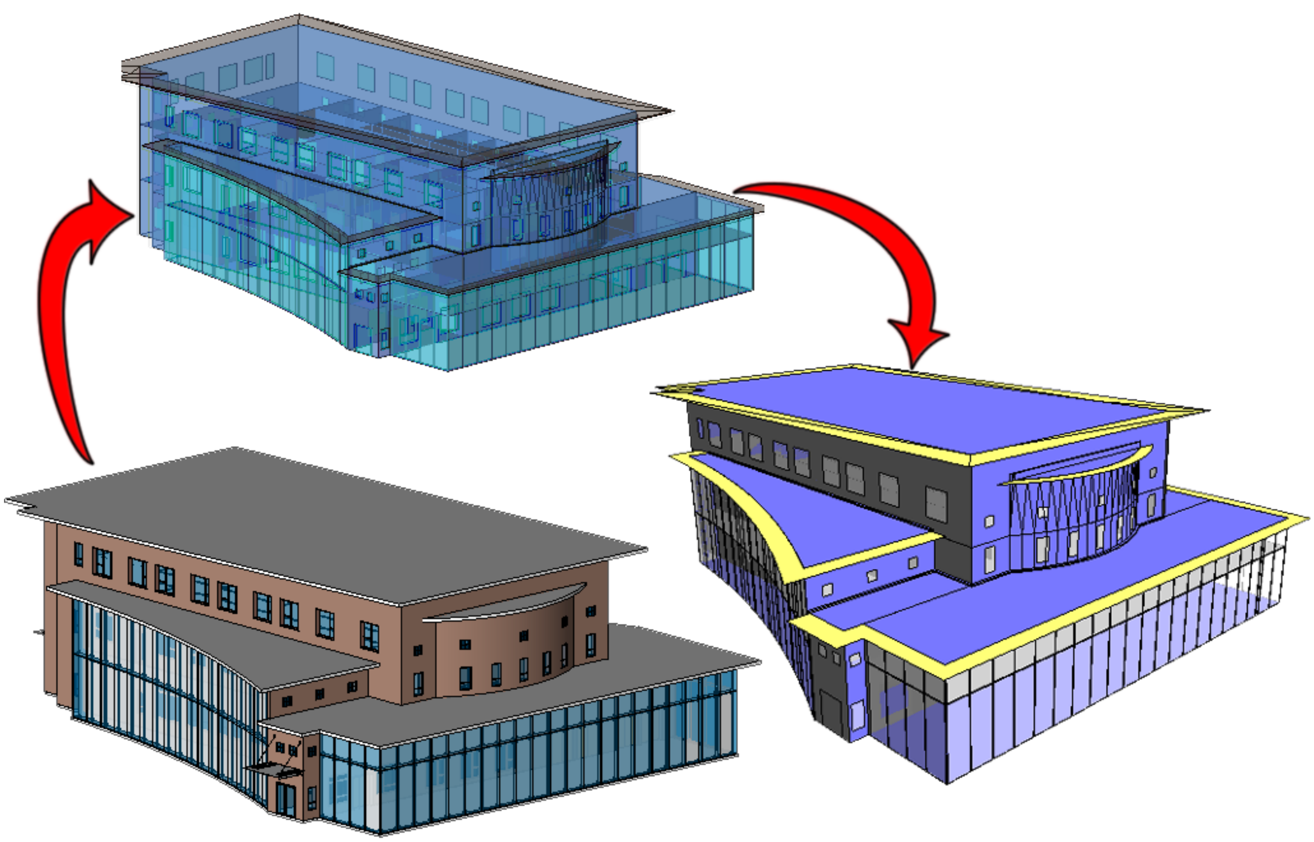
Building Performance Analysis Using Revit

Powerful new functionality in Revit allows for faster, more accurate Building Performance Analysis

One of the most time-consuming aspects of any Building Performance Analysis (BPA) is the setup required to carry out the analysis. This often is a process of re-creating the building geometry as well as setting the conditions necessary to properly represent the environment both inside and outside of the building. With the 2008 release of the Revit® family of software products, a great deal of the front end effort necessary to carry out BPA has been removed with the implementation of robust gbXML export as well as a direct link to the IES <Virtual Environment> (<VE>) analysis platform within Revit MEP.

The <Virtual Environment> is a unique software system of integrated Building Performance Analysis tools developed by Integrated Environmental Solutions. The tools available include thermal simulation with a proven capability for natural ventilation, displacement ventilation, chilled beams and ventilated facades studies, Energy analyses for LEED accreditation, daylighting (for LEED) and electric lighting, solar analyses, internal and external CFD airflow studies, occupant evacuation and many more.

In order to take advantage of this advanced workflow between the two platforms, the Revit Physical Model must be properly prepared for analysis. Like any type of analysis, the usefulness and accuracy of the results depend greatly on the quality of the inputs. This involves first an understanding of the conversion of a Revit Physical Model into an Analytical Model for BPA, and then an understanding of how that process impacts the structure of your Revit Physical Model. This paper's intent is to assist you in succeeding to leverage your Revit Physical Model to carry out Building Performance Analysis using the IES <VE> Direct Link found in Revit MEP or gbXML exports from Revit Architecture.



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Contents

1 Conceptual Understanding of Process

Without an understanding of the conversion of a Revit Physical Model into an Analytical Model, the process is just a number of rules and steps to produce a desired output. It is only with conceptual understanding that the processes involved can be put into context and a bigger picture of the process can be gathered. This can be very useful in troubleshooting situations where the desired output is not achieved. Additionally, as building design professionals it is always good to know what's going on under the hood of your design software.

1.1 *Rooms*

Rooms are a fundamental element in the process of carrying out BPA using your Revit Physical Model. They are the element that dictates the majority of the geometry generated in your Analytical Model, as well as the holder of a great deal of the additional analysis parameters passed into your analysis software. Simply put, if a Room is not accurate, there is no way to get an accurate analysis model. With these accurate Rooms, things like block loads, lighting analysis, day lighting analysis, and computational fluid dynamics can be carried out with confidence.

NOTE: Within the gbXML schema the Space is the equivalent to a Room. For the purposes of clarity in this paper we will refer to these items as Rooms in all cases.

1.2 *Bounding Elements*

The extents of Rooms are defined by the Elements that surround them. These Bounding Elements can be things like Walls, Floors and Roofs. In the conversion of a Revit Physical Model to an Analytical Model, Bounding Elements are converted into 2D surfaces that represent their geometry. In the organizational hierarchy of the Analytical Model, surfaces are "children" of the Rooms that they bound.

Bounding Elements are frequently broken down into multiple surfaces to allow for proper analysis. One such example is a curved wall. Since surfaces must be represented by 2D shapes, a curved wall must be broken down into many surfaces to best represent the curved geometry in the Revit Physical Model, see Figure 1 below.

