Innovative Approach of Integrated Building Enclosure and HVAC Systems Modeling to Improve Building Energy Efficient Design

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ABSTRACT

The paper primarily focuses on the innovative method of create a data model and exchange information system using generic, iterative, and recursive algorithms. This enabling interoperability technology provides a model framework of bidirectional information sharing and data reuse capabilities that links between building information, parametric relationships, and energy simulation through Virtual Model Environment Framework (VME) and Virtual Model System (VMS). A proposed VME and VMS are aimed to accomplish correct data format and work flow between building information, environmental conditions, and energy use. The purpose is to improve energy modeling and simulation of building enclosure system for heating, cooling, and ventilation. This is done while maintaining the integrity, quality, and standard of building's model, and increases the level of accuracy of the results. VME mitigates energy consumption and minimizes impacts on outdoor surroundings, and allows for the detailed thermal performance simulation of building envelope and HVAC systems. The paper addresses implementation issues concerning decreasing the time for iterations, data regeneration and duplication, and reducing possible interpretation errors by giving immediate design information feedback to the user. This design process substantially reduces the time and cost for simulating climate responsive buildings with complex building systems and control despite many unknown building parameters. VMS has a information exchange model that has database system and interoperable capabilities for the compliant applications, the smart models/contents/objects have been created to identify and validate their important elements and relationship, and rules for design guidelines to improve the design process, and scenarios to inform the creative process. The bidirectional data exchange capabilities enables design professionals to make better informed decisions concerning the energy performance of buildings and their sustainability.

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INTRODUCTION

During the past three 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 of building. Within these complex networks, most simulation software used was developed under different computer platforms using their own language. This makes it difficult to send and share information with a receiver who needs to view the information. Most architectural and engineering firms nowadays still rely on hand labor to query data, working from drawings, generating construction documents, specifications, schedules and work plans in the traditional way. Despite of the present building modeling integrity advancement to 5-dimensional modeling (2-dimension + space = 3-dimension + time + information = 5-dimension), most of the building energy simulation software are still using 2-dimensional building components modeling tool to perform energy analysis. Use of a 3-dimensional model of the building has been used primarily as a rendering tool, not as the actual working representation of the project. Today's drawings and physical models can be converted to digital form, and even full-scale construction can virtually be exchanged or shared with energy simulation tools

"The original focus of CAD applications was to represent 2D geometry via graphical elements, such as lines, arcs, symbols, et al. In this context, walls, for example, are merely represented as parallel lines. To establish some meaning behind these graphical elements, the concept of layering was introduced to group related elements, such as the lines used to represent walls on a given wall layer. By doing so, discrete 2D drawing files could be generated and plotted from CAD, but more complex information, such as the relationships between elements could not be represented. The emergence of 3D CAD initially focused almost entirely on creating geometry in support of visualization, and subsequent advances concentrated on creating realistic rendering, performance and lighting effects" (Howell and Batcheler 2003).

Since the early 1960's, the use of computer modeling and simulation tools by the building industry has steadily increased. These tools have progressed from simple, single task applications with limited input and output requirements (Howard 1960), to quite sophisticated modeling systems that can simultaneously analyze a range of performance parameters. In

1973, as a result of the energy crisis at that time, there was more emphasis on development of computation energy analysis tools. Some focus of development in this area has long been on the accurate simulation of fundamental physical processes such as the mechanisms of heat flow through materials and assemblies, and the transmission of light. Adequate description of boundary conditions for such calculations usually required very detailed mathematical models (Manning, 1987). For almost twenty years during which building design and energy simulation tools were being developed, new technologies emerged called Object-Oriented Building Information Systems, which are capable of representing the behavior of common building elements. These building elements can be displayed in multiple views, as well as having information attributes assigned to them. The inclusion of parametric 3D geometry, with variable dimensions and assigned rules, permitted the representation of complex geometric and functional relationships between building elements. In these systems, building design is no longer just a drawing on the paper but an object which contained elements, and associated properties. Abstracting the objects, such as a space, can be defined by the relationships between physical building elements, identified (e.g. room number, room name, etc.), described (e.g. area, volume, use, occupancy, etc.), and referenced (e.g. listed a room schedule, counted to calculate total floor area, etc.) (Howell and Batcheler 2003).

These new approaches strive to address the need to exchange more intelligent project data. These include IFC-based model exchange from International Alliance Industry (IAI) (i.e. to transfer objects, their relationships and associated property sets), 3D DWF from Autodesk and 3D support in PDF from Adobe, and XML software vendor such as Geopraxis or Green Building Studio, who developed Green Building XML (gbXML) schema that provides a standard exchange mechanism between sources of a building model and CAD information (including Architectural Desktop, REVIT, and ArchiCAD), and energy analysis and simulation products (including Energy Plus, and TRACE). GbXML has grown to support six different sources of BIM data (building information models) and nine different energy analysis/simulation products. Most of energy simulation software is still tied strongly with the CAD model. Up till now there are data inefficiencies and loss in the process due to the different algorithm and data structure between CAD model and energy simulation model. Building simulation takes longer time because of its nature to re-use project data and the iterative nature of the design process. Overcoming the lack of integrity, consistency, and coordination with the model and clash between these different models – is critical to the success of our profession and industry. There is increasing demand for open data and library standards and non-proprietary access to data. To be able to define a single building model as one authoritative semantic definition of building elements or parts, and to coordinate every building element in one database and to encapsulate related information and characteristics of different building parts or processes still remains an unresolved issue.

