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BIM-DRIVEN ENERGY ANALYSIS FOR ZERO NET ENERGY TEST HOME (ZNETH)

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ABSTRACT: As an on-going research project, **Z**ero **N**et **E**nergy **T**est **H**ome (ZNETH) project investigates effective approaches to achieve whole-house environmental and energy goals. The main research objectives are (1) to identify energy saving solutions for designs, materials, and construction methods for the ZNETH house and (2) to verify whether ZNETH house can produce more energy than the house uses by utilizing Building Information Modeling (BIM) and energy analysis tools. The initial project analysis is conducted using building information modeling (BIM) and energy analysis tools. The BIM-driven research approach incorporates architectural and construction engineering methods for improving whole-building performance while minimizing increases in overall building cost. This paper discusses about advantages/disadvantages of using BIM integrated energy analysis, related interoperability issues between BIM software and energy analysis software, and results of energy analysis for ZNETH. Although this investigation is in its early stage, several dramatic outcomes have already been observed. Utilizing BIM for energy analysis is an obvious benefit because of the ease by which the 3D model is transferred, and the speed that an energy model can be analyzed and interpreted to improve design. The research will continue to use the ZNETH project as a testing bed for the integration of sustainable design into the BIM process.

Keywords: Building Information Modeling (BIM); Energy Analysis; interoperability; Zero Net Energy; Modeling, IFC, gbXML

1. INTRODUCTION

The Architecture/Engineering/Construction(AEC) industry is rapidly changing the way it has operated for decades through the steady adoption of Building Information Modeling (BIM) technologies. BIM technology allows users to fully integrate 3D modeling to aid in the generating of construction documents, estimating cost tracking, as well as scheduling. This holistic approach to project design and management allows for a free flow of information and communication that has always been difficult to achieve within the industry. The benefits of utilizing BIM are widely noted as promoting cost savings and increasing quality/accuracy of the product.

In much the same way that Building Information Modeling is sweeping the industry the same can be said about how the concepts of green building are taking root. According to McGraw-Hill Construction's annual SmartMarket Trends Report in 2008, green building accounted for approximately twelve billion US dollars, and is expected to reach a projected 60 billion dollars just an year later in 2009 (McGraw Hill 2008). Further exemplifying green building's explosive growth is the number of Leadership in Energy and Environmental Design (LEED) certified buildings currently in the works. According to the United States Green Building Council, as of February 2008, 1,283 LEED Certified Projects have been completed since the organization was founded, and 9,876 Projects in all 50 states and 41 Countries are currently registered with the United States Green Building Council as working towards, or waiting for certification (USGBC 2008).

The growth in market share sustainable building is currently seeing, translates to an imperative need for designers to quickly and efficiently analyze building performance from an energy standpoint. Previously the tedious tasks of generating completely separate independent energy models for analysis had to be built in addition to the building's design model. This method required designers to become proficient at modeling in multiple software packages.

The expanding size of both industries has put them both on a collision course with each other. BIM software providers are now acquiring or partnering with previously independent energy software companies to integrate the process of creating energy models within BIM platforms, and energy programs are focusing more effort on making their product BIM compatible. Where BIM is present, energy modeling is never far behind. Figure 1 illustrates that 57% of all sustainable projects utilize some form of Building Information Modeling (McGraw-Hill 2008).

Realizing the importance of being able to effectively interface between BIM models and energy models, this investigation will focus on the design and construction of a Zero Net Energy Test Home (ZENTH) utilizing both BIM and Energy Software.

2. BACKGROUND OF RESEARCH PROJECT

2.1 The Zero Net Energy Test Home

In June of 2008 the Peter Kiewit Institute at the University of Nebraska initiated a collaborative research project called the Zero Net Energy Test Home, or ZNETH. The primary objective of the ZNETH project is to design and construct a home that has a negligible effect on the environment. It is a goal of the Peter Kiewit Institute (PKI) to use the ZNETH project as a living laboratory for all involved, as well as a real world platform for sustainable education.

From its inception, students, faculty and professionals have collaborated on ZNETH's design and construction to identify and implement sustainable materials, construction methods, and operating protocol. As was hoped, throughout the collaborative process of building a zero net energy home, a number of specific research objectives have been identified. Several of these objectives are currently being investigated or will be investigated in the future.

