

# Application of IFC Standard in Interoperability and Energy Analysis

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## ABSTRACT:

In this research, a new methodology to perform building energy analysis using Industry Foundation Classes (IFC) standard has been studied. With the help of Archicad 14 modeling software, a 3D test model is generated and then exported to IFCXML format. A ruby code program retrieves the building information from the resulting IFCXML file using Nokogiri library. An INP file is created and gets ready for next energy analysis step. DOE 2.2 program analyzes the INP file and gives a detailed report of the energy cost of the building. Case study shows when using the IFC standard method, the Interoperability of the energy analysis is greatly improved. The main stream 3D building modeling software supports IFC standard. DOE 2.2 is able to read the INP file generated by IFC file. This means almost any 3D model created by main stream modeling software can be analyze in terms of energy cost Thus, IFC based energy analysis method has a promising future. With the development and application of IFC standard, designers can do more complex and easy-to-run energy analysis in a more efficient way.

*Keywords: Building Information Modeling; Energy Simulation; IFC standard; Interoperability, DOE-2.2*

## 1. INTRODUCTION

Building energy analysis is a hot topic in architectural and civil engineering. Using Industry Foundation Classes would greatly enhance the interoperability between the building modeling software and speed up the whole building energy analysis process thus promote the widely use of building energy analysis method . For the past years, a lot of 3D modeling software, like Archicad and Autodesk has been developed. Each software uses its own file standard to save and transfer the building information. Many BIM technologies are developed at the same time. One of the promising technologies is Industry Foundation Classes (IFC). This data format contains all building information. It is a future bridge between different 3D modeling software. Also, many building energy cost analysis methods have been developed. One of the best of this kind of method is the use of DOE 2.2. They are all very successful technologies. But there is a lack of interoperability between them. For example, with a 3D model file created in Archicad, it is not easy to do the building energy analysis immediately. Creating a input file based on this 3D model to do energy analysis in DOE2.2 is difficult and time consuming. Few studies has been done to solve this problem. This is part of the reason why energy analysis is not widely used in architectural industry field.

In order to do programming, Ruby programming language is selected. Ruby is a dynamic, open source programming language with a focus on simplicity and productivity. It has an elegant syntax that is natural to read and easy to write. The most important thing is that Ruby is good at analyzing and generating txt file which is the file format that INP file uses. And it also has a XML reader parser which can efficiently process IFCXML file. The program interface is Google Sketchup. The reason why it is chosen is that it has a very friendly ruby programming console. Archicad 14 is selected to build test building model. DOE 2.2 is the energy analysis software. Based on these technologies, a Ruby program can process the IFCXML file and then generate INP file for DOE2.2. A building energy analysis can soon be done in this way.

This paper presents how to utilize IFCXML standard to build a ruby program in Google Sketchup and then use this program to do building energy analysis. In the methodology section, the reason why those research technologies are selected are described. The whole research process is shown. Basic structure of ruby code is presented. In the case study section, a test building model Ifcxml file is analyzed by ruby program in Sketchup 8.0 in terms of energy cost. By using this approach, we can see that the Interoperability between the software is greatly improved and the process is simplified.

## 2. LITERATURE REVIEW

For the past 50 years, a wide variety of building energy simulation (BES) analysis tools have been developed, enhanced, and applied throughout the building energy community. Examples of these tools are BLAST, EnergyPlus, eQUEST, TRACE, DOE2, and ECOTECH. These tools are complex, text-based applications which require a great deal of time to learn. Building designers consider energy analysis a time-consuming process and leave it to mechanical or electrical engineers late in the design process. However, very little attention has been given to the significance of early design energy analysis even though decisions made early in a project have a strong affect on the life cycle costs of a building (Kim et al, 2009; Dahl et al, 2005). It has been noticed that building designs (conceptual and detailed designs) affect about 60-70 percent of the life cycle costs of the construction and operation of a building (Paulson, 1976).