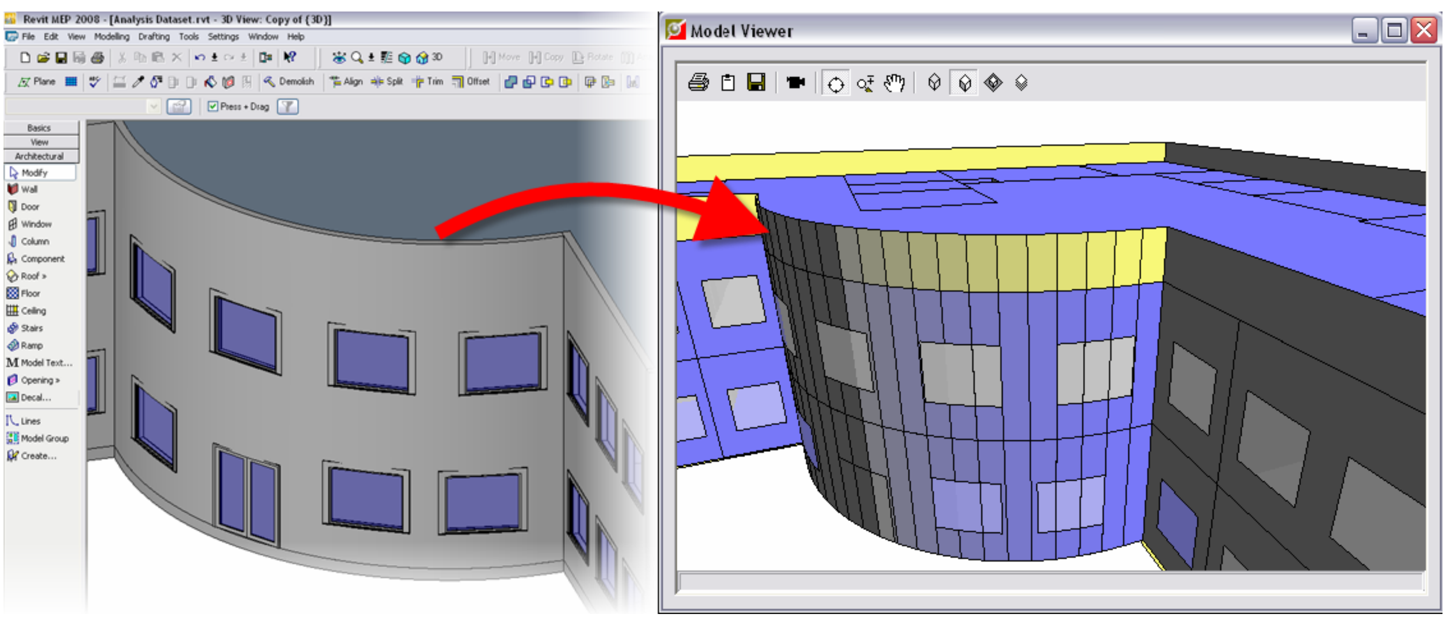


Figure 1 - Curved Wall Conversion

Another situation where a Bounding Element is broken up into multiple surfaces is when there are multiple Rooms adjacent to it. In order to allow for situations where one adjacent Room is unconditioned, while the other is conditioned, the Wall is broken into two surfaces in the Analytical Model, see Figure 2 below.

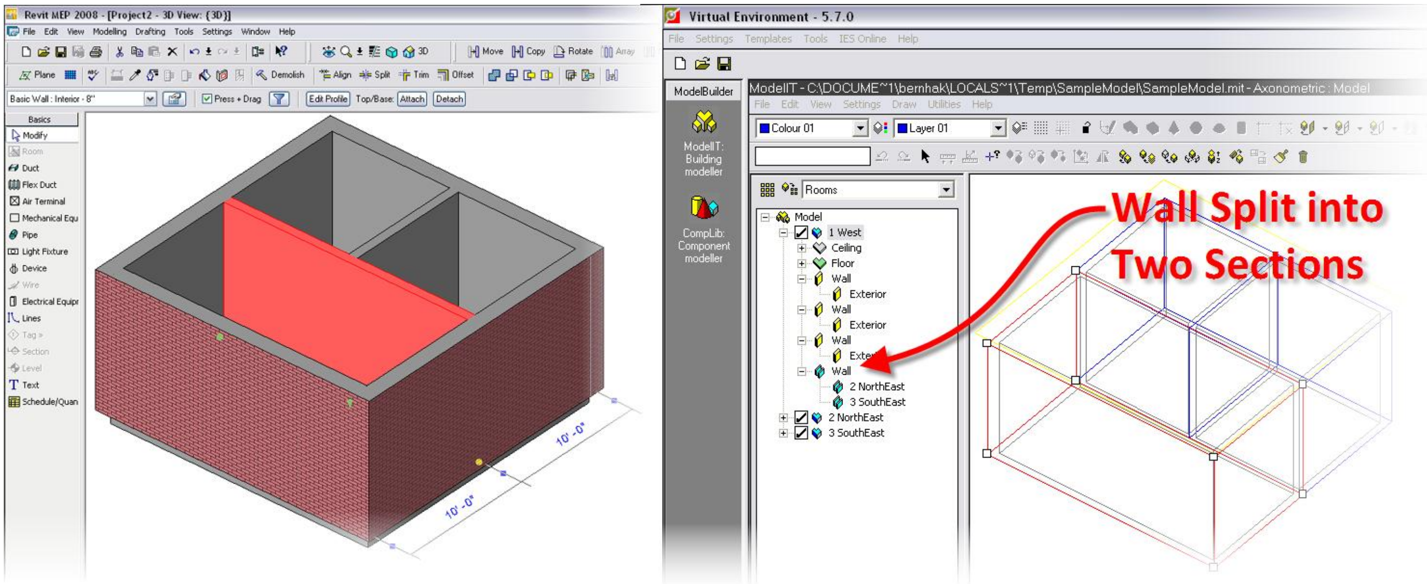


Figure 2 - Breaking a Wall into Two Surfaces in <VE> Analytical Model

Understanding the relationship between Bounding Elements and surfaces will help you interpret the Analytical Model that's produced from your Revit Physical Model.

1.3 Openings

The next element down in the Analytical Model hierarchy is the Opening. These are things like Windows, Doors, Openings and Skylights. These Elements are "children" of the surfaces generated from Bounding Elements, just like a Window is hosted in a Wall in the Revit Physical Model.

Like Surfaces, Openings are represented by 2D surfaces within the Analytical Model. An example of these can be seen in Figure 3 below, where there are windows, doors and a skylight all properly translated from the Revit Physical Model to the Analytical Model.

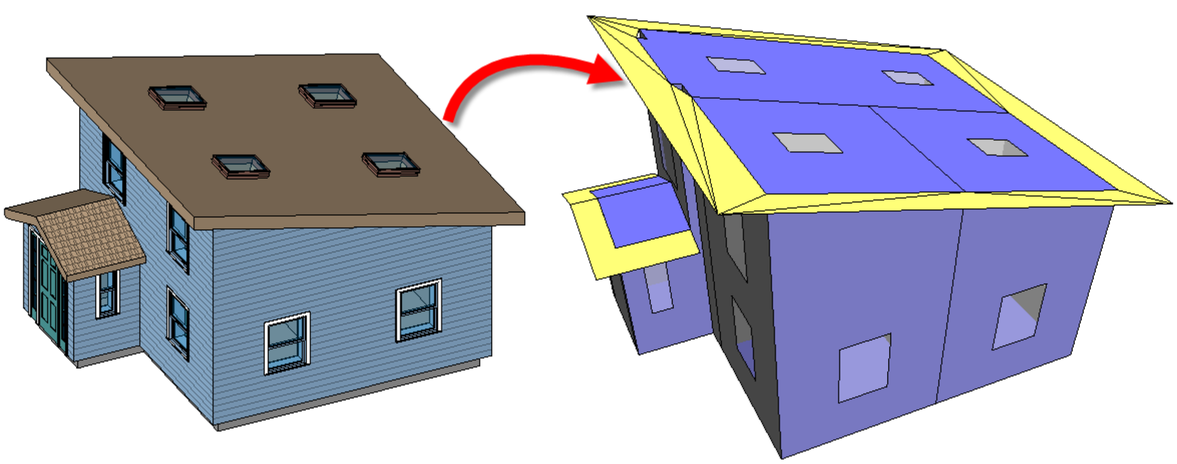


Figure 3 - Openings Transferred to the <VE> Analytical Model

Properly representing openings is critical to carrying out an accurate analysis, such as the <VE> daylighting analysis in Figure 4 below.