ZNETH is a registered LEED for Homes project located in Omaha, Nebraska, and was designed to obtain a Platinum certified rating by the US Green Building Council (USGBC).

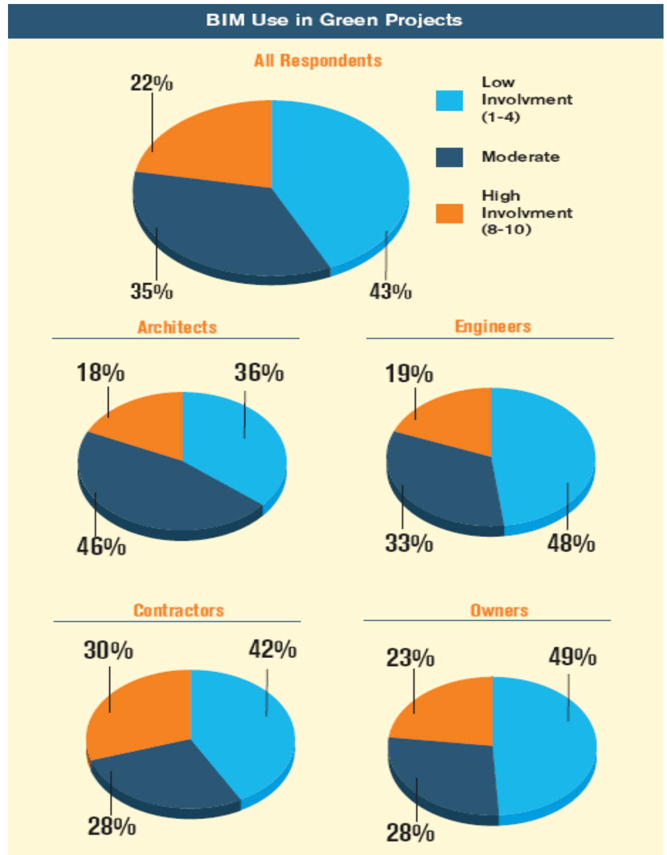

Figure 2. Level of Involvement of BIM on Sustainable Projects (McGraw-Hill 2008)

The initial design phase of the ZNETH has been difficult, as there are limited resources to draw from in regards to zero net energy projects in the area. It is a goal of those involved with the project that the ZNETH project be a home that incorporates feasible building practices and readily available building materials. The project is to demonstrate to homeowners the practicality of the home's materials and building systems and thereby encouraging them in adopting some of the ZNETH's characteristics.

The ZNETH project incorporates a number of green building techniques and sustainable systems. Insulated concrete forms(ICF) are being utilized in the lower two levels, with 2x6 framing and closed cell soy based spray foam being used on the second floor. High efficiency windows are being used throughout the house to mitigate solar heat gain in the summer months and heat loss through the winter months. The ZNETH project uses a PEX plumbing system for all water fixtures, as well as a grey water reclamation system used for flushing toilets and landscape irrigation. Geothermal wells have also been installed in the project. Both a horizontal system looping around the house at a depth of approximately 8'-9", and a vertical system reaching typical depths of 235' will be compared. Radiant heat floor panels are to be installed on all floors of the home, making a furnace unnecessary in the ZNETH. The house will be lit using low energy LED light as well as practical day lighting methods.

For on-site power generation, the home is expected to produce approximately 1 kilowatt energy via an array of photo-voltaics on the rooftop. Additionally, a residential wind turbine capable of supplying 2 kilowatts of power will also be installed on the home's roof mounted to a 25' mast. Both units will be integrated into a net metering system. Net metering is the process of selling on site generated electricity back to the power company at wholesale prices by essentially pumping unused energy back into the power grid.

It is clear that the ZNETH project has research applications that are far reaching across a number of disciplinary fields. It provides a wonderful test bed for a multitude of exciting and innovative research applications.

2.2 The BIM Model

The BIM model for the ZNETH project was created using Vico Software's *Constructor 2008*. *Constructor* was originally developed by Graphisoft as *ArchiCAD* and later sold to Vico Software for integration within their *Virtual Construction Suit* which is touted as being a complete 5D package designed specifically for constructors and owners.

