# SUSTANABLE DESIGN THROUGH INTEROPERABILITY: BUILDING INFORMATION MODELS (BIM) AND ENERGY ANALYSIS PROGRAMS, A CASE STUDY

KENSEK, Karen Marie, Associate Professor, University of South California, USA
kensek@usc.edu

KUMAR, Sumedha, Master of Building Sciences Student, University of South California, USA, sumedhal@usc.edu

## 1 ABSTRACT

Building information modeling (BIM) is being marketed as one possible solution in providing architects a tool to help with sustainable design, a descriptive building component tool that would provide the missing link between CAD programs and performative energy analysis programs. The intent of this study was to assess whether BIM software was robust enough to allow seamless interoperability of its building model with the analytical model. The BIM software used for the study was Autodesk Revit MEP [AUTODESK] and for energy analysis IES <VE> [IES] was chosen because of its integration with Revit MEP. The other part of the study improved upon the MEP-IES interface by building a Revit template file, designed as a "patch" to address the gap between these programs. This template file defined a set of Revit MEP families that derived their values from the IES Apache construction database. This template file could be imported into a Revit project, making the BIM model more accurate and informative, when used in conjunction with IES <VE>.

## 2 INTRODUCTION

Building information modeling (BIM) technology has an increasingly significant role to play in the architecture, engineering, and construction (AEC) industry today. Its strength lies in being a multifaceted, data rich model that provides the user with a database of building information including items like wall, window, floor, and roof types. One intent of having this wealth of data about the building is to allow the architect the ability to share these characteristics with other features of the program such as preliminary cost analysis, take-offs of sustainable materials, and scheduling. It also allows the possibility of linking to other software programs.

Software interoperability is the ability of two or more systems or elements to exchange information. Interoperability should ideally be a seamless exchange of data among software tools, eliminate the need for duplicate data generation, and allow for data to have bidirectional updates such that the changes in one program should be able to flow between the programs. At present, almost 3% of the projects costs are related to the lack of software interoperability. Software incompatibility often leads to redundant work and a need to spend more time and money in non-standard solutions that drive the project costs up. [DCI] Using a building information model results in early decision making that often helps control costs. Interoperability of building information models (BIM) with energy analysis programs is an emerging area and is gaining increasing attention in the building industry. In order that BIM programs be robust and truly informative, their interoperability with energy modeling programs and/or techniques needs to be established.

Interoperability between BIM and energy analysis can be done at two levels: 1) data transfer from BIM to energy models and vice versa via interoperable files and 2) incorporation and integration of energy analysis functions within BIM software. At present, interoperable file formats are being developed. Industry groups and technology providers are experimenting with open standards in order to establish universally accepted ways of transferring data across different software packages and seamlessly exchange information. Efforts such as the Industry foundation classes (IFC) and extensible markup language (XML) are a step in this direction. Although these formats were also explored, that topic is beyond the scope of this paper.

The incorporation of energy analysis functions into BIM programs eliminates the need to import and export information through interchangeable file formats, but limits the choices of the software used to those predetermined by the software manufacturer. One example of this has been the Revit MEP-IES<VE> connection that was launched in February 2007. A subset of an energy analysis program was incorporated *within* the BIM engine, so that simple energy calculations can be performed. This study looks at the MEP-IES<VE> interface and how it can be improved.

## 3 The MEP-IES<VE> Interface

The IES interface in MEP allows the user to select and define values for building type, building services, building construction assignments, place, and location. These values exist as a drop down menu in the interface and are independent of the options available to the user in the modeling screen.

### 3.1 Building performance analysis in Revit MEP

There are two types of building performance analysis through Revit. One is done within the Revit program and gives heating/cooling loads. The second method converts the Revit model to an IES format, opens IES, runs the simulation, and is able to give a more comprehensive analysis.

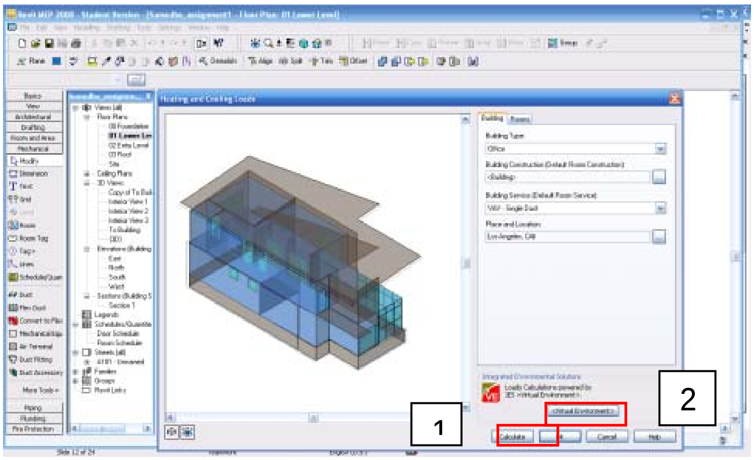



**Figure 1: Two types of analysis possible in this interface**

1) For the energy analysis within the Revit engine, the calculations are done by the IES component that is installed within Revit MEP. On using the "Calculate" button, the engine computes the heating and cooling load, and gives additional information about the sensible and latent loads, analytical areas and volumes.

