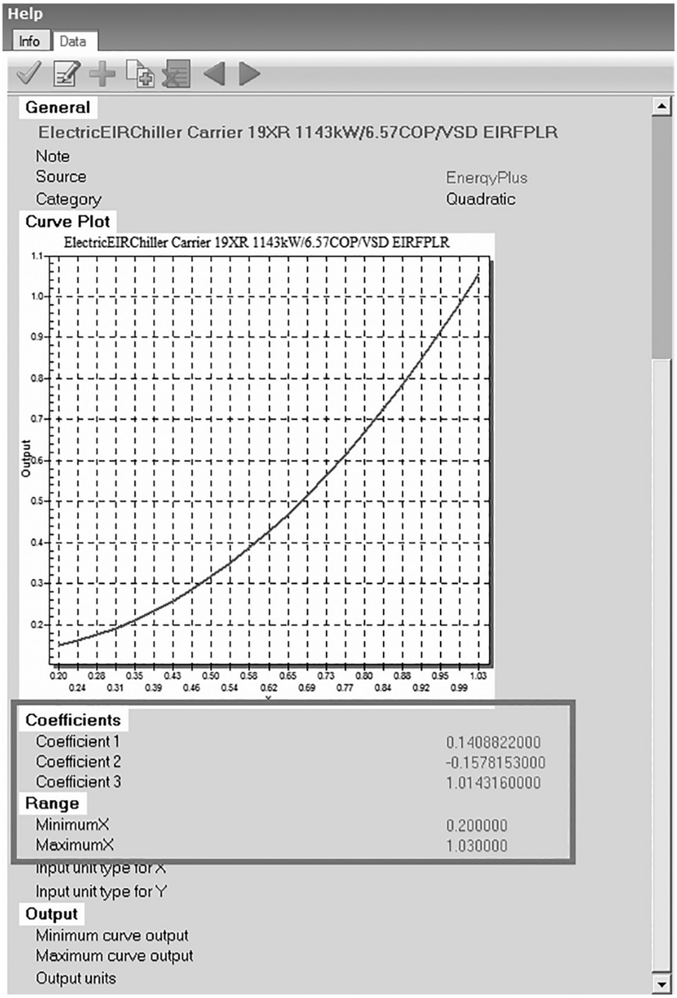
Step 9: Repeat the previous steps to select **ElectricEIRChiller Centrifugal Carrier 19XR 1143kW/6.57COP/VSD**.





VSD on the chiller provides you better efficiency while operating in part-load conditions.

You can also view the curve coefficients.



Step 10: Simulate the model and record the results.

Compare the energy consumption for both cases (Table 8.2).

Table 8.2 Effect of VSD on the chiller

	Annual energy consumption (kWh)	
	Chiller without VSD	Chiller with VSD
Room electricity	153,342.90	153,342.90
Lighting	221,613.80	221,613.80
System fans	168,257.40	168,257.40
System pumps	13,138.87	14,004.84
Heating (gas)	100,853.20	100,853.20
Cooling (electricity)	302,814.30	115,774.90
Heat rejection	80,947.34	82,738.82

There is a significant reduction in cooling energy consumption with the VSD chiller. If you want to analyse the results, you need to look at the cooling load profile of the building.

Installing VSD on the chiller provides you better efficiency while operating in part load conditions.

TUTORIAL 8.3 Evaluating the impact of VSD on a chilled water pump

GOAL

To evaluate the impact of VSD on a chilled water pump on the building energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Modelling the variable speed chilled water pump

PROBLEM STATEMENT

In this tutorial, you are going to use the water-cooled chiller model saved in Tutorial 8.1 (50 m × 25 m model with 5 m perimeter depth, six floors).

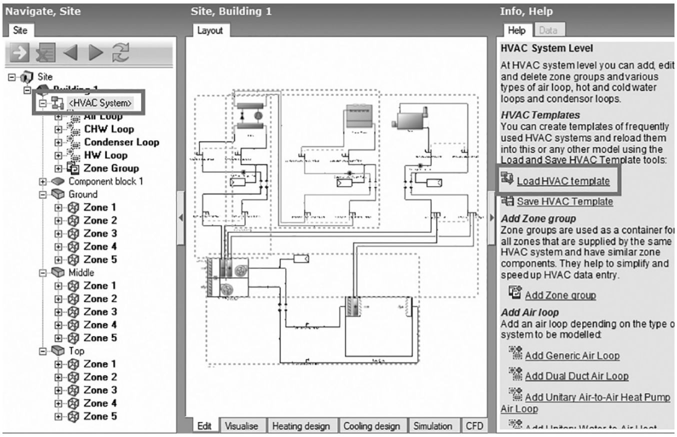
You need to select the following two configurations of the chilled water pump and compare energy consumption in both cases:

1. Constant flow
2. Variable flow

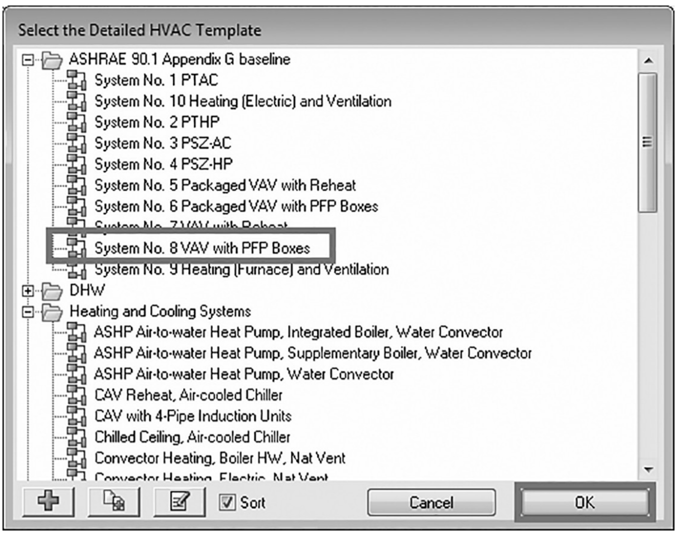
Use **FL – MIAMI, USA** weather location. Miami has a tropical monsoon climate with hot, humid summers and short, warm winters, with a marked drier season in the winter.

SOLUTION

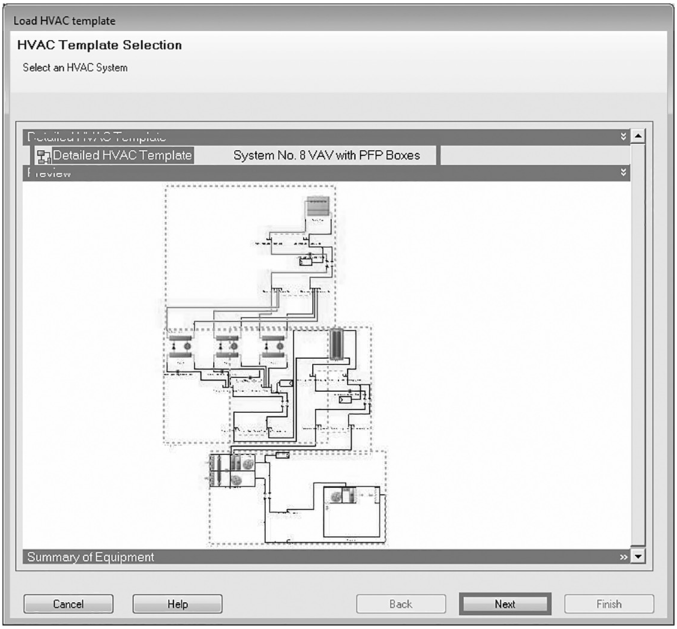
Step 1: Open the simulation model saved in Tutorial 8.1. Click <**HVAC System**> in the navigation pane. Click **Load HVAC template**.



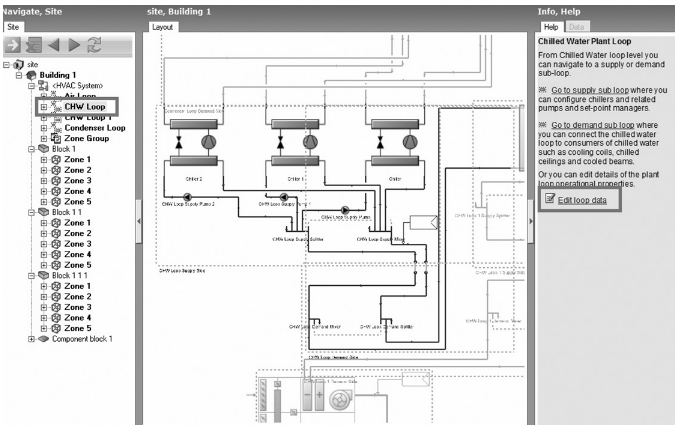
Step 2: Select **System No. 8 VAV with PFP Boxes** from ASHRAE 90.1 Appendix G baseline. Click **OK**. The **Load HVAC template** appears.



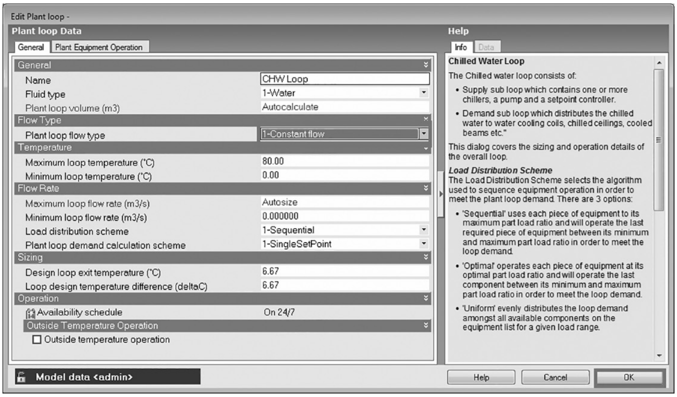
Step 3: Click **Next**. Select all the check boxes from the **Zones** section. Click **Finish**. It displays the system layout.



Step 4: Select **CHW Loop**. Click **Edit loop data** under the **Help** tab. The **Edit Plant loop** screen appears.

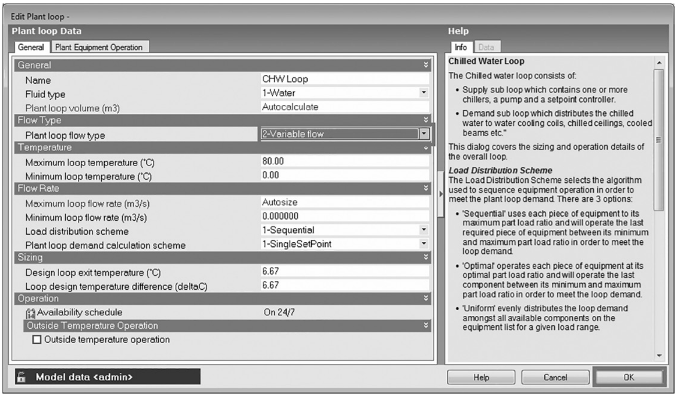


Step 5: Select **Constant flow** from the Plant loop flow type.



Step 6: Perform annual energy simulation and record the results.

Step 7: Repeat the previous steps for **Variable flow** CHW Loop.



Step 8: Perform annual energy simulation and record the results.

Save the simulation model to use in subsequent tutorials.

Compare the energy consumption in both cases (Table 8.3).

Table 8.3 Energy consumption for constant and variable flow on the chilled water pump

	Annual energy consumption (kWh)	
End-use category	Constant flow	Variable flow
Room electricity	153,342.90	153,342.90
Lighting	221,613.80	221,613.80
System fans	72,965.29	72,965.28
System pumps	255,151.10	235,740.20
Heating (electricity)	8,253.35	8,253.35
Cooling (electricity)	297,860.90	296,225.90
Heat rejection	117,246.00	117,093.10

You can observe that there is a reduction in pump energy, cooling energy and energy consumption for heat rejection. Where variable flow is used, it can be clearly seen that there is less energy consumption for system pumps. Also there is a small decrease in cooling energy consumption of chiller and heat rejection due to the change in operating conditions of the chiller.

TUTORIAL 8.4 Evaluating the impact of a cooling tower fan type

GOAL

To evaluate the impact of a cooling tower fan type on the building energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Modelling the cooling tower with a single speed fan
- Modelling the cooling tower with a double speed fan

PROBLEM STATEMENT

In this tutorial, you are going to use the variable flow model saved in Tutorial 8.3 (50 m × 25 m model with 5 m perimeter depth, six floors).

You need to select the following two configurations of the chilled water pump and find out energy consumption in both cases:

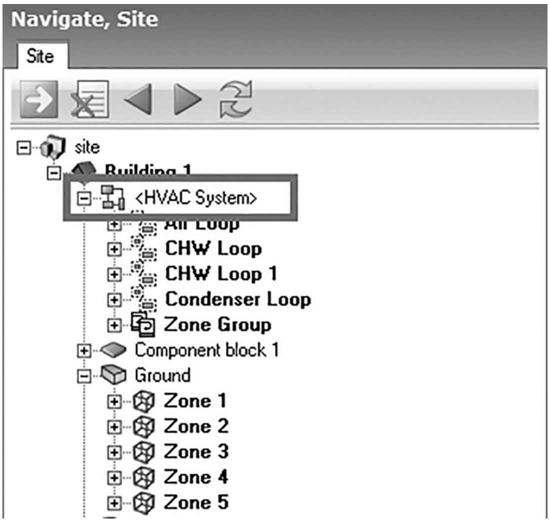
1. Single speed fan cooling tower
2. Double speed fan cooling tower

Use **AZ-PHOENIX/SKY HARBOR, USA** weather location.

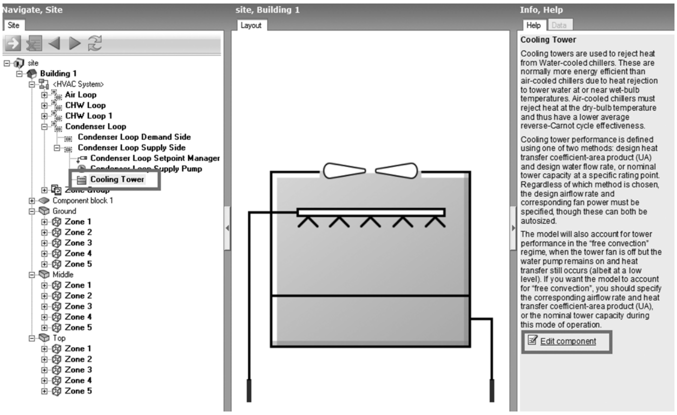
A cooling tower is an equipment that rejects heat extracted from the building to the atmosphere by the evaporation of water. Cooling tower fans help in governing the air flow and rate of evaporation.

SOLUTION

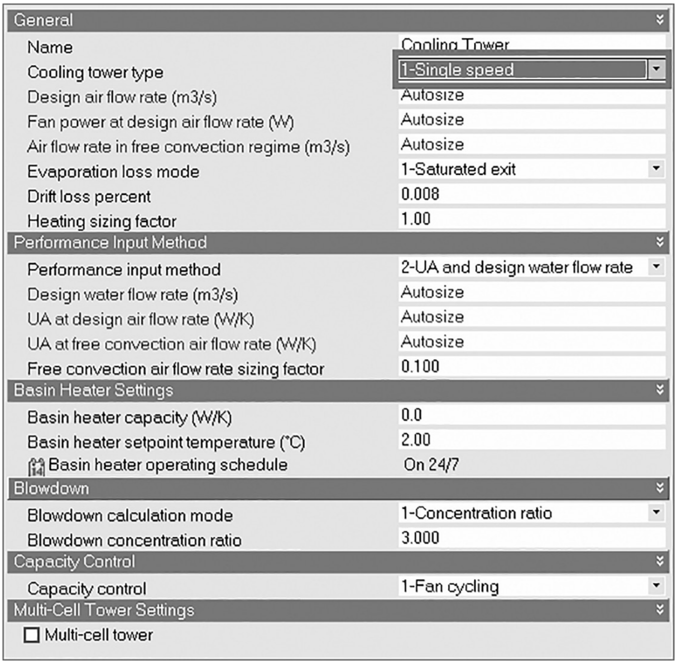
Step 1: Open the variable flow model saved in Tutorial 8.3. Expand **<HVAC System>** in the navigation pane.



Step 2: Select **Cooling Tower** under **Condenser Loop Supply Side**. Click **Edit component** under the **Help** tab. The **Edit Cooling Tower** screen appears.

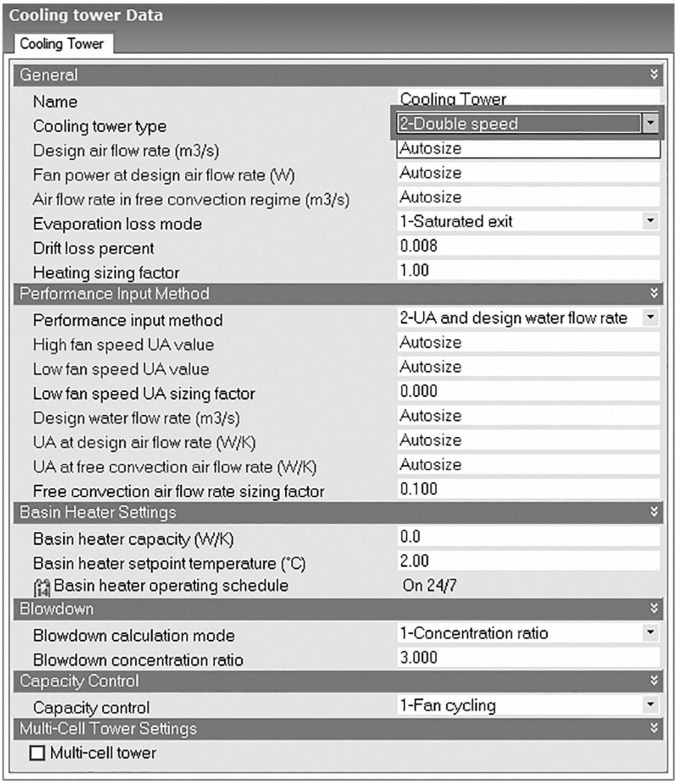


Step 3: Select **Single speed** for cooling tower type.



Step 4: Simulate the model and record the results.

Step 5: Repeat the previous steps to select **Double speed** cooling tower type.



Multi-speed/Variable Speed Drive (VSD) fan is the preferred method of capacity control for cooling towers. By matching the fan motor speeds to the required heat rejection, multi-speed/VSD cooling towers can significantly reduce energy consumption for heat rejection.

Step 6: Perform annual energy simulation and record the results.

Save the simulation model to be used in the next tutorial.

Compare results for both cases (Table 8.4).

Table 8.4 Energy consumption for single speed and double speed cooling tower fans

End-use components	Annual energy consumption (kWh) Single speed cooling tower fan	Double speed cooling tower fan
Room electricity	153,342.90	153,342.90
Lighting	221,613.80	221,613.80
System fans	95,181.46	95,181.46
System pumps	165,284.00	165,284.00
Heating (electricity)	52,254.34	52,254.34
Cooling (electricity)	202,158.00	202,158.00
Heat rejection	82,768.20	28,458.18

You can observe from the results that there is a significant reduction in energy consumption under heat rejection.

TUTORIAL 8.5 Evaluating the impact of condenser water pump with VSD

GOAL

To evaluate the impact of using VSD with a condenser water pump on the building energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Modelling VSD on the condenser water pump

PROBLEM STATEMENT

In this tutorial, you are going to use the double speed model saved in Tutorial 8.4 (50 m × 25 m model with 5 m perimeter depth, six floors).

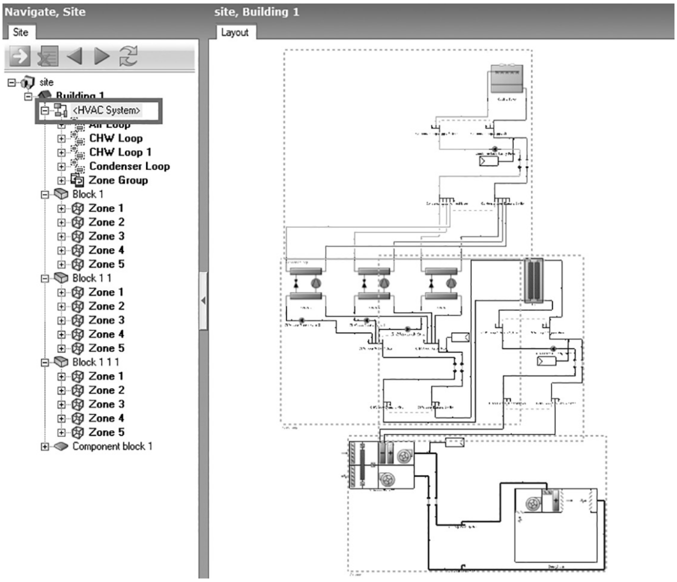
You need to select the following two configurations of the condenser water pump and find out energy consumption in both cases:

1. One speed condenser water pump
2. Variable speed condenser water pump

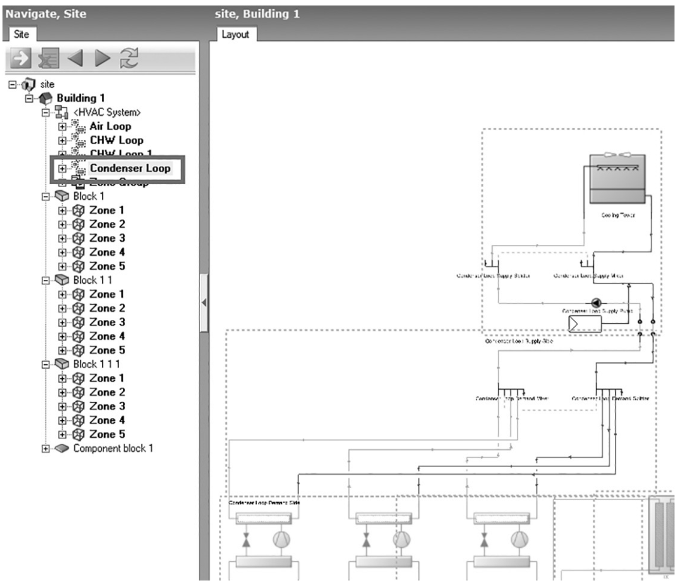
Use **FL – MIAMI, USA** weather location.

SOLUTION

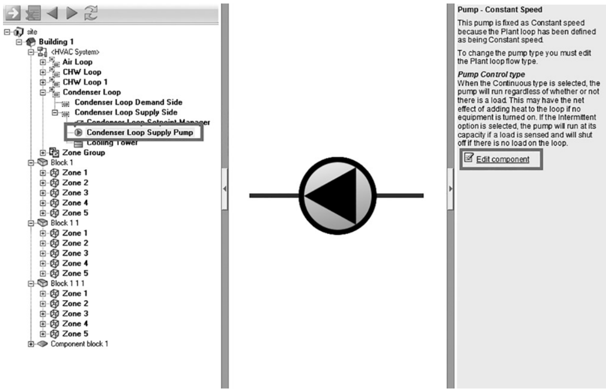
Step 1: Open the double speed model saved in Tutorial 8.4. Expand **<HVAC System>** in the navigation pane.



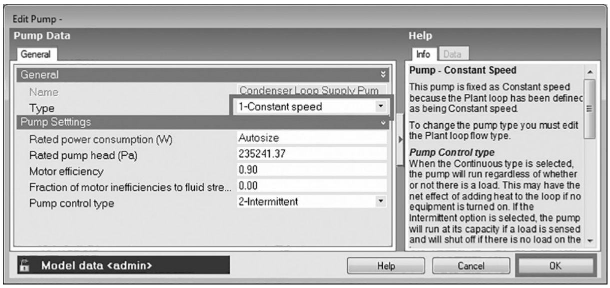
Step 2: Click **Condenser Loop**. It displays a condenser loop diagram in the **Layout** tab.



Step 3: Click **Condenser Loop Supply Pump**. Click **Edit component** under the **Help** tab. The **Edit Pump** screen appears.

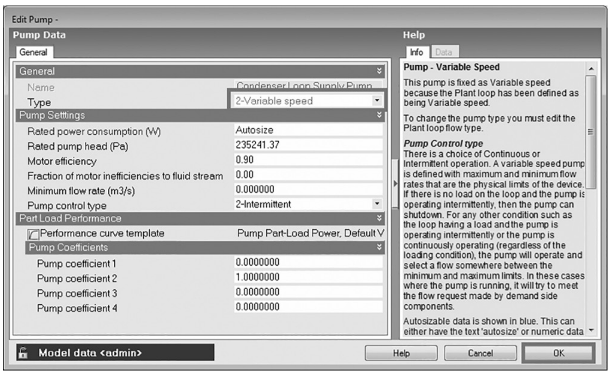


Step 4: Select **Constant speed** from the **Type** drop-down list. Click **OK**.



Step 5: Simulate the model and record the results.

Step 6: Repeat the previous steps to select **Variable speed** from the **Type** drop-down list.



Step 7: Simulate the model and record the results.

Table 8.5 Energy consumption for the single speed and variable speed condenser water pumps

	Annual energy consumption (kWh)	
End-use category	Single speed condenser water pump	Variable speed condenser water pump
Room electricity	153,342.90	153,342.90
Lighting	221,613.80	221,613.80
System fans	72,965.28	72,965.28
System pumps	235,740.20	110,578.00
Heating (electricity)	8,253.35	8,253.35
Cooling (electricity)	296,225.90	295,302.80
Heat rejection	117,093.10	110,880.00

Compare energy consumption for both cases (Table 8.5).

A reduction in energy consumption under system pumps can be seen in the case of a variable speed condenser water pump. A small reduction in energy consumption for heat rejection can also be seen.

TUTORIAL 8.6 Evaluating the impact of an air-side economiser

GOAL

To evaluate the impact of an air-side economiser on building energy performance.

WHAT ARE YOU GOING TO LEARN?

- Modelling the air-side economiser (free cooling system)

PROBLEM STATEMENT

In this tutorial, you are going to use the variable flow model saved in Tutorial 8.3 (50 m × 25 m model with 5 m perimeter depth, six floors).

Model the unitary HVAC system with the following options for the air-side economiser:

1. None
2. Fixed dry bulb temperature based
3. Fixed enthalpy based

Find the change in energy consumption for all three cases.

Use **New Delhi/Palam, India** weather location. The climate of New Delhi is a monsoon-influenced humid subtropical climate with high variation between summer and winter in terms of both temperature and rainfall. The temperature varies from 46°C in summers to around 0°C in winters.

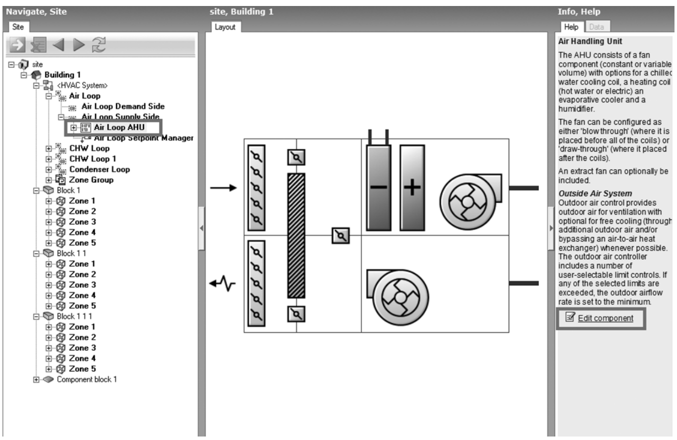
An economiser is an adjustable fresh air intake unit that can draw up to 100% outside air when the outside air is cooler than the temperature inside the building and not humid, thereby providing free cooling.

Air-side economisers in HVAC can save energy in buildings by using cool outside air to cool the indoor space. When the temperature and/or enthalpy of the outside air is less than the temperature/enthalpy of the recirculated air, conditioning the outside air is more energy efficient than conditioning recirculated air. When the outside air is both sufficiently cool and dry (depending on the climate), no additional conditioning is required; this portion of the air-side economiser control scheme is called free cooling.

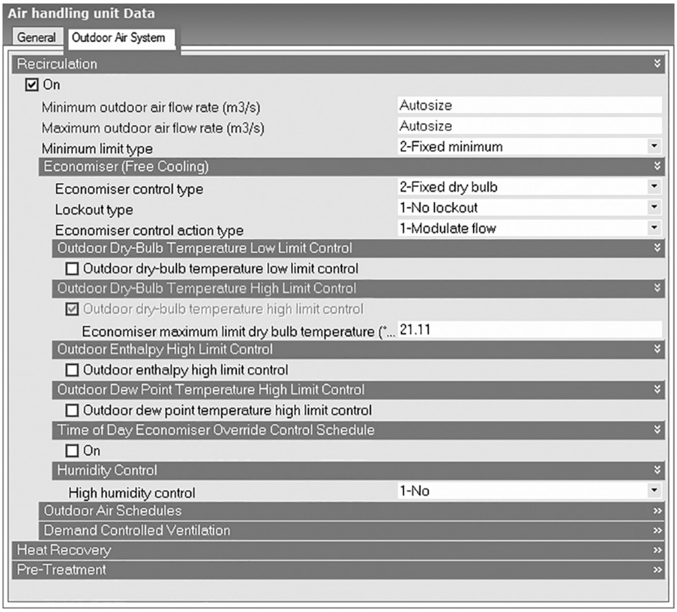
SOLUTION

Step 1: Open the variable flow model saved in Tutorial 8.3.

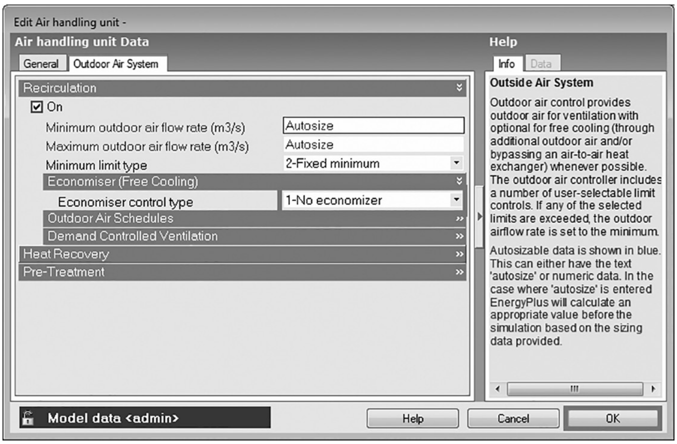
Step 2: Click **Air Loop AHU**. Click **Edit component** under the **Help** tab. The **Air handling unit Data** screen appears.



Step 3: Select the **Outdoor Air System** tab.



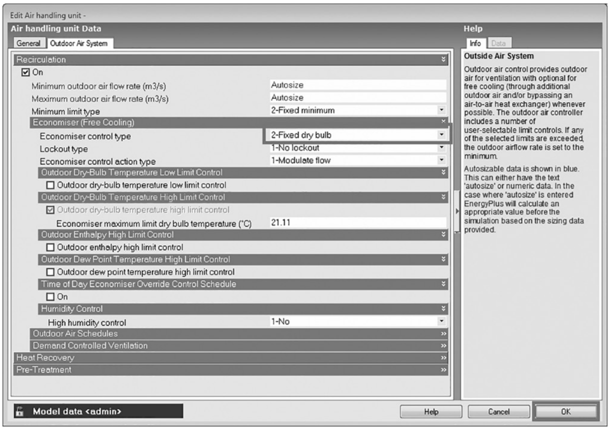
Step 4: Select **No economiser** from the **Economiser control type** drop-down menu under **Economiser (Free Cooling)**.



Step 5: Simulate the model and record the results.

Repeat the previous steps to select the fixed dry bulb air-side economiser control type.

Step 6: Select **Fixed dry bulb** from the Economiser control type drop-down menu under Economiser (Free Cooling).



Step 7: Simulate the model and record the results.

Repeat the previous steps to select fixed enthalpy air-side economiser control type.

Step 8: Select **Fixed enthalpy** from the Economiser control type drop-down menu under Economiser (Free Cooling).

Enthalpy is the total heat content of the air. This covers the combined effect of temperature and humidity.

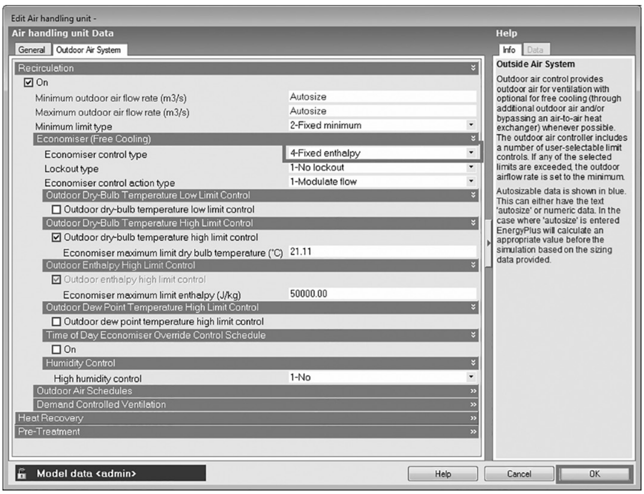


Table 8.6 Energy consumption for no, fixed DBT and fixed enthalpy-based economisers

	Annual energy consumption (kWh)		
End-use category	No economiser	Fixed dry bulb temperature-based economiser	Fixed enthalpy-based economiser
Room electricity	153,342.90	153,342.90	153,342.90
Lighting	221,613.80	221,613.80	221,613.80
System fans	92,796.03	92,794.31	92,793.84
System pumps	244,590.30	196,796.50	196,773.80
Heating (electricity)	29,138.51	33,129.39	33,129.37
Cooling (electricity)	313,250.80	289,159.50	288,984.30
Heat rejection	80,399.58	80,292.47	80,233.80

Step 9: Simulate the model and record the results. Compare the results (Table 8.6).

You can observe that application of free cooling leads to reduction in annual cooling energy consumption. Enthalpy type air-side economiser leads to higher energy savings as compared to a dry bulb type economiser. There is a reduction in energy consumption of all the HVAC components, namely, cooling, pumps and heat rejection.

Save the model with no economiser for use in further tutorials.

Exercise

Compare the energy savings in **Miami**, **Florida** and **London Gatwick** using both types of air-side economisers.

TUTORIAL 8.7 Evaluating the impact of supply air fan operation mode during unoccupied hours

GOAL

To evaluate the impact of fan operation mode during unoccupied hours on energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Changing fan operation mode during unoccupied hours

PROBLEM STATEMENT

In this tutorial, you are going to use the No economiser model saved in Tutorial 8.6 (50 m × 25 m model with 5 m perimeter depth, six floors).

You need to simulate the model with the following two options for **New Delhi/Palam, India** weather location for supply air fan operation:

1. Stay off
2. Cycle on any

Find energy consumption in both cases.

Applicability schedule (night cycle)
This schedule determines whether or not for a given time period this mechanism is to be applied. Schedule values greater than zero (usually 1 is used) indicate the night cycle mechanism is to be applied, whereas schedule values less than or equal to zero (usually 0 is used) denote that it is not used for this time period.

Control type
The possible inputs are as follows:

- **Stay off** means that the night cycle mechanism will have no effect – AHU on/off will be determined by the fan schedule.
- **Cycle on any** means that if any zone served by the air loop incorporating this AHU has an air temperature outside the cooling or heating setpoints, the central fan will turn on even though the fan schedule indicates the fan is off.

(*Continued*)

This setting is used to enable cycling of an air system when one or more zones become too hot or too cold. A common requirement for this mechanism is where the AHU is turned off at night. However, if the building gets too cold, there might be condensation on the walls and other damage. Thus, the control system is usually programmed to turn the system on if either a specified control thermostat or any thermostat shows a zone temperature of less than a nighttime setpoint. Similarly, there might be a concern about a building getting too hot. Again the control system is programmed to turn the AHU back on if one or any zone temperature exceeds a nighttime cooling setpoint.

This mechanism offers considerable flexibility in determining how the nighttime on/off decision will be made. The temperature in one specific zone may be used or the temperatures in all the zones connected to the AHU may be sampled. You can specify a temperature tolerance and a run time for the system once it switches on. There is also an applicability schedule for scheduling when this mechanism may be applied.

Source: http://www.designbuilder.co.uk/helpv4.7/#Generic_AHU.htm?Highlight=Generic Air Handling Unit (AHU)

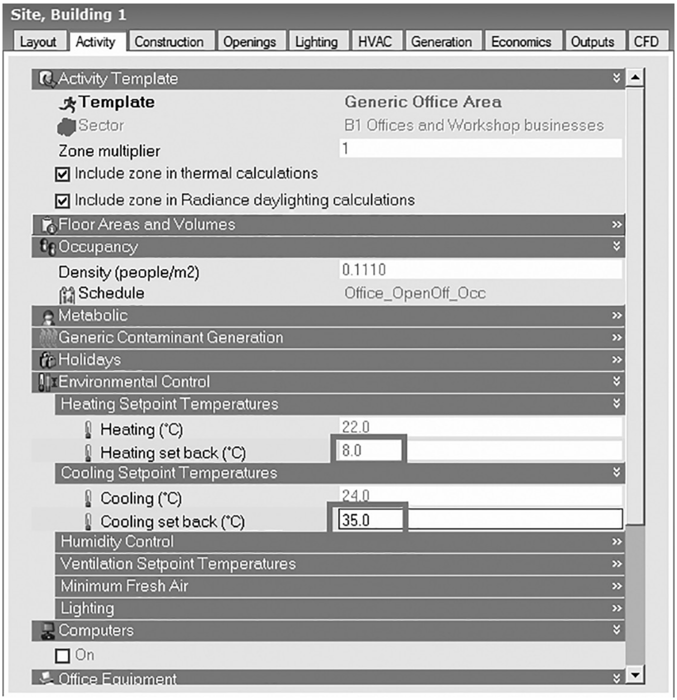
Heating setback setpoint temperature
Some buildings require a low level of heating during unoccupied periods to avoid condensation/frost damage or to prevent the building from becoming too cold and to reduce peak heating requirements at start-up. Enter the setpoint temperature to be used at nighttime, weekends and other holidays during the heating season.

Cooling setback setpoint temperature
Some buildings require a low level of cooling during unoccupied periods to prevent the building from becoming too hot and to reduce the start-up cooling load the next morning. Enter the setpoint temperature to be used at nighttime, weekends and other holidays during the cooling season.

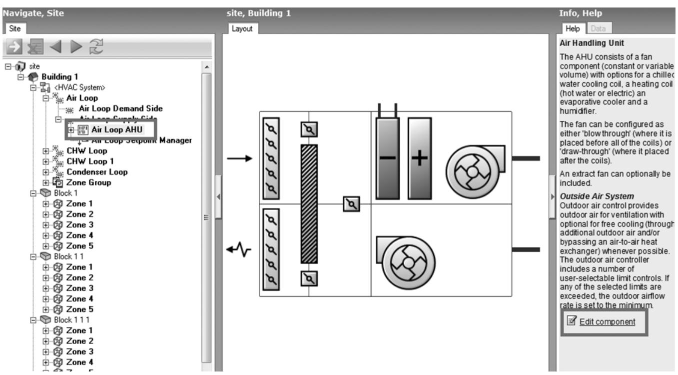
Source: http://www.designbuilder.co.uk/helpv4.7/Content/_Environmental_comfort.htm

SOLUTION

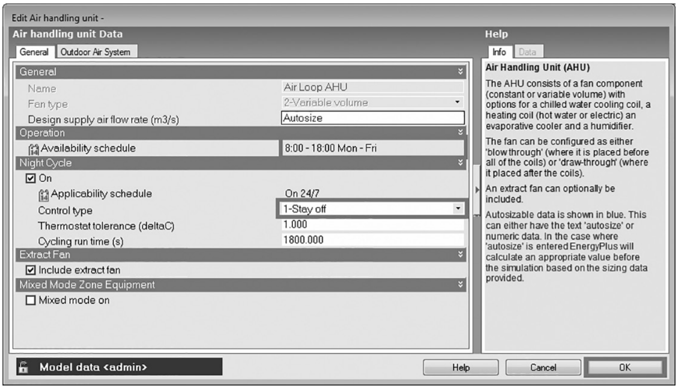
Step 1: Open the fixed dry bulb model saved in Tutorial 8.6. Enter **8.0** in Heating set back (°C) and **35.0** in Cooling set back (°C) text boxes in the **Activity** tab.



Step 2: Click **Air Loop AHU** in the navigation tree. Click **Edit component** under the **Help** tab. The **Edit Air handling unit** screen appears.

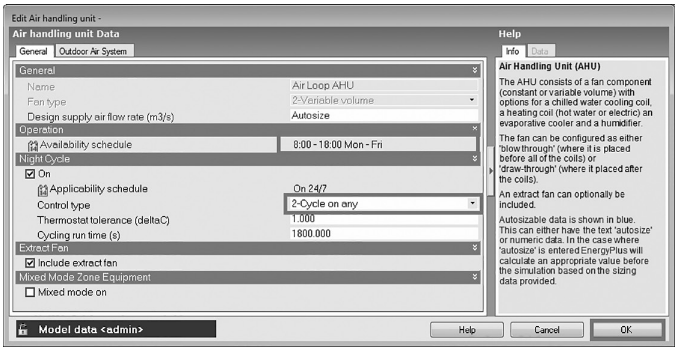


Step 3: Under the Night Cycle section, select **Stay off** from the **Control type** drop down menu and select **8:00 - 18:00 Mon - Fri** under the **Operation** section and make sure **Heat Recovery** check box is clear under **Outdoor Air System** tab.



Step 4: Simulate the model and record the results.

Step 5: Repeat the previous steps to select **Cycle on any** from the **Control type** drop down menu and select **8:00 - 18:00 Mon - Fri** under the **Operation** section.



Step 6: Simulate the model and record the results.

Compare the results (Table 8.7).

You can observe that there is an increase in systems fans, cooling and heating energy consumption. This is due to the reason that when the **Cycle on any** option is selected, fan runs for additional duration in unoccupied hours.

Table 8.7 Energy consumption in changing supply air fan operating mode

	Annual energy consumption (kWh)	
End-use categories	Stay off	Cycle on any
Room electricity	153,342.90	153,342.90
Lighting	221,613.80	221,613.80
System fans	36,524.22	61,160.97
System pumps	4,894.60	11,862.04
Heating (electricity)	161.73	32,574.40
Cooling (electricity)	149,971.20	258,275.00
Heat rejection	17,444.70	40,430.50

Codes such as ASHRAE 90.1-2010 Appendix G, requires that schedules for HVAC fans, which provide outdoor air for ventilation, shall run continuously whenever spaces are occupied and shall be cycled on and off to meet heating and cooling loads during unoccupied hours.

TUTORIAL 8.8 Evaluating the impact of heat recovery between fresh and exhaust air

GOAL

To evaluate the impact of recovering heat between fresh air intake and exhaust on building energy performance.

WHAT ARE YOU GOING TO LEARN?

- Modelling the heat recovery system

PROBLEM STATEMENT

In this tutorial, you are going to use the air-cooled chiller model saved in Tutorial 8.1 (50 m × 25 m model with 5 m perimeter depth, six floors).

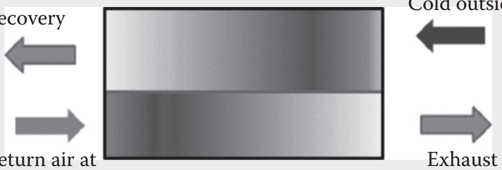
You need to simulate the model with the following three options:

1. No heat recovery
2. Sensible heat recovery
3. Enthalpy-based heat recovery

Find out energy for all the cases.

Use **New Delhi/Palam, India** weather location.

Energy recovery ventilation is the energy recovery process of exchanging the energy contained in air exhausted from building or space air and using it to treat (precondition) the incoming outdoor ventilation air in HVAC systems. Air-to-air energy recovery reduces energy use and can significantly reduce heating and cooling system sizes. The driving force behind the exchange is the difference in temperatures between the opposing air streams, which is also called the thermal gradient.



There are two types of heat recovery:

1. Sensible
2. Enthalpy (The enthalpy of moist and humid air includes the enthalpy of the dry air – the sensible heat and the enthalpy of the evaporated water – the latent heat.)

Sensible heat recovery is possible by the use of fixed plate heat exchangers. A fixed plate heat exchanger has no moving parts, and consists of alternating layers of plates that are separated and sealed. Typical flow is cross current, and since the majority of plates are solid and non-permeable, sensible only transfer is the result. Sensible heat recovery is also possible through a rotating wheel heat exchanger.

