

# Implementation of semi-automated energy performance simulation: building geometry

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**ABSTRACT:** The methodology for semi-automatic building energy performance (BEP) simulation eliminates arbitrary decisions from the simulation process. Based on the use of IFC-based BIM, its key feature is the automatic transformation of data from their original source and formatting to what is needed in BEP simulation, per unambiguous data transformation rules that cannot be manually manipulated; it results in semi-automatic generation of input for simulation. When implemented, the methodology reduces preparation of simulation input for a building from days, weeks or months to minutes, eliminates human error, and makes simulation preparation virtually free of cost and resource consumption. GST/IDF Generator tool semi-automatically transforms building geometry properly defined in IFC format into ready-to-execute building geometry defined in input format for “whole building” BEP simulation tools like EnergyPlus. The tool’s performance was publicly demonstrated live in the OGC AECOO-1 Testbed in March and May 2009.

## 1 INTRODUCTION

Building energy performance (BEP) simulation is still not used as often as one would expect, given the growing concern with the amount of energy spent in buildings both in the U.S. and worldwide. When used, its results rarely have an impact on the eventual energy performance of the constructed and occupied building (Torcellini et al. 2004). Quantitative results often represent *substantial* over- or under-prediction of performance, and are reliable only under special circumstances (Mills et al. 2004, Janda & von Meier 2004, Scofield 2002). Questions have been raised about the validity of the LEED “green buildings” rating systems which partially depends on the prediction of buildings’ energy performance (Richter 2008). Quantitative results from the current practice of BEP simulation are essentially not reproducible (Bazjanac 2008a). In addition, the preparation for simulation input is usually labor-intensive, too costly and too slow.

These are only some of the symptoms of deeply rooted structural problems in the way BEP simulation is used today. Modeling of thermal views of buildings and the corresponding definition of data needed in the simulation is often arbitrary in today’s practice (Bazjanac 2008a). Multiple modelers modeling the same building using the same software tools inevitably create multiple simulation models that differ from each other, often substantially.

Preparation of simulation requires the definition of input data. Simulation input for a “whole building” simulation program like EnergyPlus contains three distinct major parts (Figure 1): the definition of building geometry and data related to it, the definition of HVAC equipment, systems and plant and data related to them, and the definition of internal loads as well as use and operating schedules for the building.

Original sources of information depend on the type of information they provide. Architects and the documentation they generate are the original source of data about the building’s placement and orientation, building geometry, construction materials and any other information architects generate originally. Mechanical designers and the documentation they generate are the original source of data about the building’s HVAC equipment and energy delivery systems, as well as any other information they generate originally. Building programs (or briefs), applicable codes and standards, and the building owners and/or their representatives are the source of information about internal loads and building use and operation schedules. The modeler is the original source of information only for simulation run control data; modelers who modify others’ original information for their purpose (i.e. to “adjust” original data so simulation “can run”) usually do so in an arbitrary fashion and at a high risk of data integrity loss.