METHODOLOGY

The complexity of a building enclosure can be represented as an object oriented, where the building model, energy performance and parameters, and design variables are defined as classes, subclasses, and events. Data in building's objects (Both Graphics and Attributes) are stored as the instance of class (integer, double, float, string, Boolean or they can refer to objects in other class) which defines type of the object, as well as the kind of the operations that it performs. The operation that data can act on and objects can respond to are called method. VME and VMS use the abstract data type (ADT) class and generic algorithms in providing data exchange between building and energy performance simulation. The main **class** contains building enclosure and system's data that applies and links to energy, environment in the building of this **class**, and which can show class hierarchy where classes are derived from each other, and that determine which properties and function are inherited. Subclasses contain data that is specific to each subclass and inherit the properties and method of the classes which they are belongs. Building enclosure systems can be represented in the real world and tracked as operating and even driven object models.

Figure 1 illustrated VME and VMS as a framework and a set of tools in acquiring information and application program interface of data mapping, shared data model and software interoperability between the building model. Application Program Interface (API) provided the implementation which enabled the most efficient interoperability of information model. VMS used a framework API from VME to access model graphical and parametric data and extract information from building model that has been created, and store in the database. VMS use iterative and recursive algorithms to sort, link, map, query, bind and store data in the database in both instance and building type parameters, and design variables, thus create energy input parameters for pre-processing and input data model and simulation engine parameters for energy simulation. This process which allowed for the reusability of components or parts as a library can be called from multiple areas of the applications. VMS has the ability to link both graphical and numerical data and coordinate every building element in one database, thus providing users the ability to immediately see the results of any design revisions made in the model, have them reflected in the associated views (drawings), as well as to detect any coordination issues.

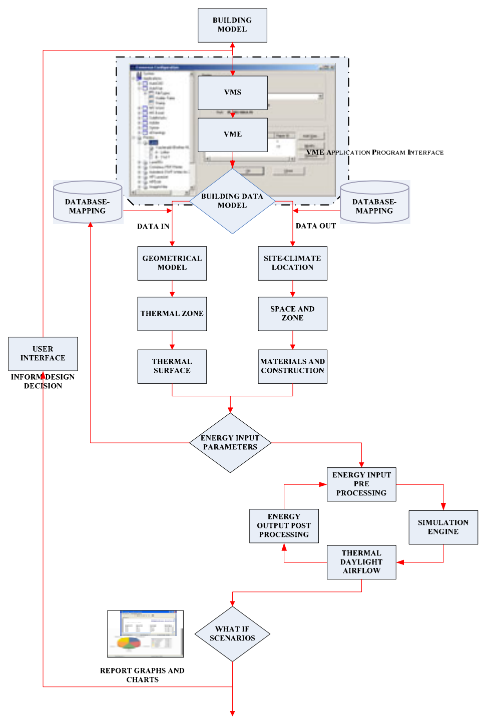


Figure 1. VME and VMS as a framework and a set of tools.

After constructing the building model as objects, the next step is to create a set of information or design criteria which represent a method and system of parametric information and how that data and information relate to other information that DOE-2 can understand. This set of parametric information consists of energy parameters for building envelope, HVAC systems and Plants. Using the iterative and recursive list model and search and sort algorithms, it is possible to extract this set of information, transferring or translating between the building model and energy input model for simulation. VMS provides the graphical and data exchange through Application Programming Interface (API) which linked with a database of project information and maintained throughout the life cycle of a building.the model

CASE STUDY:

The objective of this case study is to explore a prototype laboratory that is affordable, energy efficient, and sustainable, with healthy construction. This case study was the project I used to work on while I was working at the CADWorks company. The building model was created using Autodesk Revit Architecture 2008 and Revit Building System 2008. After a set of energy input parameters were created, all the data will be send to DOE 2.1E engine for energy simulation. The generic algorithm allows defining a class for a set of formal type's parameters. DOE-2.1E.considers spaces and zones that are not typically considered as rooms in an architectural model must be assigned Room components. This includes spaces such as attic spaces and the spaces between a ceiling and the floor above. The rooms in the building model should be defined to the center line of bounding walls and from floor height to floor height, so that there are no gaps between the spaces in a building.

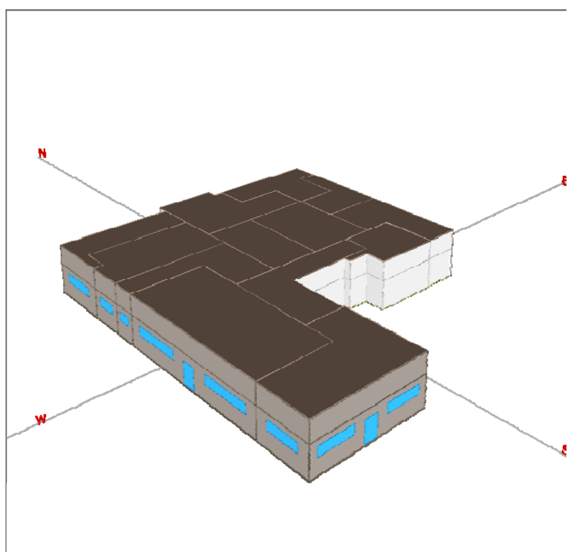


Figure 2. Object Representation of the Model Left: 3D Model and Plan

The followings are the set of parameters information to integrate building enclosure and HVAC system modeling and data exchange.