Enthalpy heat recovery is possible by the use of a rotating wheel heat exchanger. Rotating wheel heat exchanger is composed of a rotating cylinder filled with an air permeable material resulting in a large surface area. The surface area is the medium for the sensible energy transfer. As the wheel

(*Continued*)

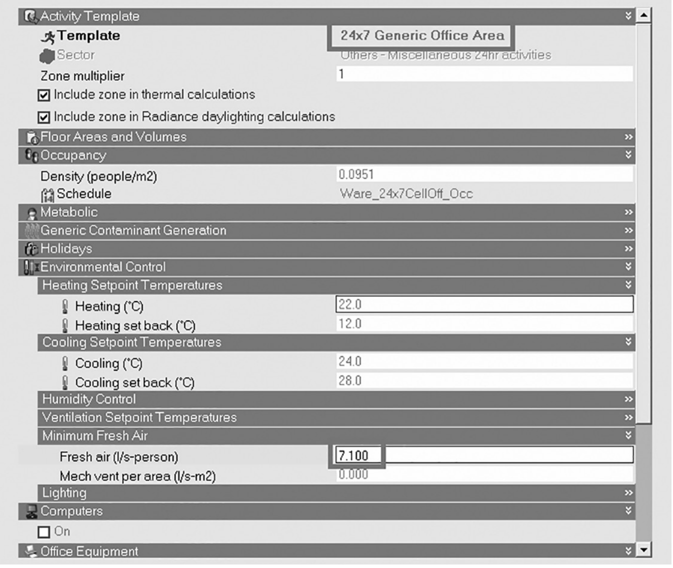
rotates between the ventilation and exhaust air streams, it picks up heat energy and releases it into the colder air stream.

The enthalpy exchange is accomplished through the use of desiccants. Desiccants transfer moisture through the process of adsorption that is predominantly driven by the difference in the partial pressure of vapour within the opposing air streams. Typical desiccants consist of silica gel and molecular sieves.

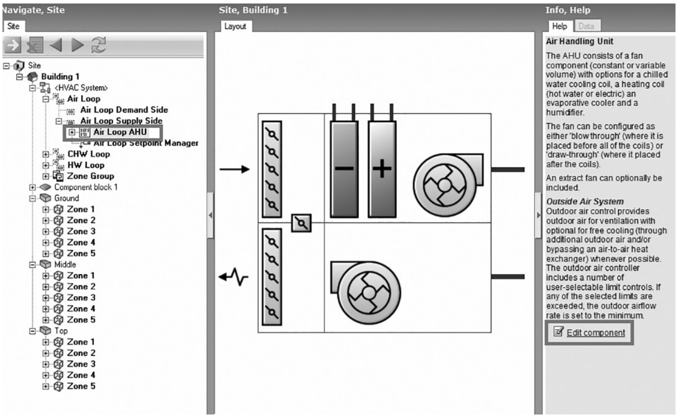
Source: http://www.designbuilder.co.uk/helpv4.7/Content/Unitary_Heat_Recovery.htm

SOLUTION

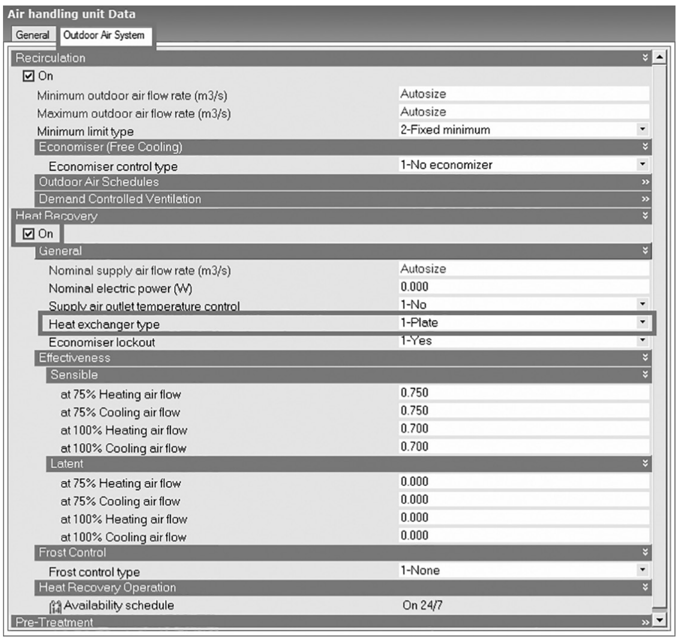
Step 1: Open the air-cooled chiller model saved in Tutorial 8.1. Select the **Activity** tab. Enter **7.100** in the **Fresh air (l/s-person)** text box in the **Minimum Fresh Air** tab and select **24×7 Generic Office Area** as Template.



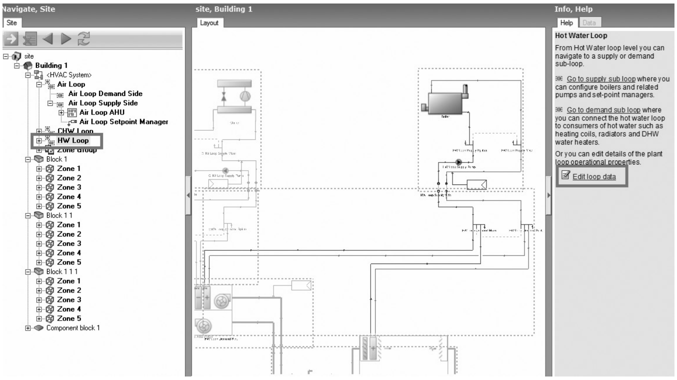
Step 2: Click **Air Loop AHU** in the navigation tree. Click **Edit component** under the **Help** tab. The **Edit Air Handling Unit Data** screen appears.



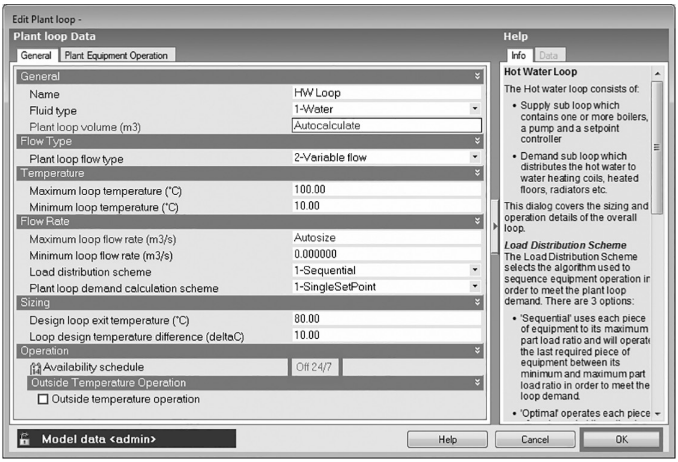
Step 3: Select the **Outdoor Air System** tab. Select the **On** checkbox under **Heat Recovery**. Make sure that **Plate** is selected from the **Heat exchanger type** drop-down list.



Step 4: Click **HW Loop** in the navigation tree. Click **Edit loop data** under the **Help** tab. The **Edit Plant loop** screen appears.

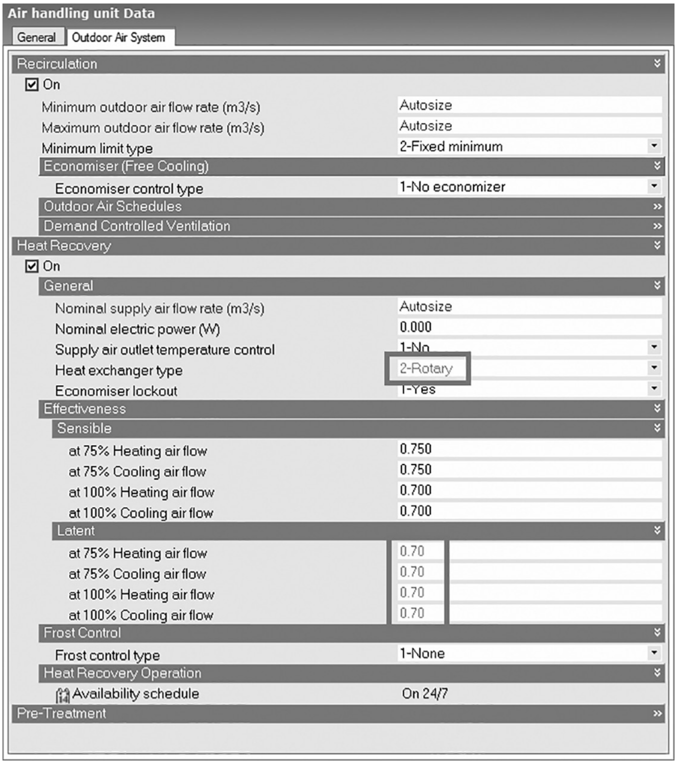


Step 5: Select **Off 24/7** in the **Availability schedule**. Click **OK**.



Step 6: Simulate the model and record the results.

Step 7: Select **Rotary** from the **Heat exchanger type** drop-down list. Enter **0.70** under **Latent effectiveness**. Click **OK**.



Step 8: Simulate the model and record the results.

Step 9: Simulate the model and record the results without heat recovery. You can do it by clearing the **On** check box under the **Heat Recovery** section. Click **OK**.

Compare the results (Table 8.8).

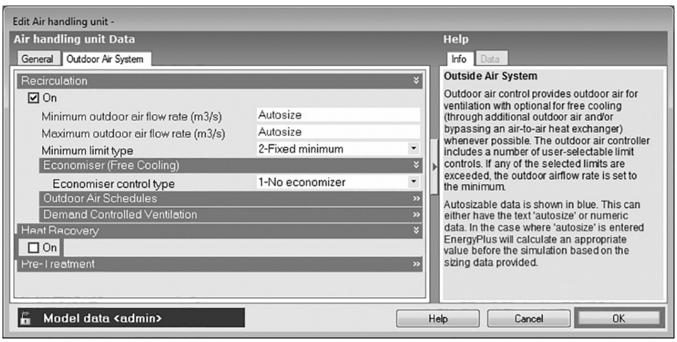


Table 8.8 Effect of exhaust air heat recovery in the HVAC system

	Annual energy consumption (kWh)		
	None	Sensible heat recovery	Enthalpy heat recovery
Room electricity	271,405.70	271,405.70	271,405.70
Lighting	619,839.30	619,839.30	619,839.30
System fans	186,069.30	186,036.80	186,031.70
System pumps	2,306.85	2,264.16	1,989.80
Cooling (electricity)	630,411.30	613,200.20	578,378.80

You can observe that there is a decrease in cooling energy consumption with sensible heat recovery. Use of enthalpy heat recovery gives higher savings.

Generally, there is an increase in fan energy consumption with the heat recovery system. This is due to the increase in static pressure of the fan for the heat recovery wheel. To model this effect in the compact option, you need to change the fan pressure rise.

Building an air conditioning system requires fresh air supply to maintain indoor air quality. There are different standards such as ASHRAE 60.1-2010 that specify minimum fresh air requirements in different space types. In a cold climate, the temperature of fresh air is lower than the exhaust air (which is nearly at the room temperature). Bringing fresh air temperature from low to room temperature requires heating energy. Similarly, in hot climates bringing fresh air temperature from hot to room temperature requires cooling energy. Recovering heat/coolth from outgoing air offers energy saving opportunity.

Nominal electric power
This is the electric consumption rate of the device (W). Electric power is considered constant whenever the unit operates. This numeric input can be used to model electric power consumption by controls (transformers, relays, etc.) and/or a motor for a rotary heat exchanger. None of this electric power contributes thermal load to the supply or exhaust air streams. The default value for this field is 0.

Economiser lockout
This input denotes whether the heat exchanger unit is locked out (bypassed for plate type heat exchangers or the rotation is suspended for rotary type heat exchangers) when the air-side economiser is operating. Both the economiser and high humidity control activate the heat exchanger lockout as specified by this input. The input choices are **Yes** (meaning locked out) or **No**.

Sensible effectiveness at 100% heating air flow
The sensible heat exchange effectiveness at the heating condition defined in the above table with both the supply and exhaust air volume flow rates is equal to 100% of the nominal supply air flow rate specified in the previous input field. The default value for this field is 0.

Latent effectiveness at 100% heating air flow
The latent heat exchange effectiveness at the heating condition defined in the Operating Conditions for Defining Heat Exchanger Performance table with both the supply and exhaust air volume flow rates is equal to 100% of the nominal supply air flow rate. Specify this value as 0.0 if the heat exchanger does not transfer latent energy. The default value for this field is 0.

Sensible effectiveness at 75% heating air flow
The sensible heat exchange effectiveness at the heating condition defined in the Operating Conditions for Defining Heat Exchanger Performance table with both the supply and exhaust air volume flow rates is equal to 75% of the nominal supply air flow rate. The default value for this field is 0.

Latent effectiveness at 75% heating air flow
The latent heat exchange effectiveness at the heating condition defined in the Operating Conditions for Defining

(*Continued*)

Heat Exchanger Performance table with both the supply and exhaust air volume flow rates is equal to 75% of the nominal supply air flow rate. Specify this value as 0.0 if the heat exchanger does not transfer latent energy. The default value for this field is 0.

Sensible effectiveness at 100% cooling air flow
The sensible heat exchange effectiveness at the cooling condition defined in the Operating Conditions for Defining Heat Exchanger Performance table with both the supply and exhaust air volume flow rates is equal to 100% of the nominal supply air flow rate. The default value for this setting is 0.

Latent effectiveness at 100% cooling air flow
The latent heat exchange effectiveness at the cooling condition defined in the Operating Conditions for Defining Heat Exchanger Performance table with both the supply and exhaust air volume flow rates is equal to 100% of the nominal supply air flow rate. Specify this value as 0.0 if the heat exchanger does not transfer latent energy. The default value for this setting is 0.

Sensible effectiveness at 75% cooling air flow
The sensible heat exchange effectiveness at the cooling condition defined in the Operating Conditions for Defining Heat Exchanger Performance table with both the supply and exhaust air volume flow rates is equal to 75% of the nominal supply air flow rate. The default value for this setting is 0.

Latent effectiveness at 75% cooling air flow
The latent heat exchange effectiveness at the cooling condition defined in the Operating Conditions for Defining Heat Exchanger Performance table with both the supply and exhaust air volume flow rates is equal to 75% of the nominal supply air flow rate. Specify this value as 0.0 if the heat exchanger does not transfer latent energy. The default value for this field is 0.

Source: http://www.designbuilder.co.uk/helpv4.7/#Generic_AHU.htm?Highlight=Generic AHU.htm

Exercise

Repeat the tutorial for Montreal, Canada climate.

TUTORIAL 8.9 Evaluating the impact of boiler nominal thermal efficiency

GOAL

To evaluate the impact of boiler efficiency on building energy performance.

WHAT ARE YOU GOING TO LEARN?

- Changing boiler efficiency

PROBLEM STATEMENT

In this tutorial, you are going to use the air-cooled chiller model saved in Tutorial 8.1 (50 m × 25 m model with 5 m perimeter depth, six floors).

You need to simulate the model with the following boiler efficiencies ranging from 0.89 to 0.95 in increment of 0.02. Find out energy consumption for all the cases.

Use **PARIS-AEROPORT CHAR, France** weather location.

Nominal thermal efficiency
This is the heating efficiency (as a fraction between 0 and 1) of the boiler's burner relative to the higher heating value (HHV) of fuel at a part load ratio of 1.0. Manufacturers typically specify the efficiency of a boiler using the higher heating value of the fuel. For the rare occurrences when a manufacturer's (or particular data set) thermal efficiency is based on the lower heating value (LHV) of the fuel, multiply the thermal efficiency by the lower-to-higher heating value ratio. For example, assume that a fuel's lower and higher heating values are approximately 45,450 and 50,000 kJ/kg, respectively. For a manufacturer's thermal efficiency rating of 0.90 (based on the LHV), the nominal thermal efficiency entered here is 0.82 (i.e. 0.9 multiplied by 45,450/50,000).

Heating value: The amount of heat produced by a complete combustion of fuel and it is measured as a unit of energy per unit mass or volume of substance (e.g. kcal/kg, kJ/kg, J/mol and Btu/m^3).

(*Continued*)

HHV is defined as the gross calorific value, defined as the amount of heat released when fuel is combusted and the products have returned to a temperature of 25°C. The heat of condensation of the water is included in the total measured heat.

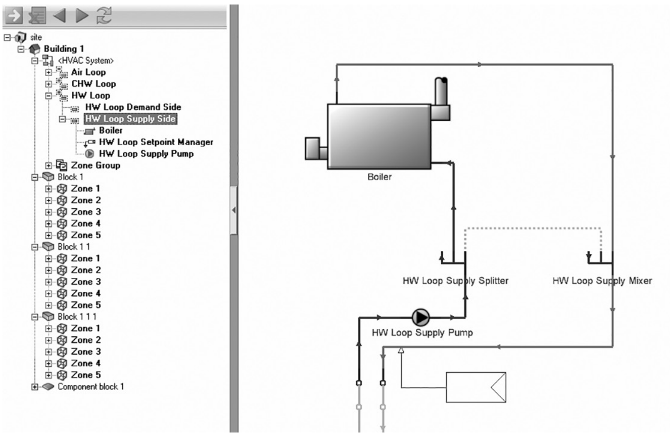
The LHV is defined as the net calorific value and is determined by subtracting the heat of vaporization of water vapour (generated during combustion of fuel) from the HHV.

Source: http://www.designbuilder.co.uk/helpv4.7/#Boilers.htm

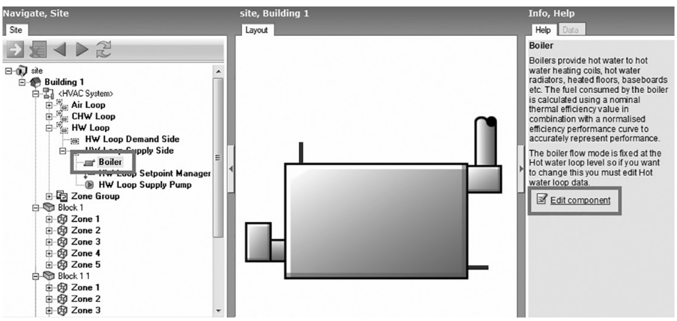
SOLUTION

Step 1: Open the simulation model created in Tutorial 8.1 with an air-cooled chiller. Click **HW Loop**.

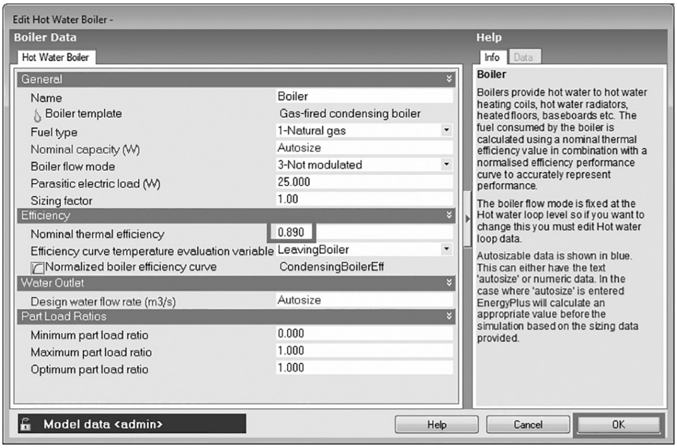
Step 2: Click **HW Loop Supply Side**.



Step 3: Click **Boiler**. Click **Edit component** under the **Help** tab. The **Edit Hot Water Boiler** screen appears.



Step 4: Enter **0.890** in the **Nominal thermal efficiency** text box under the **Efficiency** subtab.



Step 5: Simulate the model and record the results.

Step 6: Repeat the previous steps to simulate the model with **0.91**, **0.93** and **0.95** nominal thermal efficiencies (Table 8.9).

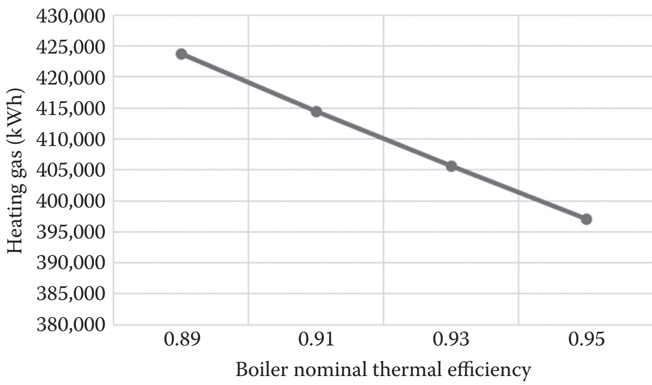


Table 8.9 Energy consumption with change in nominal thermal efficiency

End-use category	Annual energy consumption (kWh)			
	0.89	0.91	0.93	0.95
Room electricity	153,342.90	153,342.90	153,342.90	153,342.90
Lighting	221,613.80	221,613.80	221,613.80	221,613.80
System fans	128,277.70	128,277.70	128,277.70	128,277.70
System pumps	419.34	419.34	419.34	419.34
Heating (gas)	423,825.50	414,510.70	405,596.40	397,057.60
Cooling (electricity)	255,680.80	255,680.80	255,680.80	255,680.80

CHAPTER NINE

Simulation Parameters

This chapter will help you to understand the nuances of simulation engine settings that not only affect the accuracy of calculations but also affect the run time of a model. This becomes very important especially for large building models. Three concepts covered in this chapter are time step, which may be treated analogous to the least count of the model, method of calculation for energy balance and the algorithm for convective heat transfer in various building components. Simulation tools offer freedom to choose a smaller time step at the cost of a significant increase in running time. Similarly, the calculation method and convection algorithm are also associated with the accuracy of calculation at the cost of run time. These tutorials help in understanding the methods as well as the extent of difference that is obtained in the results while using different approaches. This information can be useful to the simulator to decide the appropriate simulation setting as per the availability of computing power, time and requirement of accuracy.

TUTORIAL 9.1 Evaluating the impact of time steps per hour on run time

GOAL

To evaluate the change in simulation run time with the change in time steps per hour.

WHAT ARE YOU GOING TO LEARN?

- Changing time steps per hour

PROBLEM STATEMENT

In this tutorial, you are going to use the water-cooled chiller model saved in Tutorial 8.1 (50 m × 25 m model with 5 m perimeter depth, six floors).

You are going to use the following time steps per hour:

2, 10, 30 and 60.

Find the change in energy consumption and run time for all cases.

Use **Brisbane Aero, Australia** weather location.

Simulation time steps define the interval at which the heat transfer calculations are performed. In EnergyPlus (which is the simulation engine of DesignBuilder), this minimum time step is 1, which means that the heat transfer and load calculation are performed on an hourly basis. The maximum number of time steps that can be assigned is 60, which means the calculations are performed for every minute. The allowed options for time steps are 1, 2, 3, 4, 5, 6, 10, 15, 20, 30 and 60. The higher the number of time steps, the more precise are the results.

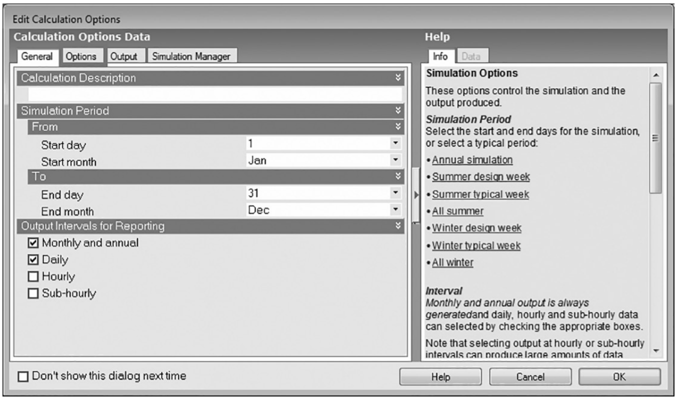
Source: http://www.designbuilder.co.uk/helpv4.7/Content/Calculation_Options.htm

Caution: Note the difference between simulation time steps, simulation period (also called run period) and run time. A run period is the time of the year for which the calculation should be performed, whereas time step is the frequency at which these calculations are performed. Further, run time is the time taken for performing energy simulation. Run time depends on several factors such as the complexity of the model, the speed of the computer hardware, run period and the time step.

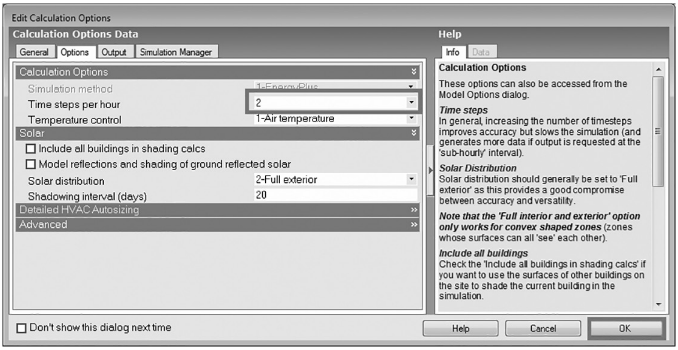
SOLUTION

Step 1: Open the simulation model saved in Tutorial 8.1. Select the **Simulation** tab. The **Edit Calculation Options** screen appears.

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



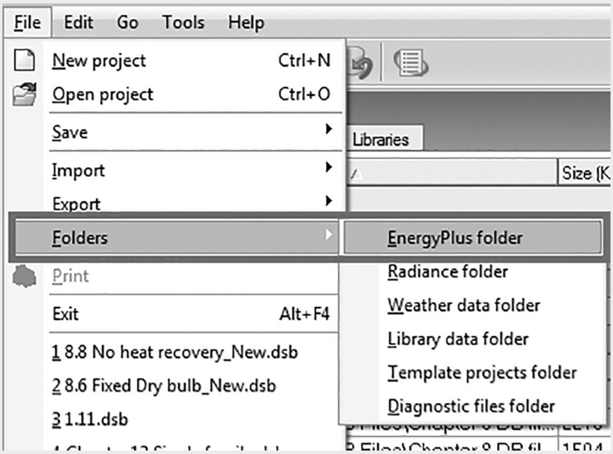
Step 3: Select **2** from the **Time steps per hour** drop-down list and click **OK**.



Step 4: Perform annual simulation and note down the results for energy and run time.

How to record the run time:

After the simulation is complete, open the **eplusout.err** file from the **EnergyPlus folder**. You can use any text editor to view this file.



At the end of the file, you can find Elapsed Time.

You need to record the elapsed time.

Source: http://www.designbuilder.co.uk/helpv4.7/Content/_DesignBuilder_files_location_and_extensions.htm

Step 5: Repeat the previous steps for the time steps 10, 30 and 60.

Compare the run time for all the cases (Table 9.1).

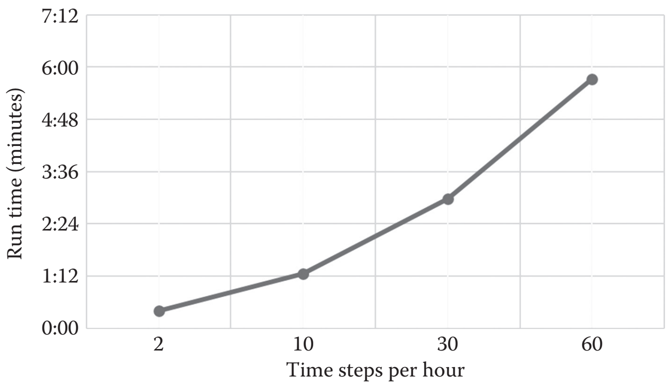


Table 9.1 Variation of annual energy consumption with variation in time steps

	Time steps 2 per hour	Time steps 10 per hour	Time steps 30 per hour	Time steps 60 per hour
Run time (min)	0:24	1:15	2:59	5:43
Room electricity	153,342.9	153,342.9	153,342.9	153,342.9
Lighting	221,613.8	221,613.8	221,613.8	221,613.8
System fans	132,544	133,927.5	134,233.3	134,310.2
System pumps	8,179.506	8,246.28	8,260.38	8,264.02
Heating (gas)	80,341.41	85,960.33	87,098.55	87,375.35
Cooling (electricity)	231,246.2	232,903.3	233,253.2	233,372.8
Heat rejection	53,253.13	55,180.27	55,330.14	55,359.05

You can observe from the results that as the number of time steps per hour increases, the simulation run time also increases. You can also observe a slight change in the HVAC energy consumption due to the change in the resolution of energy calculations. Please note that since the above-mentioned run times depend on the system configuration, your results might differ from the ones shown above. However, the trend would remain the same. In most cases, the difference in the results is very less, of the order of 1%; hence, unless necessary, use of smaller time steps is not recommended.

Save the simulation model with time steps 2 per hour to use in subsequent tutorials.

TUTORIAL 9.2 Evaluating the impact of the solar distribution algorithm

GOAL

To evaluate the impact of the solar distribution algorithm on energy consumption and simulation run time.

WHAT ARE YOU GOING TO LEARN?

- Changing the solar distribution algorithm

PROBLEM STATEMENT

In this tutorial, you are going to use the time steps 2 per hour as the model saved in Tutorial 9.1 (50 m × 25 m model with 5 m perimeter depth, six floors). Add 1 m overhang on all the windows.

You need to select the following solar distribution:

a. Full exterior
b. Minimal shading

Find the change in energy consumption for both cases.

Use **AZ – PHOENIX/SKY HARBOR, Arizona, USA** weather location.

This option determines how EnergyPlus treats beam solar radiation and reflectance from exterior surfaces that strike the building and, ultimately, enter the zone.

(1) Minimal shadowing: in this case, there is no exterior shadowing except from window and door reveals. All beam solar radiation entering the zone is assumed to fall on the floor, where it is absorbed according to the floor's solar absorptance. Any reflected by the floor is added to the transmitted diffuse radiation, which is assumed to be uniformly distributed on all interior surfaces. If no floor is present in the zone, the incident beam solar radiation is absorbed on all interior surfaces according to their absorptances. The zone heat balance is then applied at each surface and on the zone's air with the absorbed radiation being treated as a flux on the surface.

(*Continued*)

(2) Full exterior: in this case, shadow patterns on exterior surfaces caused by detached shading, wings, overhangs, and exterior surfaces of all zones are computed. As for Minimal shadowing, shadowing by window and door reveals is also calculated. Beam solar radiation entering the zone is treated as for 'Minimal shadowing'—all beam solar radiation entering the zone is assumed to fall on the floor, where it is absorbed according to the floor's solar absorptance. Any reflected by the floor is added to the transmitted diffuse radiation, which is distributed among interior surfaces according to view factors. If no floor is present in the zone, the incident beam solar radiation is absorbed on all interior surfaces according to their absorptance.

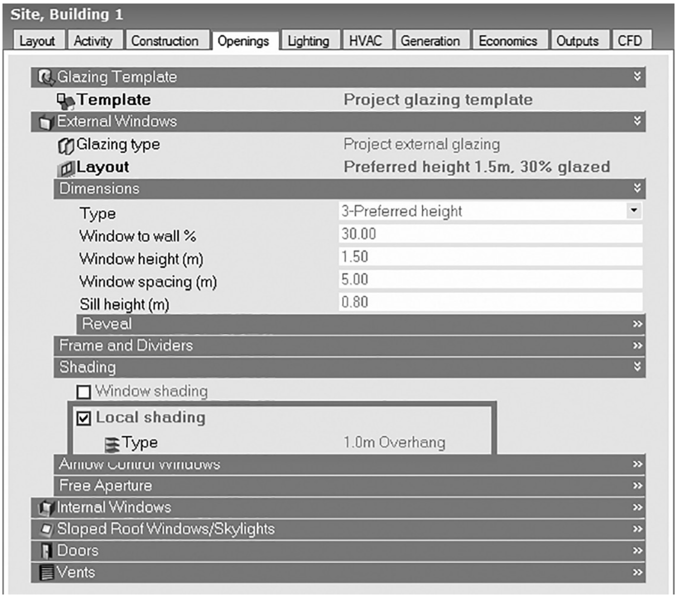
(3) Full interior and exterior: this is the same as Full exterior except that instead of assuming all transmitted beam solar falls on the floor the program calculates the amount of beam radiation falling on each surface in the zone, including floor, walls and windows, by projecting the sun's rays through the exterior windows, taking into account the effect of exterior shadowing surfaces and window shading devices. If this option is used, you should be sure that the surfaces of the zone totally enclose a space. This can be determined by viewing the eplusout.dxf file with an external DXF viewer program.

Source: http://www.designbuilder.co.uk/helpv4.7/#Solar_Options.htm

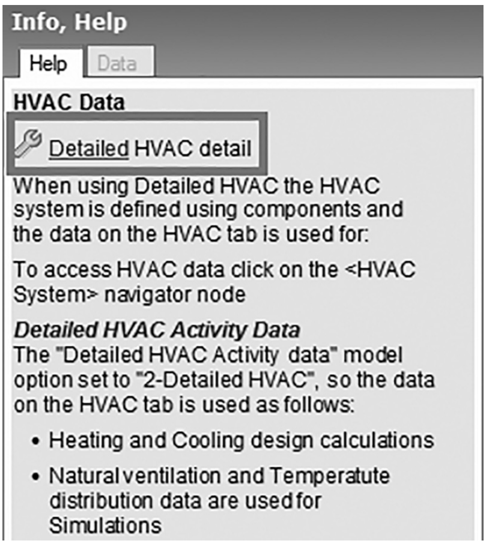
SOLUTION

Step 1: Open the simulation model saved in Tutorial 9.1 with time steps per hour as 2.

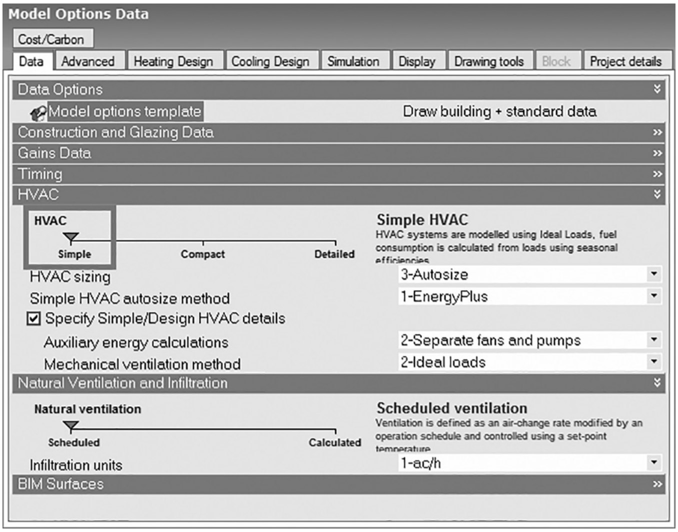
Step 2: Select the **Openings** tab. Select the **Local Shading** check box in the **Shading** section. Select **1.0 m Overhang** as Type.



Step 3: Select the **HVAC** tab and select **Detailed HVAC detail** under Info, Help.

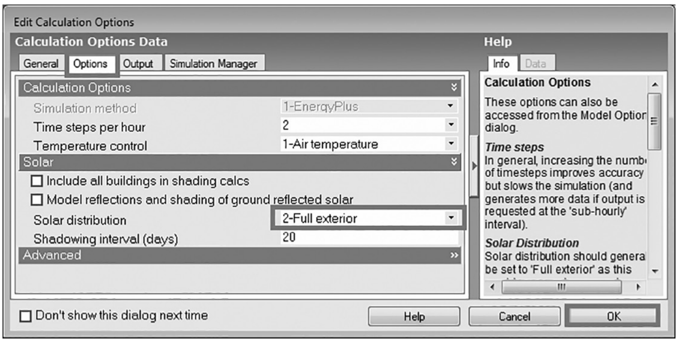


Step 4: Click **Simple** under the HVAC slider.



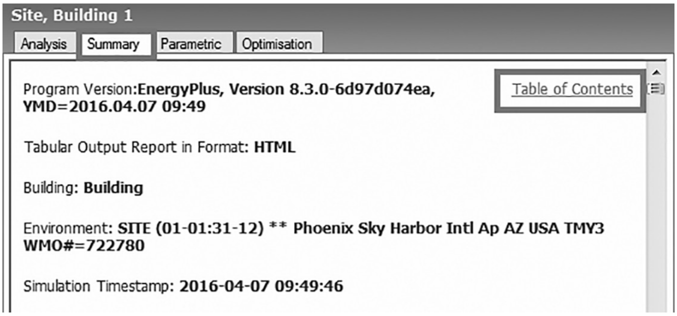
Step 5: Select the **Simulation** tab. The **Edit Calculation Options** screen appears.

Step 6: Select the **Options** tab. Expand the **Solar** section. Select **Full exterior** from the **Solar distribution** drop-down list. Click **OK**.

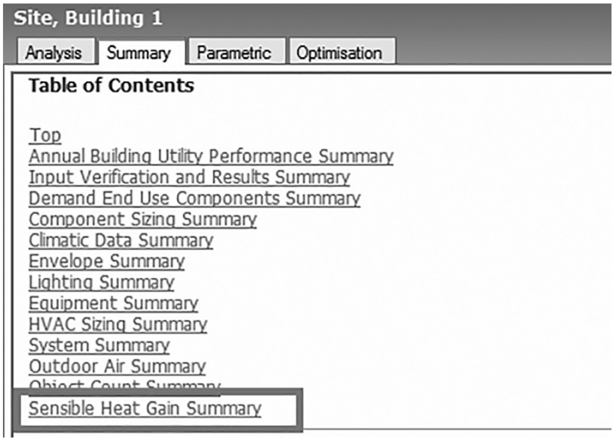


Step 7: Simulate the model and record the results for energy and simulation run time.

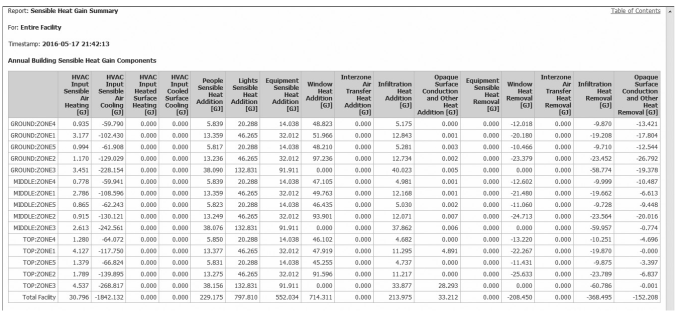
Step 8: Select the **Summary** tab and click **Table of Contents**.



Step 9: Click the **Sensible Heat Gain Summary** link.



Step 10: Copy the table **Annual Building Sensible Heat Gain Components** to a spreadsheet program. (You need to select the table and right click and select copy and paste in the spreadsheet.)



Report: **Sensible Heat Gain Summary**

For: **Entire Facility**

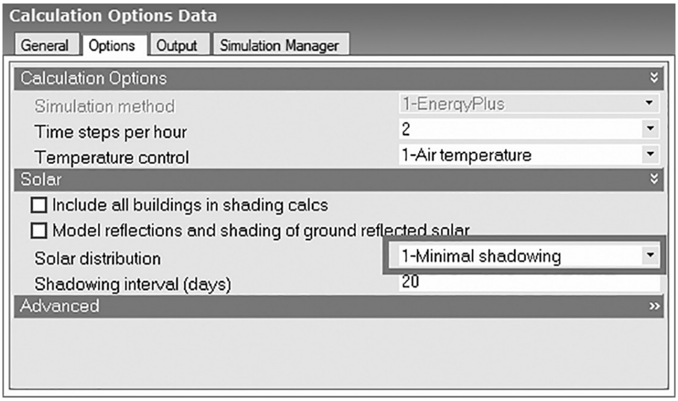
Timestamp: **2016-05-17 21:42:13**

Table of Contents

Annual Building Sensible Heat Gain Components

	HVAC Input Sensible Air Heating [GJ]	HVAC Input Sensible Air Cooling [GJ]	HVAC Input Heated Surface Heating [GJ]	HVAC Input Cooled Surface Cooling [GJ]	People Sensible Heat Addition [GJ]	Lights Sensible Heat Addition [GJ]	Equipment Sensible Heat Addition [GJ]	Window Heat Addition [GJ]	Interzone Air Transfer Heat Addition [GJ]	Infiltration Heat Addition [GJ]	Opaque Surface Conduction and Other Heat Addition [GJ]	Equipment Sensible Heat Removal [GJ]	Window Heat Removal [GJ]	Interzone Air Transfer Heat Removal [GJ]	Infiltration Heat Removal [GJ]	Opaque Surface Conduction and Other Heat Removal [GJ]
GROUND:ZONE4	0.935	-59.790	0.000	0.000	5.839	20.288	14.038	48.823	0.000	5.175	0.000	0.000	-12.018	0.000	-9.870	-13.421
GROUND:ZONE1	3.177	-102.430	0.000	0.000	13.359	46.265	32.012	51.966	0.000	12.843	0.001	0.000	-20.180	0.000	-19.208	-17.804
GROUND:ZONE5	0.994	-61.908	0.000	0.000	5.817	20.288	14.038	48.210	0.000	5.281	0.003	0.000	-10.466	0.000	-9.710	-12.544
GROUND:ZONE2	1.170	-129.029	0.000	0.000	13.236	46.265	32.012	97.236	0.000	12.734	0.002	0.000	-23.379	0.000	-23.452	-26.792
GROUND:ZONE3	3.451	-228.154	0.000	0.000	38.090	132.831	91.911	0.000	0.000	40.023	0.005	0.000	0.000	0.000	-58.774	-19.378
MIDDLE:ZONE4	0.778	-59.941	0.000	0.000	5.839	20.288	14.038	47.105	0.000	4.981	0.001	0.000	-12.602	0.000	-9.999	-10.487
MIDDLE:ZONE1	2.786	-108.596	0.000	0.000	13.359	46.265	32.012	49.763	0.000	12.168	0.001	0.000	-21.480	0.000	-19.662	-6.613
MIDDLE:ZONE5	0.865	-62.243	0.000	0.000	5.823	20.288	14.038	46.435	0.000	5.030	0.002	0.000	-11.060	0.000	-9.728	-9.448
MIDDLE:ZONE2	0.915	-130.121	0.000	0.000	13.249	46.265	32.012	93.901	0.000	12.071	0.007	0.000	-24.713	0.000	-23.564	-20.016
MIDDLE:ZONE3	2.613	-242.561	0.000	0.000	38.076	132.831	91.911	0.000	0.000	37.862	0.006	0.000	0.000	0.000	-59.957	-0.774
TOP:ZONE4	1.280	-64.072	0.000	0.000	5.850	20.288	14.038	46.102	0.000	4.682	0.000	0.000	-13.220	0.000	-10.251	-4.696
TOP:ZONE1	4.127	-117.750	0.000	0.000	13.377	46.265	32.012	47.919	0.000	11.295	4.891	0.000	-22.267	0.000	-19.870	-0.000
TOP:ZONE5	1.379	-66.824	0.000	0.000	5.831	20.288	14.038	45.255	0.000	4.737	0.000	0.000	-11.431	0.000	-9.875	-3.397
TOP:ZONE2	1.789	-139.895	0.000	0.000	13.275	46.265	32.012	91.596	0.000	11.217	0.000	0.000	-25.633	0.000	-23.789	-6.837
TOP:ZONE3	4.537	-268.817	0.000	0.000	38.156	132.831	91.911	0.000	0.000	33.877	28.293	0.000	0.000	0.000	-60.786	-0.001
Total Facility	30.796	-1842.132	0.000	0.000	229.175	797.810	552.034	714.311	0.000	213.975	33.212	0.000	-208.450	0.000	-368.495	-152.208

Step 11: Repeat the previous steps to select **Minimal shadowing** from the **Solar distribution** drop-down list.



Step 12: Click **OK**. Record the results.

Compare results for both simulations (Tables 9.2 and 9.3).

It can be observed from the results that with the Minimal shading option, there is an increase in the HVAC energy consumption, as there is no exterior shadowing considered in the calculations except from window and door reveals.

The results also show that the window heat gain is lesser with Full exterior. This is because the shadow patterns on the exterior surface caused by overhangs and exterior surfaces are taken into account for calculations.

