

# IFC HVAC INTERFACE TO ENERGYPLUS – A CASE OF EXPANDED INTEROPERABILITY FOR ENERGY SIMULATION

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## ABSTRACT

Tedious manual input of data that define a building, its systems and its expected pattern of use and operating schedules for building energy performance simulation has in the past diverted time and resources from productive simulation runs. In addition to its previously released IFCtoIDF utility that semi-automates the import of building geometry, the new IFC HVAC interface to EnergyPlus (released at the end of 2003) makes it possible to import and export most of the data that define HVAC equipment and systems in a building directly from and to other IFC compatible software tools. This reduces the manual input of other data needed for successful simulation with EnergyPlus to a minimum.

The main purpose of this new interface is to enable import of HVAC equipment and systems definitions, generated by other IFC compatible software tools (such as HVAC systems design tools) and data bases, into EnergyPlus, and to write such definitions contained in EnergyPlus input files to the original IFC files from which building geometry was extracted for the particular EnergyPlus input. In addition, this interface sets an example for developers of other software tools how to import and/or export data other than building geometry from and/or into EnergyPlus.

This paper describes the necessary simplifications and shortcuts incorporated in this interface, its operating environment, interface architecture, and the basic conditions and methodology for its use with EnergyPlus.

## INTRODUCTION

Traditionally, users of HVAC design and simulation tools have had to manually transcribe information from other sources that define the building (that is subject of design, analysis and/or simulation) and its systems. While most of that effort could be apportioned to the transcription of building geometry, the input of data that describe HVAC equipment and systems in a

building often takes a significant effort. Such manual efforts typically constitute duplication of data available from other sources, such as descriptions residing in other software tools, data bases, catalogues and the similar.

Such transcription and duplication of data is extremely wasteful. It delays productive work, often results in numerous errors and omissions, and inevitably adds dramatically to the cost of the project [Bazjanac and Crawley 1997]. The obvious solution to that problem is software interoperability: seamless exchange/sharing of data among participating software tools [Bazjanac 2001]. An international consortium of “major players” in the Architecture/Engineering/Construction/Facilities Management (AEC/FM) industry (i.e. some of the leading construction companies, building product manufacturers, architecture and engineering design and consulting firms, building owners and operators, building and government officials, industry software vendors, research institutions and universities) – the International Alliance for Interoperability (IAI) – was formed in 1995 to enable and promote software interoperability in the industry [IAI 1995].

Point-to-point data exchange (i.e. direct data exchange between two software tools via a dedicated interface) and data exchange within integrated suites of tools constitute limited and partial interoperability. True interoperability is achieved when exchange/sharing of data is accomplished on the basis of a commonly *shared data model* of buildings and among *multiple* tools.

The IAI created a comprehensive, multidisciplinary and intelligent data model of buildings that defines data throughout a building’s life cycle: the Industry Foundation Classes (IFC). The data model is still under development, but its latest version – IFC2x2, released in 2003 [IAI 2003] – is the first IFC version that supports data exchange/sharing among tools that are used downstream in the building procurement process. While other (mostly partial) data models of buildings already exist or are under development, the

IFC are the *only* such model that is *open*. They are also the *only* such model that is an *ISO standard*.

EnergyPlus is the first building energy performance simulation model able to import data directly from a Building Information Model (BIM) that describes a given building in IFC format. Its IFCtoIDF utility allows users to seamlessly acquire data that completely describe a given building geometry in format needed for the simulation [Bazjanac 2001].

This paper describes the new IFC *HVAC* interface to EnergyPlus. It is used to convert HVAC data found in Industry Foundation Classes (IFC) version 2x2 data files into corresponding definitions in EnergyPlus Input Data Files (IDF), and can also be used to convert and add HVAC data contained in EnergyPlus 1.1.0, 1.1.1 and 1.2 data files to IFC2x2 data files.

