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This version of the "GSA Building Information Modeling Guide Series 05 – Energy Performance is identified as Version 1.0. With its publication, a GSA BIM Guide pertaining to energy performance, for the first time, 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.

Currently, the following Series

- GSA Building Information Modeling Guide Series 01 – Overview, version 0.60
- GSA Building Information Modeling Guide Series 02 – Spatial Program Validation, version 0.96
- GSA Building Information Modeling Guide Series 03 – 3D Imaging, version 1.0

are available for download, review, and comment.

For further information about GSA's National 3D-4D-BIM Program, to download BIM Guide Series, or to submit comments or questions, please visit http://www.gsa.gov/bim.

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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 1.0 — February 2009

United States General Services Administration (GSA)
Public Buildings Service (PBS)
Office of the Chief Architect and Capital Construction Programs (OCA-CCP)

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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. 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 the Chief Architect & 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 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.

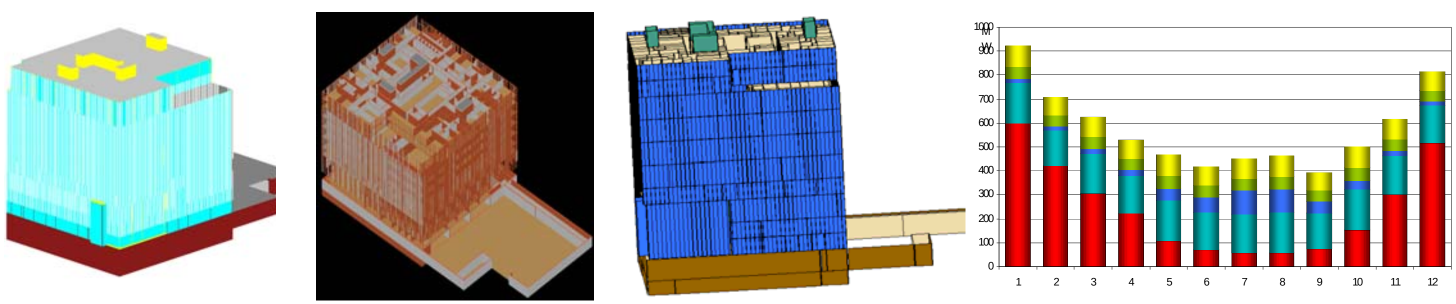


Figure 1: Energy Modeling from GSA Pilot Project

Series 05 (*Energy Performance*) is divided into two 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.

Section 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 are involved to determine the energy characteristics of the building and its building 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), constructions, operating schedules, equipment loads (lighting, computer, etc.), heating, ventilating, and air-conditioning (HVAC) systems, local weather data, and utility rates (Figure 2). It performs an annual hourly simulation (at least) first calculating the building loads then calculating the system requirements to meet those loads.

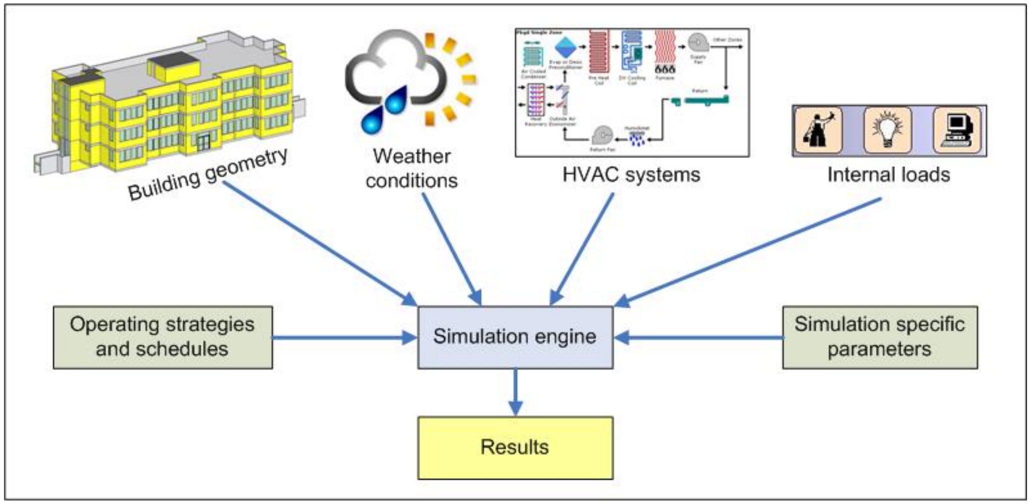


Figure 2: General data flow of simulation engines[4]

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 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 into 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 enable the user an easier generation of input files, initiate the simulation with the engine and process the output files to illustrate results in a more graphical manner.

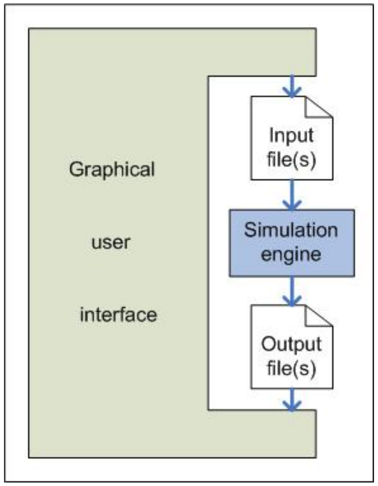


Figure 3: General architecture of energy simulation tools[5]

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 comfortable indoor conditions for building occupants in an efficient manner, to optimize the building material and system performance, and to compare design options based on lifecycle costs. With an enhanced understanding of how the built environment impacts our health, environment, productivity, and overall well-being, it is clear that more attention must be made to 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.