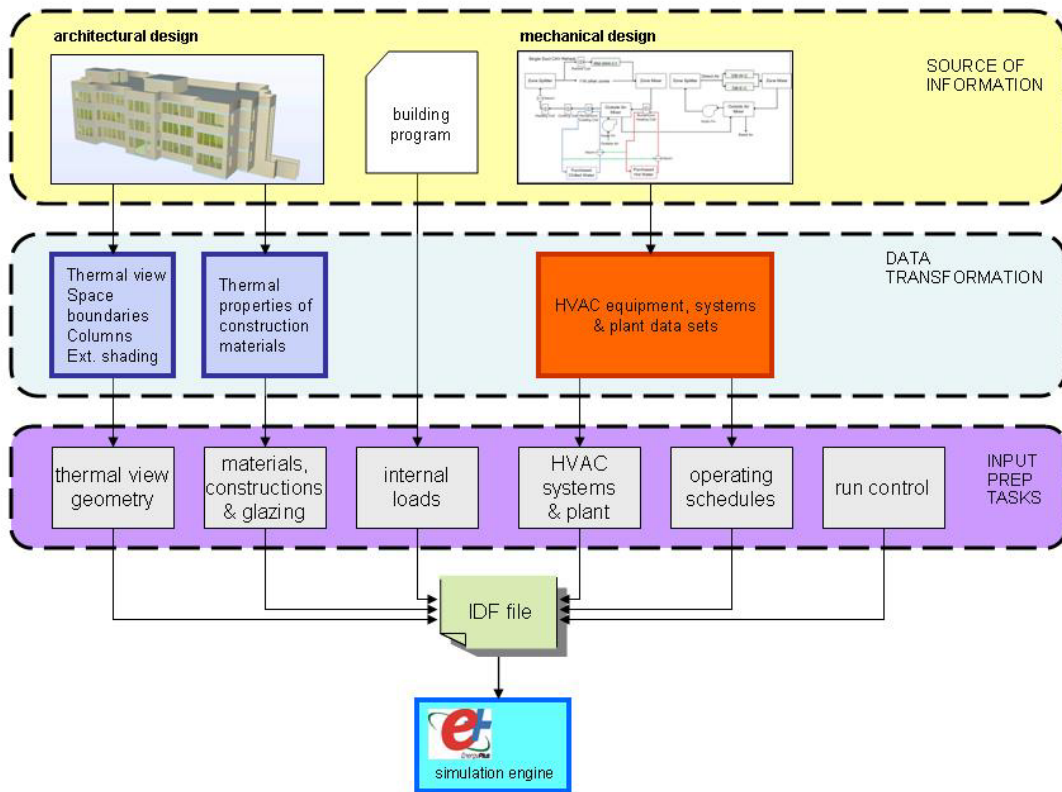


Figure 1. Typical input structure for “whole building” BEP simulation with tools like EnergyPlus.

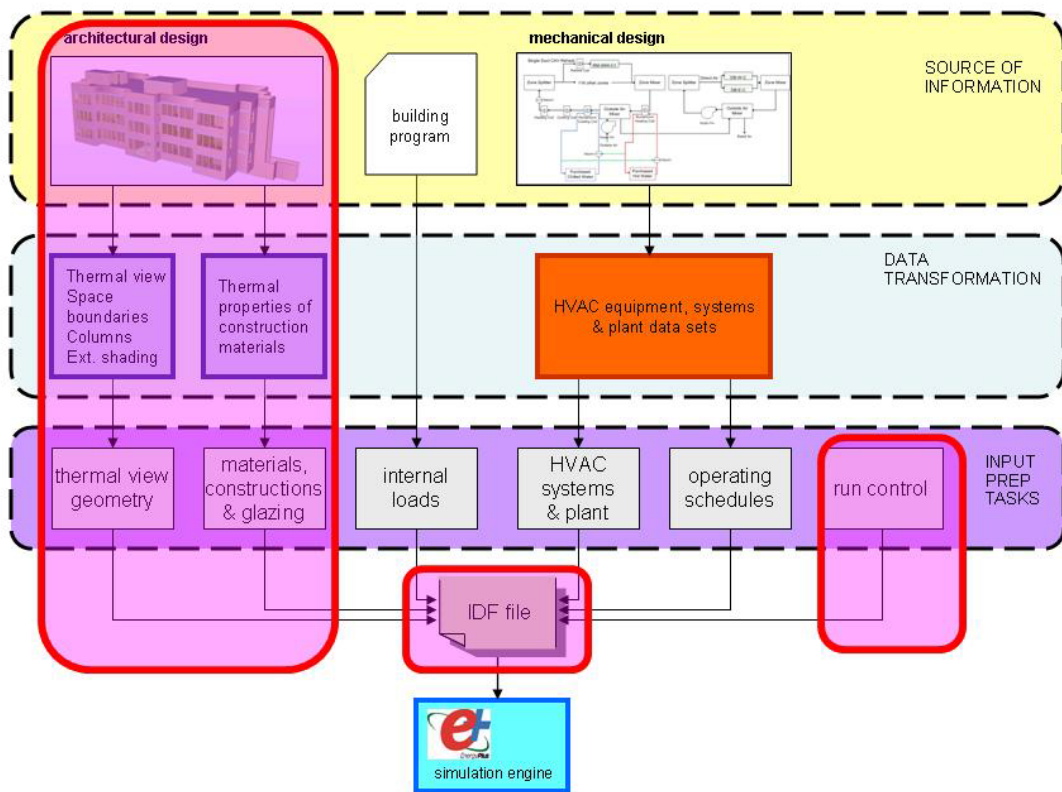


Figure 2. GST/IDF Generator implementation of the methodology for semi-automated BEP simulation.

