U.S. General Services Administration
Public Buildings Service

March 2012

This version of the "GSA Building Information Modeling Guide Series 05 – Energy Performance is identified as Version 2.0. With its publication, a GSA BIM Guide pertaining to energy performance becomes available publicly for review and comment. It will continue to serve as the basis for further development, pilot validation, and professional editing. All readers of this provisional guide are encouraged to submit feedback to the National 3D-4D-BIM Program. Updated versions will continue to be issued to address and incorporate on-going feedback in an open and collaborative process.

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BIM Guide for Energy Performance

GSA BIM Guide Series 05

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GSA Building Information Modeling Guide Series

05 - GSA BIM Guide for Energy Performance

Version 2.0 — March 2012

United States General Services Administration (GSA)
Public Buildings Service (PBS)
Office of Design and Construction (ODC)

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BIM Guide 05: Energy Performance

Foreword:

The United States General Services Administration (GSA), through its Public Buildings Service (PBS), provides and maintains quality workplaces for over a million Federal associates in approximately 8,500 owned or leased buildings across the United States. Through facilities managed by GSA, Department of Defense (DOD), Veterans Administration (VA), Bureau of Prisons (BOP) and other agencies, the Federal Government is the largest consumer of energy in the Nation, consuming a total of approximately 14.9 trillion BTUs per year at a cost of over $250,000,000 annually.[1]

Existing Mandates

GSA facilities are required to meet a number of energy and water management goals mandated through Executive Orders, legislation and other requirements addressing energy conservation.[2] Executive Order 13423 is a national initiative to reduce the average annual energy consumption of the GSA's building inventory. Specifically its goal is to reduce facility energy use per square foot (including industrial and laboratory facilities) by 3 percent per year through the end of 2015 or by 30 percent by the end of FY 2015, relative to 2003 baseline. To achieve this goal, GSA's inventory must reach a metered annual energy consumption of approximately 55,000 BTU/GSF. In addition, the Energy Policy Act of 2005 (EPACT 2005) requires that federal buildings be designed to use 30% less energy than they would by complying with ASHRAE Standard 90.1, and increase the renewable electricity consumption by the federal government to at least 3 percent in FY2007-FY2009, 5% percent in FY2010-FY2012, and 7.5% in FY2013 and each fiscal year thereafter. The Energy Independence and Security Act of 2007 (EISA 2007) requires GSA to reduce designed energy consumption with respect to the average commercial building energy usage as determined by the Department of Energy's Energy Information Agency. Starting in 2010, GSA must use 55% less energy than the average, and through incremental decreases every five years, by 2030, it must construct all new facilities to be net zero energy buildings. Finally, EISA 2007 stipulates that every 5 years, GSA must select a third-party green building certification system and level, to facilitate the overall sustainable performance of GSA's new and modernized buildings.

GSA Goals

To meet these goals, GSA is exploring the use of BIM in energy modeling practices to strengthen the reliability, consistency, and usability of predicted energy use and energy cost results. Specific benefits to a project team using BIM related energy and operation tools may include: more complete and accurate energy estimates earlier in the design process, improved life-cycle costing analysis, increased opportunities for measurement and verification during building occupation, and improved processes to achieve high performance buildings.

Introduction: Energy Performance

GSA's mission is to "help federal agencies better serve the public by offering, at best value, superior workplaces, expert solutions, acquisition services and management policies." Within GSA, PBS manages over 352 million square feet[3] of workspace for the civilian federal government and uses 14.9 trillion BTUs of energy on an annual basis to keep these workspaces functioning. GSA PBS Office of Design and Construction Programs provides leadership and policy direction to all 11 GSA regions in the areas of architecture, engineering, urban development, construction services, and project management.

Much interest exists at GSA and in the building industry in general to advance sustainability throughout building lifecycles. While many opportunities for reduced environmental impact can be realized during design and construction, building occupation holds the highest potential for efficiencies resulting from shared information and interoperability. As a building owner and manager, GSA is committed to maximizing efficiency and energy performance without sacrificing occupant comfort and productivity. This Series is intended to promote efficiencies using BIM technologies during all phases of a building's lifecycle: pre-design, design, construction, and operation. Of particular interest is the achievement of operational efficiencies through better energy modeling techniques and superior facility management practices.

Series 05 (Energy Performance) is intended for GSA associates and consultants interested in using BIM practices to improve thermal performance in new construction and major modernization projects, or in owned or leased buildings managed by GSA. The main goal of this BIM Guide Series is to highlight the opportunities and provide best-practice guidance to project teams for achieving improved energy and thermal comfort performance of GSA's current and future building stock through the use of emerging BIM-based energy modeling technologies. It is intended to increase the usability and accessibility of BIM-based energy modeling technologies for GSA project teams throughout the building lifecycle with the goal of improving the accuracy and consistency of energy estimates and the efficiency of actual building performance through the implementation of BIM-related technologies as applicable and productive during design, construction, commissioning, and operations.

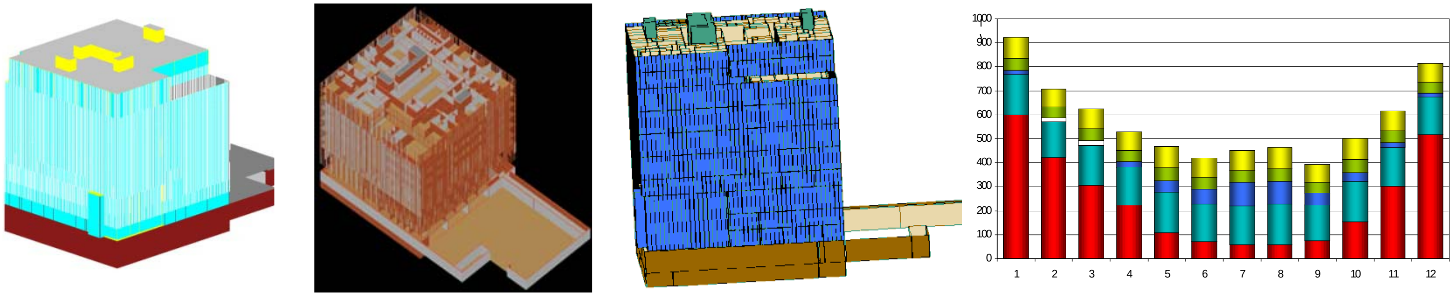


Figure 1: Energy Modeling from GSA Pilot Project

Series 05 (*Energy Performance*) is divided into three main sections:

Energy Modeling for Design, Construction, and Operations: This section details the factors that a project team must consider when evaluating and/or implementing BIM-based energy modeling during the design, construction, and operations of a project. The role of BIM-based energy modeling during these phases is discussed.

Energy Modeling and BIM: This section details the role BIM plays in the energy modeling process, and the issues that should be considered when conducting a BIM-based energy analysis.

Energy Modeling Case Studies: This section includes case studies that describe the building energy modeling process for different GSA projects and how BIM was leveraged to achieve the project goals.

1 Energy Modeling for Design, Construction, and Operations

1.1 Overview

This section is intended for GSA associates to evaluate the use of BIM-based energy modeling during the design, construction, and operational phases of their projects. It describes the types of business needs and goals addressed through energy modeling, how energy models can be used throughout the project lifecycle, and identifies the main factors for consideration. First, a brief background on energy modeling is given. Second, an overview of the decision-making process for including BIM-based energy modeling techniques on a project is discussed. Third, a summary of how BIM-based energy modeling differs from traditional energy modeling is provided. Finally, opportunities and feasibility of the implementing these methodologies are considered.

1.1.1 Energy Modeling - A Background

Energy consumption in buildings is the result of a complex set of interrelationships between the external environment, the shape and character of the building components, equipment loads, lighting, mechanical systems, building envelope, and air distribution strategies. Building optimization, achieving the greatest possible efficiency and environmental soundness with the least expenditure of resources, requires an understanding of these interrelationships and an integrated “whole building” design process. These relationships are difficult to predict without the use of computers and energy simulation tools.

Building energy simulation is a powerful method for studying energy performance of buildings and for evaluating architectural and mechanical designs. Energy simulation modeling allows the design team to evaluate the thermal impacts of various design options that are being considered, and to develop an effective building form and design strategies. Complicated design problems can be investigated and their performance can be quantified and evaluated using computer simulation models. This process can reveal synergies, trade-offs, cascading effects, and other interrelationships that could otherwise not be recognized and managed effectively using non-computerized methods.

Calculation of building thermal loads and energy consumption is required to determine the energy characteristics of the building and systems. Load calculation will determine peak design loads for equipment and plant sizing, while energy simulation will estimate annual energy requirements for the facility. Simulation results provide information on building energy consumption and utility costs, indoor environmental conditions, and thermal comfort.

Energy simulation tools typically consist of a graphical user interface (GUI) and a thermal calculation engine. The simulation engine requires the user to provide inputs giving a description of the building geometry and layout (including thermal zoning, which is discussed later), construction, operating schedules, equipment loads (lighting, equipment, etc.), heating, ventilating, and air-conditioning (HVAC) systems, local weather data, and utility rates (Figure 2). It performs an annual hourly simulation (minimum 8760 hours per year), first calculating the building loads and then calculating the system capacities required to meet those loads.

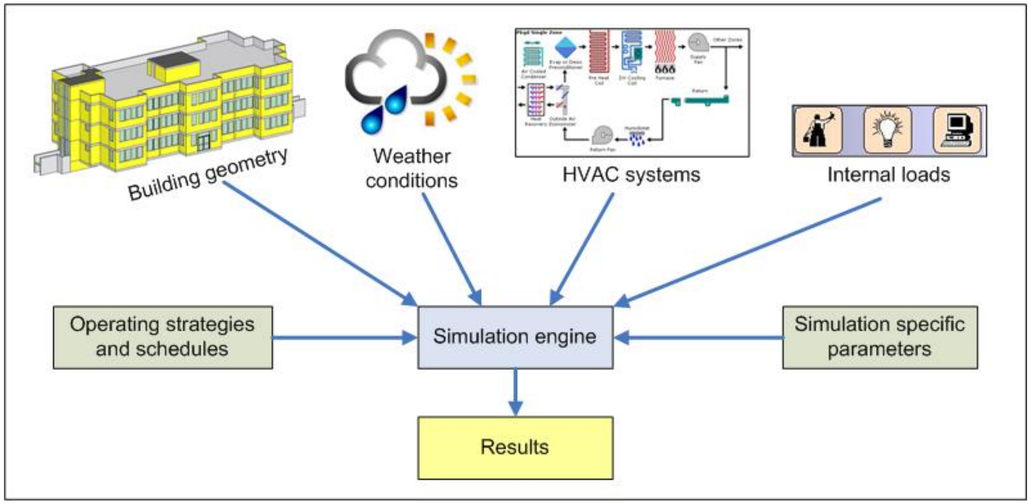


Figure 2: General data flow of simulation engines[4]

The thermal calculation engine is based on thermodynamic equations, principles, and assumptions which attempt to predict the actual thermal processes occurring in a building. The general data flow principle between simulation engines and the GUI is illustrated in Figure 3. The simulation engine uses an input file (or files) of a defined format that contains a representation of the previously described input. Based on this input, the engine performs a simulation and writes its output in one or more output files. While the output files contain results from the simulation, they also contain information about the simulation run itself, such as warning messages or additional information to evaluate the input. Graphical user interfaces usually wrap around this process and provide easier input for the user, initiate the simulation with the engine, and process the output files to illustrate results in a more graphical manner.

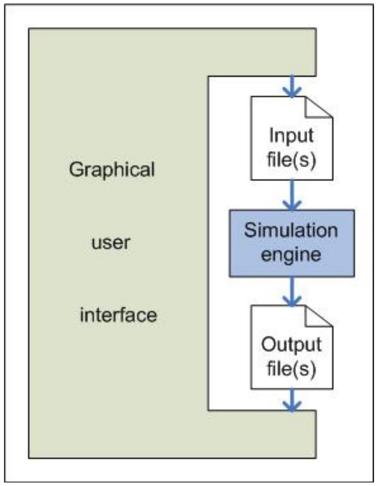


Figure 3: General architecture of energy simulation tools[5]

The motivation behind accurately being able to predict the heating and cooling loads of a proposed design, and the energy required to meet those loads, is to provide the required indoor conditions for building occupants and equipment in an efficient manner, to optimize the building materials and system performance, and to compare design options based on lifecycle costs. Load calculations shall properly address diversities within the building thermal loads (based on maximum simultaneous system loads due to operating schedules) to avoid over sizing of equipment, which decreases efficiency. With an enhanced understanding of how the built environment impacts our health, environment, productivity, and overall well-being, it is clear that more attention is required in how we design our working and living environments.

1.1.2 The Decision-Making Process

Figure 4 shows the recommended steps in the decision-making process for a project team considering the use of energy modeling and possible BIM-based energy modeling. First, the project team must define their business needs. Second, candidate software applications must be identified. Next, an iterative process of scope definition and refinement should accompany the consideration of software. Finally, the implementation and evaluation options are addressed.

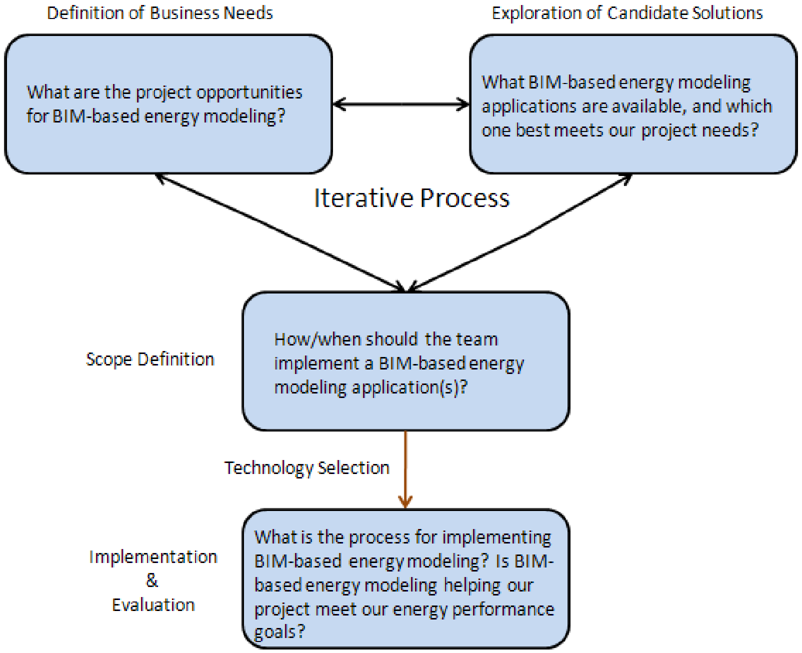


Figure 4: Process for adopting energy modeling

1.1.3 Traditional Energy Modeling vs. BIM-Based Energy Modeling

To understand the benefits of BIM-based energy modeling, one must first understand how it differs from traditional energy modeling. When we speak of "traditional" energy modeling, we refer to energy modeling practice that adheres to the following process: an energy modeler uses information from drawings, specifications, photos, or other project data available on the proposed or existing architectural design to independently construct a model within the energy simulation program. The energy modeler creates this model using either a graphical user interface (GUI) to the simulation engine, which is simply an input process to the engine, or by creating in input file directly using a text editor. All required parameters such as space loads (lighting, equipment, and occupant), HVAC systems, operating schedules, etc. are input by the modeler directly or using a GUI. Many times, simplifications to the proposed geometric design are made to make the input of the design into the simulation program manageable. Restrictions of the simulation programs may also require simplifications be made to operating schedules (such as "averaging" the lighting schedule for a floor, rather than assigning a more accurate lighting schedule to each space), thermal zoning schemes (assuming two thermally different spaces are one thermal zone), and other input parameters. Such simplifications result in building models that serve as limited approximations of the building as understood by the modeler. Misinterpretations of the building geometry from the CAD in energy model translation can also occur, and these misinterpretations are often inconsistent and do not conform to industry energy performance rating methods (such as contained within ANSI/ASHRAE/IESNA Standard 90.1). Furthermore, if the building design changes, such as the building geometry, the energy model must be revised directly, which currently requires manual duplication of the modification through changes to the geometry in the energy model. All these factors result in a very time consuming process for architects and engineers.