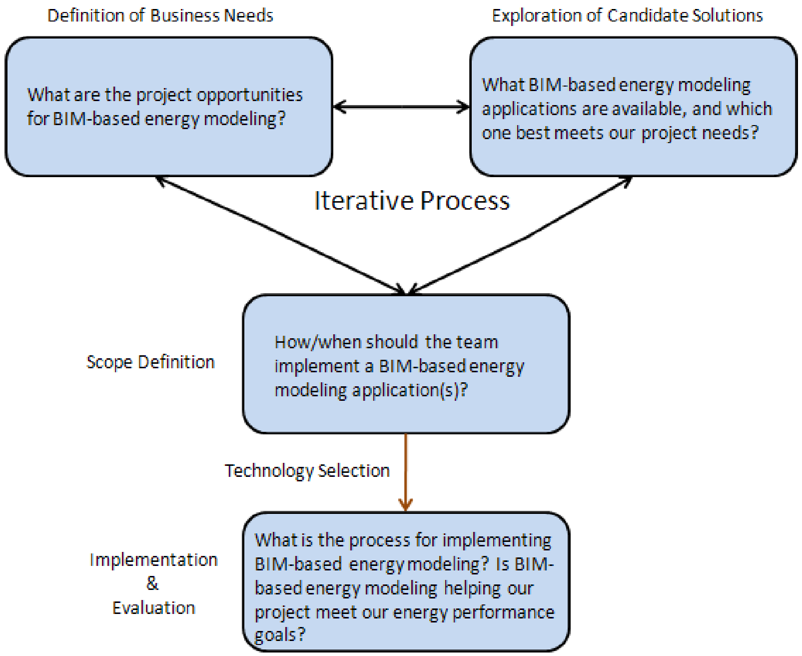


Figure 4: Process for adopting energy modeling

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. Misinterpretations of the building geometry in the CAD to energy model translation are quite common, and these misinterpretations are often inconsistent. It is not uncommon to have multiple engineers creating different models from the same set of plans. All required parameters such as space loads (lighting, computer, 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. 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 significantly reduce the simulation time and improve the accuracy of the energy model. Also, by using BIM, the process of creating an energy model becomes 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. 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	Estimated annual energy consumption that meets or exceeds GSA/Architecture 2030 requirements, 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 GSA/Architecture 2030 requirements, 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.

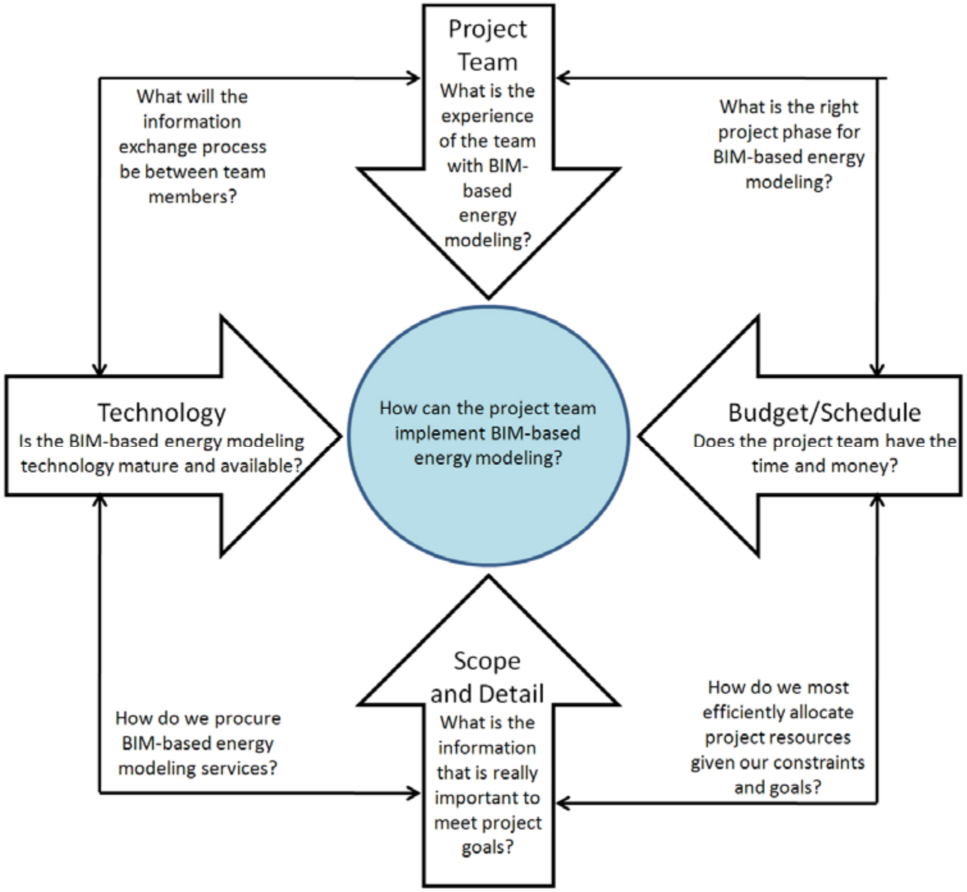


Figure 5: Decision Loop for Implementing Energy Modeling

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]

Energy modeling itself is a complex activity, which requires a certain level of engineering experience and judgment to be successful. 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 software applications allow more simplistic energy modeling during the early design stages, and also support more detailed analyses for later stages.

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 significant 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 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% DDs, and 100% 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 design development or construction document phases has very limited impact compared to modeling started earlier in the design 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.