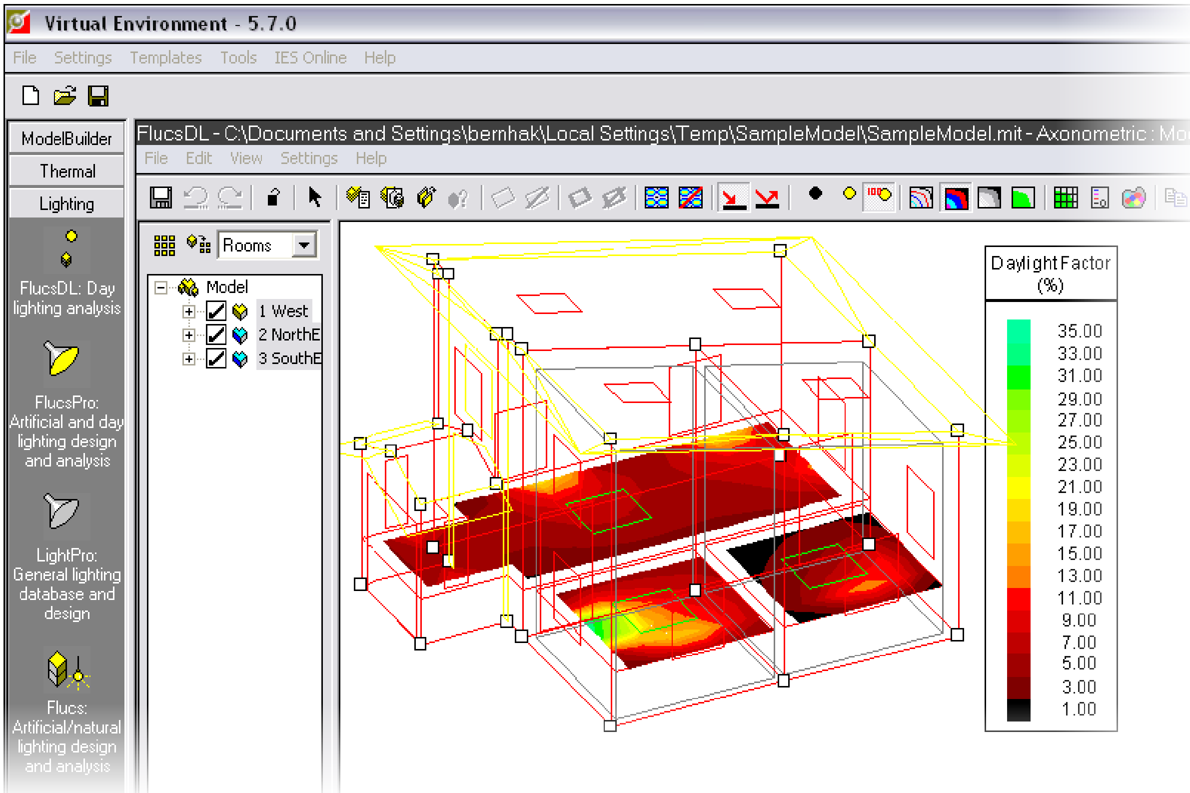


Figure 4 – Day Lighting Analysis in the <VE>

1.4 Shading Surfaces

The one instance of a surface that does not have a Room as a "parent" in the Analytical Model is a Shading Surface. These surfaces are necessary to properly analyze the impact of the sun in your BPA. These surfaces are generated when Bounding Elements in the Revit Physical Model do not actually bound any Rooms. An example of this can be seen in Figure 5 below, where the overhangs of the Roof and the Balcony are converted to Shading Surfaces.

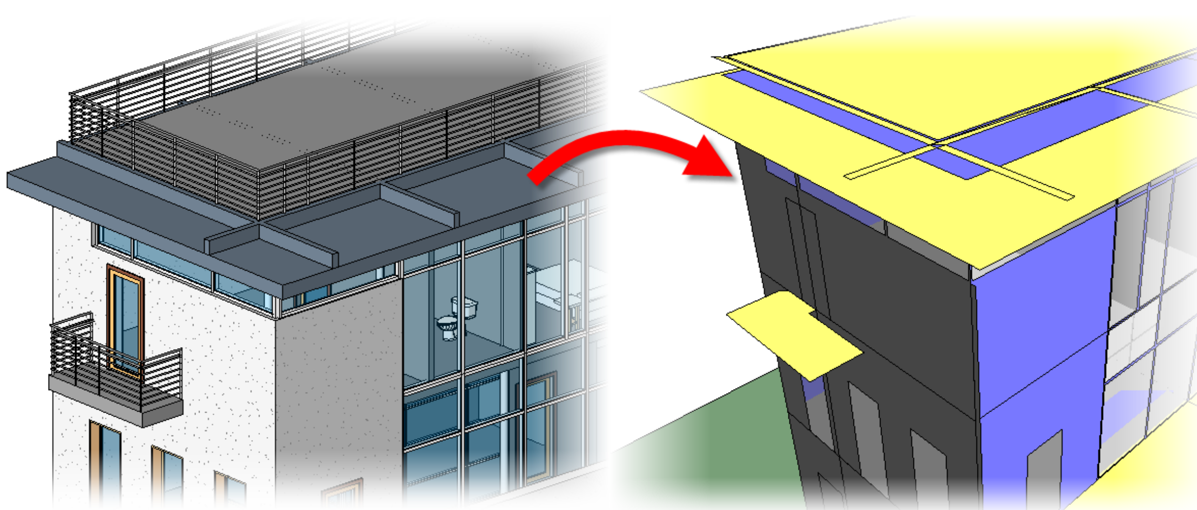


Figure 5 - Shading Surfaces in the <VE> Analytical Model

Understanding these surfaces will allow you to produce a more complete Analytical Model.

NOTE: Within the <VE> Shading Surfaces are known as Obstructions. For the purpose of clarity in this paper, these items are referred to as Shading Surfaces in all cases.

1.5 Hierarchy Overview

To summarize the hierarchy of the elements contained in the Analytical Model, let's look at Figure 6 below.

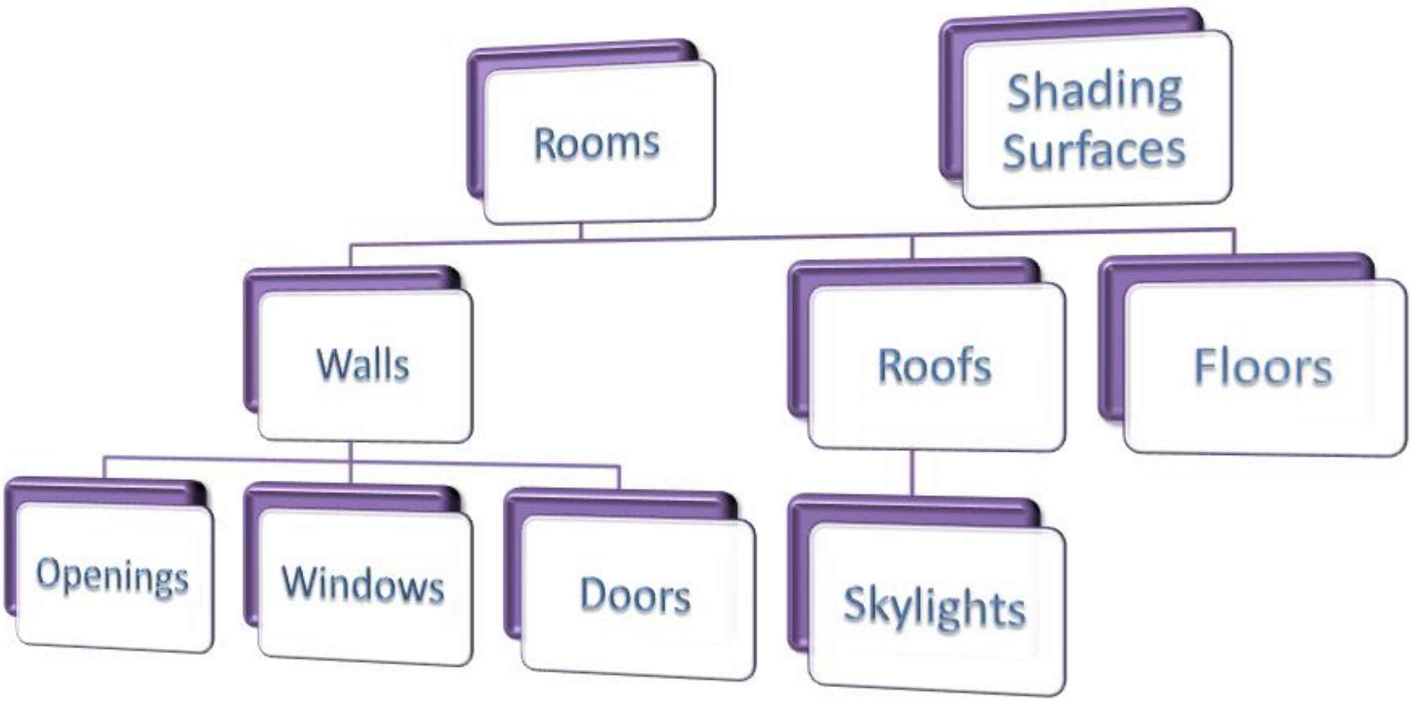


Figure 6 - Hierarchy of Elements in the Analytical Model

With the concepts of the main Elements in the Analytical Model and their relationship to the Revit Physical Model now covered, we can move on to other important concepts.

1.6 Adjacencies

In order for the Elements in the Analytical Model to assemble into a logical representation of your Revit Physical Model, they must be put into context of their location in the building. This means determining whether a surface, and its openings, is exterior or interior. This is done by determining the adjacencies of a surface within the Analytical Model. The surfaces here include not only walls, but all other Bounding Elements like roofs and floors.

If a surface has an adjacent Room on both sides of it, it is deemed Interior. If it has only one Room adjacent to it, then it is deemed Exterior. As previously mentioned, if a surface has no Rooms adjacent to it, then it is deemed a Shading Surface.

1.7 Different Volumes Produced in the Analytical Model

In order to allow for the accurate calculation of different analysis results, two different Room volumes, the Analytical and the Inner volumes, are computed in the energy analysis model. The true Inner volume is used for air computations and lighting calculations. The Analytical volume is used for thermal and energy calculations.