Climate Location

Model Phenomenon consists of building site, climate location and weather data. The site location is determined by the project site, location, climate location and weather data to match with energy simulation weather data. Chicago climate is in Latitude of 41.98, Longitude of -87.9, and Altitude of 658.136 feet above sea level, time zone (6) and provide necessary weather data, with very fluctuated in day and night temperature. Building orientation is the direction of the Plan to North or South

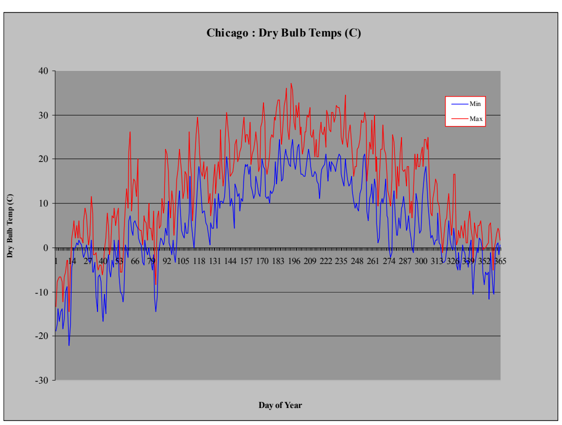
Table 1 Project Parameters

Project name and location:	Building type:	Building size	Floor to floor	Floor to ceiling
		ft²	Ft	ft
Griffinth Lombard, Illinois	Laboratory	25,198	15	10'-11"

Table 2. Optimum Solar Radiation facing South

Solar	M-btuh/ft2 for 8,760 Hours			10% of	M-btuh /	KW /	Total	Total
Rad.	MAX	AVG	SUM	SUM	ft2 / Yr	ft2/Yr	kwh/Yr	Mbtuh/Yr
Total	325.4	56.2	491,925	49,193	0.049	14.4	734,572	2,506
Direct	267.5	34.0	297,878	29,788	0.030	8.7	444,808	1,518
Total	333.6	58.9	516,044	51,604	0.052	15.1	770,587	2,629
Direct	276.9	36.1	315,875	31,587	0.032	9.3	471,683	1,609
Total	337.9	58.5	512,382	51,238	0.051	15.0	765,119	2,611
Direct	275.4	35.7	312,507	31,251	0.031	9.2	466,654	1,592
Total	330.7	54.9	481,217	48,122	0.048	14.1	718,582	2,452
Direct	271.4	32.9	287,940	28,794	0.029	8.4	429,969	1,467
Total	311.5	48.6	425,678	42,568	0.043	12.5	635,648	2,169
Direct	260.2	27.9	244,699	24,470	0.024	7.2	365,399	1,247

Based on Chicago (42° latitude)



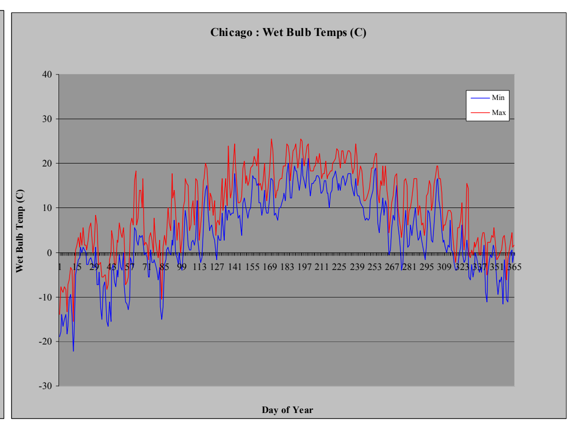


Figure3 Left: Chicago Dry bulb Right: Chicago Wet bulb

Building Geometrical Model

Building geometrical 3D model which served as the basis for establishing an energy input model consists of relevant geometrical, coordinate and topological data. It is equipped with attributes such as boundary conditions, footprint shape, an initial surface mesh, and a volume mesh. Figure 4 show that the building floor plan which has 59 rooms, 25,198 ft², one story 15'-0"high.To perform an effective energy analysis and simulation can only be done if the entire volume of the building model is included in a set of parameters information that sending to and from DOE$ 2.1E. The model is identified as a triangulation area, zone and space component graph, a graph of room faces, a room graph and a relational object graph, which explain algorithms to derive these relations.