The Architecture/Engineering/Construction industry is experiencing great change because of BIM and its increasing popularity (Eastman et al. 2008; Sacks et al. 2004). Many different energy modeling techniques have been applied to numerous studies in attempts to predict future energy usage over the years including: artificial neural networks, statistical analysis of building consumption data, decision trees, and computer simulations programs (Catalina et al, 2008; Ekici et al, 2009; Olofsson et al, 2009; Heipe et al, 2008; and Pan et al, 2007). Previous work has shown that using computer simulations takes a considerable amount of time to properly input data correctly, even for qualified practitioners (Zhu, 2006 and Catalina et al, 2008). At the same time, DOE-2 specifically was applied in the study of predicting energy consumption in the building sectors of major U.S. cities to determine energy consumption profiles, but is very timely due to intensive labor requirements (Heiple et al, 2008). In hopes to alleviate some of the time requirements in this process several groups have begun creating new methodologies for energy modeling using EnergyPlus (Zhu, 2006).

While BIM technology allows designers to run energy simulations (Kim et al, 2009), there are limits on its usefulness in the current state of energy simulation programs. Several researchers have pointed out that there is a need for improved interoperability between energy simulation and building information modeling programs (Messener et al, 2006). Construction practitioners have also identified that one of their greatest interests in the field of BIM is improving the interoperability between BIM and energy simulation programs (Becerik-Gerber et al, 2010). The time required to read and reconstruct the geometry of a BIM file in an energy analysis program can amount up to 50% of the time required to run the energy simulation and because of this poor interoperability the usage of energy analysis during design is restricted (Krygiel et al, 2008). Due to intense labor requirements in the energy modeling process design decisions are often made without the consultation of energy modeling (Korkmaz et al, 2010).

## 3. RESEACH METHODOLOGY

In this research project, several different kinds of concepts and technologies have been utilized:

IFCXML standard. IFCXML is a subtype file format of IFC format. IFC is called Industry Foundation Classes. Among all the BIM technologies, IFC is the most promising. This new data format contains almost all kinds of the building information. All the building modeling software can exchange the needed building data information like even physical properties. XML is another commonly used data format. It organizes data in a tree format. And this kind of data organization helps to reduce the file size. IFCXML has the advantages that those two data format both have. It is the most generally used data format.

Archicad 14. Archicad 14 is a 3D modeling software developed by Gosoft. It is very compatible with IFCXML data format. For example, in building energy analysis, building materials should be defined first and then recognized by energy analysis engine. In Archicad 14 this can be done.

Sketchup 8.0. Sketchup is a 3D modeling program developed by Google. It is light , fast. It also has a ruby programming interface which greatly enhances its capability. In this research, small ruby code is created in Sketchup 8.0 through Ruby programming language. Ruby has a xml reader library which is called Nokogiri. Nokogiri analyzes Xml file very fast. That is why it is chosen in this research project.

The building energy analysis engine used in this research is DOE 2.2. It is developed by US Department of Energy. DOE 2.2 provides detailed energy analysis report. In order to run this analysis engine, INP file is needed. INP file contains all the information needed to do DOE 2.2 energy analysis. It is written in BDL language and generated by ruby programming language.

The most import part is the ruby code program. This program has two sections and each section has several methods to analyze the imported IFCXML file. Each method uses Nokogiri grammar to search a certain IFCXML node which contains a certain building information.

The ruby program is divided into two parts. The first one is to retrieve Ifcxml geometry data. The second one is to retrieve Ifcxml material data. Each part includes several processes. In each process, the physical properties of building elements are parsed, retrieved and stored.

The hierarchy that geometry data parsing part and material parsing part has is shown in figure 1 and figure 2. All these structures are coded in Ruby programming language. The building elements information has properties like polygon point coordinates, depths, origin coordinates, story coordinates, widths and direction ratios. Ruby code program is used to retrieve these building information.