Analytical Room Volume

The Analytical Room Volume (see Figure 7 below) is bounded by the center plane of walls and the top plane of roofs and floors. This Room volume is what you see in the preview window in the Heating and Cooling Loads dialog and with blue lines in the <VE>.

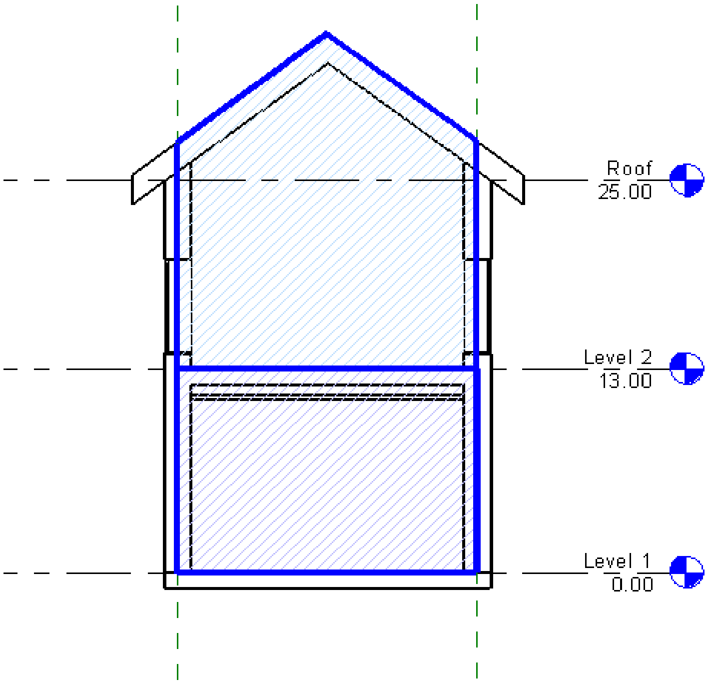


Figure 7 – Analytical Room Volume

Inner Room Volume

The Inner Room Volume is bounded by the interior surfaces (see Figure 8 below). This Room volume is shown with grey lines in IES <VE>. It is not shown in the Heating and Cooling Loads dialog. It is computed when you actually start the loads calculation.

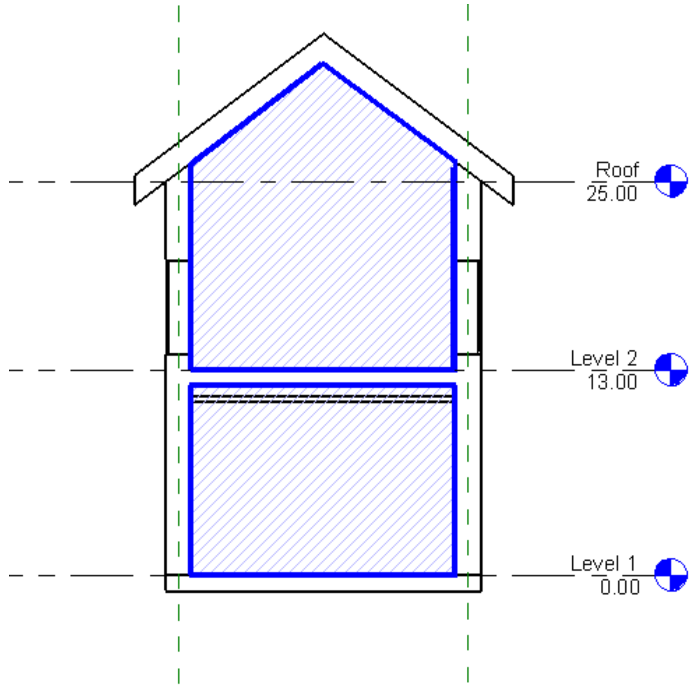


Figure 8 – Inner Room Volume

2 Preparing the Revit Physical Model for Conversion

We now have a firm grasp of the concepts involved with creating an Analytical Model from your Revit Physical Model. We can now address the specific processes and factors that apply to the Revit platform and the <VE>.

2.1 Room and Area Settings

There are many important settings that are contained in the *Room and Area Settings* dialog, found in the *Settings* dropdown menu.

2.1.1 Compute Room Volumes

One of the most critical, and easily missed, requirements for proper conversion of your Revit Physical Model to an Analytical Model is the *Compute Room Volumes* toggle. This toggle turns on the calculation to handle your Rooms as 3D elements within the model. Only with this box checked will the application properly calculate your Room as a 3D Object, detecting the Bounding Elements in all directions. Without it checked, the produced Analytical Model will most certainly be incorrect.

Having this setting turned ON does have a performance impact associated with it, so if the sole purpose is to produce an accurate Analytical Model, then toggle it ON before starting the conversion process. Once calculations are completed, toggle it back OFF.

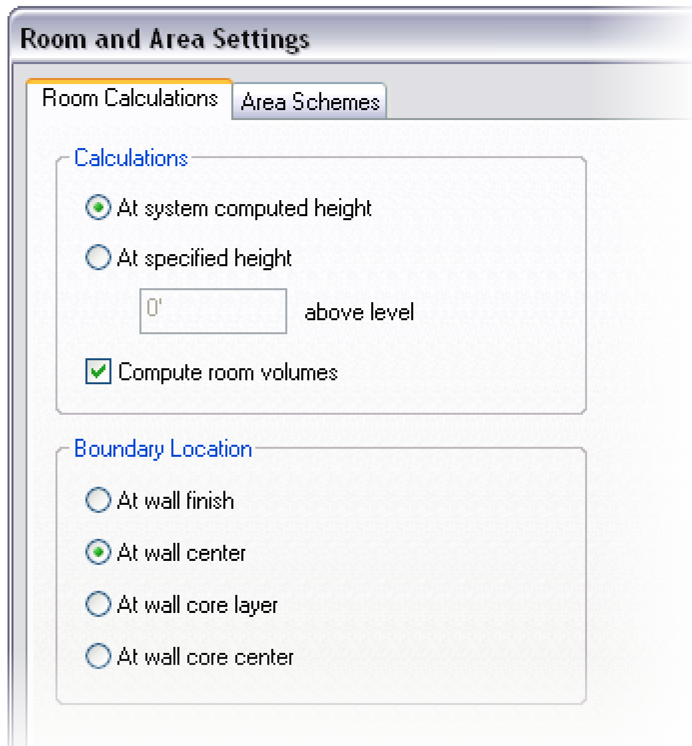


Figure 9 – Room and Area Settings

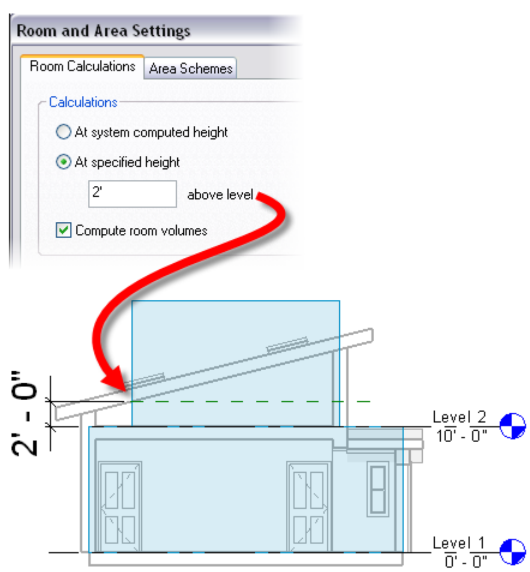
2.1.2 Boundary Location

This setting does not have an impact on the Rooms that are created in the Analytical Model. However, setting Boundary Location to *At Wall Center* will allow Analytical Room Volumes to be visualized in floor plans in Revit.

2.1.3 Calculations

In order to produce an accurate representation of a Room's space, it is a best practice to have the *At system computed height* radio button set. Problems can occur if the *At specified height* radio button is set.

This can be seen in the example to the right with an attic below a sloped roof. The *At specified height* radio button is set to 2' above level. This results in Revit determining the boundaries of the Room starting at 2' above the level. At 2' the sloped Roof is detected as a Bounding Element for the Room perimeter, and the Room geometry does not account for the entire attic space.



2.2 Rooms

Since Rooms are the "parent" of a great deal of the information held in your Analytical Model, there are very important considerations that must be understood if the produced Analytical Model is to be correct.

2.2.1 Upper Limit

As mentioned in the Adjacencies section earlier in this paper, all Bounding Elements are impacted by the adjacency rules in the creation of an Analytical Model. This means that the Upper Limit for your Rooms plays a large role in the accuracy and usefulness of your produced model.