2) For a more comprehensive analysis, the user can click the "Virtual Environment" button, in which case, the model gets exported to the IES <VE> and opens it there. The Apache simulator in IES provides two sets of calculations for energy analysis: the Apache Sim calculations and the ASHRAE Loads method. Apache Sim runs the simulation for the entire year and calculates the annual total energy consumption in MMBtu and breaks up into heating, cooling, fans, pumps and controls, lights, and equipment for each month. The ASHRAE loads method runs for a period of May to September in a specific location for its cooling load calculations. It calculates the system heating and cooling loads as well as the room heating and cooling plant loads.

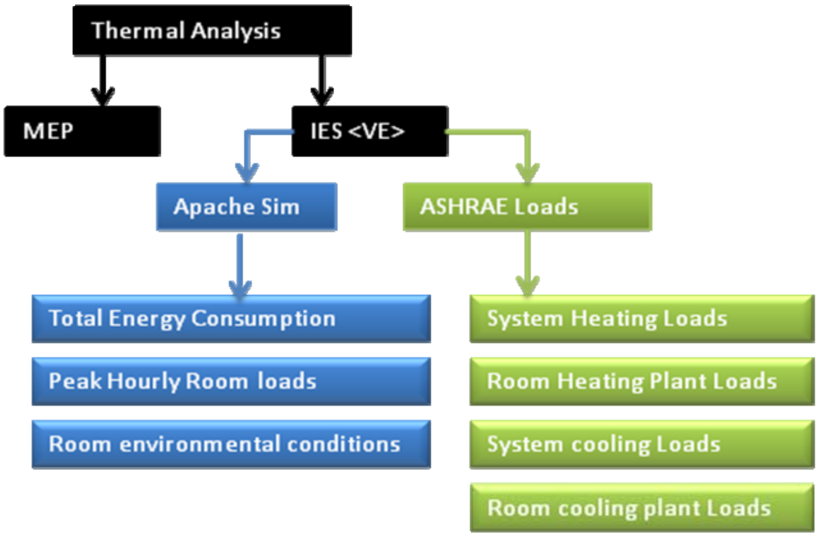
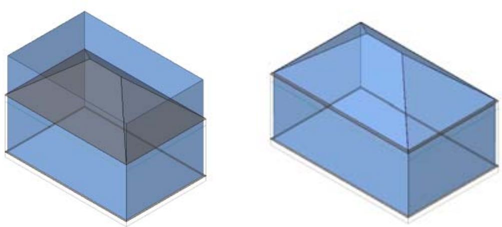
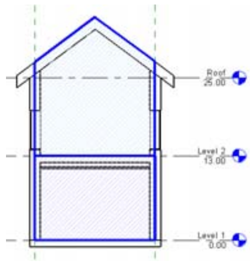



**Figure 2: Thermal loads calculations in IES<VE>**

### 3.2 CONVERSION OF A REVIT MODEL INTO AN ANALYTICAL MODEL

For an efficient workflow between the two platforms, the Revit building model is first converted into an analytical model. In Revit, a room has to be a completely enclosed space, bound by its floors, walls, and ceiling/roof and is the basic unit for which heat loads are calculated. Once defined, the bounding elements are converted to 2 D surfaces that represent their geometry. Openings such as windows, doors, openings and skylights act as children elements. For a more accurate analysis, the "Compute Room Volume" toggle, found in the "Room and Area Settings" dialogue, is turned on. This is able to detect the bounding elements in all directions and turns on the calculation to handle rooms as 3 D elements.





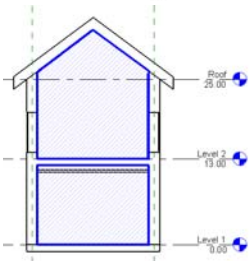


**Figure 3: A model showing analytical volumes with the "Compute Room Volume" toggle off and on**

**Figure 4: Analytical volume and inner volume calculated by MEP. Source: http://images.autodesk.com/adsk/files/building_performance_analysis_using_revit.pdf**

Revit MEP calculates two volumes for computations: analytical and inner room volume. The analytical room volume is used for thermal and energy calculations and is bounded by the center plane of walls and top plane of roofs and floors. The inner room volume, is bounded by interior volumes, and is used for air computations and lighting calculations. [ABS]