Software that generates original data about the building usually has a different data structure than the BEP simulation software and often represents a different “view” of the building (IAI 2006). This requires transformation of format, and sometimes also of the content, of original data to form valid input for the BEP simulation. For example, building geometry in a CAD file typically represents the architect’s view of the building, not its thermal view; building geometry data have to be transformed as necessary to represent the thermal view. Or, definitions of construction materials defined in a CAD tool have to be extended with data that define their respective thermal properties. Correspondingly, performance specifications of a piece of mechanical equipment may have to be “adjusted” to fit the specifications’ input format required by the particular BEP simulation software. If any such transformation or extension of original data is not performed according to established and agreed upon (i.e. standardized) rules, the transformation is likely to be *arbitrary*. It is worth noting that *manual* redrawing the original building geometry definition into a thermal view usually amounts to *arbitrary* transformation of original geometry data, no matter how sophisticated the used CAD tool may be.

A typical complete input file for “whole building” (i.e. comprehensive) BEP simulation with a tool like EnergyPlus (EnergyPlus 2009) contains several distinct segments (Figure 1): thermal view geometry, thermal properties of construction materials and assemblies, internal loads and schedules, HVAC equipment, systems and plant definitions, HVAC operating schedules and simulation run control data.

Input file for EnergyPlus is called the IDF (Input Definition Format) file. Each input segment contains data bits and/or strings that define the building in the simulation, wrapped in the input syntax of the given simulation tool.

## 2 SEMI-AUTOMATED PREPARATION OF INPUT FOR BEP SIMULATION

Manual preparation of BEP simulation input, particularly when combined with arbitrary data transformation, has a great potential of including errors and omissions that are difficult to detect before the simulation is executed. Insufficient and/or missing explanations of decisions that had to be reached in the modeling of the building can often result in misunderstandings and misinterpretations later.

To circumvent these pitfalls, LBNL developed a methodology for BEP simulation that automates everything in the simulation creation process that can be reasonably automated, and that at the same time is based on the principles of information science (Bazjanac 2008a). The goals of this methodology are to make the process and its results consistently reproducible, to enable the integration of BEP simulation and analysis tools into suites of interoperable tools that are routinely used in building design, and to make the use of such tools productive and attractive throughout the AECOO industry. The methodology is based on the use of IFC-based Building Information Models (BIM) as the authoritative repository of data about buildings (IAI 2007).

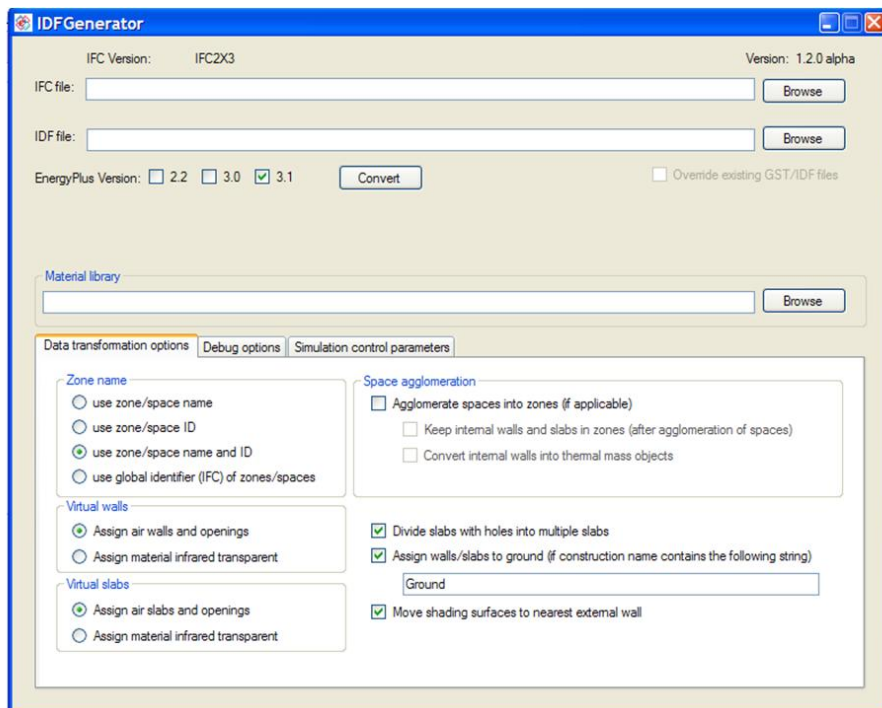


Figure 3. Initial window of the GST/IDF Generator GUI.