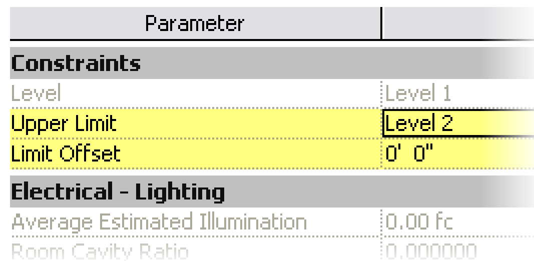


Figure 10 - Room Upper Limit Parameters

If the Upper Limit is set to be the ceiling of your given level, then there will be a void between that Room and the Rooms on the next level above, since the above Rooms begin at a zero offset. This void will result in not only the bottom Room having an unbounded top surface, but that surface and the bottom surface of the Room above will be recognized as External in the Analytical Model as seen below in Figure 11.

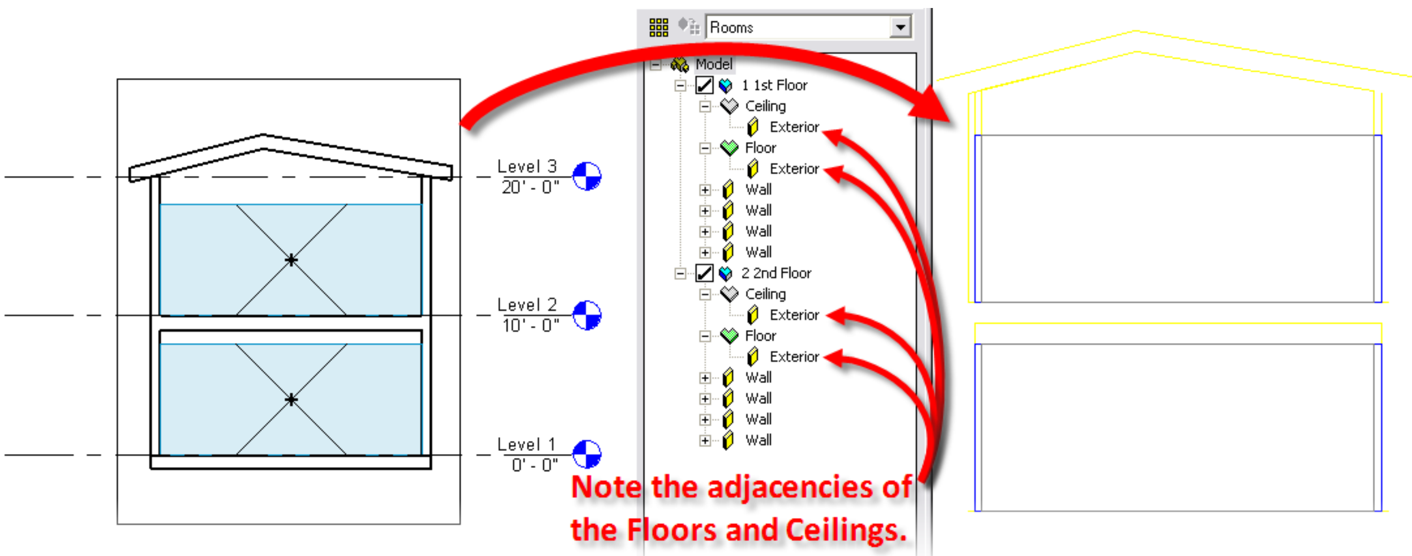


Figure 11 - Impact of Incorrect Room Upper Limit

Obviously this result is incorrect and will result in inaccurate energy analysis results. As a general rule, it is a good practice to set the Upper Limit for your Rooms to the next level, and set your Limit Offset to zero. In the case of Rooms below Roofs, ensure the upper limit of the Room is set higher than the top surface of the Roof, this is covered in greater detail in the Roofs section.

2.2.2 Room Separation Lines

Often, the design engineer will be required to calculate HVAC loads for a space within a defined Room. The Room Separation Line allows you to add and adjust Room boundary lines without adding Walls. Room Separation Lines are Room bounding. They are useful for designating one space within another space; such an example is defining the first 15' from the building outside wall as a perimeter space. This will define that space within the Room as a new Room to correctly determine that space HVAC load. Separation lines are visible in plan views, 3D views, and perspective views.

2.2.3 Building Voids

Most likely the Revit Physical Model will contain volumes that are not represented by a 3D Room. These can be spaces like a small closet or an elevator shaft. These "voids" will result in undefined volumes in the Analytical Model which cannot be properly analyzed, and the Bounding Elements adjacent to them will be recognized as Exterior in the model. This will produce incorrect analysis results.

In order to remedy this situation, Rooms must be created to fill these voids so that the Analytical Model properly accounts for all volumes in the building. For example, in the event that there is a plenum space that exists above a recessed ceiling, a Room needs to be created to account for that volume. Creating a Level at the Ceiling height will allow for these Rooms to be created. Once these Rooms have been created, the Analytical Model will contain all of the necessary volumes to establish proper adjacencies of surfaces and properly represent the Revit Physical Model geometry.

2.3 Bounding Elements

Except for Floors and Ceilings, you can control whether potential Bounding Elements are actually used as Bounding Elements when the Analytical Model is created by Revit. This is done by toggling the *Room Bounding* parameter that's available in the *Element Properties* dialog.

With this parameter unchecked, such an element will not be added to the Analytical Model. This can have a major impact on the accuracy of your model. If an Element is not to be included in the Analytical Model, simply uncheck the Room Bounding parameter for that Element.

There are some items to be aware of regarding certain types of Bounding Elements.

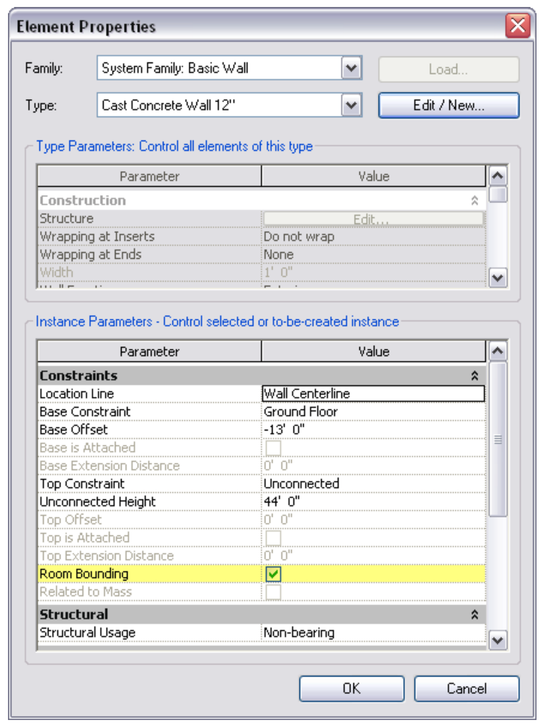


Figure 12 - Room Bounding Parameter

2.3.1 Shading Surfaces

Understanding how Shading Surfaces are created from section 1.4 and the impact of the *Room Bounding* parameter, it is important to understand that only elements that have the *Room Bounding* parameter checked (except Floors & Ceilings) and no adjacent Rooms will be converted into Shading Surfaces in the Analytical Model. This means that items like Railings will not be used as Shading Surfaces in the model.

2.3.2 Floor Slabs

The top surface of any Floor Slab will be seen as a Bounding Element for the Analytical Model. There is no setting to toggle this off. The location of the bottom surface of a Floor Slab relative to the Level it is hosted on determines how that Floor Slab bounds a Room. If the bottom of a Floor Slab is at the same elevation or lower than the level, then the top of that Floor Slab will represent the bottom surface of a Room defined on that level, see Figure 13 below on the left. If the bottom of a Floor Slab is at a higher elevation than the level, then the top of that slab will represent the top surface for a Room defined on that level; see the right side of Figure 13.