The development of this interface was part of the IAI BS-8 (Building Services) project series. The primary goals of this project, conducted at and lead by the Lawrence Berkeley National Laboratory (LBNL) were to extend the IFC data model of buildings with schemata that define Heating, Ventilation and Air Conditioning (HVAC) equipment and systems, and to enable seamless data exchange between building energy performance simulation tools (like EnergyPlus) with other tools that define or use HVAC data [IAI 2001]. Institut für Kernenergie und Energiesysteme (IKE) at the University of Stuttgart participated in the definition of this domain in the IFC model, as well as in the development of the HVAC extensions schemata for the IFC data model and their implementation in this interface. VTT Building and Transport (Technical Research Center of Finland) participated in the definition of the HVAC domain and contributed to the development of the HVAC extensions schemata. In addition, several other institutions, trade organizations (including ASHRAE) and industry organizations worldwide participated in the definition of the HVAC domain.

## ENERGYPLUS SIMULATION TOOL

### **Brief General Description**

EnergyPlus is a “whole building” energy performance simulation program that models building envelope and structure and their behavior (including shading), its heating, cooling, natural and electrical lighting, natural and mechanical ventilation, internal air flow, its occupancy, use and operation, its local generation of energy, and almost anything else that affects building energy performance [US-DOE 2004]. It does that for a design day or days, or for any period of time (given a file that contains appropriate weather data). It

combines the best features of its predecessors (BLAST and DOE-2) and can be linked to external tools (such as SPARK, COMIS, etc.) to improve a particular aspect of simulation.

The basic simulation concept in EnergyPlus is integrated simulation (loads, systems and plant simulation within the same time unit). Its internal data model consists of objects and their parameters, but does not represent a fully object oriented architecture. Its architecture itself is completely modular, which facilitates addition of new modules and functionalities. Some of EnergyPlus modules are still in development, with more to come.

### **HVAC Definitions in EnergyPlus**

Conditioning and air/fluid movement are defined in EnergyPlus in terms of loops (demand-side and supply-side), branches, components and nodes. Components have design and performance parameters, but virtually no geometry – when geometry has an impact on performance, it is approximated and accounted for in parameter values

A thermal zone is the fundamental “unit” recipient of HVAC service in EnergyPlus. Definitions of each zone include its boundary geometry, as well as its use and operating regime, but not the geometry and specific location of any HVAC components.

Every simulation model inevitably includes at least some simplifications to reduce complexity. This is just as true of EnergyPlus. Perhaps the most critical simplification is the reliance on rules of loop and branch topology in the definition of HVAC equipment and systems. Such simplifications necessitate the making of assumptions and can also result in incompatibility with internal data models of other HVAC software tools. The latter can cause serious complications in the definition of mechanisms for data exchange and/or sharing.

## THE IFC2X2 MODEL

### **Brief Description**

Unlike the internal data model of EnergyPlus, the IFC data model is completely object oriented. All object definitions include attribute sets, relationships and inheritances, though at present only single inheritance is permitted. The model is based on ISO-STEP technology and is defined in EXPRESS.

The data model contains four layers; these are (from bottom up) the resource schemata layer, the kernel, the shared elements layer, and the domain extensions layer. Definitions in each layer make use of definitions in

layers below (but not above). The bottom two layers constitute the model core that is kept stable – definitions within core cannot change, but can be expanded or added – for a minimum of three to five years to provide a stable environment for software development. The current model core was stabilized in 2002; it is not expected to change at least until 2006.

The definition of property sets (P-sets) is one of the key features of IFC. These provide valid substitutes to the definition of object/attribute/relationship sets for entities that are not yet completely ready for inclusion in the data model, have not yet been entirely agreed upon, or for which it has not yet been unequivocally decided where they fit in the data model. Once individual P-sets have been commonly implemented by multiple software tools, they are transformed and become regular object/attribute/relationship sets in the next version of the data model. This facilitates the continuous addition of definitions needed in specific domain extensions of the IFC data model by software tools that operate in such domains.