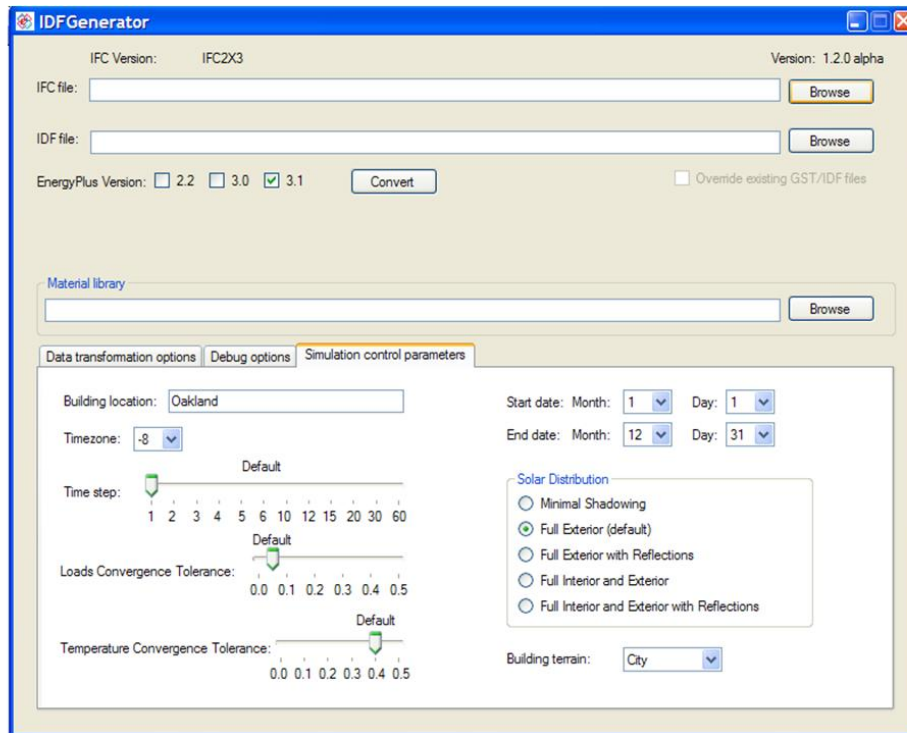


Figure 4. Simulation run control parameters definition window.

The methodology prevents arbitrary and manual data definition, preserves the integrity of original data, and assures transformation of original data per *unambiguous rules embedded in software* (Bazjanac & Kiviniemi 2007); its complete implementation facilitates a semi-automated input data definition process. This dramatically shortens the time and reduces resource expenditure needed for BEP simulation input preparation; it also prevents errors and omissions that result from arbitrary and manual data definition and transformation.

Full implementation of the methodology for semi-automated BEP simulation requires the development of three potentially separate software tools that read original information from an IFC-based BIM, transform original data as necessary per embedded rules of transformation, and export a file with a complete portion of the BEP simulation input file. The three tools each deal with data related to the tools domain:

- Building geometry (thermal view) and related data;
- HVAC definitions and related data;
- Internal loads, building use and operations, and related data.

LBNL has already developed a software tool that semi-automatically creates the building geometry (thermal view) portion of the EnergyPlus input file, and demonstrated it as part of the OGC AECOO-1 Testbed demonstrations (see below). The new tool is

called Geometry Simplification Tool, or GST/IDF Generator. The tool also allows the user to specify EnergyPlus simulation run control parameters, which allows the execution of created files without the need to externally define additional information. Boxes bound by red lines in Figure 2 identify parts of the methodology for semi-automated BEP simulation implemented in GST/IDF Generator.

### 3 SEMI-AUTOMATED INPUT OF BUILDING GEOMETRY: GST/IDF GENERATOR

GST/IDF Generator imports original building geometry defined in an IFC-based BIM by an architectural model-based CAD tool, transforms the data as needed by applying data transformation rules embedded in software code, and generates building geometry definitions in input format required by EnergyPlus. The generated complete building geometry definition includes the definition of construction materials (including glazing) as defined by the original building design.