Table 9.2 Variation of annual energy consumption with variation in local shading

	Annual fuel breakdown consumption (kWh)	
	Full exterior	Minimal shading
Run time	0:16	0:14
Room electricity	153,342.90	153,342.90
Lighting	221,613.80	221,613.80
Heating (gas)	10,616.47	8,836.53
Cooling (electricity)	256,906.00	287,547.30
DHW (electricity)	13,875.00	13,875.00

Table 9.3 Heat gains from window

	Window heat addition (GJ)	
	Minimal	Full exterior
Ground: West	72.42	48.44
Ground: North	57.40	51.35
Ground: East	71.50	47.74
Ground: South	169.90	96.46
Ground: Core	–	–
Middle: West	68.29	45.60
Middle: North	53.42	47.73
Middle: East	67.08	44.72
Middle: South	161.26	91.53
Middle: Core	–	–
Top: West	69.19	46.11
Top: North	54.05	47.96
Top: East	68.17	45.24
Top: South	162.27	91.54
Top: Core	–	–
Total facility	1,074.94	704.41

Save the model to use in the next tutorial.

Exercise 9.1

Repeat the above tutorial for the Full interior and exterior solar distribution algorithm.

TUTORIAL 9.3 Evaluating the impact of the solution algorithm

GOAL

To evaluate the building energy performance and the run time with the change in the solution algorithm.

WHAT ARE YOU GOING TO LEARN?

- Changing the solution algorithm

PROBLEM STATEMENT

In this tutorial, you are going to use the simulation model saved in Tutorial 9.1 with time steps per hour as 2.

You need to select the following algorithms:

1. Conduction Transfer Function
2. Finite Difference

Find the change in energy consumption with both cases.

Use **AZ – PHOENIX/SKY HARBOR, Arizona, USA** weather location.

CTF: the default method used in EnergyPlus for CTF calculations is known as the state space method. CTF is a sensible heat-only solution not taking into account moisture storage or diffusion in the construction elements.

Finite Difference: this solution technique uses a 1-D finite difference solution in the construction elements. It is a sensible heat-only solution and does not take into account moisture storage or diffusion in the construction elements.

Finite Difference Settings

The settings below are required when the general solution algorithm is set to 2-Finite Difference or if any constructions used in the simulation override the general setting to use the Finite Difference algorithm.

Difference Scheme

This field determines the solution scheme used by the Conduction Finite Difference model.

There are two options:

(1) Fully implicit first-order scheme, which is first order in time and is more stable over time. But it may be slower than option 2.

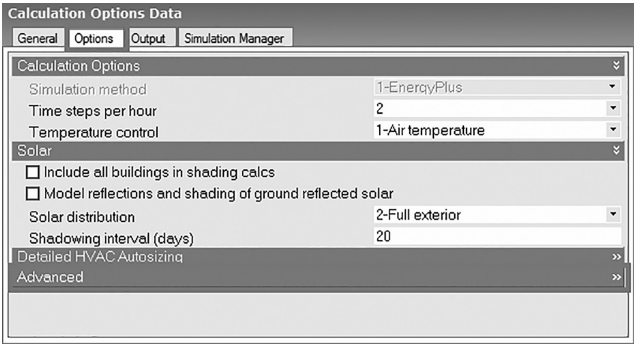
(2) Crank Nicholson second order, which is second order in time and may be faster than option 1, but it can be unstable over time when boundary conditions change abruptly and severely.

Source: http://www.designbuilder.co.uk/helpv4.7/ Content/Advanced_Calculation_Options.htm

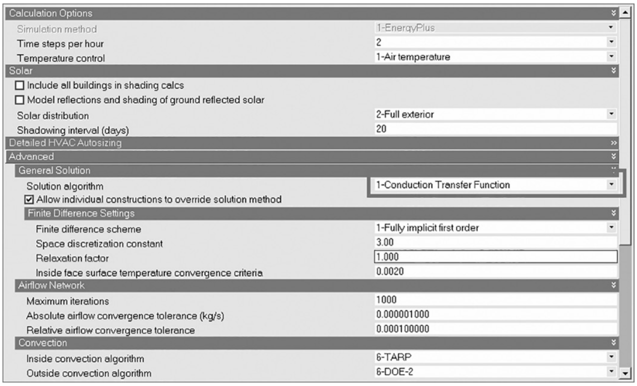
SOLUTION

Step 1: Open the simulation model saved in Tutorial 9.1 with time steps per hour as 2. Select the **Simulation** tab.

Step 2: Select the **Options** tab and expand the **Advanced** section.



Step 3: Select **Conduction Transfer Function** from the **Solution algorithm** drop-down list.



Step 4: Simulate the model and record the results.

Step 5: Repeat previous steps and select **Finite Difference** from the **Solution algorithm** drop-down list.

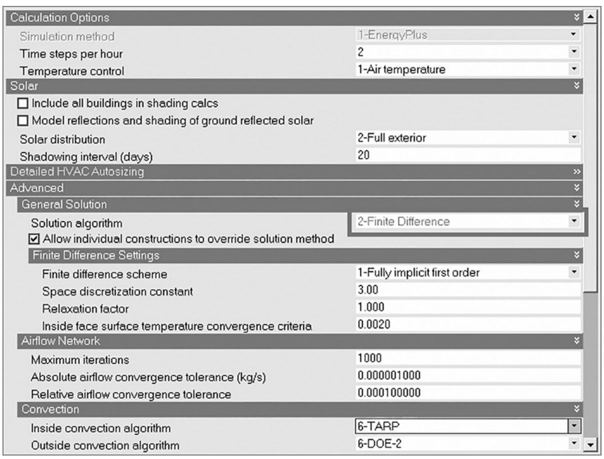


Table 9.4 Variation in simulation run time with variation in the solution algorithm

	Annual fuel breakdown consumption (kWh)	
	Conduction Transfer Function	Finite Difference (fully implicit first order)
Run time	0:27	3:57
Room electricity	153,342.90	153,342.90
Lighting	221,613.30	221,613.80
System fans	155,002.60	156,511.60
System pumps	7,939.26	8,021.31
Heating (electricity)	101,686.90	106,023.80
Cooling (electricity)	230,764.70	232,707.50
Heat rejection	51,146.54	51,847.43

Step 6: Simulate the model and record the results.

Compare the results for both simulations (Table 9.4).

It can be seen from the results that with the Finite Difference method there is an increase in the simulation run time.

TUTORIAL 9.4 Evaluating the effect of the inside convection algorithm

GOAL

To evaluate building energy performance with the change in the inside convection algorithm.

WHAT ARE YOU GOING TO LEARN?

- Changing the inside convection algorithm

PROBLEM STATEMENT

In this tutorial, you are going to use the simulation model saved in Tutorial 9.1 with time steps per hour as 2.

You are going to select the following algorithms:

1. Adaptive convection
2. Simple
3. CIBSE
4. TARP

Find the change in energy consumption for all cases.

Use **PARIS-AEROPORT CHAR, France** weather location.

Inside convection algorithm

You can select from six main EnergyPlus inside convection algorithms for calculating the convection between internal zone surfaces and the rest of the zone air in the simulation calculations. Unless you have a good reason to do so, you are advised to use the default TARP convection algorithm.

- **1-Adaptive convection algorithm**: this advanced option provides a dynamic selection of convection models based on conditions. Beausoleil–Morrison (2000, 2002) developed a methodology for dynamically managing the selection of h_c equations, called the adaptive convection algorithm. The algorithm is used to select among the available h_c equations for the one that is most appropriate for a given surface at a given time. As Beausoleil–Morrison notes, the adaptive convection algorithm is intended to be expanded and altered to reflect different classification schemes and/or new h_c equations. The adaptive convection algorithm implemented in EnergyPlus for the inside face has a total of 45 different categories for surfaces and 29 different options for h_c equation selections. The tables provided in the Engineering document summarize the categories and the default assignments for h_c equations.
- **2-Simple**: the simple convection model uses constant coefficients for different heat transfer configurations, using the criteria to determine reduced and enhanced convections. The coefficients are taken directly from Walton (1983). Walton derived his coefficients from the surface conductance for ε = 0.90 found in the ASHRAE Handbook (1985) in Table 1 on p. 23.2. The radiative heat transfer component was estimated at 1.02 * 0.9 = 0.918 BTU/h ft^2 F and then subtracted off. Finally, the coefficients were converted to SI units to yield the following values. For a vertical surface, $h_c = 3.076$. For a horizontal surface with reduced convection, $h_c = 0.948$. For a horizontal surface with enhanced convection, $h_c = 4.040$. For a tilted surface with

(*Continued*)

reduced convection, $h_c = 2.281$. For a tilted surface with enhanced convection, $h_c = 3.870$.

- **3-CIBSE**: applies constant heat transfer coefficient derived from traditional CIBSE values.
- **4-Ceiling diffuser**: a mixed and forced convection model for ceiling diffuser configurations. The model correlates the heat transfer coefficient to the air change rate for ceilings, walls and floors. The ceiling diffuser algorithm is based on empirical correlations developed by Fisher and Pedersen (1997). The correlation was reformulated to use the room outlet temperature as the reference temperature. The correlations are shown below. For floors, $h_c = 3.873 + 0.082 \times \text{ACH} ^ 0.98$. For ceilings, $h_c = 2.234 + 4.099 \times \text{ACH} ^ 0.503$. For walls, $h_c = 1.208 + 1.012 \times \text{ACH} ^ 0.604$.
- **5-Cavity**: this algorithm was developed to model convection in a 'Trombe wall zone' that is the air space between the storage wall surface and the exterior glazing. (See the later sections on Passive and Active Trombe Walls below for more information about Trombe walls.) The algorithm is identical to the convection model (based on ISO 15099) used in Window5 for convection between glazing layers in multipane window systems. The use of the algorithm for modelling an unvented Trombe wall has been validated against experimental data by Ellis (2003). This algorithm gives the convection coefficients for air in a narrow vertical cavity that is sealed and not ventilated. This applies both to the air gap in between panes of a window and to the air gap between the Trombe wall glazing and the inner surface (often a selective surface). These convection coefficients are really the only difference between a normal zone and a Trombe zone. See also the note below.
- **6-TARP**: based on variable natural convection based on the temperature difference from ASHRAE algorithms. This is the same as the old 'Detailed' Inside convection algorithm provided in earlier versions of DesignBuilder.

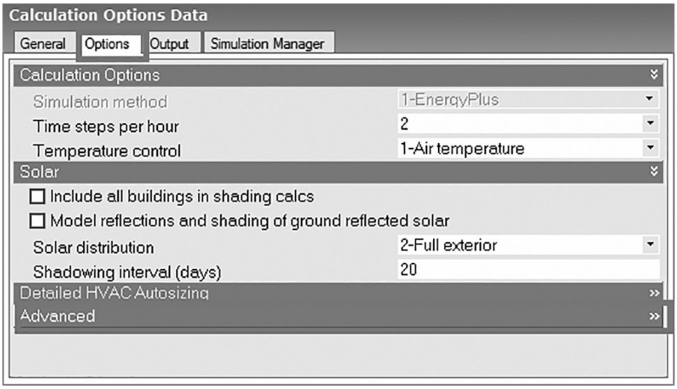
Source: http://www.designbuilder.co.uk/helpv4.7/Content/Surface_Convection.htm

SOLUTION

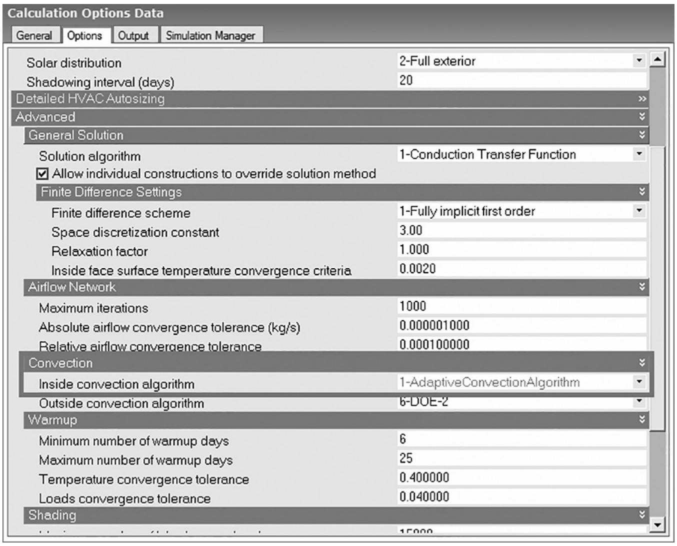
Step 1: Open the simulation model saved in Tutorial 9.1 with time steps per hour as 2.

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

Step 3: Select the **Options** tab and expand the **Advanced** section.



Step 4: Select **Adaptive Convection Algorithm** from the **Inside convection algorithm** drop-down list in the Convection section.



Step 5: Click **OK** and note down the results.

Table 9.5 Variation in simulation run time with variation in the inside convection algorithm

	Annual fuel breakdown consumption (kWh)			
	Adaptive convection algorithm	Simple	CIBSE	TARP
Run time (min)	0.27	0.22	0.19	0.20
Room electricity	153,342.90	153,342.90	153,342.90	153,342.90
Lighting	221,613.80	221,613.80	221,613.80	221,613.80
System fans	122,129.20	131,199.00	134,431.30	128,277.70
System pumps	4,215.91	4,841.64	5,136.61	4,664.57
Heating (gas)	417,841.00	437,897.80	440,730.00	423,825.50
Cooling (electricity)	86,390.53	98,280.73	102,366.10	94,650.77
Heat rejection	26,360.16	30,413.91	31,752.80	29,144.83

Step 6: Repeat the previous steps for **Simple, CIBSE and TARP** from the Inside convection algorithm drop-down list.

Compare the results for simulations (Table 9.5).

Difference in the HVAC energy consumption and the run time while using different algorithms can be noted from the above table.

Exercise 9.2

Repeat the above tutorial to evaluate the building energy performance with the change in the outside convection algorithm.

You need to select the following algorithms:

1. Adaptive convection
2. Simple combined
3. TARP
4. DOE-2

Use **PARIS-AEROPORT CHAR, France** weather location.

TUTORIAL 9.5 Evaluating the impact of the shadowing interval

GOAL

To evaluate the impact of the shadowing interval on the building energy consumption.

WHAT ARE YOU GOING TO LEARN?

- Changing the shadowing interval

PROBLEM STATEMENT

In this tutorial, you are going to use the simulation model saved in Tutorial 9.2 with Full exterior.

You are going to simulate the model for the following intervals:

5, 10, 20 and 30 days

Use **New Delhi/Palam, India** weather location.

Shadowing interval is important for determining the amount of sun entering your building and by inference the amount of cooling or heating load needed for maintaining the building. Though termed ‘shadowing’ calculations, it in effect determines the sun’s position on a particular day in a weather file period simulation. (Each design day will use the date of the design day object.) Even though weather file data contain the amount of solar radiation, the internal calculation of the sun’s position will govern how it affects various parts of the building.

By default, the calculations are done for every 20 days throughout a weather run period; an average solar position is chosen and the solar factors (such as sunlit areas of surfaces) remain the same for that number of days. More integrated calculations are needed for controlling dynamic windows or shades.

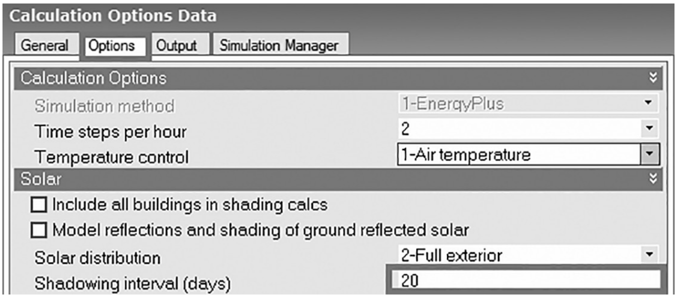
Source: EnergyPlus InputOutput Reference

SOLUTION

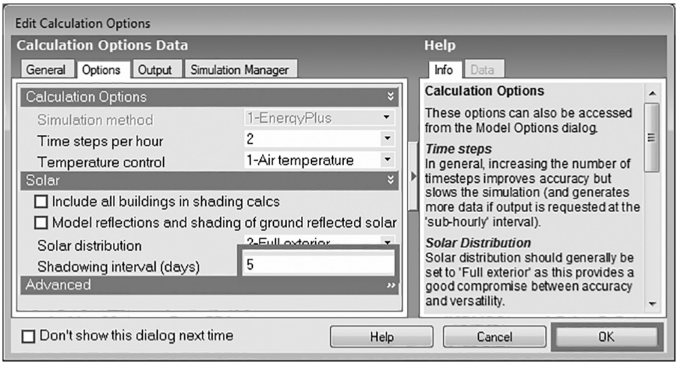
Step 1: Open the simulation model saved in Tutorial 9.2.

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

Step 3: Select the **Options** tab.



Step 4: Type **5** in the **Shadowing interval (days)**.



Step 5: Simulate the model and record the results.

Step 6: Repeat previous steps for shading intervals of 10, 20 and 30 days.

Compare the data for all the cases (Table 9.6).

Table 9.6 Variation in simulation run time with variation in the shadowing interval

Annual fuel breakdown data				
End use component	Shading interval			
	5 days	10 days	20 days	30 days
Run time (min)	0:18	0.15	0.14	0.13
Room electricity	153,342.90	153,342.90	153,342.90	153,342.90
Lighting	221,613.80	221,613.80	221,613.80	221,613.80
Heating (gas)	10,568.76	10,578.89	10,616.47	10,658.09
Cooling (electricity)	256,742.50	256,770.60	256,906.00	256,897.60
DHW (electricity)	13,875.00	13,875.00	13,875.00	13,875.00

CHAPTER TEN

Natural Ventilation

The method of simulating natural ventilation is somewhat different from that of simulating HVAC components. Natural ventilation is often achieved either using windows or using ventilation fans. Simulation tools can model both the cases and can predict the thermal conditions of indoors. Mixed-mode buildings, which use both natural ventilation when ambient conditions are moderate and HVAC system when it is harsh, can also be modelled by defining the opening of windows and operation of HVAC in the simulation model. In this chapter, the method of modelling naturally ventilated buildings is explained through six tutorials. Various aspects of modelling of natural ventilation, such as how to define window opening, how to define scheduled opening and closing of windows and the impact of window opening on indoor conditions are explained. Design issues such as the size of the openable window and the temperature-controlled automatic opening of windows are also discussed.

TUTORIAL 10.1 Evaluating the impact of wind speed on natural ventilation

GOAL

To evaluate the impact of the change in wind speed on ventilation rate.

WHAT ARE YOU GOING TO LEARN?

- Modelling natural ventilation
- Defining glazing area openings for natural ventilation

There are two general approaches to natural ventilation and infiltration modelling in DesignBuilder depending on the setting of the Natural ventilation model option:

- **Scheduled** in which the natural ventilation change rate is explicitly defined for each zone in terms of a maximum ACH value and a schedule, and infiltration air change rate is defined by a constant ACH value. A range of control options are provided.
- **Calculated** where natural ventilation and infiltration are calculated based on window openings, cracks, buoyancy and wind-driven pressure differences, crack dimensions and so on. Control options are provided.

Source: http://www.designbuilder.co.uk/helpv4.7/Content/_Natural_ventilation_modelling.htm

PROBLEM STATEMENT

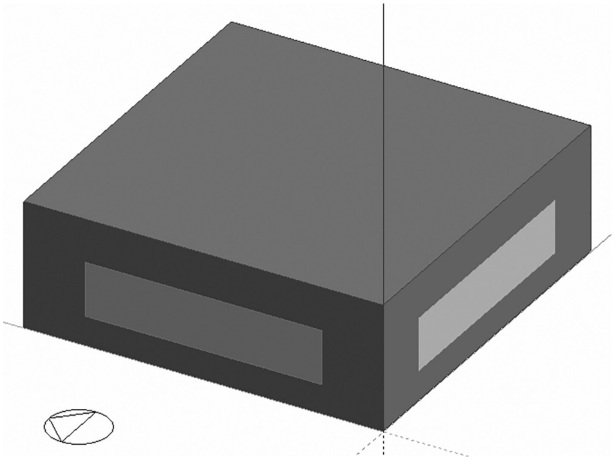
In this tutorial, you are going to use a 10 m × 10 m single-zone model.

Find zone air changes for the model with natural ventilation.

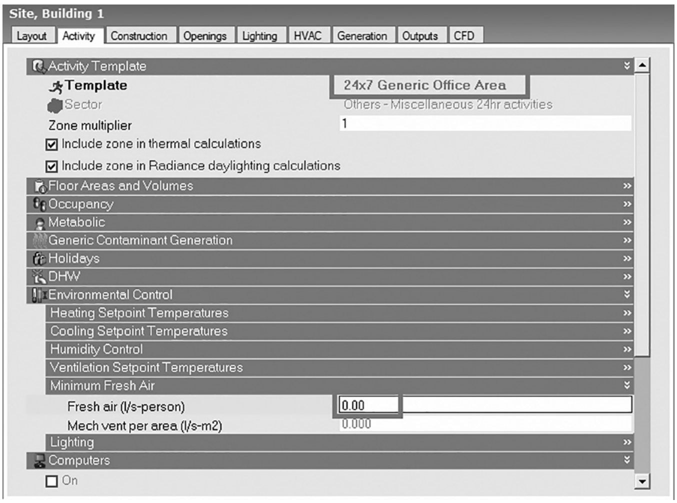
Use **New Delhi/Safdarjung, India** weather location.

SOLUTION

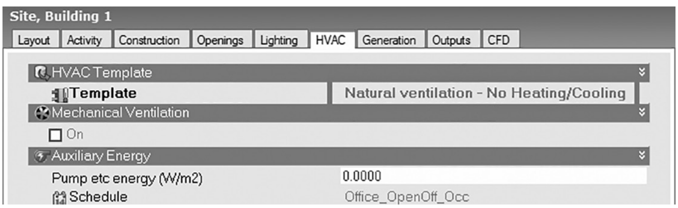
Step 1: Open a new blank project file and create a **10 m × 10 m** single-zone building. Select the **Activity** tab.



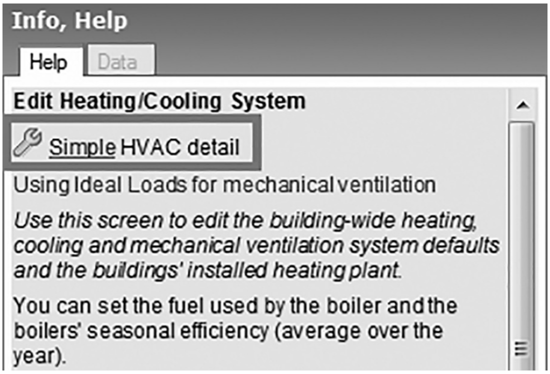
Step 2: Select the **24×7 Generic Office Area** template. Set **Fresh air (l/s-person)** and **Mech vent per area (l/s-m²)** to **0**.



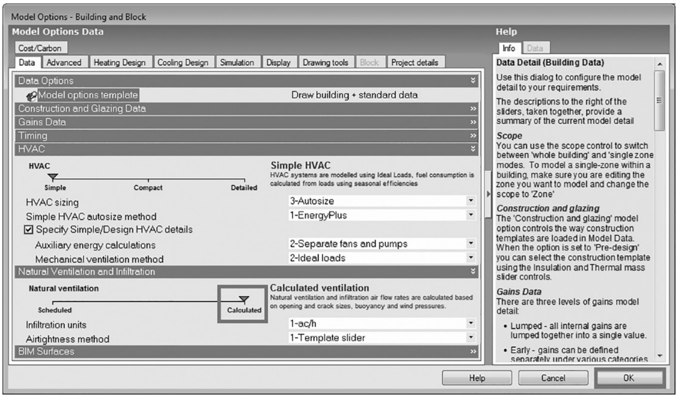
Step 3: Select the **HVAC** tab. Select the **Natural ventilation – No Heating/Cooling** template.



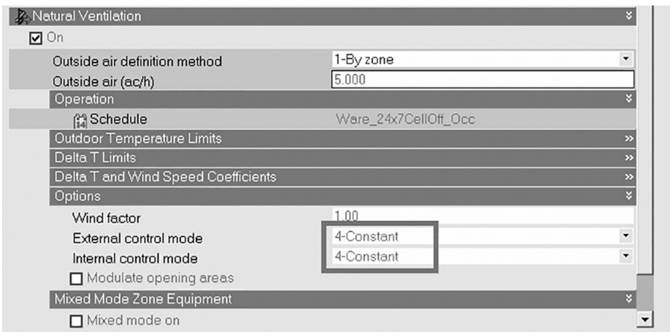
Step 4: Click **Simple** under the **Help** tab.



Step 5: Click **Calculated** under Natural ventilation. Click **OK**.



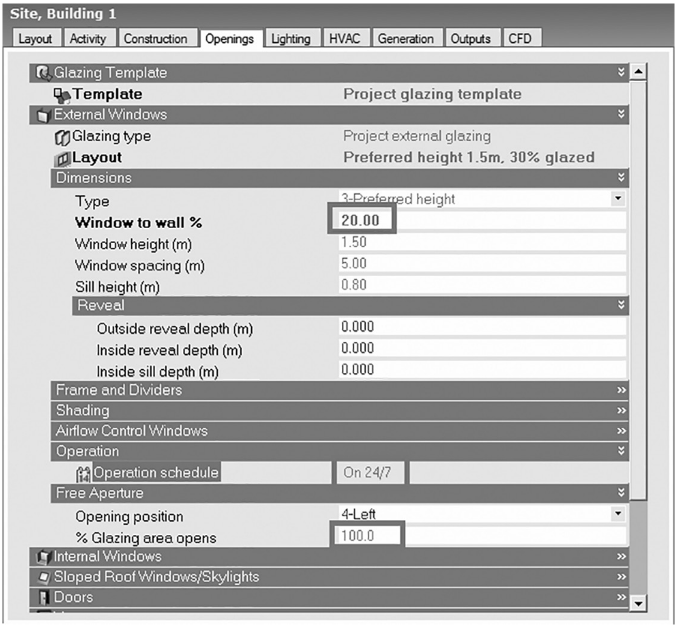
Step 6: Click the **Options** sub-section in the **Natural Ventilation** section and select **Constant** for the External control mode and Internal control mode drop-down lists.



Constant – Whenever an opening's operation schedule allows venting, all of the zone's openable windows and doors are open, independent of indoor or outdoor conditions. Note that 'Constant' here means that the size of each opening is fixed while venting; the air flow through each opening can, of course, vary from time step to time step. This option allows modelling of a window that is opened for fresh air regardless of inside/outside temperature/enthalpy.

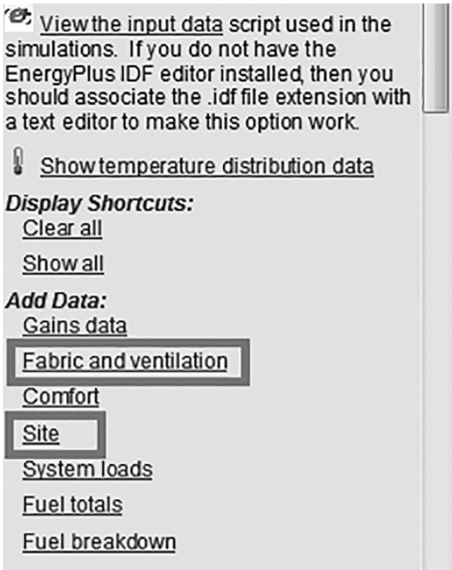
Source: http://www.designbuilder.co.uk/helpv4.7/Content/CalculatedNatVent.htm

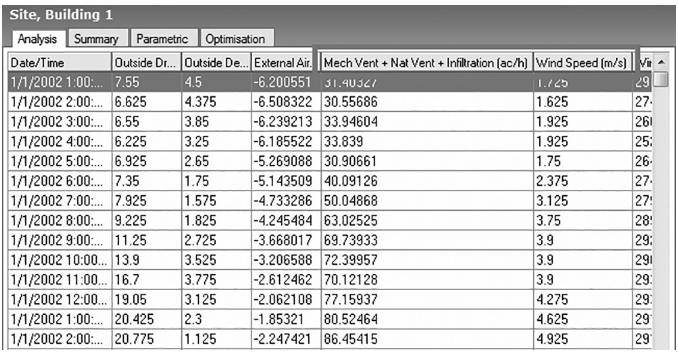
Step 7: Select the **Opening** tab. Set Window to wall % to **20.00**. Click the **Free Aperture** section. Set % Glazing area opens to **100.0** and select **On 24/7** in Operation schedule.



Step 8: Perform hourly simulation. After simulation, click **Clear all**.

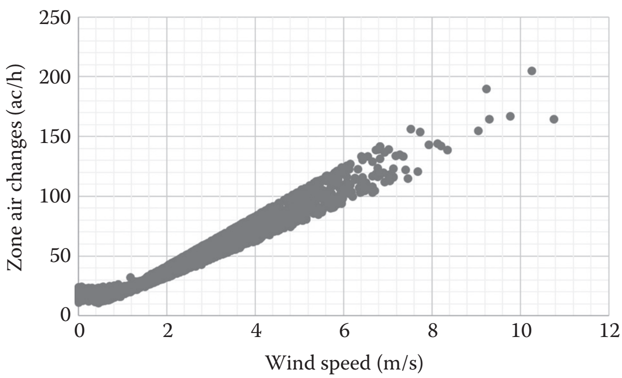
Step 9: Now click the links **Fabric and ventilation** and **Site** from **Add Data** to record the results for Wind speed and Mechanical ventilation. Select **Grid** in the Show as dropdown list.





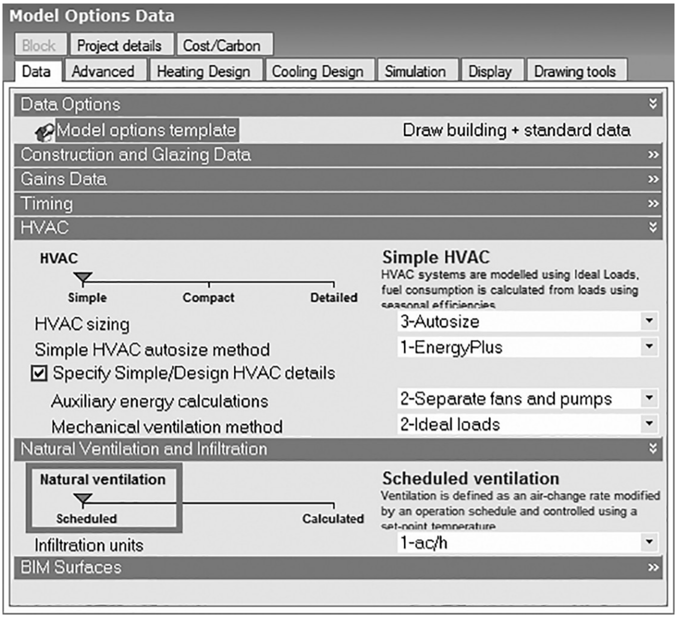
Date/Time	Outside Dr...	Outside De...	External Air...	Mech Vent + Nat Vent + Infiltration (ac/h)	Wind Speed (m/s)	Wi
1/1/2002 1:00:...	7.55	4.5	-6.200551	31.40327	1.725	29
1/1/2002 2:00:...	6.625	4.375	-6.508322	30.55686	1.625	27
1/1/2002 3:00:...	6.55	3.85	-6.239213	33.94604	1.925	26
1/1/2002 4:00:...	6.225	3.25	-6.185522	33.839	1.925	25
1/1/2002 5:00:...	6.925	2.65	-5.269088	30.90661	1.75	26
1/1/2002 6:00:...	7.35	1.75	-5.143509	40.09126	2.375	27
1/1/2002 7:00:...	7.925	1.575	-4.733286	50.04868	3.125	27
1/1/2002 8:00:...	9.225	1.825	-4.245484	63.02525	3.75	28
1/1/2002 9:00:...	11.25	2.725	-3.668017	69.73933	3.9	29
1/1/2002 10:00...	13.9	3.525	-3.206588	72.39957	3.9	29
1/1/2002 11:00...	16.7	3.775	-2.612462	70.12128	3.9	29
1/1/2002 12:00...	19.05	3.125	-2.062108	77.15937	4.275	29
1/1/2002 1:00:...	20.425	2.3	-1.85321	80.52464	4.625	29
1/1/2002 2:00:...	20.775	1.125	-2.247421	86.45415	4.925	29

Export the results to a spreadsheet and plot a scatter graph between Mech Vent + Nat Vent + Infiltration (ac/h) and Wind speed (m/s).



You can observe that with an increase in wind speed, there is an increase in zone air change.

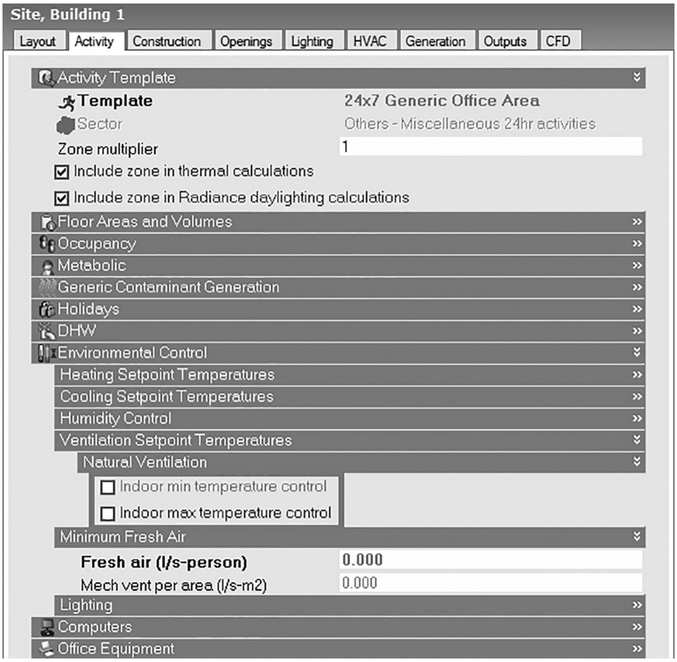
Step 10: Repeat the above tutorial with **Scheduled** under Natural ventilation.



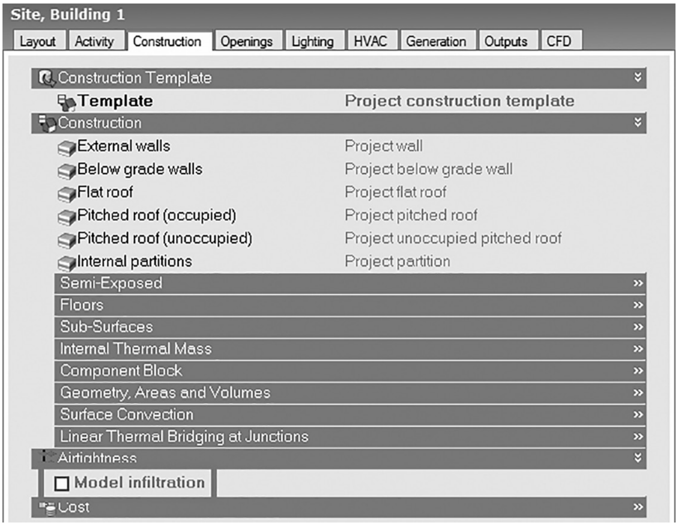
Scheduled – the ventilation rates are predefined using a maximum air change rate modified by operation schedules.

Source: http://www.designbuilder.co.uk/helpv4.7/Content/_Ventilation_model_detail.htm

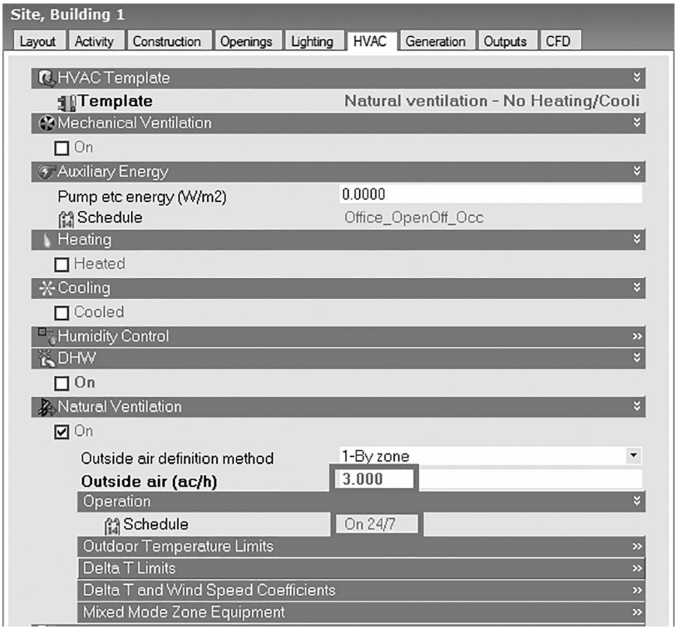
Step 11: Select the **Activity** tab. Clear both **Indoor min and max temperature control** checkboxes in the Natural Ventilation section.



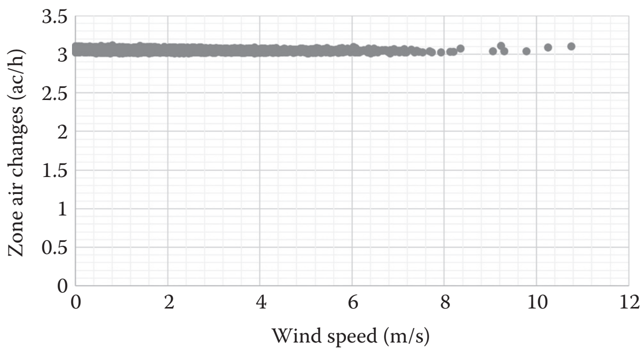
Step 12: Select the **Construction** tab. Clear **Model infiltration** in the Airtightness section.



Step 13: Enter **3.000** for **Outside air (ac/h)** under the Natural Ventilation section and select **On 24/7** in the Operation section.



Perform hourly simulation and record the results.



You may note that there is no change in ventilation rate with wind speed, since in this option, the ventilation is fixed.

Exercise 10.1

Repeat the above tutorial for % Glazing area opens to 50. Plot the chart between zone air changes (ac/h) with Wind speed (m/s). Observe the change in Air changes per hour.

TUTORIAL 10.2 Evaluating the impact of natural ventilation with constant wind speed and direction

GOAL

To understand the impact of natural ventilation with constant wind and direction.

WHAT ARE YOU GOING TO LEARN?

- Changing the weather data file for wind speed and direction

PROBLEM STATEMENT

In this tutorial, you are going to use a 10 m × 10 m single-zone model with a window on the north and south façades. You are going to change wind velocity and direction in the weather file.

- Wind velocity 1 and 2 m/s
- Wind direction 0° (wind from the north to south)

Then simulate the weather file and observe the effect on Air changes per hour.

Use **New Delhi/Safdarjung, India** weather location.

SOLUTION

First, you are going to modify the weather data file for wind speed and direction.

Step 1: Download the weather data for New Delhi from the following link and download the .epw file.*

Or

Copy from the Weather data folder.

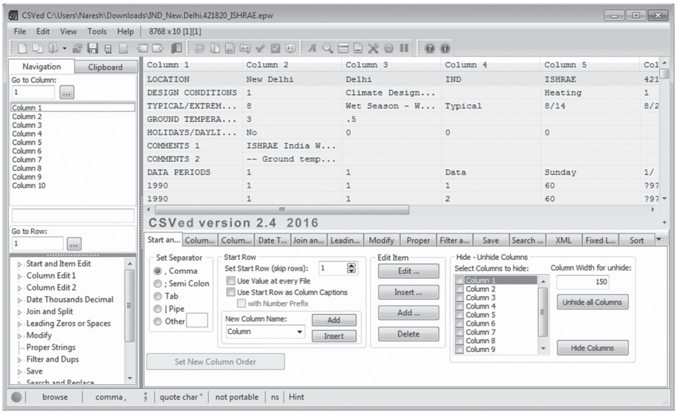
Step 2: Download the following CSV editor tool.† (You can use any csv editor.)

(For this tutorial, we have used CSVed 2.4.)

Step 3: Open the CSV editor tool and select the downloaded .epw file of New Delhi weather location.

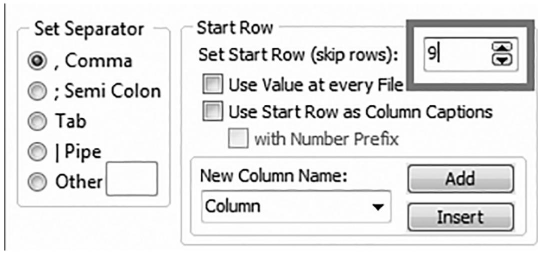
* https://energyplus.net/weather-location/asia_wmo_region_2/IND//IND_New. Delhi.421820_ISHRAE

† http://csved.sjfrancke.nl (by Sam Francke)

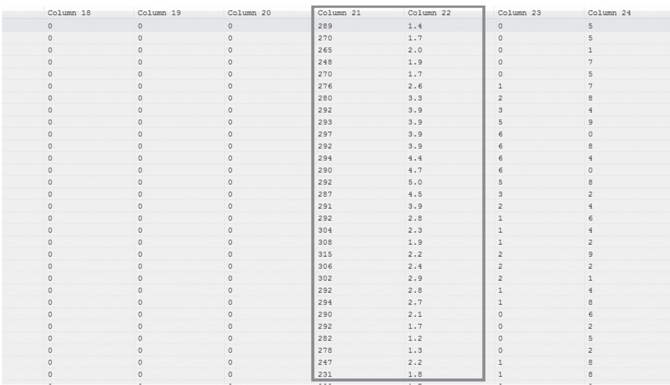


Source: From http://csved.sjfrancke.nl/.

Step 4: After opening the file, go to **Set Start Row** in **Start and Item Edit** tab. Set **Start Row** to **9**.



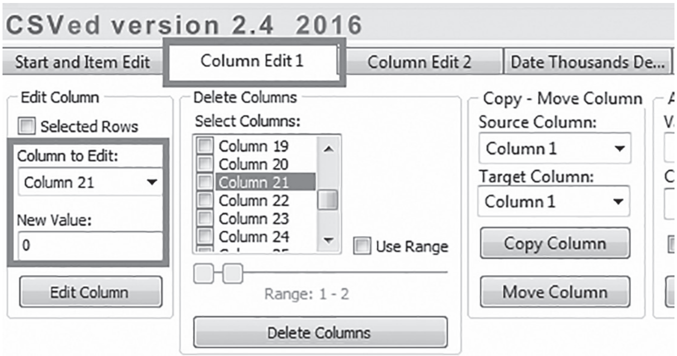
In the .epw file, Columns 21 and 22 represent the Wind direction and speed, respectively.



Column 18	Column 19	Column 20	Column 21	Column 22	Column 23	Column 24
0	0	0	289	1.4	0	5
0	0	0	270	1.7	0	5
0	0	0	265	2.0	0	1
0	0	0	248	1.9	0	7
0	0	0	270	1.7	0	5
0	0	0	276	2.6	1	7
0	0	0	280	3.3	2	8
0	0	0	292	3.9	3	4
0	0	0	293	3.9	5	9
0	0	0	297	3.9	6	0
0	0	0	292	3.9	6	8
0	0	0	294	4.4	6	4
0	0	0	290	4.7	6	0
0	0	0	292	5.0	5	8
0	0	0	287	4.5	3	2
0	0	0	291	3.9	2	4
0	0	0	292	2.8	1	6
0	0	0	304	2.3	1	4
0	0	0	308	1.9	1	2
0	0	0	315	2.2	2	9
0	0	0	306	2.4	2	2
0	0	0	302	2.9	2	1
0	0	0	292	2.8	1	4
0	0	0	294	2.7	1	8
0	0	0	290	2.1	0	6
0	0	0	292	1.7	0	2
0	0	0	282	1.2	0	5
0	0	0	278	1.3	0	2
0	0	0	247	2.2	1	8
0	0	0	231	1.8	1	8

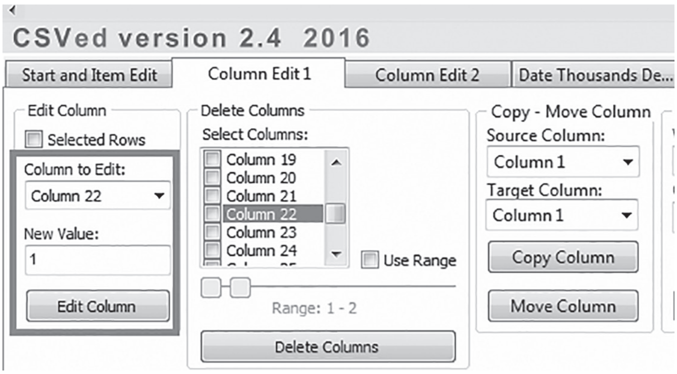
Source: From http://csved.sjfrancke.nl/.