Energy modeling using BIM has the potential to simplify the process described above by leveraging building information that exists in the architectural or mechanical models created by the project design team. This information may include geometric data, construction types and the associated thermal properties, space loads, as well as other useful simulation parameters. Leveraging this data to eliminate duplicate construction of, or revisions to, the energy model can potentially reduce the time required to construct the energy model and improve its accuracy. Also, by using BIM, the process of creating an energy model has the potential to become automated and formulaic, so that, at the very least, the geometry and other assumptions specified in the architectural model remain consistent across users and are not subject to interpretation or improper simplification. However, a process must be adopted that ensures accuracy of the information transfer to the energy model using BIM, or the problems associated with traditional energy modeling described above will not be avoided, and may even be exacerbated. BIM-based energy modeling is discussed in more detail in Section 2.

1.1.4 Opportunities

In new construction, major renovation, and building operations, one area of major concern for GSA and the building industry is energy efficiency and building performance. The following table shows some opportunities to use BIM-based energy modeling during design to promote energy efficiency:

Table 1: BIM-Based Energy Modeling Opportunities

Project Type	Project Challenge	Goal	Metrics for Success
New Construction and Major Renovation	Accurate analysis and prediction of building performance during design, construction, and operations	Consistent and accurate energy predictions that result in energy efficient designs based on life-cycle costing	Life-cycle cost and estimated annual energy consumption that meets or exceeds project goals, accuracy and consistency in energy models
Renovation and Modernization	Accurate modeling of as-built conditions, calibration of energy models, reliable evaluation of existing mechanical design and performance	Consistent and accurate energy predictions that result in the identification of the most cost effective energy efficient retrofits	Life-cycle cost and estimated annual energy consumption that meets or exceeds project goals, accuracy and consistency in energy models
Existing Building	Continuous commissioning using real-time energy modeling to evaluate actual future building performance	Develop an energy modeling feed-back loop which evaluates building performance in real-time	Optimized energy performance, meeting or exceeding design intent, accuracy and consistency in energy models

1.1.5 Feasibility

1.1.5.1 Overview

The following figure represents project level decisions that need to be made in regard to incorporating BIM-based energy modeling into a specific project.

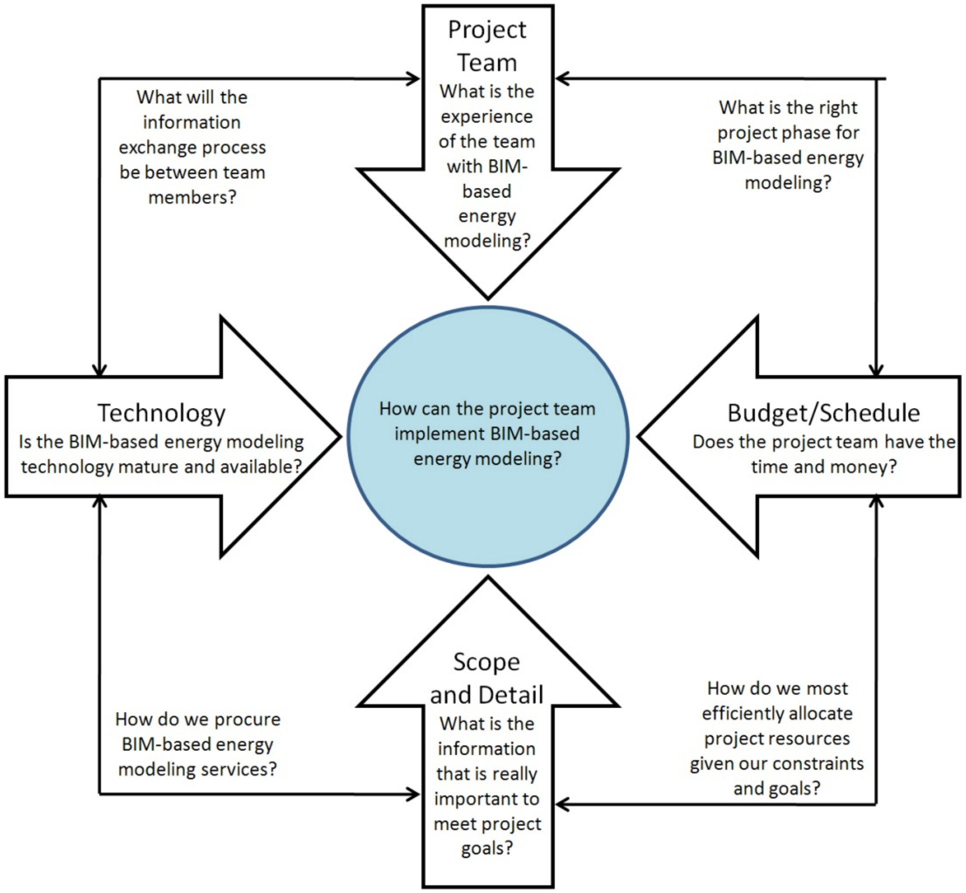


Figure 5: Decision Loop for Implementing Energy Modeling

1.1.5.2 Project Team

Energy modeling is not a stand-alone process, but is intended to support integrated design. Integrated building design is a process in which multiple disciplines and design elements are integrated to allow for synergies between the various systems and components. Successful realization of this process requires coordination and collaboration between the owner, developer, architect, mechanical, electrical, and structural engineers, landscape architect, and any other relevant design team members throughout the entire design process. Integrated Project Delivery (IPD) allows design teams to make design decisions earlier in the project when the opportunity to influence positive outcomes is maximized and the cost of changes is minimized, as is shown in Figure 6.6 The decisions made at the earliest stage of the design process often have most impact on the building performance in terms of energy and sustainability. As the GSA and building industry's concern for energy-efficient and sustainable buildings grows, the need for building performance information and the adoption of the IPD process will likely increase to facilitate a greater degree of holistic performance assessment into the process.

Energy modeling itself is a complex activity, which requires a certain level of engineering experience and judgment to be successful. For example, currently throughout the industry, a high degree of variability exists between predicted and actual energy performance,[7] and between individual energy modeler's results.

In general there are two approaches to energy modeling in support of integrated design: early conceptual/schematic studies and more detailed design analysis during later stages of design and construction. Many building analysis strategies and software applications allow more simplistic energy modeling during the early design stages, and also support more detailed analyses for later stages. Although it depends on the details of the particular building and systems, simplistic energy modeling is typically not accurate enough for detailed design and cost analysis, it can be useful in rapidly screening high-level concepts, particularly from an architectural standpoint. Project teams need to exercise caution and manage their expectations when interpreting the results of simplistic energy models to avoid misinformation from being used in the design process.

1.1.5.3 Budget/Schedule

With increased attention to the sustainable design of buildings, more and more design teams are enhancing their in-house energy modeling expertise and/or working more with consultants to meet their clients' modeling demands. This phenomenon, in conjunction with the continued development and improved usability of energy simulation programs, has resulted in a decrease in energy modeling costs in recent years. With more firms in the market to provide these services, competition has made it possible to secure more cost-effective services.

GSA's primary driver for energy modeling is the PBS P-100 requirement for load and energy calculations at final concept, 100% Design Development (DD), and 100% Construction Documentation (CD). Since GSA requires new construction projects to obtain LEED Certification, A/Es will typically also choose to utilize energy modeling during design to maximize its integrated design efforts and LEED compliance process. If the design team suggests that energy modeling will only be conducted in the late design stages to meet LEED requirements, the GSA project manger should insist on strategic energy modeling starting during preliminary concept design. Energy modeling commenced during the design development or construction document phases typically has very limited impact compared to modeling started earlier in the design process.

It is recommended that for each project the specific goals of the energy modeling activities be clearly defined early, so that the proper team maybe assembled and software programs chosen to meet those goals. Depending on the building and systems involved, energy modeling requires varying levels of architecture and engineering experience. Depending on the capabilities of the core project team, outside consultants and/or advanced technical support from a software vendor may be required to correctly perform advanced energy simulations, particularly when the building systems and software applications involved are newer to the industry. The level of support required and available should be confirmed early in the energy modeling process.

1.1.5.4 *Scope and Detail*

Integrated design relies on participation and collaboration by all members of the design team. In general, the earlier issues regarding building performance are considered in design, the bigger the gains achieved, and at less cost. The following diagram demonstrates this principle.

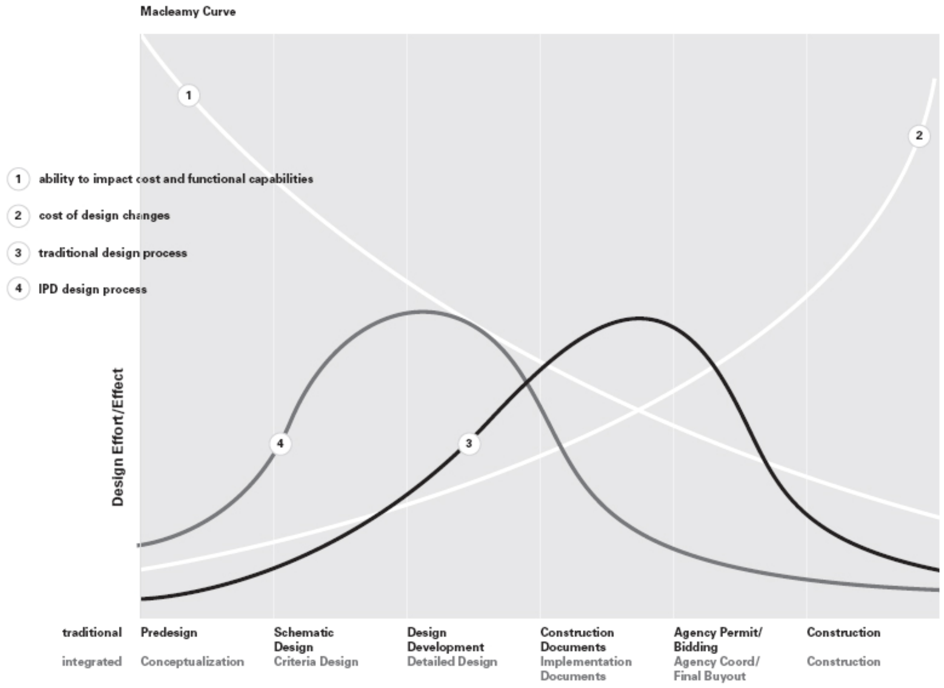


Figure 6: The “MacLeamy Curve”[8] demonstrates the value of an integrated design process and the evaluation of building performance during early design.

The scope and level of detail of energy analysis to be performed depends upon project constraints, performance goals, and project phase. The scope of the project should also be discussed. The level of detail in analysis greatly depends on the questions the project team must answer. Below is a summary of the type of modeling detail and depth of analysis that can be expected during various project phases:

Table 2: Modeling Detail and Depth of Analysis

Phase	Modeling Detail	Depth of Analysis
Preliminary Concept Design	Site location, building orientation, massing, and default assumptions	Quickly assess large-scale impacts of design alternatives
Final Concept Design	Building geometry, preliminary layout, construction, mechanical equipment, and intermediate assumptions	Evaluate and compare proposed design schemes, intermediate analysis, preliminary code compliance
Design Development	Building geometry, detailed layout, detailed construction and envelope design, mechanical equipment, building controls, and detailed assumptions	Estimate final design energy performance, detailed analysis, preliminary code compliance
Construction Documents	Detailed model	Finalize estimated energy performance and code compliance
Construction	Detailed model	Assess impact of change orders and construction detailing
Operations	Detailed model	Evaluate actual building energy performance, including HVAC control systems

It is recommended that each project team create a shared “Basis of Modeling” document in the conceptual phase that clearly outlines the scope of the energy modeling activities to meet the project’s goals as well as summarizes all the relevant energy modeling inputs, assumptions, and results. This document should be considered a coordination tool and a supplement to the project’s BIM Execution Plan to clearly define what the BIM will and will not be used for in energy modeling. A basis of modeling document should ideally contain a listing of all project team members involved, including specification of which team members will perform energy modeling, who will be responsible for providing required inputs to the energy simulations, and when the information transfers need to occur. Reference to specific BIM Levels of Detail (LOD 100-500, for example) and the BIM execution plan can assist this process. The purpose of a Basis of Modeling document is make the energy modeling process more transparent for all stakeholders and ensure that inputs are properly coordinated and can be verified by parties without access to the particular energy simulation software, inputs, or results files. For example, requirements of the architectural BIM for proper transfer to analysis software (i.e. geometric definition, closure of spaces, spatial information, etc.) may be defined by the energy modeler within the document to reduce bottlenecks further into the energy modeling process, and vice-versa by the architect to confirm design decisions and ensure that “moving targets” are not being modeled more than necessary. Such documentation also provides greater visibility into the energy modeling process and performance data for all team members. A basis of modeling document should contain relevant information on the following items (when applicable to the project):

- Introduction
- Simulation team and scope (stakeholders, tools, workflow, etc.)
- Project data (building codes, weather, utility rates, etc.)
- Building geometry
- Construction materials
- Space use type and scheduling
- Base and process loads
- On-site generation
- Mechanical systems
- Cooling and heating plants
- Utility rates
- Documentation of results

Of particular importance is the consideration of BIM-based energy simulation during early design. In the case of the GSA, this encompasses Preliminary Concept Design and Final Concept Design, though for other project teams, early design may be identified as “Pre-Design”, “Conceptual Design”, and “Schematic Design”. Early design building performance evaluation considers the relative (and to a certain degree absolute) thermal performance of multiple designs options to inform major project team decisions on geometry and passive design strategies.

The scope of implementing BIM-based energy modeling is typically unique for every building project. For example, in smaller projects it can be faster to make adjustments to the building design in the energy model directly, rather than using a workflow involving an export from a BIM-authoring application to a simulation tool. In smaller, yet complex, projects, manual modeling of building geometry also allows the energy modeler to gain a greater insight into the zoning and construction of the building, which may facilitate easier coordination of the building systems and development of baseline models. More energy-modeling efficiencies may be gained with BIM in larger projects with complex geometries and many different space types. The selected analysis tool (which may be a function of system type and not building type, size, or complexity) may also impact the workflow. For example, some building analysis applications have the capability to apply templates to certain building features within the model, making change management of those features faster in the analysis tool and not the BIM. If an analysis tool is used that does not have this type of functionality, it may be faster to import changes from the BIM. Building design teams should be aware that a significant portion of energy modeling activities are not directly related to the geometric properties of the BIM and involve definition of systems, cooling and heating plants, customized operating schedules, utility rates, building reference data or baseline models, and analysis and quality-assurance of the energy model results.

A challenge currently facing design teams is how to merge previous design strategies employed during early design and those made possible by BIM. The project team employing BIM-based technologies must acknowledge and account for the types and level of detail of information that design teams will typically require and have available during early design in current practice. In many instances, this level of information is not adequate to support early design performance analysis. However, if standard information was made more readily available within BIM applications, then the semi-automated design analysis tools that are becoming available to designers could potentially be used with more confidence. In a sense, design teams are tasked with “redefining” what they could and should do during early design to generate the quality of information needed to make informed, intelligent decisions about how to meet their project performance goals.

When properly used with building performance analysis tools, BIM has the potential to enable completely different design mentalities and strategies, creating a completely new design process that expands a design team’s capabilities and allows for information typically considered during later design to be used upstream during earlier design stages. This does increase the amount of information and time required during the early design phases, which is exactly the intent of IPD as shown in Figure 6.

1.1.5.5 Technology

The determination of the most appropriate technology/software to fulfill the project team’s needs is a crucial step in the process. The software application that best suits a project’s goals will vary on a project-by-project basis. Selecting a building analysis tool in haste could have budget and schedule consequences for the project. In particular, thorough analysis of building systems involving alternative or renewable energy typically involves specialty software that is potentially fragmented from the whole building energy model. Though software capabilities are increasing rapidly, the project team may find that a particular project proposal or desired analysis is simply not well supported by a given tool’s functionality and/or the technical support capabilities of the software vendor. However, most modeling needs encountered by GSA project teams have valuable and cost effective simulation tools available to meet those needs. GSA associates are encouraged to contact their Regional BIM Champions and the ODC BIM team to discuss specific software selection.