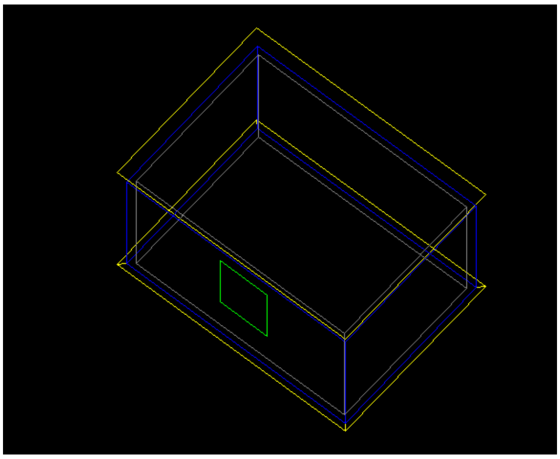


**Figure 5: The blue line in IES shows analytical volume and grey shows inner volume**

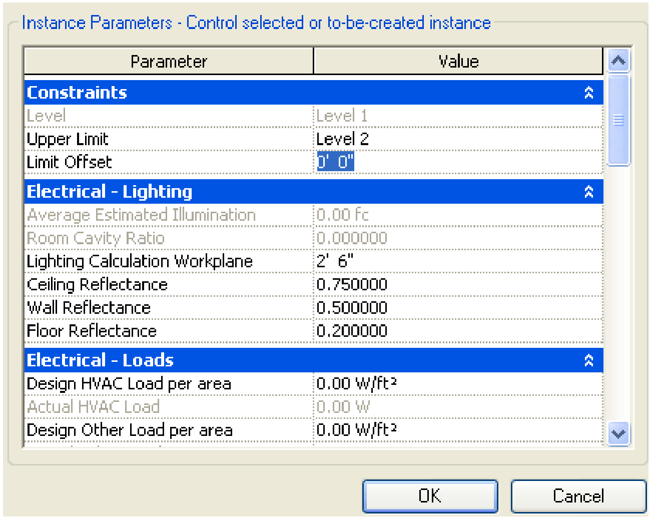



**Figure 6: Settling the "Upper Limits" in a Revit model**

The "upper limit" of the model is set to the next level in Revit, and the "limit offset" is set to zero. By default, the rooms are created with an 8' limit offset with the upper limit set to current level in MEP. To ensure that bounding elements are used as such, the user can do so by toggling the "Room Bounding" parameter that is available in the "Element Properties" dialog.

## 4 Input Values

The Revit MEP Interface has four sets of input values required from the user: building type, building construction (default room construction), building services, and place and location.

### 4.1 Building Type

The options for building type are available in the form of a drop down menu and contain some 32 choices including office, hospital, multifamily etc. Predefined parameters that define each building type already exist in MEP.

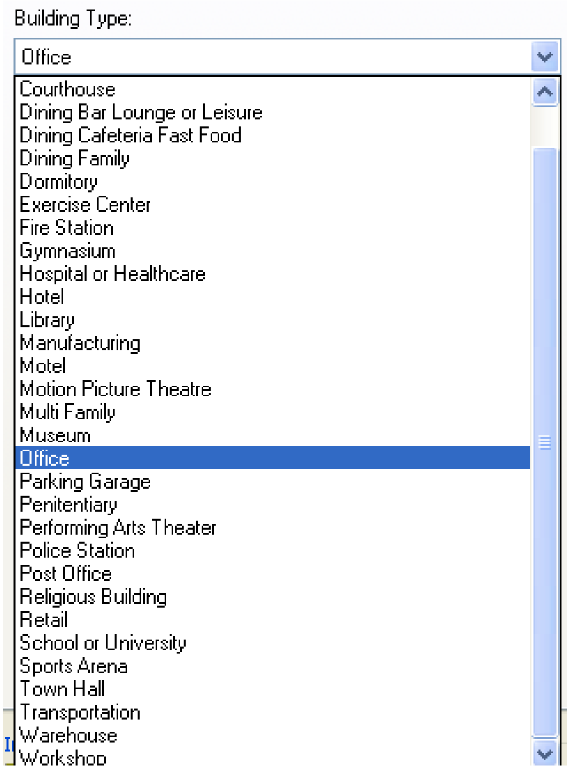



**Figure 7: Options for building type**

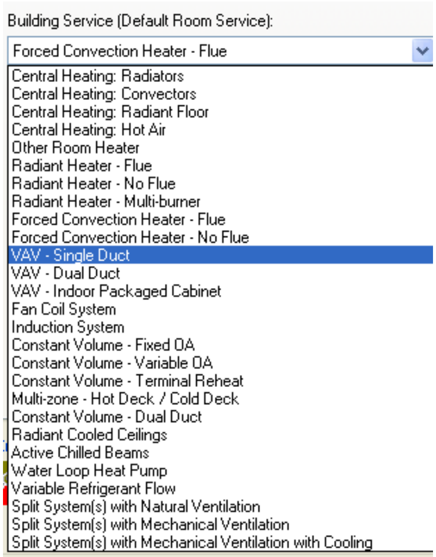



**Figure 8: Options for building services**

## 4.2 Building Services

The options for building services are available in the form of a drop down menu and contain some 27 choices such as VAV single duct, split systems with natural ventilation, radiant heating, and others.

