Title

HVAC component data modeling using industry foundation classes

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ABSTRACT

The Industry Foundation Classes (IFC) object data model of buildings is being developed by the International Alliance for Interoperability (IAI). The aim is to support data sharing and exchange in the building and construction industry across the life-cycle of a building.

This paper describes a number of aspects of a major extension of the HVAC part of the IFC data model. First is the introduction of a more generic approach for handling HVAC components. This includes type information, which corresponds to catalog data, occurrence information, which defines item-specific attributes such as location and connectivity, and performance history information, which documents the actual performance of the component instance over time. Other IFC model enhancements include an extension of the connectivity model used to specify how components forming a system can be traversed and the introduction of time-based data streams.

This paper includes examples of models of particular types of HVAC components, such as boilers and actuators, with all attributes included in the definitions. The paper concludes by describing the on-going process of model testing, implementation and integration into the complete IFC model and how the model can be used by software developers to support interoperability between HVAC-oriented design and analysis tools.

INTRODUCTION

The International Alliance for Interoperability (IAI) has been developing a general object oriented data model of buildings, the Industry Foundation Classes (IFC) for the Architecture, Engineering, Construction, and Facilities Management (AEC/FM) industry since 1995 [IAI 1995]. IFC model development is an on-going effort, but the model is now developed well enough to support very useful direct data exchange among several types of professional AEC/FM software applications. IFC compatible commercial software appeared on the market first in 1999 (architectural CAD applications for the German market). Today several "downstream" commercial applications are IFC compatible, in addition to all major industry CAD software products. Some of the vendors of interoperable industry software formed a partnership in 2000, the Building Lifecycle Interoperable Software (BLIS), to develop and promote software that supports interoperability through a building's lifecycle [BLIS 2000]. EnergyPlus, the "new generation" building energy performance simulation engine, is a member of BLIS and is interoperable: it can import building geometry from a CAD file that is saved in IFC format [US-DOE 2002].

The current release of the IFC data model is IFC2*x* [IAI 2000]. It is the only existing *comprehensive* data model of buildings; it will eventually include definitions of everything that is part of a building. The model employs contemporary modeling technology that includes intelligence: class relationships and inheritance. The main functionality of the current model release is the *exchange of building geometry*, though some other types of information can be exchanged as well [Bazjanac 2001]. However, the current model includes only rudimentary definitions of HVAC equipment, systems and components.

The limitations of the HVAC component definitions in the current IFC data model release make it impossible to exchange rich data sets with HVAC content. This prompted the launching of the BS-8 project in 2001 to complete the IFC HVAC domain schemata and make such exchanges possible. (BS-8 is the designation for IAI "Building Services project number 8.") The main objective of the project is to enable the exchange of HVAC data needed in energy performance simulation. The project is based at the Lawrence Berkeley National Laboratory (LBNL) of the University of California and is jointly funded by the U.S. Department of Energy (DOE) and the California Energy Commission (CEC). International BS-8 project collaboration includes 13 organizations and institutions from eight countries with their own private industry or government funding.

Technical work on the project is divided into 10 tasks; seven of these involve the development of HVAC definitions in one form or another. All basic technical development tasks have been virtually completed. What follows is a description of results of that work.

CONNECTIVITY MODEL

The underlying representation of the system is defined by a *network.* It is a representation of elements that are connected together in a systematic way to form a directed graph. Here, the term *system* is used in a very broad sense: a set of piped or ducted components forms a distribution system just as a connected set of structural elements can be regarded as a structural system. The connectivity model defines the network in a domain-independent way (i.e. in a generic way that is independent of any domain or professional views and definitions, and can thus be applied to any such view or definition). It consists of three major parts: *elements*, *ports* and *connectors*. An element can be any component that can be connected to neighboring elements using one or many *ports*. A port is a point in the network at which elements are connected to each other. Two ports are connected via a *connector*. An element that performs the connection (e.g. a bolt) can be associated with that specific connector as well.

In the Building Services domain, the connectivity model is extended to describe how elements are assembled in order to form a distribution system. For this purpose, the connectivity model introduces the notions of *distribution element* and *distribution port*. A distribution port is a point in the distribution network at which the medium enters or leaves the distribution element. A distribution port can reference a geometric profile that defines its shape, in addition to its local placement relative to the distribution element. A distribution port also holds information that indicates the direction in which the medium is flowing, and references data describing the physical state of the medium (e.g. pressure, mass flow, temperature etc.) at that point in the network. A connector contains no additional information pertinent to the distribution system.

The compositional aspect of the connectivity model supports three possible relationships: *aggregation*, *containment* and *nesting*. An aggregation relationship can be applied to all subtypes of elements. An aggregation indicates that a component and its parts can be considered independently. Containment implies a stronger form of composition, where the components cannot be considered independently: where the definition of the whole element depends on the definition of its parts and the parts depend on the existence of the whole element. Nesting is the strongest kind of the composition. A nesting relationship can be applied to all subtypes of an element, though it requires both the whole element and its parts to be of the same element type.

