Interoperability of Computer Aided Design and Energy Performance Simulation to Improve Building Energy Efficiency and Performance

Pongsak Chaisuparasmikul, Ph.D
Illinois Institute of Technology
3140 South Michigan Avenue., #604, Chicago, IL U.S.A
pongsak_archenergy@sbcglobal.net

Abstract: The paper describes very significant novel interoperability and data modeling technology for existing building that maps a building information parametric model with an energy simulation model, establishing a seamless link between Computer Aided Design (CAD) and energy performance simulation software. In the past, architects, engineers and building commissioners visualized their designs and measurements by working with drawings, physical models and full-scale construction. But today's models are digital, and even full-scale construction can be also virtual. With this innovative digital exchange and simulation technology, architects, building designers, and commissioners can improve, maintain and visually analyze dynamic building energy performance in response to changes of climate and building parameters. This software interoperability provides full data exchange bidirectional capabilities, which significantly reduces time and effort in energy simulation and data regeneration. Data mapping and exchange are key requirements for building more powerful energy simulations. An effective data model is the bidirectional nucleus of a well-designed relational database, critical in making good choices in selecting design parameters, and in gaining a comprehensive understanding of existing data flows throughout the simulation process. Despite the variety of energy simulation applications in the lifecycle of building design and construction projects, there is a need for a system of data integration to allow seamless sharing and bidirectional reuse of data.

Key words: building information model; parametric model; energy model; data model; energy performance simulation; web browser; interactive; interface; internet; client-server.

1. INTRODUCTION

There are millions of people and thousands of companies exchanging information and communicating over computer and networks such as the Internet. Within these complex innovation and network, much software is also operated on their own language with various computer platforms. This can make it difficult to know how to send or share information, and the receiver will use to view information.

During the last four decades, building designers have utilized information and communication technologies for creating environmental representations in order to communicate spatial concepts or designs and for enhancing spaces. Most architectural firms nowadays still rely on hand labor, working from drafted drawings, generating construction documents, specifications, schedules and work plans in traditional means. 3D modeling has been used primarily as a rendering tool, not as the actual representation of the project.

Building model is a complete, integrated, digital representation of a project that can be used for many purposes while enabling design professionals to share data allow collaboration between architects, engineers, consultants, contractors, developers, and owners, whom are mutually benefit from many different aspects of data, which describe different aspects of building design and operation, health and comfort, energy efficiency performance and sustainability. Lack of interoperability is a major obstacle that limits the work flow usability due to difficulty in acquires information from building geometries, coordinates, climate location, thermal zones, construction and materials properties etc.

2. LITERATURE REVIEW

2.1 Need for Interoperability

Building information model and software interoperability have become increasingly important in facilitating information sharing and data integration. It helps offer advanced building services through the use of tools in a collaborative project. It is inevitable in the traditional design process to recreate the same building model as much as seven or eight times (architecture, structure, mechanical, electrical, plumbing, energy analysis and simulation, construction documents, lighting, code checking, cost estimation etc.). The largest portion of the effort to prepare building performance simulation input is absorbed by the definition of building geometry, due to the reason that effort to comprehend and extract the pertinent information of 2D drawings to define 3D building geometry is required for carry out simulation. Tradition means of building performance simulation must be improved to level of automation in the acquisition of building geometry. It would be most desirable if the output data of CAD drawing can be directly imported into a energy simulation tool and converted into ready to use graphic interface.

2.2 Industrial Foundation Class (IFC) and Leading Software Companies

Industrial Foundation Classes (IFC) is data model developed by the International Alliance for Interoperability (IAI) since 1995 to provide data exchange capabilities for the AECFM industry. IFC represent the parts of buildings or elements of the processes, IAI defines IFC specifications and six releases have been published. IFC specifications provide common attributes and data structure of shared objects in various domains for modeling. IFC does not provide information exchange between software applications that have special conversion algorithm and process such as energy software program that has HVAC system and mechanical equipment programs. Many related software companies have planned or developed their products that share data objects with IFC or are based on IFC specifications and protocol. At the present time, there is no data exchange capabilities for building industry that can achieve the complexity of open system, multi-models, and bidirectional concepts of interoperability.

2.3 Virtual Model System (VMS) framework

The author of this paper has developed Virtual Model System (VMS) framework, which offers the innovative data collaboration, integration and sharing capabilities between CAD and software applications for energy performance simulation and prediction. VMS builds on systematic framework or platform of building information model, which facilitating information sharing and data integration, offer advanced building services through the use of tools in a collaborative project. VMS improves the traditional design process that has to recreate the same building model for energy simulation. VMS improves means of building performance simulation to level of automation in the acquisition of building geometry. Output data of CAD drawing can be directly imported into a simulation tool and converted into ready to use graphic interface. Its automation to manipulate a program's object model and database enables the users to reuse and update the data bidirectional through editors.