1.2 Preliminary Concept Design

The use of energy modeling during the Preliminary Concept Design phase can provide the design team with valuable information to inform design decisions. A rough energy model may be created with simplified thermal zoning to evaluate the impacts of site location, building massing, envelope choices, building orientation, and alternative energy sources. For example, a first round of energy modeling can be used to compare architectural schemes with four different building orientations, which may have large variability in solar load and energy consumption, but cannot be easily revised after the concept phase. While keeping the internal loads the same for all schemes, preliminary energy modeling can compare the geometry and envelope changes between the preliminary design concepts. Energy modeling tools within BIM applications that assume internal loads, schedules, and systems for early conceptual models can identify qualitative benefits of architectural options but cannot quantify them accurately in terms of energy usage and cost without refinement of the MEP systems using more robust tools and modeling. Some detailed design decisions may be able to be influenced by the modeling at this stage, but project teams need to evaluate the validity of the assumptions. At a minimum, those assumptions should align with the requirements of Appendix A.6 of PBS P-100 for GSA projects, as well as other industry standards where applicable. As stated earlier, information from rough energy models, while not accurate enough in absolute terms at this stage for cost analysis, do help to grade the performance of one design alternative relative to another. This type of order-of-magnitude feedback can allow the design team to eliminate extremely inefficient design options early on in the design process.

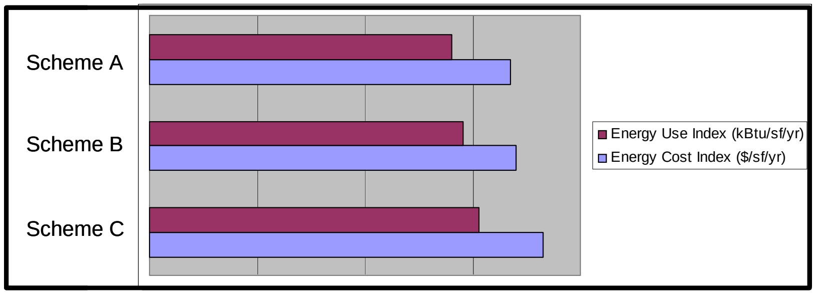


Figure 7: Example of Preliminary Conceptual Design modeling results on a Federal Courthouse project

1.3 Final Concept Design

During final concept design, energy modeling allows the design team to evaluate various design alternatives, as is the case during Preliminary Concept Design, however on a more detailed level. Frequently after a site location, orientation, and other basic design decisions have been made, multiple building designs with various layouts, HVAC systems, fuel types, construction types, and basic architectural features are considered. Comparing the relative energy performance of these various designs and determining the impact of the various system or component variations allows the design team to effectively and efficiently determine which of the proposed concept designs is best suited to meet the project's program, performance goals (including LEED), and budget. Figure 8 shows three proposed design alternatives for a GSA Land Port of Entry Station and their respective energy modeling results.

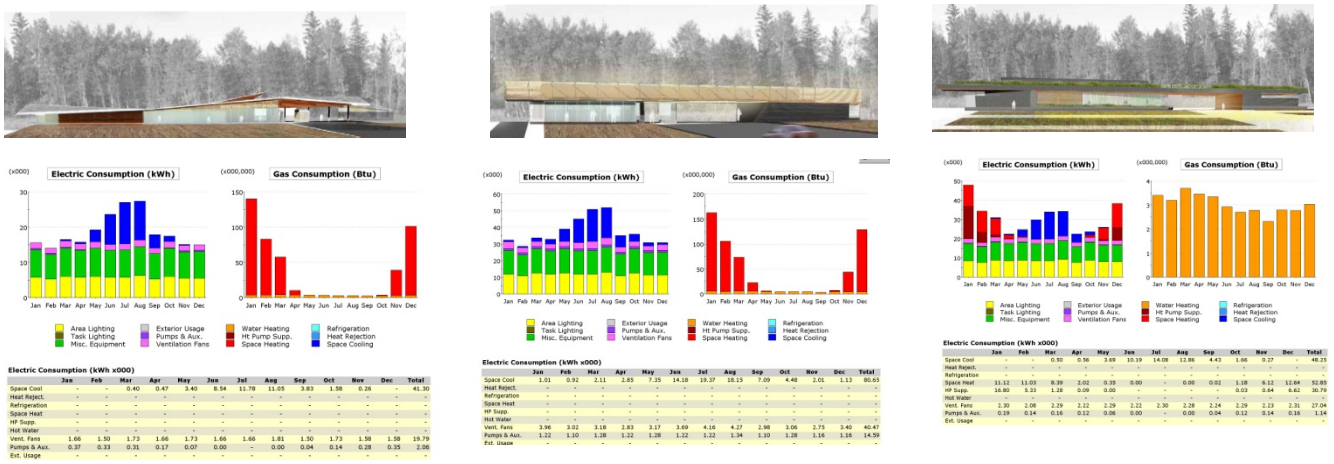
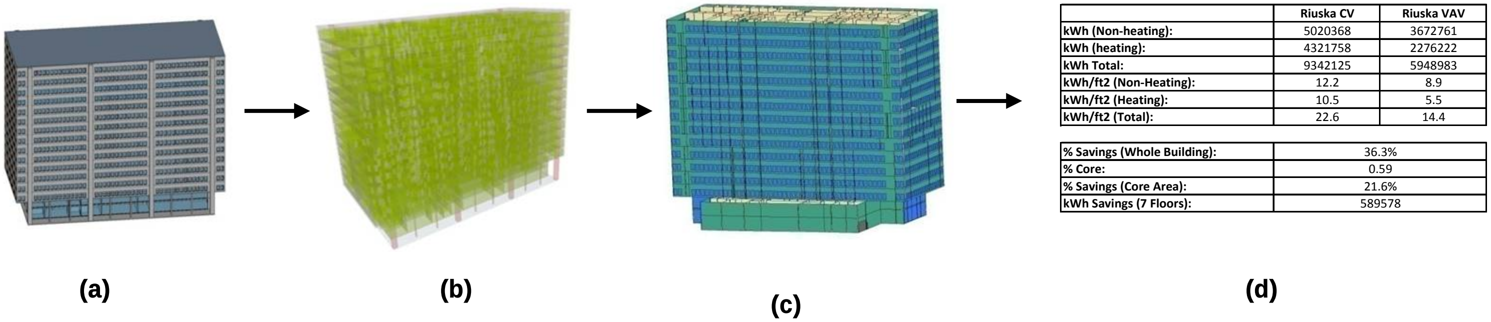


Figure 8: Using energy modeling to evaluate three alternative designs for a Land Port of Entry Station[9]

1.4 Design Development

During design development, energy modeling allows the design team to conduct parametric analyses on the selected design. Parametric analyses allow the design team to determine the relative impact of design modification to various building systems and sub-systems, such as changing window types, insulation values, HVAC system configuration, control strategies, etc. By determining the relative impact of modifying these parameters, the most desirable design option may be selected. For example, a design team may want to add additional thermal protection to the building facade. Due to budget constraints, only one of two possible measures is available. The team can either add an additional layer of rigid board insulation to the exterior facade, or they can install spectrally selective low-e coatings to the windows to the south and west facades. An energy simulation can be run to quantify the relative impact of these alternatives, and the savings results can be analyzed relative to costs. The results may show that the improved windows will result in the shortest simple payback (Total cost/Annual Cost Savings). GSA recently conducted a BIM-based energy analysis to determine the potential energy and cost savings of retrofitting several floors of an office building with variable air volume (VAV) HVAC systems rather than constant volume (CV) systems (Figure 9). The results of such analysis can provide GSA with information to inform retrofit funding allocation decisions.



	Riuska CV	Riuska VAV
kWh (Non-heating):	5020368	3672761
kWh (heating):	4321758	2276222
kWh Total:	9342125	5948983
kWh/ft2 (Non-Heating):	12.2	8.9
kWh/ft2 (Heating):	10.5	5.5
kWh/ft2 (Total):	22.6	14.4

% Savings (Whole Building):	36.3%
% Core:	0.59
% Savings (Core Area):	21.6%
kWh Savings (7 Floors):	589578

Figure 9: A BIM-based energy analysis starting with (a) a BIM model (b) exported to a model checker (c) exported to an energy simulation program provided the GSA with (d) valuable information on a potential HVAC retrofit.

Another methodology that may be applied to determine the relative impacts of various design alternatives is called elimination parametrics. Elimination parametrics is a diagnostic technique where a series of simulations are run in which only one component of energy use is set to zero within each simulation, allowing the design team to clearly determine the relative value of each component in isolation to the energy performance of a particular building and prioritize opportunities for energy-efficiency.[10] Properties of only one specific building component can also be varied in a parametric manner to test the relative impact of that component's specification. Similarly, the impact of "value engineering" on the building performance can also be analyzed during this stage using energy models.

At the end of the design development phase, the project team should have a clear definition of the energy-related components of the building required to meet the project's performance goals (including LEED) and budget.

1.5 Construction Documents

During the construction document phase, energy modeling is used to further evaluate any design decision that have yet to be resolved on the overall energy performance of the design, as well to ensure that the design meets all relevant mechanical or energy codes. Final simulations are also run to provide the required documentation for any sustainable building certification the project may be pursuing, such as LEED.

1.6 Construction

Energy simulation is rarely conducted during the Construction Phase and building commissioning. Nonetheless, energy modeling can play a significant role by allowing the project team to evaluate the impact of change orders for materials or equipment on the design using the energy models.

Typically, commissioning has been accomplished with the use of a variety of diagnostic tools, including tools that allow for the process of detecting incorrect operation and diagnosing the cause of the problem[11], with no integration with energy simulation programs. This has occurred primarily due to the fact that most energy simulation programs are developed for design, not for building operation. They lack the functional user interface to integrate data from a building's EMCS into the simulation program. Additionally, there has been a lack of integration between a building's EMCS and diagnostic tools, resulting in underutilized EMCS data.[12] There are three primary methodologies of integrating energy simulations into the commissioning process, the most common being the calibration of whole building energy simulation models. The second method, component based fault detection/simulation, may require energy simulation tools that perform time steps much smaller than one hour and will not be addressed further in this guide. In the third method, the energy simulation runs in real time, connected to the EMCS, which provides current weather data as input to the simulation and submetered consumption data for comparison with the simulation output. In a recent proof-of-concept demonstration, EnergyPlus was connected to the EMCS in two buildings at Naval Station Great Lakes and was used to detect operational problems.[13] [14]

1.7 Operations

During the operational phase, energy modeling may be used to evaluate actual building performance and diagnose improperly functioning building systems. This level of analysis requires metering and monitoring of a facility through a building energy management control system (EMCS), and the calibration of the energy model to this trended data. For the purposes of this guide, the term "operations" is intended to include retro-commissioning, continuous commissioning, and retrofits.

Calibration of energy models is applicable to retrofit analysis (discussed below) and to continuous performance assessment in cases where the basis of design is no longer applicable and the objective is to determine if the performance of the building has degraded from the condition it was in when the calibration data was collected. The calibration process compares the results of the simulation with measured data and tunes the simulation until its results closely match the measured data. Measured data may be obtained from utility billing data (typically monthly), utility interval metered data and sub-metered data, data from an EMCS, and data from installed data loggers. One significant hindrance in this process is the ability to effectively integrate the collected data into the energy simulation model. As more advanced user interfaces for engines such as EnergyPlus are developed, this barrier will be alleviated. Additionally, identification of problematic building systems may be more difficult in existing buildings. Equipment and controls have had time to degrade, and frequently the building operations manager in the facility will not have been in that position for very long, and therefore is not well versed on how the building was originally intended to operate. These situations present the greatest opportunity for the benefits of retro-commissioning and continuous commissioning to be realized. The difficulty in applying calibrated simulation data to new construction is the lack of historical building performance data for calibration. More fundamentally, the objective in new building commissioning for energy performance is to determine how the actual performance compares to the basis of design, so the objective should be to compare to the design model and not to calibrate the differences between expected and actual performance.

The use of energy modeling for retrofit analysis is very common. Engineers usually try to create a baseline model that reflects the current operating conditions of the facility. Though calibration of these baseline models using utility billing data is common, calibration of an energy simulation with any other type of metered data has generally been considered too difficult to be part of the retrofit analysis procedure. Frequently, there are only a few systems or subsystems that the modeler wants to establish a baseline for, and those systems may only be affected by a few building parameters, preventing the need to accurately model the entire building. In this situation, calibrating the model to utility billing data is more challenging since the billing data is typically reported at the facility level, and the particular contribution of just a few systems to the entire consumption data set is difficult to determine. Nonetheless, energy simulations are a useful and effective tool when conducting a retrofit analysis. Once the baseline is determined, the modeler may evaluate the impact on electricity and gas consumption of various energy efficiency measures (EEMs), and determine the annual dollar savings and the resulting payback period.

2 Energy Modeling and BIM

2.1 Leveraging BIM Data for Energy Modeling

The advantage of BIM-based energy modeling over the traditional approach is that the model does not always have to be manually recreated or modified, which tends to be time-consuming and labor-intensive. Instead, a BIM-based energy model's geometry can be generated directly from pre-existing BIM files. In addition, using existing and augmented databases, input assumptions can be readily assigned (and re-assigned) to the spaces themselves. This allows for potentially greater specificity, accuracy, and granularity of inputs, which ultimately are more representative of actual building occupation. Thermal zone assignments can be made automatically in BIM-based energy modeling to allow the user to more closely match the thermal zones for energy modeling to the mechanically designed HVAC zones, rather than theoretical thermal zones typically created by the energy modeler for simplification and time-saving purposes. Finally, the BIM-based process should be repeatable and transparent, minimizing the type of modeling variations encountered in practice today.

It is important to note that the BIM-based process currently involves emerging products and technologies, and limitations in the process of transferring information from BIM to energy simulation programs do exist. The primary limitation is that many BIM-authoring applications do not support many of the information exchange requirements for energy modeling that could be contained within the model. Some examples include occupant, lighting and HVAC schedules, thermal zoning capabilities, as well as other operational characteristics, although some BIM vendors have some limited support for this type of data. Also, the current export of building information to data models such as IFC and XML is imperfect and does not always provide a reliable source of geometric data, but rather must be manually checked and modified. However, software developments are underway to improve the interoperability capabilities of various software tools. The GSA has collaborated with the Open Geospatial Consortium (OGC) Architecture, Engineering, Construction, Owner, and Operator (AECOO) Testbed in developing early design exchange requirements for Building Performance and Energy Analysis (BPEA).[17] Many of the exchange requirements that were specified in this effort will serve as a foundation for future GSA BIM requirements for energy simulation.

2.2 Data Schemas for Building Information Exchange

2.2.1 Current Data Schemas

2.2.1.1 IFC

Industry Foundation Classes (IFC)[18] is a task and schema specification that provides standard ways to define information contained in BIM. IFC is an object-oriented data model developed by the International Alliance for Interoperability (IAI) used to describe the relationships and properties of building specific objects. The IFC format is non-proprietary and is available globally to anyone defining AEC objects. An object model is an integrated database of a building or facility. The IFC format describes the behavior, relationship, and identity of a component object within a model. The IFC format does not standardize data structures in software applications, only the shared information. IFC provides a framework for organizations to produce interoperable software in order to exchange information on building objects and processes, and creates a language that can be shared among the building disciplines, with discipline-specific views specified through Model View Definitions (MVD) and at times, implementer agreements. Most BIM-authoring vendors are currently compliant with the Coordination View, with partial implementations towards other MVDs. Certification processes exist for vendors wishing to be compliant with particular MVDs. BIM-authoring tools and vendors with current IFC support (to varying degrees) are listed at http://buildingsmart-tech.org/implementation/implementations.

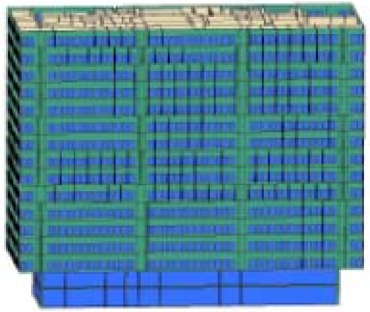


Figure 10: GSA Office Building, IFC imported by Riuska

2.2.1.2 XML

Extensible Markup Language (XML) is also a task and schema specification that provides standard ways to define information like that contained in BIM. XML is a set of rules for designing text formats to structure information. It is an outgrowth of the popular

HTML code used to develop Web pages and sites. XML supports data transaction between different software applications, leading to a better way to communicate information.[19] Several industry-specific sets of rules of XML-based schemas are currently being developed for the AEC industry including green building XML (gbXML), ifcXML, and aecXML. gbXML and ifcXML are the most relevant to building performance analysis, with gbXML being by far the most common.