Step 5: For changing the wind direction to 0°, select **Column Edit 1** tab and select **Column 21** from the drop-down and enter **0** in the **New Value** text box. Click **Edit Column**.



Source: From http://csved.sjfrancke.nl/.

Step 6: Similarly, for changing the wind speed to 1 m/s, select **Column 22** and enter **1** in the **New Value** text box. Click **Edit Column**.

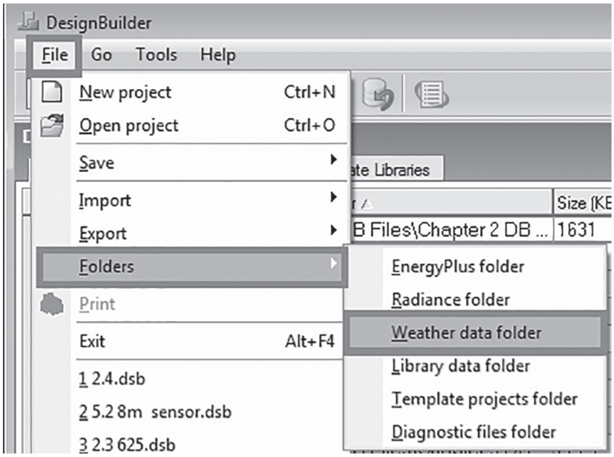


Source: From http://csved.sjfrancke.nl/.

Step 7: Save the file with the name **Delhi Constant Wind.epw** on Desktop.

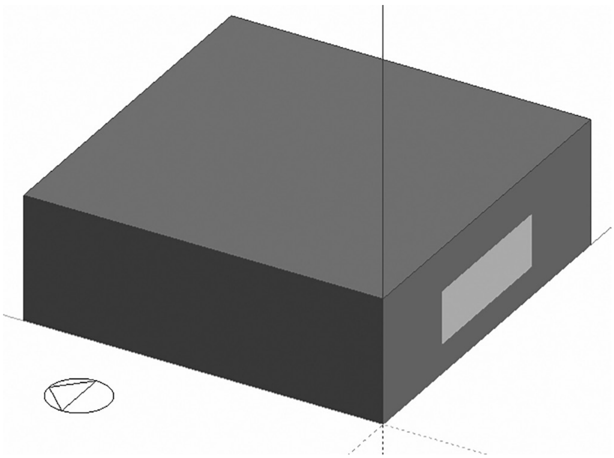
Open **DesignBuilder**.

Select the **File > Folders > Weather data** folder and paste it as the **Delhi Constant Wind.epw** weather file.

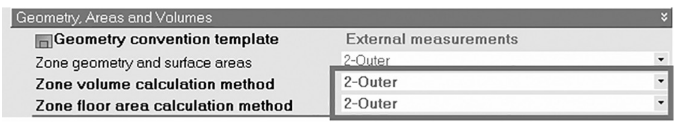


Source: From http://csved.sjfrancke.nl/.

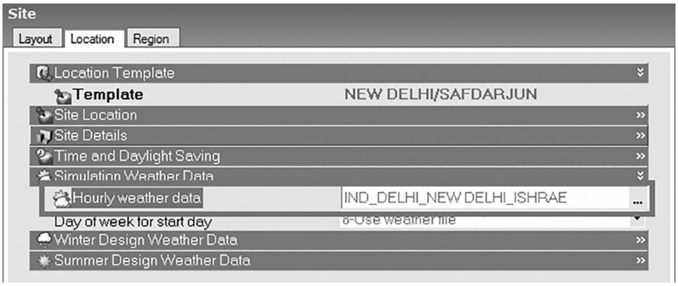
Step 8: Open the project file saved in Tutorial 10.1 with calculated Natural ventilation and delete both east and west façades.



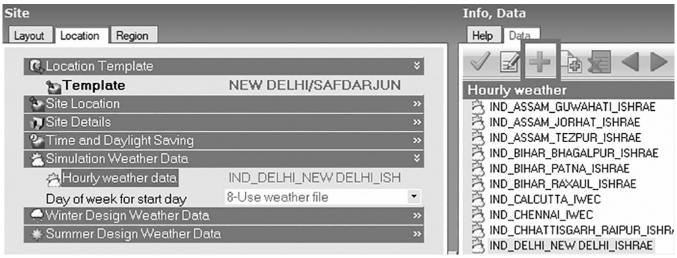
Step 9: Select the **Construction** tab. Select **Outer** for the **Zone volume calculation method** and **Zone floor area calculation method** in the **Geometry, Areas and Volumes** section.



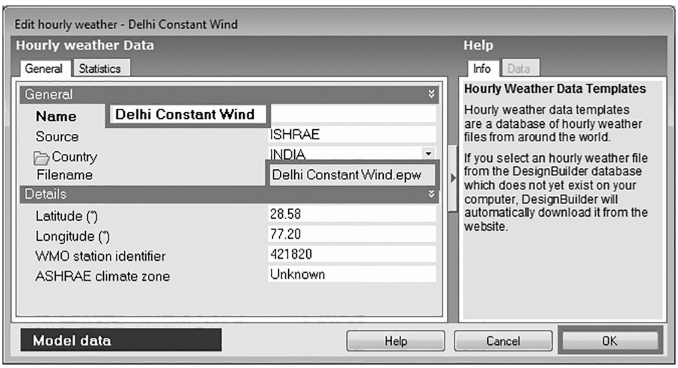
Step 10: Select the **Location** tab and select **Hourly weather data** under the **Simulation Weather Data** section.



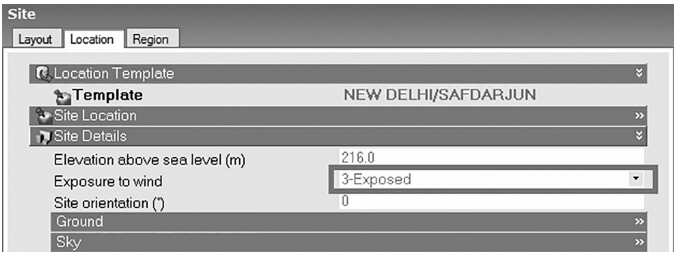
Step 11: Click the **Add new item** icon under the **Help** tab.



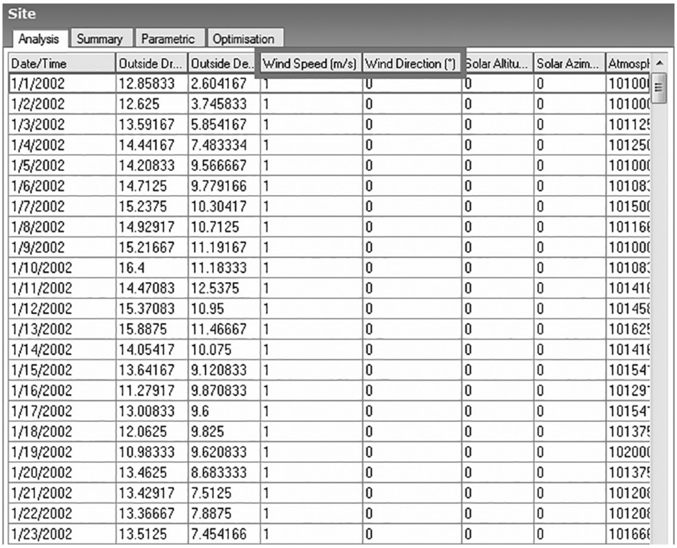
Step 12: In the **Edit hourly weather - Delhi Constant Wind** screen, rename with your custom weather file and search for the file by clicking **Filename**. Click **OK** to successfully select the file.



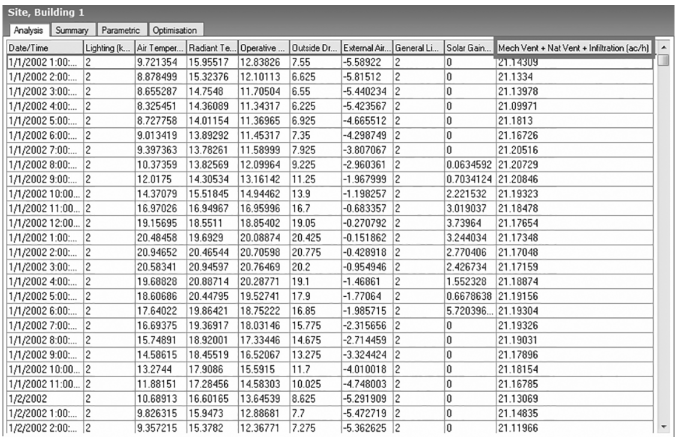
Step 13: Select **Exposed** from the **Exposure to wind** drop-down list under the **Site Details** section.



Step 14: Simulate the model and record the results. Observe the results in Wind Speed, Wind Direction and Mech Vent + Nat Vent + Infiltration (ac/h).



Date/Time	Outside Dr...	Outside De...	Wind Speed (m/s)	Wind Direction (°)	Solar Altitu...	Solar Azim...	Atmosph
1/1/2002	12.85833	2.604167	1	0	0	0	10100
1/2/2002	12.625	3.745833	1	0	0	0	10100
1/3/2002	13.59167	5.854167	1	0	0	0	10112
1/4/2002	14.44167	7.483334	1	0	0	0	10125
1/5/2002	14.20833	9.566667	1	0	0	0	10100
1/6/2002	14.7125	9.779166	1	0	0	0	10108
1/7/2002	15.2375	10.30417	1	0	0	0	10150
1/8/2002	14.92917	10.7125	1	0	0	0	10116
1/9/2002	15.21667	11.19167	1	0	0	0	10100
1/10/2002	16.4	11.18333	1	0	0	0	10108
1/11/2002	14.47083	12.5375	1	0	0	0	10141
1/12/2002	15.37083	10.95	1	0	0	0	10145
1/13/2002	15.8875	11.46667	1	0	0	0	10162
1/14/2002	14.05417	10.075	1	0	0	0	10141
1/15/2002	13.64167	9.120833	1	0	0	0	10154
1/16/2002	11.27917	9.870833	1	0	0	0	10129
1/17/2002	13.00833	9.6	1	0	0	0	10154
1/18/2002	12.0625	9.825	1	0	0	0	10137
1/19/2002	10.98333	9.620833	1	0	0	0	10200
1/20/2002	13.4625	8.683333	1	0	0	0	10137
1/21/2002	13.42917	7.5125	1	0	0	0	10120
1/22/2002	13.36667	7.8875	1	0	0	0	10120
1/23/2002	13.5125	7.454166	1	0	0	0	10166



Date/Time	Lighting (k...	Air Temper...	Radiant Te...	Operative ...	Outside Dr...	External Air...	General Li...	Solar Gain...	Mech Vent + Nat Vent + Infiltration (ac/h)
1/1/2002 1:00:...	2	9.721354	15.95517	12.83826	7.55	-5.58922	2	0	21.14309
1/1/2002 2:00:...	2	8.878499	15.32376	12.10113	6.625	-5.81512	2	0	21.1334
1/1/2002 3:00:...	2	8.655287	14.7548	11.70504	6.55	-5.440234	2	0	21.13978
1/1/2002 4:00:...	2	8.325451	14.36089	11.34317	6.225	-5.423567	2	0	21.09971
1/1/2002 5:00:...	2	8.727758	14.01154	11.36965	6.925	-4.665512	2	0	21.1813
1/1/2002 6:00:...	2	9.013419	13.89292	11.45317	7.35	-4.298749	2	0	21.16726
1/1/2002 7:00:...	2	9.397363	13.78261	11.58999	7.925	-3.807067	2	0	21.20516
1/1/2002 8:00:...	2	10.37359	13.82569	12.09964	9.225	-2.960361	2	0.0634592	21.20729
1/1/2002 9:00:...	2	12.0175	14.30534	13.16142	11.25	-1.967999	2	0.7034124	21.20846
1/1/2002 10:00...	2	14.37079	15.51845	14.94462	13.9	-1.198257	2	2.221532	21.19323
1/1/2002 11:00...	2	16.97026	16.94967	16.95996	16.7	-0.683357	2	3.019037	21.18478
1/1/2002 12:00...	2	19.15695	18.5511	18.85402	19.05	-0.270792	2	3.73964	21.17654
1/1/2002 1:00:...	2	20.48458	19.6929	20.08874	20.425	-0.151862	2	3.244034	21.17348
1/1/2002 2:00:...	2	20.94652	20.46544	20.70598	20.775	-0.428918	2	2.770406	21.17048
1/1/2002 3:00:...	2	20.58341	20.94597	20.76469	20.2	-0.954946	2	2.426734	21.17159
1/1/2002 4:00:...	2	19.68828	20.88714	20.28771	19.1	-1.46861	2	1.552328	21.18874
1/1/2002 5:00:...	2	18.60686	20.44795	19.52741	17.9	-1.77064	2	0.6678638	21.19156
1/1/2002 6:00:...	2	17.64022	19.86421	18.75222	16.85	-1.985715	2	5.720396...	21.19304
1/1/2002 7:00:...	2	16.69375	19.36917	18.03146	15.775	-2.315656	2	0	21.19326
1/1/2002 8:00:...	2	15.74891	18.92001	17.33446	14.675	-2.714459	2	0	21.19031
1/1/2002 9:00:...	2	14.58615	18.45519	16.52067	13.275	-3.324424	2	0	21.17896
1/1/2002 10:00...	2	13.2744	17.9086	15.5915	11.7	-4.010018	2	0	21.18154
1/1/2002 11:00...	2	11.88151	17.28456	14.58303	10.025	-4.748003	2	0	21.16785
1/2/2002	2	10.68913	16.60165	13.64539	8.625	-5.291909	2	0	21.13069
1/2/2002 1:00:...	2	9.826315	15.9473	12.88681	7.7	-5.472719	2	0	21.14835
1/2/2002 2:00:...	2	9.357215	15.3782	12.36771	7.275	-5.362625	2	0	21.11966

You can observe that Air changes per hour are almost constant throughout the year.

Step 15: Modify the weather data with Wind speed as **2 m/s** and Wind direction as **0°** with the help of previous steps.

Step 16: Simulate the model and note down the results. Observe the results in Wind Speed, Wind Direction and Mech Vent + Nat Vent + Infiltration (ac/h).

Site, Building 1

Analysis | Summary | Parametric | Optimisation

Date/Time	Outside Dr...	Outside De...	Wind Speed (m/s)	Wind Direction (°)	Solar Altitu...	Solar Azim...	Atmospheri...	Direct Nor...
1/1/2002	12.85833	2.604167	2	0	-14.77771	177.6181	101000	5.58675
1/2/2002	12.62292	3.732292	2	0	-14.73057	177.5012	101000	5.796
1/3/2002	13.56458	5.822917	2	0	-14.679	177.3857	101125	5.565
1/4/2002	14.44375	7.479167	2	0	-14.62301	177.2715	101250	4.794
1/5/2002	14.19792	9.55625	2	0	-14.56261	177.159	101000	3.252
1/6/2002	14.71771	9.784375	2	0	-14.49779	177.0482	101083.3	3.968
1/7/2002	15.24271	10.30625	2	0	-14.42856	176.9393	101489.6	5.029
1/8/2002	14.92188	10.70417	2	0	-14.35493	176.8323	101177.1	4.499
1/9/2002	15.19167	11.16979	2	0	-14.27691	176.7273	101000	3.015
1/10/2002	16.41042	11.19583	2	0	-14.1945	176.6246	101083.3	2.69575
1/11/2002	14.48958	12.54375	2	0	-14.10772	176.5241	101406.3	1.041
1/12/2002	15.33958	10.93437	2	0	-14.01657	176.426	101458.3	3.1395
1/13/2002	15.89063	11.46667	2	0	-13.92108	176.3304	101625	3.504
1/14/2002	14.08125	10.10312	2	0	-13.82125	176.2413	101416.7	3.609
1/15/2002	13.65521	9.14375	2	0	-13.71711	176.1782	101541.7	4.135
1/16/2002	11.27917	9.847917	2	0	-13.60867	176.1158	101302.1	0.43
1/17/2002	13.00417	9.6	2	0	-13.49596	176.0542	101531.3	2.3445
1/18/2002	12.06667	9.825	2	0	-13.37899	175.9934	101375	1.818
1/19/2002	10.99167	9.628125	2	0	-13.25779	175.9336	102000	1.084
1/20/2002	13.45625	8.692708	2	0	-13.13239	175.875	101385.4	4.5675
1/21/2002	13.42708	7.504167	2	0	-13.00281	175.8176	101208.3	5.16375
1/22/2002	13.37604	7.890625	2	0	-12.8691	175.7617	101208.3	4.905
1/23/2002	13.49375	7.451042	2	0	-12.73127	175.7073	101656.3	5.745
1/24/2002	13.84896	5.819792	2	0	-12.58937	175.6545	101468.8	6.68275
1/25/2002	13.79688	5.7375	2	0	-12.44343	175.6036	101166.7	6.17425
1/26/2002	13.975	6.060417	2	0	-12.29349	175.5545	101281.3	5.36675
1/27/2002	13.97917	9.466666	2	0	-12.1396	175.5075	101458.3	3.841
1/28/2002	14.92396	9.523958	2	0	-11.98179	175.4626	101416.7	5.445
1/29/2002	15.26667	10.61875	2	0	-11.82012	175.4199	101302.1	4.9165
1/30/2002	15.43333	11.53021	2	0	-11.65463	175.3795	101333.3	3.978
1/31/2002	15.64167	11.60729	2	0	-11.48538	175.3415	101333.3	3.67575

Site, Building 1

Analysis | Summary | Parametric | Optimisation

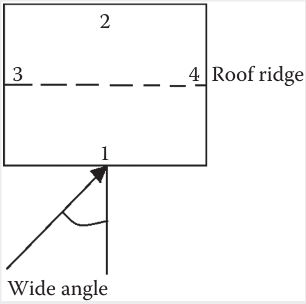
Date/Time	Lighting (k...	Air Temper...	Radiant Te...	Operative ...	Outside Dr...	External Air...	General Li...	Solar Gain...	Mech Vent + Nat Vent + Infiltration (ac/h)
1/1/2002	48	13.43512	16.55211	14.99361	12.85833	-71.44456	48	20.46565	42.40253
1/2/2002	48	13.23312	16.53766	14.88539	12.62292	-75.60387	48	20.65007	42.40345
1/3/2002	48	14.06458	16.67644	15.37051	13.56458	-61.96915	48	20.30718	42.39244
1/4/2002	48	14.95918	17.58778	16.27348	14.44375	-63.888	48	18.74929	42.40048
1/5/2002	48	14.71339	17.58712	16.15026	14.19792	-63.2599	48	15.46985	42.39462
1/6/2002	48	15.22552	17.87527	16.55039	14.71771	-62.55011	48	17.15997	42.39699
1/7/2002	48	15.74263	18.36096	17.0518	15.24271	-61.86818	48	19.3339	42.39691
1/8/2002	48	15.45935	18.2917	16.87553	14.92188	-66.27816	48	17.81438	42.40128
1/9/2002	48	15.674	18.23991	16.95695	15.19167	-59.18798	48	14.79877	42.39451
1/10/2002	48	16.87027	19.20712	18.0387	16.41042	-56.2439	48	14.10314	42.39755
1/11/2002	48	15.03912	18.25718	16.64815	14.48958	-67.45989	48	9.394398	42.39695
1/12/2002	48	15.76976	17.99518	16.88247	15.33958	-53.10181	48	15.38769	42.38715
1/13/2002	48	16.38739	19.07148	17.72943	15.89063	-61.21595	48	16.23146	42.39942
1/14/2002	48	14.70097	18.33269	16.51683	14.08125	-76.21751	48	16.33938	42.41026
1/15/2002	48	14.23923	17.53168	15.88546	13.65521	-72.29655	48	17.44697	42.4035
1/16/2002	48	11.87076	15.40755	13.63916	11.27917	-73.19688	48	5.370644	42.39591
1/17/2002	48	13.43093	15.73781	14.58437	13.00417	-52.94247	48	12.20812	42.38873
1/18/2002	48	12.58444	15.64777	14.1161	12.06667	-64.07486	48	11.81416	42.39665
1/19/2002	48	11.53574	14.75872	13.14723	10.99167	-67.99506	48	9.737206	42.39683
1/20/2002	48	13.86004	15.90719	14.88362	13.45625	-50.12586	48	18.38432	42.38223
1/21/2002	48	13.95228	16.73211	15.3422	13.42708	-65.14606	48	18.80874	42.39901
1/22/2002	48	13.91903	16.74391	15.33147	13.37604	-67.50484	48	17.40286	42.40156
1/23/2002	48	14.01518	16.79054	15.40286	13.49375	-65.02526	48	19.85939	42.39923
1/24/2002	48	14.39279	17.35601	15.8744	13.84896	-67.47822	48	21.5369	42.39879
1/25/2002	48	14.40482	17.66574	16.03528	13.79688	-75.24442	48	20.63347	42.40715
1/26/2002	48	14.53029	17.48887	16.00958	13.975	-68.70015	48	19.1846	42.40103
1/27/2002	48	14.50237	17.18624	15.8443	13.97917	-65.14906	48	16.17116	42.40168
1/28/2002	48	15.42192	17.92839	16.67516	14.92396	-61.99186	48	19.29823	42.39928

You can calculate the Air changes per hour for two windows with the following equation:*

$$Q = U_w * \sqrt{\frac{C_{p1} - C_{p2}}{\frac{1}{(A_1 * C_1)}^2 + \frac{1}{(A_2 * C_2)}^2}}$$

where C_p is the pressure drag coefficient, C is the discharge coefficient, U is the wind speed and A is the area of the opening.

Wind pressure coefficient data



Low-rise buildings (up to three storeys)

Length-to-width ratio: 1:1

Shielding condition: exposed

Wind speed reference level = building height

Wind angle (Table 10.1)

Table 10.1 Wind pressure coefficient data

Location	0	45	90	135	180	225	270	315
Face 1	0.7	0.35	–0.5	–0.4	–0.2	–0.4	–0.5	0.35
Face 2	–0.2	–0.4	–0.5	0.35	0.7	0.35	–0.5	–0.4
Face 3	–0.5	0.35	0.7	0.35	–0.5	–0.4	–0.2	–0.4
Face 4	–0.5	–0.4	–0.2	–0.4	–0.5	0.35	0.7	0.35

Source: http://www.designbuilder.co.uk/downloads/AIVCWindPressureCoefficientData.pdf

http://www.designbuilder.co.uk/helpv4.7/Content/Pressure_Coefficients_Data.htm

* ASHRAE Handbook of Fundamentals – 2015. ©ASHRAE, www.ashrae.org. (2015) ASHRAE Handbook—(Fundamentals).

Wind pressure coefficient templates
Wind pressure coefficients are used when the Natural ventilation model option is set to 'Calculated'. The EnergyPlus Airflow Network calculations use pressure coefficients when calculating wind-induced pressure on each surface during simulations when the Calculated Natural ventilation option is selected.

DesignBuilder is supplied with a database of wind pressure coefficients based on the data from Martin Liddament, Air Infiltration Calculation Techniques, An Applications Guide, AIVC. The C_p data are buildings of three storeys or less, with square surfaces and for three levels of site exposure. The data are given in 45° increments.

http://www.designbuilder.co.uk/downloadsv1/AIVCWindPressureCoefficientData.pdf

http://www.designbuilder.co.uk/helpv4.7/Content/Pressure_Coefficients_Data.htm

Wind speed provided in the weather file is for 10-m height. You can use the following formula to calculate the wind speed at 2-m height:

$$u = u_r \left(\frac{z}{z_r} \right)^{\alpha}$$

α is approximately 1/7, or 0.143 (it varies with local topography).

Tables 10.2 and 10.3 gives the calculation for natural ventilation in the zone.

Table 10.2 Calculation of zone air changes per hour at a wind speed of 1 m/s at 10-m height

Wind speed at 2 m	0.72	m/s
Area of window	6.59	m^2
C_{p1}	0.7	
C_{p2}	–0.2	
C_1	0.65	
C_2	0.65	
Q	2.07	m^3/s
Q	7,442	m^3/h
Zone volume	350	m^3
Air changes	21.26	ac/h

Table 10.3 Calculation of zone air changes per hour at a wind speed of 2 m/s at 10 m-height

Wind speed at 2 m	1.44	m/s
Area of window	6.59	m^2
C_{p1}	0.7	
C_{p2}	–0.2	
C_1	0.65	
C_2	0.65	
Q	4.13	m^3/s
Q	14,885	m^3/h
Zone volume	350	m^3
Air changes	42.53	ac/h

Exercise 10.2

Repeat the above tutorial for the window area 16 m^2.

TUTORIAL 10.3 Evaluating the impact of window opening and closing schedule

GOAL

To evaluate the impact of window opening and closing schedule.

WHAT ARE YOU GOING TO LEARN?

- Defining window opening and closing schedule for natural ventilation

PROBLEM STATEMENT

In this tutorial, you are going to use the model saved in Tutorial 10.2 and add windows in remaining two directions.

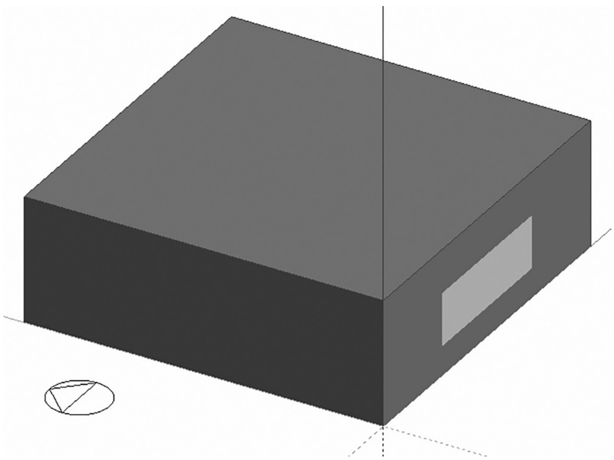
You need to simulate the model for the following two window operation schedules:

1. On (windows are always open)
2. 8:00–18:00 Mon–Sat

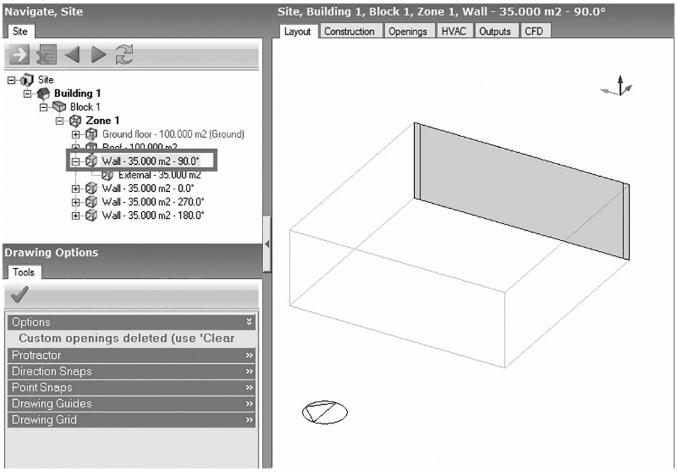
Use **New Delhi/Safdarjung, India** weather location.

SOLUTION

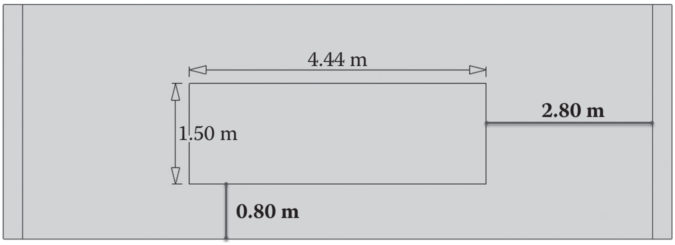
Step 1: Open a project saved in Tutorial 10.2.



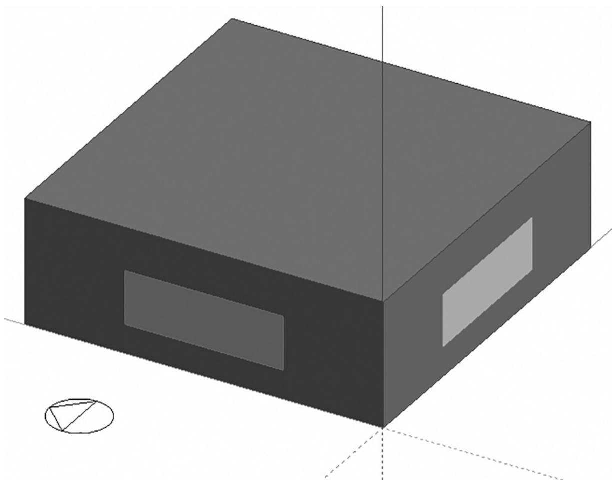
Step 2: In the navigation tree select East facing wall by selecting **Wall – 35.000 m^2 – 90.0°**.



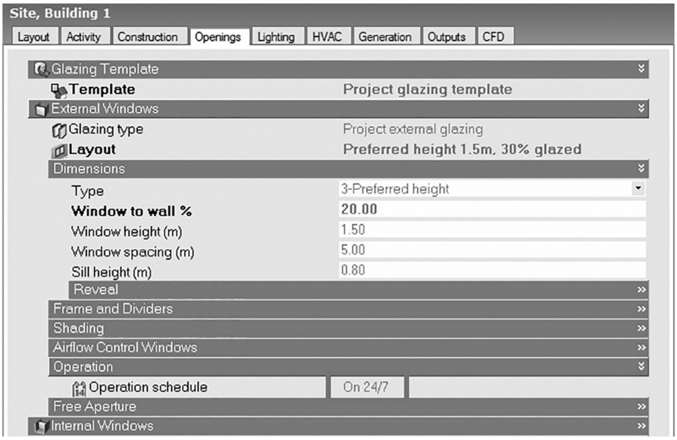
Step 3: Select **Left** in the View rotation dropdown list then select **Draw window** in the **Help** tab to draw a window with the same dimensions as that on the north or south side.



Step 4: Similarly, draw the west window.



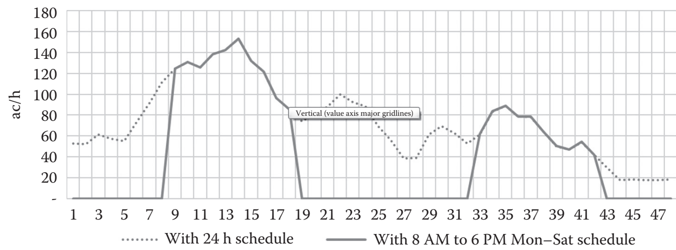
Step 5: Select the **Openings** tab. Click the **Operation** section. Make sure that Operation schedule is **On 24/7**.



Simulate the model and record the results by exporting them to the spreadsheet.

Step 6: Repeat the above steps for Operation schedule **8:00 - 18:00 Mon - Sat**.

Simulate the model and record the results. Plot the graph for January 1 and 2 for Mech Vent + Nat Vent + Infiltration (Air changes per hour, ac/h).



You can observe the impact of window opening and closing on air change rate.

TUTORIAL 10.4 Evaluating the impact of window opening control based on temperature

GOAL

To evaluate the impact of window opening control based on zone and outdoor air temperature.

WHAT ARE YOU GOING TO LEARN?

- Defining window operation control for natural ventilation

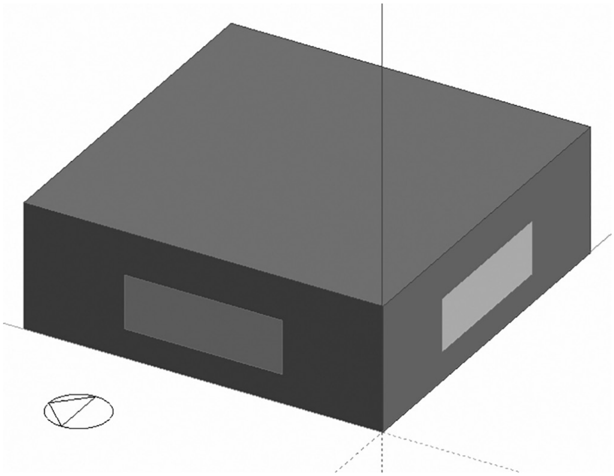
PROBLEM STATEMENT

In this tutorial, you are going to use the calculated model saved in Tutorial 10.1. You are going to simulate the model for Temperature control mode.

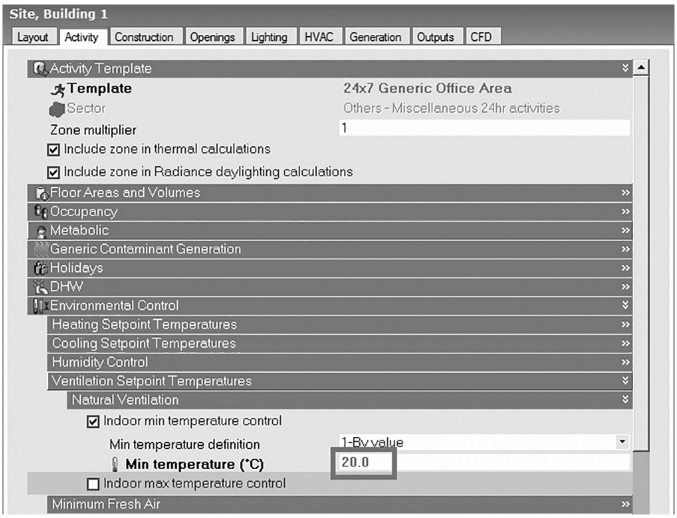
Use **New Delhi/Safdarjung, India** weather location.

SOLUTION

Step 1: Open the model saved in Tutorial 10.1 with natural ventilation set to calculate.



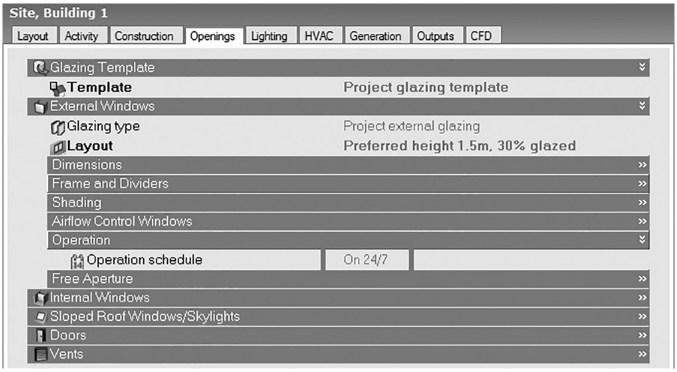
Step 2: Select the **Activity** tab. Set **Min temperature** to **20.0**.



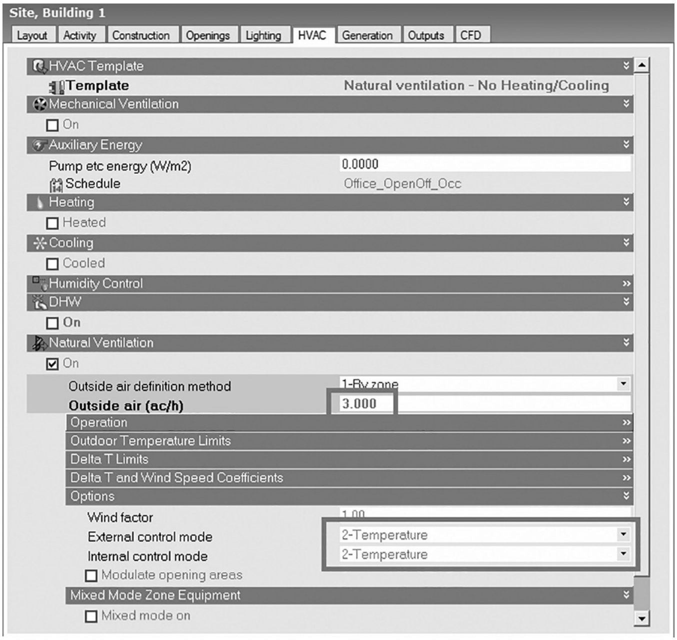
Natural ventilation min temperature
This is the fixed indoor temperature below which ventilation is shut off. The control is visible when the 1-By value option is selected for Min temperature definition. It can be thought of as the cooling setpoint temperature which controls the activation of natural ventilation. If the inside air temperature is greater than this setpoint temperature (and the natural ventilation operation schedule is on), then natural ventilation can take place.

http://www.designbuilder.co.uk/helpv4.7/Content/_Environmental_comfort.htm

Step 3: Select the **Openings** tab. Click the **Operation** section. Make sure that Operation schedule is **On 24/7**.



Step 4: Select the **HVAC** tab. Enter Outside air (ac/h) as **3.000**. Select **Temperature** for the **External and Internal Control mode** drop-down lists.



To see the effect of window opening controls, we need the following:

1. Generate and view the results at system time steps instead of fixed user defined time steps. This can be achieved by selecting the 'detailed' frequency option on an HVAC output variable (e.g. Zone Air Temperature).
2. Generate more output variables such as window opening factor, zone infiltration and zone air temperature.

Field: Ventilation Control Mode

Specifies the type of zone-level natural ventilation control. The windows are 'open' when:

$T_{zone\_air} > T_{setpoint}$ AND $T_{zone\_air} > T_{outside\_air}$ AND the schedule value = 1

where $T_{outside\_air}$ is equal to the outdoor air temperature, T_{zone_air} is equal to the previous time step's zone air temperature, $T_{setpoint}$ is equal to the Vent Temperature Schedule value.

http://www.designbuilder.co.uk/helpv4.7/Content/_Operation2.htm

System time step is a variable-length time step that governs the driving time step for HVAC and Plant system modelling. The user cannot directly control the system time step (except by use of the ConvergenceLimits object). When the HVAC portion of the simulation begins its solution for the current zone time step, it uses the zone time step as its maximum length but can then reduce the time step, as necessary, to improve the solution.

Users can see the system time step used if they select the 'detailed' frequency option on an HVAC output variable (e.g. Zone Air Temperature). In contrast, the 'Zone' variables will only be reported on the zone time step (e.g. Zone Mean Air Temperature).

Note that hourly data (such as outdoor conditions expressed by Design Days or Weather data) are interpolated to the Zone Time step.

Source: EnergyPlus InputOutput Reference

Zone Mean Air Temperature (°C)
Zone Mean Air Temperature is the average temperature of the air temperatures at the system time step. Remember that the zone heat balance represents a 'well-stirred' model for a zone; therefore, there is only one mean air temperature to represent the air temperature for the zone. This is reported only at the zone time step.

Zone Air Temperature (°C)
This is very similar to the mean air temperature. The 'well-stirred' model for the zone is the basis, but this temperature is also available at the 'detailed' system time step.

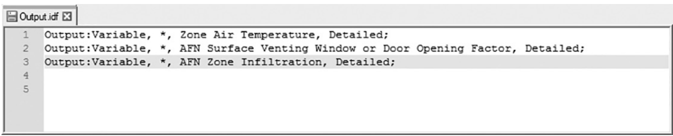
Source: EnergyPlus InputOutput Reference

Step 5: Minimize the DesignBuilder window. Create a new file named **output.idf**. Write additional output variables as follows:

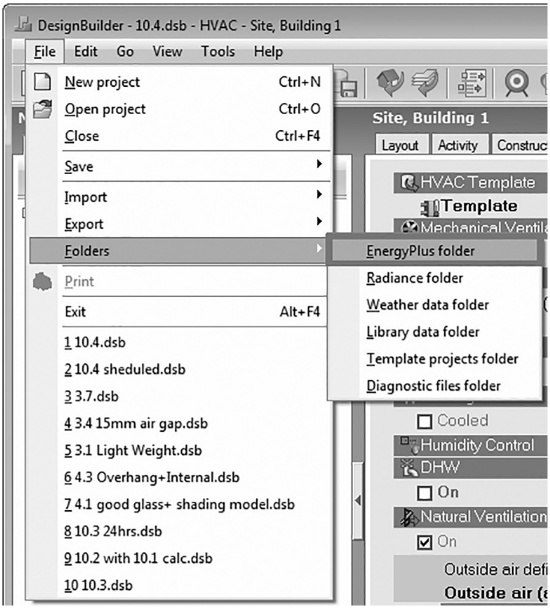
Output:Variable, *, Zone Air Temperature, Detailed;

Output:Variable, *, AFN Surface Venting Window or Door Opening Factor, Detailed;

Output:Variable, *, AFN Zone Infiltration, Detailed;

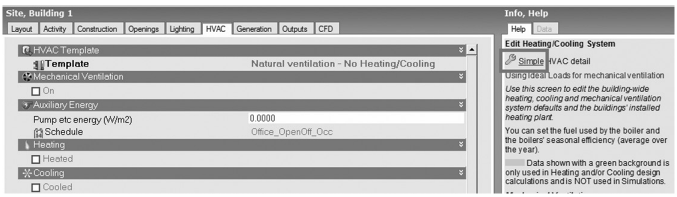


This .idf file needs to be placed in the following path:

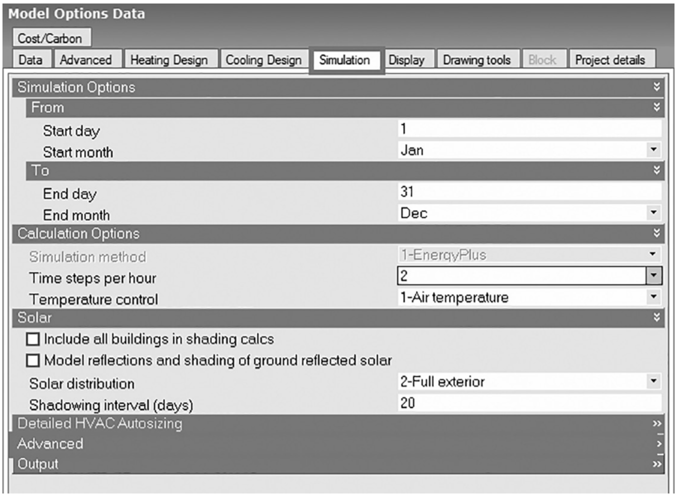


You can use any text editor such as Notepad++ and Editplus.

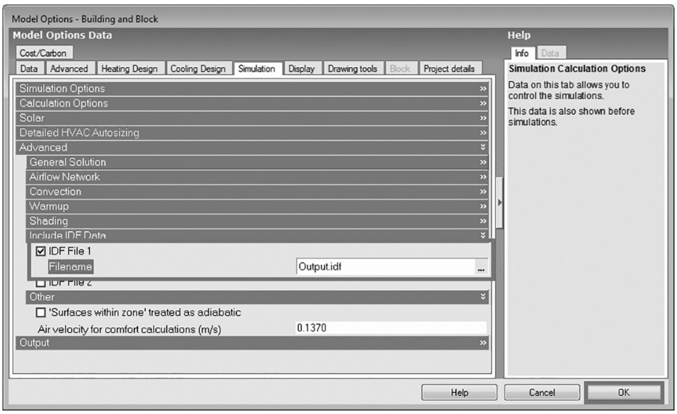
Step 6: Maximize the DesignBuilder window and select the **HVAC** tab. Click **Simple** under the **Help** tab. The **Model Options – Building and Block** screen appears.



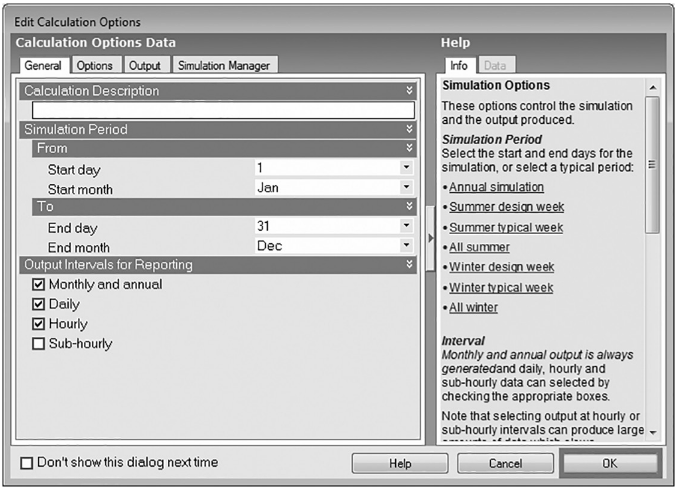
Step 7: Select the **Simulation** tab. Click the **Advanced** section.