The tool actually consists of two separate software applications: Geometry Simplification Tool (GST) and IDF Generator. GST reads the IFC file that contains building geometry, ignores object data redundant to energy simulation, transforms (as needed) data for EnergyPlus per embedded data transformation rules, and writes out processed and transformed data in ASCII format. IDF Generator

reads the ASCII file generated by GST, makes a few adjustments to data per additional embedded data transformation rules, wraps numerical data with EnergyPlus input syntax, and writes out an EnergyPlus input file that contains building geometry and construction materials definitions that are ready for simulation. It also provides the user with an opportunity to define EnergyPlus simulation run control parameters.

The use of GST/IDF generator starts by displaying the initial window of IDF Generator's graphic user interface (GUI), shown in Figure 3. The user identifies the IFC file which contains the building geometry, specifies the directory in which IDF generator will place the EnergyPlus input file, identifies the link to the EnergyPlus library of materials, and chooses the appropriate version of EnergyPlus input format. The user then selects the zone naming convention, how to deal with virtual walls and slabs, whether to agglomerate spaces into zones, how to deal with slabs that contain voids, whether to establish relationships between walls or slabs and ground, and whether to move external shading surfaces to nearest external surfaces of walls.

The GUI simulation run control window (Figure 4) allows the user to identify the location of the building and its corresponding time zone (relative to GMT), the number of simulation time steps within an hour, and the loads and temperature convergence tolerances to be used in the simulation. This window also allows the user to define the simulation period, as well as the type of solar distribution in the simulation. The user can also identify the type of terrain that surrounds the building in the simulation. Finally, the user starts the execution of GST/IDF Generator from this window.

During its execution, the tool transforms data imported by GST from the IFC file per data transformation rules embedded in the tool's code. Each embedded rule is represented by one or more algorithms which actually perform the transformation, or (in some cases) generate new data and/or definitions derived from imported original data. GST/IDF Generator, version 1.2.0 contains algorithms in its code which represent the following data transformation rules and perform tasks required to apply each corresponding rule:

- Skipping of internal wall objects when walls are entirely contained within the same thermal zone;
- Reversal of the order of construction material layers for "other side" second-level space boundaries for walls and slabs which have asymmetric construction;
- Redefinition of embedded columns as separate wall objects;

- Definition of the remaining wall construction parts when columns are only partially embedded in walls;
- Recognition of exterior building shade types;
- Positioning of exterior building shades right outside the exterior space boundaries of exterior walls; Detection and redefinition of virtual walls and slabs;
- Assignment of "virtual constructions" to virtual walls and slabs;
- Identification of floor and ceiling surfaces of a slab;
- Subdivision of slabs with voids into "void-free" segments;
- Redefinition of "exterior ceilings" as roofs;
- Connection of slab-on-grade objects to the ground object;
- Creation of the parent wall's space boundaries for windows (if missing);
- Adjustment of window area to effective glass area;
- Linking of glazing definitions to Window 6.2 tool;
- Linking of material and construction objects to the EnergyPlus library of materials' thermal properties.

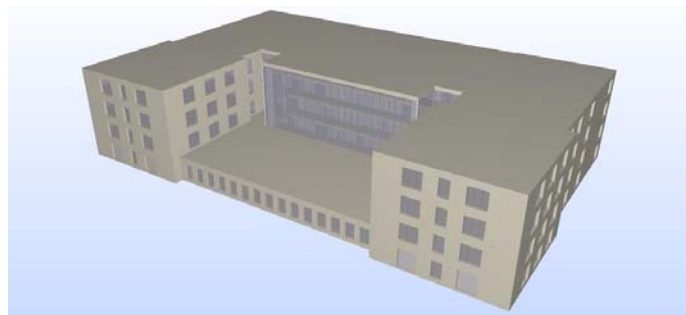


Figure 5. Model of the 98,400 sqft. four-story test building with a four-story atrium, shown in SMC.