Both IFC and XML create a common language for transferring BIM information between different BIM and building analyses applications while maintaining the meaning of different pieces of information in the transfer. This reduces the need of remodeling the same building in each different application. It also adds transparency to the process. A wide variety of data specific formats are available to enable interoperability which can be customized to process specific needs, but more research is needed to establish how to apply these standards to conceptual building design for energy, thermal comfort, and daylighting.

2.2.1.2.1 gbXML

The gbXML[20] schema allows for a detailed description of a single building or a set of buildings for the purposes of energy and resource analysis. It allows for data interoperability between sophisticated BIM applications and sophisticated building analysis programs such as DOE-2.2 and EnergyPlus. Its focus is the data exchange between 3D CAD geometry and energy simulation tools, and it is the most widely supported data format for the exchange of building information between BIM/CAD and energy performance applications. BIM-authoring tools and vendors with gbXML support (to varying degrees) are listed at http://www.gbxml.org/software.php.

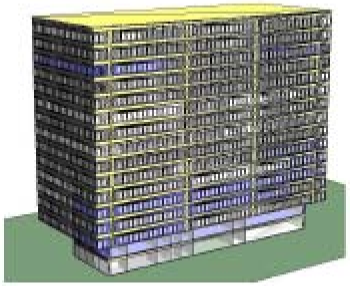


Figure 11: GSA Office Building model, gbXML imported by IES <VE>

2.2.1.2.2 ifcXML

The ifcXML[21] specification provides an XML schema specification that is a conversion of the EXPRESS (ISO 10303 part 1) representation of the IFC schema. The mapping from EXPRESS to XML schema is guided by a configuration file that controls the specifics of the translation process. This specification targets the XML community by providing guidelines on using and implementing the IFC standard using XML technologies.

2.2.1.3 Open Standard Building Analysis Tools

2.2.1.3.1 Simergy

The upcoming release of Simergy (public beta Spring 2012) provides a comprehensive graphical user interface that enables users to harness the capabilities of the EnergyPlus analysis engine (version 7 & 7.1). Simergy is a free tool developed through a public and private partnership. Simergy provides versatile workflow options allowing users to import geometry from BIM and other sources via IFC-Concept Design BIM and gbxml, and takes on the challenge of BIM to BEM translation by integrating the Geometry Simplification Tool (GST) and the Space Boundary Tool (SBT) to enable more effective creation of the BEM. In addition, users can build geometry from imported floor plans or build their own geometry using Simergy's modeling tools, and they can also set up a number of Design Alternatives that are associated with the Simergy file. Within Simergy the user can set up the HVAC system design by using the set of HVAC system templates, which provide the full definition of system types such as for a Radiant System with Dedicated Outdoor Air System, and/or using the 'drag and drop' capabilities to build or adapt the system. Validation rule sets are incorporated into Simergy to assess the integrity of the model being created and to provide guidance to the user of adjustments that need to be made prior to running a simulation. Once a simulation or set of simulations has been run, a set of predefined reports (graphic and tabular) provides users a quick way to review the results for the current model and how it compares to others. If users want to take the results investigations further they can utilize the Results Visualization capabilities that allows visualization of any of the EnergyPlus output variables in a number of ways for a single result set or multiple results sets.

2.3 Zone-Based Modeling vs. Space-Based Modeling

2.3.1 Thermal Zones

At the heart of any energy simulation is the concept of a thermal zone. A thermal zone is a single space or group of indoor spaces that has uniform thermal load profiles and conditioning requirements. A simple way to think of a thermal zone is as a space that can effectively be conditioned using only one thermostat. Thermal zoning of a building helps the engineer determine the number and type of HVAC systems required. However, defining thermal zones requires a certain amount of engineering judgment. For example, perimeter offices all facing a similar orientation (N, S, E, W), could logically be combined into one thermal zone since the solar, occupancy, lighting, and equipment loads are all similar amongst all the offices (Figure 12). However, differences in personal thermal comfort may make it more prudent for the engineer to zone the offices in groups of three, etc. in the design so that the occupants have more individual control over their environment. Care needs to be taken that the grouped rooms in the energy model thermal zones are similar in all aspects, if not then the average of the zone will not represent actual operation. Strategies for thermal zoning can differ significantly by building type. For example, hotels frequently have multi-perimeter and core thermal zones due to the wide range of thermal conditions (e.g. some people like it warm, some like it cool). Small residences typically have only one conditioned thermal zone (one thermostat), plus unconditioned spaces such as unconditioned garages, attics, and crawlspaces, and unconditioned basements.

When creating an energy model, the goal is to accurately represent the thermal zones in the model as used to determine the mechanical system design in reality. The most straight-forward modeling approach is to match the thermal zones one-to-one in the model to the thermal zones as designed. In traditional energy modeling, however, thermal zones are created manually and significant simplifications are often made by the modeler (Figure 12). In many cases, simplification of zones is appropriate and even beneficial in reducing the computational overhead to achieve the same results. However, in most projects this is not an issue, and by using BIM-based energy modeling thermal zoning may be more intuitive. It allows energy modelers to more easily create discrete zones based more on the actual spaces modeled in BIM (Figure 12), and less on engineering judgments which may vary project-to-project.

2.3.2 Zone-Based Modeling

When creating a model for an energy simulation, in particular during early design, standard energy modeling practice requires the energy modeler to make engineering judgments in creating thermal zones when the actual HVAC design has not been determined. Spaces that are deemed thermally similar are combined into the same thermal zone, and an HVAC system is assigned to that thermal zone. While this simplification is appropriate in many cases, in others it is not. Zone-based models may potentially be over-simplified, since multiple rooms/spaces that have very different thermal loads (e.g. an office space with significant computer loads that has windows and an interior break room with no equipment) may be mistakenly aggregated and assigned the same loads (W/ft^2), schedules (% on per hour), and HVAC system. Such simplification often results in less accurate simulation results. When the actual HVAC system design is known, possibly during Design Development (DD), the actual mechanical zoning scheme should be used to the extent possible.

2.3.3 Space-Based Modeling

Space-based energy modeling generally uses the same input parameter types as zone-based modeling, but assigns them on the space level. Currently, most BIM-based energy simulation programs assume each space imported is its own thermal zone. There is currently limited functionality to allow thermal zones, defined as a group of spaces within the BIM-authoring tool, to be transferred directly into the energy modeling tool. BIM-based energy modeling adheres to the following process: a BIM of the building is exported from a BIM-authoring tool in the file format required by the simulation application (e.g. IFC or gbXML) and input into a BIM-based energy simulation application (e.g. RIUSKA, IES, Green Building Studio, Ecotect), additional inputs and assumptions are entered by the energy modeler to complete the required input process, and the BIM-based “front-end” runs the energy simulation. By leveraging the import of the building geometry into the energy simulation program, significant time savings are realized by not having to recreate the geometry from scratch. Some space-based simulation programs allow for the aggregation of spaces into larger zones in the energy model itself, if the user so desires. Additionally, multiple thermal zones may be aggregated into a single HVAC zone, since some HVAC system types have the capability to serve multiple zones with different thermal profiles at the same time. Note that the ability to model each space as a thermal zone does not necessarily mean that the user should define all the spaces in the architectural model for use in an energy model. This issue is addressed further in Section 2.5.2.

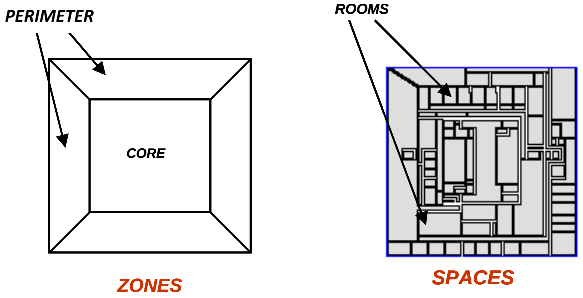


Figure 12: Simplified Zone-Based Energy Model Partitioning vs. Space-Based Energy Model Partitioning with BIM

2.4 BIM Data Exchange with Energy Models

2.4.1 Geometric Data

2.4.1.1 Benefits

By importing geometric models into an energy simulation model, significant time savings can be realized by not having to create the building geometry within the simulation interface. Additionally, modifications to building geometry within the BIM may be replicated in the energy model by simply exporting a new geometric data model and importing it back into the energy simulation application. Current data schemas commonly used to accomplish this are IFC, gbXML, DXF, and DWG. Typically, the latter two are imported as 2D plans, and the 3D building geometry is then created by tracing the 2D plans. In general, the first two methodologies are “BIM-based” and are preferred, if available, since the 3D building geometry can be transferred directly, along with any other data intelligence the software supports.

Two more benefits of geometric data exchange using BIM are repeatability and consistency. Rules of geometry simplification are defined in the software and are not subject to user interpretation. BIM-based data exchanges eliminate most of the need for interpretation and modeling judgment as required when creating models manually.

Typical building element data that may be transferred to the building analysis tool include walls, windows, curtain walls, slabs/floors, roofs/ceilings, columns, and spaces (see Section 2.5).

2.4.1.2 Limitations

Current geometric model transfer functionality is not perfect. Frequently, building elements may end up missing, misplaced, or deformed. The quality of the data transfer depends on four variables: the quality of the building model (e.g. no missing elements or invalid wall connections), the quality of the BIM-authoring tool writer/exporter, the ability of the data schema used to clearly organize the information, and the building analysis tool translator/importer. Errors may occur if there is a deficiency in any one of these areas.

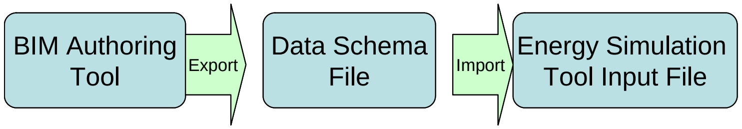


Figure 13: Current sequence of information transfer in BIM-based energy modeling

When geometric errors do occur, it is difficult to determine the source of error. One of the most difficult challenges in standardizing how this geometric information is organized is that each data schema, while technically adequate, may have a number of different ways to express the same objects and relationships. Therefore, to prevent geometric errors in the future, vendors, implementers, and downstream building analysis tools must agree on which methodology is to be utilized. Additionally, information transfer from a BIM-authoring tool to an energy analysis tool is generally a one-way process. Although still evolving, many tools do not currently have the capability to export changes from energy models back to the BIM-authoring tool for use. If exporting of data back to the BIM is supported, the scope of capabilities is typically limited.

As a general principle and given the current functionality of many building analysis tools, the greater the complexity of a geometric model, the greater the risk for errors in translating that geometry from a BIM to an energy analysis tool. Therefore, it is recommended to minimize the number of unnecessary elements to be translated. In particular, users frequently attempt to translate all the interior walls from a BIM into an energy simulation model or some other building analysis tool. This practice provides limited benefit in most energy simulations, since heat transfer between interior spaces with similar thermal conditions is generally negligible. Also, some energy simulation programs do not calculate heat transfer between interior surfaces. In these situations, the interior walls that do not separate thermal zones should be deleted, or at least modeled as separate elements such that export of the geometric model for analysis may be made without them. A future goal of BIM is to eliminate the need to make these adjustments, and enable the designer to seamlessly export the entire BIM model to a building analysis tool, independent of the level of complexity. Any modifications that need to be made would be automated in the export/import process by filtering out unnecessary elements.

If a model requires significant work to correct geometry errors once imported into the building analysis tool, performing further required geometric modifications directly within the same tool may be the most efficient procedure. For example, suppose an architect creates a geometric model with the geometry defined to the best of their ability. The architect sends the model to a consultant to conduct daylighting analysis. However, the model does not translate properly due to deficiencies in the quality of the building model. It takes the consultant one hour to correct the geometry errors (wall and floor elements in this example) in the model after it is imported into a daylighting program. They then run the daylighting simulation. A week later, the architect changes the configuration of two windows, and wants to see the impact on the daylighting performance of the building. A new model is sent to the consultant. In this case, the consultant makes the required changes to the windows directly within the daylighting simulation tool, since that takes significantly less time than importing the new model and re-correcting the geometry errors which were originally encountered. In each case, the modeler must make a judgment as to which methodology is less time consuming.

2.4.1.3 Recommended Future Developments

Based upon GSA pilot case studies, the BIM team has identified several areas related to modeling geometric data for energy analysis that should be further developed. The following are some recommended future developments:

- Improved transfer of curved surfaces
- Improved transfer of curtain wall data
- Diagnostic tools to assist the user in troubleshooting data translation issues (both in terms of visualizing the model being imported and automatic error-checking capabilities)
- View definitions that specifically define what and how data should be defined in a BIM so software applications can exchange it reliably.
- Use of standard "benchmark" models to test exporting capability of BIM-authoring tools to analysis software, and vice-versa.

GSA encourages BIM-authoring and energy modeling vendors to further develop these functionalities within their software.

2.4.2 Construction/Material Data

2.4.2.1 Benefits

The ability to import construction thermal data such as material layer sets and material properties such as thermal conductivity, specific heat, emissivity, reflectivity, etc., into energy models directly from a BIM would significantly reduce not only time in the energy modeling process, but also uncertainty. There is a potential for modelers to make assumptions about thermal properties based solely on the general construction type of the building. These assumptions are often inaccurate and not coordinated with the proposed design. This is frequently caused by a lack of communication between the architect and the person conducting the modeling. Defining the thermal data in the BIM would greatly alleviate this problem. Frequently the architect may only have information on construction types and not thermal data, either due to availability of the data or lack of knowledge. In this case, automated association of construction type to thermal data, either within the BIM-authoring application or during import into an energy simulation, would be desirable.

2.4.2.2 Limitations

Currently, few BIM tools export this type of construction data in IFC or gbXML, and most building analysis tools do not import it. The data schemas do support this type of information, yet data structure protocols and organizational methodologies have yet be agreed upon and standardized across the industry.

2.4.2.3 Recommended Future Developments

Based upon GSA pilot case studies, the BIM team has identified several areas related to modeling construction/material data for energy analysis that should be further developed. The following are some recommended future developments:

- Effective transfer of construction types, material layer sets, thermal bridges, and material properties such as thickness,thermal conductivity, specific heat, reflectivity, transmissivity, absorptivity, and emissivity
- Industry-standard databases of typical material properties and constructions (e.g. ASHRAE data) that are available within the BIM-authoring application, either internally or web-based
- Links that bridge the gap between architectural information and the data that is needed for energy simulation
- Functionality to perform automatic comparative energy analysis of multiple architectural options ("rapid prototyping") to provide high-level performance information early in the design process
- Use of BIM to populate data needed to confirm compliance with relevant LEED credits

GSA encourages BIM-authoring and energy modeling vendors to further develop these functionalities within their software.

2.4.3 Mechanical Data

2.4.3.1 HVAC Equipment

2.4.3.1.1 Benefits

The ability to import HVAC equipment data into energy models directly from a BIM would significantly reduce not only time in the energy modeling process, but also uncertainty. There is a potential for modelers to make assumptions about HVAC operational parameters based on the system type and prior experience; however these assumptions are often inaccurate and not coordinated with the proposed design. The ability to store operational data within a BIM object of that equipment would reduce the potential for incorrect assumptions. Ideally, equipment manufactures could post BIM objects on their website for free download. This object would contain all the equipment properties, such as make, model, capacity, efficiency, performance curves, etc., in a format that is compatible with the most common BIM tools. This operational information, in theory, could be transferred directly into the simulation engine for analysis.

2.4.3.1.2 Limitations

Currently, BIM tools have limited export capabilities for HVAC equipment data in IFC or gbXML, and most building analysis tools do not import it. The data schemas do support this type of information, yet data structure protocols and organizational methodologies have yet be agreed upon and standardized across the industry.

Containing the HVAC equipment information within BIM objects presents additional challenges. For example, if an energy modeler wants to simulate different types, efficiencies, or sizes of HVAC components, then they have to go back to the BIM, make the change, and potentially rebuild or correct the model in order to perform the simulation. This may hinder the iterative process of energy modeling which is essential to optimize the design and operation of the building.