### HVAC Domain Schemata in IFC

The IFC data model contained only rudimentary HVAC definitions before the release of version 2x2. The new HVAC extension schemata are much more complex and complete the definition of HVAC *components and systems* needed in the design and simulation of performance. Most of the new schemata are contained in the HVAC domain of the IFC domain layer (the top layer in the data model), with some (time series and connectivity) added to the resource layer.

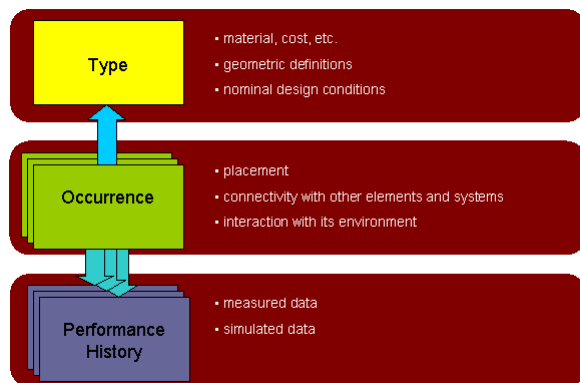


Figure 1 – HVAC component modeling concept in the IFC2x2 data model (by courtesy of Jim Forester)

HVAC domain schemata in IFC2x2 employ two new concepts in modeling HVAC components and their relationships to each other. The first concept provides data separation into three different information layers (Figure 1). “Occurrence” contains information that

defines placement, connectivity and interaction with its environment for each instance of the component. “Type” defines component’s makeup, geometry and design conditions. “Performance history” keeps the record of measured and simulated data related to the component [Bazjanac 2002].

The second concept relates to how connections between HVAC components are defined. Relationship objects in IFC2x2 define components as connected to *ports* and then define the connection between them (i.e. between the component and the port). Thus, a “port” is an intermediary element that connects two components. This concept is very similar to the connection concept in EnergyPlus, where nodes are defined in-between connected components. The only difference in the connection concepts of the two models lies in the number of connection objects between the components. While the EnergyPlus model usually uses only one node (two only in some cases) to connect two components, IFC definitions always need *two* ports for that connection.

The IFC data model currently allows the defining of HVAC data in different ways. This necessitates the formulation of agreements on how particular data types are defined and interpreted by different software tools. Such agreements define anything that can be defined or interpreted differently in detailed implementation of the IFC data model in software interfaces (e.g. assumptions that are needed to simplify the definition of some of the encountered conditions, data reduction, minimal data sets to implement, etc.); they are called “implementers’ agreements.” Such agreements have not been widely reached for the HVAC domain yet, as implementation of IFC in HVAC software has not yet reached “critical mass.” However, assumptions and interpretations made in the development of the IFC HVAC interface to EnergyPlus are likely to become de facto implementers’ agreements.

### IFC HVAC INTERFACE TO ENERGYPLUS

HVAC definitions in the IFC2x2 extension schemata are implemented in the IFC HVAC interface to EnergyPlus. Unlike the IFCtoIDF utility that can import building geometry from IFC files that represent previous versions of the IFC data model, this interface works only with IFC2x2 files. It can import HVAC data from such files and convert them to the corresponding input code for EnergyPlus in IDF syntax and format (IDF stands for Input Data Format for EnergyPlus), and can convert HVAC component definitions found in IDF files into IFC format and write them to IFC2x2 files.

Two features that set rules how to define HVAC systems and how to connect simple components to a complex one should be noted. The interface employs a hierarchy of definitions that describe HVAC systems (Figure 2), developed to combine data related to loop definitions in EnergyPlus. This hierarchy applies to the definition of all HVAC systems the interface may encounter in an IFC file. The interface finds system specific components in the IFC file that correspond to elements in the systems hierarchy (e.g. a fan in an air loop), translates them independently from each other, and then assembles them in a form that follows the topology of the hierarchy.