The software allows for the model to be constructed by building component entirely in the virtual world. Information regarding costs and estimating, as well as scheduling information is tied to the individual components to create the BIM model. This model allows for quick and seamless estimating and budget monitoring, while also efficiently managing scheduling components throughout the project.

For use in this investigation only, the 3D model with material information tied to it is needed. The BIM model can be seen in Figure 2. Budget, and scheduling information does not fall within the scope of the current research parameters, however, the ability to later investigate these aspects are available.

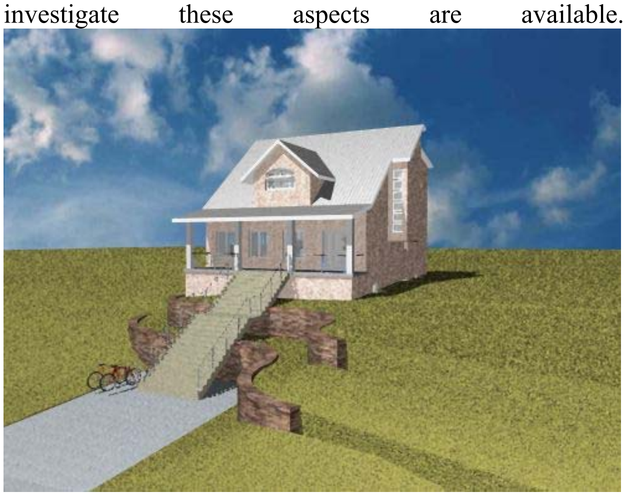

Figure 3. 3D Model of ZNETH

The ZNETH project was designed and constructed using best practice methods without the use of 3D modeling or energy analysis software. One of the primary objectives of this investigation is to compare how the as built version of the house performs compared to the virtual as built model and energy critiqued model. It is for that reason that throughout the construction of the test home, all of the existing building components from walls, windows, doors, skylights, and even outlets have been painstakingly measured out in the field and placed in the virtual model to create as close to a perfect representation of the house as it stands in the real world as possible.

2.3 The Energy Model

Today, more than ever, it is essential for designers to be able to efficiently and confidently make decisions that promote sustainability throughout the entire process. Paramount are the decisions made during initial design stages. During this process, rough estimates of energy usage, ventilation costs, lighting, etc. can be quickly analyzed for sustainability and budgetary information. Late energy analysis often leads to the introduction of significant cost variables due to the time and energy required to address issues that surface late in the design and even construction phases. To remedy this tired and costly way of designing, Marsh, the creator of Ecotect and energy software tool, has suggested an alternative, performative design. Performative design is an iterative process that designers should follow to help in sustainability, or building performance, and drive the overall design (Thoo 2008). It is described graphically below.

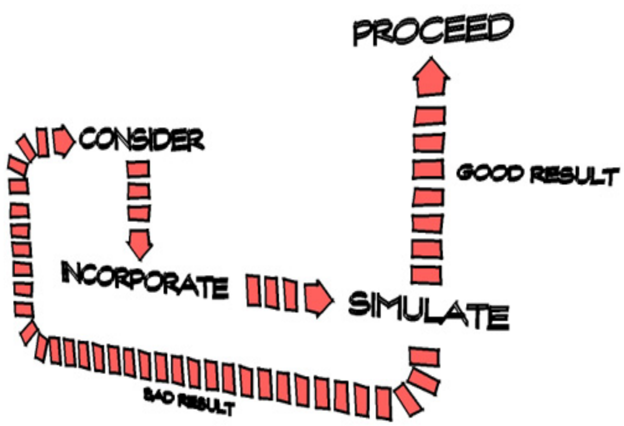

Figure 3. Iterative Path of Performative Design (Thoo 2008)

To follow this design procedure, tools capable of allowing for the quick efficient analysis are needed. There are several energy modeling software programs that integrate in some fashion with 3D modeling software. Some of the energy software programs on the market today include: Autodesk's Green Build Studio, Autodesk's Ecotect, Bentley's Hevacomp, and EnergyPlus via a Sketch UP plug-in. Autodesk's Ecotect was settled on for its abilities to meet the parameters of this research for several reasons to be discussed later.