2.4.3.1.3 Recommended Future Developments

Based upon GSA pilot case studies, the BIM team has identified several related to modeling mechanical equipment data for energy analysis that should be further developed. The following are some recommended future developments:

- Transfer of equipment names, numbers, types, capacities, and locations within building
- Transfer of equipment full-load and part-load efficiencies (performance curves)
- Transfer of control mechanisms (e.g. type of controls, interlocks with other systems, Building Automation System control points, etc.) and data such as temperature set points (minimum/maximum), set point ranges (e.g. +/- 2%), normal control limits, and alarm limits (e.g. high/low).
- The ability to specify distribution system information such as total length of piping and ducting, and the associated pressure drop characteristics for those systems
- Transfer of system hierarchy and topology as related to operation and building zoning
- Equipment commissioning and maintenance requirements
- Use of BIM to populate data needed to confirm compliance with relevant LEED credits

GSA encourages BIM-authoring and energy modeling vendors to further develop these functionalities within their software.

2.4.3.2 Lighting, Occupant, and Equipment Loads

2.4.3.2.1 Benefits

The ability to import load data into energy models directly from a BIM would significantly reduce not only time in the energy modeling process, but also uncertainty. There is a potential for modelers to make assumptions about internal loads based on the area type and building mechanical/energy code requirements; however these assumptions are often inaccurate and not coordinated with the proposed design. For example, the ability to store lighting load data in the space object or within a BIM equipment object (which would be converted to the associated space load based on the space in which it was placed) would reduce these incorrect assumptions and improve the process of information transfer. Ideally, lighting equipment manufacturers could post BIM objects on their website for free download. These objects would contain all the equipment properties, such as make, model, wattage, lumens/watt, etc., in a format that was compatible with the most common BIM tools. This load information, in theory, could be transferred directly into the simulation engine for analysis. Another desirable option would be to have required mechanical/energy code assumptions based on industry standard sources of data (e.g. ASHRAE, PBS P-100) automatically assigned to the space object based on space type selected.

2.4.3.2.2 Limitations

Currently, only a few BIM tools export load data in IFC or gbXML, and most building analysis tools do not import it. The data schemas do support this type of information, yet data structure protocols and organizational methodologies have yet be agreed upon and standardized across the industry.

2.4.3.2.3 Recommended Future Developments

Based upon GSA pilot cases, the BIM team has identified several areas in modeling load data for energy analysis that should be further developed. The following are some recommended future developments:

- Continued development of load data transfer in terms of watts/ft^2, occupants/ft^2, etc. at the space level
- Effective transfer of load data for objects such as lighting, motors, and computers
- Use of BIM to populate data needed to confirm compliance with relevant LEED credits

GSA encourages BIM-authoring and energy modeling vendors to further develop these functionalities within their software.

2.4.3.3 Spatial Data

2.4.3.3.1 Benefits

BIM spatial data is the data associated with a modeled space. Space and zone objects (not to be confused with HVAC zone objects that are an aggregate of multiple spaces) contain area and volume data used for load and energy consumption analysis. Population of these space objects with relevant load data for thermal analysis can significantly reduce modeling time requirements. Space loads (see Section 1.4.2.2), design temperatures, outside air requirements, and conditioning schedules are all examples of spatial data.

2.4.3.3.2 Limitations

Currently, all BIM tools export spatial data, which includes information such as area and volume (see Section 2.5.2). Building analysis tools require these space objects for importing. Only a few BIM authoring tools support the export of additional mechanical information for the spaces. However, only a few building analysis tools can read and translate this BIM data, as addressed in the previous section.

2.4.3.3.3 Recommended Future Developments

Based upon GSA pilot case studies, the BIM team has identified several areas in modeling spatial data for energy analysis that should be further developed. The following are some recommended future developments:

- Transfer of space design and operating temperatures
- Transfer of outside air requirements and full-load flow data
- Transfer of space conditioning, occupancy, and load schedules (for understanding of occupant behavior)

- Further functionality to aggregate spaces into zone objects/thermal zones, and multiple thermal zones into HVAC zones
- The ability to assign HVAC equipment to thermal/HVAC zones
- Use of BIM to populate data needed to confirm compliance with relevant LEED credits
- The ability to automatically define reference (baseline) building and systems types and/or Energy Use Intensity (EUI) per industry energy performance rating methods (such as contained within ANSI/ASHRAE/IESNA Standard 90.1).

GSA encourages BIM-authoring and energy modeling vendors to further develop these functionalities within their software.

2.5 BIM Building Elements and Spaces

2.5.1 Building Elements for Design

Physical elements (as opposed to spaces) in a building model are objects defined as building elements. These include walls, doors, windows, floors, ceilings, roofs, beams, columns, and other building components. In order for these objects to be included as the intended object types when exporting to a given data schema, they must be either (a) created using authoring tools for the intended object type (e.g., a wall creation tool), or (b) created from a data schema-compatible library provided by the vendor or others for the BIM-authoring application.

BIM users often create building elements using the wrong toolset in a BIM-authoring application. For example, inclined beams are sometimes modeled as roof elements, and columns are often modeled as very short walls. Although such cases may serve the purpose of visual representation (they look correct in the drawing), they become an issue when exporting to the desired data schema as they will be exported with the wrong object types. Whenever a tool is available in the BIM-authoring application to create the correct object type, it should be used.

In cases where such tools are limited in functionality or not available (e.g., some applications cannot create sloped beams), the user should consistently create a generic object that can be assigned a building element type. Most BIM-authoring applications support creation of such generic objects and mapping of such elements to IFC or gbXML object types so that the resulting model contains elements with correct geometries and correct object types.

With respect to the capital program delivery process, A/Es should create BIM models during the Concept design stage (See BIM Series 02 for more information.) While GSA realizes that A/Es may prefer to use stacking and bubble diagrams at this stage, GSA requires basic building elements at Final Concept design and A/Es should produce a spatial program BIM that meets the requirements outlined in this Series.

At a minimum, A/Es are required to have BIM elements for spaces, interior walls, exterior walls, doors, windows (including skylights), slabs, beams, columns, and shading devices. The following sections provide information for each of these building element types that are required for energy simulation. Please see section 2.5.2 of this guide for requirements of modeling spaces.

Table 3: Building Elements Required for Energy Simulation

Building Elements	Section
- Walls	2.5.1.1
o Windows	2.5.1.1.1
o Curtain Walls	2.5.1.1.2
o Doors	2.5.1.1.3
- Slabs/Floors	2.5.1.2
- Roofs/Ceilings	2.5.1.3
- Columns (optional, relevant for daylighting)	2.5.1.4
- Shading Devices	2.5.1.5

2.5.1.1 Walls

Wall elements define vertical enclosure of spaces and are critical components in energy simulation. For energy analysis, A/Es will need to differentiate between interior and exterior walls. In IFC or XML BIMs, walls must have relationships to their adjoining (connected) walls and the spaces they bound. This relationship between walls is typically created automatically by the BIM-authoring application when the walls' base lines are connected. The bounding relationship to spaces is also created automatically when the faces of the wall and the space are coplanar. Users should consult with their BIM-authoring application documentation for instructions on how to ensure that these relationships will be included in the export to an IFC or XML BIM.

In conventional building designs, the vast majority of walls are straight and of uniform height. These are easily modeled using the appropriate tools found in most BIM-authoring applications. If the BIM-authoring application supports the use of multiple or generic tools for component creation, the user must ensure that components are assigned the correct Building Element types so that they are exported as the correct types to an IFC or XML BIM.

For early design energy modeling, it is best to keep interior walls to a minimum, in particular when they separate spaces that are anticipated to have uniform thermal loads and conditioning requirements. Having unnecessary interior walls provides little added benefit to an energy simulation, and can cause significant problems with data export and import. The more building elements your model has, the greater the chance that the IFC or XML exporter in the BIM-authoring tool will have problems properly defining the building geometry. Additionally, several energy simulation tools do not even calculate heat transfer through interior walls, presenting no marginal benefit in modeling interior walls. In general, a useful methodology is to keep the critical wall elements needed for the energy simulation on a separate layer from the wall elements that are not needed.

This methodology requires the modeler to judge whether the criticality of the wall elements and their contribution to the thermal performance of the building warrants them to be included in the model. For example, if thermal mass in the building is significant (e.g., the building has a large percentage of glass or if passive solar contributions are to be investigated), then definition of the interior walls in the BIM-authoring tool is important to track solar penetration through the building. Without that definition, solar gain might be assigned to surfaces that will not receive any solar radiation (e.g. floors) instead of interior walls, which in turn transmit heat to the adjacent rooms. Treatment of building internal thermal mass and heat transfer through walls should be considered in both the development of the BIM and the selection of the building analysis tools to be utilized.

It is common practice for architects to create wall objects that span several floors. This can cause problems when importing the geometry model in a building analysis tool. Several BIM-authoring applications require wall elements for each space to be associated with the level to which the space is assigned. Therefore, a second floor space that is bound by a two-story wall that was modeled starting on the first floor may be exported as not having an adjacent wall. Although this is not the case for all building analysis tools, it is good practice to model each wall as only extending up one level, copythat wall element, and paste it to be aligned on the level above it if needed.

2.5.1.1.1 Windows

Window objects should be created using the appropriate tool in the BIM-authoring application. Windows should always be inserted into a wall component and they must not extend outside the wall geometry.

Creating a window by first cutting an opening in the wall and then inserting a window may cause problems if the wall object is not linked to the window object. In this situation BIM-authoring applications must keep track of two different relationships (i.e., opening-wall relationship and window-opening relationship). If windows are created using the designated window tool, only one relationship (i.e., wall-window relationship) is needed.

2.5.1.1.2 Curtain Walls

Many building designs include configurations in which an entire wall or face consists of windows and possibly also doors (e.g., a storefront) (see Figure 14). In these cases, GSA requires that the windows and doors be modeled as “contained” in a wall object. If a curtain wall is modeled as a “wall” rather than a “window” in a wall, building analysis tools frequently will interpret the curtain wall as being opaque, particularly when using the IFC schema. Care should also be taken to ensure that doors and windows don’t extend outside the wall area. This situation may be accidentally created in the corner of a building (corner windows) or in staircases, where windows can span multiple floors. Special attention must be given to setting the relative height of the window. Modeling curtain walls in this manner will ensure that the IFC or XML import into the building analysis tool will result in the proper designation of the transparent window surfaces.

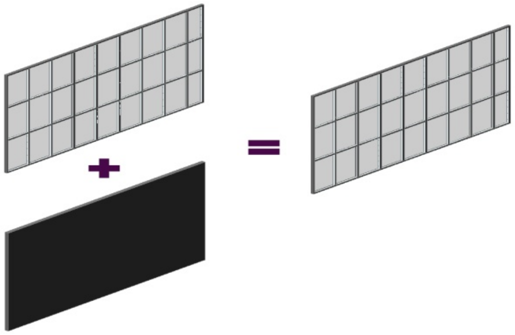


Figure 14: Wall component that is fully glazed

In cases where walls are modeled separately for each building floor and windows span floors, the user must ensure that there are openings in the walls for each building floor. Without a host wall a window will be orphaned and floating, without the expected bounding relationship to spaces. This can cause errors or unexpected results in analysis such as energy simulation calculations. Another option when such openings cover most of the wall area and span multiple floors is for the wall to be modeled as one multi-story wall, if allowed by the BIM-authoring application.

An example of a window area spanning multiple floors is shown in Figure 15.

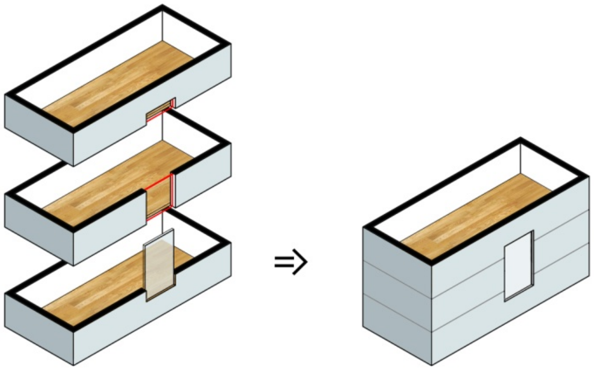


Figure 15: Window on the first floor may require openings added on next two floors

2.5.1.1.3 Doors

Door objects should be created using the appropriate tool in the BIM-authoring application. In most cases, this tool can also model passageways or other access openings between spaces that do not have doors. Similar to windows, doors should always be inserted into a wall component and they must not extend outside the wall geometry.

Creating a door by first cutting an opening in the wall and then inserting a door may cause problems if the wall object is not linked to the door object. In this situation BIM-authoring applications must keep track of two different relationships (i.e., opening-wall relationship and door-opening relationship). If doors are created using the designated door tool, only one relationship (i.e., wall-door relationship) is needed.

2.5.1.2 Slabs/Floors

Floor slab objects should be created using the appropriate tool in the BIM-authoring application. If the BIM-authoring application does not include a designated tool for this purpose, or if the tool's functionality is limited (e.g., does not support slabs with irregular profiles), the user should create a generic object that can be assigned a Building Element type (in this case, Floor Slab). Most BIM-authoring applications support creation of such generic objects and mapping of such elements to existing IFC or XML BIM object types, so that the model contains elements with correct geometries and correct object types when imported into building analysis software.

It is essential that the floors are modeled as slab objects and that the joints between walls and slabs are modeled as accurately as possible, with the information known at that time, for export of the BIM for accurate thermal analysis.

2.5.1.3 Roofs/Ceilings

Roof and ceiling objects should be created using the appropriate tool in the BIM-authoring application. If the BIM-authoring application does not include a designated tool for this purpose, or if the tool's functionality is limited (e.g., does not support roofs with irregular profiles), the user should create a generic object that can be assigned a Building Element type (in this case, Roof Slab). Most BIM-authoring applications support creation of such generic objects and mapping of such elements to existing IFC or XML BIM object types, so that the model contains elements with correct geometries and correct object types when imported into building analysis software.

2.5.1.4 Columns

For most building energy simulations, columns are not critical. Columns rarely reduce the volume of the space sufficiently to make a noticeable difference in the simulation results, and several energy simulation programs won't allow columns to be modeled. However, in existing buildings with large masonry columns, the thermal mass of the structure can fundamentally change the energy performance of the building. In addition, for CFD and daylighting/thermal insolation studies, columns can have a significant impact on the simulation results via solar shading and airflow obstruction, and should be modeled using the appropriate tool in the BIM-authoring application. If the BIM-authoring application does not include a designated tool for this purpose, or if the tool's functionality is limited (e.g., does not support columns with irregular profiles), the user should create a generic object that can be assigned a Building Element type (in this case, Column). If the required data format does not support column object types, they should be modeled directly within the CFD/daylighting simulation tool.

For more information on how columns may be modeled within a BIM-authoring tool, please see section 4 of the BIM Guide 02-Spatial Validation.

2.5.1.5 Shading Devices

Shading devices, including overhangs and fins, impact the amount of incoming solar radiation that penetrates through windows and curtain walls. Some BIM-authoring tools allow for the explicit specification of shading objects, however in others the user must use “work arounds”, such as using slab or wall tools to create shading devices. The ability of downstream building analysis applications to interpret shading devices correctly when these alternative definitions are used varies widely. Until robust shading device tools become common in BIM-authoring applications, A/E’s should model overhangs as individual objects using slab tools. Floor slabs should *not* be extended to produce overhangs.

2.5.2 Spaces/Rooms/Zones

Spaces are one of the most important object types in energy simulations. During pre-design, client requirements are described in terms of spatial program requirements; furthermore, throughout building design and operation many performance metrics utilize spatial data. Consequently, modeling spaces accurately is one of the most important tasks in creating BIMs. Space objects are normally represented in plan drawing view with a data tag (e.g., name, number, area, volume, etc.).

To meet spatial validation requirements, spatial information will be used for design assessment relative to the spatial program issued by GSA to the A/E. This will include space area calculations and comparisons to the original Space Program, using *PBS Business Space Assignment Policy* (ANSI/BOMA definitions) area calculation rules.