Step 8: Select the **IDF File 1** check box and select the Output.idf file from the EnergyPlus folder. Click **OK**.



Step 9: Select the **Simulation** tab. The **Edit Calculation Options** screen appears. Click **OK**.

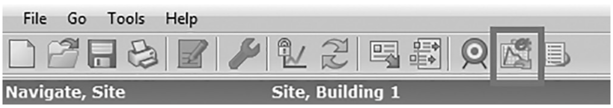


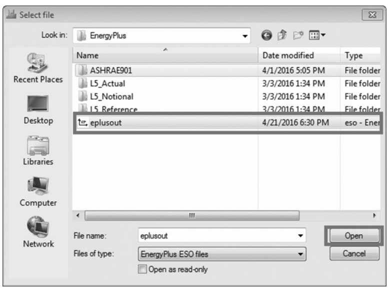
After simulation, the results on the screen appear, but DesignBuilder does not support viewing 'Detailed' reporting frequency.

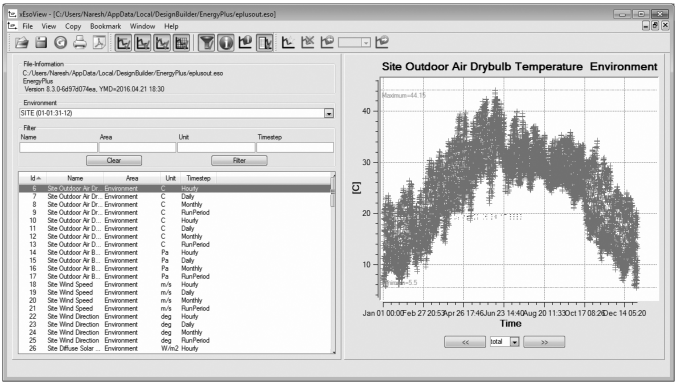
After simulation, an ESO file is generated in the EnergyPlus folder which contains results at detailed reporting frequency. You can view this in the **xESOView** tool.

xESOView can be downloaded from http://xesoview.sourceforge.net/.

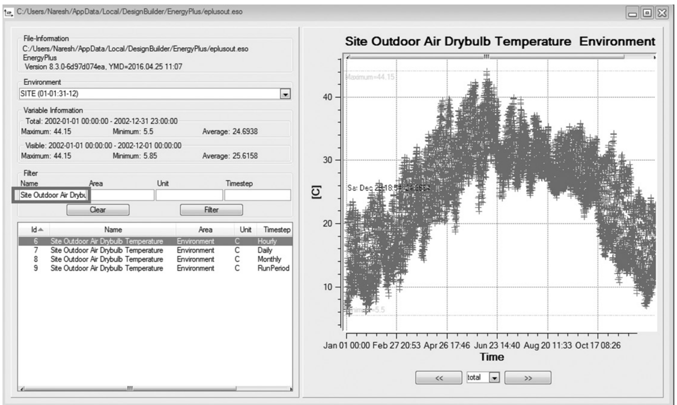
Step 10: Click the **View EnergyPlus results** icon. From the EnergyPlus folder, select the **eplusout.eso** file. xESOView tool will open.





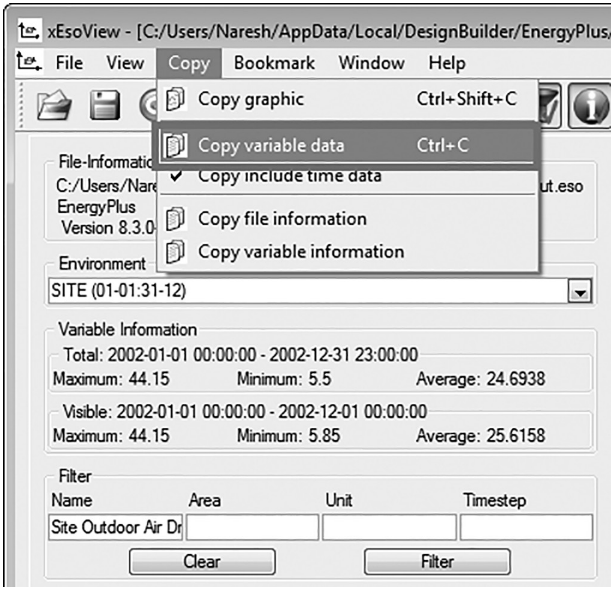


Step 11: Enter **Site Outdoor Air Drybulb Temperature** in the Name field of the Filter section to view the variable. From the filtered list select the variable with hourly Timestep.



You can copy the variable data to view in a spreadsheet.

Step 12: Click **Copy** and select **Copy variable data**.



You can copy only one variable at a time.

Step 13: Open a spreadsheet program and paste the data as shown in the below screen.

	A	B	C	D	E	F	G
1	Date/Time	Site Outdoor Air Drybulb Temperature Environment [C]	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_2_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_3_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_4_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_5_0_0_0_0_0_WIN []	AFN Zone Infiltration Air Change Rate BLOCK1:ZONE1 [ach]
2	1/1/22 12:: AM	7.55	0.868534	0.868534	0.868534	0.868534	0.01
3	1/1/22 12:2: AM	7.55	0	0	0	0	0.01
4	1/1/22 12:4: AM	7.55	0	0	0	0	0.01
5	1/1/22 12:6: AM	7.55	0	0	0	0	0.01
6	1/1/22 12:9: AM	7.55	0	0	0	0	0.01
7	1/1/22 12:11: AM	7.55	0	0	0	0	0.01
8	1/1/22 12:13: AM	7.55	0	0	0	0	0.01
9	1/1/22 12:16: AM	7.55	0	0	0	0	0.01
10	1/1/22 12:18: AM	7.55	0	0	0	0	0.01
11	1/1/22 12:2: AM	7.55	0	0	0	0	0.01
12	1/1/22 12:23: AM	7.55	0	0	0	0	0.01
13	1/1/22 12:25: AM	7.55	0	0	0	0	0.01
14	1/1/22 12:27: AM	7.55	0.87345	0.87345	0.87345	0.87345	0.01
15	1/1/22 12:3: AM	7.55	0	0	0	0	0.01
16	1/1/22 12:32: AM	7.55	0	0	0	0	0.01
17	1/1/22 12:35: AM	7.55	0	0	0	0	0.01
18	1/1/22 12:38: AM	7.55	0	0	0	0	0.01
19	1/1/22 12:4: AM	7.55	0	0	0	0	0.01

Similarly, copy and paste the below variables with time step as hourly:

- AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_2_0_0_0_0_0_WIN []
- AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_3_0_0_0_0_0_WIN []

- AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_4_0_0_0_0_0_WIN []
- AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_5_0_0_0_0_0_WIN []
- AFN Zone Infiltration Air Change Rate BLOCK1: ZONE1 [ach]
- Zone Air Temperature BLOCK1:ZONE1 [C]

I379 | fx =IF(AND(H379>B379,H379>20),TRUE,FALSE)

	A	B	C	D	E	F	G	H	I
1	Date/Time	Site Outdoor Air Drybulb Temperature Environment [C]	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_2_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_3_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_4_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_5_0_0_0_0_0_WIN []	AFN Zone Infiltration Air Change Rate BLOCK1:ZONE1 [ach]	Zone Air Temperature BLOCK1:ZONE1 [C]	Check if Tzone > Tout and Tzone>20
375	1/1/22 4:42: PM		0.971402	0.971402	0.971402	0.971402	1.00E-02	19.3989	FALSE
376	1/1/22 4:48: PM		0	0	0	0	1.00E-02	20.6136	TRUE
377	1/1/22 4:54: PM		0.969861	0.969861	0.969861	0.969861	1.00E-02	19.3941	FALSE
378	1/1/22 4:: PM	17.9	1.00E-02	1.00E-02	1.00E-02	1.00E-02	30.4174	1.00E-02	FALSE
379	1/1/22 5:: PM		0	0	0	0	1.00E-02	20.477	TRUE
380	1/1/22 5:2: PM		0.966227	0.966227	0.966227	0.966227	1.00E-02	19.6049	FALSE
381	1/1/22 5:4: PM		0	0	0	0	1.00E-02	19.702	FALSE
382	1/1/22 5:6: PM		0	0	0	0	1.00E-02	20.5935	TRUE
399	1/1/22 5:4: PM		0	0	0	0	1.00E-02	20.259	TRUE
400	1/1/22 5:42: PM		0.963407	0.963407	0.963407	0.963407	1.00E-02	19.3331	FALSE
401	1/1/22 5:45: PM		0	0	0	0	1.00E-02	19.3737	FALSE
402	1/1/22 5:47: PM		0	0	0	0	1.00E-02	20.2602	TRUE
403	1/1/22 5:49: PM		0.963394	0.963394	0.963394	0.963394	1.00E-02	19.3339	FALSE
404	1/1/22 5:51: PM		0	0	0	0	1.00E-02	19.3771	FALSE
405	1/1/22 5:53: PM		0	0	0	0	1.00E-02	20.2648	TRUE
406	1/1/22 5:55: PM		0.963349	0.963349	0.963349	0.963349	1.00E-02	19.3365	FALSE
407	1/1/22 5:57: PM		0	0	0	0	1.00E-02	19.3781	FALSE
408	1/1/22 5:: PM	16.85	1.00E-02	1.00E-02	1.00E-02	1.00E-02	15.3434	1.00E-02	FALSE
409	1/1/22 6:: PM		0	0	0	0	1.00E-02	20.2575	TRUE
410	1/1/22 6:2: PM		0.957921	0.957921	0.957921	0.957921	1.00E-02	18.9839	FALSE
411	1/1/22 6:5: PM		0	0	0	0	1.00E-02	18.9261	FALSE

You can observe from the above that if the following conditions are true, then there is natural ventilation.

$$T_{\text{zone\_air}} > T_{\text{setpoint}} \text{ AND } T_{\text{zone\_air}} > T_{\text{outside\_air}}$$

Please note that the zone setpoint is 20°C. You can see that the windows open in the succeeding time step after the above mentioned condition is met. Please note that the Zone infiltration air change rate is reported hourly and not on the system timestep. Hence, even when the windows are open the zone ventilation will not be reported in that timestep, it will be reported in the hourly time step.

TUTORIAL 10.5 Evaluating the impact of window opening area modulation on natural ventilation

GOAL

To evaluate the impact of window opening area modulation based on zone and outdoor air temperature.

WHAT ARE YOU GOING TO LEARN?

- Defining window opening area modulation

PROBLEM STATEMENT

In this tutorial, you are going to use the model saved in Tutorial 10.4.

You are going to simulate the model for Temperature control mode.

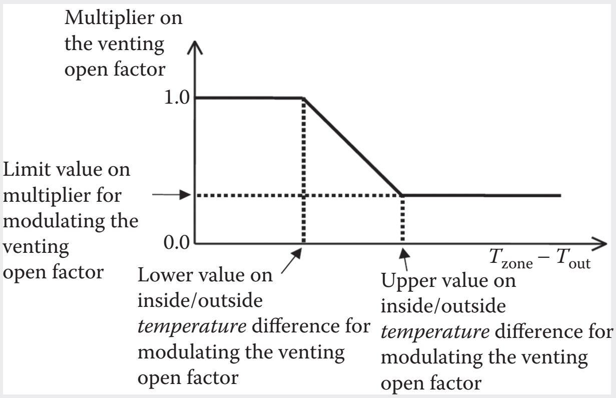
Use **New Delhi/Safdarjung, India** weather location.

The modulation takes the following form when Ventilation Control Mode = Temperature.

$T_{zone} - T_{out}$ = [Lower value on inside/outside temperature difference for modulating the venting open factor]; then multiplication factor = 1.0.

[Lower value on inside/outside temperature difference for modulating the venting open factor] < $T_{zone} - T_{out}$ < [upper value on inside/outside temperature difference for modulating the venting open factor]; then multiplication factor varies linearly from 1.0 to [limit value on multiplier for modulating the venting open factor].

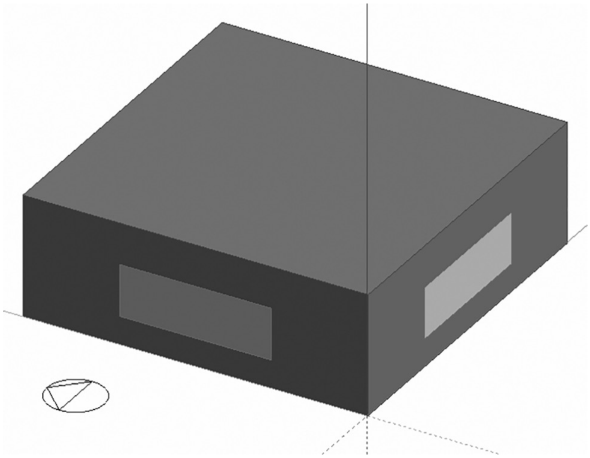
$T_{zone} - T_{out}$ = [upper value on inside/outside temperature difference for modulating the venting open factor]; then multiplication factor = [limit value on multiplier for modulating the venting open factor].



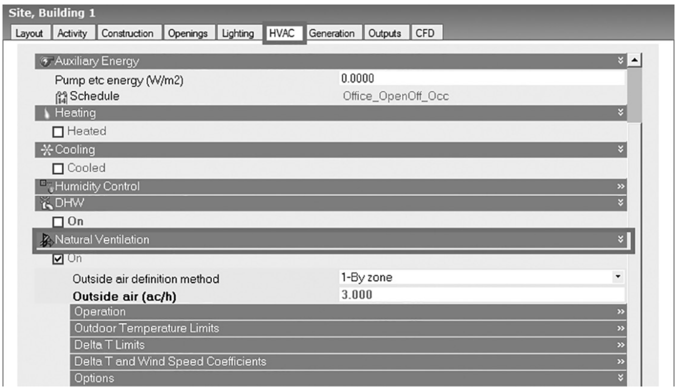
Ref: EnergyPlus InputOutput Reference.

SOLUTION

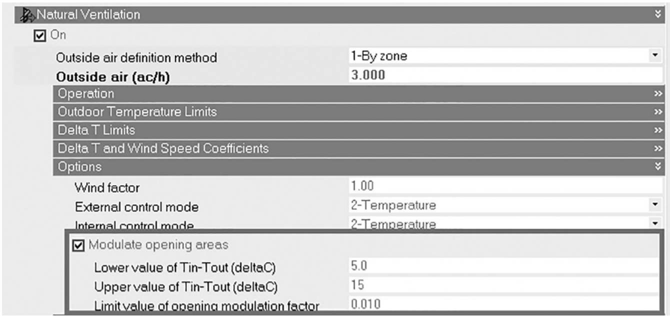
Step 1: Open the project saved in Tutorial 10.4.



Step 2: Select the **HVAC** tab. Expand the **Natural Ventilation** section.



Step 3: Select the **Modulate opening areas** check box. Enter the lower value of $T_{in} - T_{out}$ as **5.0** and the upper value as **15**.

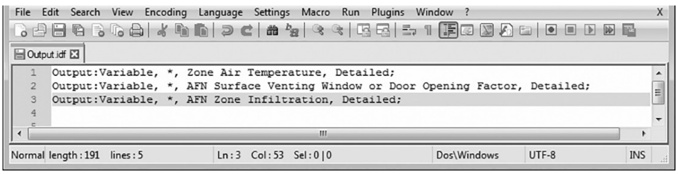


Step 4: Minimize the DesignBuilder window. Create an output.idf file. Write additional output variables:

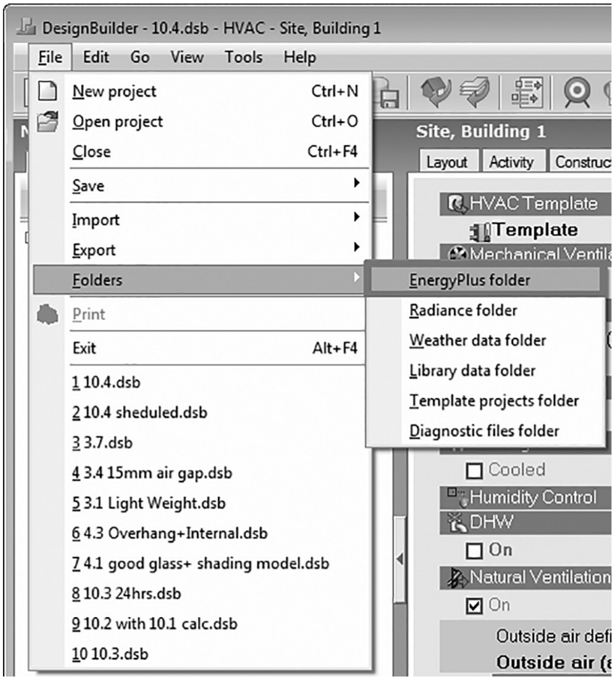
Output: Variable, *, Zone Air Temperature, Detailed;

Output: Variable, *, AFN Surface Venting Window or Door Opening Factor, Detailed;

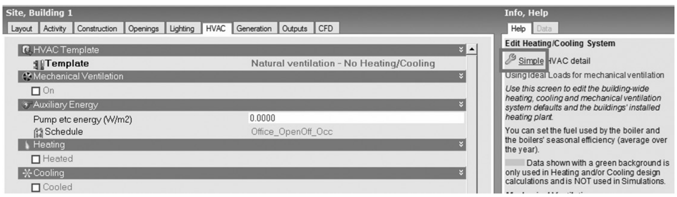
Output: Variable, *, AFN Zone Infiltration, Detailed;



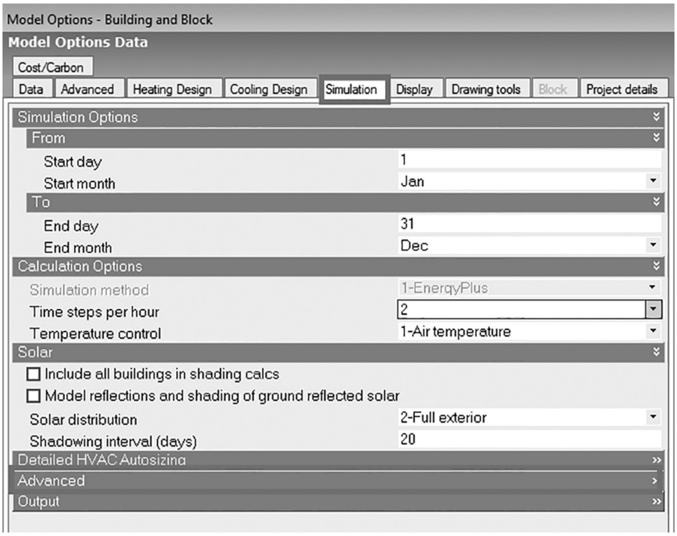
This .idf file needs to be placed in the following path:



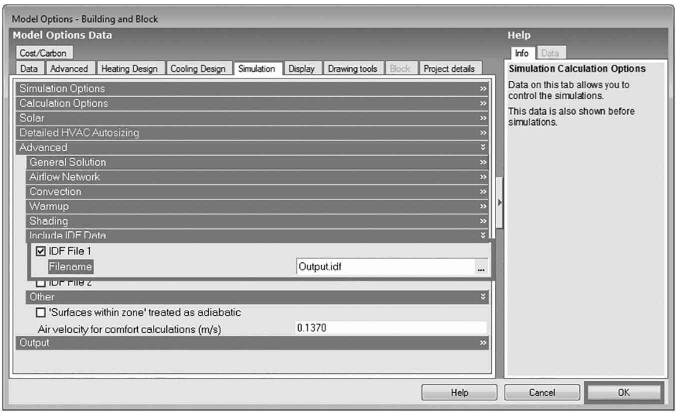
Step 5: Maximize the DesignBuilder window and select the **HVAC** tab. Click **Simple** under the **Help** tab. The **Model Options – Building and Block** screen appears.



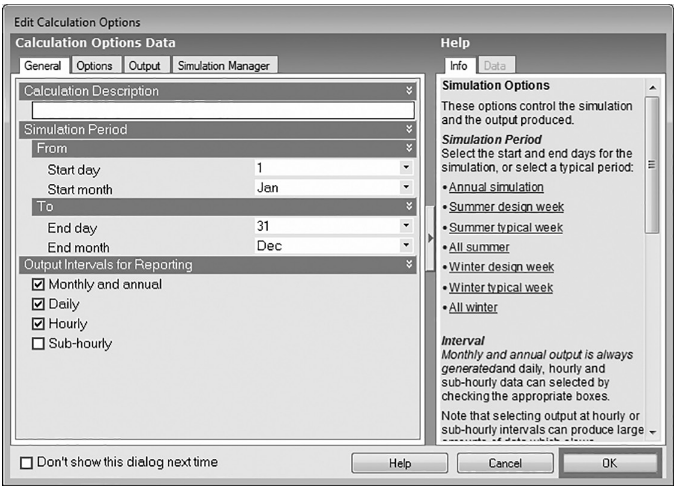
Step 6: Select the **Simulation** tab. Click the **Advanced** section.



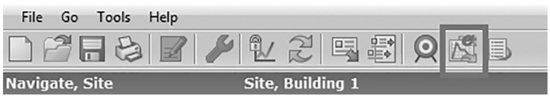
Step 7: Select the **IDF File 1** check box and select the Output.idf file from the EnergyPlus folder. Click **OK**.

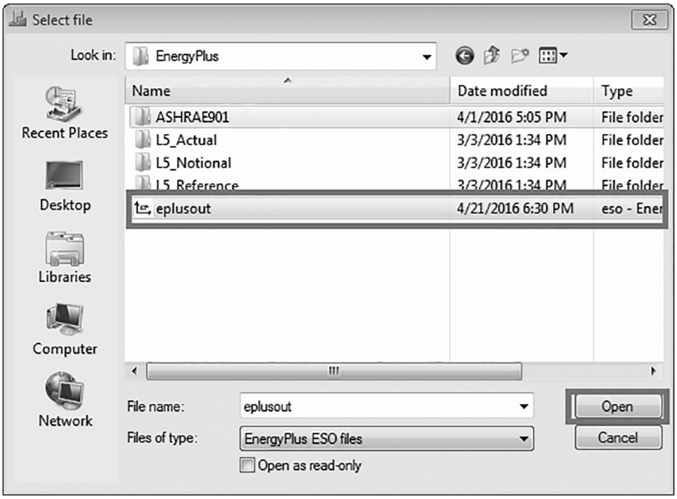


Step 8: Select the **Simulation** tab. The **Edit Calculation Options** screen appears. Click **OK**.

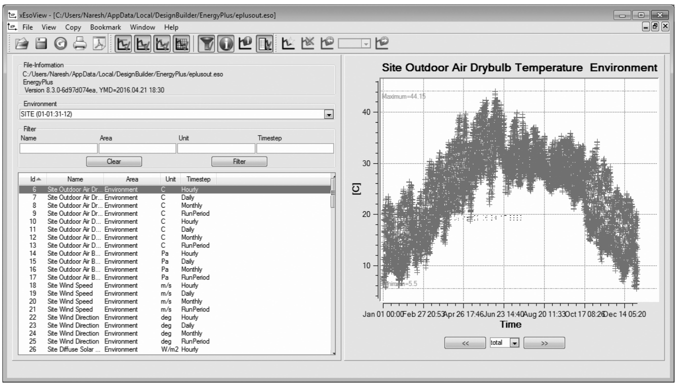


Step 9: Select the EnergyPlus results. Select **eplusout** file, so that the file will automatically open in the xESO-View tool.

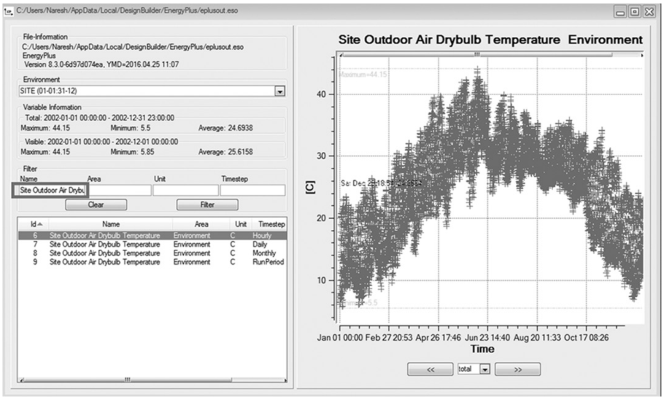




The xEsoView screen appears:

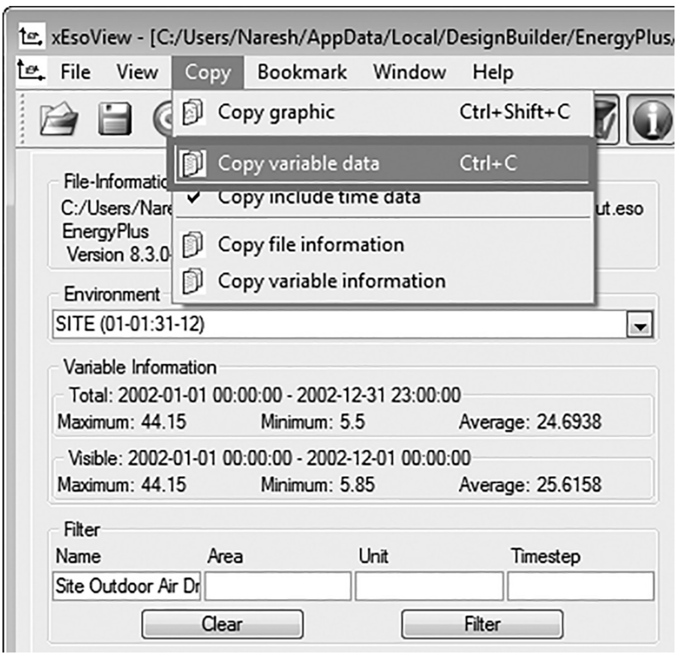


Step 10: Enter **Site Outdoor Air Drybulb Temperature** in the Name field of the Filter section to view the variable.



You can copy the variable data to view in a spreadsheet.

Step 11: Click **Copy** and select **Copy variable data**.



Step 12: Open a spreadsheet and paste the data.

	A	B	C	D	E	F	G
1	Date/Time	Site Outdoor Air Drybulb Temperature Environment [C]	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_2_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_3_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_4_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_5_0_0_0_0_0_WIN []	AFN Zone Infiltration Air Change Rate BLOCK1:ZONE1 [ach]
2	1/1/22 12:: AM	7.55	0.868534	0.868534	0.868534	0.868534	0.01
3	1/1/22 12:2: AM	7.55	0	0	0	0	0.01
4	1/1/22 12:4: AM	7.55	0	0	0	0	0.01
5	1/1/22 12:6: AM	7.55	0	0	0	0	0.01
6	1/1/22 12:9: AM	7.55	0	0	0	0	0.01
7	1/1/22 12:11: AM	7.55	0	0	0	0	0.01
8	1/1/22 12:13: AM	7.55	0	0	0	0	0.01
9	1/1/22 12:16: AM	7.55	0	0	0	0	0.01
10	1/1/22 12:18: AM	7.55	0	0	0	0	0.01
11	1/1/22 12:2: AM	7.55	0	0	0	0	0.01
12	1/1/22 12:23: AM	7.55	0	0	0	0	0.01
13	1/1/22 12:25: AM	7.55	0	0	0	0	0.01
14	1/1/22 12:27: AM	7.55	0.87345	0.87345	0.87345	0.87345	0.01
15	1/1/22 12:3: AM	7.55	0	0	0	0	0.01
16	1/1/22 12:32: AM	7.55	0	0	0	0	0.01
17	1/1/22 12:35: AM	7.55	0	0	0	0	0.01
18	1/1/22 12:38: AM	7.55	0	0	0	0	0.01
19	1/1/22 12:4: AM	7.55	0	0	0	0	0.01

You can check if natural ventilation is working as per the controls applied.

I248 =IF(AND(H248>B248,H248>20),TRUE,FALSE)

	A	B	C	D	E	F	G	H	I
1	Date/Time	Site Outdoor Air Drybulb Temperature Environment [C]	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_2_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_3_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_4_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_5_0_0_0_0_0_WIN []	AFN Zone Infiltration Air Change Rate BLOCK1:ZONE1 [ach]	Zone Air Temperature BLOCK1:ZONE1 [C]	Check if Tzone > Tout and Tzone >20
247	1/1/22 9:15: AM	11.25	0	0	0	0	1.00E-02	19.4544	FALSE
248	1/1/22 9:17: AM	11.25	0	0	0	0	1.00E-02	20.5136	TRUE
249	1/1/22 9:19: AM	11.25	0.926861	0.926861	0.926861	0.926861	1.00E-02	16.969	FALSE
250	1/1/22 9:21: AM	11.25	0	0	0	0	1.00E-02	15.6437	FALSE
258	1/1/22 9:37: AM	11.25	0	0	0	0	1.00E-02	16.7314	FALSE
259	1/1/22 9:38: AM	11.25	0	0	0	0	1.00E-02	17.1751	FALSE
260	1/1/22 9:4: AM	11.25	0	0	0	0	1.00E-02	18.2332	FALSE
261	1/1/22 9:42: AM	11.25	0	0	0	0	1.00E-02	19.337	FALSE
262	1/1/22 9:44: AM	11.25	0	0	0	0	1.00E-02	20.2929	TRUE
263	1/1/22 9:45: AM	11.25	0.943068	0.943068	0.943068	0.943068	1.00E-02	17.7963	FALSE
264	1/1/22 9:47: AM	11.25	0	0	0	0	1.00E-02	16.7258	FALSE
265	1/1/22 9:49: AM	11.25	0	0	0	0	1.00E-02	17.1582	FALSE
266	1/1/22 9:51: AM	11.25	0	0	0	0	1.00E-02	18.2154	FALSE
267	1/1/22 9:52: AM	11.25	0	0	0	0	1.00E-02	19.3217	FALSE
268	1/1/22 9:54: AM	11.25	0	0	0	0	1.00E-02	20.2802	TRUE
269	1/1/22 9:56: AM	11.25	0.943195	0.943195	0.943195	0.943195	1.00E-02	17.7908	FALSE
270	1/1/22 9:58: AM	11.25	0	0	0	0	1.00E-02	16.7245	FALSE
271	1/1/22 9:: AM	13.9	1.00E-02	1.00E-02	1.00E-02	1.00E-02	10.8368	1.00E-02	FALSE
272	1/1/22 1:: AM		0	0	0	0	1.00E-02	19.0569	FALSE

You can observe from the above that if the following conditions are true, then there is natural ventilation

$$T_{\text{zone\_air}} > T_{\text{setpoint}} \text{ AND } T_{\text{zone\_air}} > T_{\text{outside\_air}}$$

and Window opening fraction is dependent on the $T_{\text{zone}} - T_{\text{out}}$.

TUTORIAL 10.6 Evaluating the impact of mixed mode operation

GOAL

To evaluate the impact of mixed mode operation on energy performance.

WHAT ARE YOU GOING TO LEARN?

- Modelling mixed-mode ventilation

PROBLEM STATEMENT

In this tutorial, you are going to use the model saved in Tutorial 10.4.

Find out the energy consumption for the following two cases:

1. With mixed mode
2. Fully air conditioned

Use the **New Delhi/Safdarjung, India** weather location.

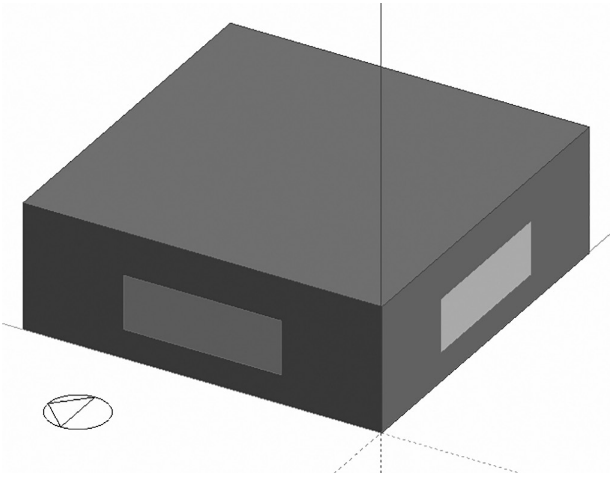
Mixed-Mode Cooling
In mixed-mode buildings, natural ventilation is used as the primary means of providing cooling, and active cooling is introduced when this is inadequate to provide comfort conditions.

Mixed-Mode Building
Mixed mode refers to a hybrid approach to space conditioning that uses a combination of natural ventilation from operable windows (either manually or automatically controlled) and mechanical systems that include air distribution equipment and refrigeration equipment for cooling. A well-designed mixed-mode building begins with an intelligent façade design to minimize cooling loads. It then integrates the use of air conditioning when and where necessary, with the use of natural ventilation whenever it is feasible or desirable, to maximize comfort while avoiding the significant energy use and operating costs of year-round air conditioning.

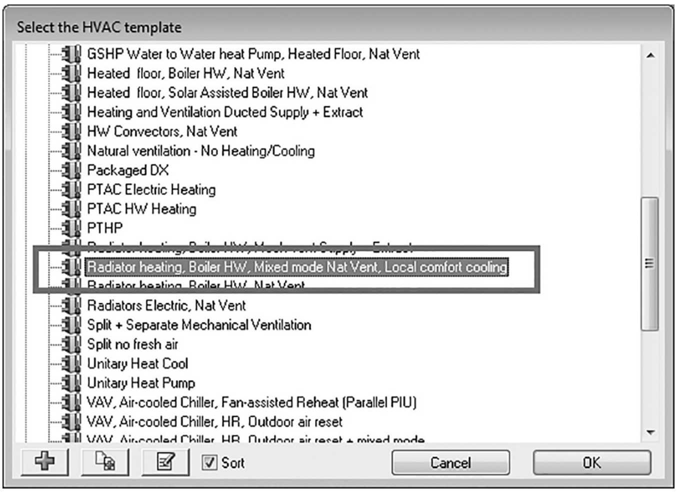
Source: http://www.cbe.berkeley.edu/mixedmode

SOLUTION

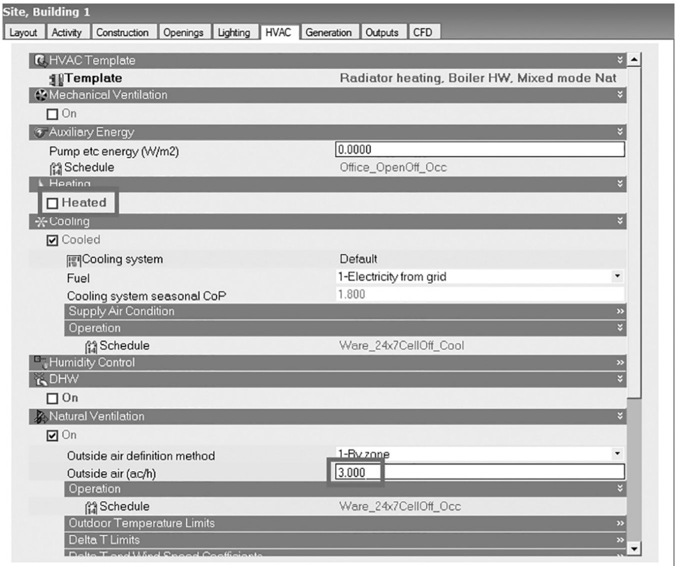
Step 1: Open the file saved in Tutorial 10.4.



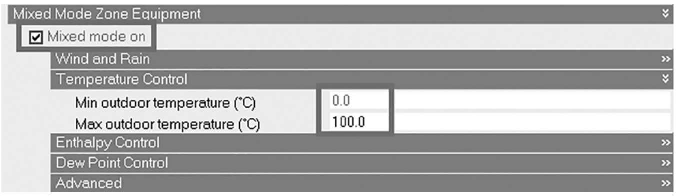
Step 2: Select the **HVAC** tab. Select the HVAC template as **Radiator heating, Boiler HW, Mixed mode Nat Vent, Local comfort cooling**.



Step 3: Clear the **Heated** checkbox in the Heating section and make sure Outside air (ac/h) is **3.000**.



Step 4: Ensure the **Mixed mode on** check box is selected.



Step 5: Minimize the DesignBuilder window. Create an output.idf file. Write additional output variables as follows:

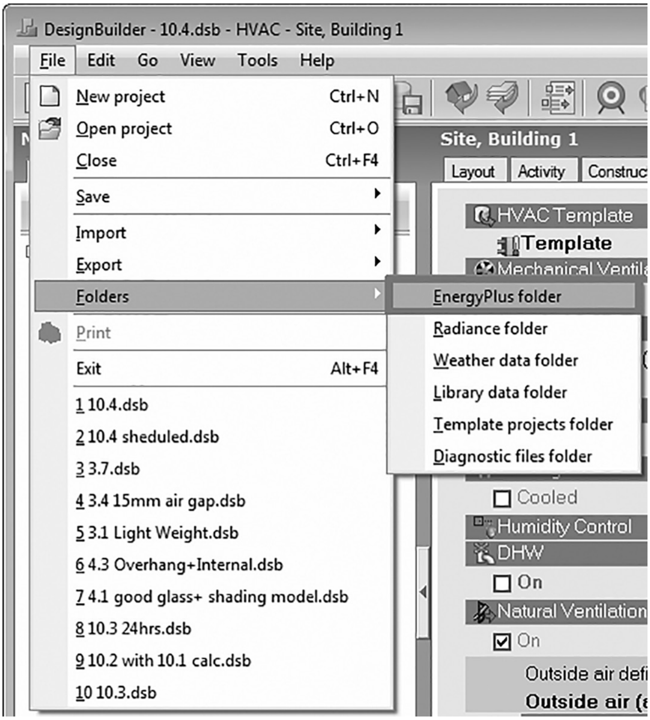
Output: Variable, *, Zone Air Temperature, Detailed;

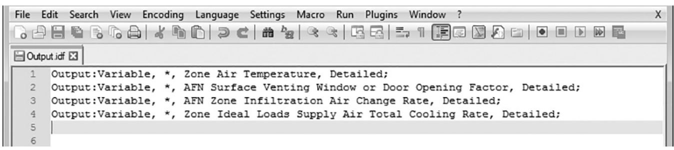
Output: Variable, *, AFN Surface Venting Window or Door Opening Factor, Detailed;

Output: Variable, *, AFN Zone Infiltration Air Change Rate, Detailed;

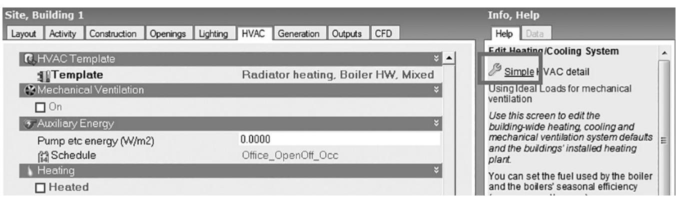
Output: Variable, *, Zone Ideal Loads Supply Air Total Cooling Rate, Detailed;

This .idf file needs to be placed in the following path:

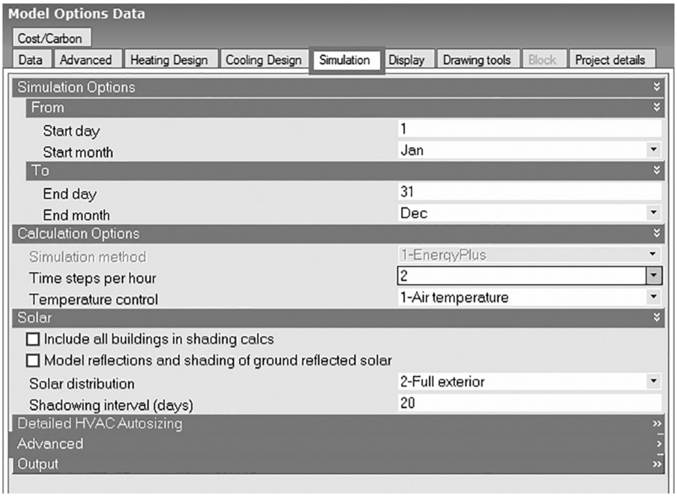




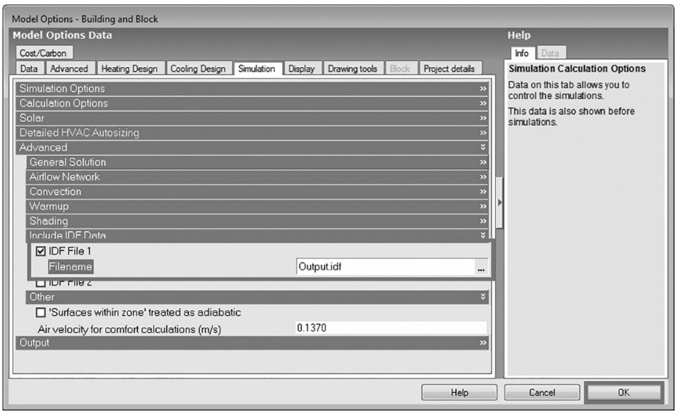
Step 6: Maximize the DesignBuilder window and select the **HVAC** tab. Click **Simple** under the **Help** tab. The **Model Options – Building and Block** screen appears.



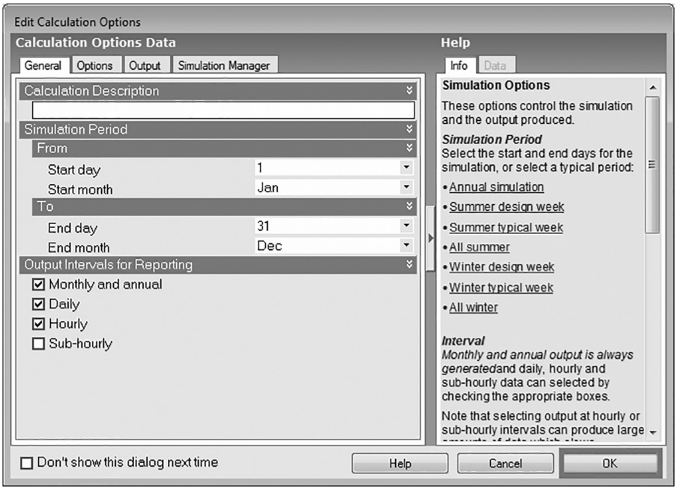
Step 7: Select the **Simulation** tab. Click the **Advanced** section.



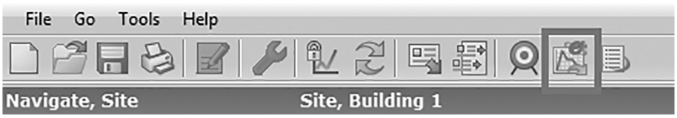
Step 8: Select the **IDF File 1** check box and select the Output.idf file from the EnergyPlus folder. Click **OK**.

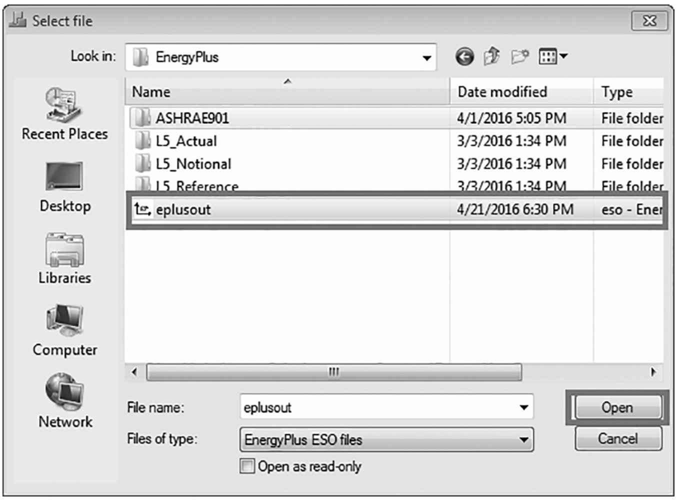


Step 9: Select the **Simulation** tab. The **Edit Calculation Options** screen appears. Click **OK**.