## 4.3 Place and Location

This option consists of a drop down menu containing a list of cities around the world, along with their latitudes and longitudes. The location option is used for orientation and position of the project on the site and in relation to other buildings. There may be many shared locations defined in one project. The user can also define the angle from project north to true north.

## 4.4 Building Construction (Default Room Construction)

The following options are available to the user for construction assignments: exterior walls, interior walls, slabs, roofs, floors, doors, exterior windows, interior windows and skylights. The values for the construction assignments are derived from the construction database in IES<VE>, called the Apache construction database. This list became **crucially important** during this study.

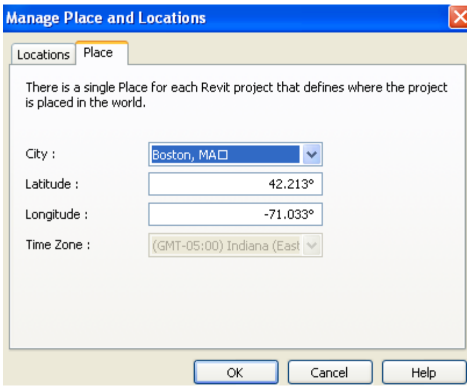



**Figure 9: Options for place and locations.**

| Construction type | Construction Assignment |
|---|---|
| **Exterior Walls** | 8 in Light Weight Concrete Block (U=0.1428) |
| **Interior Walls** | Frame Partition with 0.75 in Gypsum Board(U=0.2595) |
| **Slabs** | Un-Insulated Solid-Ground Floor (U=0.1243) |
| **Roofs** | 4 In Light Weight Concrete(U=0.2245) |
| **Floors** | 8 In Light Weight Concrete Floor Deck (U=0.2397) |
| **Doors** | Metal Door(U=0.652) |
| **Exterior Windows** | Large Double-Glazed Windows(Reflective Coating)-Industry (U=0.5141) |
| **Interior Windows** | Large Single-Glazed (U=0.6498) |
| **Skylights** | Large Double Glazed Windows(Reflective Coating)-Industry(U=0.5628) |

Figure 10: Default construction assignments for the construction types.

## 5 TESTING INTEROPERABILITY

In order to test interoperability between building model and the analytical model, the model was tested for building material and thickness. Input variables were kept constant in the base case, and testing was done with one alteration at a time.

### 5.1 BUILDING MATERIAL

A base case room, 12’x8’, located in Los Angeles, with a south facing window 6’x4’, was modeled in Revit MEP, using the wall default material assignment, 8” generic wall. The wall material was changed to 8” heavy weight concrete block using the construction assignments defined in IES for this material. The same option was selected in the MEP-IES interface for building construction assignments (exterior wall). Heating and cooling loads runs were done in MEP and IES.

| Modeling | MEP Selection | MEP Loads | IES Loads |
|---|---|---|---|
| 8" Heavy weight Concrete Block | 8" Heavy weight Concrete Block(U=0.3671) | 7082.0 Btu/h 5757.7 Btu/h | 17.311 MMBtu |
| Timber Frame Wall | 8" Heavy weight Concrete Block(U=0.3671) | 7082.0 Btu/h 5757.7 Btu/h | 17.311 MMBtu |
| Timber Frame Wall | Timber Frame Wall (U=0.1018) | 5579.8 Btu/h 2491.7 Btu/h | 15.148 MMBtu |
| | | | |

**Figure 11: Comparison of loads with different material selections**

| Modeling menu | MEP Selection | MEP Loads | IES Loads |
|---|---|---|---|
| 8" Heavy weight Concrete Block | 8" Heavy weight Concrete Block (U=0.3671) | 7082.0 Btu/h (CL) 5757.7 Btu/h (HL) | 17.311 MMBtu |
| 16" Heavy weight Concrete Block | 8" Heavy weight Concrete Block (U=0.3671 | 7179.1 Btu/h (CL) 5907.5 Btu/h (HL) | 17.534MMBtu |

Figure 12: Comparison of loads with different material thicknesses

In order to test whether material choice in the model was carried over for analysis, a new material was assigned to the model. The wall material was changed to timber frame wall. The option selected in the MEP IES interface for the construction assignments (exterior wall) was kept as the original. A quick run in the MEP and IES results show that the result is exactly the same. This seems to indicate that the assigned material in the Revit model does **not** have a bearing on the results.