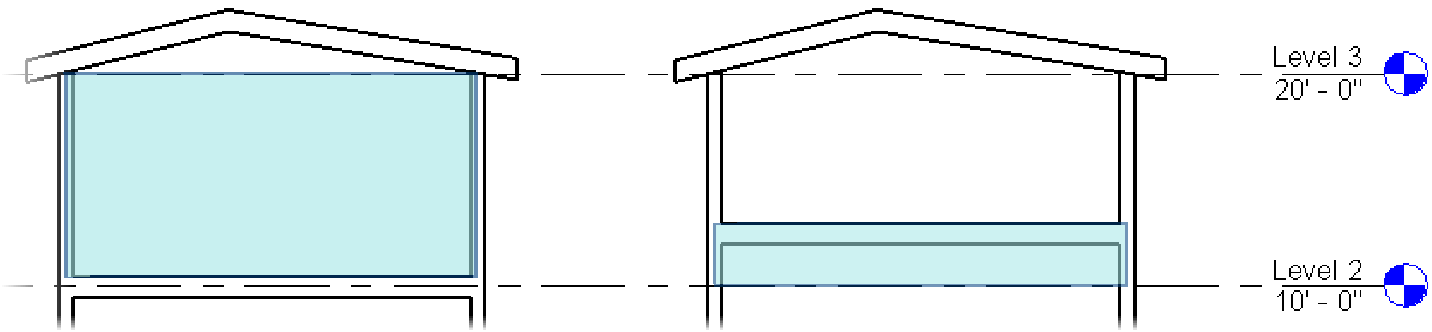


Figure 13 - Floor Slab Room Bounding Behavior

2.3.3 Ceilings

Although Ceilings impact the volume of a Room in the Revit Physical Model, they are not used as Bounding Elements in the Analytical Model. Because the Analytical Model needs to be a complete representation of the Revit Physical Model geometry without voids, as covered in sections 1.6 and 2.2.3, Ceilings are not transferred to the Analytical Model. Allowing Ceilings to be Room bounding would result in many voids between Ceilings and the Level above, impacting the accuracy of analysis results. The solution to this situation is covered in the Building Voids section.

2.3.4 Columns

In order for a column to be included in the Analytical Model, the *Room Bounding* parameter must be set. This will impact the volume of the Rooms created in the model.

Comparison of two similar Rooms shows the importance of this. In Figure 14 to the right, Room 1 has columns that are defined as Room Bounding, Room 2 does not.

This impact on the Room boundary carries over to the Analytical Model as a reduced volume for the Room, since the column volume is subtracted from the total Room volume.

Also note that columns do not have a center-line so the surface of the column inside the Room bounding Walls (effectively the inner surface) is used to calculate the Analytical Room Volume. This can be seen in the <VE> in Figure 15 below.

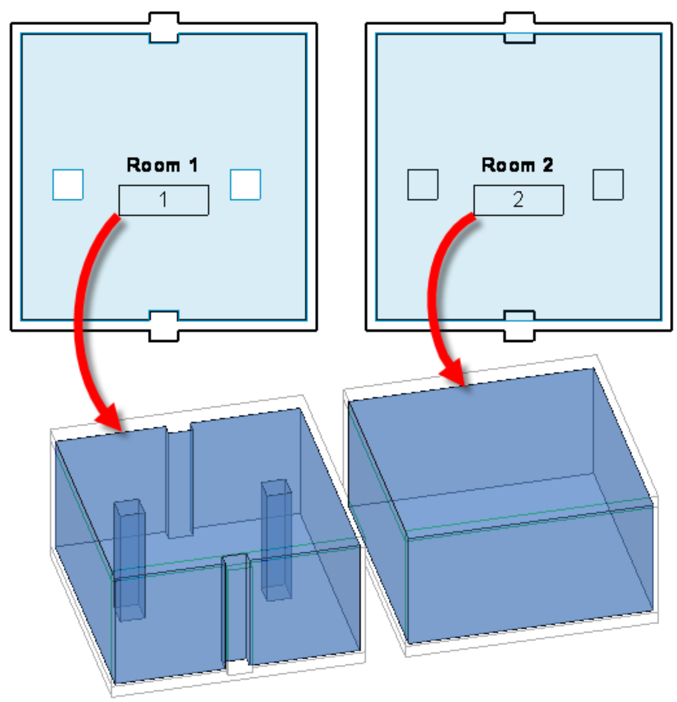


Figure 14 - Column Room Bounding Impact on Revit Room

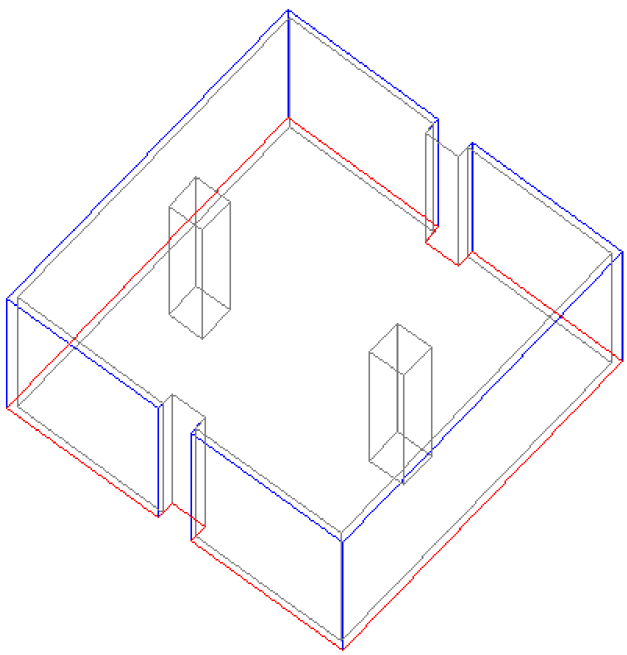


Figure 15 - Columns in the <VE>

You can see that the blue line indicating the Analytical Room volume does not pass through the middle of the Column. The full Column volume will be removed from the Analytical Room Volume in this case.

There are some limitations associated with the use of Columns in your Analytical Model, refer to section 2.6.4.

2.3.5 Roofs

When specifying the Upper Limit for a space beneath a Roof, specify the Upper Limit above the top of the Roof. The Roof is a Bounding Element and the volume for attic spaces is calculated based on the Room bounding components. This will also ensure that there are no unnecessary Shading Surfaces in the Analytical Model due to the Roof. Verify *Room Bounding* is checked in the Roof *Element Properties*.

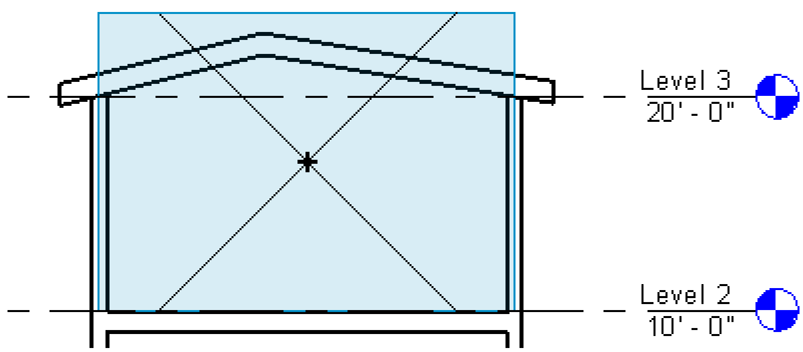


Figure 16 - Defining Room Upper Limit for Roofs

2.3.6 Curtain Walls

Curtain Walls are "converted" into Surfaces and Openings in the Analytical Model. A Curtain Wall will be represented in IES <VE> as a Wall Surface. For every Panel in the Curtain Wall there will be a Window Opening. If the Curtain Wall is arced or cylindrical, it will be faceted to several planar Wall Surfaces. The Window Openings will be projected onto the planar surfaces and clipped to the bounds of each surface.

A Curtain Panel in a Curtain Wall or a Curtain System will normally be converted to a Window Opening.

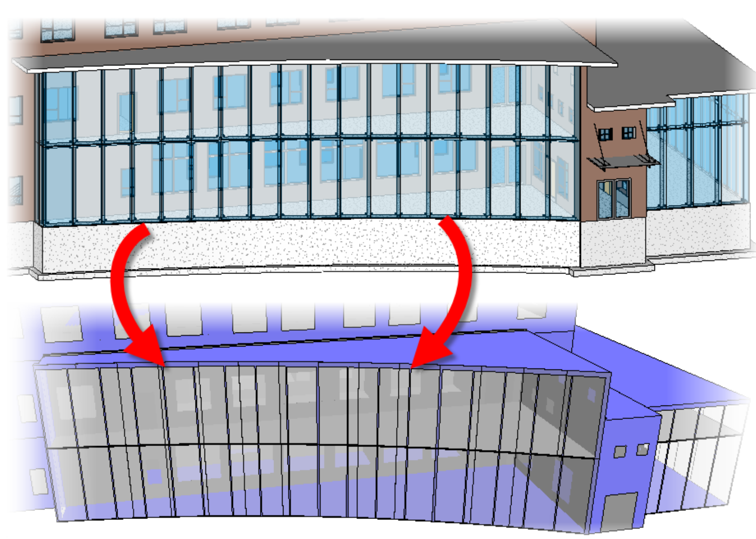


Figure 17 - Curtain Wall Conversion

There is one exception, if the assigned material (*Material* parameter) for the panel has less than 3% Transparency, it will be treated as a solid panel. In situations where a user creates a Curtain Wall type, Curtain Panels will have no Material defined by default. These Curtain Panels will be interpreted as Windows in the <VE>, but keep in mind the 3% transparency requirement when setting a Material for the Curtain Panels.