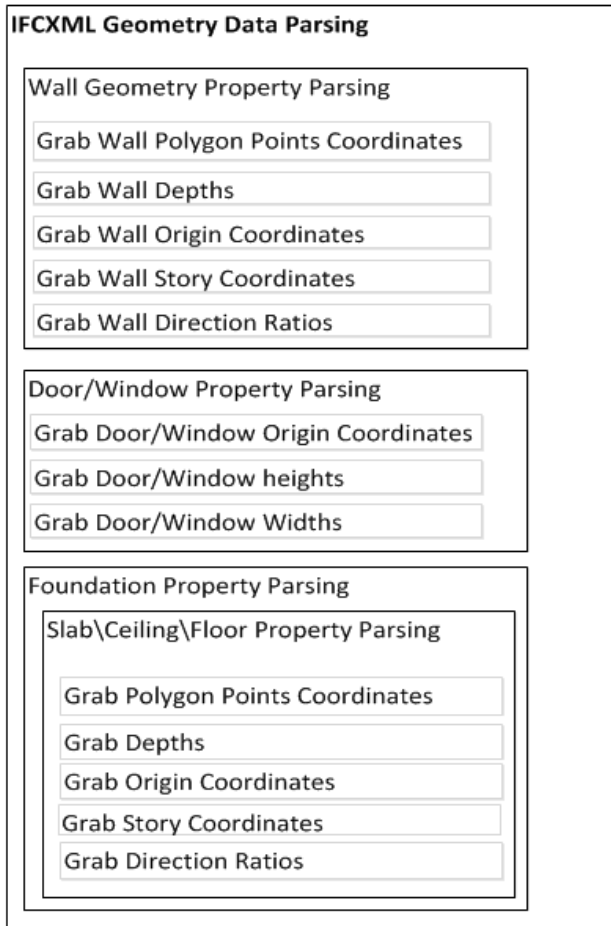


Figure 1. Geometry Data Parsing hierarchy



Figure 2. Material Data Parsing hierarchy

Figure 3 shows the detailed process of “Grab Wall Direction Ratios”. Other processes have the similar structure. The pattern basically is locating a node, retrieve a reference number, based on this reference number locating another node and so on.