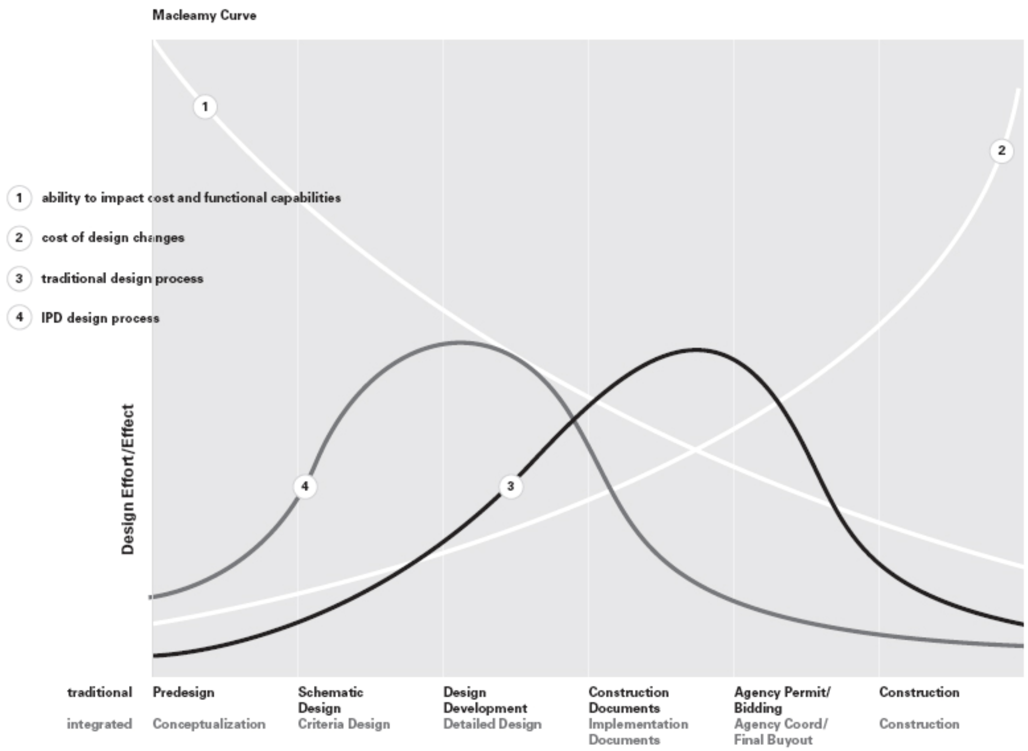


Figure 6: The "MacLeamy Curve"[8] demonstrates the value of an integrated design process and the evaluation of building performance during early design.

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, constructions, and mechanical equipment, and intermediate assumptions	Evaluate and compare proposed design schemes, intermediate analysis, preliminary code compliance
Design Development	Building geometry, detailed layout, more detailed constructions and envelop 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

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”, depending on whom you ask. 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.

A challenging 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 of information that design teams will typically require and have available during early design in current practice, account for the level of detail of that information, and identify and include the types and level of detail of information that design teams should be considering to support early design performance analyses and could have available to them using BIM applications and robust, possibly semi-automated design analysis tools that are becoming available to designers. In a sense, they are tasked with “redefining” what a design team 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 used with building performance analysis tools, BIM can 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. 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. 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 OCA 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, and building orientation. For example, a first round of energy modeling can be used to compare three architectural schemes. 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. This type of information, while not accurate in absolute terms, provides valuable information regarding 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.

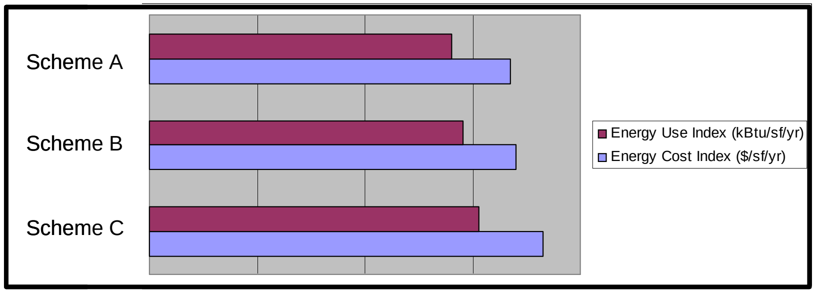


Figure 7: Example of Preliminary Conceptual Design modeling results on a Federal Courthouse project

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 system, fuel type, constructions, 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 designs best meets the project's program, performance goals, and budget. Figure 8 shows three proposed design alternatives for a GSA Border Station and their respective energy modeling results.

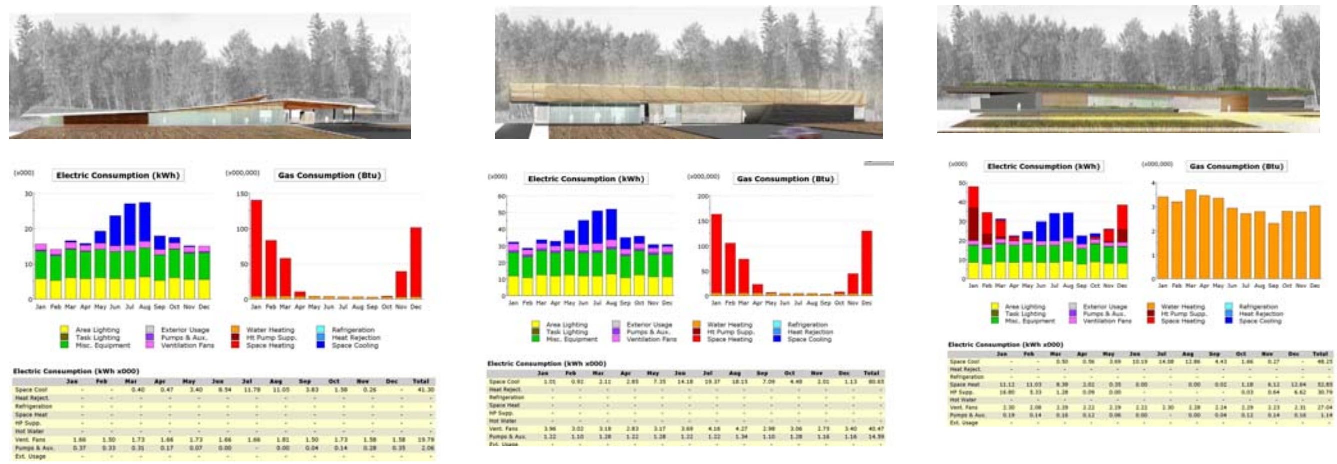
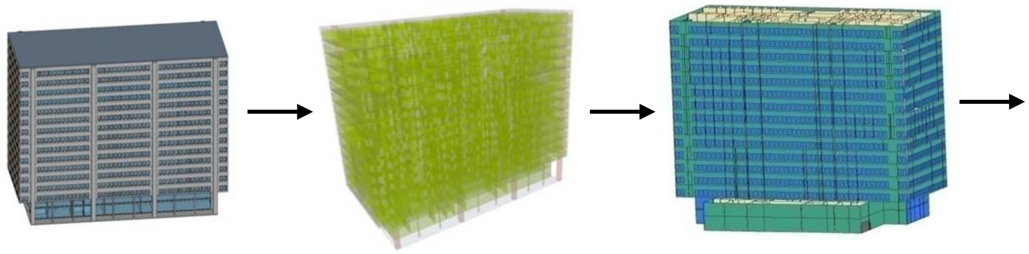


Figure 8: Using energy modeling to evaluate three alternative designs for a Border Station[9]

1.4 Design Development

During design development, energy modeling allows the design 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.