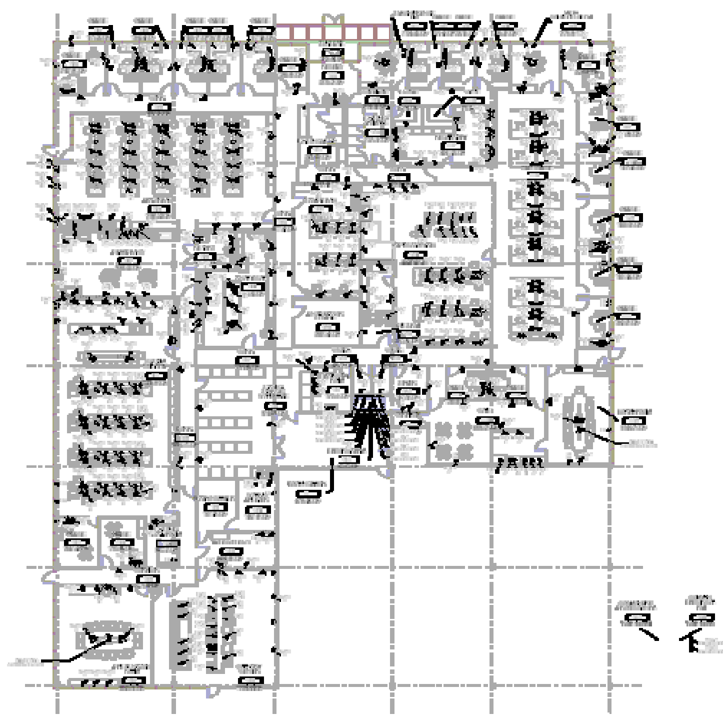


Figure 4 Building Floor Plan

Rooms or Space Geometrical Model

Building model was transferring and translated its geometrical, topological and coordinates data into floor area, rooms or space volume model, decomposing into a so-called connection model and then extracting volume bodies into elements and components. Air flow and thermal energy model are derived from rooms or space geometric model, and shows knowledge of linkage between model hierarchies where the coupling strategies are implemented. Figure 5 show the technique is demonstrated within the scope of building energy simulation by dividing the space into zones for setting up a thermal multi-zone model and a geometrical model. The algorithm is basically applicable to any building energy simulation software tool. Room parameters are definable spatial relationships, which can show the relationship between any elements, properties and space in a floor plan.

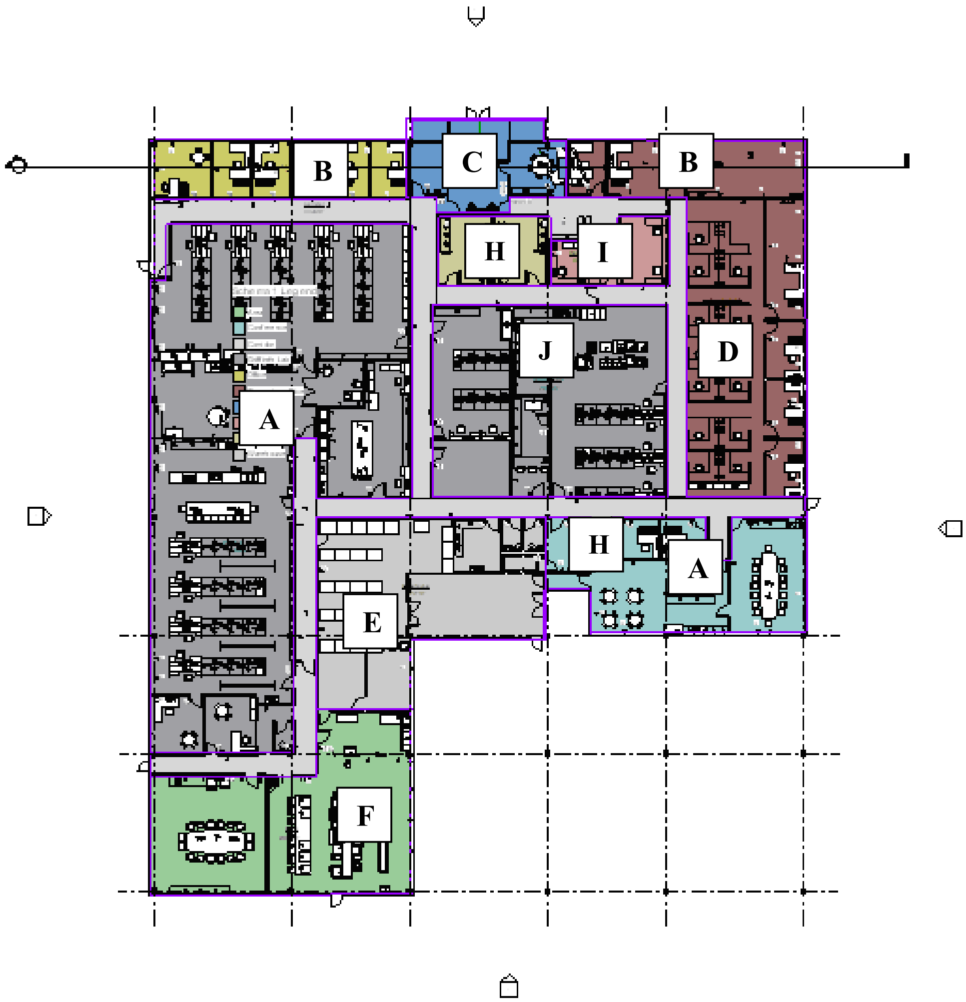


Figure 5 show the technique is demonstrated by dividing the space into zones

HVAC Thermal Zone Model

Thermal zone model in turn is a dimensionally reduced model. It can be described by an geometric representations of thermal zones, and for each thermal zone that enclosed heat transfer surfaces, which represents the building structure in a hierarchical manner, i.e. the model is organized in building level, rooms, building components, layers, materials, etc The prerequisites for establishing a numerical coupling between both approaches are incidence matrices relating models and components. In other words, a CFD and HVAC simulation requires volume bodies of air volumes together with boundary conditions while a thermal multi-zone simulation.