The paper is intended to prove that VMS system can integrate disciplines and project phases and improve the effectiveness and efficiency of energy uses during the building life cycle operations. Integration or interoperability can come best when they are the objectives of VMS implementation and management using VMS method. The followings are the unique features of VMS;

- Builds on systematic framework or platform of building information model, which facilitating information sharing and data integration, offer advanced building operation through the use of tools in a collaborative project.
- Offers data collaboration, integration and sharing capabilities and allows seamless sharing and bidirectional reuse of data, provides a new way to share information and collaborate on design data between applications through files,

database, and energy analysis software programs.

- Enables to quickly update and refines the design model easily even more accurate, reduce design errors, cost, time, while speed up project delivery.
- Addresses the quality and consistency of sustainability compliance information in 3D model, native 2D drawings, construction documents, specifications, scheduling, and shop model fabrication by mapping with energy simulation and downstream users who are doing 3D shop or mockup fabrication.
- Full-automated acquisition and expansion of building geometry through the commercial available computer aided design (CAD) object model. Mapping engine provides translating of the commercial available CAD model to energy analysis software. Data extracted of a CAD model and drawing such as geometries, coordinates, building materials and properties are directly imported. Data that beyond capabilities of the CAD shared object model to provide like climate and weather data, building operating schedule, HVAC systems have to go through data manipulation by database. Model calculating and editing engine provide automating calculation task through energy modeling, analysis and simulation program.
- Interactive and interfacing application provides user-friendly graphical interface over the internet. Data Model extends capabilities of interoperability to any CAD, energy and available software.

Figure 1 shows the proven model of Virtual Model System (VMS) Framework that has been tested its data modeling concept and method. Figure2 shows the VMS's Integrated Development Environment (IDE)

Fig. 1.Proven Model of VMS framework

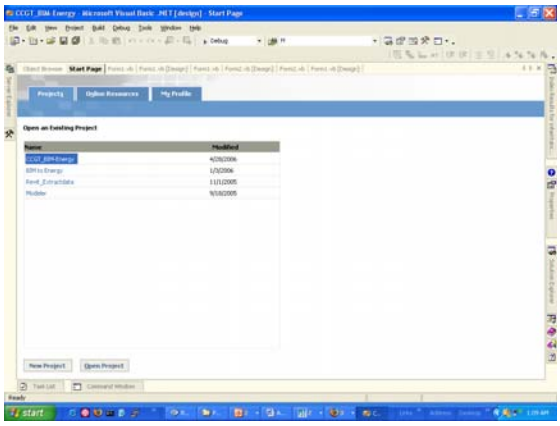

Fig. 2.Virtual Model System (VMS) Framework IDE

3. METHODOLOGY

The paper introduces 5 phases of VMS, which through the methods, intends to define, deliver, and operate the energy efficient building by using VMS method and technique, and to gain competitive advantage of sustainable architecture. The automation in VMS manipulates a object model and database, enables the users to reuse and update the data through editors, and translates building elements, geometries, coordinate, location, orientation, area, zone, and space.

Phase 1: created a project's representations in Autodesk Revit Building 8.1

Phase 2: extracted object's data from CAD model. VMS framework will translate building elements, geometries, coordinate, location, orientation, area, thermal zones and surfaces, and space. Data extracted of a CAD model and drawing such as geometries, coordinates, thermal zones and surfaces, building materials and properties are directly imported. Data that beyond capabilities of the CAD shared object model to provide like climate and weather data, building operating schedule, HVAC systems have to go through data manipulation by database.

Phase 3: design the database systems.

Phase 4: design model mapping, calculating and editing engine in VMS, which will provide creating energy input files, and calculation task through DOE2.1E energy analysis and simulation program.

Phase 5: design graphics interface that run on the web browser, which will display building's energy performance simulation results on the internet.

4. EXPERIMENTING VMS RAMEWORK

The following's work example is the residential project that being used for the purpose to carry out the ideas and concept. VMS translated the project, which has been created in Autodesk® Revit® Building 8.1, into thermal-based DOE-2.1E model for energy simulation. VMS read and extracted coordinates, geometries, thermal zones, and construction and material properties from Autodesk® Revit® Building, then translated in order to create DOE-2 input files, and perform energy analysis and calculation. For storing complete building information in a computer model and integrating all of the geometric model information requires the database system to hold geometrical data. The generation or extraction of data embedded in objects aims at generating floors, space, zones, walls, interior walls, roof, windows, doors, ceilings, and lists of building construction and materials to the thermal objects (zones and surfaces). Building geometry is essential to energy simulation engine such as DOE-2. The usability of DOE-2 performance simulation can be improved due to full capacity of acquiring bidirectional information.

4.1 Phase 1: Created a project representations

Representations range from small objects, to buildings and up to site or landscapes models and support various phases of the design process: recording and analyzing existing building's environments, creating visualizations of the design process and/or the designed space and finally communicating completed designs, creating new representations that integrate architectural design and the construction process, so that design teams work out how a building is to be constructed as they design it. Information and communication technologies have been used for enhancing mediated communication of physical environments in order to create spatial high performance contexts for sustainable design.