2.3.7 Upgraded Projects

In certain cases where the Revit Physical Model originates from an earlier version of Revit, to ensure existing 2D Room functionality, elements like Roofs will have their *Room Bounding* parameter unchecked. In these cases you need to select all Roofs and check the *Room Bounding* parameter.

2.4 Custom Families

It is important to use the appropriate templates for creating custom Families. Of major concern to BPA is the use of custom Doors and Windows. Custom Doors and Windows should be created based on the appropriate templates in order to bound Rooms as expected. Doors that "are not really doors" will cause the Room creation to extend beyond the area expected. Windows that "are not really windows" will affect the analysis calculations by allowing air flow where none is present.

2.5 Ground Level Setting

In the *Settings* dropdown menu, select *Project Information*, in the *Element Properties* dialog select Edit for the *Energy Data* parameter. Click the Value column for *Ground Plane*, and specify the level that will serve as the Ground Plane reference for the building.

Rooms below the elevation of this level are considered to be underground.

2.6 Limitations

There are certain situations where there are limitations in the conversion of a Revit Physical Model to an Analytical Model.

2.6.1 Room Enclosing a Room or Empty Space

Although it is possible in Revit to create a Room that completely encloses another Room or empty space, this will not be properly converted in the Analytical Model and the resulting load calculations will be incorrect. This situation can be avoided by adding Room Separators (or Walls) in such a way to prevent any Room from completely enclosing a separate Room or void space.

One way to detect this problem is to compare the Room area that is reported in the Loads Summary Report to the Room area that is listed in the Room *Element Properties* within Revit. If a Room is enclosing another Room or a void space, then the area that is displayed in the Loads Summary Report will be greater than the actual Room area, as displayed in the Room *Element Properties*. The primary limitation here is that the methods for creating an Analytical Model do not detect inner void areas within a Room.

An example of this is shown in Figure 18, where the two Room Separation Lines are placed to remedy the situation. Although breaking the outer Room into two separate Rooms may not be ideal, this is the best way to produce accurate analysis results.

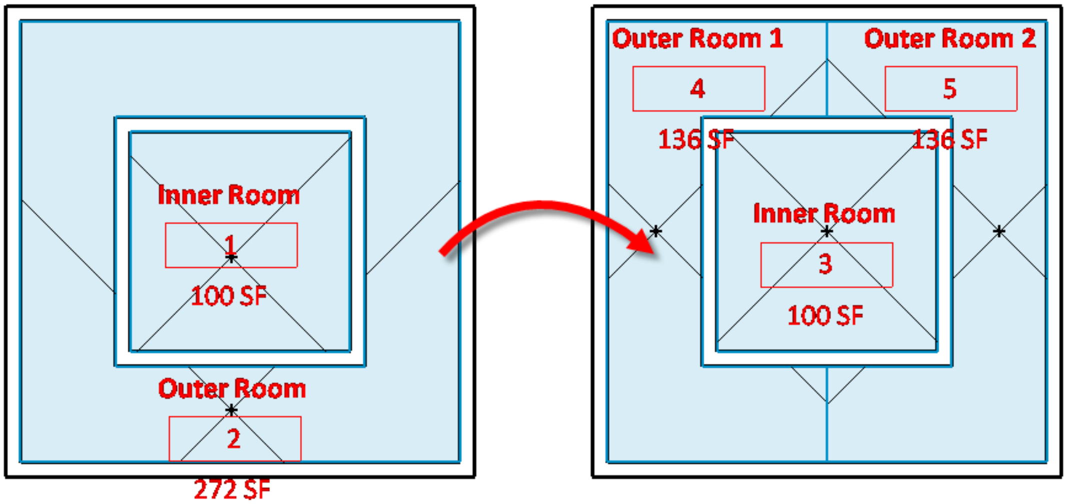


Figure 18 - Room in Room Solution

2.6.2 No Lower Offset

There is currently no setting for *Lower Offset* on a Room. This means that the lower extent of a Room needs to be a level within the Project, and cannot be an offset relative to another Level. This may require creating additional Levels to create Rooms representing items like Plenums.

2.6.3 Elevator Doors

The recommended method of modeling Elevators is to create an elevator door Family. If an Elevator is required, then another Family should be created. The elevator door Family should be based on the Door template.

Attempts to model an elevator as a box with a door will not work because the elevator's door is not a Room Bounding Door Element. An Elevator Door should be placed at each level the elevator crosses.

2.6.4 Columns in Analytical Models

With a Column set as Room Bounding, the result in the Analytical Model is a set of Walls that represent the geometry of the Columns. Since there is no Room defined inside of the Column, the result when the model is imported into the <VE> is that the Walls are deemed Exterior. This may have a significant impact on the results of Energy Analyses. If this issue is to be avoided, Columns will need to be non-Room Bounding, and re-created in the <VE>, if they are to be included for Building Performance Analyses.

3 Things to Know in the <VE>

When the Revit Physical Model is converted to an Analytical Model and used in the <VE> there are a few things to keep in mind to help ensure success.

3.1 One-to-One Mapping Requirement

When a Revit Physical Model is converted to an Analytical Model for use in the <VE>, the Analytical Room Volume and Inner Room Volume are calculated as covered in section 1.7. In the <VE> workspace the Analytical Room Volume model is displayed by blue lines and the inner volume model by the grey lines within.

When the <VE> imports the Analytical Model it seeks a one-to-one mapping between every inner surface and a corresponding outer surface in the Analytical Model. This technique is used to accurately simulate thermal transfers across Room adjacencies.

It is possible to create elements in Revit that do not have a corresponding outer surface (on the wall center-line) for each inner surface. When this occurs for a Room, the Inner Room Volume is dropped and all calculations are performed on the Analytical Room Volume. This is shown in the <VE> by a Room with no Inner Room Volume visible. Such Rooms have a yellow symbol in the Room Browser,  , and Rooms passed with an inner volume are shown blue,  .

We can see this in Figure 19, where on the left the Room configuration results in no Inner Room Volume being created in the <VE>. By reconfiguring the Rooms a bit, as shown on the right, an Inner Room Volume can be effectively created.