In the third case, the timber frame wall was modeled as the wall material, and the same option was selected in the MEP IES interface. The difference in the results indicates that the selection in the MEP-IES interface overrides any selection made during modeling of the building. This indicates a **gap/problem** in the information transfer in the building model and analytical model.

## 5.2 MATERIAL THICKNESS

The base case was modeled in Revit MEP, with the wall type as selected in the previous example, 8" heavy weight concrete block. In order to test whether the program was carrying the thickness of materials to the model, the wall thickness was changed from 8" to 16". This was done such that internal volume of the space remained the same. A quick run in MEP and IES showed that the result differs slightly from the original case. This seemed to indicate that the wall thickness modeled in the program, **was** being carried over for the analysis, but could not be proved so conclusively. The IES Technical Support confirmed that the building model is able to transfer only geometry to the analysis interface. The discrepancy in the results arises due to an increased external surface area and therefore an increased heat transfer.

### 5.3 SUMMARY

The building wall construction family in Revit MEP was **not** transferred to IES automatically. It had to be chosen again from a limited list, the Apache construction database. The surface area of the model (with the increased thickness of the walls taken into account) was being carried over.

## 6 IMPROVING THE MEP-IES<VE> INTERFACE

In order to improve the interface between Revit MEP and IES, a Revit template file was developed, and eventually, the information associated with this file could be imported into the user's Revit project. In a typical Revit model, at the modeling stage, the user has the option of selecting certain wall types that exist as default values, for instance 6", 8" or 12" generic walls. However, when running a thermal analysis the user may opt for a completely different wall selection according to the choices existing in the interface.

This case study developed a template file that contained this information about building components that is, walls, roofs, floors, slabs, doors and windows. Values for parameters associated with these components were derived from their counterparts in IES<VE>.The user, then, could import this file into the Revit project, and model the exact material that one was doing an analysis for. The intent was to provide the user with a pre-defined list of families that exactly matched those available in the Apache construction database.

Two templates were created. Walls, floors and roofs belong to the system family type and were made into a system family template. Windows, roof lights, and doors are types of standard component families and were defined as that.

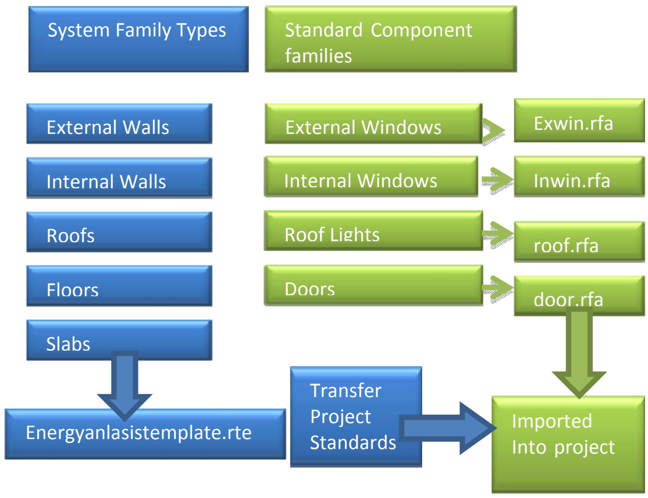



**Figure 13: Development of the system family types and standard component families**

## 6.1 THE SYSTEM FAMILY TEMPLATE

System families are predefined within Revit and consist of primary building components of a building such as walls, roofs, and floors. These can be duplicated or modified in a project but cannot be created in a project. Therefore, all these categories were created as ***types*** and stored as a Revit template file, with the extension rte.

The system families for the project include external walls, internal walls, roofs, slabs and floors. The parameters defined for the family template are the following: construction material (layers and their respective thicknesses, conductivity, density and specific heat capacity); U-value; thermal bridging coefficient; emissivity (outside and inside surface); resistance (outside and inside surface); and absorbtance(outside and inside surface). The following is an example of the creation of a specific new wall type and includes the steps taken to insert it into the template file.

Step 1: Deriving values for parameters in the database

The project constructions for a 4" face brick (ID ASHWL-59) are defined in the Apache construction database in IES<VE>. It has the following values associated with it.