The followings are the work samples that show possible development of various kinds of representations;

Project

The project establishes the context, which including geometric representation context for information to be exchanged or shared. There is only one shared project within the exchanged context.

Site

The site represents an area and comprises one or more building. The site location is determined by the project site, location, climate location and weather data to match with energy simulation weather data. Project site data provided for DOE-2 to generate building latitude (41.8), longitude (87.8), altitude (186 feet above sea level, time zone (6), and provide necessary weather data.

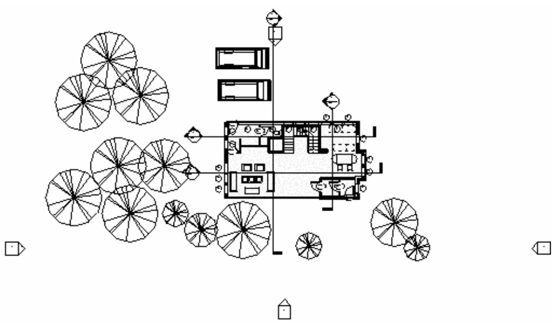

Fig. 3.The Site Location is in Chicago, IL

Building

Building comprises a basic element within the spatial structure hierarchy and number of stories.

Fig. 4.Building Representations

Building Envelope

Building envelope consists of building level, area, area schemes, space or rooms, and thermal zones.

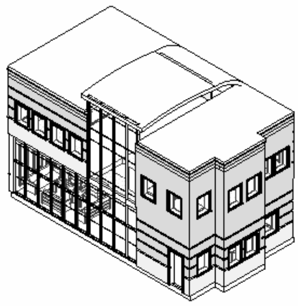

Fig. 5.Building Envelope Representations

Building Elevation and Level

Building level comprises an elevation and represents a horizontal aggregation of space (Rooms) that are vertically bound.

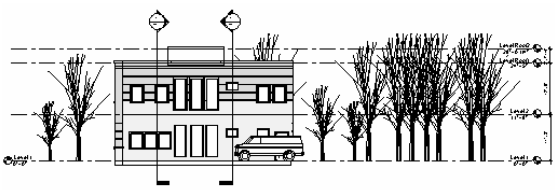

Fig. 6. Building Elevation and Level Representations

Building Area

Area consists of building area and area schemes

Area schemes

Area schemes define as a color-fill diagram depicts function by programmatic area, with real-time, automatically generated area tabulations.

Rooms or Space

Room or Space represents an area or volume bounded by surfaces. The geometric representation of rooms or space is given by shape and placement allowing multiple geometric representations. The space boundary information can be acquired by space boundary.

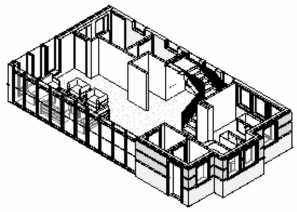

Fig. 7 Architectural Space or Rooms Representations (2nd floor)

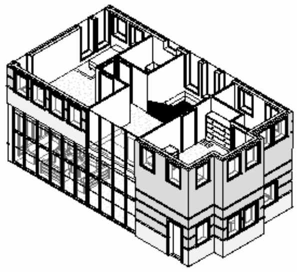

Fig. 8 Architectural Space or Rooms Representations (2nd floor)

Walls

Walls consist of exterior wall and interior wall. Walls are defined with certain constraints for the provision of parameters and geometric representation. The geometric representation of walls is given by shape and placement allowing multiple geometric representations.

Windows

Windows represents opening, recess, or chess, and reflecting void. There are 2 types of windows, opening and recess or niche, which are defined by attribute object-type. Windows have to be inserted into a wall element, which is part of the building elements and has the element relationship. The geometric representation of windows is given by shape and placement allowing multiple geometric representations.

Doors

Doors define as the opening elements, which are inserted into a wall element and become part of the building elements and have the element relationship. The geometric representation of doors is given by shape and placement allowing multiple geometric representations.

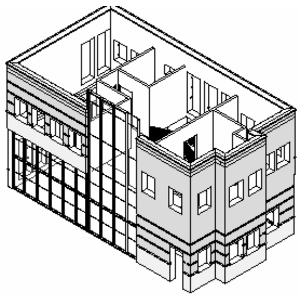

Fig 9 show walls Representations

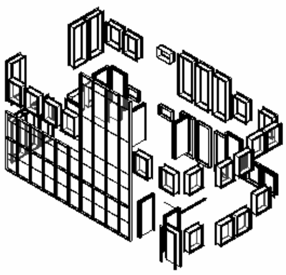

Fig 10 show window and doors representations

Roof, Floors, Ceilings

There are the components that enclose room or space vertically. They can provide for lower support (Floor), upper support in the room (Ceiling), or upper construction in the building (Roof). The geometric representation of these components is given by shape and placement allowing multiple geometric representations.