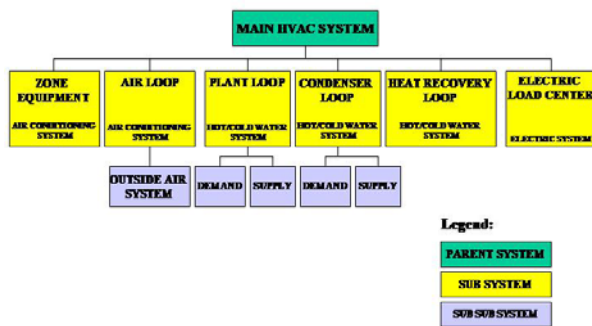


Figure 2 – Outline of system definition hierarchy

When connecting simple component definitions to a complex component the interface follows the concept of “containers.” This concept applies whenever the interface encounters such a case. Figure 3 shows an example of this concept in which a coil is defined by a coil type and a cooled beam type, when both are needed to define all necessary parameters to properly describe this coil.

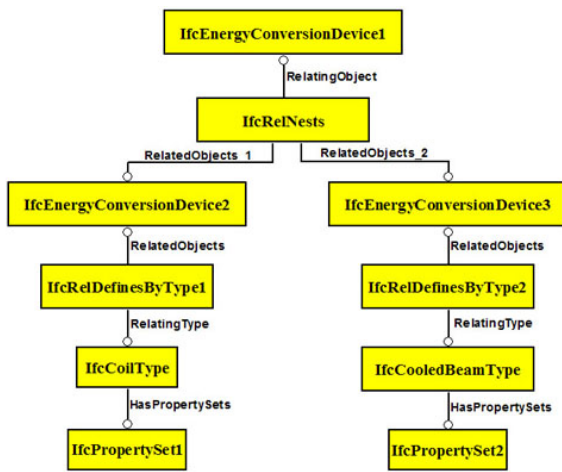


Figure 3 – An example of the concept of containers

Since even the IFC2x2 data model does not contain a few component type definitions that are necessary to fully describe information that may be contained in an EnergyPlus file (this is due to continuous inclusion of new features in EnergyPlus), new P-sets have been introduced in this interface. These include P-sets that define component types such as a DX empirical coil or a direct evaporative cooler (to name a few) definable in EnergyPlus, and will be part of future implementers’ agreements. Other IFC compatible HVAC tools will have to implement these P-sets together with the rest of HVAC object/attribute/relationship sets and P-sets that are defined in IFC2x2.

The interface is based on the latest version of the IFC data model (IFC2x2) and its latest HVAC extension schemata; these are currently implemented only by one other HVAC related software tool that deals with piping and ducting and involves only a very limited set of HVAC components. As no IFC files that contain diverse IFC2x2 based HVAC data can be generated by other tools at the moment, the interface cannot yet be rigorously tested with IFC files other than those created by the interface itself.

### Provided Functionality

The interface provides two major functionalities: data conversion from IFC to IDF format, and vice versa. In both conversion processes conversion is limited to data that directly describe HVAC components and systems in EnergyPlus. All other data, such as those defining various schedules (even if they pertain to the defined HVAC components and systems), are ignored.

To successfully convert data from IFC to IDF format and vice versa, IDF data must be consistent with IDF syntax. To assure that, the internal data structure of the interface is based on EnergyPlus Input Data Dictionary (IDD) that unambiguously defines all objects in EnergyPlus; all conversions to and from IDF format strictly follow definitions and rules defined in the IDD file associated with (and part of) the particular version of EnergyPlus. This enables the interface to support multiple EnergyPlus versions (1.1.0, 1.1.1 and 1.2) – it allows it to successfully import/export data to/from IDF files generated by different versions of EnergyPlus.

The interface is employing the IFC SECOM Server [SECOM 2003] to read and write data from/to an IFC file. The server is free-ware and can be downloaded at no cost from <http://groups.yahoo.com/group/ifcsvr-users/IFCsvrR300/>. This server provides methods to easily read and write IFC object/attribute/relationship data within the file. Since this server can also manage BLIS-XML files [Adachi et al. 2000], this functionality

could be easily added to the interface once the support for BLIS-XML for IFC2x2 is added to the server.