Thermal Surfaces

Thermal surfaces refer to heat transfer surfaces to describe the thermal representations of building surfaces, such as walls, roof, windows, doors, ceiling, and floor. Each surface has some attributes to determine its interaction between internal and external environment. The surfaces in Table 5 allow to fill information regarding surfaces to represent inter zone heat transfer. Thermal surfaces are the basic ingredients of the thermal simulation. A simulation project aggregates a number of zones, where the latter aggregate one or more air volumes. Air volume objects are aware of the corresponding set of adjacent bodies and their semantics. Structural elements themselves are composed of a multilayered structure with respective individual materials. Although they form part of the geometric model, we also tore the surface geometry and vertex coordinates.

Table 4 surface geometry and vertex coordinates.

Space Zone	Block	Area	Zone Origin			Perimeter
		ft²	X	Y	Azimuth	
Griffinth Lab 1	A	6805	0' 0"	49' 10"		430' - 4 5/32"
Office	B	953	0' 0"	175' 10"		157' - 1 5/8"
Reception	C	829	65' 6"	175' 10"		128' - 8 19/32"
Open plan office	D	3183	129' 8"	99' 10"		301' - 0 13/16"
Warehouse	E	2207	41 2"	45 5"		212' - 8 3/16"
Kitchen Dining	F	2385	0' 0"	0' 0"		225' - 4 7/8"
Conference	G	1689	99' 8"	65' 8"		234' - 9"
Toilet	H	490	70' 3"	153' 11"		91' - 3 13/32"
Regulatory	I	422	104' 0"	153' 11"		95' - 2 3/16"
Griffinth Lab 2	J	2906	70' 3"			216' - 9 7/16"
Corridor	K	3329				866' - 5 1/32"
Grand total: 11		25198				

Building Construction and Materials

The other fundamental requirements for conducting thermal, daylight, airflow, and energy simulation include physical constructions and the thermal material properties and parameters of building elements. One of the great capabilities of data mapping in VME Framework is directly acquired building element construction and materials properties from BIM model, and retrieved and queried directly to create DOE-2 input for energy simulation. Figure 5 shows the building elements (walls, windows, roof, floors, doors, ceilings, and skylight) that are physically configured with layers of materials. Each layer, form outside to inside, is described with thermal and other material properties and parameters.

Table 5 allow to fill information regarding surfaces to represent inter zone heat transfer.

Space Zone	Block	Total Surface Area	Wall-Area	Glass-Area	Door-Area	Dor+Glss	% Area of Activity
		ft²					
Griffinth Lab 1	A	6805					27.00
Office	B	953					3.78
Reception	C	829					3.29
Open plan office	D	3183					12.64
Warehouse	E	2207					8.75
Kitchen Dining	F	2385					9.46
Conference	G	1689					6.70
Toilet	H	490					1.95
Regulatory	I	422					1.67
Griffinth Lab 2	J	2906					11.53
Corridor	K	3329					13.21
Grand total: 11		25,198					

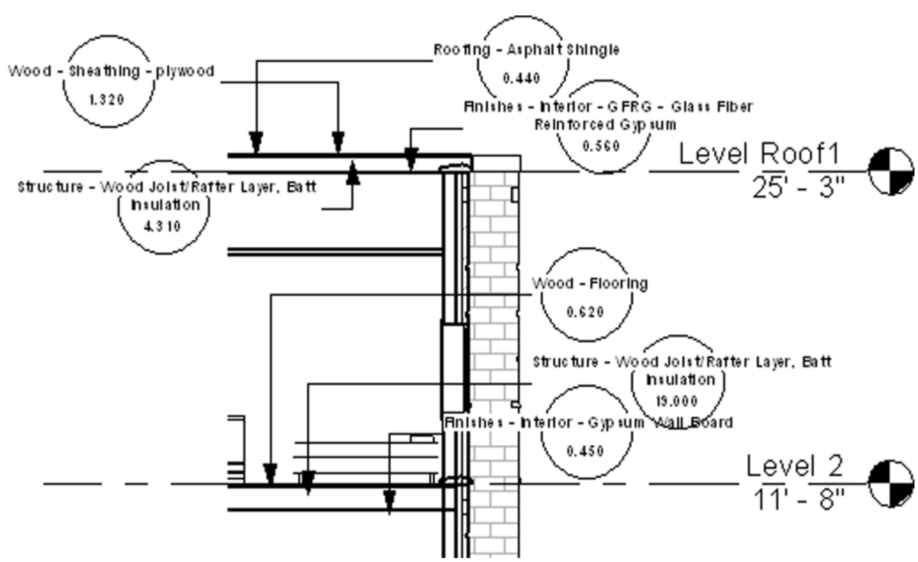


Figure 6 Section show the building assemblies and materials

Table 6 Baseline ASHRAE standard 90.1 and proposed material and construction values for building enclosure