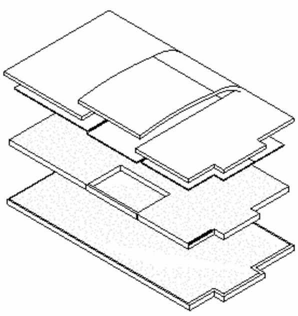

Fig. 11: Roof, Floor, Ceiling Representations

4.2 Phase 2: Extracted Data from CAD Model Translating into Energy Input

VMS framework created the prototype interface and prepared in the format required by DOE2.1E input data file. The fundamental requirements for performing energy efficiency analysis and simulation with DOE-2 include:

- Climate and weather data describe the design climate and location for the city where the building is situated. The weather period is normally one year.
- Building operating schedule describe building use information to allow specification of the number of people, lighting, and equipment (either electric, gas, or other fuel types) in each thermal zones.
- Building thermostatic condition control schedule describe temperature control and thermal zone condition in each zone of the building.
- Geometric representation of the thermal zones and enclosure of heat transfer surfaces for each thermal zone.
- Geometric representation of the thermal surfaces, which converts from building elements such as walls, windows, doors, floors, ceilings, and roofs.
- Physical construction and thermal material properties of building elements describe specification of building geometry and surface materials and constructions.
- Building use information to allow specification of the lighting and equipment (electric, gas, or other fuel), people in the building.
- HVAC system information to allow specification and scheduling of the system.
- Plant system information to allow specification and scheduling of the system.
- Economics of energy saving system information to allow specification and scheduling of the system.

- Thermal design parameters for specifying the intended simulation settings.

Data Mapping of Thermal Zones

Thermal zone defines a thermal instead of architectural space, which is the basic information of simulation. The geometric representations of thermal zones may or may not be identical to architectural space in the CAD drawing. For each of thermal zone, information regarding enclosure of heat transfer surfaces need to be obtained. A thermal zone requires parametric information of zone north axis, origin, type, ceiling height, zone volume, and convection algorithm.

Data Mapping of Thermal Surfaces

Thermal surfaces refer to heat transfer surfaces to describe the thermal representations of building elements, such as walls, roof, windows, doors, ceiling, and floor. Each surface has some attributes to determine its interaction between internal and external environment. A surface may have interaction with another surface to represent inter zone heat transfer. Thermal surfaces are the basic ingredients of the thermal simulation.

Data Mapping of Building Location and Climate

The database server in Virtual Model System Framework provides mapping for building location (figure 18), and climate such as monthly temperature (figure 19), and weekly temperature (figure 20).

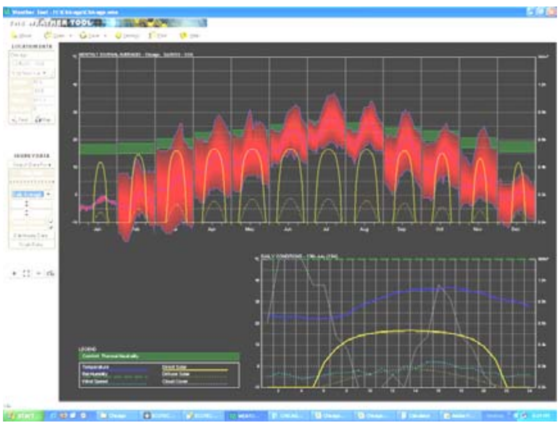

Fig. 12 Data Mapping of Monthly Temperature

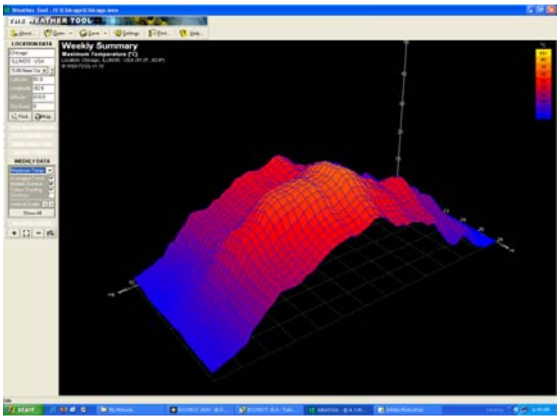

Fig. 13. Data Mapping of Monthly Temperature

Data Mapping of Building Construction and Materials

One of the great capabilities of database in Virtual Model System Framework is directly acquire building element construction and materials properties from Revit Building and export directly to DOE-2 INPUT files for energy simulation. Figure 21 show data mapping for wall construction and materials. Figure 22 show data mapping for window construction and materials

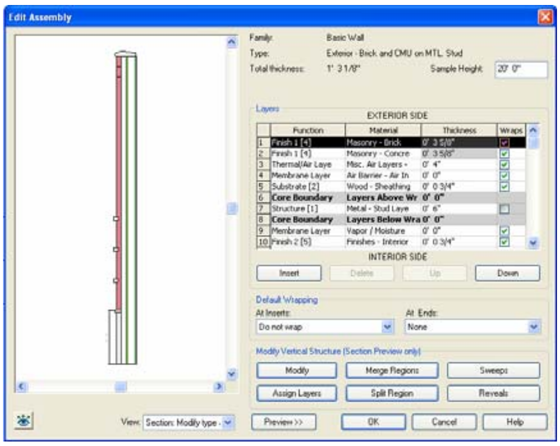

Fig. 14 Data mapping for wall construction and materials

Data Mapping of Coordinates and Geometries

The database server in Virtual Model System Framework provides 3D modeling engine for mapping of geometric, coordinate system and topological thermal object representation. Normally CAD information model performs calculation of 3D geometries, coordinates and topological model, which captured by mapping engine during exporting process. Figure 23 show the mapping of floor plan coordinates and geometries captured from exporting Autodesk Revit Building.