When spaces are defined properly using surrounding walls, the area inside them is defined precisely. In a BIM process, the space itself is a 3-D object. The space object is typically created automatically with its geometry aligned with the inside faces of surrounding building elements (e.g., walls, floors, ceilings, etc.) If the geometry of these building elements changes, the space object should also be updated to reflect the new geometry of the space. Some BIM-authoring applications maintain relationships between the space and surrounding building elements, and thus are capable of automatically updating the space data. Others require that such updates are performed by the user, and most provide tools for this purpose. Users should consult product-specific instructions to learn the procedures for a specific BIM-authoring application.

Some BIM-authoring applications provide several ways to create space objects. Ensuring that space heights are properly defined (up to ceiling, up to slab, overlapping slab, etc.) is a critical step in the process, and the users should consult with the BIM-authoring application vendor to learn the recommended method for creating space objects that will be exported to an IFC or gbXML file. Some details about how this is done in BIM-authoring applications for IFC can be found in BIM Guide Series 02-Spatial Program Validation.

2.5.2.1 Required Spatial Information for all Projects

BIM Guide 02-Spatial Validation requires that A/Es define spaces for any area over 9 ft^2 (0.8 m^2). For all individual spaces over 9 ft^2 (0.8 m^2), A/Es are required, at a minimum, to designate the information listed in Table 4:

Table 4: Required Spatial Information

GSA Requirement	Example
Space Name	OFFICE
Space Number	08006
GSA PBS Space Category	Building Joint
GSA PBS Space Type	TTO (Total Office)
Occupant Organization Name	General Services Administration
GSA BIM Area (formerly GSA Net Area)*	114.27 m^2
GSA Design Gross Area*	GSA_DesignGross_Floor_B1 135.5 m^2

*GSA BIM Area (formerly GSA Net Area) is a specific type of area calculation (described in BIM Guide 02), and is not found in the *PBS Business Space Assignment Policy* or the ANSI/BOMA standards. In addition to these requirements on individual space objects, A/Es must also create a full building floor space (with a space name and number) that represents GSA Design Gross Area.

The only spatial information requirements relevant to BIMs used for energy models are the approved space names from the BIM Guide Series 02- Spatial Validation. Most software applications do not yet take full advantage of the additional information that may be associated with the space, such as watt/ft^2 lighting load, people/ft^2 occupant load, and heating and cooling setpoints. Once the schemas and software applications have matured to allow more in-depth use of this type of information, GSA requirements will be revised to include more information content for BIM spaces.

2.5.2.2 Unoccupied or “Cavity” spaces

GSA spatial validation requirements only require areas over 9 ft^2 (0.8 m^2) to be defined as spaces. However, when preparing a BIM for energy simulation, *all of the areas must be defined as spaces*, regardless of how small they are. This requirement is due to the fact that most building analysis tools will recognize a wall element as “exterior” if only one side has a space adjacent to it. Therefore, an undefined cavity in the middle of a building will result in the adjacent interior wall being considered as exterior. This may cause the building analysis tool to erroneously assign an exterior wall construction type to it, invalidating the simulation results. Although some building analysis applications allow the user to redefine the nature of the wall (or any other object) within its interface, others do not.

2.5.2.3 Space Height and Plenums

Spaces shall be defined and modeled with a vertical extent from finished floor to finished ceiling. Several applications require the bounding floors and ceilings to be slightly overlapped with the space boundary. When a space contains suspended ceilings and the resulting plenum area, spaces must be made for both the room space and the plenum space. Space heights for the room must be modeled up to the intended height of the suspended ceiling. Space heights for the plenums must be modeled from the height of the suspended ceiling up to the height of the floor slab above it. Modeling practices for space heights differ between software applications. Users should consult product-specific instructions to learn the procedures for a specific BIM-authoring application.

Spaces should be checked visually in a 3-D viewing platform to ensure they are modeled with the correct height. Since many designers still work and view models in 2-D, a typical space modeling error is to model spaces with zero height, or at the default height of the BIM-authoring tool (frequently 10 feet).

2.5.2.4 Room Separation Lines

Physically-bound building volumes that have several functionally-different spaces contained within them are required to be separated in the BIM using a room separation line. One physical space in the BIM may contain several areas that are treated individually in the GSA spatial program. According to the PBS Business Space Assignment Guide, spaces should be represented and broken down into functional spaces (e.g., office area, storage area, building common area, vertical penetration, etc.) as defined in the GSA spatial program, even though they may be part of a larger physical space. If two areas have different functional space classifications they shall be modeled as two separate spaces, even if they are within the same physical space. For example, there may be a security checkpoint area within a lobby. In this case, the security checkpoint area (Office) and the remainder of the lobby area (Building Common) must be modeled as separate non-overlapping spaces.

Most building analysis tools do not recognize the “virtual” nature of a room separation line. When imported, room separation lines are frequently interpreted as opaque walls. This interpretation can result in erroneous simulation results. Some simulation tools allow the user to delete the “false” opaque wall, make it invisible, or place a large void in the wall. This type of functionality allows the room to be simulated correctly, although it may be time consuming to make the required modifications. Since room separation lines are virtual boundaries that do not impact thermal or fluid flows over or through them, it is recommended in most situations to remove the room separation lines before exporting from the BIM-authoring tool, and reorganize the spatial information where required in the building analysis tool after importing. The preferred methodology will depend on the exact configuration of the spaces, the analysis required, and the functionality of the tool being used for analysis.

2.5.2.5 Space Boundaries

Space boundaries form a critical concept for a) correctly defining appropriate relationships between spaces and the building elements that enclose a space and b) defining the geometry associated with the spaces independent from the geometry of the bounding elements. Space boundaries can be broken down into two primary types: 1st level space boundaries and 2nd level space boundaries (Note: 3rd, 4th, and 5th level space boundaries exist, but they are not discussed in this Guide). 1st level space boundaries typically correspond to the “architectural” space boundaries and are defined irrespective of adjoining spaces. 2nd level space boundaries are defined by accounting for adjacent spaces, and are sometimes referred to as "thermal" space boundaries. Figure 16 demonstrates the difference between the two types of space boundaries. In this example, the single long wall (WALL 1) will result in Space 3 being assigned a 1st level space boundary spanning the entire length of Wall 1. However, a thermal calculation engine requires knowledge of what fraction of that wall is adjacent to different spaces on the other side of it (with potentially different thermal conditions) in order to determine conductive and convective heat transfer between the spaces. Therefore, for energy modeling purposes, Wall 1 needs to be divided into multiple 2nd level space boundaries (BOUNDARY 1 & 2) so that appropriate relationships between a thermal space (in this case Space 3) and its surrounding spaces (Spaces 1 and 2) are defined in the simulation engine for determining heat transfer between the spaces.[22] Based on this space boundary concept, the intersecting portion of the two walls (illustrated in red) is ignored in the thermal simulation model, because of the typical one-dimensional heat transfer assumption used in most energy simulation engines. This intersection can only be described if two dimensional heat transfer calculation is available.[23]

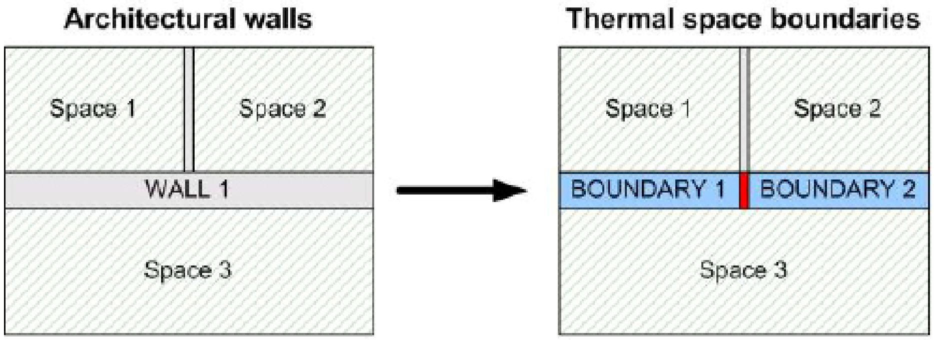


Figure 16: 1st Level Wall Space Boundaries (Architectural) vs. 2nd Level Wall Space Boundaries (Thermal)[24]

The creation of 2nd level space boundaries is also necessary in some energy simulation when different instances of wall elements (i.e. construction types) bound a single space. Figure 17 illustrates such a scenario.

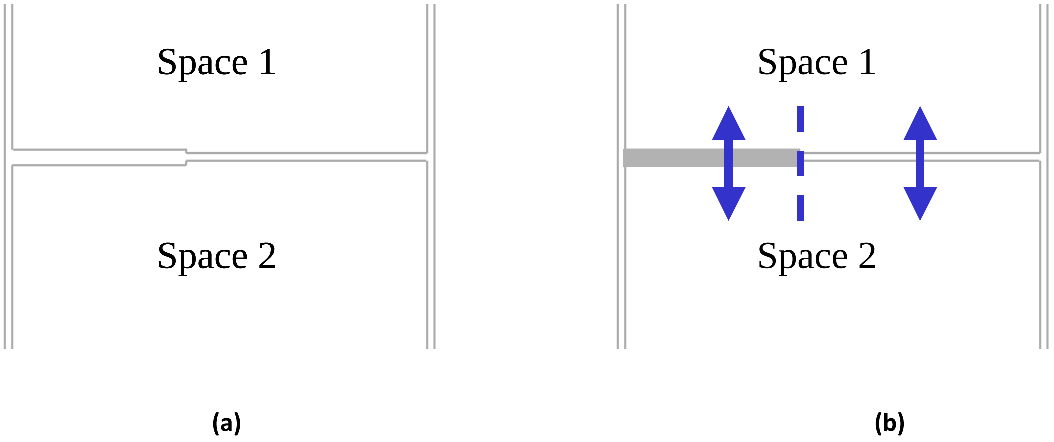


Figure 17: 1st Level Wall Space Boundaries (a) vs. 2nd Level Wall Space Boundaries (b) for multiple wall Instances[25]

Finally, when spaces do not align vertically (spaces on one floor does not match up one to one with spaces above and below), 2nd level space boundaries must be defined to correctly define their thermal relationships, as shown in Figure 18.

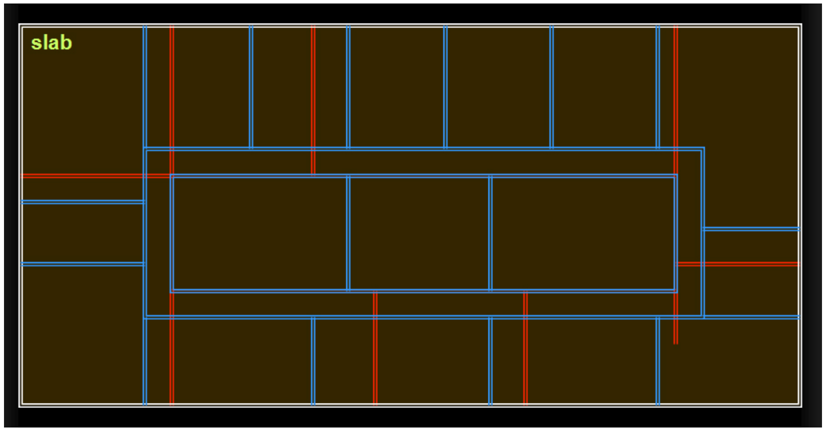


Figure 18: The need for 2nd level space boundaries is evident by the non-uniform wall space boundaries between adjacent floors.[26]

Most BIM-authoring applications specify 1st level space boundaries in IFC to some degree, although current functionality for 2nd level space boundaries is limited. Further development by BIM-authoring tool vendors to enable IFC-based 2nd level space boundaries will be required as BIM-based energy analysis becomes more common, and there is ongoing work in developing implementation guidelines and MVDs for 2nd level space boundaries through the OGC AECOO Testbed. gbXML is based on the principle of heat transfer surfaces (which are the equivalent of 2nd level space boundaries), therefore any gbXML-compliant BIM-authoring tool inherently supports this concept. However, as with IFC, more standardization between tools in how gbXML is implemented for certain building configurations is needed. Users should check the documentation for their BIM-authoring application to ensure they are modeling spaces and surrounding building elements in the manner recommended by the application vendor in order to ensure that the correct relationships are included in the IFC or XML file.

2.5.2.6 Updating Space Boundaries

Modeling building spaces properly in BIM requires great care and attention to detail. Users must ensure that space object geometry is updated when surrounding walls, floors, or ceilings are moved or changed. A common problem is that spaces are not updated to maintain alignment with the walls as the design evolves and changes. This results in area calculation errors and the potential for problems in correctly defining thermal relationships, as described earlier this Guide. Changes to any elements that bound spaces should be followed by a corresponding update to the space object boundary. In many BIM-authoring applications, updating space boundaries to re-align to the inside face of bounding elements can be automated or semi-automated. The user must ensure that any automatic updates in the BIM-authoring application are occurring correctly.

Some BIM-authoring applications are designed to automatically resize contained space objects when space-bounding elements are moved. If a space-bounding element is converted to another object type (e.g., changing a wall to a column) and subsequently moved, the affected space may not be resized properly. In this case, the user may need to manually invoke a “resize” of the space object. Please see BIM Guide Series 02-Spatial Validation for specific BIM-authoring application instructions.

Inaccurate or careless modeling of walls, partitions, floors, and ceilings can result in problems with space objects. For example, in some BIM-authoring applications, a small gap between walls that appear to be connected can cause the space object to “leak” into an area that should really be another space. Space objects should be checked to ensure there are no missing space areas. Users should look for missing space areas, overlapping spaces, or gaps between spaces and adjacent bounding elements.

2.5.2.7 Zones

Spaces can be grouped for many different analysis and organizational purposes. These groups are often referred to as Zones. A space can belong to several such zones and the members of any particular zone do not have to be adjacent. For example, in a historic preservation project, there may be multiple historic zones in the building, but these zones may be in different areas of the building. In addition to being a historic zone, some of these zones may also be part of a security zone or belong to an organizational department zone.

For energy simulation, spaces should be assigned to an appropriate Thermal Zone, and if different Thermal Zones should be assigned the appropriate HVAC Zone. Some typical zones on GSA projects include Security Zones, Preservation Zones, Fire Zones, Occupant Zones, Daylighting Zones, and HVAC Zones. Some zones are only required in certain types of projects (e.g., courthouses, historic buildings). A/Es should consult with ODC and the GSA project teams to determine what additional zone types and properties are required. The designation and use of BIM zonal information in facilities operations and maintenance can reduce operating costs and support more effective building management.

A/Es should consult their BIM-authoring application documentation for instructions on how to create such zones for export to an IFC or XML file.

2.6 Model Checker Development

The development of model-checking software to facilitate the use of BIM for energy modeling is in an early stage. Model-checking software may potentially be used to ensure that a BIM is correctly designed and populated with the necessary information to successfully perform energy simulation. This process would screen a BIM prior to exporting to a building analysis application using a set of pre-defined rules specific to the particular application's data requirements. Note that these requirements may differ between building analysis applications. For example, spaces may be defined at the wall centerline or on the bounding walls interior face. Ideally, as the industry continues to develop and energy modeling using BIM becomes more standardized, these "rule sets" will become more and more streamlined, with one set possibly used for checking BIMs for export to the vast majority of building analysis software. Several ongoing efforts exist, including projects at GSA, LBNL, and ASHRAE to identify the building geometry, elements, and properties that must be checked to ensure an effective transfer of information to an energy simulation program.

An ideal model checker would also have the functionality to generate a report that warns users of errors and/or missing data prior to exporting a data schema file or information directly to building analysis software. The following sections summarize a few types of information that a model checker could potentially verify.

2.6.1 Proposed Model Checker Capabilities

2.6.1.1 Space Definition

A model checker could determine if spaces are properly defined using correct wall space boundaries (e.g. inner face vs. wall centerline), the correct height (e.g. up to ceiling surface vs. overlapping ceiling surface), and space boundary types (e.g. 2nd level space boundaries).

2.6.1.2 Spatial Data

The completeness of the following spatial data could be checked: lighting and equipment loads (watts/ft^2 or total wattage), occupant loads (ft/person or number of occupants), conditioning requirements (heated, cooled, heated and cooled, unconditioned), conditioning schedules (e.g. hours per day on/off), design space temperatures and setbacks/setforwards (degrees F or C), outside air requirements (e.g. cfm/person), infiltration rates (e.g. air changes per hour), and lighting, equipment and occupant schedules.