The IDF file generated by GST/IDF Generator contains building geometry, materials of construction, and simulation run control data. As such, this file can be immediately executed in EnergyPlus; because this input file does not contain any other data, EnergyPlus in this case can only simulate the performance of an empty building without any energy systems in it. For a full BEP simulation run one currently has to *externally* define a separate IDF file or files that contain HVAC equipment, systems and plant, internal loads and schedules, schedules of use and operation, and all other definitions needed for a

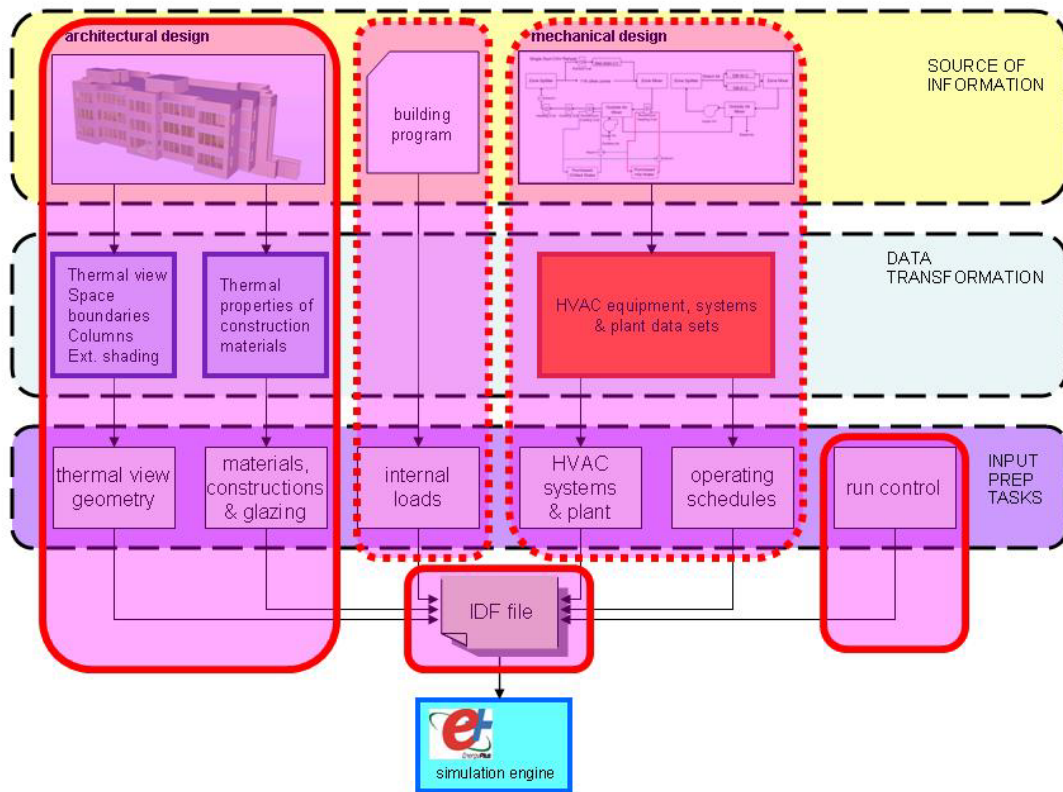


Figure 6. Complete implementation of the methodology for semi-automated BEP simulation.

full run. This is done using the IDF Editor – included in EnergyPlus software distribution – or with some other suitable tool. The additional IDF files are then merged with the IDF file generated by GST/IDF Generator; the resulting (merged) IDF file contains the complete input sufficient for execution of EnergyPlus.

Current “whole building” BEP simulation tools, like EnergyPlus, have some common limitations. For example, they cannot deal with curved geometry; thus, GST/IDF Generator delivers only planar multi-polygon surfaces based on CAD wire-frame representations of curved objects. EnergyPlus does not have a beam object, so GST/IDF Generator automatically ignores all beams defined in the original building geometry. The current version of GST/IDF Generator has limitations itself: It cannot yet define extruded external building shades, columns embedded in walls at non-perpendicular angles, and windows and skylights in slabs. These will be rectified in the next version of the tool.

Building geometry transformed with GST could be used by other BEP simulation tools (not only EnergyPlus) as well, even by tools used in other disciplines which need a transformed building geometry. One could replace parts of IDF Generator with code that would, as appropriate, wrap the ASCII output from GST with the syntax of the other tool, and generate input for the other tool in (for example) gbXML or in the other tool’s own input format. In

that case GST/IDF Generator would become GST/[other tool’s input format] Generator.