3 Streamlining Energy Modeling

For designers to be able to effectively utilize the integration between BIM and energy software, these platforms must be compatible with each other. Compatibility issues have been one of the biggest problems in communication between designers, owners, and contractors. Previously, it was almost essential for all the key players in the building process to use the same software programs so information could be easily shared. This is particularly true of energy modeling (Malin 2008).

3.1The Integrated Approach

Recently, industry has begun to remedy the compatibility obstacles inherent to the building process in a couple of ways. First, as noted above, larger established design programs, such as Autodesk, have begun to simply integrate energy modeling applications such as Camel Software, completely within their software (Malin 2008). In this approach it allows designers to seamlessly perform energy analysis with confidence. Confidence in the energy analysis is achieved because the designer is looking directly at the building components that were placed in the model knowing that the correct material properties, placement, etc. are being looked at by the energy tool, rather than hoping all the information painstakingly modeled in one program is correctly construed within the separate energy program.

3.2The Interoperable File Type Approach

The convenience of integrating energy software within current BIM programs is great for some designers, and the applications the software is capable of performing suits those designer's needs. However, there are a few key reasons why complete integration is not and should not always be the case.

For some designers the integrated software simply does not meet their specific needs. There are a number of different energy analysis software packages on the market today, but most of them tend to focus on a few key aspects of analysis. For example Ecotect has the ability for acoustical analysis, whereas eQuest does not (Crawley 2008).

In addition, today's marketplace demands a choice. Forcing the use of one particular energy tool drastically limits the versatility of design, and could completely undermine a reservoir of knowledge designers already have on other specific tools. In fact, market reports compiled by McGraw Hill Construction found that, "Interoperability is cited as the most important aspect that users want software companies to improve" (McGraw Hill 2008).

Lastly, designers often require the development and implementation of brand new tools to solve new unique problems or to refine the solution of established problems. For that reason there must be platforms from which to jump off from in regards to designing new useful tools for the effective analysis of problems capable of increased interoperability to promote superior results and increased communication. Luckily, a couple of these platforms are taking root.

3.2.1 IFC File Format

Industry Foundation Class (IFC) was established in 1995 by the International Alliance for Interoperability (IAI). The IAI has operated under the name *buildingSMART* since 2005 whose vision is "To provide a universal basis for process improvement and information sharing in the design, construction, and facilities management industries" (BuildingSMART 2009). The NIBS-Facility Information Council describes IFC as an object oriented "open standard" from which building data contained in a BIM model can be exchanged and shared among several different team members using several different software packages (BuildingSMART 2009).

IFC is quickly becoming recognized as the leading data schema from which a lot of software development is structured due to its standardized open specifications that are not controlled by any one vendor. The IFC schema is constantly improved with new versions being published periodically, its most recent being IFC2x4 alpha (IAI-Tech 2009). Though IFC format continues to improve and promote the interoperability between software applications within the AEC industry, it is not yet perfected, specifically in terms of energy analysis.

IFC format and in general BIM models do not yet seamlessly support all the information needed for proper energy models. In addition, as noted earlier export between one software to another, e.g., BIM to Energy modeler, via IFC file format may distort or incorrectly change valuable energy related building data (Stumpf 2008). Thoo (2008), an Australian architect, also notes that IFC for the exchange of building information is not yet perfected, citing an example within Ecotect v5.6 and its ability to entirely import an IFC file, but its ability to extract the special definitions needed for zone by zone analysis.

3.2.2 gbXML File Format

Green build XML (gbXML) is the other primarily used schema for the transfer between modeling software and energy software. gbXML was developed in 2002 by Green Build Studio to aid in the interoperability between BIM platforms and "a variety of engineering analysis tools and models available today" (Kumar 2008). The format is based on Extensible Markup Language, or XML. It is basically a way to encode only useful data or information, e.g. building models and leaving out all processing or procedural data that usually comes along with information saved with a specific program (Ojbuji 2004). In short, it is a way of saving only the information one sees on the screen. That information can later be viewed by different users with different software.