2.6.1.3 Thermal/HVAC Zones

A model checker could verify that all spaces are assigned to a Thermal Zone object, that all the Thermal Zones are assigned to an HVAC Zone, and that all HVAC Zones are assigned an HVAC equipment type (if conditioned). This could facilitate the correct assignment of systems to spaces once imported in the energy model.

2.6.1.4 Space Loads Based on Object Types

Instead of having to manually assign a load value to each space in the energy model (e.g. watts/ft^2 lighting), it would be beneficial if the modeler(s) could define load-producing equipment objects (e.g. lighting fixtures, motors, computers) in the room space or define load values in the space object within the BIM, and have the load values of those objects read and the appropriate parameters translated to the energy model. For example, the modeler could choose to place (10) 15 watt compact fluorescent light fixture (CFL) objects in a 200 ft^2 room. The BIM model would then calculate that the lighting load for the room would be 0.75 watts/ft^2. A model checker could determine if the appropriate object information, such as lighting and equipment loads, exist within a particular room given its occupancy type.

2.6.1.5 HVAC Equipment Object Types

Instead of assigned equipment parameters within the energy model, which frequently uses default operating data, it would be beneficial if the modeler(s) could define HVAC equipment objects (e.g. chillers, pumps, fans) in the BIM model, including the operating characteristics (e.g. full-and part-load efficiency, capacity, control type, etc.),with the appropriate parameters imported to the energy model. A model checker could determine if the proper HVAC equipment objects and characteristics exist within a BIM.

2.6.1.6 Construction Object Types

A model checker could verify if the appropriate construction material data, such as thermal conductivity, thermal mass properties, and surface finish properties, etc. are assigned to room bounding surfaces.

2.6.1.1 Adiabatic vs. Non-Adiabatic Adjacencies

Space-bounding surfaces could be checked to see whether they have been designated as adiabatic (heat transfer exists) or non-adiabatic (no heat transfer exists). This information could be used to reduce the run time required for the energy simulation, and potentially allow users to not export an internal wall object if it is designated as adiabatic. This would prevent users from having to delete/filter internal walls solely to simplify the model for energy analysis.

2.6.1.2 Code Compliance

An model checker could automatically determine if the modeled space loads, equipment efficiencies, etc. met a particular mechanical or energy code, such as ANSI/ASHRAE/IESNA 90.1, ANSI/ASHRAE 55, ANSI/ASHRAE 62.1, CA Title 24 Part 6, or the International Energy Conservation Code (IECC). For example, consider a building design that is being analyzed and has a lighting density of 1 watt/ft^2, but the local energy code requires 0.8 watts/ft^2 maximum for that particular space type. The International

Code Council (ICC) SMARTcodes[27] project is currently working to automate and simplify code compliance checking against the ICC International Codes (I-Codes), with one area of work being envelope and lighting checking for energy code compliance, which addresses several of the categories listed above.

3 Energy Modeling Case Studies

3.1 Peter W. Rodino Federal Building

Originally constructed in 1968, the Peter W. Rodino Federal Building is located in downtown Newark, NJ and is the largest Federal building in the State, comprising nearly 527,000 square feet over 16 stories. The American Recovery and Reinvestment Act authorized a $146 million modernization of the existing building, which had not been updated significantly throughout its 41-year history. The design-build upgrade project consists of construction of a new glass curtain wall over the existing precast concrete building envelope, renovation of interior spaces, upgrades to high-performance lighting systems, complete abatement of asbestos materials for the entire building, and new high-efficiency HVAC and plumbing systems, including new air handling units and central chilled water plant equipment. The new “double-skin” façade will provide an aesthetic and thermal performance improvement for the building, as well as blast protection. Construction work began in October 2010 and completion is anticipated for Spring 2015.

Figure 18: Rendering of the Rodino Federal Building Modernization Project in Newark, NJ[28]

The building includes tenant office space, a cafeteria with kitchen, a parking garage in the basement level, and various support and storage spaces. The major building energy efficiency measures include:

- Double Skin Façade: Increased envelope U-value, high-performance insulating glass with frit pattern lowers overall SHGC when compared to existing glass
- Reduced Lighting Loads: Overall average building lighting power densities lower when compared to ASHRAE 90.1 2004 values
- Daylight Dimming: Perimeter daylight sensors dim electric light when room level is 50fc or more
- Demand Control Ventilation: Outdoor air control using CO_2 (carbon dioxide) sensors.
- Airside Economizer: Uses outdoor air to cool spaces when possible reducing load on chiller plant; monitored by differential dry bulb conditions
- Chilled Water Delta: Chilled water plant utilizes a 14°F system temperature difference for reduced pumping energy when compared to the ASHRAE 90.1 value of 12°F
- Premium Efficiency Variable Speed Pumps: Higher efficiency motors compared to the baseline standard efficiency motors
- Photovoltaic Power: Rooftop photovoltaic panels sized to provide 60kW of on-site renewable energy

The major building system modifications include:

- Replacement of the central water-cooled chillers and chilled water piping distribution system, including pumps
- Replacement of cooling towers and condenser water distribution system, including pumps
- Replacement of supplemental air-cooled chiller equipment and pumps for 7x24 systems
- Replacement of building heating hot water pumps and dual temperature pumps serving perimeter Fan Coil Unit systems
- Replacement of tenant constant-volume HVAC systems with Variable Air Volume (VAV) air handling units and new VAV air distribution on certain floors
- Replacement of amenity space HVAC systems (cafeteria, fitness center, etc.), including kitchen exhaust system
- Replacement of perimeter dual temperature system Fan Coil Units on certain floors
- Providing new HVAC system for entryway loggia (including radiant floor heating and cooling)
- Replacement of various 7x24 packaged HVAC systems
- Replacement of main toilet and general exhaust fans
- Providing AHU variable frequency drives and terminal units for tenant spaces on certain floors

A rainwater harvesting system was also added to reduce city water consumption for cooling tower make-up (non-potable) water end uses, as well as a solar thermal hot water system to reduce natural gas usage for service hot water heating for certain floors of the building.

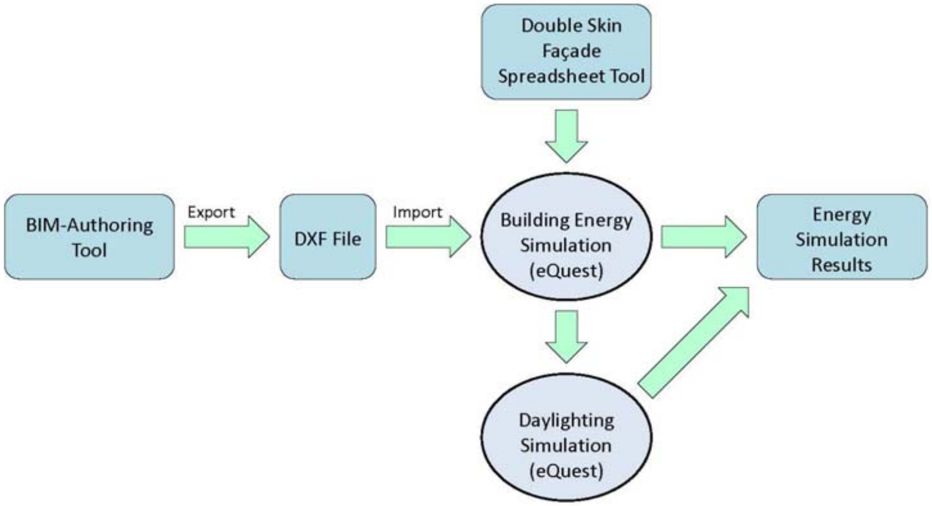
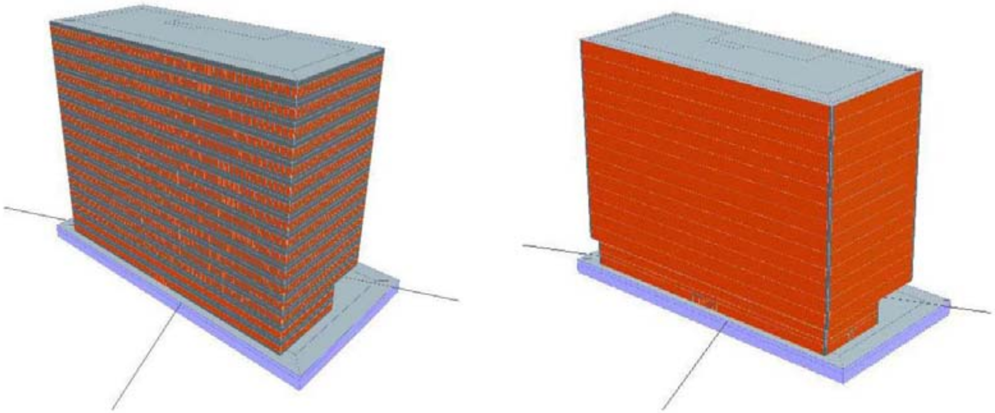


Figure 19: Sequence of information transfer for energy modeling in the Rodino project

The Rodino building was modeled to simulate energy performance in order to confirm achievable Energy and Atmosphere Credit 1 for existing building renovations for LEED certification. This entailed developing models under the guidelines of ANSI/ASHRAE/IESNA Standard 90.1-2004 Performance Rating Method (contained in Appendix G). For this project, the design team utilized eQuest v3.63 to develop the building energy model, including geometry, space use and classification, zoning, and the building systems. The eQuest model utilized exported DXF data from the BIM to initially define the building geometry and thermal zoning.

Two parts of the Performance Rating Method modeling methodology used for the project that differ significantly from that of new construction relate to the envelope and existing-to-remain HVAC systems. Since most of the existing envelope is merely being upgraded, Appendix G allows for those conditions to be modeled reflecting the existing conditions prior to any revisions (except for the loggia space, which is new building area that did not exist previously). Regarding the existing-to-remain HVAC systems, Appendix G requires that both the proposed and baseline building performance must be modeled to reflect the existing conditions of areas and/or systems not modified in the project. These methodologies were identified early in the modeling process and influenced where modeling inputs occurred and when (i.e. since many of the features that impact the building's energy use were existing or not in the scope of work for the project, the BIM could not be used for energy modeling directly).



(a)

(b)

Figure 20: Rodino Federal Building energy models for (a) performance rating method baseline and (b) proposed design with double skin façade[29]

Integrating the performance of the double skin façade (DSF) into the energy modeling presented some challenges for the design team. The DSF reduces solar gain in perimeter spaces, with motorized louvers to ventilate the cavity between the overcladding and the existing façade. The louvers are controlled according to the outside air temperature (i.e. they are closed during the winter to allow the cavity space temperature to increase and reduce heat loss from the perimeter spaces to the outdoors). First, the design team partnered with a consultant to fully understand the thermal benefits of the DSF wall cavity during heating and cooling. The consultant utilized a proprietary spreadsheet-based tool to provide information on the airflow and temperatures that may be expected within the cavity for the 8760 hours required by the whole building energy model. This data was imported into the eQuest model using the software's "sunspace" functionality, which is an additional layer of construction that allows a number of features such as temperature to be specified and solar gains to be passed to the perimeters spaces in the energy model. This process allowed for the hourly cavity temperatures to be integrated into the model using an unmetered energy schedule in order to control the cavity (sunspace in eQuest) temperature and account for the DSF benefit for the perimeter spaces. One drawback of this approach is that eQuest does not allow daylight dimming to be calculated for spaces that include a sunspace. Therefore a separate eQuest model was created that was identical to the baseline model but with glazing and lighting characteristics from the proposed model to quantify the effect of the daylight dimming system on the lighting energy use of the building. This lighting energy use was assumed in the final proposed building modeling results in order to capture the benefit of the daylight dimming in the LEED calculations.

The GSA also conducted separate BIM-based energy analysis using IES <VE> for the Rodino project in order to validate the assumptions used in the energy model as well as its results. It was initially discovered that when the raw BIM model is exported, a satisfactory model for analysis within the software is not produced. A number of iterations were required involving modification of the BIM model settings before the model could be exported correctly. These corrections to the BIM model were made using IES guidance together with additional updates regarding some settings within the BIM model for the DSF configuration.

Additional geometry updates for the DSF were made directly within the analysis software, as the changes could be made quicker and with better quality than could currently have been made in the BIM model. The geometry errors could have been avoided if the BIM model had been configured for energy modeling during the concept phase. When importing a model it is important that the geometry be correctly prepared to ensure thermal zones are correctly recognized and their boundaries defined within the thermal model.

Since the <VE> model was based on a BIM import where every room within the building was individually modeled, more control over the floor areas associated with each activity type was gained. The higher resolution of thermal zoning also contributed to a difference in solar thermal response time between the models due to the mass associated with all of the internal partitions. The inputs used in the preparation of the eQuest model were replicated in the <VE> model as much as possible in an attempt to keep the output similar. It was not possible to match all the inputs exactly, either due to differences in the geometry complexity, calculation methods, and software input options. For example, the DSF was modeling using the <VE> bulk airflow module, Macroflo. Using Macroflo, the <VE> simulation was able to include the effects of air movement passing through the outer skin, by modeling the cavity as a free-floating zone without any level of space conditioning. This cavity was split at each floor level and by each façade orientation. The resulting temperature is affected by the conduction gains from the perimeter office zones, conduction to outside, solar gain, and from air exchanges between the zones representing the cavity. This stimulates the buoyancy effects and allows the model to represent the temperature difference up through the façade.

The project's goal is to achieve a LEED Silver rating and the energy modeling confirmed that that building design incurs 29% less energy cost than the ANSI/ASHRAE/IESNA Standard 90.1-2004 baseline, and will earn 8 LEED EA Credit 1 points to help achieve that goal. The separate <VE> modeling calculated a 24% energy cost reduction. Overall, the separate analyses results are comparable and demonstrate similar trends between the dominant energy loads within the building. The main characteristics which caused the differences in the model results include the granularity of the building geometry and zoning, elevator and service water heating inputs, modeling of the pumping systems, and modeling of the DSF. The energy modeling processes utilized for the Rodino Federal Building are an example of how multiple energy modeling platforms may be used in an integrated fashion to simulate the effect of non-standard building construction and system interaction and provide for exceptional calculation methodology under LEED NC.

3.2 Wayne Aspinall Federal Building

Constructed in 1918, The Wayne Aspinall Federal Building and Courthouse is located in Grand Junction, CO and includes over 24,000 net square feet of usable space for a variety of government agencies. The building was originally used as a post office and courthouse, and was expanded with a major addition in 1939. The American Recovery and Reinvestment Act authorized a $15 million partial modernization of the existing building, including replacement of the mechanical, lighting, electrical, elevator, and plumbing systems with new energy-efficient infrastructure. The design/build project also includes replacement of the roof, public and interior space upgrades with reconfiguration of tenant spaces, exterior restoration, and security and fire life safety upgrades. Project completion is scheduled for 2013. The high-level goal of the project is provide an energy-efficient, high-performance green building while also accentuating the historic nature of the existing Wayne Aspinall Federal Building.

Specific energy-related goals of the project include achieving LEED Platinum certification under LEED 2009, the highest level awarded by the U.S. Green Building Council, and Net Zero Energy Usage, meaning that the facility should produce enough energy to balance the net electrical consumption of the building to zero or better on an annual basis.

The major energy-related elements of the final design include a 123.2 kW photovoltaic array on the roof and canopy, and a geothermal system consisting of 32 475-foot-deep wells with water-source heat pumps and decoupled ventilation systems. The geothermal system efficiently absorbs heat from the building in the summer and provides heat in the winter. A 40-year life cycle was considered in the design of the building and its systems, which allowed the higher capital cost of the geothermal well system to be justified through its future energy cost savings in the life cycle cost analysis required by GSA, as compared to a few other systems which were considered.