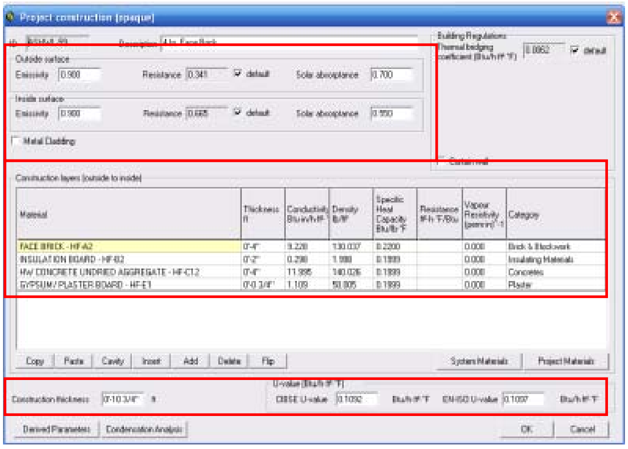


**Figure 14: Project constructions for a 4 inch face brick wall type**

| Description | 4” Brick face | | | |
|---|---|---|---|---|
| | Outside surface | | Inside surface | |
| Emissivity | 0.900 | | 0.900 | |
| Resistance | 0.341 | | 0.665 | |
| Solar Absorbtance | 0.700 | | 0.550 | |
| Thermal bridging coefficient | 0.0062 Btu/h ft$^2$ deg F | | | |
| Construction thickness | 10 ¾” | | | |
| EN ISO U Value | 0.1097 | | | |
| **Material** | **Thickness** | **Conductivity Btu in/h ft$^2$** | **Density Lb/ft $^3$** | **Specific heat capacity Btu/lb deg F** |
| Face brick | 4” | 9.228 | 130.037 | 0.2200 |
| Insulation Board | 2” | 0.298 | 1.998 | 0.1999 |
| HW concrete undried aggregate | 4” | 11.995 | 140.026 | 0.1999 |
| Gypsum plasterboard | ¾” | 1.109 | 50.005 | 0.1999 |

**Figure 15: Deriving parameter values from the Apache project constructions**

Step 2: Defining the “type parameters” in Revit MEP.

In the Revit template file, the “type parameters” for a wall were defined using the “Project Parameters” dialogue box.

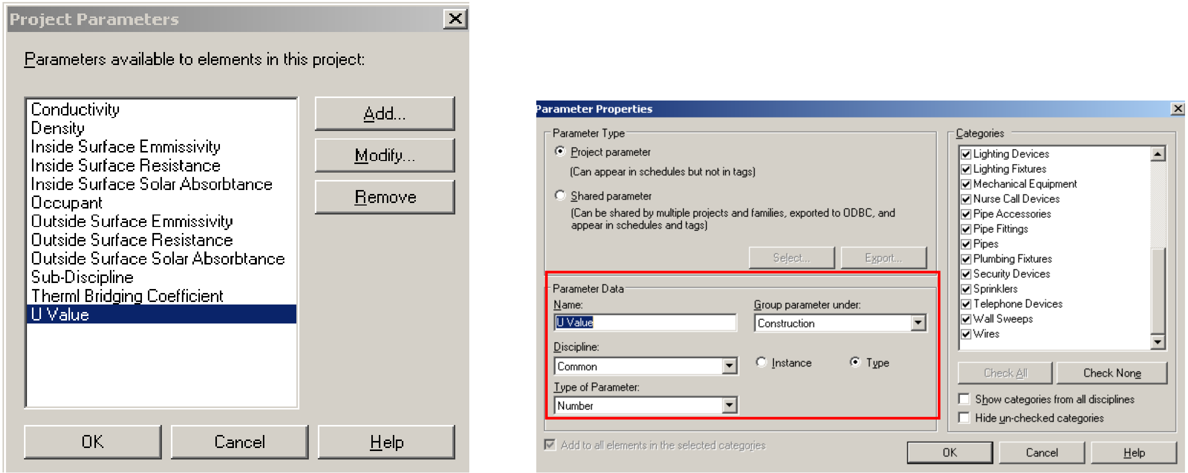



**Figure 16: Defining parameters in the template**

The following table shows the values assigned to the different parameters, and their categories in the "Parameter properties" dialogue box above.

| Parameter Name | Discipline | Type of Parameter | Group Parameter under |
|---|---|---|---|
| **U Value** | Common | Number | Construction |
| **Conductivity** | Common | Number | Construction |
| **Density** | Common | Number | Construction |
| **Inside Surface Emissivity** | Common | Number | Construction |
| **outside Surface Emissivity** | Common | Number | Construction |
| **Inside Surface Resistance** | Common | Number | Construction |
| **Outside Surface Resistance** | Common | Number | Construction |
| **Inside Surface Solar Absorbtance** | Common | Number | Construction |
| **Outside Surface Solar Absorbtance** | Common | Number | Construction |
| **Thermal Bridging Coefficient** | Common | Number | Other |

**Figure 17: Defining "type parameters" in the template**

Construction layers, (that is face brick, insulation board, HW concrete, gypsum plasterboard) and their respective thicknesses were also defined.