(a) (b) (c)

	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

(d)

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 one component of energy use is set to zero each time, allowing the design team to clearly determine the relative value of each component in isolation to the energy performance of the building. [10] The impact of "value engineering" on the building performance can also be analyzed during this stage using energy models.

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

Typically, energy modeling is not conducted during the Construction Phase. 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.

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 commissioning, retro-commissioning, continuous commissioning, and retrofits.

In the past, energy simulation has been rarely used for building commissioning. Typically, commissioning has been accomplished with the use of a variety of diagnostic tools, 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. There lacks 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 two 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, will not be addressed in guide.

Calibration of energy models is applicable to new construction commissioning, retro-commissioning, and continuous commissioning. The primary difference for new construction, as opposed to retro-commissioning and continuous commissioning, is the lack historical building performance data for calibration. 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 an 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. It is these situations that the greatest benefit to retro-commissioning and continuous commissioning can be realized.

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. However, when is the case, calibrating to utility billing data is more challenging for the billing data typically is represented at the facility level, and the particular contribution of just a few systems to 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.

Section 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 a 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 limitations in the current 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, other operational characteristics, though 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 is currently collaborating 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).[13] Many of the exchange requirements that are 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)[14] 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 vendors with IFC support (to varying degrees) include Autodesk Revit Architecture and MEP, Autodesk AutoCAD Architecture and MEP, Bentley Architecture and Building Mechanical Systems, Graphisoft's ArchiCAD, Digital Project by Gehry Technologies, Onuma Planning System, Nemetschek's Vectorworks, MagiCAD, and Google SketchUp. Building performance applications that support IFC include Autodesk Ecotect, Granlund's Riuska, and EnergyPlus via IDF Generator and IFCtoIDF Utility, both still under development at Lawrence Berkeley National Laboratory (LBNL) and the National Renewable Energy Laboratory (NREL).

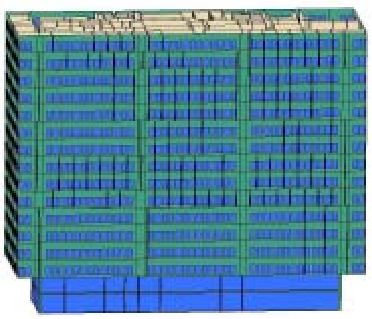


Figure 10: GSA Office Building, IFC imported by Riuska

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.[15] 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[16] 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 vendors with gbXML support (to varying degrees) include Autodesk Revit Architecture and MEP, Autodesk AutoCAD Architecture and MEP, Bentley Architecture and Building Mechanical Systems, Bentley speedikon Architectural, Graphisoft's ArchiCAD, and Google SketchUp. Building performance applications that support gbXML include Autodesk Ecotect and Green Building Studio, Integrated Environmental Solutions Virtual Environment (IES <VE>), Trane's Trace, Carrier's HAP, CADLine's Cymap, EDSL's TAS, mh-Software, Elite Software, and Solar Computer. EnergyPro is the in process of developing gbXML functionality.

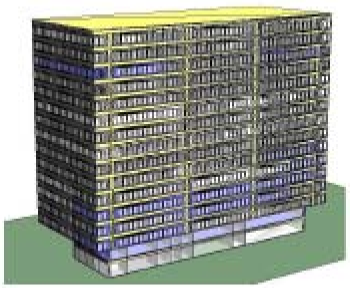


Figure 11: GSA Office Building model, gbXML imported by IES <VE>

2.2.1.2.2 ifcXML

The ifcXML[17] 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.

2.3 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 10). However, differences in personal thermal comfort may make it more prudent for the engineer to zone the offices in groups of three, etc. so that the occupants have more individual control over their environment. 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. As a result, significant simplifications are often made by the modeler (Figure 12.) In BIM-base energy modeling thermal zoning is more streamlined, and allows energy modelers to more easily create discrete zones based on the spaces modeled in BIM (Figure 12).

2.3.2 Zone-Based Modeling

When creating a model for an energy simulation, in particular in early design, standard energy modeling practice requires the energy modeler to make judgment calls 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 are frequently over-simplifications, 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, treated as similar and assigned the same loads (W/SF), schedules (% on per hour) and HVAC system. Such simplification often results 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, or BIM-enabled energy modeling, generally uses the same inputs parameter types, but assigns them on the space level. Currently, most BIM-based energy simulation programs assume each space imported is its own thermal zone. Soon the functionality will be available to allow thermal zones, defined as a group of spaces within the BIM-authoring tool, to be transferred directly into the energy modeling tool, and there is currently limited support for this functionality. 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 address further in Section 2.5.2.

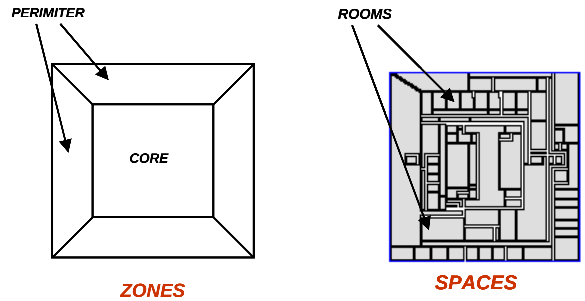


Figure 12: Traditional Energy Modeling Partitioning vs. BIM-Based Energy Modeling Partitioning

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, which can be considered the "BIM-based" ones, 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 by "hand."