Data Mapping of Space and Zone Condition

The database server in Virtual Model System Framework provides mapping of artificial lighting object representation of lighting types, quantities, power generated and location of each room or architectural space in the building.

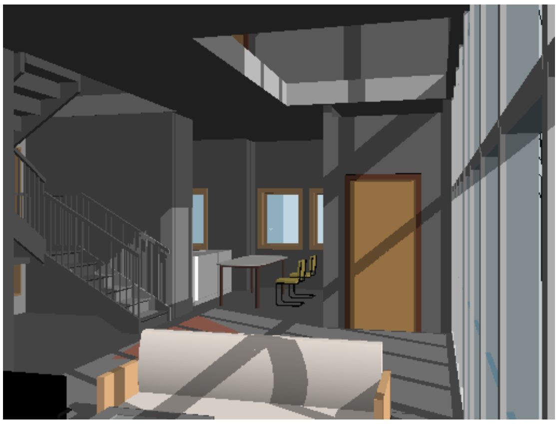

Fig. 15 Data Mapping of Space and Zone

4.3 Phase 3: Design Database Systems

One of the best solutions is to use a common language, which is known as database. Database enables to construct information so that when the others retrieve the project data, they will be able to view it no matter what kind of computers or applications they are using.

- Automate bidirectional data mapping.
- Provide standard tool and analysis throughout lifecycle workflow.
- Enhance workflow from data regeneration to interface and presentation
- Capture resource and incorporate into standards.

Data Provider

A data provider in the Virtual Model System Framework serves as a bridge between an application and a data source. A data provider is used to retrieve data from a data source and to reconcile changes to that data back to the data source. Data provider provides functionality for connecting to a data source, executing commands, and retrieving results. Those results can be processed directly, or placed in an dataset for further processing while in a disconnected state.

Data Provider in figure 2 extracts and retrieves data from building information 3D model, and provides full data exchange bidirectional capabilities between 3D models, 2D design drawings, construction documents and specifications, and energy analysis programs.

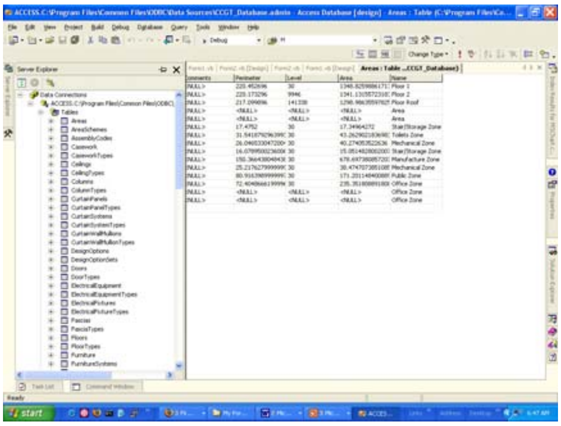

Fig. 16 ODBC Data Provider

Data Mapping

Data mapping mapped the graphic and non-graphic information from building information model and stored in the database. Data Mapping allowed establishing a correspondence between data in CAD and data provider. Table 1 show the object model representations that has been mapping using data mapping engine in Virtual Model System Framework.

Data Binding

Data Binding used information read from building information model and creates data relationship for looking at related data.

Data Relation

Data Relation related all the data table components and linked them together. When the energy models or any software programs look up in one dataset, they can see other project's database and get the data they need at the same time. Figure 3 show a data table of the object model representations. Figure 4 show the relationships of the data tables