### Limitations to the Interface

The interface’s data conversion processes are limited to the HVAC information that is directly related to a building. The IFCtoIDF utility converts building geometry data from IFC format into IDF. However, even when the interface and the IFCtoIDF utility are used in conjunction with each other, some definitions that are necessary to complete a valid EnergyPlus input file will be missing from the IDF file. The missing data include all types of schedules (conversion of HVAC and other schedules is currently outside of the scope for this interface) and simulation control parameters, as well as all objects needed in EnergyPlus simulation that are not defined in the IFC data model. Such data must be added externally to the IDF file.

Since the current version 1.0 beta interface bases some of its conversions on the concept of HVAC systems definition hierarchy, all systems present in an IFC file must be identified by corresponding IFC objects (i.e. as instances of “IfcSystem”). to identify the relating loops. No HVAC objects can be found and no loops can be identified without these; correspondingly, no IDF objects can be created either. Plans for the next version of the interface include additional functionality that will make identifying systems in an IFC file not mandatory.

### INTERFACE ARCHITECTURE

The interface internal architecture consists of two major parts: a dynamically linked library (DLL) and a graphical user interface (GUI).

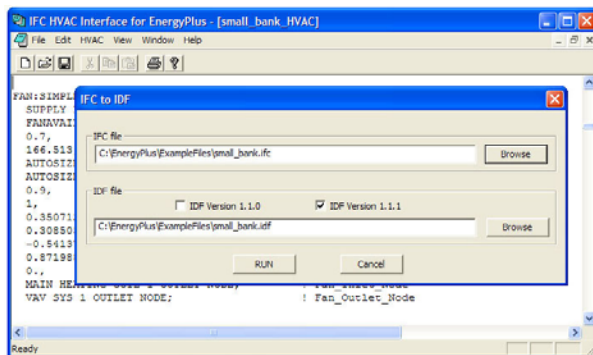


Figure 4 - Screenshot of the GUI

The GUI, in form of a simple text editor, provides the user with the ability to read, write and change any and all files that are involved in the data conversion processes. The user is able to select between IFC and IDF files, depending on which is needed in the data

conversion process at the time. Since the interface supports multiple EnergyPlus versions, the GUI also allows the user to select and load the proper EnergyPlus Input Data Dictionary (IDD). Figure 4 shows a screenshot of the GUI.

### POPULATING IDF AND IFC FILES

The new interface provides two major functionalities that allow the interface to function as a pre- and/or post-processes to EnergyPlus. Before an EnergyPlus input file can be executed, it must contain definitions of building geometry, HVAC equipment and systems, and several other sets of information.

Building geometry can be seamlessly imported from a BIM using the IDFtoIFC utility; such an act creates the initial IDF file for the simulation. If the BIM is based on the IFC2x2 data model and contains HVAC data, the interface can create another IDF file that contains only HVAC data for EnergyPlus simulation. The second file is then spliced into the first IDF file (that contains the EnergyPlus definition of building geometry). Subsequently, additional data are then input externally into that IDF file to complete it before execution.

If the BIM does not include HVAC data, the interface cannot be used as a pre-processor to EnergyPlus. In that case, the user adds HVAC data manually to the IDF file that contains the EnergyPlus definition of building geometry. This is best accomplished by loading the IDF geometry file into IDF Editor, and then using it to complete HVAC definitions and other information necessary to run the simulation.

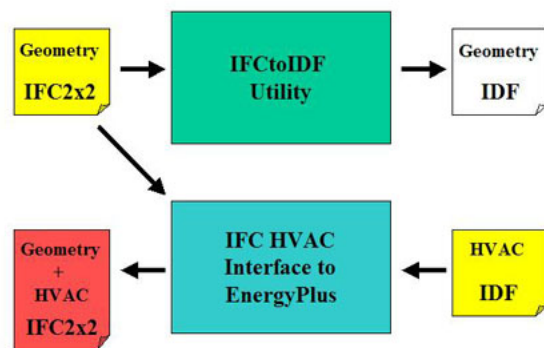


Figure 5 –Data conversion:IFC2x2 and IDF files

Figure 5 shows diagrammatically how HVAC data contained in an IDF file can be converted and placed in an IFC file by using the interface. Used as a post-processor, the interface reads only HVAC data it finds in an IDF file (data that are preexisting in the file). It

also reads the corresponding IFC file to obtain geometry references, such as the Global Unique ID (GUID) for each space or zone served by HVAC equipment and systems. If the name of a zone associated with HVAC definitions in the IDF file does not match the corresponding GUID, it has to be changed to the GUID. The interface then converts the found HVAC data into IFC2x2 format and writes the converted data to the IFC file that contains building geometry it read previously.