As the name suggests gbXML's primary purpose is for the development of green building, e.g. energy modeling. The gbXML file format is quickly gaining popularity within the AEC industry due to its open source standardized schema like IFC. In fact many major HVAC companies like Trane and Carrier have already adopted it (Stumpf 2008). Additionally the three major BIM players, Autodesk, Graphisoft, and Bently Systems all have the capability to save gbXML files.

Where IFC currently falls short of having the capabilities to store energy analysis related data, the opposite is true for gbXML. This means that gbXML is not a truly “comprehensive, ‘all-of building’ schema like IFC” (Thoo 2008). GbXML also falls short when one considers true interoperability. Once information is changed within a gbXML file, it currently cannot be added back into the original data source (Thoo 2008). So, if a house model is exported via gbXML file format for analysis and a window is added within the independent energy software to aid in daylighting the updated design, it cannot be imported back into the original BIM model.

4 Why Ecotect

The energy model was created with the use of Autodesk’s Ecotect, acquired from Square One Research in 2008. Ecotect was ultimately selected to be used in conjunction with this investigation. As was noted previously, for a few key reason: 1) The broad range of tests and analysis possible within the program, 2) the graphic driven analysis, 3) the 3D modeling application within the program, and 4) the file type choice, e.g., IFC, gbXML, and 3ds.

Crawly(2005) of the US department of energy investigated 20 of the markets most prevalent energy packages in 2005. He describes Ecotect as being one of the most complete building design and analysis tools. Ecotect is able to investigate nearly every design aspect of a building; covering resource usage, acoustics, lighting, shading thermal and energy analysis.

Ecotect’s strong relationship with graphical data representation was also appealing. Similar to several other packages, Ecotect provides feedback in the form of traditional charts and graphs. However where Ecotect really excels is its ability to map results directly over the building objects being investigated (Crawley 2005).

It was important to the research for a program with 3D modeling capabilities to be used. Previously most energy analyses were completed by simply inputting data into excel-like programs to get results. For designers to not have the capability to graphically see how a simple design change will affect overall building performance has always inhibited the sustainable design process. Ecotect has always integrated a 3D modeler to solve this problem (Riether 2008). Previously, the entire building needed to be remodeled independently within Ecotect to obtain an energy model. The release of Ecotect v5.6 in 2008 eliminates the need for designers using Ecotect to learn another 3D modeling software due to its new found ability to import complete 3D models as well as BIM models in gbXML and IFC formats.

One of the primary goals of this research is to investigate how well BIM software communicates with independent energy software, in this case Graphisoft’s ArchiCAD and Autodesk’s Ecotect. Graphisoft has the ability to save information in three of the most used file types Ecotect needs for model import. The file types include IFC, gbXML, and 3ds.

5 ArchiCAD and Ecotect in Action

5.1 Exporting the Model

The ZNETH project’s BIM model almost entirely is completed via Archicad or Constructor. Encina Ltd. developed a plug-in for Archicad in 2008 that enabled it with gbXML file saving capabilities. Care was taken to prepare the model for correct export to Ecotect by following Encina’s *ArchiCAD gbXML Export Manual*, as well as Graphisoft’s reference manual on the same subject, *Preparing ArchiCAD Models for Analysis in ECOTECT***.** The completed zones ready for export, as well as imported Ecotect model are shown in Figures 4 and 5.

Figure 4. Interior Zones In ArchiCAD Ready For Export to Ecotect

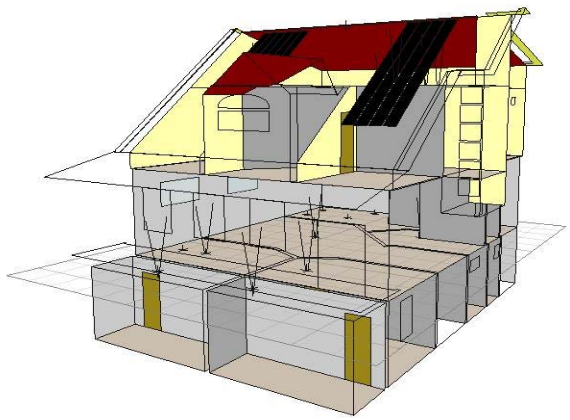

Figure 5. Imported Model From ArchiCAD in Ecotect

First, unique interior and exterior zone categories were created. For analysis in Ecotect, it is important to specifically define different zones for analysis. Zone by Zone analysis is intuitive to energy analysis, whereas whole building analysis would clearly be cumbersome. The interior zones, shown in Figure 4, define all the room spaces and locations designers have interest in, and the exterior zone simply gives Ecotect the building's boundaries so it does not attempt to investigate the characteristics of the outdoors.