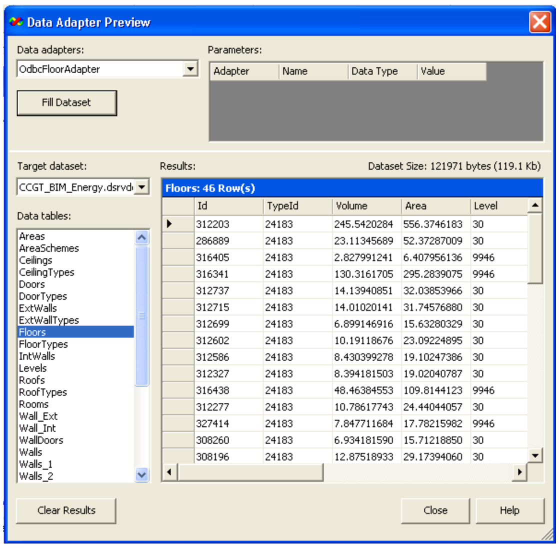

Fig.17 Show data table of the object model representations

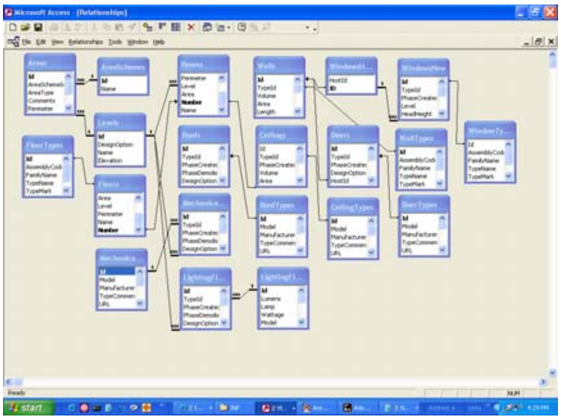

Fig. 18 show data Relation of the data tables

4.4 Phase 4: Model mapping, Calculating and Editing engine in VMS

A model is a representation of computer aided design information and how information related to other information such as energy efficiency analysis and simulation like DOE-2.1E. A model of computer aided design information is an object model; while a model of energy efficiency analysis and simulation information is a process model. An object model represents the information and structure of an object and its underlying components, which also are objects. A process model represents the information and structure of a workflow and its underlying processes. At the present time there is no technology or invention that can map through both object model and process model. This is making Virtual Model System (VMS) framework a challenging in providing a form of specification that can be used to create software applications. Once the ASCII input file is created, it is possible to call and query DOE-2 as an operating command engine from VMS. DOE-2 then calculates the heating cooling, and lighting loads necessary to maintain thermal and daylight control set points and conditions through out the secondary HVAC system and coil loads, and the energy consumption of primary plant equipment as well as many other simulation details that are necessary to verify that the simulation is performing as the actual building would.

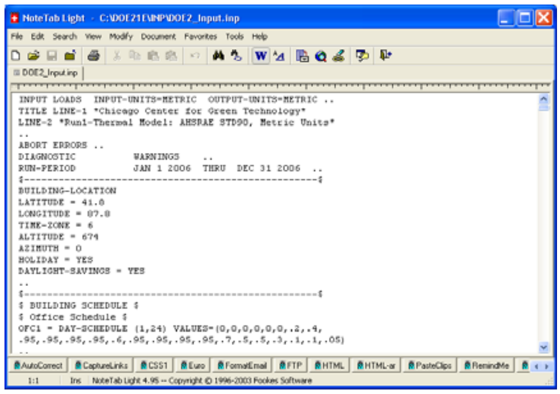

Fig. 19 VMS created DOE21E input

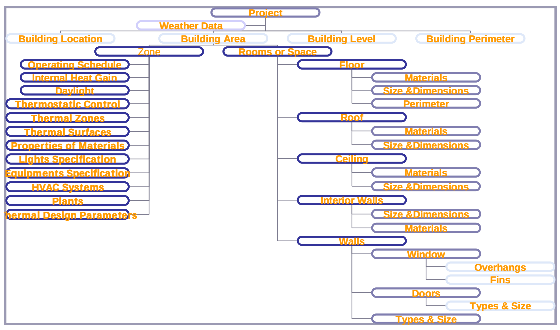

Fig. 20 show data structure of mapping model engine

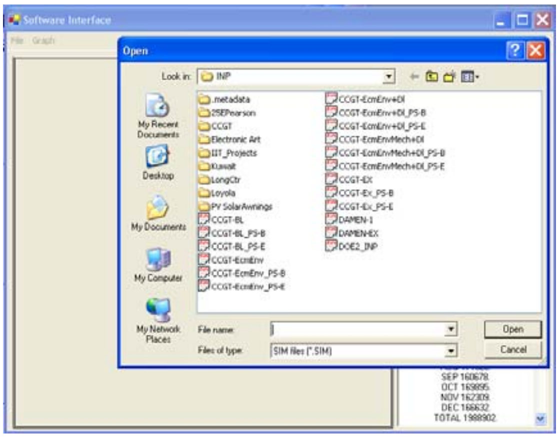

Fig. 21 Energy scenarios consumption reports resulted from running simulation.

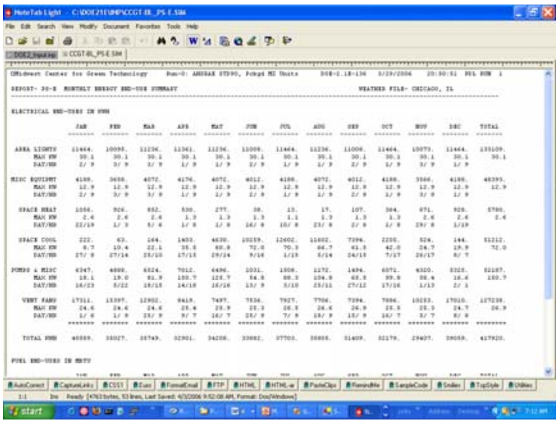

Fig. 22 shows the energy consumption data resulted from perform simulation.