The interface makes it possible for the first time to add HVAC component and systems definitions to an IFC file that did not contain them before. The complete process, parts of which are described in more detail above, is shown in Figure 6.

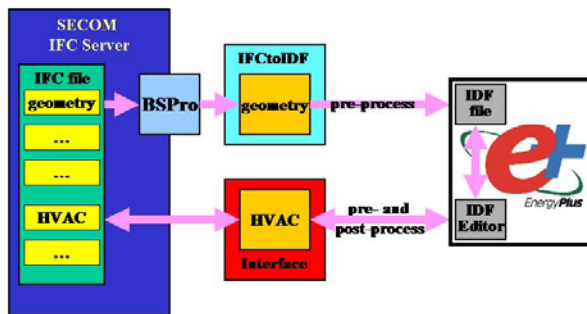


Figure 6 – Diagram of data paths

An IFC file that represents a partial BIM and does not contain HVAC data that are sufficient for EnergyPlus simulation is loaded into SECOM IFC server. The IFCtoIDF utility invokes BS Pro server, middleware that is bundled with EnergyPlus [Granlund 2003]. BS Pro resolves any encountered space boundary issues and simplifies the rich definition of geometry in the IFC file into less complex parametric definitions needed by EnergyPlus. The IFCtoIDF utility then wraps the resulting building geometry into IDF syntax and writes the initial IDF file. After the IDF file has been loaded into IDF Editor and completed with manual definition of HVAC and other information needed to run an EnergyPlus simulation, the interface reads the completed IDF file, transcribes EnergyPlus HVAC data it finds there into IFC format and writes them into the original IFC file. In this way the interface adds HVAC information to the BIM that is represented by the IFC file and makes the BIM more complete.

## OPERATING ENVIRONMENT

The interface was developed for Microsoft Windows and will therefore run only on these platforms. In addition, the interface input/output action requires the

use of the IFC SECOM Server; thus, this server must be installed as well. Since the internal data structure of the interface is based on EnergyPlus Input Data Dictionary (IDD), the IDD file from the version of EnergyPlus in use must be present and accessible.

While the interface is used as a pre- and/or post-processor before and/or after EnergyPlus simulation runs, it is not necessary to have EnergyPlus installed to run this interface.

## CONCLUSION

The IFCtoIDF utility for EnergyPlus previously resolved the seamless import of building geometry from building information models into simulation of building energy performance with EnergyPlus. The IFC HVAC interface to EnergyPlus provides seamless import of HVAC data from building information models and/or HVAC design and other simulation tools into EnergyPlus, and exports HVAC data from EnergyPlus into building information models and/or HVAC design and other simulation tools. It complements the IFCtoIDF utility and constitutes another crucial step in eventually achieving complete interoperability for EnergyPlus.

It does that by operating in a data sharing environment set for the future – it uses building information models defined in IFC that are resident on IFC servers. This allows it to accept data from partial building information models, as well as benefit from querying technology, resident server tools and web services for communication with servers; these will all become part of the standard way of dealing with building information models in the future.

In addition, this interface provides other significant benefits. It further reduces manual input of data that have to be defined in EnergyPlus input, which further reduces opportunities to make mistakes. It sets a precedent and a useful example how to implement IFC2x2 extension schemata in interfaces to other HVAC tools. It provides opportunities to use the same building information model (or the same IFC file representing it) with different tools and then compare results from these tools; this should prove to be very helpful in tool validation.

## ACKNOWLEDGMENTS

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