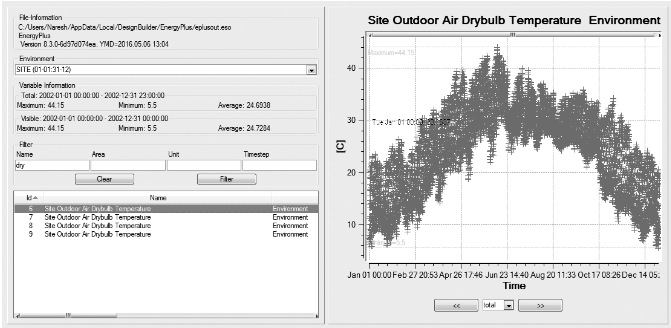


Step 10: Select the **EnergyPlus** results. Select **eplusout** file, so that the file will automatically open in the xESO-View tool.

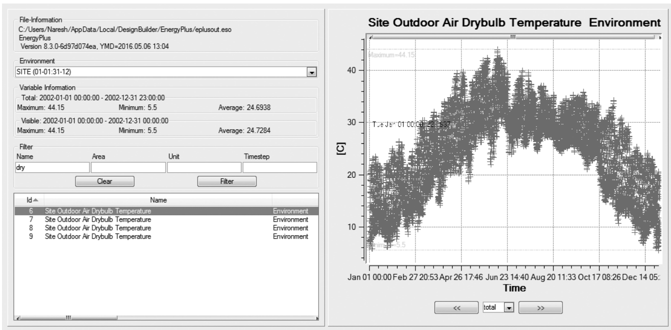




The xEsoView screen appears:

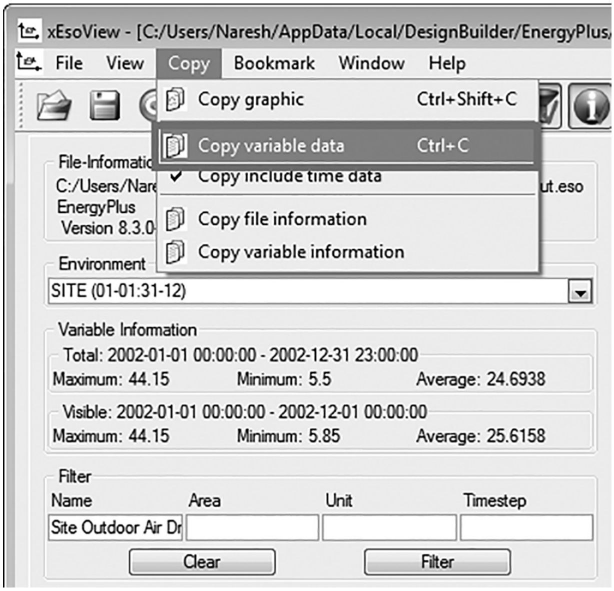


Step 11: Enter **Site Outdoor Air Drybulb Temperature** in the Name field of the Filter section to view the variable.

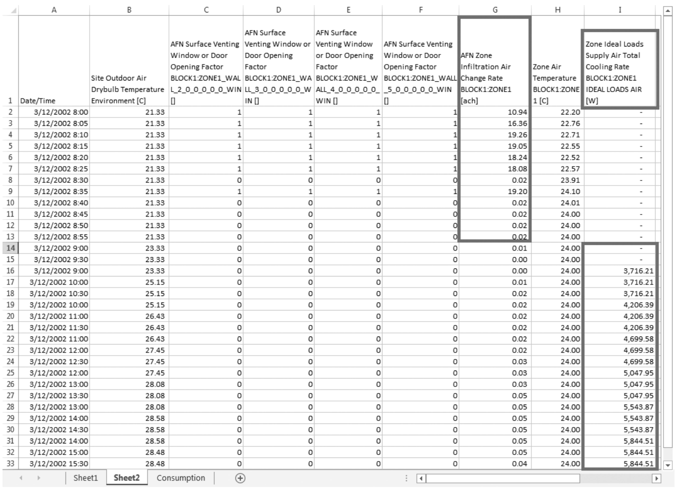


You can copy the variable data to view it in a spreadsheet.

Step 12: Click **Copy**; then select **Copy variable data**.



Step 13: Open a spreadsheet and paste the data.



	A	B	C	D	E	F	G	H	I
1	Date/Time	Site Outdoor Air Drybulb Temperature Environment [C]	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_2_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_3_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_4_0_0_0_0_0_WIN []	AFN Surface Venting Window or Door Opening Factor BLOCK1:ZONE1_WALL_5_0_0_0_0_0_WIN []	AFN Zone Infiltration Air Change Rate BLOCK1:ZONE1 [ach]	Zone Air Temperature BLOCK1:ZONE1 [C]	Zone Ideal Loads Supply Air Total Cooling Rate BLOCK1:ZONE1 IDEAL LOADS AIR [W]
2	3/12/2002 8:00	21.33	1	1	1	1	10.94	22.20	-
3	3/12/2002 8:05	21.33	1	1	1	1	16.36	22.76	-
4	3/12/2002 8:10	21.33	1	1	1	1	19.26	22.71	-
5	3/12/2002 8:15	21.33	1	1	1	1	19.05	22.55	-
6	3/12/2002 8:20	21.33	1	1	1	1	18.24	22.52	-
7	3/12/2002 8:25	21.33	1	1	1	1	18.08	22.57	-
8	3/12/2002 8:30	21.33	0	0	0	0	0.02	23.91	-
9	3/12/2002 8:35	21.33	1	1	1	1	19.20	24.10	-
10	3/12/2002 8:40	21.33	0	0	0	0	0.02	24.01	-
11	3/12/2002 8:45	21.33	0	0	0	0	0.02	24.00	-
12	3/12/2002 8:50	21.33	0	0	0	0	0.02	24.00	-
13	3/12/2002 8:55	21.33	0	0	0	0	0.02	24.00	-
14	3/12/2002 9:00	23.33	0	0	0	0	0.01	24.00	-
15	3/12/2002 9:30	23.33	0	0	0	0	0.00	24.00	-
16	3/12/2002 9:00	23.33	0	0	0	0	0.00	24.00	3,716.21
17	3/12/2002 10:00	25.15	0	0	0	0	0.01	24.00	3,716.21
18	3/12/2002 10:30	25.15	0	0	0	0	0.02	24.00	3,716.21
19	3/12/2002 10:00	25.15	0	0	0	0	0.02	24.00	4,206.39
20	3/12/2002 11:00	26.43	0	0	0	0	0.02	24.00	4,206.39
21	3/12/2002 11:30	26.43	0	0	0	0	0.02	24.00	4,206.39
22	3/12/2002 11:00	26.43	0	0	0	0	0.02	24.00	4,699.58
23	3/12/2002 12:00	27.45	0	0	0	0	0.02	24.00	4,699.58
24	3/12/2002 12:30	27.45	0	0	0	0	0.03	24.00	4,699.58
25	3/12/2002 12:00	27.45	0	0	0	0	0.03	24.00	5,047.95
26	3/12/2002 13:00	28.08	0	0	0	0	0.03	24.00	5,047.95
27	3/12/2002 13:30	28.08	0	0	0	0	0.05	24.00	5,047.95
28	3/12/2002 13:00	28.08	0	0	0	0	0.05	24.00	5,543.87
29	3/12/2002 14:00	28.58	0	0	0	0	0.05	24.00	5,543.87
30	3/12/2002 14:30	28.58	0	0	0	0	0.05	24.00	5,543.87
31	3/12/2002 14:00	28.58	0	0	0	0	0.05	24.00	5,844.51
32	3/12/2002 15:00	28.48	0	0	0	0	0.05	24.00	5,844.51
33	3/12/2002 15:30	28.48	0	0	0	0	0.04	24.00	5,844.51

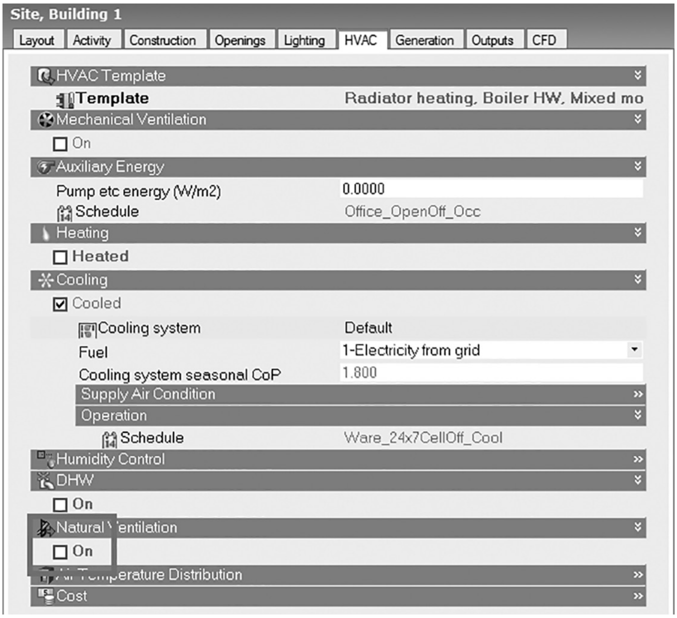
Sheet1 Sheet2 Consumption

You can observe from the above that if the following conditions are true, then there is natural ventilation.

$$T_{zone\_air} > T_{setpoint} \text{ AND } T_{zone\_air} > T_{outside\_air}$$

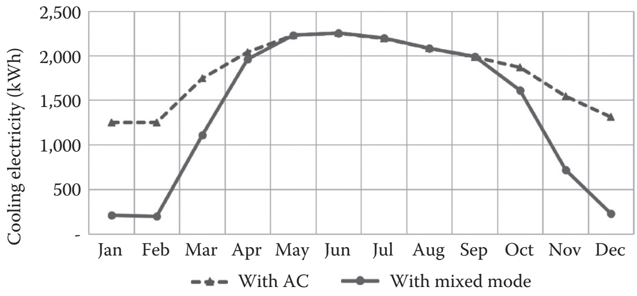
When the outside temperature is more than zone temperature, natural ventilation in OFF and mechanical cooling takes place.

Step 14: Clear the **On** check box to switch off the natural ventilation, so that the zone runs in the air condition mode.



Simulate the model and record the monthly energy consumption results.

Compare the results in both cases.



You can observe that natural ventilation is effective in climate of New Delhi from January to March and October to December.

Exercise 10.6

Repeat the above tutorial for the window area modulation based on zone and outdoor air temperature.

CHAPTER ELEVEN

Building Energy Code Compliance

Building energy code compliance in most countries has the following two paths:

1. Prescriptive
2. Performance-based

Prescriptive path give specific requirements for all the building components and all the requirements have to be met for compliance. This generally limits design freedom.

Performance-based path provides more design freedom and can lead to innovative design but involves more complex energy simulations and trade-offs between systems. Residential and smaller commercial buildings with singular heating ventilation and air conditioning (HVAC), service hot water and lighting systems are more likely to be designed by using a prescriptive approach. Larger commercial buildings that have multiple systems or varied uses and loads may find it more advantageous to follow a performance-based path for code compliance.*

The performance-based path requires the whole building energy simulation.

ASHRAE 90.1-2010 has two methods for the whole building simulation:

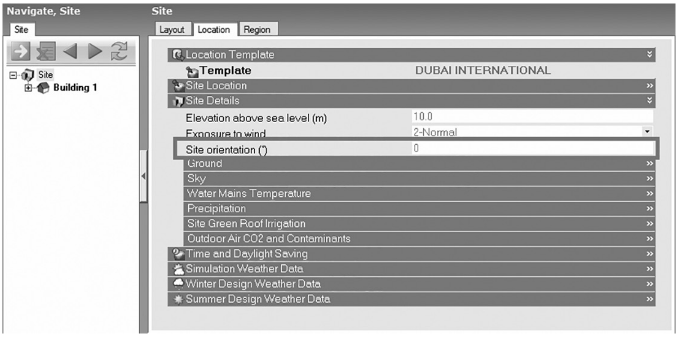
a. Energy cost budget (ECB) method
b. Performance rating method given in ASHRAE 90.1 Appendix G

* https://www.energycodes.gov/resource-center/ace/enforcement/step2

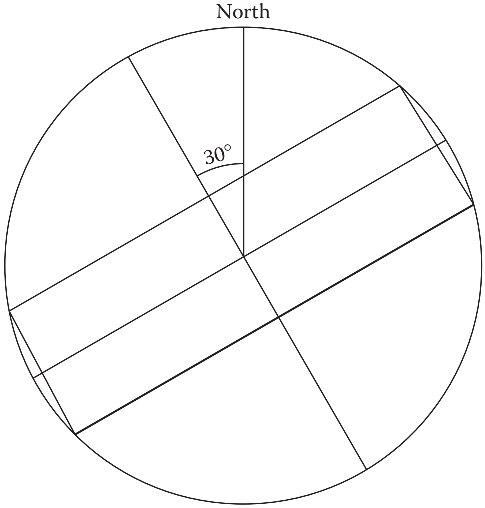
Both methods require energy simulation of the proposed building design and the budget building design.

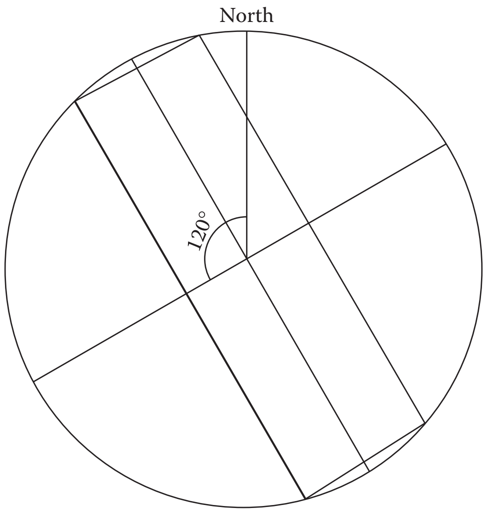
TUTORIAL 11.1 Simulating building performance in four orientations

The baseline building performance shall be generated by simulating the building with its actual orientation and again after rotating the entire building by 90°, 180° and 270°, and then deriving the average from the results. This is illustrated by the following example. The field Site orientation can be use for achieving the desired orientation.

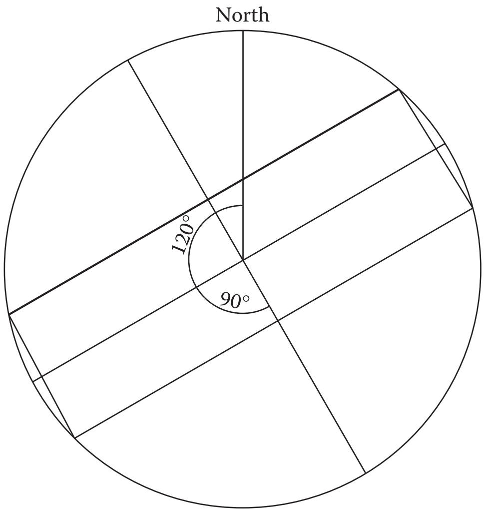


The building face is 150° from the north. (The rectangle inside the circle is the building, and the face is shown with the bold line.)

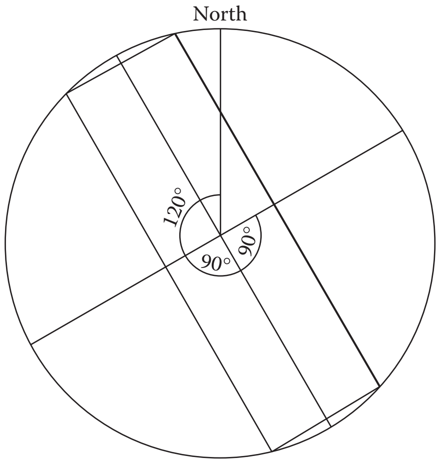




With 90° rotation from the building face.



With 180° rotation from the building face.



With 270° rotation from the building face.

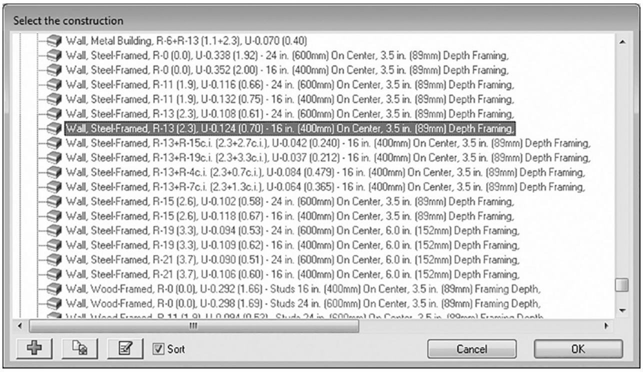
TUTORIAL 11.2 Creating the base case external wall for ASHRAE 90.1-2010 Appendix G

The ECB method requires modelling of opaque assemblies such as roof and walls with the same heat capacity as of the proposed design, whereas in Appendix G, the performance-based method requires these to be modelled as lightweight/steel-framed.

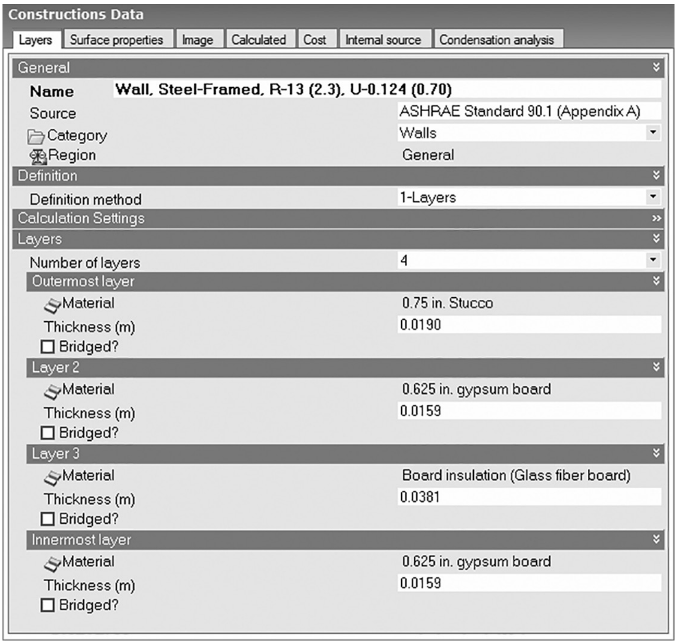
ASHRAE 90.1-2010 Appendix G requires that the external wall be steel-framed. You can refer to TABLE 5.5-1 of ASHRAE 90.1 for the U-value.

In this tutorial you need to create a steel-framed external wall with a U-value of 0.705 W/m^2-K.

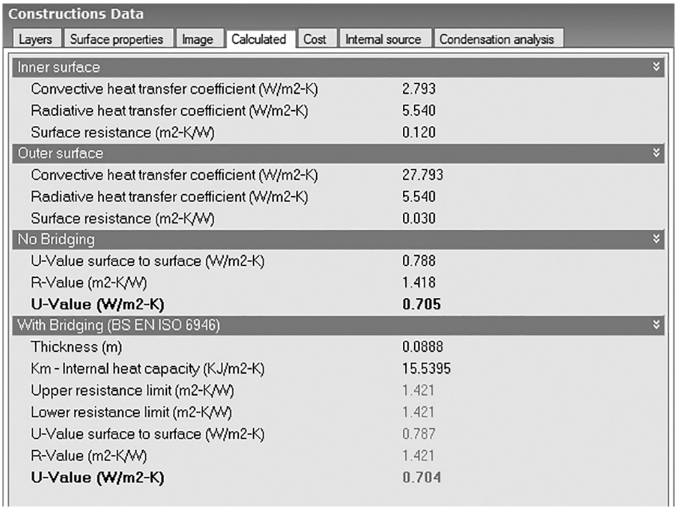
Step 1: Create a new external wall and select **Wall, Steel-Framed, R-13 (2.3), U-0.124 (0.70) - 16 in. (400mm) On Center, 3.5 in. (89mm) Depth Framing**.



Step 2: Edit the construction to view properties.



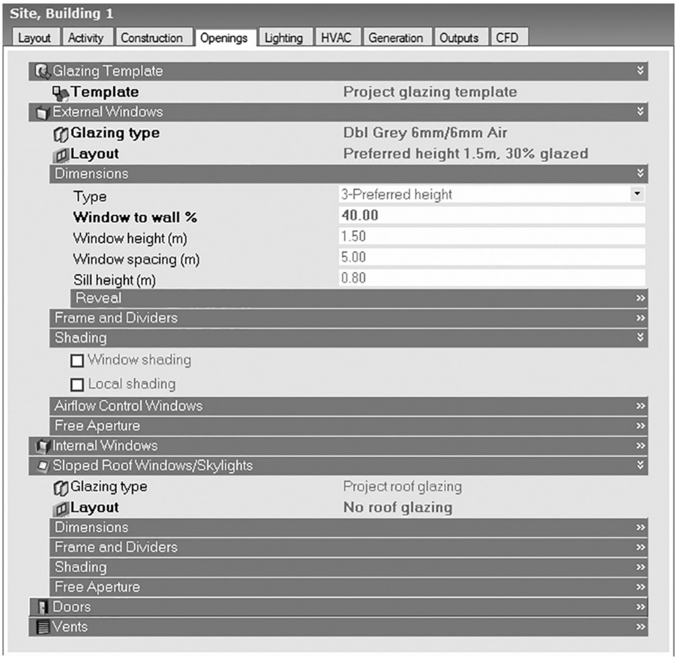
Step 3: Select the **Calculated** tab. It displays all construction properties.



Please refer to Tutorial 3.1 to understand the effect of steel-framed and mass walls.

TUTORIAL 11.3 Modelling flush windows for the base case

As per ASHRAE 90.1-2010 Appendix G Table G 3.1, you must not model shading projections on the fenestration of the base case building. The fenestration needs to be modelled as flush with the exterior wall or roof.



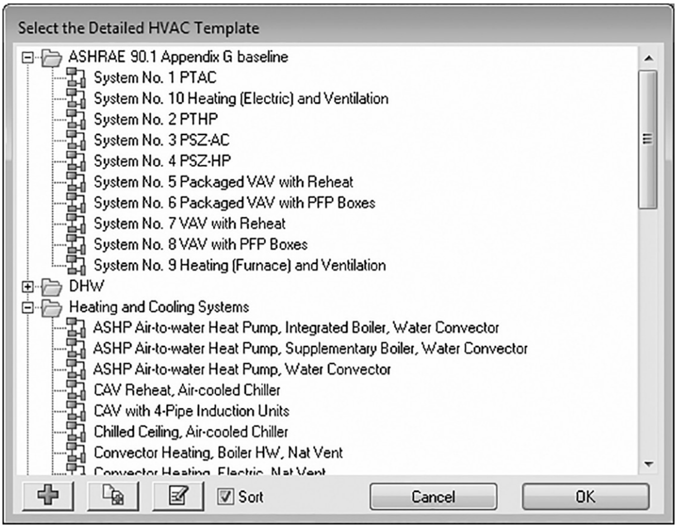
In the **Reveal** section, make sure that the **Outside reveal depth (m)** is zero for the base case.

Window shading and Local shading must not be modelled.

TUTORIAL 11.4 Selecting HVAC system for the base case

As per ASHRAE 90.1-2010 Section G3.1.3, building type can be determined based on the conditioned floor area, number of floors and the fuel type.

In DesignBuilder, you can select ASHRAE 90.1 Appendix G baseline systems from the template.



TUTORIAL 11.5 Calculating fan power for the base case

As per ASHRAE 90.1-2010 Section G3.1.2.10, for the base case system fan electrical power for supply, return, exhaust and relief (excluding power to fan-powered VAV boxes) needs to be calculated with the following formulae:

For systems 1 and 2,
P_{fan} (watts) = $CFM_s \times 0.3$
For systems 3 and 4,
Baseline fan motor brake horsepower = $CFM_s \times 0.00094 + A$
Baseline fan motor brake horsepower = $CFM_s \times 0.0013 + A$
Where A = sum of ($PD \times CFM_D/4131$)
CFM_s = The maximum design supply air flow rate to conditioned spaces served by the system in cubic feet per minute
CFM_D = the design airflow through each applicable device in cubic feet per minute
PD = each applicable pressure prop adjustment
(Please refer to Table 6.5.3.1.1B of ASHRAE 90.1 for PD adjustment values.)
Modelling in DesignBuilder[*]

$$\text{Delta P} = 1000 \times \text{SFP} \times \text{Fan total efficiency}$$

[*] http://www.designbuilder.co.uk/helpv4.7/Content/Fans.htm

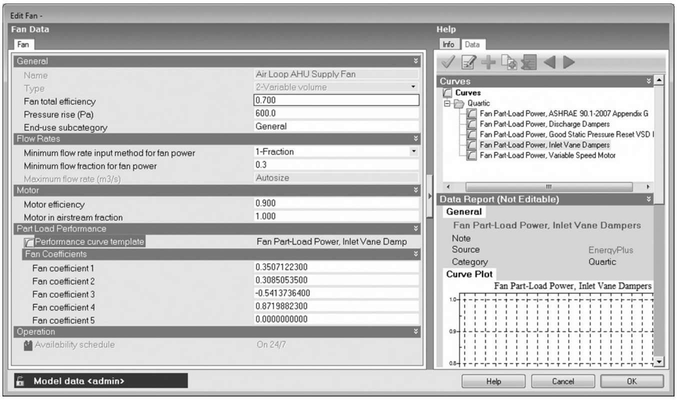
The Specific Fan Power (SFP) is a function of the volume flow of the fan and the electrical power input and is quoted for a particular flow rate.

$$SFP = P_e \text{ (W)/V (l/s)}$$

where:

V is volume flow (l/s)

P_e is electrical power input (W) to the fan system or complete air movement installation



In this tutorial you will calculate the base case power (kW) requirement for the AHU having the supply air volume 4000 CFM (2.359 m^3/s) (1888 l/s) for system 8. (Assume that air-filtering system's pressure drop is less than 1 inch WG when filters are clean.)

Variable volume systems 5–8

Baseline fan motor brake horsepower = CFMs × 0.0013 + A

Where A = sum of (PD × CFM_D/4131)

PD = each applicable pressure drop adjustment

$A = 0.97$

Baseline fan motor brake horsepower = 6.17 BHP = 4601.54 W

$SFP = P_e$ (W)/V (l/s)

SFP = 4601.54/1888 = 2.4 W/(l/s)

Let fan efficiency be 0.6

Delta P = 1000 × SFP × fan total efficiency

Delta P = 1000 × 2.4 × 0.6

Delta P = 1440 Pa

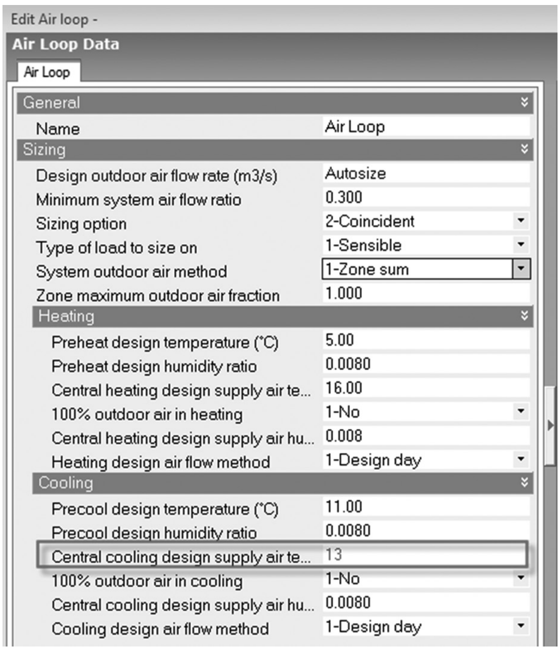
TUTORIAL 11.6 Understanding fan cycling

As per ASHRAE 90.1-2010 Section G3.1.2.5, Fan System Operation, supply and return fans shall operate continuously whenever spaces are occupied and shall be cycled to meet heating and cooling loads during unoccupied hours. Supply, return and/or exhaust fans will remain on during occupied and unoccupied hours in spaces that have health- and safety-mandated minimum ventilation requirements during unoccupied hours.

You can refer to Tutorial 8.7 for more details.

TUTORIAL 11.7 Specifying room air to supply air temperature difference

As per ASHRAE 90.1-2010 Section G3.1.2.5, System Types 1 through 8, system's supply air flow rates for the baseline building design shall be based on a supply-air-to-room-air temperature difference of 11°C (20°F), or the minimum outdoor air flow rate, or on the air flow rate required to comply with applicable codes or accreditation standards, whichever is greater.



For example, if your room's air temperature setpoint is 24°C, then for the base case, you need to set the supply air temperature to 13°C.

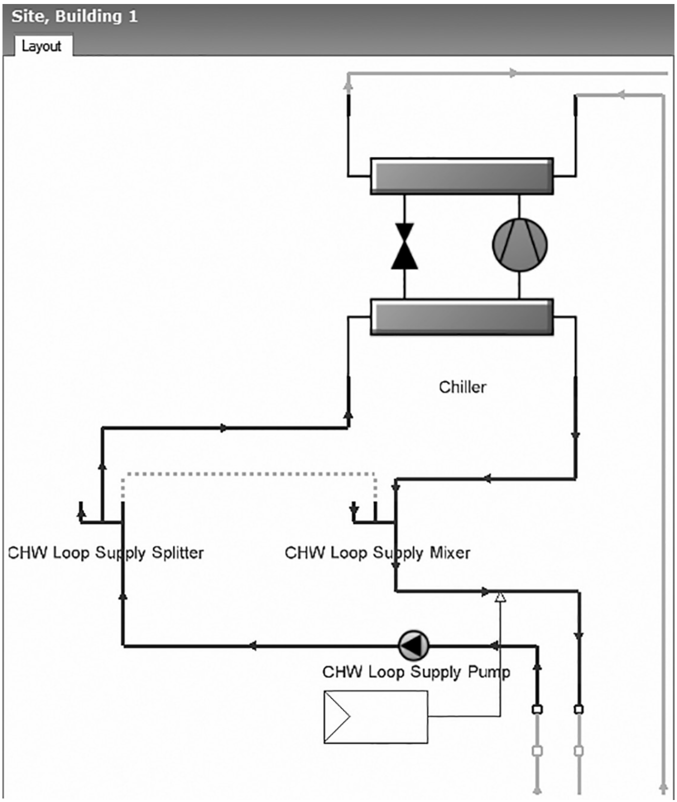
TUTORIAL 11.8 Number of chillers in the base case

As per ASHRAE 90.1-2010 Section G3.1.3.7, Type and Number of Chillers (Systems 7 and 8), electric chillers shall be used in the baseline building design regardless of the cooling energy source.

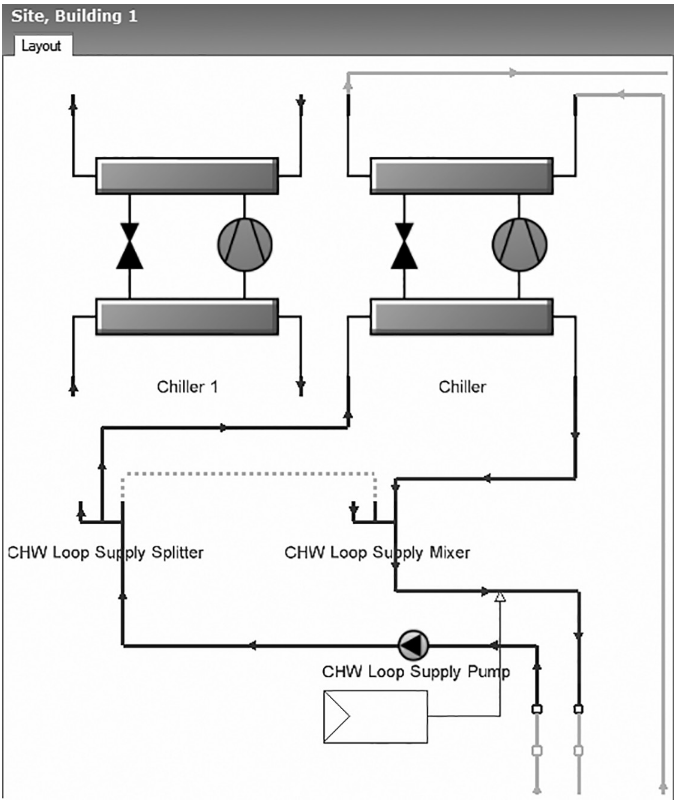
To choose the number of chillers in the base case, you need to find out the building peak cooling load. Based on the building cooling load you can refer to Table G3.1.3.7 of ASHRAE 90.1 to know about the numbers and type of the chillers.

In DesignBuilder, you can add chillers with the following steps:

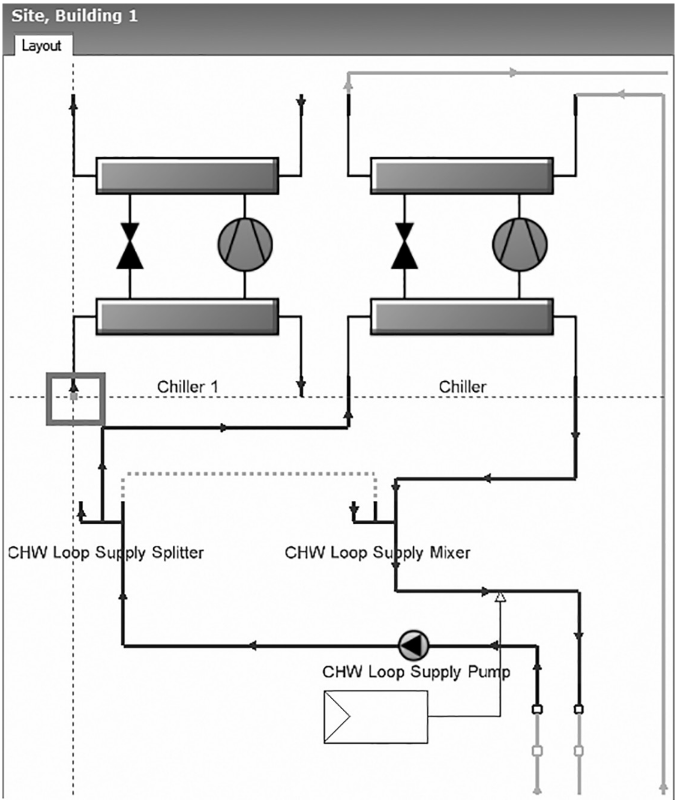
Step 1: Click **Chiller**. It shows the chiller layout.



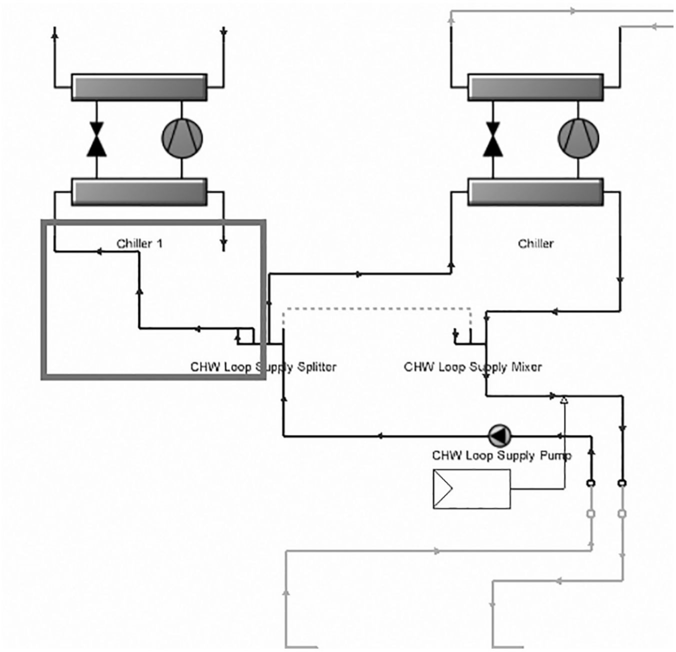
Step 2: Click the **Add Chiller** link. It displays one more chiller on the layout screen.



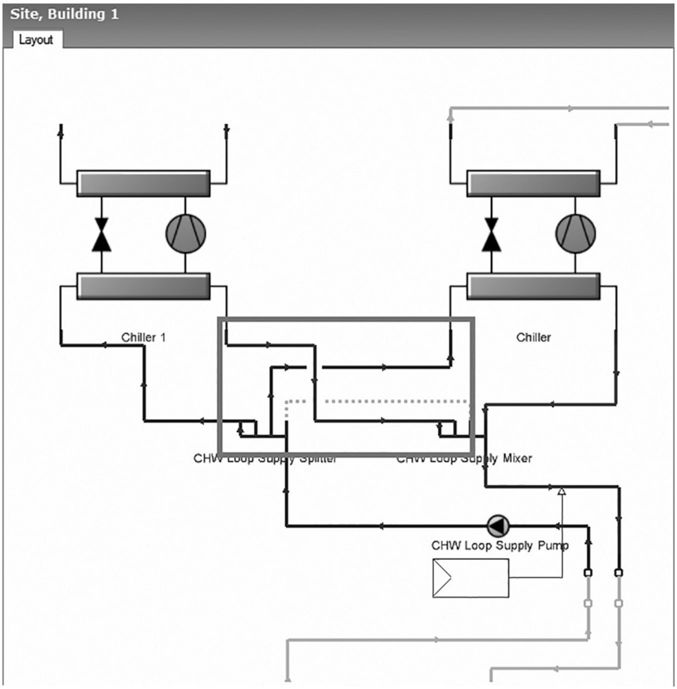
Step 3: Click **Connect components**. It shows a green dot when you click on the node of the chiller.



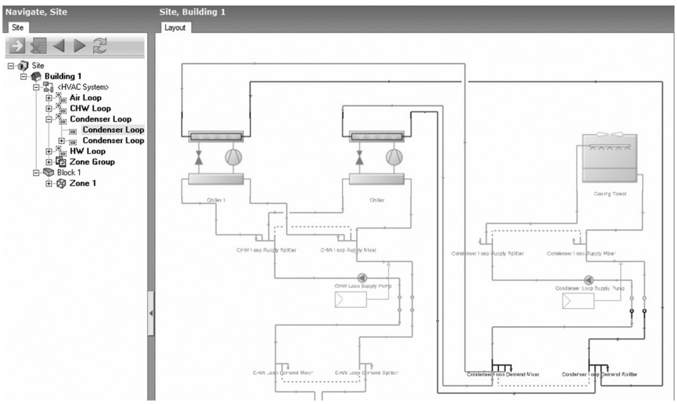
Step 4: Connect **connector** to the chilled-water loop splitter.



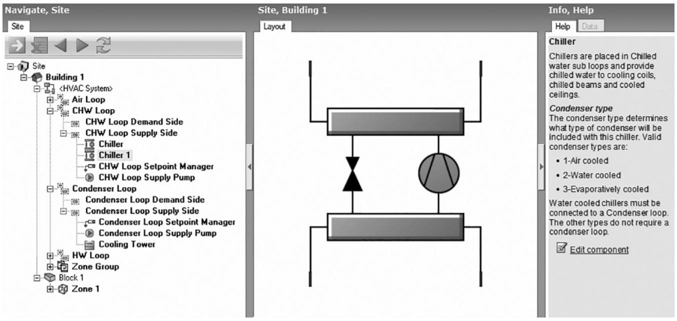
Step 5: Repeat step 4 to connect the chilled-water output loop.

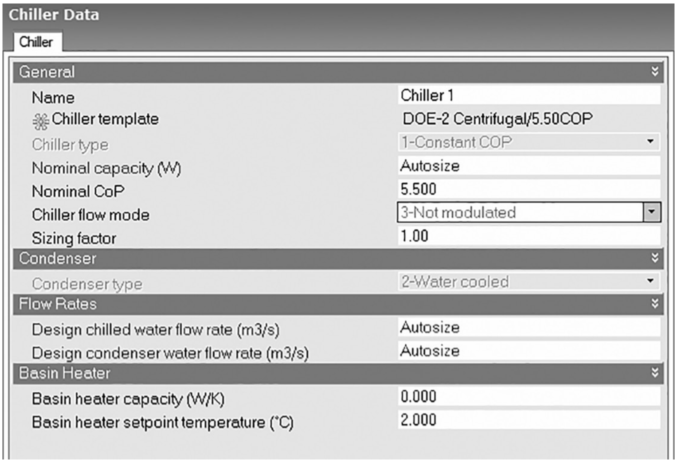


Step 6: Connect the **condenser water loop** nodes.



You can change the type of chiller by clicking on **Edit component.**

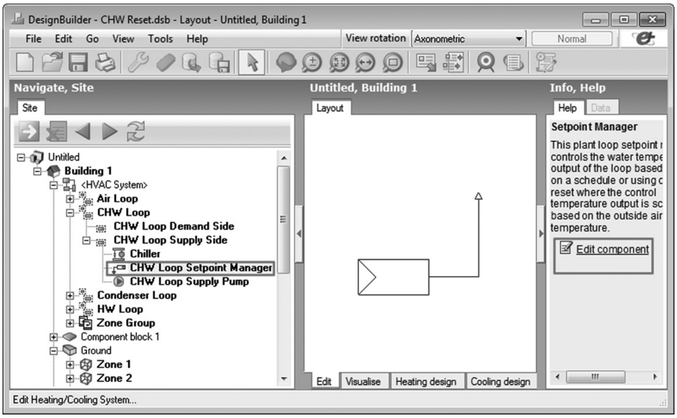


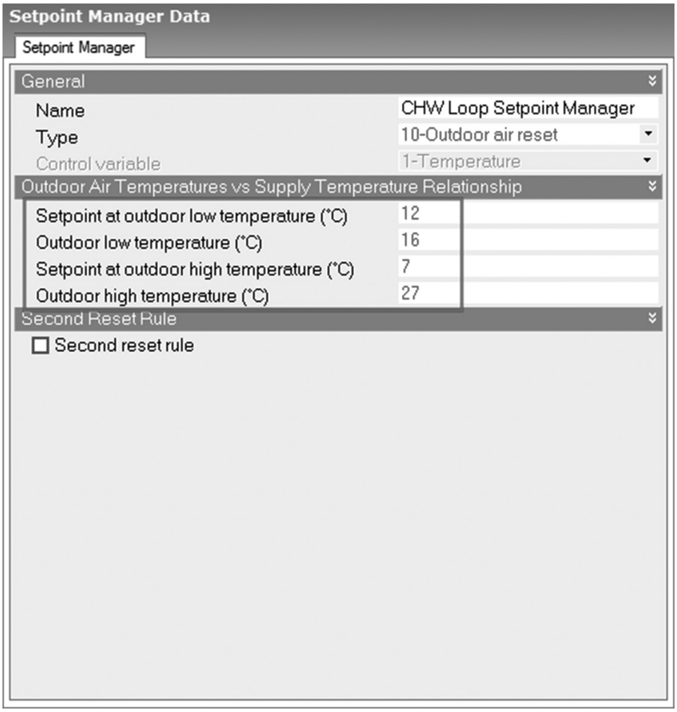


TUTORIAL 11.9 Defining chilled-water supply temperature reset for the base case

As per ASHRAE 90.1-2010 Section G3.1.3.9, Systems 7 and 8, the chilled-water supply temperature shall be reset based on the outdoor dry-bulb temperature by using the following schedule:

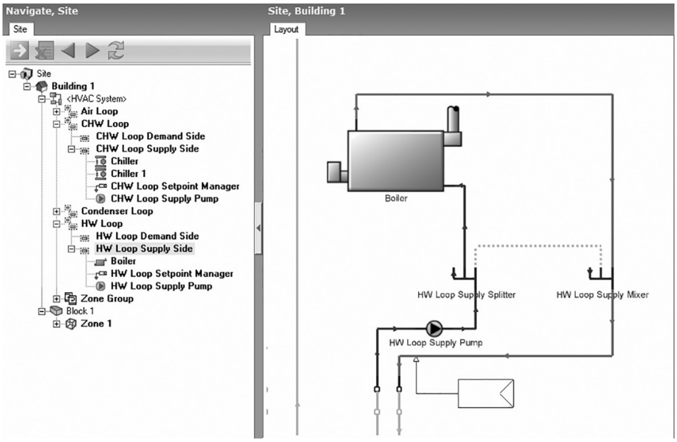
- Chilled-water temperature 7°C at DBT 27°C and above
- Chilled-water temperature 12°C at DBT 16°C and below
- Chilled-water temperature ramped linearly between 7°C and 12°C at outdoor dry-bulb temperatures between 27°C and 16°C

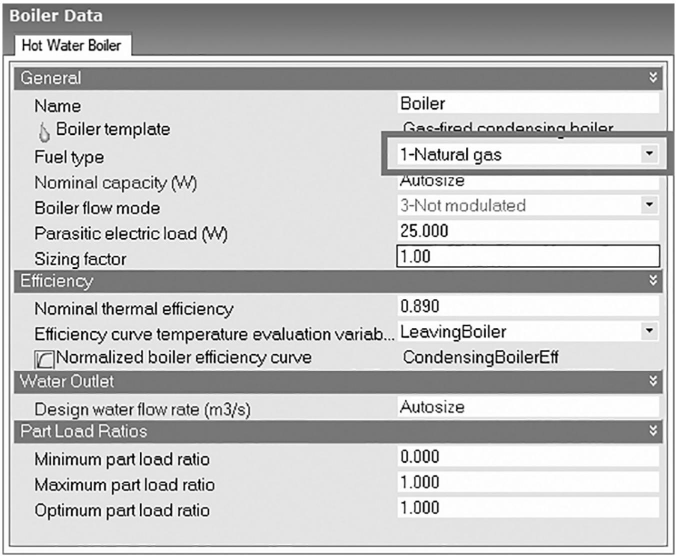

DesignBuilder - CHW Reset.dsb - Layout - Untitled, Building 1
File Edit Go View Tools Help
View rotation
Axonometric
Normal
Navigate, Site
Site
Untitled
Building 1
<HVAC System>
Air Loop
CHW Loop
CHW Loop Demand Side
CHW Loop Supply Side
Chiller
CHW Loop Setpoint Manager
CHW Loop Supply Pump
Condenser Loop
HW Loop
Zone Group
Component block 1
Ground
Zone 1
Zone 2
Untitled, Building 1
Layout
Edit
Visualise
Heating design
Cooling design
Info, Help
Help
Data
Setpoint Manager
Edit component
Edit Heating/Cooling System...