After zone boundaries were created in each of the rooms, and separately for each floor, care needed to be taken to ensure correct zone height. Zones on multiple floors, across different rooms would not always be apparent after export to Ecotect, and would produce erroneous energy data (Graphisoft 2008).

5.2 Observed Problems with Transfer

Although particular care was taken to follow both reference manuals, several problems were still observed after the transfer to Ecotect.

Material data tied to objects within the BIM model have not transferred to Ecotect very well at all. In this particular case, material types do not seem to match as close as they could. This could be getting overly cumbersome as the walls of the ZNETH project are somewhat complex Insulated Concrete Forms (ICF) walls; nonetheless, this occurred with other simple elements.

Some elements have lost their assigned names. For example many of the floors in the BIM model have become ceilings in the Ecotect model, and vice versa. Additionally, some elements have kept their correct purpose, however they have taken on material characteristics of other elements. To give another example, a floor remains a floor after transfer, but it has taken on material characteristics common to a wall being constructed of brick. .

Upon further inspection of the Ecotect model, it was also discovered that no element considered a "roof" was present. In fact it appears that the roof has simply been cut away in the y direction of any placed archiCAD zone for no apparent reason (Figure 6). The elevation of many of the doors has also moved in relation to the placed zones within the BIM model. Some of the doors moved as much as eight inches above the floor.

On a whole, however, the research team has found Ecotect to do an excellent job in the overall data transfer from ArchiCAD regarding gbXML. Most geometry and elements appear to have retained their original characteristics .

An IFC file transfer has not yet been thoroughly investigated within the scope of this project. However a comparison between the two formats using the same BIM model could prove to be a very interesting research topic at a later date.

6 Analyses

6.1 Current Analysis

After the general guidelines for the BIM model were followed and a little background knowledge in Ecotect was gained, energy analysis was found to be fairly simple and intuitive. Figure 7 shows a thermal analysis for the nineteen zones of ZNETH project. It shows the hourly heat gain caused by a number of factors in mid-summer. It is clear from the graph that as would be assumed, the heat gain from the HVAC unit during the afternoon is larger than in the morning. Looking also at the Inter-Zonal heat gain in this area of the house, heat is not easily gained in the afternoon from other parts of the house. The graph does not necessarily demonstrate great design; it merely depicts how easy it is for designers to analyze graphical outputs so that simple changes can be made. For example, large heat gains are shown in this room due to direct solar energy. This could be easily remedied with some shade providing vegetation, exterior sunshades or blinds.