4.5 Phase 5: Designed Interactive Software Interface that run on the Web Browser

The energy analysis and calculation results are sending to web browser for graphical user interface. There are many great benefits of using web browser graphic interface are that they enable designers and building professional to collaborate, share and improve the relationships of building parametric elements and systems that affect energy efficiency and sustainability of a building design on the internet. Energy performances are displayed in easily well-defined graphical forms. They can effectively communicate, link and apply information, test options, compare the scenarios, make quick decisions, and determine the most efficient solutions in minutes

<u>Thermal Performance</u>

Thermal design software interface is one of energy module interface that simulates the exchanges of heat through the outer skin of the building, and shows yearly estimates for the required heating and cooling energy, heat gain and heat loss through building components. The software provides the building energy performance and amount of energy electricity consumption (Kwh) and gas (Therm). Energy consumption is break down into lighting, equipment, space heating, space cooling, pump, and fan.

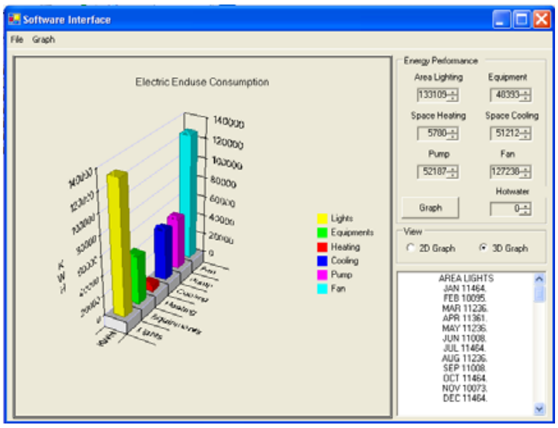

Fig. 23 Interactive software on the web browser displayed 3D graph of electrical consumption by end uses (kwh).

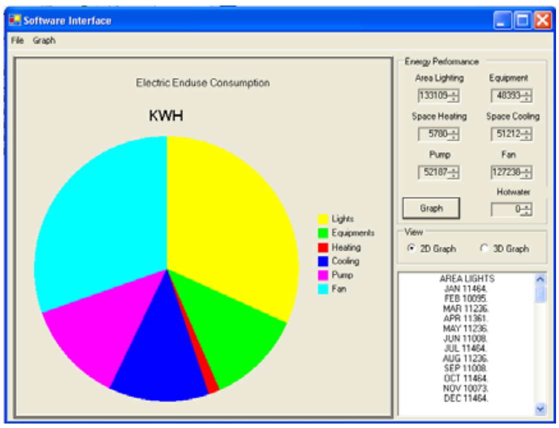

Fig.24. Interactive software on the web browser displayed 3D graph of electrical consumption by end uses (kwh) in 2D Graph.

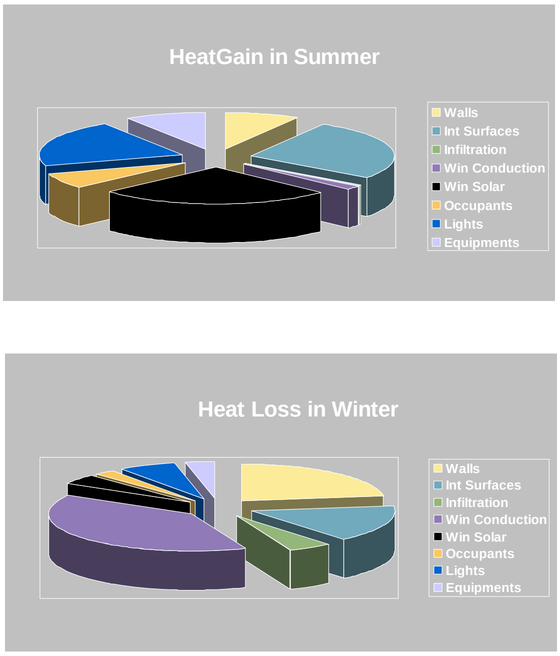

Figure 25 Heat Gain and Heat Loss through Building Components on Web Browser

Daylight factor software interface

Day-lighting predicts the distribution of sunlight in the room, according to time of day and location, and calculates a yearlong average of the amount of daylight projected onto work surfaces in the room. Day lighting then offers an estimate of the amount of electrical lighting energy required to make up for the lack of natural daylight in certain areas of the room. Since the software retains weather data for every hour of the year, in each of the cities where a user may situate his building, the modules are run on an hourly basis. Daylight factor result is plotted for each combination of window and reference point in a daylight space. The software interface provides daylight information for space, window, and reference point. Daylight factor is calculated by preprocessor for 20 values of solar altitude and azimuth covering the annual range of sun position at the location being analyzed. The software projected the results on a space working plane between the elevation and floor plan. The window's size, shape, and position are reflected from the CAD drawings and be able to updated both at the source or the interface program through editor.