Exterior Envelope		
Parameter	**0 = Baseline STD90.1**	**1 = Proposed**
Exterior Walls	8 In. Light Weight Concrete Block (U=0.084)	8 In. Light Weight Concrete Block (U=0.060)
Interior Walls	Frame Partition With 0.75 In. Gypsum Board (U=0.2589)	Frame Partition With 0.75 In. Gypsum Board (U=0.2589)
Slabs	Un-Insulated Solid-Ground Floor (U=0.125)	Un-Insulated Solid-Ground Floor (U=0.125)
Roofs	4 In. Light Weight Concrete (U=0.2254)	4 In. Light Weight Concrete (U=0.2254)
Floors	8 In. Light Weight Concrete Floor Deck (U=0.2395)	8 In. Light Weight Concrete Floor Deck (U=0.2395)
Doors	Metal Door (U=0.6516)	Metal Door (U=0.6516)
Exterior Windows	Large Double-Glazed Windows (Reflective Coating) Glass (U=0.46, SC=0.31, SHCC=0.265, Vis=0.65,)	Large Double-Glazed Windows (Reflective Coating) Glass (U=0.29, SC=0.31, SHCC=0.265, Vis=0.65,)
Interior Windows	Large Single-Glazed Windows (U=0.6498)	Large Single-Glazed Windows (U=0.6498)
Skylights	Large Double-Glazed Windows (Reflective Coating) - Industry (U=0.5636)	Large Double-Glazed Windows (Reflective Coating) - Industry (U=0.5636)

Specify Space and Zone Parameters for Energy Analysis and Simulation

Room instance parameters that were used for energy analysis and simulation and calculating heating and cooling loads are

- Condition type or the type of conditioning for the room which consisting of the followings;
    - Heated

- Cooled
- Heated and cooled
- Unconditioned
- Vented
- Naturally vented only

- Airflow consists of supply, return, and exhaust airflow.
    - Supply airflow is the sum of the supply airflow for all the supply air terminals in the room.
    - Return airflow is the return airflow for all the return air terminals in the room.
    - Exhaust airflow is the sum of the exhaust airflow for all the exhaust air terminals in the room.

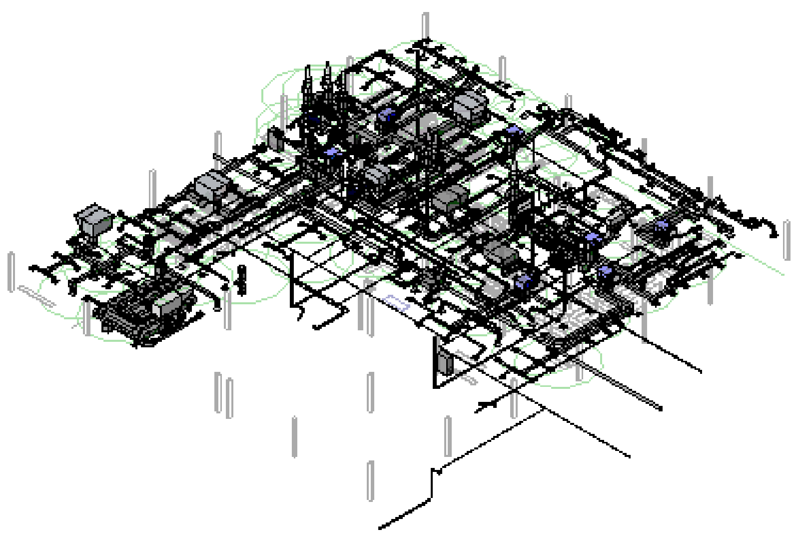


Figure 7 HVAC System Model

- People Loads is the people in the room occupying a space, which consist of
    - Number of People to specify a value based on the number of people assumed to occupy the room for load calculations.
    - Area per Person to specify a value based on the area allotted per person.
    - Sensible Heat Gain per Person - the portion of the heat gain directly given off by people occupying the space.
    - Latent Heat Gain per Person - the load is associated with the water vapors given off by people occupying the space.

- Lighting load is the sum of the lighting load for all the lighting fixtures within the space. The value can be expressed as Watts or Watts per area or Lighting Power Per Area

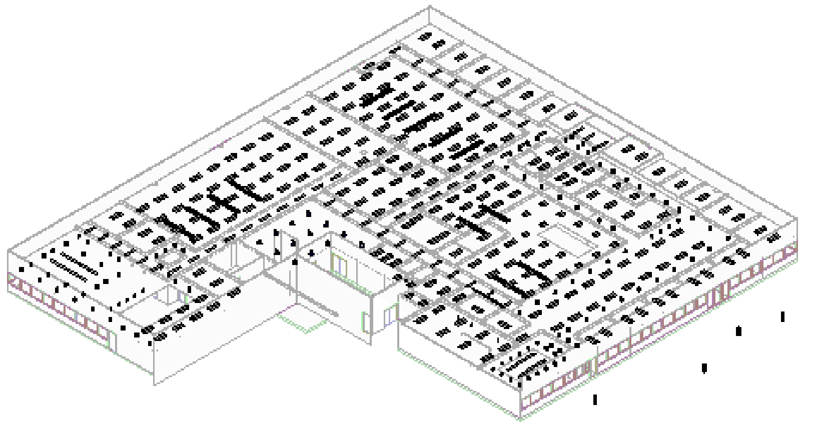


Figure 7 Lighting System Model

- Power Load is the sum of the power load for all the electrical devices within the space.