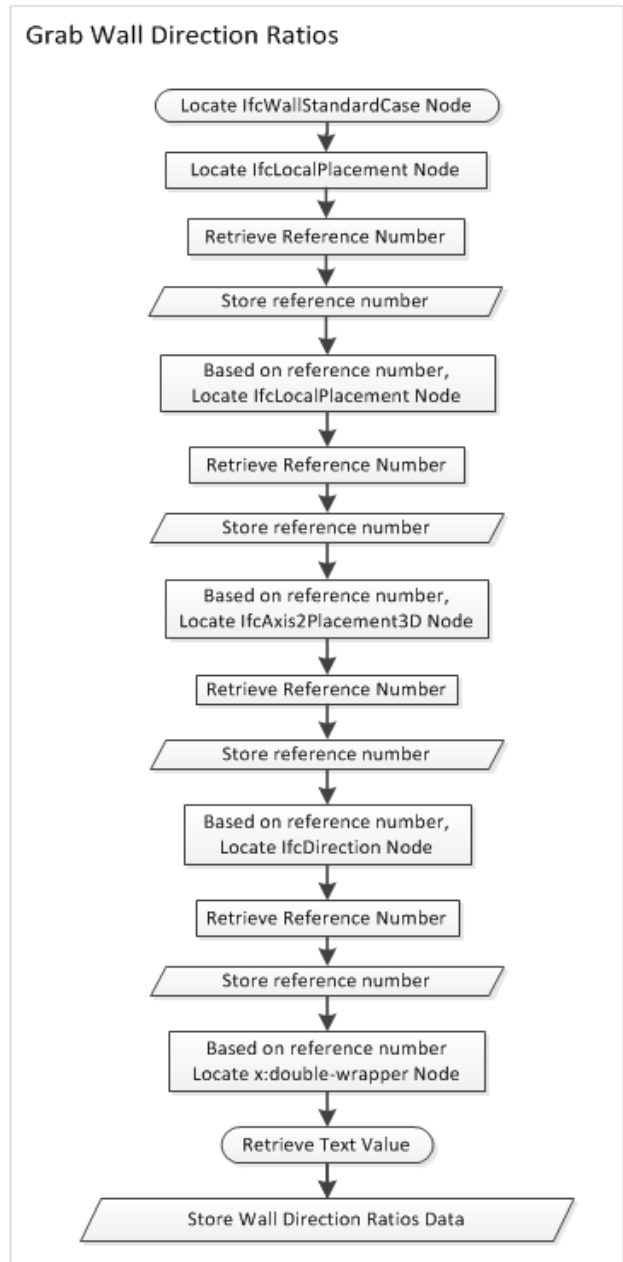


Figure 3. Grab wall direction ratios Process

Figure 4 shows all the methods that ruby code has. And figure 5 shows the detailed code of the “retrieve story height” method. Figure 6 shows the whole research process.

```

def load_xml
def slice(array, chunk_size)
def grab_text(array)
def compile(array,length)
def noko_grab_id(array,idtype)
def story_height
def grab_simple_wall_story_coords
def grab_simple_slab_story_coords
def grab_simple_wall_origin_coordinates
def grab_simple_slab_origin_coordinates
def grab_simple_door_and_window_origin_coordinates
def grab_simple_wall_polygon_points
def grab_simple_slab_polygon_points
def grab_simple_wall_depths
def grab_simple_slab_depths
def grab_door_and_window_widths
def grab_door_and_window_heights
def grab_wall_number(wall_id)
def grab_wall_ref_of_door_and_windows(int)
def grab_simple_wall_direction_ratios
def grab_simple_slab_direction_ratios
def draw_simple_walls
def draw_simple_slabs
def draw_all
def door_window_type_translation(array)
def wall_type_translation(array)
def door_window_id
def embedded_lib_1(temp)
def embedded_lib_2(temp)
def linked_lib(temp)
def new1_lib(temp)
def new2_lib(temp)
def door_window_material
def wall_type_name
def saveas_inp
def inp_write
if( not file_loaded?("Auto.rb") )
file_loaded("Auto.rb")

```

Figure 4. Ruby Code Structure

```

class Float
def load_xml
def slice(array, chunk_size)
def grab_text(array)
def compile(array,length)
def noko_grab_id(array,idtype)
def story_height
  #From the lowest floor created (IN FEET)
  floor_heights = []
  result = 1
  floor_heights = $doc_noko.css("uoeNS|IfcBuildingStorey uoeNS|Elevation", {"uoeNS" => $http}).map {|el| el.text}
  n = 0
  while n != floor_heights.length-1
    result << (floor_heights[n+1] - floor_heights[n])/12
    n = n+1
  end
  result
end
end

def grab_simple_wall_story_coords
def grab_simple_slab_story_coords
def grab_simple_wall_origin_coordinates
def grab_simple_slab_origin_coordinates
def grab_simple_door_and_window_origin_coordinates
def grab_simple_wall_polygon_points
def grab_simple_slab_polygon_points
def grab_simple_wall_depths

```

Figure 5. Retrieve Story Height Method

There are several steps in the whole research process.

First, a model should be created in Archicad. And a IFCXML file for this model should be exported. IFCXML file contains all the information of the building. Ruby code will retrieve the information by utilizing nokogiri program. These building properties include: wall geometry and material properties; Door and window geometry and material properties; Foundation geometry and material properties. All the information will be stored in computer memory.

Archicad 14 names material property a little bit differently. If Archicad 14 material property name happens to match the DOE2.2 library, the system will go with the original Archicad 14 name. If they don't match, a translation system written in ruby language should be utilized to translate the archcad 14 material property name to DOE2.2 library material property name in order to let DOE2.2 recognize the material name.