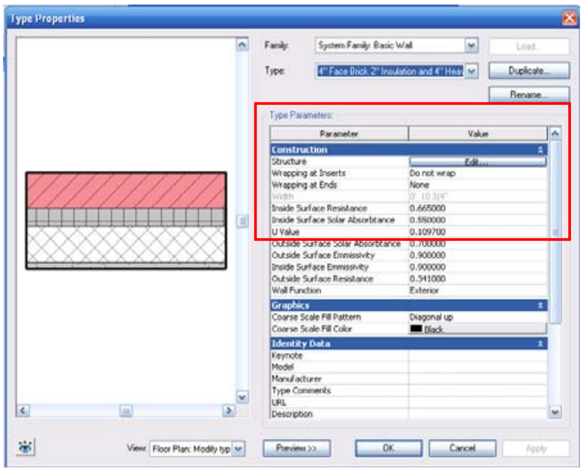


Figure 18: Defining the "type properties"

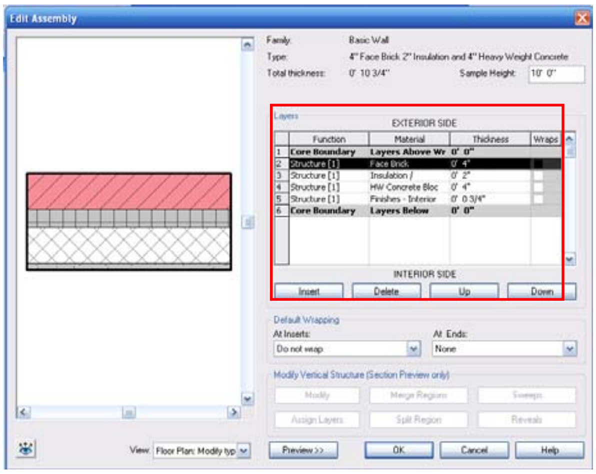


Figure 19: Defining the construction layers

Step 3: Transferring project standards

Project standards (information related to family types in a file) can be transferred from one project to the other, using "Transfer project standards." The file to be transferred has to be opened first and categories selected from the "select items to copy" dialogue box. The destination project is opened next and process is repeated. Once the template is imported into the user's project, all the family types get loaded and can be used as indicated in the figure below.

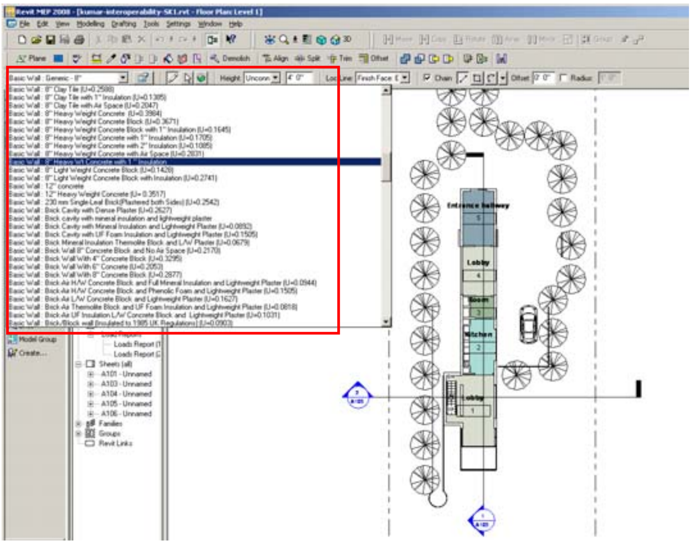


Figure 20: Various options for wall types in the template file

## 6.2 Standard component families

Standard component families (such as windows, doors, or even furniture are referred to as "families.") are loaded into the project templates and are stored by default in component libraries**.** These exist outside a specific building project and can be loaded onto projects. These have an extension .rfa.

External and internal windows, roof lights and doors were modeled as families and stored as separate .rfa files. Since these were regular family files, they were made by modifying existing window and door based families. Like the system family types, the values for the parameters were derived from IES<VE> Apache construction database. A disadvantage is that they have to be defined as separate families. Unlike the system families these are not parametric, and they have specific sizes designated to them. If the user wants a separate size for a certain family, one has to manually alter the sizes in the type properties of that component.

### 6.3 TEMPLATE FILE: CREATING A LEGEND

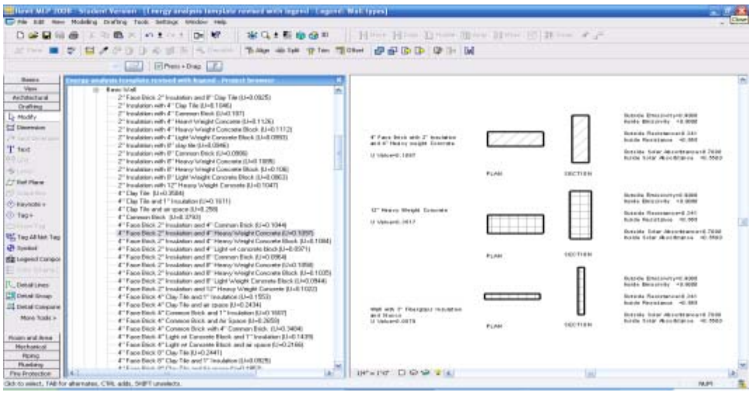


Figure 21: Defining the legend for building components

In the template file, a legend was created to make it easier for the user to know what materials were available. This legend contains a plan, section, and provides information to the user about the construction layers, U values, emissivity, resistance, and solar absorbance.