- Electrical Load is the electrical loads in the room. It lets you specify the loads imposed by lighting and power for a space. The value can be expressed as Watts or Watts per area, or Equip Power Per Area

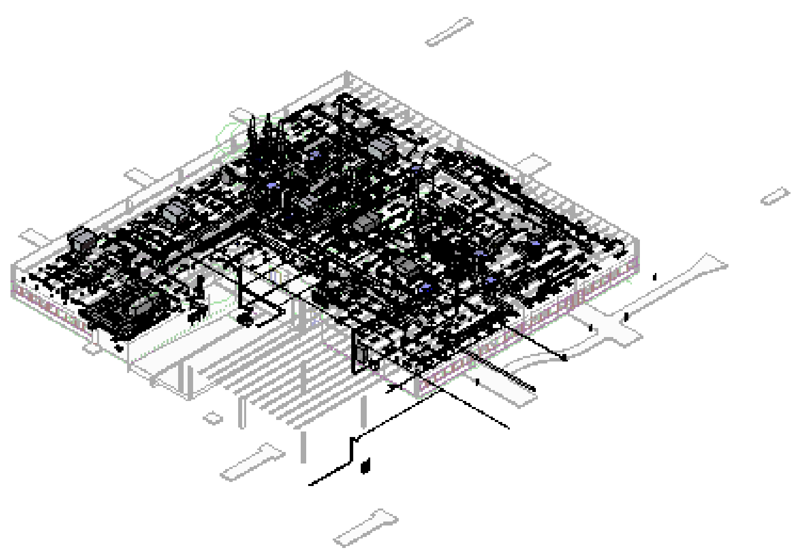


Figure 7 Power System Model

For the detail of the result, please see the APPENDIX.

ANALYSIS, RESULTS AND FINDINGS

Reusability of components as a library that can be called from multiple areas of the applications and application interface allowed the model to interact with the simulation data and match with the simulation parameters in DOE2, and predicts the hourly energy use and energy cost of a building given hourly weather information and a description of the building, and its HVAC equipment and utility rate structure. DOE2 will calculate the heating and cooling loads necessary to maintain thermal control set points, conditions throughout a secondary HVAC system and coil loads, and the energy consumption of primary plant equipment to verify that the simulation is performing as the actual building would. Designers can determine the choice of building parameters that improve energy efficiency while maintaining thermal comfort and cost-effectiveness. The purpose of DOE-2 is to aid in the analysis of energy usage in buildings; it is not intended to be the sole source of information relied upon for the design of buildings: The judgment and experience of the architect/engineer still remain the most important elements of building design. Basically, DOE-2 has one subprogram for translation of input (BDL Processor), and four simulation subprograms (LOADS, SYSTEMS, PLANT and ECON). LOADS, SYSTEMS and PLANT are executed in sequence. DOE-2 needs input files, which describe the building model and the environment surrounding it. The program produces several output files, with the output of LOADS becoming the input of SYSTEMS, and PLANT etc. The output then becomes the input to ECON. Each of the simulation subprograms also produces printed reports of the results of its calculations.

DISCUSSION

The results obtained from building simulation were aimed to improve the building energy demand and performance simulation to the next level of Zero Energy Consumption. Energy simulations can assist architects and engineers in optimizing their design and in minimizing its environmental impact. By adjusting the “What if scenarios” or “Informed design decision” strategies according to simulation results, and running further simulations based on the adjusted design, an iterative process can help to increase the design quality. Continue feeding the simulation results to the interfacing design options as the scenario model to inform the designs, architecture design process can be improved, and building energy efficient design can be enhanced by their performance as much as by their appearance. The results, which are in the form of reports and graphs, will be displayed in Virtual Model User Interface's web browser. The followings were the results that converted into ready to use data and graphical interface;

What-If scenarios (figure 9) are two dimension pie graph of annual energy consumption and three dimension bar graph of annual energy consumption There are 4 options; option-1 is energy baseline which helped to ensure that buildings meet a minimum standard of energy efficiency (Figure 9); option-2 is the energy consumption (from lights, equipmens, space heating, space cooling, ventilating air flow, pumps, and fans) resulting from installing ground loop heat pump ; option-3 is the energy consumption resulting from installing high performance glazing ; option-3 is the energy consumption resulting from installing shaidng devices. option-4 is the energy consumptions resulting from installing photovotaics.
Figure shows "What if scenarios" or "Informed design decision" strategies

Figure 13 Left: shows space cooling and heating demand (Joule/second) for each zone; Right: Zone air available (cubic meter/minutes) in relation to outdoor air requirements for each zone.