#### 4 OGC AECOO-1 TESTBED

In its quest for rapid insertion of new technology, the Open Geospatial Consortium (OGC) developed, within its Interoperability Program, a testbed methodology that facilitates hands-on prototyping and testing designed to accelerate software and software interface development and validation (OGC 2007). Actual OGC testbeds are fast-paced, rapid prototyping multi-vendor collaborative initiatives; their goal is to rapidly develop, test, validate and demonstrate new software and standards based on real world use cases. buildingSMART international (bSi 2009), then called the International Alliance for Interoperability (IAI), agreed to use the OGC testbed methodology to try to bring IFC BIM-based industry software related to early building design to its industry at an accelerated pace. This resulted in the OGC AECOO-1 Testbed, sponsored by the buildingSMART alliance (bSa) and a number of U.S. industry organizations (bSa 2008).

Testbed sponsors wanted to enable IFC BIM-based quantity take-off and cost estimating, as well as building energy performance simulation and analysis early in the building design process, so that early design solutions could be evaluated in a more

comprehensive way than has traditionally been the case. Consequently, OGC issued a “request for technology” (RFT) for three areas: quantity take-off/cost estimating (QTO), building performance energy analysis (BPEA), and decision support management. LBNL responded with a technology proposal for semi-automated BEP simulation (Bazjanac 2008b), which eventually became the technology demonstrated in the BPEA thread of the OGC AECOO-1 Testbed.

The U.S. General Services Administration (GSA), one of the AECOO-1 Testbed sponsors, provided the building geometry documentation of its headquarters building in Washington, DC (Figure 5) as the subject of testing of the new technology. A public demonstration was held for the testbed sponsors at the National Buildings Museum in Washington, DC on March 26, 2009. It was repeated as a worldwide webinar on June 28, 2009 (OGC 2009): GST/IDF Generator imported the IFC file generated with ArchiCAD 12 and “cleaned” with Solibri Model Checker (SMC), and created the building geometry and construction materials input file for EnergyPlus. This file was merged with predefined EnergyPlus macros that contained HVAC definitions of a hypothetical district cooling and heating system, internal loads, use, operating and utility cost schedules. EnergyPlus simulation calculated and reported annual summary energy performance and the predicted annual operating cost. This process was repeated for four design alternatives (smaller windows, added partial external shading, added high-tech glazing and added cool roof). It took GST/IDF Generator only 30 seconds to generate the IDF geometry file for the alternative with the most complicated geometry; the file may have taken days or weeks to create manually.

Concurrent to the BPEA thread’s generation of BEP estimates based on original building design data contained in an IFC BIM, the QTO thread was generating the corresponding cost estimates. This allowed the direct “real time” comparison of construction and operating costs for the base case as well as for all design alternatives, which potentially was the achievement of this testbed of greatest significance for the AECOO industry at large.

## 5 COMPLETING THE IMPLEMENTATION OF THE METHODOLOGY

The development of tools similar in concept to GST/IDF Generator, which import and transform original IFC BIM-based HVAC definitions and related data, as well as internal loads, building use and operations data, will complete the implementation of the methodology for semi-automated BEP simula-

tion (Figure 6). LBNL already started work on such an “HVAC” tool; this tool will import HVAC related data from an IFC-based BIM, transform them as necessary per data transformation rules embedded in the tool, and generate an “HVAC” IDF file.

A similar tool which will semi-automate the generation of simulation input files that contain internal loads, building use and operations data, will import building program data and transform them per rules defined in appropriate building and energy codes that will be embedded in the tool. Input files generated with this tool will then be merged with the corresponding geometry and HVAC input files to form complete BEP simulation input files ready for execution.

## 6 CONCLUSION

The implementation of the building geometry part of LBNL methodology for semi-automated building energy performance (BEP) simulation solves the most resource consuming and error and omission prone issue in the preparation of input for BEP simulation. Project time and cost savings resulting from the use of GST/IDF Generator are dramatic; this facilitates near real time generation of quantitative assessments of the energy performance of building designs not only early in the design process, but throughout the building procurement process. The fully implemented methodology, in conjunction with IFC BIM-based semi-automated cost estimating and other building performance analyses, will lead to optimal design decision making that will enable the design, construction and operation of truly energy efficient and sustainable buildings.

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