## 7 RESULTS

The following example uses the base case room, with material selections as listed in the following table.

| | |
|---|---|
| **Exterior Wall** | Standard Wall Construction (2002 UK regulations) (U=0.0527) |
| **Roof** | 4" Light weight Concrete (U=0.225) |
| **Floor** | 8" Lightweight Concrete floor deck (U=0.2397) |
| **Exterior Window** | Large Double Glazed Windows(U=0.5141) |

Figure 22: Construction assignments used for base case room.

| **IES (Within Revit)** | **Without using template** | **Using Template** |
|---|---|---|
| **Cooling loads** | 3334.8 Btu/hr | 3247.6 Btu/hr |
| **Heating Loads** | 3821.5 Btu/hr | 3761.5 Btu/hr |
| | | |
| **IES <VE>** | **Without using template** | **Using Template** |
| **Cooling loads** | 5.249 MBH | 5.143 MBH |
| **Heating Loads** | 3.440 MBH | 3.350 MBH |

Figure 23: Load results in MEP and IES<VE>

The tables summarize the results of the analysis within MEP and within IES, for a building model with generic materials, without using the template and then using it. There is a difference in the result, albeit a small one. As indicated in the table, cooling and heating loads increase by 2.02% and 2.62% respectively. This led to a related question: does using the template file produce a more accurate analysis? It was assumed that it would be more accurate since one was modeling exactly (materials and thicknesses) what one selected for the analysis. The IES Technical Support confirmed that using the template would improve upon the accuracy of the result; it would be useful to check this separately but a definitive comparison was beyond the scope of this study.

## 8 CONCLUSIONS

Originally, the information from Revit only informed the energy IES model of its geometry, and the building details had to be chosen from the Apache construction database. Thus it was decided to create a template file in Revit that matched the Apache construction database. The BIM model is richer because data that is inherently used for analysis is now being displayed for evaluation in the building model. The major role of the template file and families is an informative one and provides the user with information such as composition, thickness, specific heat, U-values, thermal bridging coefficient, emissivity, resistance, and solar absorbtance of each material. Using the template file will **not** cause the material, its U-value, or even its thickness to get carried over to the analytical model. However, using the template improves upon the accuracy of the model, even if only slightly so. It results in an increase or decrease in the surface area of the building model, which gets carried over to the analytical model and result in an increased/decreased heat transfer.

Because the new additional components can be included in the project and the families are available in the improved template file, the BIM builder can create the file in Revit and manually match the choices in the Apache construction database to create a self-consistent model that can easily go from Revit to IES. The model is **not** two-way interoperable – changes in the IES model are not sent back to the Revit model. It is not complete – optimally, changes in Revit families would update the Apache construction database, but they do not. The template file concept is not a long term solution for bridging the gap between BIM and energy analysis. However, it does provide one step towards making the interoperability connection more transparent and perhaps makes some sustainable design tools more accessible to architects.

## 9 References

AUTODESK Revit MEP
http://usa.autodesk.com/adsk/servlet/index?siteID=123112&id=8529972

ABS, Autodesk Building Solutions, *Building Performance Analysis Using Revit*, Autodesk, http://images.autodesk.com/adsk/files/building_performance_analysis_using_revit.pdf accessed 25 August 2007.

DCI, *Interoperability in the Construction industry*, **Design and Construction Intelligence**, 2007 interoperability issue, http://construction.ecnext.com/mcgraw_hill/includes/SMRI.pdf accessed on 20 February 2008.

IES, Integrated Environmental Solutions Ltd. http://www.iesve.com/content/

## 10 Keywords

BIM, energy analysis, interoperability, Autodesk Revit, IES <VE>, sustainable design tool

## 11 Addendum

Since the writing of this paper, Autodesk has released new versions of Revit Architecture and Revit MEP for 2009. In addition, IES has upgraded both its link within Revit and its series of <VE> Toolkits. It seems that the method used in this paper (a project template file and custom families) was **not** used to help achieve interoperability. However, progress was made with the IES building construction (default room construction) types in that they are now more integrated within Revit MEP as wall constructions, and the list of types has expanded to include more high performance options. (June 1, 2008)