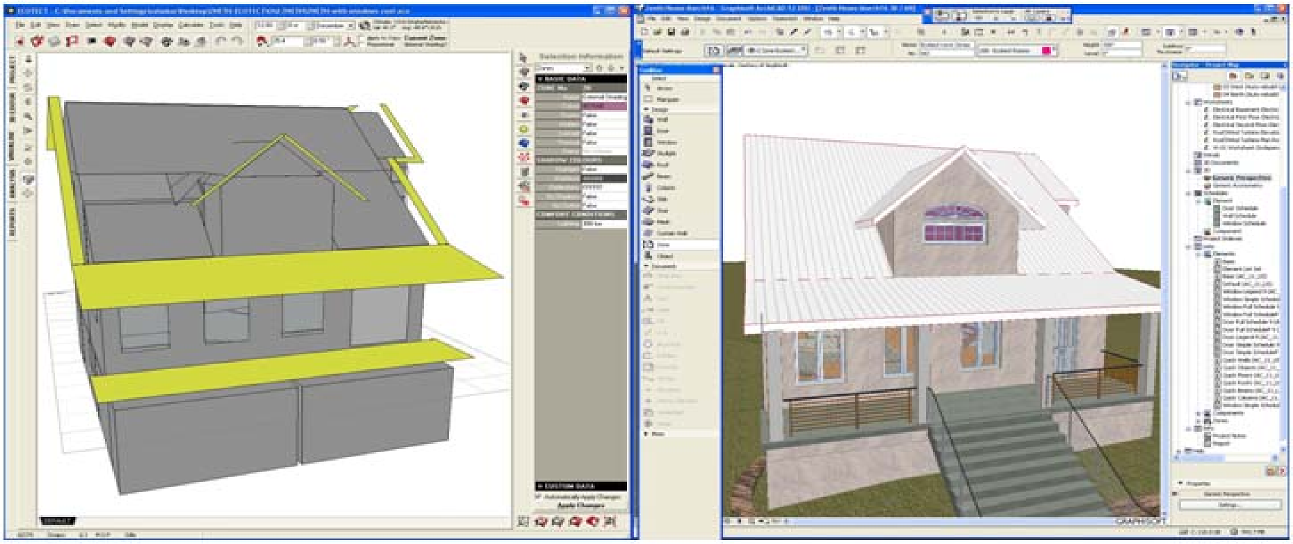

Figure 6. Ecotect Model Showing Windows and Roof Problems (left) ArchiCAD Model Ready For Export

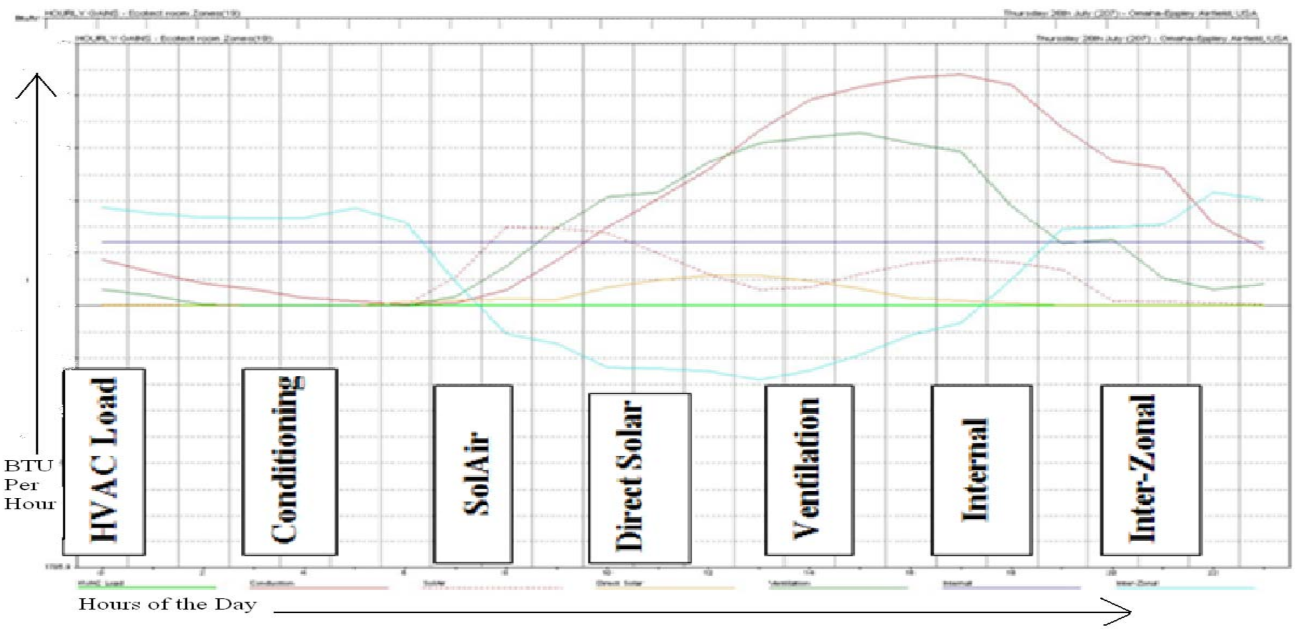

Figure 7. Heat Gains for an Individual Ecotect Zone

Even more helpful is how Ecotect graphically maps data over the analyzed surface to literally show designers what is happening. Figure 8 shows the amount of total diffuse radiation hitting the house. Diffuse radiant is the amount of solar radiation that an area receives after the direct solar ray has been scattered by the suspended molecules present in the earth's atmosphere (Bohern 2009). As expected the roof receives more radiation than the walls under the front porch.