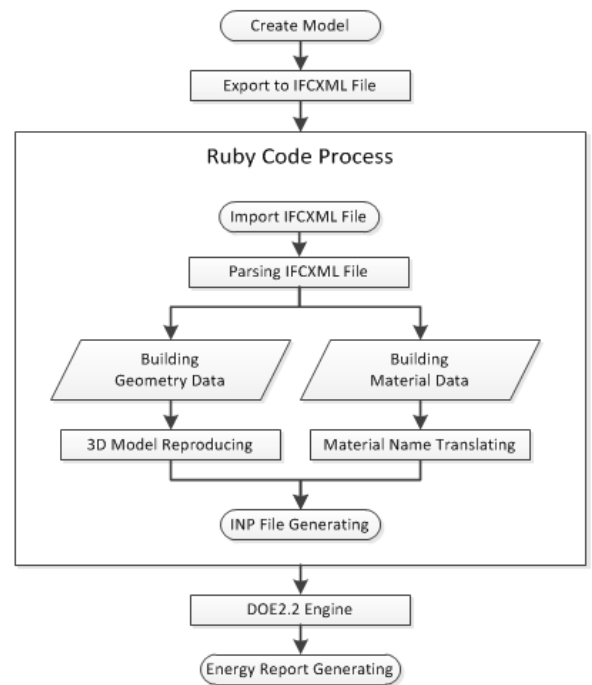


Figure 6. Whole Process

Other data will be needed to complete INP file for the building model. These data include Run period, site parameters, schedules, electricity meter information, fuel meter information, pump information, circulation loop information, plant equipment information, chiller information, heat rejection information, boiler information, hvac system information, economics information(like utility rates).

Ruby code generates INP file with the information stored in the memory and the information which are manually entered by user. The INP file is written in BDL language which can be understood by DOE 2.2 engine. User can choose where he wants to save the INP file.

Run the DOE 2.2 program, choose the right locations for DOE system files, BDL input file and DOE 2 user library. Click "Read BDL input file" button to read the INP file. And then if there are no errors, click "Perform DOE2 simulation" button to do the simulation. When it is done, simulation reports will be generated.

#### 4. CASE STUDY

In case study, A test model is built in Archicad 14. The proposed methodology was applied to this relatively simple model. The structure was designed with only basic features required for running energy simulations: exterior walls, flooring, roofing, windows and doors. It is a 2 story test model building with doors and windows.

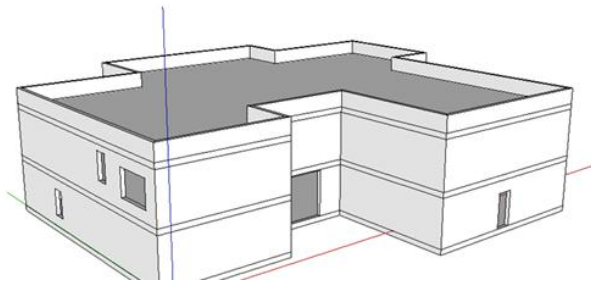


Figure 7. 3D Test Model

The material type is also set in Archicad 14. Different material type is assigned to doors windows walls slabs and roof. Doors and windows are made of aluminum. Walls slabs and roof are made of concrete. Figure 7 shows a picture of the model.