Typical building elements data to 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 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. If there is a deficiency in any one of these areas, errors may occur.

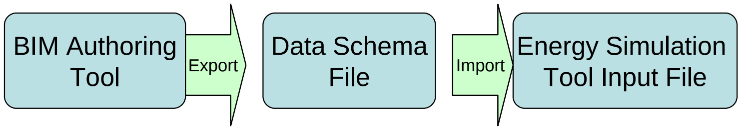


Figure 13: Current sequence of information transfer in BIM-based energy modeling

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 may have a number of different ways to express the same objects and relationships, all technically being "correct". 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 trip. Although evolving, many tools do not have the capability to export changes from energy models in order to be imported back into the BIM-authoring tool and utilized. If re-import of data is supported, the scope is typically limited.

Given the current functionality of many building analysis tools, as a general principle, the greater the complexity of a geometric model, the greater the risk for errors in translating that geometry from a BIM to energy analysis tool. Therefore, it is wise modeling practice to minimize the number of unnecessary elements that are translated. In particular, frequently users attempt to translate all the interior walls from a BIM into an energy simulation model or some other building analysis tool. This practice has diminishing returns for in most energy simulation programs, since heat transfer between interior spaces with similar thermal conditions is generally negligible. Some programs do not even 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 on a separate layer 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, no matter 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 once imported into the building analysis tool to correct geometry errors, it may be best to perform further geometric modification that must be made should be done directly within the same tool. For example, let's say an architect creates a geometric model and has correctly defined all the geometry to the best of his/her ability. The architect hands the model to a consultant to conduct a daylighting analysis. However for some reason (exporter, data schema, or importer), the model is not translating perfectly. 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, then he/she runs 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, making the required changes to the windows within the daylighting simulation tool might take far less time than having to re-correct all the other non-window geometry errors originally encountered. In each case, it is up to the judgment of the modeler which methodology would be less time consuming.

2.4.1.3 Recommended Future Developments

Based upon GSA pilot cases, the BIM team has identified several areas in 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
- View definitions that specifically define what and how data should be defined in a BIM so software application can exchange it reliably.

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. Many times modelers make assumption on thermal properties based on general construction type. However, these assumptions often turn out to be incorrect. A common cause is a lack of communication between the architect and the person conducting the modeling. Having the thermal data present in the BIM would greatly alleviate this issue. Frequently the architect may only have information on construction types and not thermal data for those constructions, either due to availability 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.

2.4.2.3 *Recommended Future Developments*

Based upon GSA pilot cases, the BIM team has identified several areas in 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, and material properties such as such as thermal conductivity, specific heat, reflectivity, transmissivity, absorptivity, and emissivity
- Industry standard databases of typical material properties and constructions (e.g. ASHRAE) that are available via the BIM-authoring application, either internally or web-based
- Links that bridge the gap between architects' information and the data that is needed for energy simulation

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. Many times modelers make assumption on HVAC operational parameters based on system type and prior experience; however these assumptions often turn out to be significantly off. 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.

2.4.3.1.3 Recommended Future Developments

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

- Transfer of equipment capacities
- Transfer of equipment full-load and part-load efficiencies
- Transfer of control mechanisms

- 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

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. Many times modelers make assumption on internal loads based on area type and building mechanical/energy code requirements; however these assumptions often turn out to be significantly off when looking at the actual design. The ability to store load data in the space object or within a BIM object of that equipment type (which would then be converted to a space load based on the space it was placed) would reduce these incorrect assumptions and significantly facilitate the process. 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, 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) 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.

2.4.3.2.3 Recommended Future Developments

Based upon GSA pilot cases, the OCA 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/ft2, occupants/ft2, etc. on the space level
- Effective transfer of load data for load producing objects such as lighting, motors, computers

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 objects (sometimes called zone objects, thought not to be confused with a zone object that is an aggregate of multiple places, such as HVAC or Security Zone) contain area and volume data used for load and energy consumption analysis. Population of these space objects with other 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 their import. Only a few tools support the export of additional mechanical information for the spaces. However, only a few building analysis tools can read and translate this data, as addressed in the previous section.

2.4.3.3.3 Recommended Future Developments

Based upon GSA pilot cases, the OCA 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 schedules
- 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

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 the like. 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 an data schema-compatible library provided by the vendor or others for the BIM-authoring application.

Note: 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 not available, or they are limited in some way (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. A/Es should be able to use the traditional techniques of stacking and bubble diagrams while still being able to 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 information on 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 this 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. The 'connected' relationship between walls is typically created automatically by the BIM-authoring application when the wall's 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 instruction 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 Wall tool 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, resulting in no marginal benefit of 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.

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 applications require wall elements for each space to be associated with the level the space is assigned two. Therefore a second floor space that is bound by a two-story wall that was modeled on the first floor will show up as not having an adjacent wall. Though this is not the case for all building analysis tools, it is good practice to model each wall as only extending up on level, then copying that wall element and pasting aligned on the level above it.

2.5.1.1.1 Windows

Window objects should be created using the Window 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 inserting a window may cause problems because the wall object is not linked to the window object. Therefore, 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 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 doors be modeled as "contained" in a wall object. Care should be taken to ensure that doors and windows don't extend outside the wall area. It is easy to accidentally create this situation in the corner of the building (corner windows) or in staircases, where windows can span multiple floors. Special attention must be given to setting the relative height for 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 appearance of the transparent window surfaces. 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.

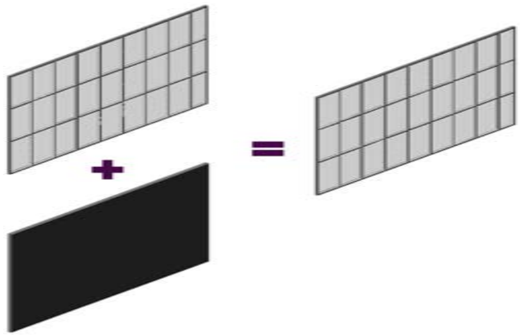


Figure 14: Wall component that is fully glazed

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 will then 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 spanning or multi-story wall.