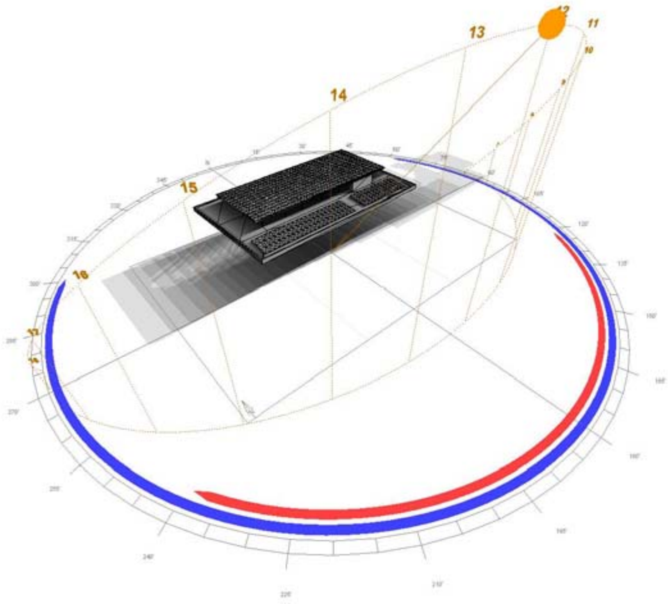


Figure 20: Performance of the new PV array for atop the Wayne Aspinall Federal Building was analyzed using Autodesk Ecotect[30]

The building energy efficiency measures include:

- Daylighting controls
- Approximately 0.7 Watts/ft^2 average lighting power demand across the building (does not include impact of occupancy and daylighting controls) via use of both fluorescent and LED technology
- Thermally-improved building envelope, including addition of spray foam insulation inboard of existing masonry
- Thermally-improved historic windows, including addition of interior storm window with high-performance solar film
- Water-source variable refrigerant flow system tied to GeoExchange loop
- Dedicated outdoor air system with air-to-air heat recovery, indirect evaporative cooling, and full space ventilation shut-off capability based on occupancy
- Extensive plug load monitoring to allow for real-time feedback and behavioral modification of occupants
- Wireless building automation technologies

TRACE 700 was utilized for the energy analysis throughout all phases of the project. Early in the project, a .gbXML file export from the BIM was used for preliminary load and energy analysis. Details such as complete closure of the building spaces and proper definition of space boundaries were required to be edited before exporting. Items such as definition of the ceiling plenum spaces were performed in TRACE since that was determined to be easiest approach, and spatial information used for occupancy, load, and scheduling were input using customized libraries in TRACE. Sections from the BIM model were also used to quickly analyze the existing building construction and make assumptions required for early parametric building energy simulation. The automatic scheduling capabilities of the BIM software also allowed the lighting designers and energy modelers to dynamically check lighting power space-by-space to meet the aggressive design goals of the project.

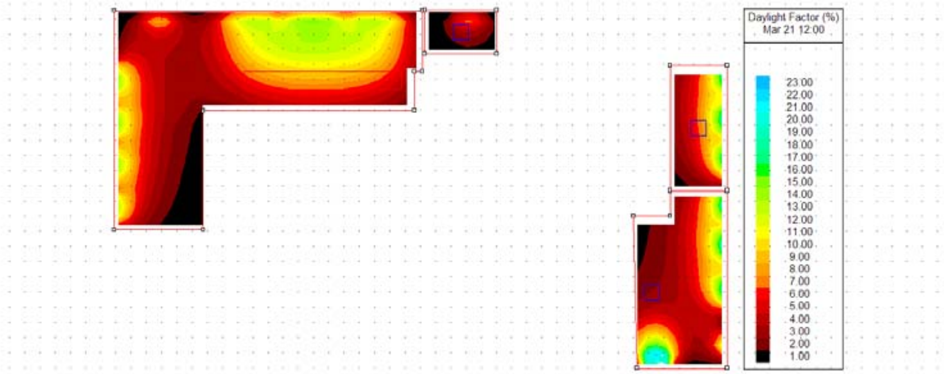


Figure 21: Daylight penetration into the Wayne Aspinall Federal Building was analyzed using Integrated Environmental Solutions Virtual Environment[31]

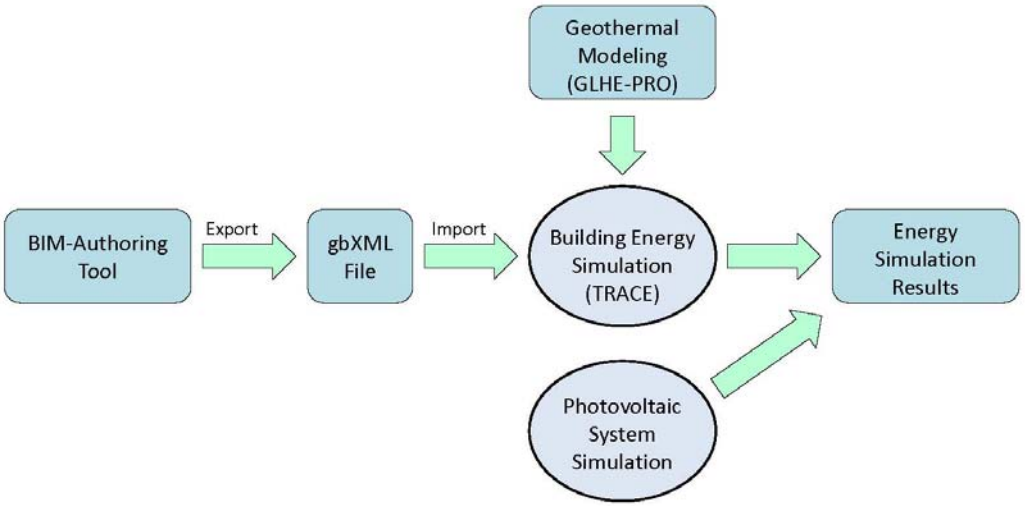


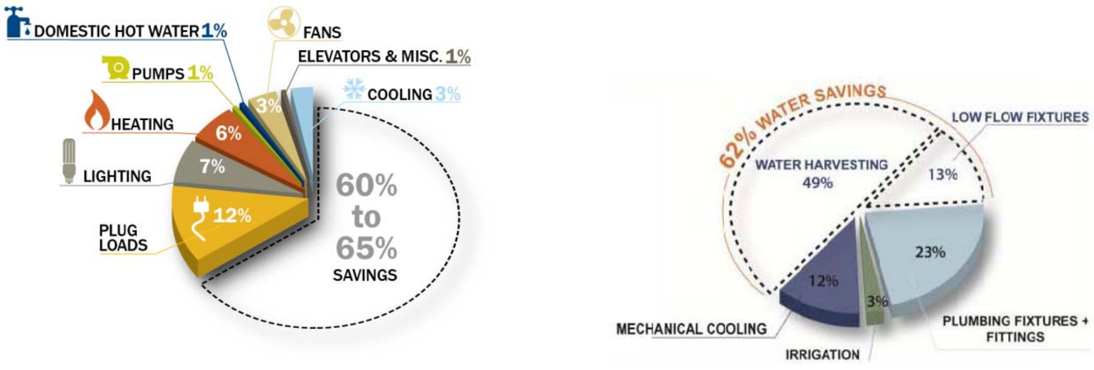
Figure 22: Sequence of information transfer for energy modeling in the Aspinall project

Other software programs were used for different system-level analysis for the Wayne Aspinall project. In order for TRACE to correctly calculate the performance of the geothermal systems, separate sizing and modeling of the geothermal loop needed to be performed using GLHE-PRO and then referenced by the whole building energy model in TRACE. Integrated Environmental Solutions Virtual Environment was also used for the daylighting and comfort analysis, and Autodesk Ecotect aided the design of the photovoltaic system. For these efforts separate models from the BIM were created in order to capture the building geometry, since that was determined to be more suitable by allowing more rapid changes to the geometry than by importing all the geometry of the building, much of which was unrelated to the design of those particular areas. Additional analysis using WUFI and THERM was also required to calculate the thermal performance of the upgrades to some existing building components, and there are currently no workflows directly from a BIM to these tools.

The energy modeling performed for the project concluded that 63.8% energy cost savings over the ANSI/ASHRAE/IESNA Standard 90.1-2007 baseline, not including the renewable energy production of the building, were achievable to meet the goals stated earlier. The energy modeling processes utilized for the Aspinall Federal Building are an example of how BIM and building analysis software data can be appropriately viewed and exported in limited and controlled manner to help the process of designing a net-zero energy building.

3.3 Edith Green Wendell Wyatt Federal Building

The Edith Green Wendell Wyatt (EGWW) Federal Building, constructed in 1974, is an 18-story office tower with two basement levels located in Portland, OR. It includes over 525,000 square feet of space for 24 different government agencies. The American Recovery and Reinvestment Act authorized a $141.5 million partial modernization of the existing building, including renovation of the interior spaces, façade, and building energy systems. A "non-traditional" integrated project delivery method was utilized for the EGWW building project, which in addition to meeting the requirements of the Energy Independence Security Act (EISA) had three primary energy-related goals: 1) achieve a specified kbtu/ft^2/year Energy Use Intensity (EUI), 2) qualify for The Energy Trust of Oregon Incentives, and 3) achieve LEED certification. It was determined through initial energy modeling that achieving the specified EUI was the most stringent goal.



(a) (b)

Figure 23: Energy modeling of the EGWW Federal Building indicated (a) 60-65% energy savings and (b) 62% water savings compared to a conventional office building[32]

The major new building HVAC system consists of radiant heating and cooling with Dedicated Outdoor Air Systems (DOAS). Early in the design, comparisons were made to optimized VAV systems and due to the long building lifetime considered, the radiant panel systems were determined to present the lowest life cycle costs and met the GSA criteria. Workarounds were utilized in eQuest to modify the space temperature setpoint assumed to capture the radiant effects of the cooling system, and referenced methodology that is contained in the newer ANSI/ASHRAE/IESNA Standard 90.1-2010 Appendix G. This system, when combined with the other building energy efficiency measures, is expected to reduce the building's overall annual energy consumption by between 60% and 65%. The building also contained a data center, which was analyzed separately and not included in the whole building energy model due to its standalone energy consumption.

The building energy efficiency measures include:

- Radiant heating and cooling with DOAS
- Building envelope optimized for daylighting and thermal efficiency by minimizing glazing to 40% of the overall wall area and through use of high performance double glazed windows, external shading devices, and light reflectors
- Daylighting controls with higher ceilings to increase daylight penetration and distribution of electric lighting
- New elevators with destination dispatch and regenerative energy technology features
- Reduction in building “plug” loads through use of LED task lighting, consolidation of appliances and use of energy-efficient units, power management settings, and “phantom” load management
- Approximately 0.6 Watts/ft^2 average lighting power demand across the building (does not include impact of occupancy and daylighting controls) via use of both high-efficiency fluorescent and LED technology
- Photo voltaic panels (PV) on new canopy roof, expected to produce up to 5% of the building’s annual electric energy usage

A rainwater harvesting system for the new roof canopy was also added to reduce city water consumption for non-potable end uses such as toilet and urinal flushing and landscape irrigation. Low-flow plumbing fixtures were also utilized.

The design team utilized an .XML data export from the BIM to initially extract building envelope geometry. The .xml files were then edited directly to provide any additional required building geometry specification as well as spatial information, schedules, and system assignments. Finally, the .xml files were imported into e-Quest, where the system and plants were modeled to comprise a whole building energy simulation. The team found that this approach was optimal, since they chose to use custom .xml information that could be input quicker than in eQuest directly, since that software does not provide the library and template functionality that is included in some other energy analysis programs. In general, the modeling consisted of a simplified core-and-shell model and detailed floor-level models which were completed as the design was completed for individual floors. Once a process was clearly defined for information transfer from BIM to an .xml file and then to eQuest, the design team estimated that approximately 100 labor hours were saved by transferring the building geometry from BIM, with even more savings found in inputting details in .xml in lieu of eQuest.

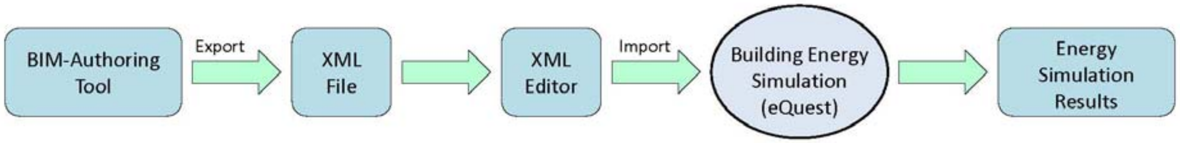


Figure 24: Sequence of information transfer for energy modeling in the EGWW project

The architectural BIM was also leveraged to analyze the impact of surrounding buildings in the city on the shading and solar insolation of the building. As a result, facade changes were made based on the impact of the afternoon sun on the building.

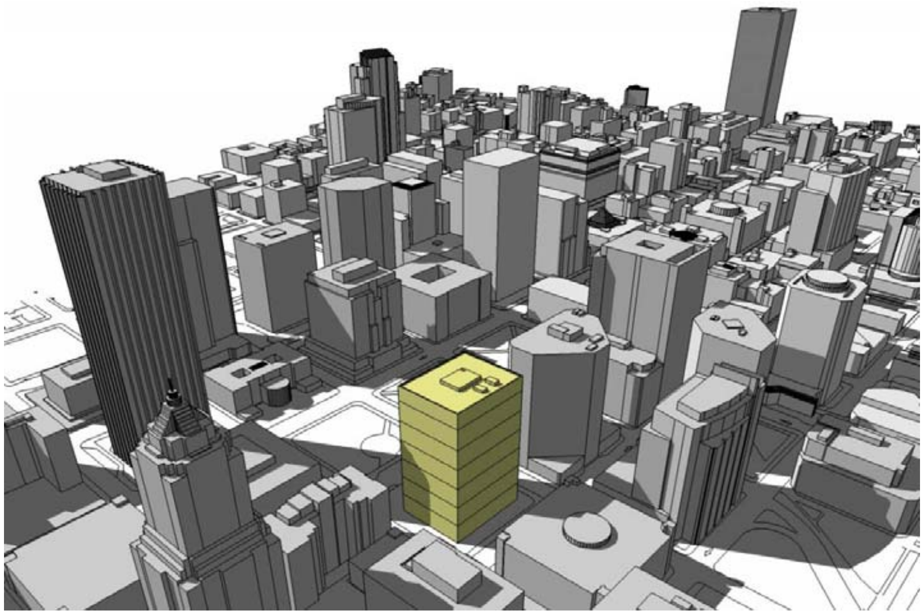


Figure 23: The impact of surrounding structures on the thermal performance of the EGWW Federal Building was studied using BIM data[33]

The team maintained a central "matrix" document listing assumptions and details that needed to be coordinated across the different design stakeholders. This facilitated valuable coordination that allowed the team to understand what information was needed from each party and when. The document was formatted so that all information was clear and understandable by all parties given their technical knowledge of the various subjects. The team also provided extensive feedback and recommendations to the BIM vendor to help them continuously improve their product. The energy modeling processes utilized for the EGWW Federal Building are an example of how a process may be implemented on a project to view and process BIM data to decrease the time required to perform the modeling inputs required for energy simulation of a high-performance building.

Conclusion

The world of BIM-based energy simulation is continuing to develop. The GSA has identified that improving the energy performance of its building inventory is one of its highest priorities over the next several decades. While there are currently a wide variety of technologies available to GSA associates and consultants to support BIM-based energy simulation, significant limitations and challenges still exist. The building industry is currently very inconsistent in terms of adopting the exportation of data from BIMs to analysis software. Although most parties agree that there is much potential in the process, variables such as the type of software and/or analysis being performed, level of experience of the modeler, physical properties of the building, and personal preferences in terms of workflow are currently dictating the level of adoption. For example, the selection of energy modeling tools to be utilized currently dictates the level of data exported from BIM within most projects, and in most cases additional designer and modeler effort is required to leverage BIM data in building analysis tools. The continuing goal is to develop a seamless, tested, and reliable interface between BIM and analysis tools, but currently building designers and modelers need to be diligent in the data extraction methods and continue to identify unique software solutions that meet the project requirements. The GSA is committed to working with the industry to develop new software technologies, design, construction, and operational strategies, and user functionality to support its environmental performance goals. This Guide is a step in that direction, and GSA welcomes industry collaboration to improve current and future design, construction, and operational requirements that support a sustainable building lifecycle.

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[28] Graphic courtesy of KlingStubbins

[29] Graphics courtesy of KlingStubbins

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[30] Graphic courtesy of Westlake Reed Leskosky
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