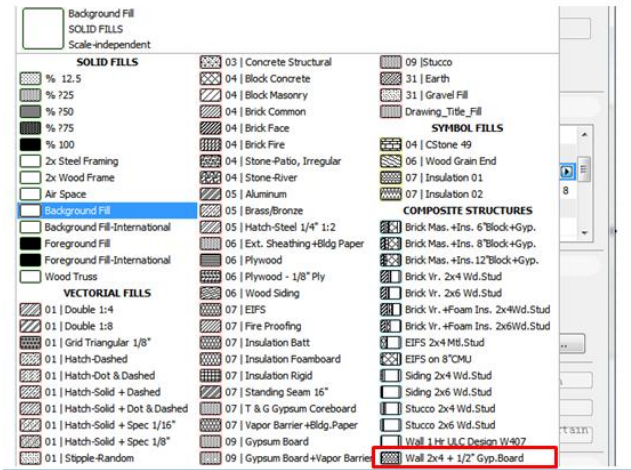


Figure 8. Element Material Selection

Ruby program is run in sketchup 8.0. The location is chosen as Chicago. After clicking start button, a INP file is generated. It is ready to use. This INP file contains all the information that DOE 2.2 needs.

Figure 8 shows how to assign a material type to an building element.

```

$ *****
$ **                                     **
$ **   Floors / Spaces / Walls / Windows / Doors   **
$ **                                     **
$ *****

"Floor Level 1" = FLOOR
AZIMUTH       = 360
POLYGON       = "Floor Polygon 1"
SHAPE         = POLYGON
FLOOR-HEIGHT  = 10.0
SPACE-HEIGHT  = 9.0
..

"Space 1" = SPACE
SHAPE        = POLYGON
ZONE-TYPE    = CONDITIONED
PEOPLE-SCHEDULE = OCCUPY-1
LIGHTING-SCHEDULE = LIGHTS-1
TASK-LIGHT-SCH = OCCUPY-1
EQUIP-SCHEDULE = EQUIP-1
INF-SCHEDULE  = INFIL-1
INF-METHOD  = AIR-CHANGE
INF-FLOW/AREA = 0.0633333
PEOPLE-HG-LAT = 200
PEOPLE-HG-SENS = 250
LIGHTING-W/AREA = ( 1.3 )
TASK-LT-W/AREA = 0
EQUIPMENT-W/AREA = ( 1.5 )
AREA/PERSON  = 225
POLYGON      = "Floor Polygon 1"
..

"Wall 1.1" = EXTERIOR-WALL
CONSTRUCTION = WALL-1
LOCATION      = SPACE-V1
..

```

Figure 9. INP File for Test Model

The INP file is imported into DOE2.2 energy analysis program. A user library is assigned to run this INP file. First, the INP file is read and then check the errors. Second, energy simulation is run to generate the energy simulation report.