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

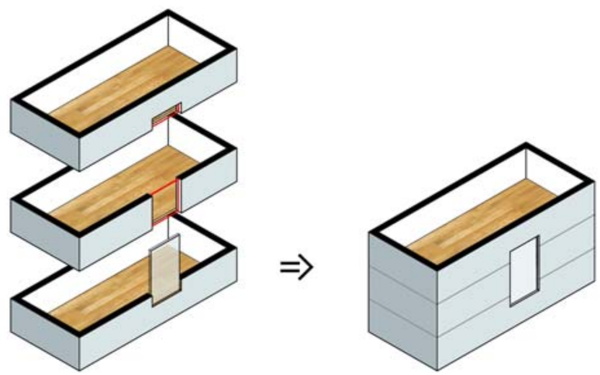


Figure 15: Window on the first floor may require openings added on next two floors

2.5.1.1.3 Doors

Door objects should be created using the Door tool in the BIM-authoring application. In most cases, Door tools can also model passageways or other access openings that do not necessarily have doors. 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 inserting a door may cause problems because the wall object is not linked to the door object. Therefore, 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 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 Slab tool in the BIM-authoring application. If the BIM-authoring application does not include such a tool, or is limited in some way (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 resulting model contains elements with correct geometries and correct object types.

For model consistency, 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.

2.5.1.3 Roofs/Ceilings

Roof and ceiling objects should be created using the Roof and Ceiling tool in the BIM-authoring application. If the BIM-authoring application does not include such a tool, or is limited in some way (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 resulting model contains elements with correct geometries and correct object types.

2.5.1.4 Columns

For energy simulations, columns are not critical. Columns rarely reduce the volume of the space sufficiently to make a noticeable difference in the simulation results. Several energy simulation programs won't model columns. However, 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 Column tool in the BIM-authoring application. If the BIM-authoring application does not include such a tool, or is limited in some way (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 columns, 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. Some BIM-authoring tools allow for the specification of shading objects, though in others the user must use "work arounds" such as using the slab or wall tools to create shading devices. The ability of downstream applications to interpret shading devices correctly when these alternative definition means are used varies widely. Until robust shading device tools become common place in BIM-authoring applications, A/E's should model overhangs as individual objects using the slab tool. 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 Assignment Guide* (ANSI/BOMA-based) 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, 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. Others require that such updates are done by the A/E, and generally provide tools for doing this. See product-specific instructions to learn how this is done for a given software application.

Some BIM-authoring applications have 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 BIM. Some details about how this is done in BIM-authoring applications for IFC can be found in the Appendices for BIM Guide Series 02-Spatial 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 s.f. For all individual spaces over 9 s.f., A/Es are required, at a minimum, to designate the following:

Table 4: Required Spatial Information

GSA Requirement	Example
Space Name	OFFICE
Space Number	08006
Occupant Organization Name	General Services Administration
GSA STAR Space Type	TTO (Total Office)
GSA BIM Area (formerly GSA Net Area in previous versions) *	114.27 m^2
“Full_Floor Space” Name *	GSA_DesignGross_Floor_B1

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 energy simulation applications do not yet read additional information that may be associated with the space, such as watt/ft2 lighting load, people/ft2 occupant load, and heating and cooling setpoints. Once simulation applications have developed the ability to read and utilize this type of information, GSA requirements will change.

2.5.2.2 Unoccupied or "Cavity" spaces

GSA spatial validation requirements only require areas over 9 ft^2 to be defined as spaces. However, when preparing a BIM for energy simulation, *all 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 of it 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 will cause the building analysis tool to erroneously assign exterior constructions to that wall, invalidating simulation results. Though 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 to the intended height of the suspended ceiling. Space heights for the plenums must be modeled from the height of the suspended ceiling to the height of the floor slab above it. Modeling practices for space heights are currently non-standard. See product-specific instructions to learn how this is done for a given software application.

> *Note: Spaces should be checked visually in 3-D to ensure they are modeled with the correct vertical extent (and thus height). Since many designers still work in 2-D, a typical space modeling error is for spaces to be modeled with zero height, or at the default height of the BIM-authoring tool, frequently 10 feet.*

2.5.2.4 Room Separation Lines

Some physically bound volumes may have several functional spaces contained within them, and are separated using a room separation line. According to the PBS Business Assignment Guide, spaces should be represented and broken down into functional spaces (i.e., office area, storage area, building common area, vertical penetration, etc.) as defined in the GSA spatial program even though they may be parts of a larger physical space. A physical space may contain several areas that are treated individually in the GSA spatial program. If two areas have different functional space classifications, even though they are within the same physical space, they shall be modeled as two separate spaces. 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. Sometime the simulation tool allows the user to delete the "false" opaque wall, make it "invisible", or to place a large void in the wall. This type of functionality allows the simulation to run correctly, though 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 many times advisable to remove the room separation lines before exporting from the BIM-authoring tool and importing into the building analysis tool. 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 are a concept for defining boundaries for spaces, and are critical for correctly defining appropriate relationships between spaces and the building elements that enclose a space and defining the geometry associated with the boundaries 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: There exists 3rd, 4th, and 5th level space boundaries, but they are not discussed in this Guide). 1st level space boundaries typically correspond to the "architectural" space boundaries, i.e. they are defined from the perspective of a single space, irrespective of adjoining spaces. 2nd level space boundaries are defined by taking into account 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 gains 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.[18] 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 is available.[19]