Setpoint Manager Data
Setpoint Manager
General
Name
CHW Loop Setpoint Manager
Type
10-Outdoor air reset
Control variable
1-Temperature
Outdoor Air Temperatures vs Supply Temperature Relationship
Setpoint at outdoor low temperature (°C)
12
Outdoor low temperature (°C)
16
Setpoint at outdoor high temperature (°C)
7
Outdoor high temperature (°C)
27
Second Reset Rule
Second reset rule

TUTORIAL 11.10 Type and number of boilers for the base case

As per ASHRAE 90.1-2010 Section G3.1.3.2 for Systems 1, 5 and 7, the boiler plant shall use the same fuel as the proposed design and shall be a natural draft, except as noted in Section G3.1.1.1 (Purchase Heat). The baseline building design boiler plant shall be modelled as having a single boiler if the baseline building design plant serves a conditioned floor area of 1400 m^2 or less and has two equal-sized boilers for plants serving more than 1400 m^2. Boilers shall be staged as required by the load.



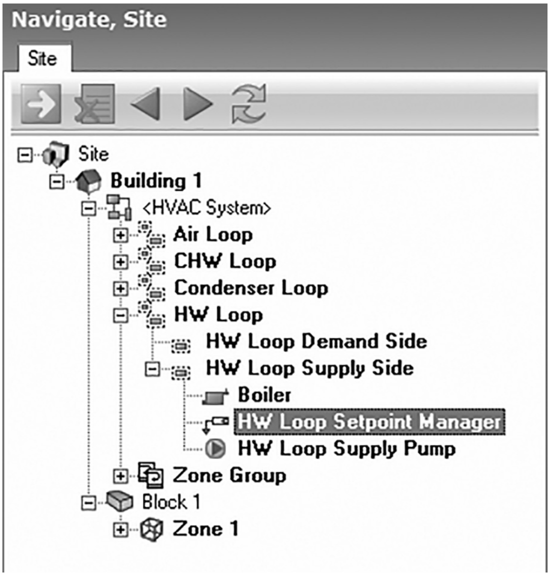


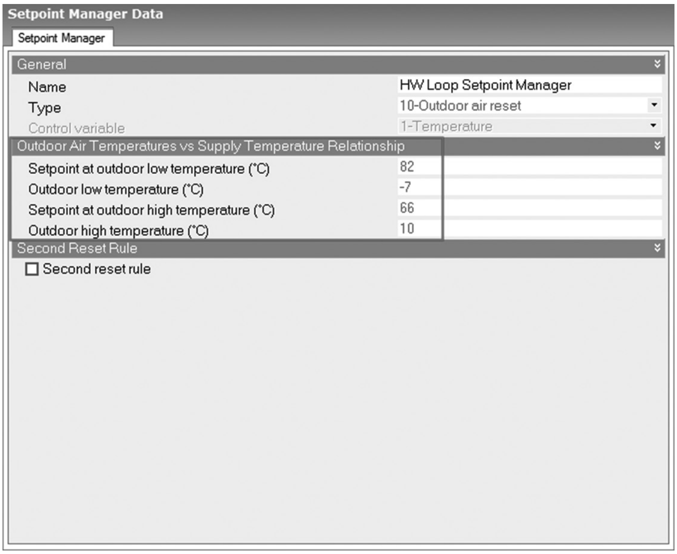
Fuel type should be the same as used in the proposed design.

TUTORIAL 11.11 Defining hot-water supply temperature reset

As per ASHRAE 90.1-2010 Section G3.1.3.4 Hot-water Supply Temperature Reset (Systems 1, 5 and 7), the hot-water supply temperature shall be reset based on the outdoor dry-bulb temperature by using the following schedule:

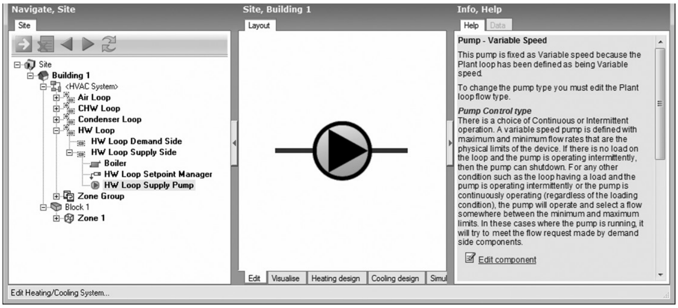
- 82°C at –7°C and below
- 66°C at 10°C and above
- Ramped linearly between 82°C and 66°C at temperatures between –7°C and 10°C

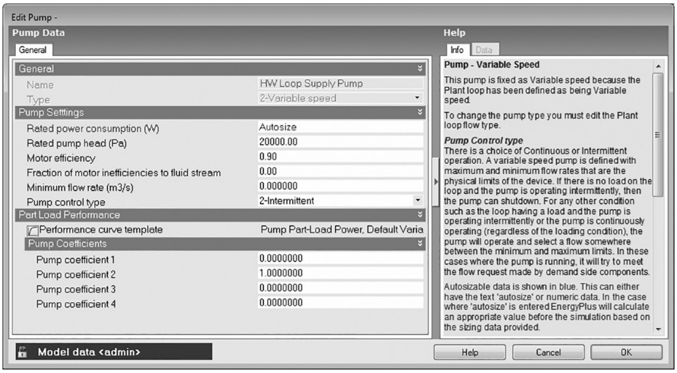

Navigate, Site
Site
Site
Building 1
<HVAC System>
Air Loop
CHW Loop
Condenser Loop
HW Loop
HW Loop Demand Side
HW Loop Supply Side
Boiler
HW Loop Setpoint Manager
HW Loop Supply Pump
Zone Group
Block 1
Zone 1


Setpoint Manager Data
Setpoint Manager
General
Name
HW Loop Setpoint Manager
Type
10-Outdoor air reset
Control variable
1-Temperature
Outdoor Air Temperatures vs Supply Temperature Relationship
Setpoint at outdoor low temperature (°C)
82
Outdoor low temperature (°C)
-7
Setpoint at outdoor high temperature (°C)
66
Outdoor high temperature (°C)
10
Second Reset Rule
Second reset rule

TUTORIAL 11.12 Hot-water pumps

As per ASHRAE 90.1-2010 Section G3.1.3.5, Hot-water Pumps, the baseline building design hot-water pump power shall be 301 kW/1000 L/s. The pumping system shall be modelled as primary-only, with a continuous variable flow. Hot-water systems serving 11,148 m^2 or more shall be modelled with variable-speed drives, and systems serving less than 11,148 m^2 shall be modelled as riding the pump curve.*





TUTORIAL 11.13 Defining exhaust air energy recovery parameters

As per ASHRAE 90.1-2010 Section 6.5.6.1, each fan system shall have an energy recovery system when the system's supply airflow rate exceeds the value listed in Table 6.5.6.1, based on the climate zone and the percentage of outdoor airflow rate at design conditions.

* http://www.designbuilder.co.uk/helpv4.7/#Pump_-_Variable_Speed.htm

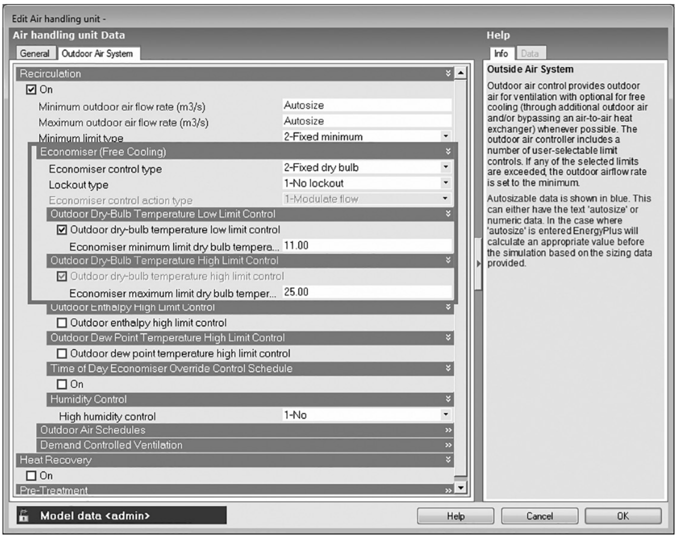
Energy recovery systems required by this section shall have at least 50% energy recovery effectiveness. Fifty percent energy recovery effectiveness shall mean a change in the enthalpy of the outdoor air supply equal to 50% of the difference between the outdoor air and return air enthalpies at design conditions. Provision shall be made to bypass or control the energy recovery system to permit air economiser operation, as required by Section 6.5.1.1. There are some exceptions to this, which you can refer to in Section 6.5.6.1.

You can refer to Tutorial 8.8 for modelling a heat recovery system.

TUTORIAL 11.14 Defining economiser parameters

As per ASHRAE 90.1-2010 Section G3.1.2.7, Economisers, outdoor air economisers shall not be included in baseline HVAC systems 1, 2, 9 and 10. Outdoor air economisers shall be included in baseline HVAC systems 3 through 8 based on climate, as specified in Table G3.1.2.6A. Exceptions can be referred to in the relevant section.

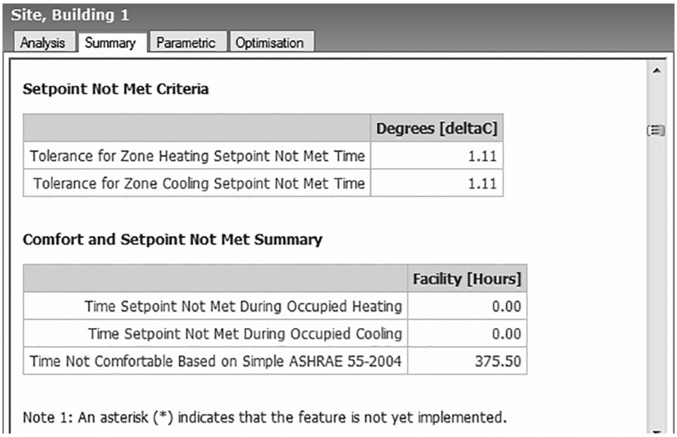
The high-limit shutoff shall be a dry-bulb switch with setpoint temperatures in accordance with the values in Table G3.1.2.6B.



You can refer to Tutorial 8.6 for more details.

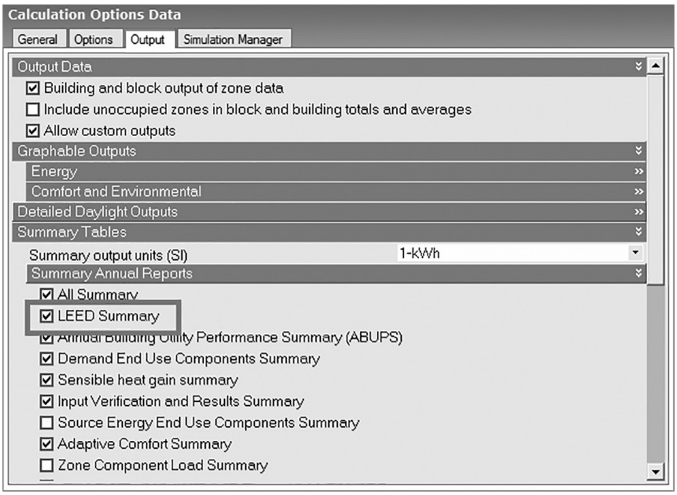
TUTORIAL 11.15 Finding unmet hours after simulation

As per ASHRAE 90.1-2010 Section G3.1.2.3, unmet load hours for the proposed or baseline building designs shall not exceed 300 (of the 8760 simulated hours). You can get unmet hours in the **Summary** tab after simulation of the building.

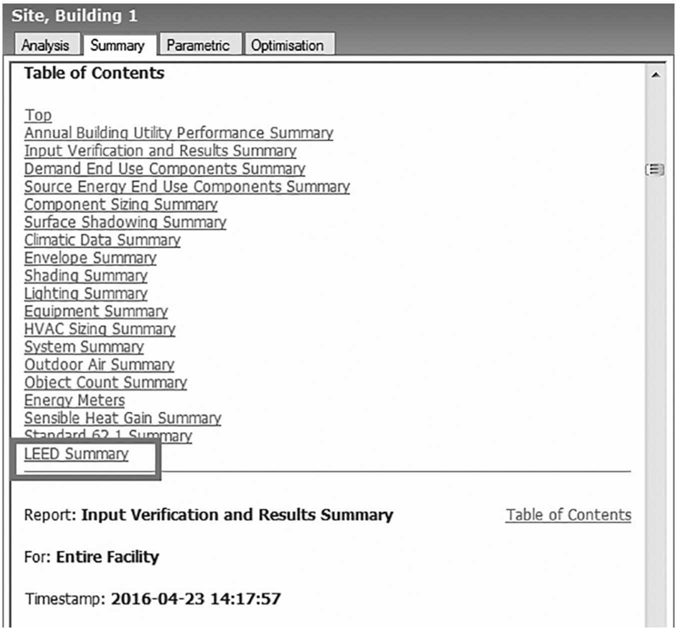


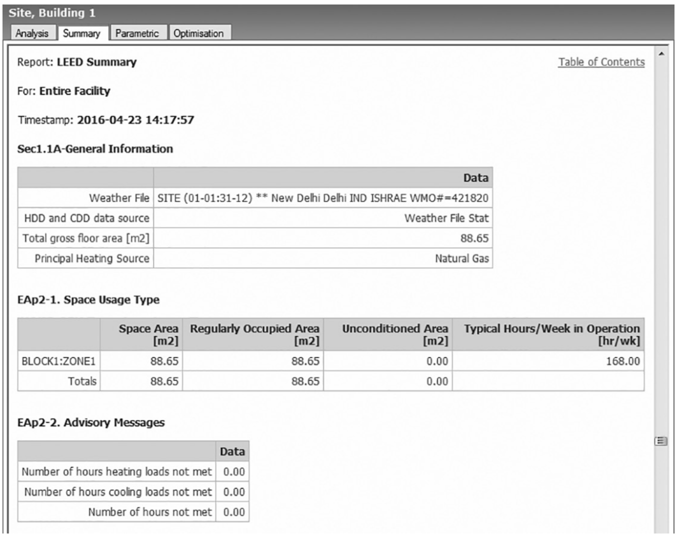
TUTORIAL 11.16 Generating the performance rating method compliance report in DesignBuilder

You can get the LEED summary in DesignBuilder by selecting the **LEED Summary** checkbox.



After simulation, you can get the LEED summary in the **Summary** tab.





EAp2-4/5. Performance Rating Method Compliance

	Electric Energy Use [GJ]	Electric Demand [W]	Natural Gas Energy Use [GJ]	Natural Gas Demand [W]	Additional Energy Use [GJ]	Additional Demand [W]
Interior Lighting	21.80	1063.84	0.00	0.00	0.00	0.00
Exterior Lighting	0.00	0.00	0.00	0.00	0.00	0.00
Space Heating	0.00	0.00	0.15	1040.01	0.00	0.00
Space Cooling	0.00	0.00	0.00	0.00	0.00	0.00
Pumps	0.23	9.11	0.00	0.00	0.00	0.00
Heat Rejection	0.00	0.00	0.00	0.00	0.00	0.00
Fans-Interior	14.16	610.94	0.00	0.00	0.00	0.00
Fans-Parking Garage	0.00	0.00	0.00	0.00	0.00	0.00
Service Water Heating	0.00	0.00	0.00	0.00	0.00	0.00
Receptacle Equipment	24.48	1064.73	0.00	0.00	0.00	0.00
Interior Lighting (process)	0.00	0.00	0.00	0.00	0.00	0.00
Refrigeration Equipment	0.00	0.00	0.00	0.00	0.00	0.00
Cooking	0.00	0.00	0.00	0.00	0.00	0.00
Industrial Process	0.00	0.00	0.00	0.00	0.00	0.00
Elevators and Escalators	0.00	0.00	0.00	0.00	0.00	0.00
Total Line	60.67		0.15		0.00	

TUTORIAL 11.17 Finding process load for the base case

Process loads must be identical for both the baseline building and the proposed building. However, project teams may follow the exceptional calculation method (ANSI/ASHRAE/IESNA Standard 90.1-2010 G 2.5) to document measures that reduce process loads. Documentation of process load energy savings must include a list of assumptions made for both the baseline and the proposed design and theoretical or empirical supporting information.

The total process energy cost must be equal to at least 25% of the baseline building performance. For buildings where the process energy cost is less than 25% of the baseline building energy cost, you should include the documentation substantiating that the process energy inputs are appropriate.

Site, Building 1

Analysis | Summary | Parametric | Optimisation

EAp2-17b. Energy Use Intensity - Natural Gas

	Natural Gas [MJ/m2]
Space Heating	1.68
Service Water Heating	0.00
Miscellaneous	0.00
Subtotal	1.68

EAp2-17c. Energy Use Intensity - Additional

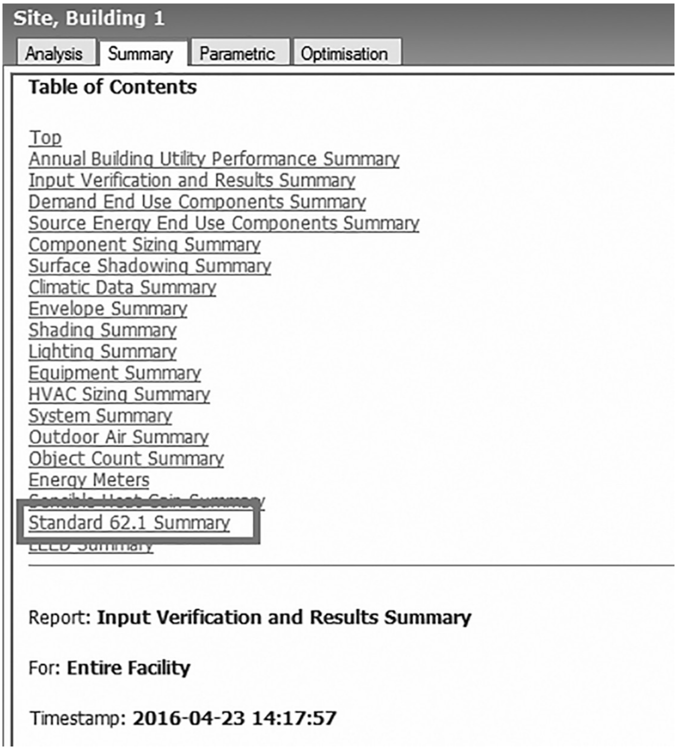
	Additional [MJ/m2]
Miscellaneous	0.00
Subtotal	0.00

EAp2-18. End Use Percentage

	Percent [%]
Interior Lighting	35.85
Space Heating	0.25
Space Cooling	0.00
Fans-Interior	23.28
Service Water Heating	0.00
Receptacle Equipment	40.26
Miscellaneous	0.37

TUTORIAL 11.18 Getting ASHRAE 62.1 standard summary in DesignBuilder

Many rating systems require meeting the minimum requirements of Sections 4 through 7 of ASHRAE Standard 62.1-2007, Ventilation for Acceptable Indoor Air Quality. You can get this summary from the DesignBuilder output.



Zone Ventilation Parameters

	AirLoop Name	People Outdoor Air Rate - Rp [m3/s-person]	Zone Population - Pz	Area Outdoor Air Rate - Ra [m3/s-m2]	Zone Floor Area - Az [m2]	Breathing Zone Outdoor Airflow - Vbz [m3/s]	Cooling Zone Air Distribution Effectiveness - Ez-clg	Cooling Zone Outdoor Airflow - Voz-clg [m3/s]	Heating Zone Air Distribution Effectiveness - Ez-htg	Heating Zone Outdoor Airflow - Voz-htg [m3/s]
BLOCK1:ZONE2	AIR LOOP	0.009440	65.31	0.000000	588.36	0.6165	1.000	0.6165	1.000	0.6165
BLOCK1:ZONE4	AIR LOOP	0.009440	10.02	0.000000	90.30	0.0946	1.000	0.0946	1.000	0.0946
BLOCK1:ZONE5	AIR LOOP	0.009440	10.02	0.000000	90.30	0.0946	1.000	0.0946	1.000	0.0946
BLOCK1:ZONE1	AIR LOOP	0.009440	22.77	0.000000	205.17	0.2150	1.000	0.2150	1.000	0.2150
BLOCK1:ZONE3	AIR LOOP	0.009440	22.77	0.000000	205.17	0.2150	1.000	0.2150	1.000	0.2150

System Ventilation Parameters

	People Outdoor Air Rate - Rp [m3/s-person]	Sum of Zone Population - Pz-sum	Area Outdoor Air Rate - Ra [m3/s-m2]	Sum of Zone Floor Area - Az-sum [m2]	Breathing Zone Outdoor Airflow - Vbz [m3/s]	Cooling Zone Outdoor Airflow - Voz-clg [m3/s]	Heating Zone Outdoor Airflow - Voz-htg [m3/s]
AIR LOOP	0.009440	130.90	0.000000	1179.30	1.2357	1.2357	1.2357

Reference

ASHRAE, *ASHRAE Standard 90.1-2010: Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta, GA: ASHRAE, www.ashrae.org.

CHAPTER TWELVE

Project: Small Office

Project goal

The goal of this project is to create a DesignBuilder model of a small office building. The office is located in Jaipur, India, which is climate Zone 1A: Hot and Dry, as defined by ASHRAE 90.1-2010. This project will help you learn to model a small office and analyse the key results of a whole building energy simulation.

Overview

The building is a small office with three floors. An overview of the building is provided in Table 12.1.

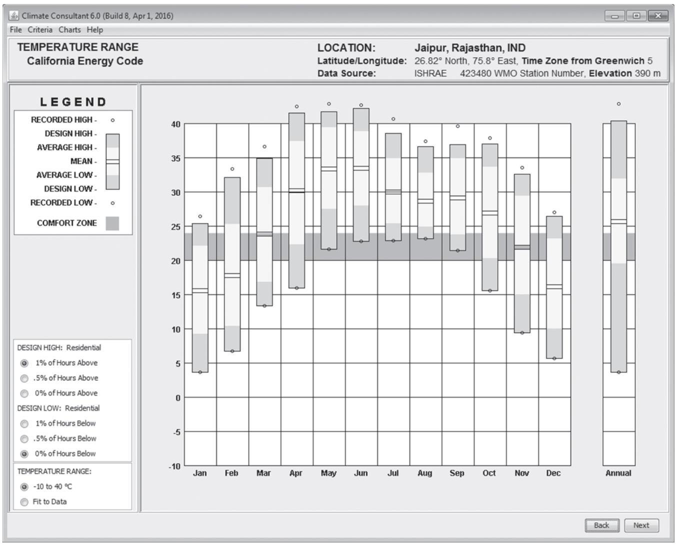
Climate and location

The building is located in Jaipur, India. In this particular climate zone, the maximum daytime temperature in summers is in the range of 32°C–44°C and night temperature ranges from 27°C to 32°C. In winters, the values are between 10°C and 25°C during the day and between 4°C and 10°C at night. The relative humidity is about 20–25% in dry periods and 55–95% in the monsoon season.

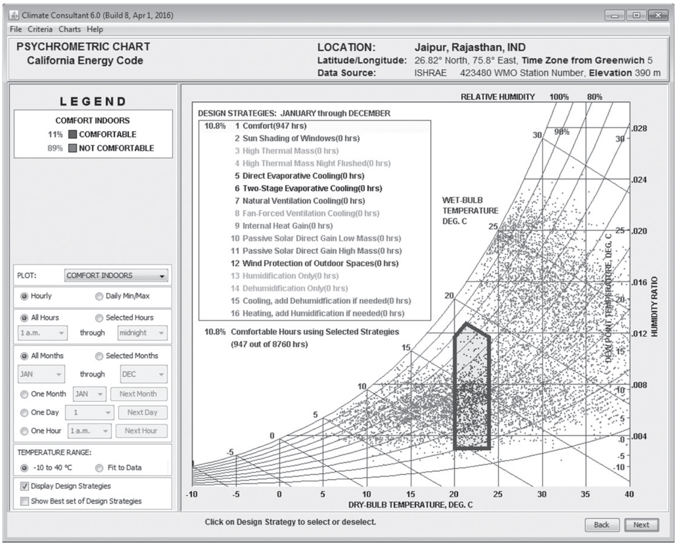
Table 12.1 Building overview

Variable	Value
Built-up area	11,306 m^2
Total air conditioned area	9,959 m^2
Building use	Office
Number of above-grade floors	3 (G+2)
Wintow-to-wall ratio	27% distributed equal in all directions in horizontal strips
Heating	None
Cooling	Variable refrigerant volume (VRV) system
Average utility costs	
Electricity	$0.12/kWh

The following figures provide the temperatures range (in degree Celsius) and Psychrometric chart for Jaipur climate, generated using Climate Consultant.



Source: From http://www.energydesign-tools.aud.ucla.edu/climate-consultant/.

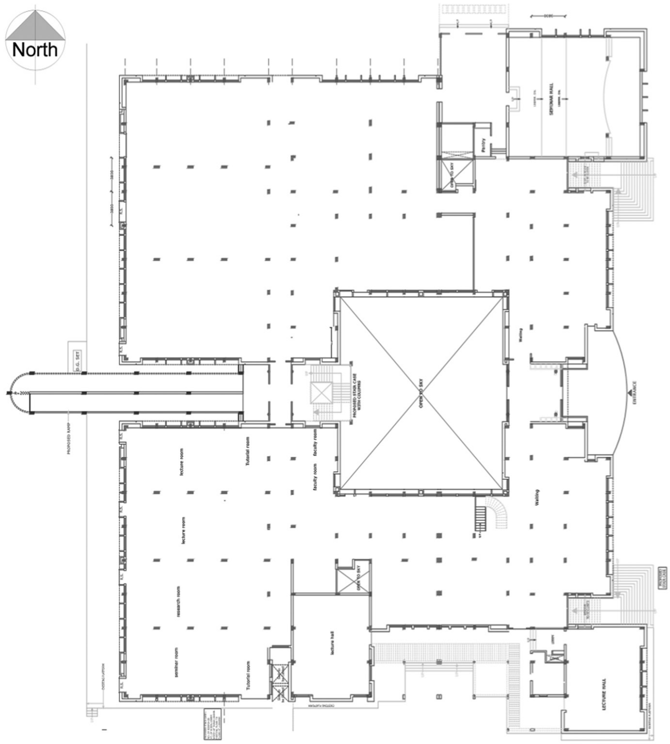


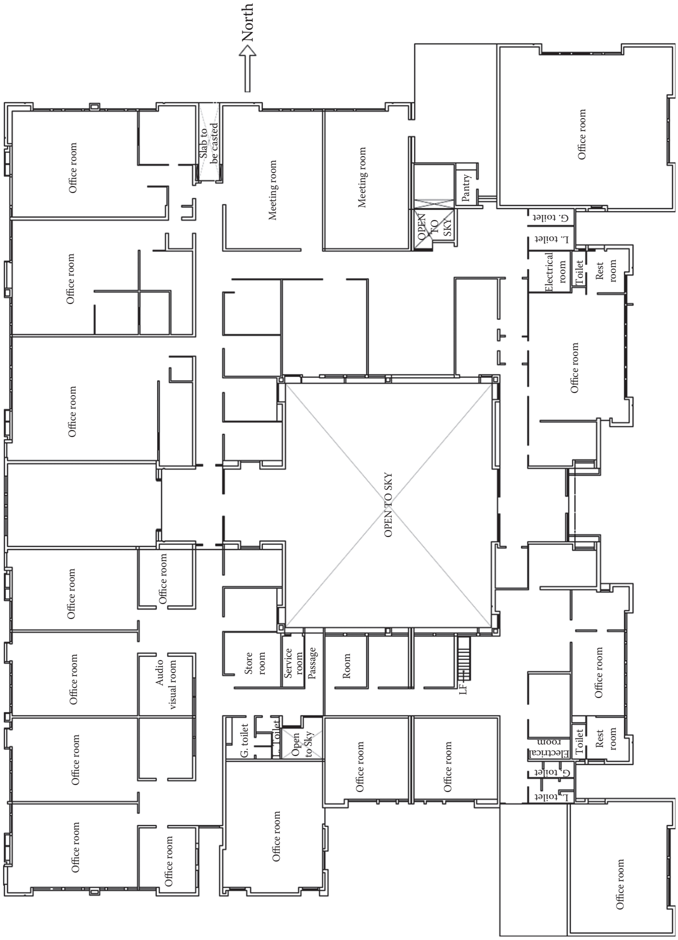
Source: From http://www.energydesign-tools.aud.ucla.edu/climate-consultant/.

Floor plans

For creating any energy simulation model, it is important to have all floor plans. The following two figures give the floor plans for the ground and the first floor.

A soft copy of CAD is provided with the book for import in DesignBuilder (https://www.crcpress.com/9781498744515).



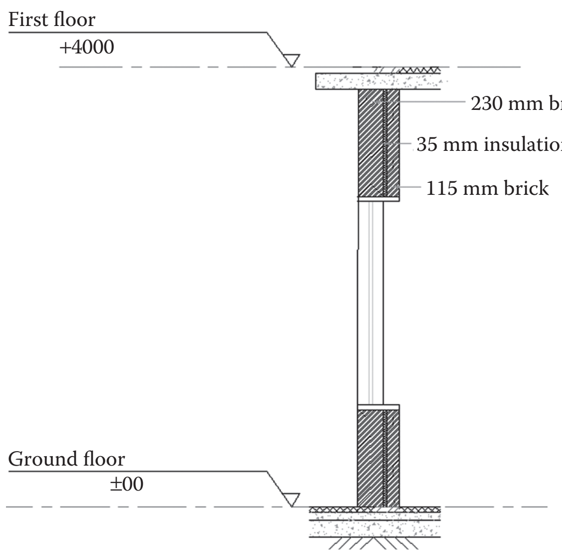


Building envelope

This small office is proposed to be constructed with parameters as shown in Table 12.2.

Table 12.2 Construction parameters

S. No.	Model input parameter	Details
1.	Exterior wall construction	Assembly U-0.72 W/m^2-K 230 mm brick + 35 mm XPS insulation + 115 mm brick
2.	Roof construction	Assembly U-value – 0.35 W/m^2-K 125 mm RCC with underdeck 75 mm XPS insulation
3.	Glazing	Double-glazed glass with low-heat gain and high visible transmittance U-value: 1.9 W/m^2-K SC (all): 0.28 & VLT: 39%
4.	Window-to-wall ratio (%)	27
5.	Roof reflectance	0.7
6.	Infiltration through envelope (ac/h)	0.5

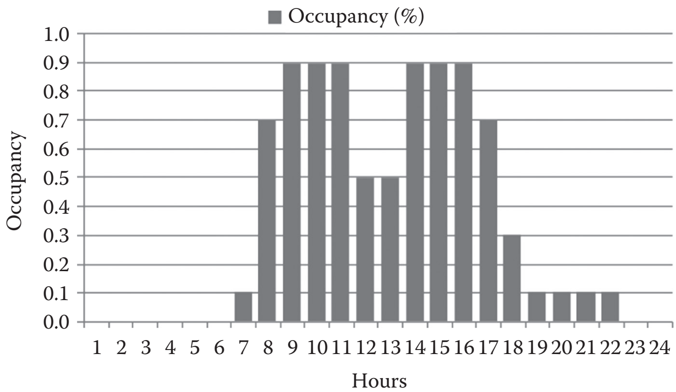


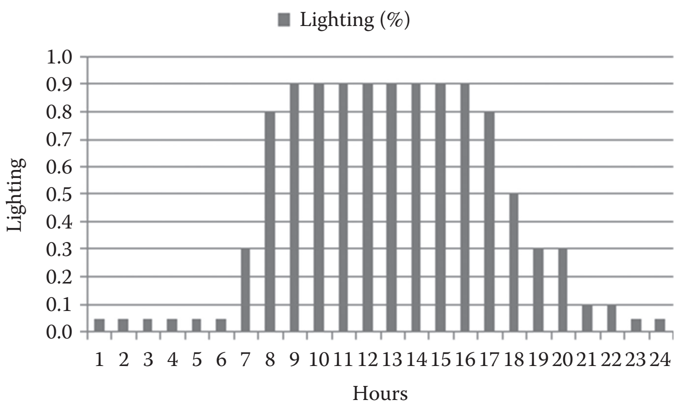
Internal loads and schedules

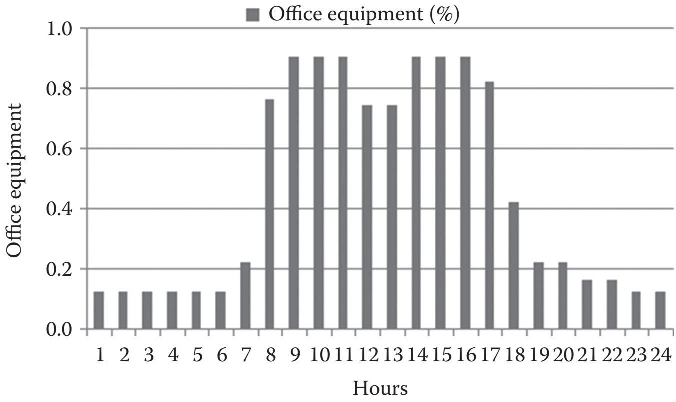
The building is a small office. Details of activity, equipment and lighting loads in each room are provided in Table 12.3.

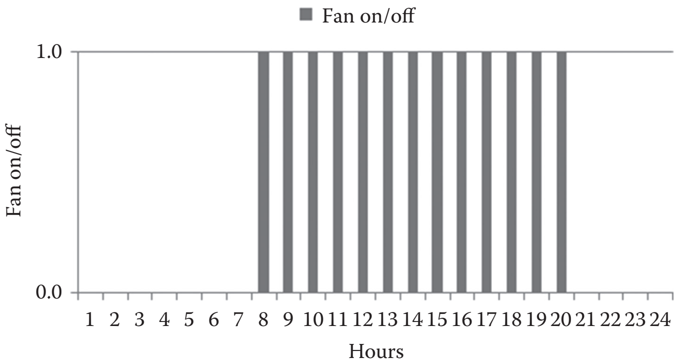
Table 12.3 Internal loads and schedule details

S. No.	Model input parameter	Details
1.	Equipment power density (W/m^2)	23
2.	Occupancy (m^2/person)	5.4
3.	Lighting power density (W/m^2)	4.6
4.	Shading devices	Overhang 0.15 m on all windows
5.	Occupancy sensors	Installed in all areas
6.	Daylight sensors	Installed in daylit areas
7.	Fresh air	30% over ASHRAE 62.1-2010









Mechanical systems

The building is cooled and heated by a ducted VRV system. Details of the HVAC systems are provided in Tables 12.4 and 12.5.

Table 12.4 HVAC efficiency details

S. No.	Model input parameter	Value
1.	HVAC system type	VRV system
2.	AHU fan power	1.5 inch WG
3.	Demand control ventilation	CO_2 sensors installed to modulate fresh air
4.	Heat recovery wheel	Enthalpy wheel type with 75% rated efficiency
5.	Winter heating source	None

Table 12.5 VRV specifications details

COP	3.75
Capacity	9.6 TR
Input power	8.93 kW
Refrigerant	R410A

You need to find base case parameters from ASHRAE 90.1-2010.

Simulate and compare the base case and design case models in Desgin Builder.

You can get more information about modelling VRF system from: https://www.designbuilder.co.uk/helpv4.7/Content/VRFOutdoorUnit.htm

On this page you will also get a link to a webinar - VRF System Design and Simulation, presented by DesignBuilder, Mitsubishi and Building Performance Team, recorded on 01.09.15.

CHAPTER THIRTEEN

Project: Single-Family Residence

Project goal

The goal of this project is to create a DesignBuilder model of a single-family detached house located in the United States. The house is located in Chicago, Illinois, which is climate Zone 5A: Cool and Humid. You will learn to model a real-world example building and analyse the key results of a whole building energy simulation.

Overview

A single-family home with two floors and one basement will be modelled in this project. An introduction of the building is provided in Table 13.1.

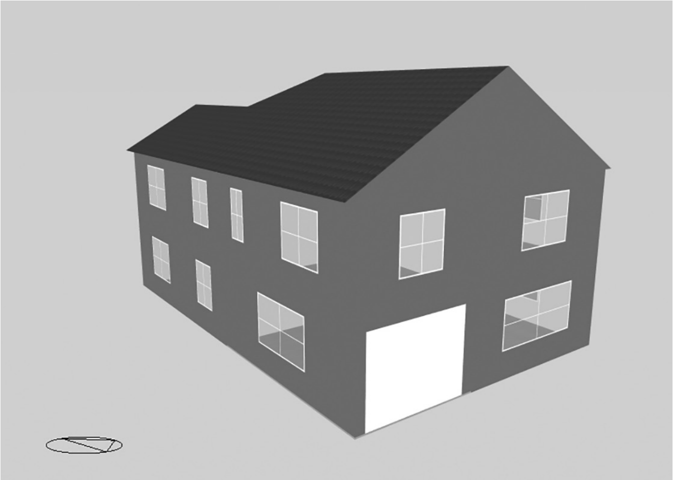


Table 13.1 Building overview

Variable	Value
Year of construction	2015
Total built-up area	280 m^2
Building use	Single-family detached
Number of floors	2 + basement
Number of above-grade floors	2
Number of floors below grade	1
Construction type	Wood-framed: advance framing
Window-to-wall ratio	20%
Heating	Gas furnace
Cooling	Air conditioner – ducted split system
Domestic hot water	Gas boiler with storage tank
Average utility costs	
Natural gas	$0.785/therm
Electricity	$0.113/kWh

Table 13.2 Building location and orientation

Variable	Value
City/state	Chicago, Illinois
Climate zone	5A (cool-humid)
Latitude	N 41°50′13″
Longitude	W 87°41′05″
Elevation	100 m
Heating design days (18.3°C baseline)	3506
Cooling design days (10°C baseline)	1689
Building orientation	0° from the true north

Climate and location

The house is located in Chicago, Illinois. Chicago has a cool and humid climate, with hot and humid summers and cold winters. Therefore, in such climates, buildings are designed to meet both the cooling and heating needs.

Table 13.2 provides information on the geography and climate of Chicago. The building is oriented to the true north, with the slopes of the roofs facing north and south.

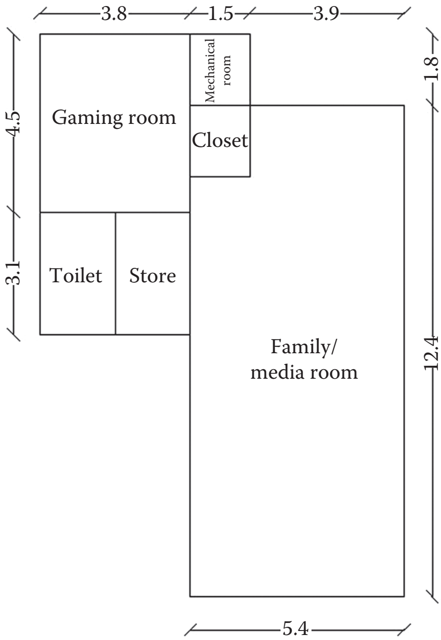
Floor plans

For creating any energy simulation model, it is important to define the area of the building within the thermal boundary. In this home, all the rooms within the building, including the attic area, are insulated, except the garage.

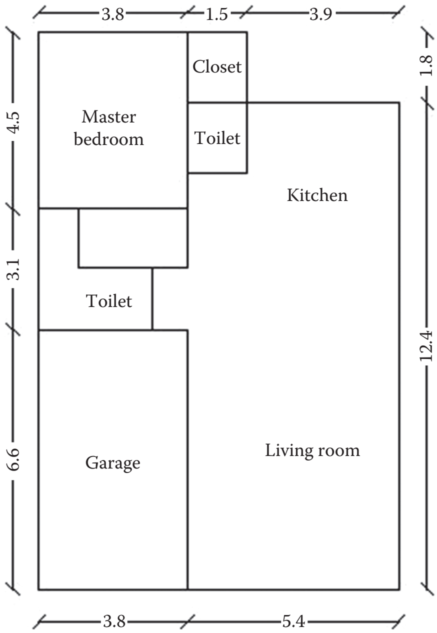
The figures that follow show the floor plans of the house. The first-level floor plan shows the kitchen, master bedroom and living room. On the second level of the home there are three bedrooms. The basement floor comprises a family room, game room, laundry room and mechanical room.

As seen in the 3D image, the building has a sloped roof and an attic under the sloped roof. The home is insulated at the ceiling level, and, hence, the attic is also a conditioned space. However, the garage on the first level is unconditioned.

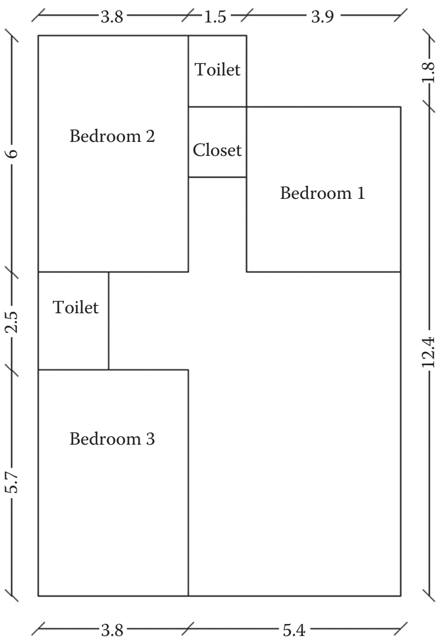
Therefore, the thermal boundary of the building, is as shown in the plan and cross-section. The complete home is centrally conditioned and is controlled with a single thermostat.



Basement floor



Ground floor



First floor

All measurements are in metre.

Internal loads and schedules

The building is a single-family residence. The occupancy of the home is five people. Details of activity, maximum occupancy, equipment load and lighting loads in each of the room are provided in Table 13.3.

Equipment load radiant fraction is 0.2.

Occupancy, equipment, lighting, and mechanical equipment schedules are provided in Tables 13.4 and 13.5.