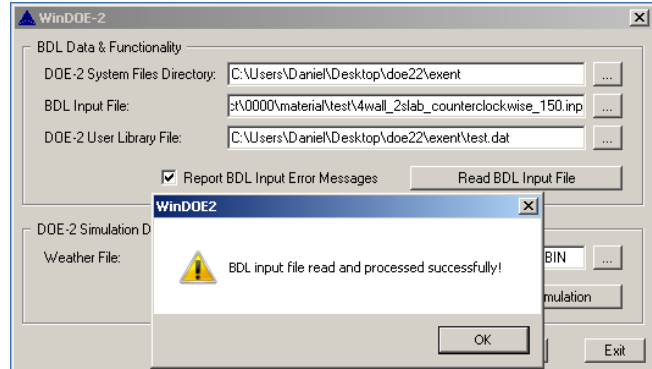


Figure 10. INP File Loading

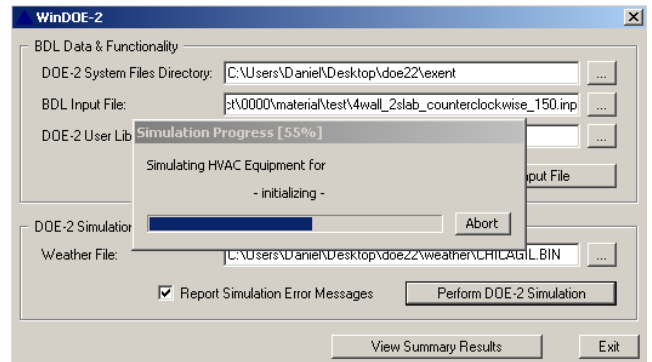


Figure 11. Simulating Process

Summary Simulation Results													
Total Site Energy:	108.83 MBTU	74.5 KBTU/SqFt*Yr	Gross Area	74.5 KBTU/SqFt*Yr	Net Area								
Total Source Energy:	274.75 MBTU	188.1 KBTU/SqFt*Yr	Gross Area	188.1 KBTU/SqFt*Yr	Net Area								
Percent of Hours Any System/Zone Outside of Throttling Range:	0.0												
Percent of Hours Any Plant Load Not Satisfied:	0.0												
Meter	Lights	Task Lights	Misc Equip	Space Heating	Space Cooling	Heat Reject	Pumps & Aux	Vent Fans	Refrig Display	Ht Pmp Suppl	Domest Hot Wtr	Ext Usage	Total
Electric Meters (kWh):													
EM-1	3287	0	2191	8030	0	0	141	2177	0	8481	0	0	24307
	3287	0	2191	8030	0	0	141	2177	0	8481	0	0	24307
Fuel Meters (Therms?):													
FM-1	0	0	0	0	0	0	0	0	0	0	259	0	259
	0	0	0	0	0	0	0	0	0	0	259	0	259

Figure 12. Simulation Summary Result

Figure 10 and Figure 11 show how the energy simulation is done in this DOE 2.2. Figure 12 and 13 show how the simulation results look like.

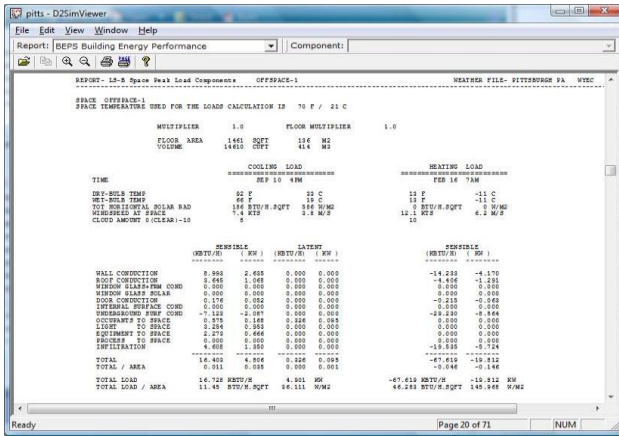


Figure 13. SIM File Result

In this energy simulation report, the total site energy is 745325MBTU and the total source energy is 1566.73MBTU. Other details about energy cost are stored in the SIM file.

### 5. VALIDATION

For validation of the results of our case study the results were then compared with a current commercial energy modeling program. One popular commercial product for running energy simulations of BIM is Green Building Studio, GBS (Figure 14). GBS is an affiliate program of Autodesk Revit and runs simulations using their custom file type gbXML. The gbXML files are similar to the IFCXML and XML files in nature but are not interchangeable, so for comparison a replication of the model used in the case study had to be recreated using Autodesk Revit. Every detail from the original BIM from ArchiCAD was recreated exactly the same in Revit, from building orientation to the slope of the roof. Once that model had been created, it was then exported from Revit as a gbXML file and uploaded into the GBS online program where the simulation is carried out. This is done using the GBS client interface.