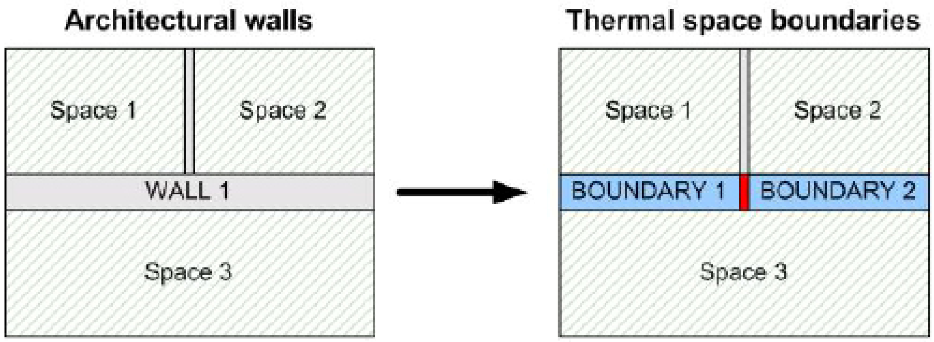
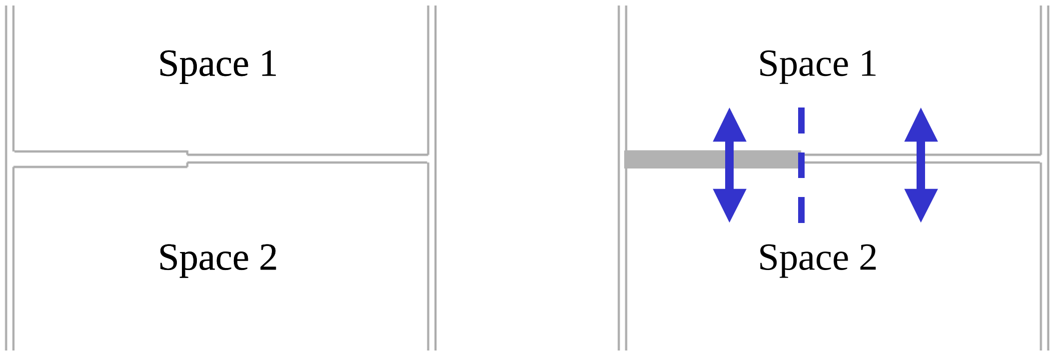


Figure 16: 1st Level Wall Space Boundaries (Architectural) vs. 2nd Level Wall Space Boundaries (Thermal)[20]

The creation of these 2nd level space boundaries is also necessary information for the energy simulation tools when different instances of wall elements (construction types) bound a single space. Figure 17 illustrates such a scenario.



(a) (b)

Figure 17: 1st Level Wall Space Boundaries (a) vs. 2nd Level Wall Space Boundaries (b) for multiple wall Instances[21]

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

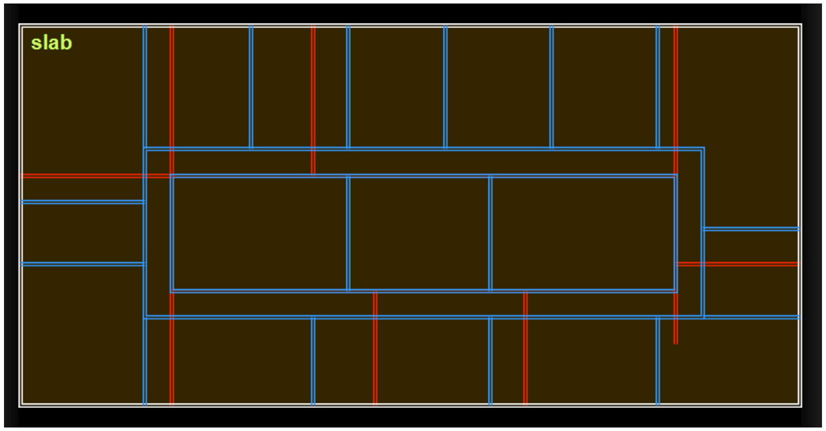


Figure 18: The need for 2nd level space boundaries is evident by the non-uniform wall space boundaries between adjacent floors.[22]

Currently, most BIM vendors specify 1^{st} level space boundaries in IFC to some degree, though further development of this functionality is required. Only one currently implements 2^{nd} level space boundaries in IFC. Further development by BIM-authoring vendors to enable IFC-based 2^{nd} level space boundaries will be required as BIM-based energy analysis becomes more common, and there is on-going work in developing implementation guidelines and MVDs for 2^{nd} level space boundaries through the OGC AECOO Testbed. gbXML is based on the principle of heat transfer surfaces (which are the equivalent of 2^{nd} level space boundaries), therefore any gbXML-compliant vendor inherently supports this concept. However, the need for common implementation strategies for vendors for certain building configurations still exists, as with IFC. End users should check 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 BIM.

2.5.2.6 Updating Space Boundaries

Modeling building spaces properly in BIM requires a good deal of care and attention to detail. Users must ensure that space object geometry is updated when surrounding walls, floors, or ceilings are moved or changed. It is common, as the design evolves and changes, that spaces are not updated to maintain alignment with the walls. This results in area calculation errors. Changes to any elements that bound spaces should be followed by a corresponding update to the spaces they bound. In many BIM-authoring applications, updating spaces to re-align to the inside face of bounding elements can be automated or semi-automated. The user must learn how to ensure that such 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 resize properly. In this case, the user may need to manually invoke a "resize" of the space object. Please see Appendix A of 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. Often, these are 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 a part of a security zone or belong to an organizational department zone.

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

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

2.6 Energy Model Checker Development

The potential for model checking software to facilitate the use of BIM for energy modeling is still early in its developmental stage. In theory, a model checking software may be used to ensure that a BIM is correctly designed and populated with the necessary information to successfully run an energy model. This process could apply a set of pre-defined rules specific to a particular application's data needs prior to importing the BIM into the building analysis application. These requirements, however, may differ by application. For example, spaces may be defined at the wall centerline or on the bounding walls interior face. Ideally, as the industry develops and energy modeling using BIM becomes more standardized, these "rule sets" will become more and more streamlined, with one rule checking set eventually being able to be used for the vast majority of building analysis software. Several on-going efforts exist to identify the building geometry, elements and properties that much be checked to ensure an effective transfer of information to an energy simulation program, including projects at GSA, LBNL, and ASRHAE. The following sections summarize a few of the types of information that an energy model checker could potentially check.