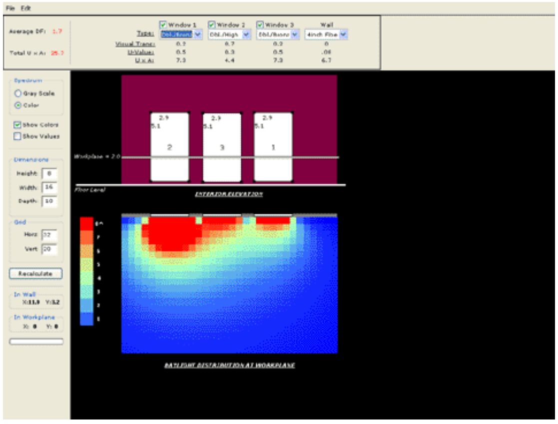

Fig. 26 Interactive software on the web browser displayed Daylight Factor projected on the room

5. CONCLUSION: RESULTS DISCUSSION

Virtual Model System (VMS) Framework is an enabling novel concept and unique AEC collaboration technology allowing full interoperability through shared information models and data modeling. The need for data interoperability and technological challenge to fully and bidirectional data sharing, updating, and reusing were reviewed. The innovative specifications and ability to link and share object-based model in CAD with performance-based model in energy simulation were introduced. The benefits of adopting Virtual Model System (VMS) Framework are the significant reduced time and effort spent in creating energy efficient building and sustainable design. A data model can be expanded to any other CAD application and energy simulation software.

The paper aims to present an innovative tool and system that map between building information models, like Autodesk Revit Building, and thermal simulation model, like DOE-2.1E. Data modeling specifications for building geometry, thermal zone, construction and material properties, and thermal design parameters, were discussed. A data mapping engine in Virtual Model System (VMS) Framework Server has been developed to accomplish the task of fully converting CAD information model to energy performance model on the web with capabilities that never has been done before. The work flow and the implementation of model mapping were presented, and the process of data mapping was demonstrated with the illustrative examples.

The results' data from the simulation and graphical interface can link to the fabrication model workshop to create a model of a prototype for energy efficient building assembly that meets the sustainable design and environmental standards. The design of the system, software, construction prototype, and public demonstration will form the research's final product. The research results will be made available to the field in a published book and report. The following is the list of results, findings, and products.

- The effective software management system that allows achieving collaboration efforts, communication, scheduling, and control;
- Database systems on the server, which serve as a center for data sharing, and;
- Interactive software for visualization, which is run on web-based browser, to ensure all parties that involved in the process have access to the energy analysis, simulation, and sustainable design interpretations.
- Energy efficient building assembly prototype model.

REFERENCES

[1] Autodesk AutoCAD Revit Building. Autodesk AutoCAD Revit Building Release 8.1, Software and Documentations, 2006.

[2] Bazjanac, V., Acquisition of Building Geometry in the Simulation of Energy Performance in: Proceeding of the 7th International IBPSA Conference, Rio De Janeiro, Brazil, August 2001, 305-312.

[3] Chaisuparasmikul,P. and R. J. Krawczyk , Innovative Software for Design of Building Envelope and Optimization of Day lighting in: CISBAT 2005 Proceedings, Renewable in a Changing Climate, Innovation in Building Envelopes and Environmental Systems, Lausanne, Switzerland, , 2005, 577-580.

[4] Chaisuparasmikul,P., Simplified Building Energy Analysis Tool for Architets, Ph.D Dissertation, Illinois Institute of Technology, 2005.

[5] Faraj, I., M. Alshawi, G. Aouad, T. Child, and J. Underwood . An Industry Foundation Classes Web-based Collaborative Construction Computer Environment: WISPER Automation in Construction 10, 79-99, 2000.

[6] Karola A., H. Lahtela, R. Hanninen, R. Hitchcock, Q.Y. Chen, S. Dajka, and K. Hagstorm, BSPro COM Server-Interoperability between Software Tools using Industrial Foundation Classes, Energy and Building 34, pp. 901-907, 2002.

[7] Lam, K.P., N.H.Wong, A.Mahdavi, K.K.Chan, Z.J.Kang, and S.Gupta, SEMPER-II: An Internet Based Multi-Domain Building Performance Simulation Environment for Early Design Support, Automation in Construction, 2004, 13(5), 651-663.

[8] Lam, K.P., N.H.Wong, L.J.Chen, E.Leong, ,W.Solihin, K.S.Au, Z.J.Kang and A.Mahdavi, Mapping of Industry Product Model for Detailed Thermal Simulation and Analysis, Report on Collaborative Research Project between National University of Singapore, novaCITYNETS Pte, Ltd., Temasek Polytechnic Singapore, and Carnegie Melon University,U.S.A. 2002.

[9] Winkelmann, F.C., B.E. Birdsall, W.F. Burl, K.L. Ellington, and A.E. Erdem (1993). DOE-2 Supplement Version 2.1E, Energy and Environment Division. Lawrence Berkeley Laboratory.