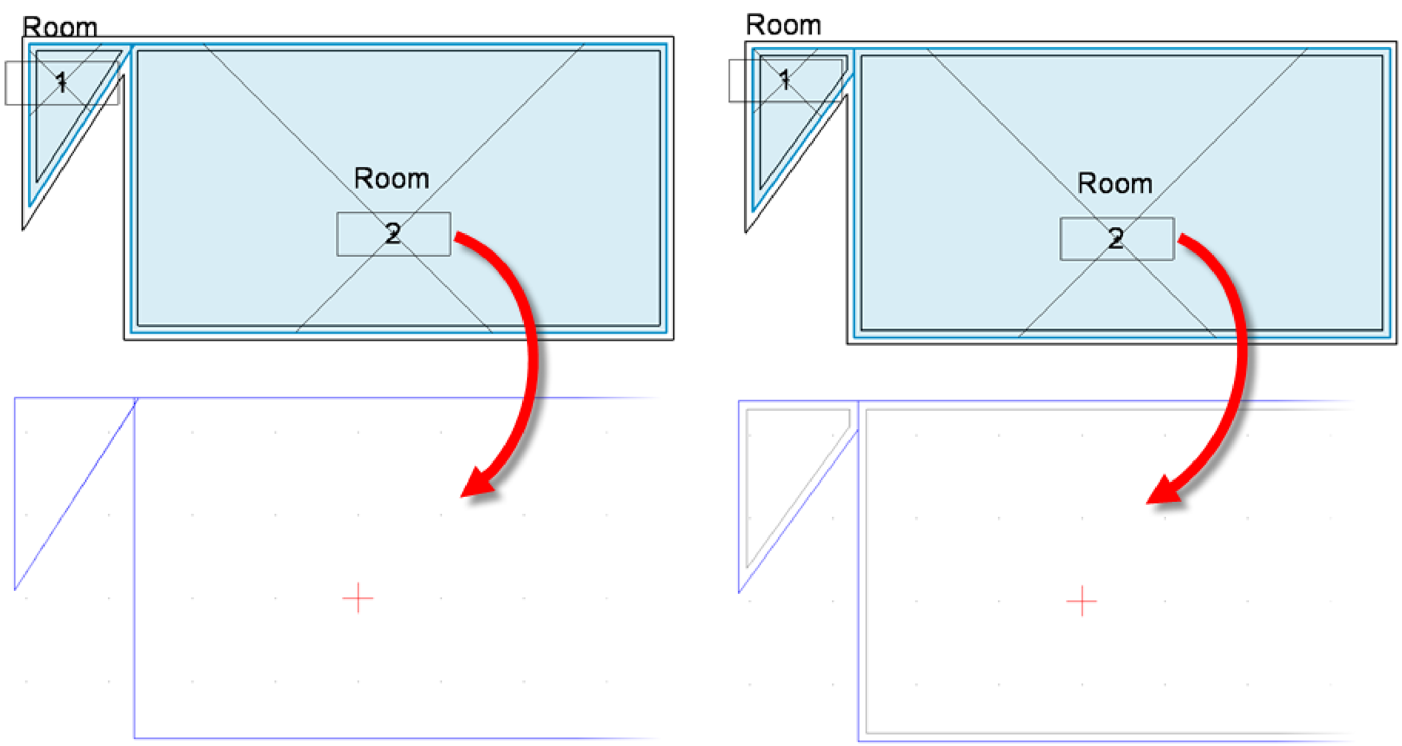


Figure 19 – One-to-One Mapping of Surfaces in the <VE>

If the design intent is to have the Room configuration that results in no Inner Room Volume, then the analysis results may be impacted.

3.2 Licensing Not Required to Inspect Models

Even without a license the <Virtual Environment> can be a very useful tool when analyzing the Analytical Model. You can look at the model as a whole or Rooms individually to ensure they were exported properly from Revit. You should spend time confirming that all Surfaces (both internal and external) are properly defined and that Openings have the correct properties. Ultimately this will ensure that any BPA performed on your Analytical Model give accurate results.

To use the <VE> it must first be installed. To do this click the <Virtual Environment> button on the Heating and Cooling Loads Dialog and follow the instructions on-screen.

If a license for <VE> has not been requested, when the <VE> is launched a dialog will appear that informs the user that there is not an active license. If the OK button is pressed, the <VE> will launch. As no license is held for the Sustainability Toolkit, these buttons will be unavailable so close this dialog. This will leave the model displayed in the basic <VE>.

3.2.1.1 Workspace

A wireframe view of the Analytical Model is displayed in the workspace. This can be viewed using the tools on the View Toolbar at the bottom of the screen.

Rooms can be highlighted by selecting them in the Model Browser.

They can be subsequently viewed without the rest of the model by selecting different levels of decomposition . This allows you to ensure details of the Analytical Model have converted as desired.

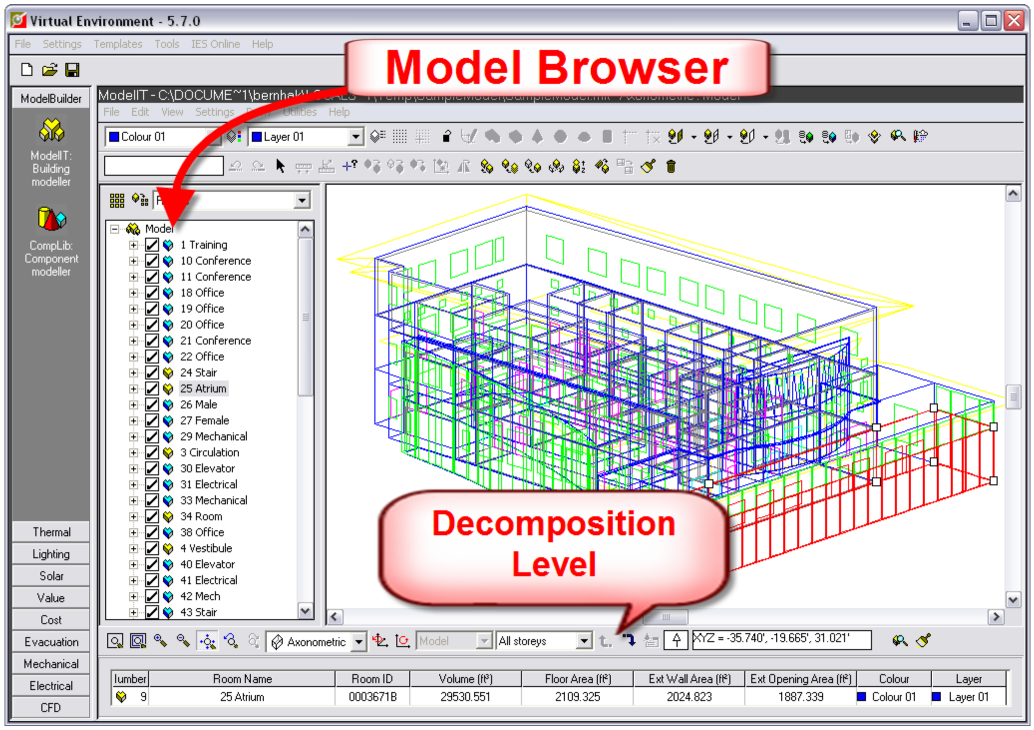


Figure 20 - Basic <Virtual Environment> Wireframe View

3.2.1.2 Model Viewer

The Model Viewer allows you to view models in more detail from any desired angle.

The Model Viewer can be used at any level of decomposition allowing the user to view individual Rooms to ensure they are properly bounded.

For further information see the IES ModelIT User Guide. This describes the tools available on the View Toolbar and in the Model Viewer.

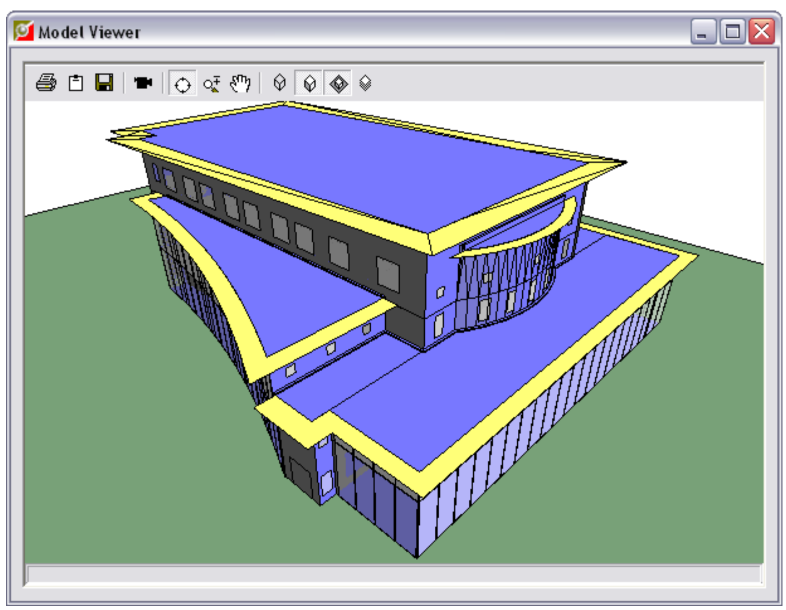


Figure 21 - <VE> Model Viewer

4 Things to Keep in Mind

There are obviously a number of items to be aware of when preparing a Revit Physical Model for conversion to an Analytical Model. The most commonly found issues are related to the following items:

- **Compute Room Volumes** - This parameter must be active in order for the resulting Analytical Model to be correct.
- **Room Top Offset** – By default, Rooms will be created with an 8' 0" Limit Offset with the Upper Limit set to the current Level. It is a good practice to have the Upper Limit set to the next floor and the Limit Offset at 0'0".
- **Bounding Element Status** – If an undesired element appears in the Analytical Model or if a desired element does not appear in the model, check the Room Bounding setting on that Element's Properties.
- **Adjacency** – The interior/exterior status of a Bounding Element depends on the adjacency of Rooms on either side of the Bounding Element.

About Revit

The Revit platform is Autodesk's purpose-built solution for building information modeling. Applications such as Revit Architecture, Revit Structure, and Revit MEP built on the Revit platform are complete, discipline-specific building design and documentation systems supporting all phases of design and construction documentation. From conceptual studies through the most detailed construction drawings and schedules, applications built on Revit help provide immediate competitive advantage, better coordination and quality, and can contribute to higher profitability for architects and the rest of the building team.

At the heart of the Revit platform is the Revit parametric change engine, which automatically coordinates changes made — in model views or drawing sheets, schedules, sections, plans. For more information about building information modeling, please visit us at http://www.autodesk.com/bim. For more information about Revit and the discipline-specific applications built on Revit please visit us at http://www.autodesk.com/revit.

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