2.6.1 Proposed Model Checker Capabilities

2.6.1.1 Space Definition

An energy 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. 2^{nd} level space boundaries).

2.6.1.2 Spatial Data

The completeness of the following spatial data could be checked: lighting and equipment loads (watts/ft2 or total wattage), occupant loads (ft/person or # 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 check to make sure 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 and HVAC equipment type (if conditioned). This could facilitate the correct auto-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 assign a load value to each space (e.g. watts/ft2 lighting), eventually it would be beneficial if the mechanical engineer could simply "place" load producing equipment objects (e.g. lighting fixtures, motors, computers) into the room space, 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 ft2 room. The BIM model would then calculate that the lighting load for the room would be 0.75 watts/ft2. An energy model checker could determine if the appropriate object types, such as lighting and computer objects, 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, eventually it would be beneficial if the mechanical engineer could simply "place" HVAC equipment objects (e.g. chillers, pumps, fans) into the BIM model to represent the central plant, and have the operating characteristics (e.g. full-and part-load efficiency, capacity, control type, etc.) of those objects read and the appropriate parameters translated to the energy model. An energy model checker could determine if the proper HVAC equipment objects exist within a BIM.

2.6.1.6 *Construction Object Types*

A model checker could check if appropriate construction 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 of the energy simulation. Additionally, it would be greatly beneficial to allow the option to not export an internal wall object if it is designated as adiabatic. This would prevent user from having to delete/filter internal walls solely to simplify the model for energy analysis.

2.6.1.2 *Code Compliance*

An energy model checker could easily determine of the modeled space loads, equipment efficiencies, etc. met a particular mechanical or energy code, such as ASRHAE 90.1, ANSI/ASRHAE 55, ANSI/ASHRAE 62.1, CA Title 24 Part 6, or the International Energy Conservation Code (IECC). For instance, a building design might be analyzed that has a lighting density of 1 watt/ft2. However, the local energy code may require 0.8 watts/ft2 for that particular space type. The International Code Council (ICC)

SMARTcodes[23] 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 code checking for energy code compliance, which addresses several of the categories listed above.

Conclusion

The world of BIM-based energy simulation is rapidly developing. The GSA has identified the improved energy performance of its building inventory as 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 limitation and challenges still exist. The GSA is committed to working with industry to develop new software technologies, design, construction, and operational strategies, and user functionality to support its environmental performance goals. This Guide is a first 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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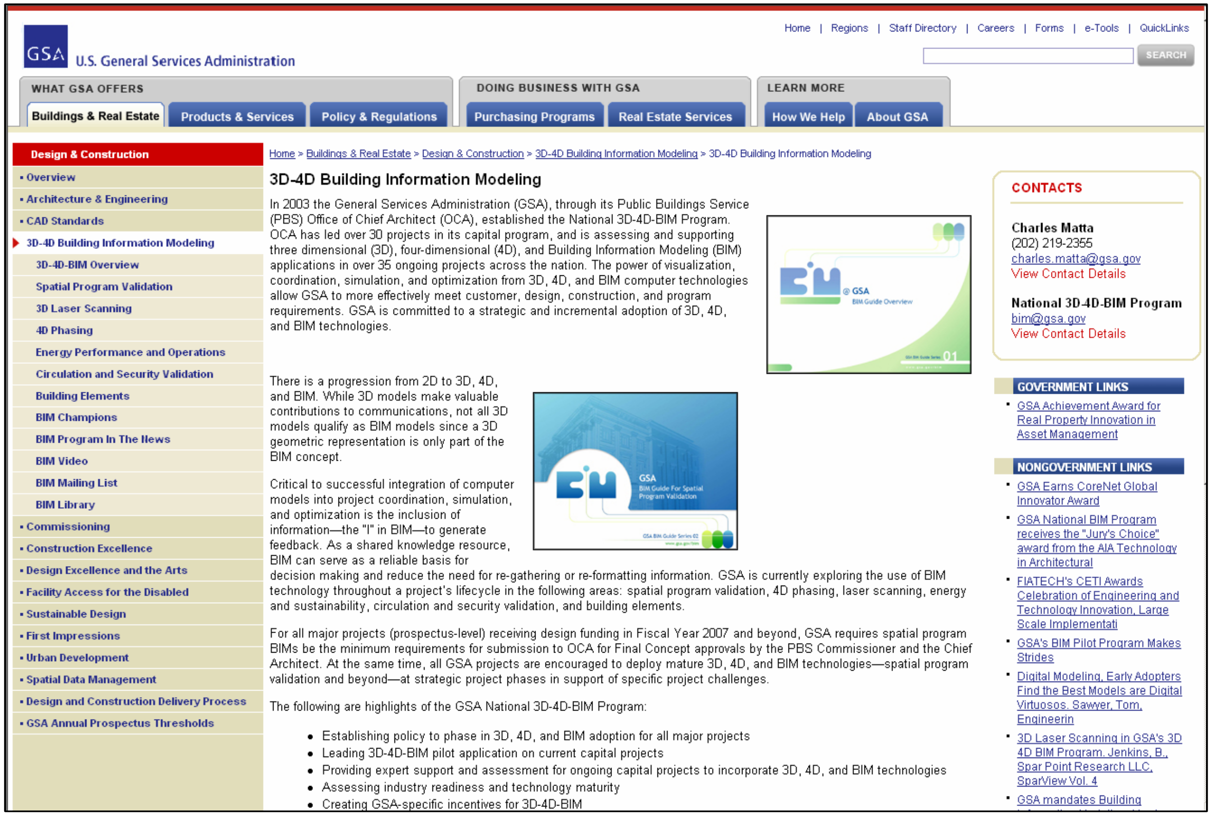

For further information about this *GSA BIM Guide Series 05 – BIM Guide For Energy Performance* or to submit comments or questions, please visit the National 3D-4D-BIM webpage at http://www.gsa.gov/bim or contact:

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