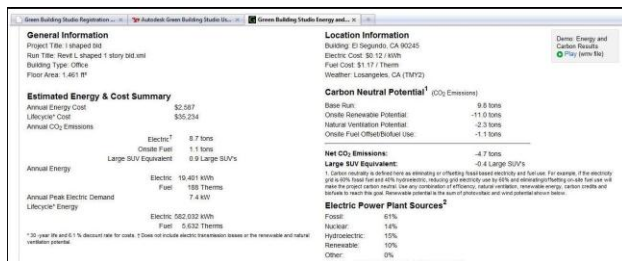


Figure 14. SIM File Result

The results produced in GBS were comparable to those produced using the methodology proposed in this paper. For Chicago GBS estimated an annual energy consumption of 124.4 MBTU compared to 108.8 MBTU produced in our estimate, a 12.5% difference. The cost estimate cost was \$2,293 compared to \$2,369, only a 3.23%

difference. Los Angeles provided the largest difference in energy estimates at 14.32%. GBS estimated 85 MBTU compared to 99.2 MBTU; however, produced the lowest cost difference at 2.04% because of different natural gas and electrical proportions (Figure 15).

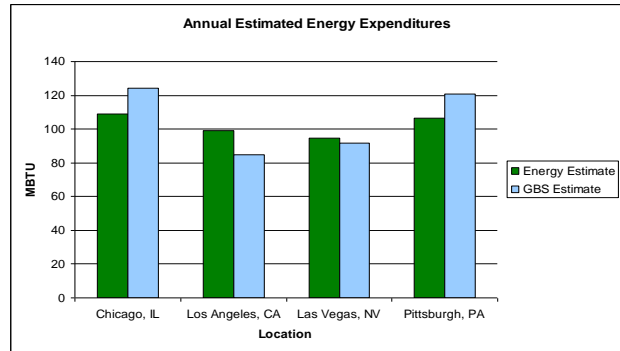


Figure 15. Energy Usage Estimations Compared with GBS by Location

The estimates varied by \$54 with GBS at \$2,587. Las Vegas provided the closest energy estimate at only a 3.34% difference and only a 1 THERM difference on the natural gas requirements. Las Vegas was estimated to have an annual energy expense of \$2,785 by GBS a 3.94% difference. Lastly Pittsburgh had the lowest disparity in price with a 1.78% difference between the two estimation methods, and an 11.83% energy consumption difference. The similarity in estimation can be seen in Figure 16. Across the four tests the differences in estimated expense and energy consumption are very comparable considering the multitude of possible variables affecting each estimate. Without knowing the exact conditions used for the simulations run in GBS, i.e. the heating and cooling set points, the estimations can only be so closely grouped to those from GBS, as slightly different conditions were considered. A few degree differences in heating and cooling set points could mean hundreds or possibly even thousands of dollars difference in estimated energy costs. In total the average difference in energy estimates between the proposed methodology in this paper and GBS was 10.50%. The estimated annual expense difference between the two methodologies amounted to an average of only 2.76%.

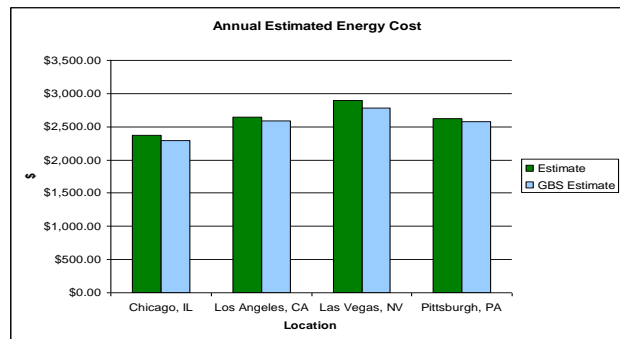


Figure 16. Energy Cost Estimations Compared to GBS by Location

## 6. CONCLUSIONS

The method for importing IFCXML file to generate INP file to do the building energy analysis is developed in this paper. By the proposed approach, the interoperability between the BIM software and energy simulation software is greatly improved. Although energy analysis is a key topic in building design industry, the common energy analysis software lacks the compatibility with next generation BIM standard which is call Industry Foundation class. Once this issue is resolved as shown in this paper, the building energy analysis program would become more and more widely used. Case study shows that this method is possible. With the aid of an easy to run and easily understood energy simulation methodology, designers will be able to make more energy conscious decisions during the design phase and as changes in design requirements arise.

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