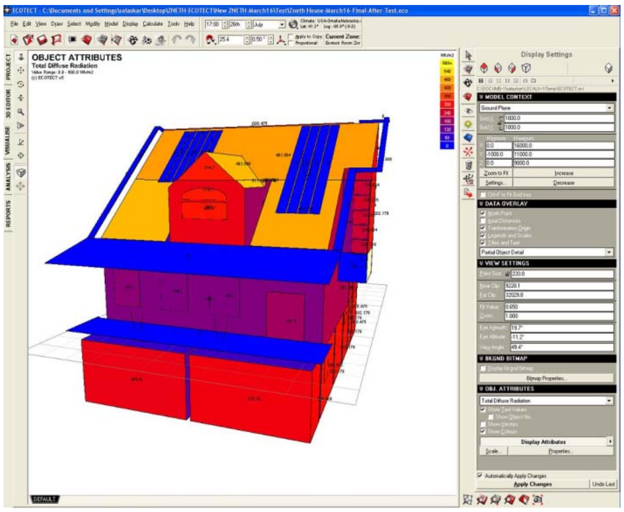

Figure 8. Total Diffuse Radiation Mapped Over ZNETH

An example of how these graphical outcomes may be helpful is the front dormer which is bright red and orange. This tells the designer that practices should be taken to either improve the shading of this area or possibly increase the specified R-Value of the dormer walls.

With the use of these types of graphical and numeric analysis, simple design changes like window placement A thermal analysis will be completed in all rooms of the building by following ASHRAE standard 55-2004, Thermal Comfort Conditions for Human Occupancy. The rooms will be tested for, but not limited to, air speed, air temperature, radiant temperature and relative humidity levels.

Ecotect has the ability to produce daily and even hourly breakdowns of anticipated energy use, lighting levels, and thermal characteristics. A comparison detailing daily or hourly collected data would provide a wealth of information for analysis, however the implications of permanently installing measuring devices within the building is certainly cost prohibitive. For that reason, it has not yet been decided if the majority of these testing units will be installed for extended periods of time, e.g. 2-3 years, or if tests will be taken only on specifically preplanned collection days.

8. CONCLUSIONS

Although this investigation is in its infancy, several dramatic outcomes have already been observed. Though

and material specifications will be made within the BIM model. In other cases, more extreme design changes will also be implemented within another model to illustrate the ease by which simple energy tools utilized during the design phase of a project and used by semi-lay persons can translate into meaningful gains in building efficiency.

6.2 Future Analysis

After the preliminary model has been completed and the existing house is being occupied, data will be collected from the real world environment for comparison against its virtual counterpart. Data collection will commence after building commission has been completed and a stable level of building operation has been achieved.

Comparison data collected from the ZNETH will be obtained from a number of different sources and methods. The first comparison will be made via air infiltration. The house will be tested in accordance with ANSI/ASTM-E779-03, Standard Test Method for determining Air Leakage Rate By Fan Pressurization, as well as the use of progressive sampling methodology as defined in the Residential Manual for Compliance with California's 2001 Energy Efficiency Standards. In addition, these tests will be supplemented with the use of an infrared camera. The camera will allow for a graphical representation of heat loss/air infiltration in a specific area.

Lighting and daylighting analysis are also needed. Target illumination levels will be set via the model and compared against light measurements taken on site. Measurements will be taken on a ten foot grid for all regularly occupied spaces under typical weather conditions for the area and at incremental times of the day.

there is somewhat of a learning curve in using Ecotect efficiently, it is not an overtaxing process to learn to do effectively. The research team is impressed with the ease by which the 3D model is transferred, and the speed that an energy model can be analyzed and interpreted to improve design. The research will continue to use the ZNETH project as a testing bed for the integration of sustainable design into the BIM process

The effect energy software has on the development of BIM is undoubtedly important. The far reaching impact of BIM on the AEC industry is vast. Coming full circle, it is the responsibility of designers to utilize the energy tools that will integrate with their process to promote sustainability. The research team is looking forward to providing industry with the findings of this project to aid in the further development of these two powerful design platforms.

Acknowledgments

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