Table 13.3 Activities and schedules

Room	Activity/ MET	Maximum occupancy	Equipment load (W/m^2)	Lighting load (W/m^2)
Living/dining room	Eating & drinking	5	10.8	5
Master bedroom	Sleeping	2	3.3	3
Bedrooms 1, 2 & 3	Sleeping	1 per room	3.3	3
Kitchen	Cooking	2	4.3	5
Game room	Light manual work	5	10.8	5
Family room	Seated quiet	5	16.1	5
Bathrooms	Standing/ walking	1 per room	2.2	2

Table 13.4 Occupancies and operating schedule

	Occupancy		Equipment		Lighting	
Type	Fraction		Fraction		Fraction	
Month	Jan–Dec		Jan–Dec		Jan–Dec	
Days	Weekdays	Sunday and holidays	Weekdays	Weekends and holidays	Weekdays	Weekends and holidays
0:00	1	1	0.2	0.2	0.2	0.2
1:00	1	1	0.2	0.2	0	0
2:00	1	1	0.2	0.2	0	0
3:00	1	1	0.2	0.2	0	0
4:00	1	1	0.2	0.2	0	0
5:00	1	1	0.5	0.5	0.5	0.2
6:00	1	1	0.8	0.8	0.5	0.2
7:00	0.8	1	1	1	0.8	0.5
8:00	0.4	1	1	1	0.5	0.5
9:00	0	1	0.5	1	0	0.2
10:00	0	1	0.2	08	0	02
11:00	0	0	0.2	0.2	0	0

(*Continued*)

Table 13.4 (*Continued*) Occupancies and operating schedule

	Occupancy		Equipment		Lighting	
Type	Fraction		Fraction		Fraction	
Month	Jan–Dec		Jan–Dec		Jan–Dec	
Days	Weekdays	Sunday and holidays	Weekdays	Weekends and holidays	Weekdays	Weekends and holidays
12:00	0	0	0.2	0.2	0	0
13:00	0	0	0.2	0.2	0	0
14:00	0	0	0.2	0.2	0	0
15:00	0	0	0.2	0.2	0	0
16:00	0.8	1	0.5	0.5	0.2	0.2
17:00	0.8	1	0.8	0.8	0.5	0.5
18:00	0.8	1	0.8	0.8	1	0.8
19:00	1	1	1	0.5	1	1
20:00	1	1	1	0.5	1	1
21:00	1	1	0.8	0.5	0.8	0.8
22:00	1	1	0.5	0.5	0.5	0.5
23:00	1	1	0.5	0.2	0.5	0.5

Table 13.5 Operating schedules for mechanical equipment

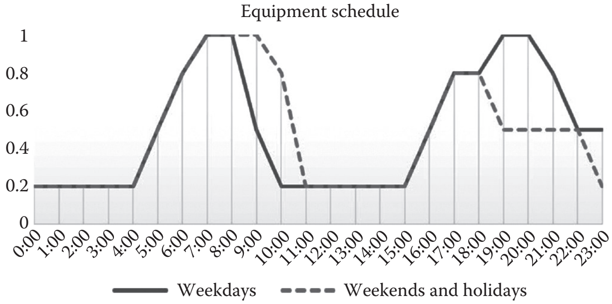
	Cooling setpoint		Heating setpoint		Cooling system		Heating system	
Type	Temperature		Temperature		On/Off		On/Off	
Month	Jan–Dec		Jan–Dec		Jun–Sep		Oct–May	
Days	Weekdays	Weekends and holidays	Weekdays	Weekends and holidays	Weekdays	Weekends and holidays	Weekdays	Weekends and holidays
0:00	24	24	21	21	1	1	1	1
1:00	24	24	21	21	1	1	1	1
2:00	24	24	21	21	1	1	1	1
3:00	24	24	21	21	1	1	1	1
4:00	24	24	21	21	1	1	1	1
5:00	24	24	21	21	1	1	1	1
6:00	24	24	21	21	1	1	1	1
7:00	24	24	21	21	1	1	1	1
8:00	24	24	21	21	1	1	1	1
9:00	30	24	16	21	0	1	0	1
10:00	30	24	16	21	0	1	0	1
11:00	30	30	16	16	0	0	0	0

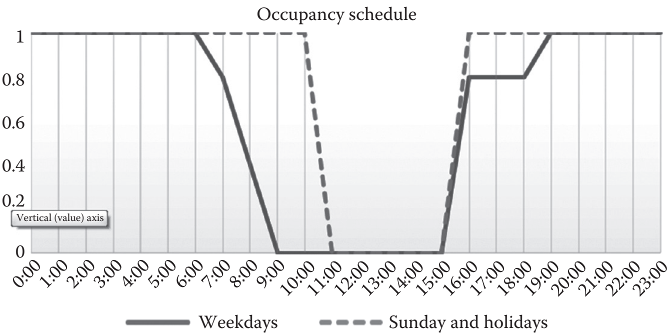
(*Continued*)

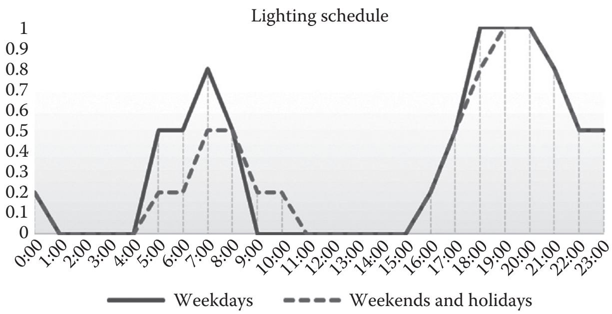
Table 13.5 (*Continued*) Operating schedules for mechanical equipment

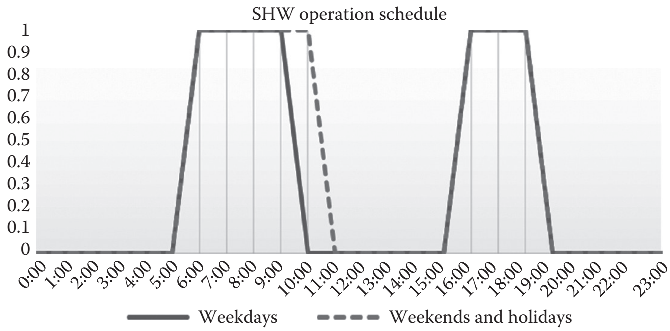
	Cooling setpoint		Heating setpoint		Cooling system		Heating system	
Type	Temperature		Temperature		On/Off		On/Off	
Month	Jan–Dec		Jan–Dec		Jun–Sep		Oct–May	
Days	Weekdays	Weekends and holidays	Weekdays	Weekends and holidays	Weekdays	Weekends and holidays	Weekdays	Weekends and holidays
12:00	30	30	16	16	0	0	0	0
13:00	30	30	16	16	0	0	0	0
14:00	30	30	16	16	0	0	0	0
15:00	30	30	16	16	0	0	0	0
16:00	24	24	21	21	1	1	1	1
17:00	24	24	21	21	1	1	1	1
18:00	24	24	21	21	1	1	1	1
19:00	24	24	21	21	1	1	1	1
20:00	24	24	21	21	1	1	1	1
21:00	24	24	21	21	1	1	1	1
22:00	24	24	21	21	1	1	1	1
23:00	24	24	21	21	1	1	1	1

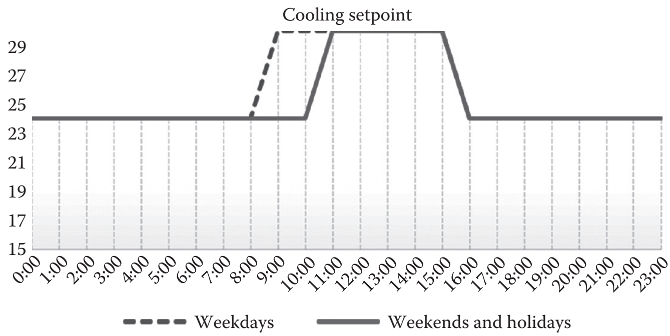
The following figures give the 24 hours schedules for various parameters.

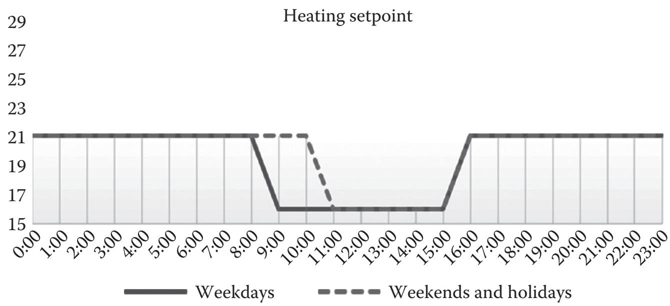


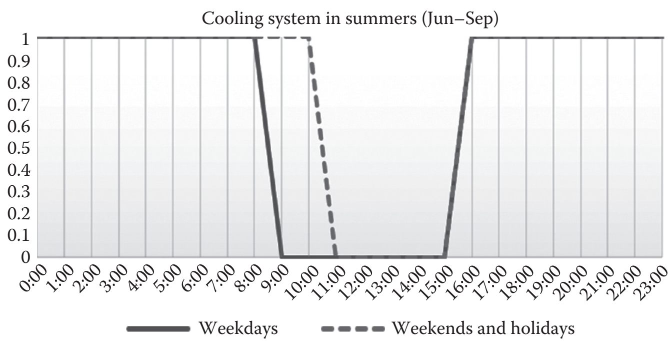


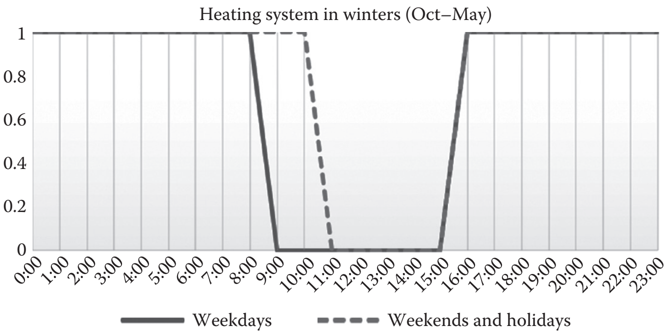



SHW operation schedule
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Weekdays
Weekends and holidays


Cooling setpoint
29
27
25
23
21
19
17
15
0:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Weekdays
Weekends and holidays


Heating setpoint
29
27
25
23
21
19
17
15
0:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Weekdays
Weekends and holidays


Cooling system in summers (Jun–Sep)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Weekdays
Weekends and holidays



Building envelope

This home is constructed using advanced framing techniques. Layer-by-layer details of the wall, roof and floors is provided. Using these details, create custom layers and, if necessary, materials under the DesignBuilder construction tab. The Window-to-wall ratio of the home is 25%, with most of the glazing on the north and south (Table 13.6).

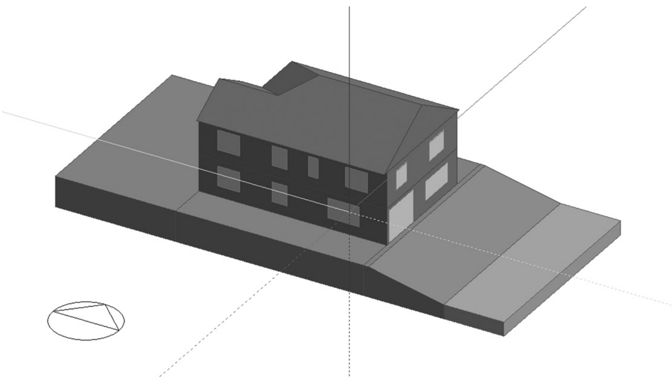


Table 13.6 Building envelope construction details

Component	Description	Construction layers (Some layers such as vapour and air barriers are not shown to maintain simplicity) outside to inside
Opaque assembly		
Roof	Unvented & insulated at roof	20 mm wood siding + 100 mm expanded polystyrene + 50 mm closed-cell spray foam + 15 mm gypsum board
Ceiling	Uninsulated	10 mm gypsum board
Above-grade exterior walls	Wood-framed	20 mm wood siding + 50 mm closed-cell spray foam + 100 mm fibre glass batt + 10 mm gypsum board
Interior floors	Wood-framed	20 mm wooden flooring
Partition wall	Interior walls	15 mm gypsum board + 20 mm air gap + 15 mm gypsum board
Below-grade walls	Insulated masonry wall	100 mm concrete masonry block + 100 mm closed-cell spray foam + 15 mm gypsum board
Slab on grade floors	Insulated concrete floor	150 mm concrete slab + 50 mm extruded polystyrene + 20 mm wooden flooring

(*Continued*)

Table 13.6 (*Continued*) Building envelope construction details

Component	Description	Construction layers (Some layers such as vapour and air barriers are not shown to maintain simplicity) outside to inside
Transparent assembly		
Window-to-wall ratio	7% on north + 10% on south + 5% on east + 3% on west	7% on north + 10% on south + 5% on east + 3% on west
Glass solar heat gain coefficient (SHGC)	Double-pane low-E glazing (700 R/SL Slider LoE-180 from WASCO WINDOWS)	0.29
Solar heat gain coefficient (SHGC)	Advanced framing: 50 mm × 150 mm framing, with 600 mm spacing centre to centre	0.49
Visible transmittance (VT)		0.62
Others		
Roof reflectance	Grey roof	0.3
Infiltration through envelope	Tight envelope	0.5 ac/h

Hint: Windows are only on the conditioned walls, and the building is completely conditioned. With the knowledge from previous examples and exercises in other chapters, should the windows be modelled in detail with exact dimensions and locations?

Tip: Using the area-weighted average method, calculate the effective R value of the insulation (fibre glass batt) used in the wall, considering 16% area for advanced framing.

The above-grade walls of the home are designed to use flash and batt insulation. Open-cell spray foam used in the cavities above dense-packed cellulose is installed.

Mechanical systems

The building is centrally heated and cooled. The heating is provided through a gas furnace, and the cooling system is a central split system. Efficiency details of the HVAC and SHW systems are provided in the following table. Both the heating and cooling systems are connected to the same air handling unit with a constant volume fan (Table 13.7).

Table 13.7 Mechanical system details

Variable	Value
Heating	
System type	Furnace
Fuel type	Natural gas
Heating system efficiency (AFUE)	80%
Maximum supply air temperature	30°C
Maximum supply air humidity ratio	0.0156
Heating system capacity	26 kW
Cooling	
System type	Central air conditioning using split system
Fuel type	Electricity
Cooling system EER	12.00
Cooling system SEER	17.50
Cooling system capacity	14 kW
Domestic hot-water system	
System type	A storage hot-water system (standalone)
System fuel	Natural gas
Energy factor	0.82
Hot-water delivery temperature	75°C
Mains supply temperature	10°C

IECC 2015 compliance

You are required to run simulation for IECC 2015 compliance.

CHAPTER FOURTEEN

Project: Large Office

Project goal

The goal of this project is to create a DesignBuilder model of a large office building located in Ulsan, South Korea. The office is located in climate Zone 4A: Mixed Humid, as defined by ASHRAE 90.1-2010. You will learn to model a large office building and analyse the key results of a whole building energy simulation.

Overview

The building is a large office with five floors. An introduction of the building is provided in Table 14.1.

Climate and location

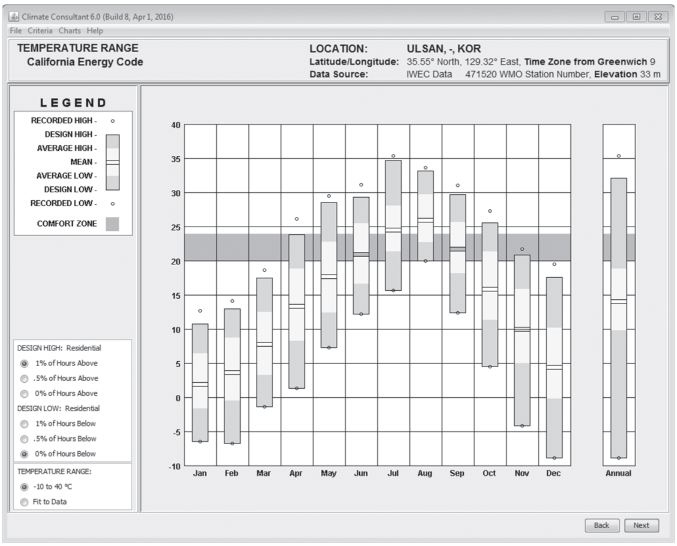
The building is located in Ulsan, Korea. Ulsan has a monsoon-influenced humid subtropical climate, with somewhat cold but dry winters and hot, humid summers (Table 14.2).

Table 14.1 Building overview

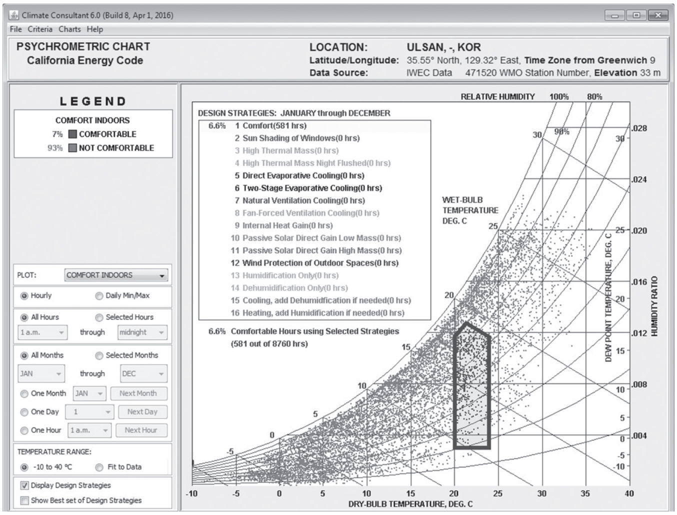
Variable	Value
Total built-up area	54,317 m^2
Building use	Office
Number of above-grade floors	2
Window-to-wall ratio	35%
Heating	Natural gas-fired steam boiler
Cooling	Water-cooled centrifugal chillers
Average utility costs	
Natural gas	$1.7/therm
Electricity	$0.08/kWh

Table 14.2 Building location and orientation

Variable	Value
City/state	Ulsan, Korea
Climate zone	4A (mixed-humid)
Building orientation	0° from the true north



Source: From http://www.energydesign-tools.aud.ucla.edu/climate-consultant/.

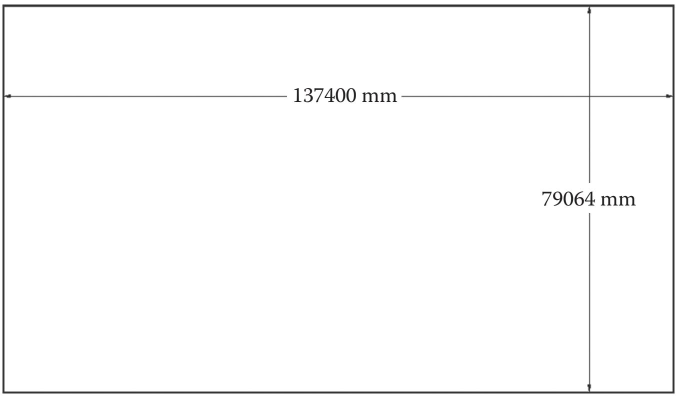


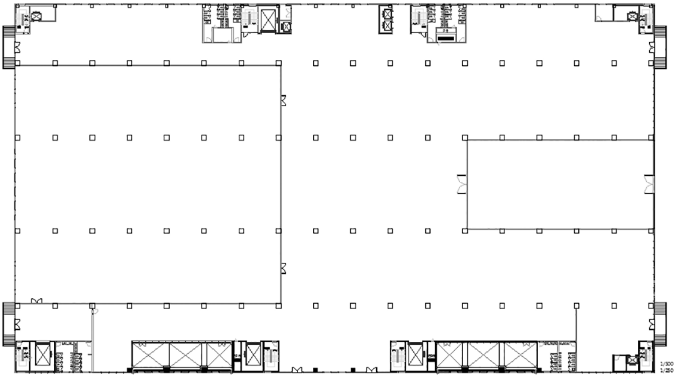
Source: From http://www.energydesign-tools.aud.ucla.edu/climate-consultant/.

Floor plans

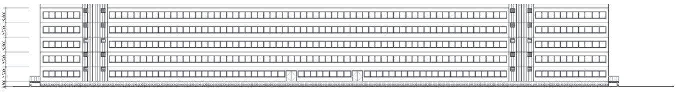
Following figures give the plan and elevations of the building.

A soft copy of CAD is provided with the book (https://www.crcpress.com/9781498744515).

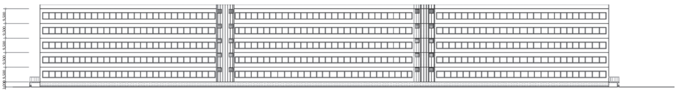




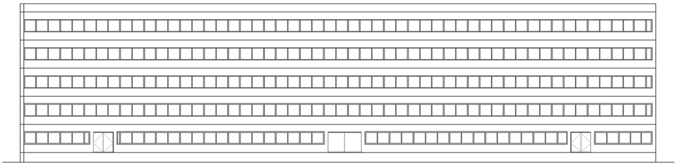
PLAN



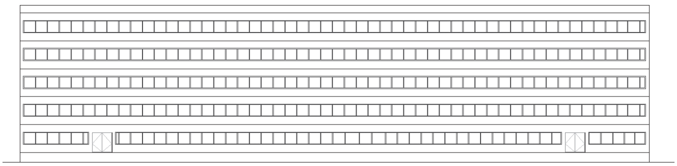
FRONT ELEVATION



REAR ELEVATION



SIDE ELEVATION-1



SIDE ELEVATION-2

Building envelope

This large office is proposed to be constructed with parameters as shown in Table 14.3.

Internal loads and schedules

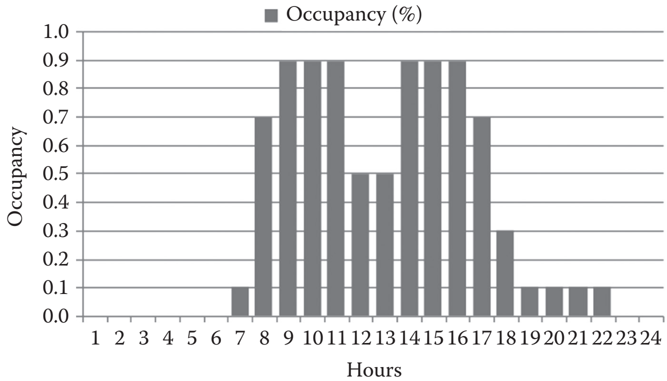
Details of activity, equipment load and lighting load in each of the room are provided in Table 14.4.

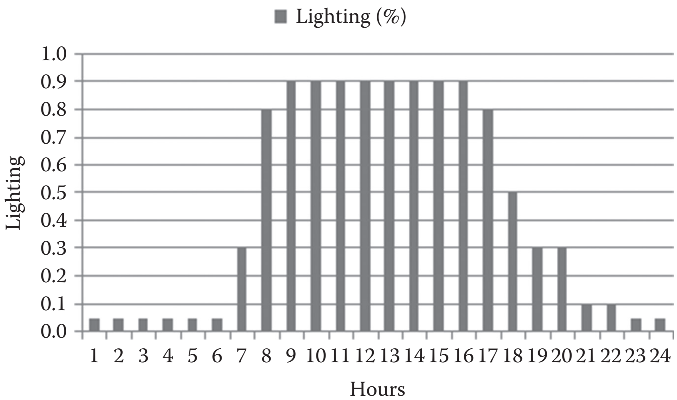
Table 14.3 Building envelope parameters

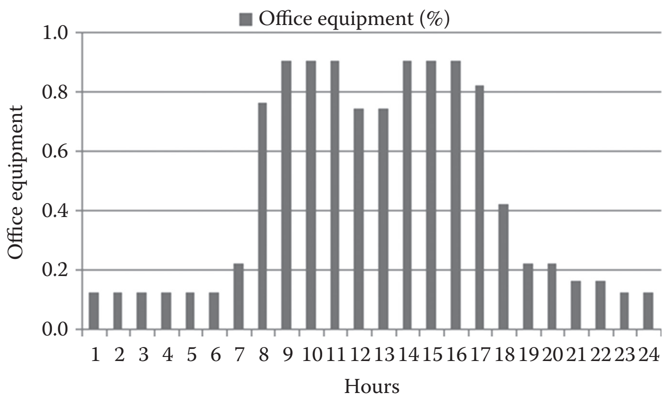
S. No.	Model input parameter	Details
1.	Exterior wall construction	Assembly U-0.340 W/m^2-K Metal panel 50 mm + 75 mm PUF thickness
2.	Roof construction	Assembly U-value: 0.340 W/m^2-K (100 mm concrete + 75 mm PUF)
3.	Glazing	U-value: 3.463 W/m^2-K SC (all): 0.6 & VLT: 50% Window frame U-value: 6.41 W/m^2-K
4.	Window-to-wall ratio	35%
5.	Roof reflectance	0.8
6.	Infiltration through envelope	0.5 ac/h
7.	Shading devices	None

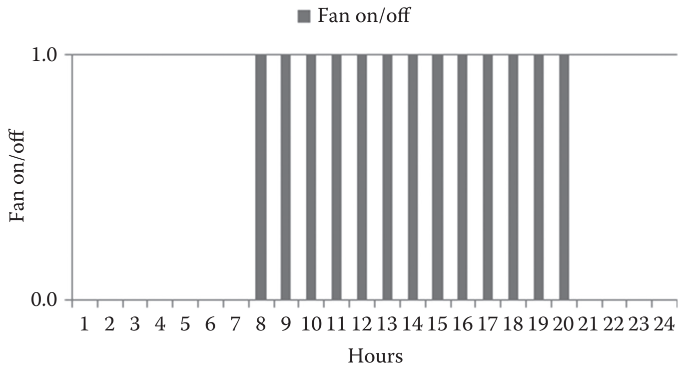
Table 14.4 Parameters related to internal loads

S. No.	Model input parameter	Details
1.	Fresh air C.F.M./person	30% over ASHRAE 62.1-2007
2.	Equipment power density (W/m^2)	15
3.	Occupancy (m^2/person)	9.30
4.	Lighting power density (W/m^2)	7
5.	Occupancy sensors	Installed in all areas
6.	Daylight sensors	None


Occupancy (%)
Occupancy
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hours


Lighting (%)
Lighting
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hours


Office equipment (%)
Office equipment
1.0
0.8
0.6
0.4
0.2
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hours



Mechanical systems

The building is centrally heated and cooled. Efficiency details of the HVAC systems are provided in Table 14.5.

Table 14.5 HVAC parameters

S. No.	Model input parameter	Value
1.	HVAC system type	VAV system
2.	AHU fan power	4 in WG
3.	Demand control ventilation	CO_2 sensors installed to modulate fresh air
4.	Heat recovery wheel	Enthalpy wheel type with 75% rated efficiency
5.	Airside economiser (100% fresh air system)	None
6.	Chiller parameter	3 numbers of 1000 TR water-cooled centrifugal chillers with COP 6.17
7.	Chilled water loop	Variable secondary flow CHW out = 6.66°C & CHW in = 12.22°C
8.	Winter heating source	Natural gas-fired steam boiler
9.	Boiler efficiency	96%
10.	Pump motor class	Standard
11.	Cooling tower fan	Variable speed

Show compliance for ASHRAE 90.1-2010

You need to find base case parameters as per ASHRAE 90.1-2010.

Prepare the DesignBuilder model for the base case and design case. Then compare energy savings (Table 14.6).

Table 14.6 Model input parameters for base case and as design case

S. No.	Model input parameter	Baseline case as per ASHRAE 90.1-2007	As design case
1.	Exterior wall construction	Steel frame, U-factor = 0.363 W/m^2-K	Assembly U-0.340 W/m^2-K Metal panel 50 mm + 75 mm PUF thickness
2.	Roof construction	U-factor = 0.272 W/m^2-K insulation entirely above deck	Assembly U-value: 0.340 W/m^2-K (100 mm concrete + 75 mm PUF)
3.	Glazing	U-value: 2.83 W/m^2-K SC (all): 0.46 For fenestration assembly	U-value: 3.46 W/m^2-K SC (all): 0.6 & VLT: 50% Window frame U-value: 6.40 W/m^2-K
4.	Window-to-wall ratio (%)	35	35
5.	Fresh air C.F.M./person	30% over ASHRAE 62.1-2007	Same as base case
6.	Equipment power density (W/m^2)	0.18	Same as base case
7.	Occupancy (m^2/person)	13.94	Same as base case
8.	Lighting power density (W/m^2)	As per ASHRAE 90.1-2007 Space by Space	7
9.	Shading devices	None	None
10.	Occupancy sensors	None	Installed
11.	Daylight sensors	None	None
12.	HVAC system type	Table G3.1.1.B System 7 – VAV with reheat (total conditioned area is 4,17,400 Sqft in five floors)	VAV system

(*Continued*)

Table 14.6 (*Continued*) Model input parameters for base case and as design case

S. No.	Model input parameter	Baseline case as per ASHRAE 90.1-2007	As design case
13.	AHU fan power	0.0011 kW/C.F.M.	4 inch WG
14.	Demand control ventilation	None	CO_2 sensors installed to modulate fresh air
15.	Heat recovery wheel	None	Enthalpy wheel type with 75% efficiency
16.	Airside economiser (100% fresh air system)	None	None
17.	Chiller parameter	2 nos water-cooled centrifugal chiller, COP 6.1	3 nos water-cooled centrifugal chiller, COP 6.17
18.	Chilled water loop	Variable secondary flow	Variable secondary flow & chilled water $\Delta T = 10°F$ CHW out = 6.66°C CHW in = 12.22°C
19.	Winter heating source	Natural gas-fired steam boiler	Natural gas-fired steam boiler
20.	Boiler efficiency	80%	96%
21.	Pump motor class	Standard	Standard
22.	Cooling tower fan	Two speeds	Variable speed
23.	Energy rates	Electricity $0.08/kWh Natural gas $1.7/therm	Same as base case

Appendix A: Working of EnergyPlus™ Simulation

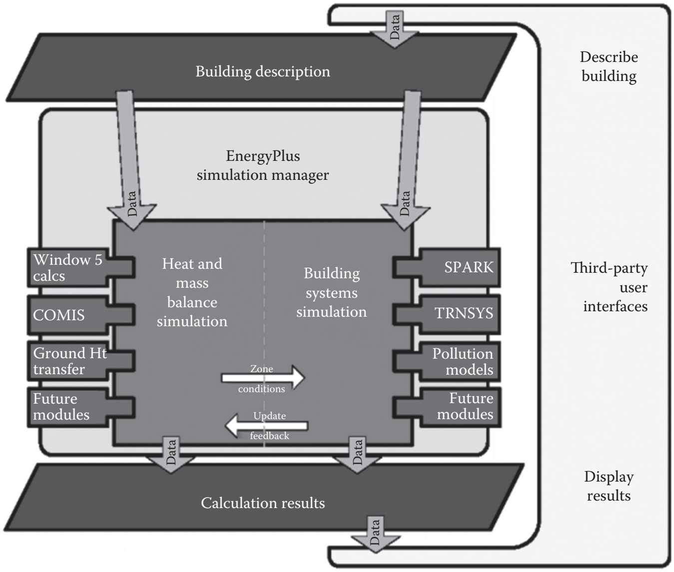
EnergyPlus™ is a whole building energy simulation program used by engineers, architects and researchers to model energy consumption for heating, cooling, ventilation, lighting and plug and process loads. EnergyPlus can also be used for simulating water use in buildings. Some of the features and capabilities of EnergyPlus include (Source: https://www.energyplus.net):

- *Integrated, simultaneous solution* of thermal zone conditions and HVAC system response that does not assume that the HVAC system can meet zone loads and can simulate un-conditioned and under-conditioned spaces.
- *Heat balance-based solution* of radiant and convective effects that produce surface temperatures thermal comfort and condensation calculations.
- *Sub-hourly, user-definable time step*s for interaction between thermal zones and the environment; with automatically varied time steps for interactions between thermal zones and HVAC systems. These allow EnergyPlus to model systems with fast dynamics while also trading-off simulation speed for precision.
- *Combined heat and mass transfer model* that accounts for air movement between zones.
- *Advanced fenestration models* including controllable window blinds, electrochromic glazings and layer-by-layer heat balances that calculate solar energy absorbed by window panes.
- *Illuminance and glare calculations* for reporting visual comfort and driving lighting controls.

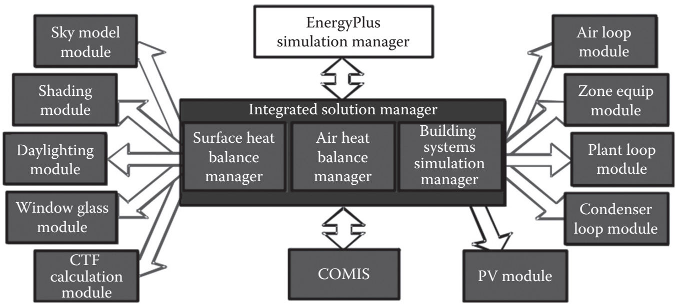
- *Component-based HVAC* that supports both standard and novel system configurations.
- *A large number of built-in HVAC* and lighting control strategies and an extensible runtime scripting system for user-defined control.
- *Functional Mockup Interface* import and export for co-simulation with other engines.
- *Standard summary and detailed output reports* as well as user definable reports with selectable time-resolution from annual to sub-hourly, all with energy source multipliers.

EnergyPlus is a console-based program that reads input and writes output to text files. It ships with a number of utilities including IDF-Editor for creating input files using a simple spreadsheet-like interface, EP-Launch for managing input and output files and performing batch simulations, and EP-Compare for graphically comparing the results of two or more simulations. Several comprehensive graphical interfaces for EnergyPlus are also available (https://energyplus.net/interfaces). One of the interfaces is DesignBuilder.

One of the strong points of EnergyPlus is the integration of all aspects of the simulation – loads, systems and plants. Based on a research version of the Building Loads Analysis and System Thermodynamics (BLAST) program called IBLAST, system and plant output is allowed to directly impact the building thermal response rather than calculating all loads first, then simulating systems and plants. The simulation is coupled allowing the designer to more accurately investigate the effect of undersizing fans and equipment, and what impact that might have on the thermal comfort of occupants within the building. The figures below show the big picture and a basic overview of the integration of these important elements of a building energy simulation.



EnergyPlus – the big picture.



EnergyPlus – internal elements.

More information on EnergyPlus can be found in the Getting Started manual available at https://energyplus.net/sites/all/modules/custom/nrel_custom/pdfs/pdfs_v8.6.0/GettingStarted.pdf.

Appendix B: Weather Data and Tools

For simulating a building, its model and weather data for the location are required. There are various formats for storing the hourly weather data. EnergyPlus uses .epw format.

In a .epw file, all the data are in SI units. The format is text-based and comma-separated. The data file format contains commas to facilitate data reading and analysis with spreadsheet programs.

More information on the .epw format is given at http://bigladdersoftware.com/epx/docs/8-2/auxiliary-programs/epw-csv-format-inout.html#epw-csv-format-inout.

Weather data for more than 2100 locations are now available in EnergyPlus weather format at https://energyplus.net/weather.

Weather data analysis tools

Climate consultant

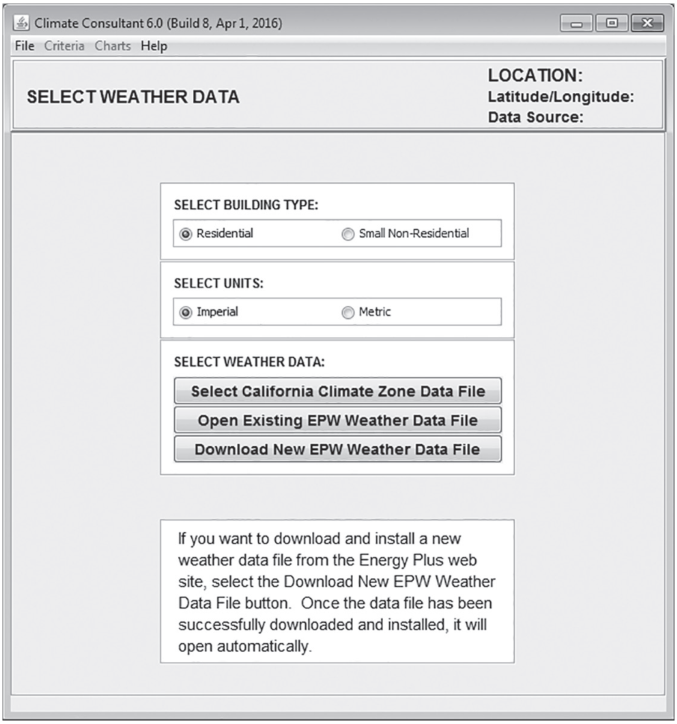
It was developed by the Department of Architecture and Urban Design, University of California, Los Angeles. Graphically, it displays climate data in either metric or imperial units in dozens of ways useful to architects.

Benefits

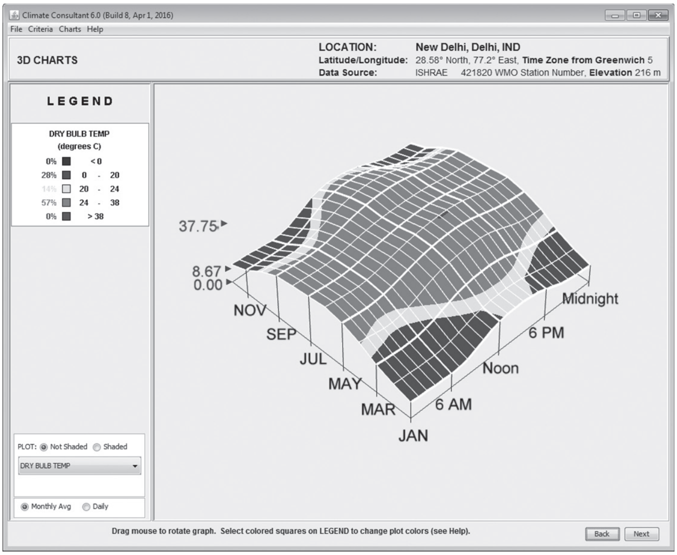
- Easier to identify unique patterns and subtle details that characterize each different climate.
- Thresholds and comfort zones are more flexible.
- In contrast to the Weather Tool, detailed technical information about the passive strategies criteria is documented and is freely available.

- The 'Wind Wheel' graphics show velocity and direction correlated with temperature and humidity and can be animated hourly, daily or monthly.
- The psychometric analysis recommends the most appropriate passive design strategies, as outlined in Givoni's *Man, Climate and Architecture*.

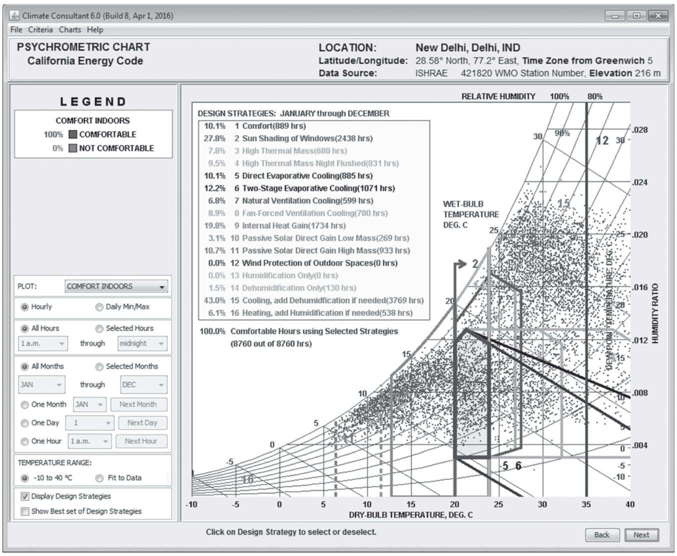
Climate Consultant is free to download from the website **http://www.energy-design-tools.aud.ucla.edu/**.



Source: From http://www.energydesign-tools.aud.ucla.edu/climate-consultant/.



Source: From http://www.energydesign-tools.aud.ucla.edu/climate-consultant/.



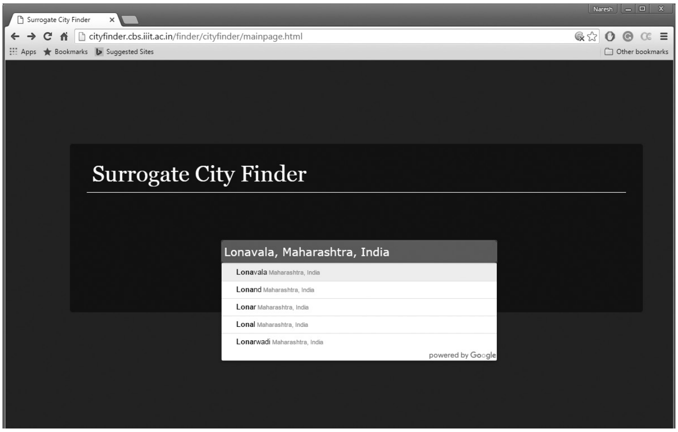
Source: From http://www.energydesign-tools.aud.ucla.edu/climate-consultant/.

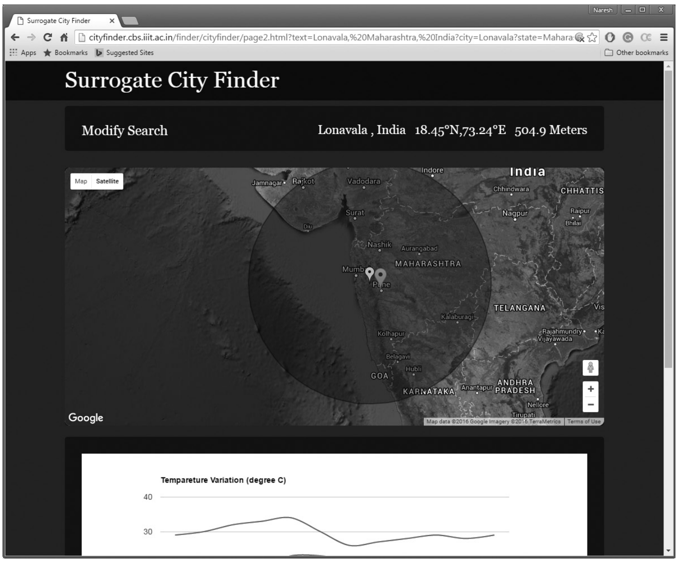
Surrogate City Finder

It is developed by the Centre for IT in Building Science (CBS), International Institute of Information Technology, Hyderabad, India. This is a web-based tool that shortlists the best-matched weather based on parameters such as the latitude, altitude and temperature range.

The Surrogate City Finder (SCF) tool has been tested by analysing the annual energy consumption of 16 reference-building models simulated for eight locations from different international climate zones and their surrogate cities to find that the deviation in annual energy consumption was mostly within the range of ±2%.

The tool can be accessed at cityfinder.cbs.iiit.ac.in.

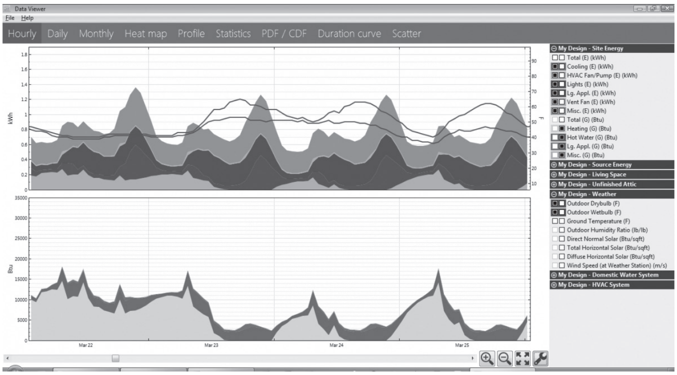




DView

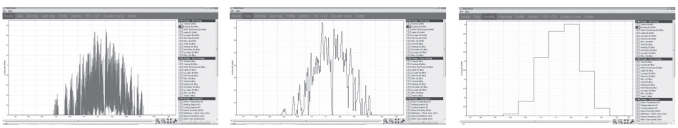
DView is used by BEopt for visualizing time-series weather data at any time step (e.g. hourly and subhourly). DView opens CSV files and also recognizes several weather data file formats, including TMY2, TMY3 and EPW files.

The hourly, daily and monthly graphs allow you to turn variables on or off with a single click and to zoom and pan very easily. DView has the ability to display simultaneous line and stacked areas, as demonstrated in the hourly graph below.



Source: From https://beopt.nrel.gov/downloadDView.

Daily and monthly time series graphs are automatically created by averaging or summing the hourly data:



Source: From https://beopt.nrel.gov/downloadDView.

DView is free to download from the website https://beopt.nrel.gov/downloadDView.

Index

Note: Page numbers followed by f and t refer to figures and tables, respectively.

C

D

E

I

L

M

N

T

U

V

W

X

Z