Figure Left: shows daylight available in foot candles for each space. According to the LEED NC 2.2 Credit 8.1 requirements, to pass the standard required requires 75% or more of the total area to be over the threshold. In this case it was 90.6%. Right: shows natural daylight comparison between the alternative testing options e.g. using high performance glazing, sun space, and skylight.

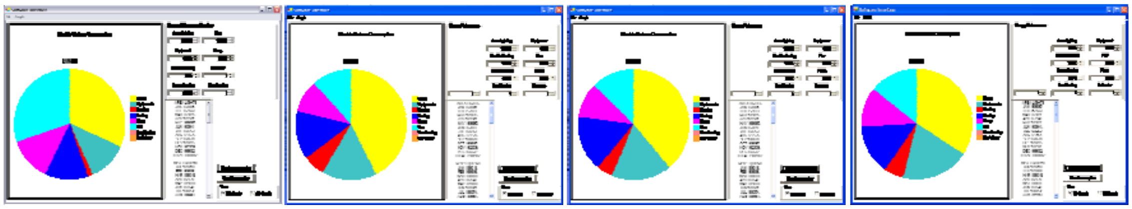


Figure 8"What if scenarios" or "Informed design decision" strategies

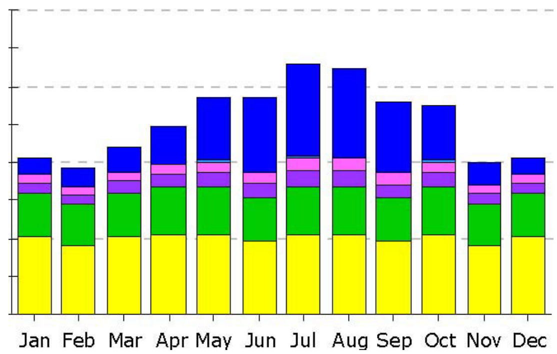


Figure9.Monthly electric consumption

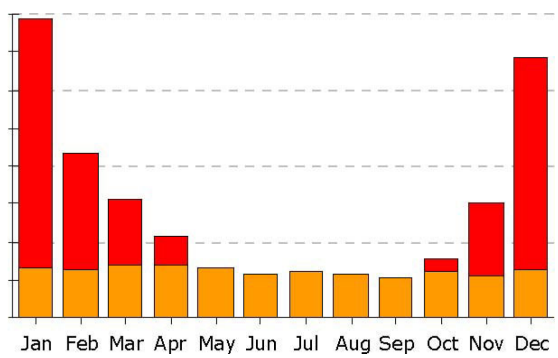


Figure10.Monthlygas consumption

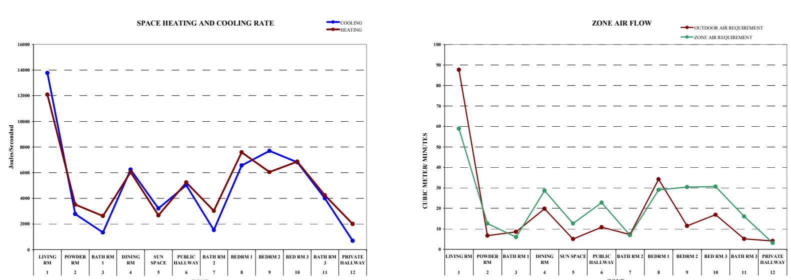


Figure 11 Left: shows space cooling and heating demand (Joule/second) for each zone; Right: Zone air available (cubic meter/minutes) in relation to outdoor air requirements.

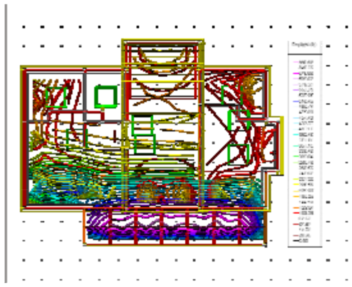
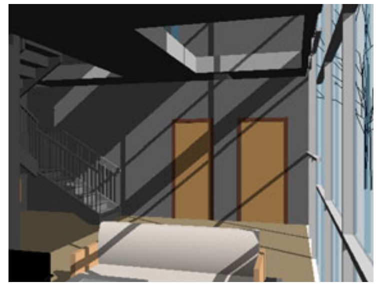
 

Figure12 Left: shows daylight available in foot candles for each space. Right: shows natural daylight comparison between the alternative testing options e.g. using high performance glazing, sun space, and skylight.

CONCLUSIONS

The innovative specifications and ability to link and share object-based model in BIM with performance-based model in energy simulation were introduced using data modeling and application framework. API specifications for modeling and mapping data of building geometry, thermal zone, construction and material properties, and thermal design parameters were discussed. A data mapping engine in VME framework server has been developed to accomplish the task of fully converting building information model to energy performance model. The work flow and the implementation of model mapping were presented, and the process of data mapping was demonstrated with the illustrative examples. The benefits of adopting VME Framework and VMS 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.

This new method of extracting, sharing, and querying data and parameters using an existing project, is presented as shared and unshared so all involved can be relational, and all the criteria can be set to achieve an indoor environmentally friendly and energy efficiency alternatives can be explored and better solutions involving the idea of sustainability can be developed.

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