GENERIC APPROACH TO HVAC COMPONENT MODELING

The area of application for this research is limited to products and components in the field of heating, ventilation and air-conditioning (HVAC). A generic approach has been developed to treat each component in the same way. This approach is equally applicable to all other aspects of the IFC model that deal with product data.

Figure 1 shows the generic approach, which includes type, occurrence and performance history data. Further clarification of design intent through performance objectives and metrics is presently outside of the scope of the project.

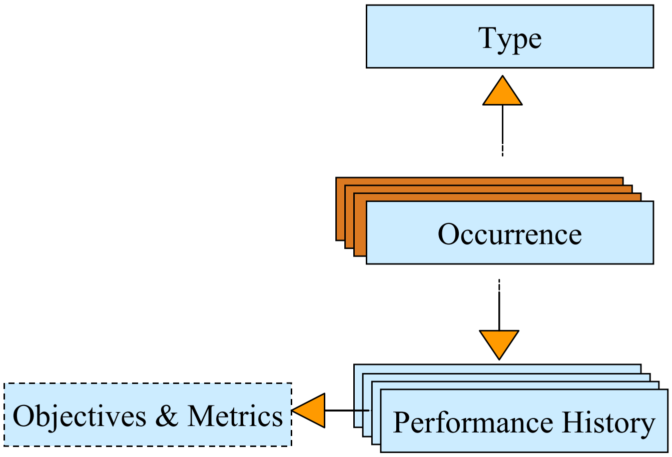

Figure 1: Generic approach for the HVAC component model

Type describes the equipment from the viewpoint of the manufacturer. Manufacturer-specific product information is currently available in the form of catalogues. Type information in this model accommodates all catalogue data needed in the selection of equipment, including information required for thermal calculations and for graphical display. Type does not establish any regulations about exchanging price information, since pricing can be directed towards different market methods and price changes are considerably more frequent then technical changes. There is *one* unique type definition for equipment instance (i.e. each unique piece of equipment).

Each component type can have one or more occurrences within a building. Each occurrence shares its type instance, which contains common manufacturer's data. The occurrence data include the local placement, connections via ports, connections to control systems and the impact on its surroundings.

MODELING OF TIME SERIES

Type and occurrence data are static information. In contrast, performance history data can be dynamic information collected over time. Performance history data document the actual time-bound performance values of a component. In practice, performance-related data are generally not easy to obtain as they can originate from different sources (e.g. they may be predicted, simulated or measured) and stages of the building life-cycle. Such time-related data cover a large spectrum, including meteorological data, schedules, operational status measurements, trend reports, etc. Their correct placement in time is essential for their proper understanding and use, and requires a time series data structure to accommodate it.

Time series are a set of data entries that are "stamped" with time. They allow a natural association of data collected over intervals of time. Time series can be regular or irregular. In a regular time series, data arrive predictably at predefined (usually uniform) intervals. In irregular time series, time intervals do not follow a repetitive pattern and unpredictable bursts of data may arrive at unpredictable points in time. Sources providing data are expected to normalize them before recording them, applying the following rules:

- All time (universal, local, daylight savings, and solar) is normalized against the ISO 8601 standard GMT/UTC (Universal Coordinated Time).
- Normalized data (in the case of piece-wise constant values, e.g. mean values) refer to the preceding time unit.
- Any rollover is handled by the source providing the data. Rollover occurs, for example, when the measurement device resets itself while measuring and the recorded data do not include the data measured before the reset.
- Bi-temporal models distinguish between data taking and data recording time. The time series do not permit bi-temporality. Only the time when data are taken is recorded.

This approach to the HVAC component model clearly defines responsibilities for data procurement. The type information is to be defined by manufacturer. The occurrence information is provided throughout the entire design, sizing and development process. Finally, the performance history data are generated throughout all of the different phases of the building's life-cycle until its destruction.

HVAC COMPONENTS

HVAC components that are included in the IFC2*x* data model extended with the new HVAC schemata are listed in Table 1.

actuator	damper	heat recovery device
air handler	diffuser	humidifier
boiler	duct	pipe
chiller	duct silencer	pump
coil	evaporative cooler	sensor
controller	fan	space heater
cooled beam	fan coil	terminal box
cooling tower	filter	valve

Table 1: HVAC components

The attributes for each component in the model were collected from ASHRAE Handbooks, the EnergyPlus input data dictionary [US-DOE 2002] and other HVAC simulation tools, dominant manufacturer's catalogs, building commission and fault detection, control software, the IAI's BS-7 project [IAI 1998] and the IFC2x data model [IAI 2002]. The attribute lists were reviewed by BS-8 members, ASHRAE GPC-20 members and individual experts. The review process took about six months before reviewers reached mutual agreements and the attribute lists were finalized.

The attribute lists were initially drafted in spreadsheets in a format that can be easily understood by building systems experts without any data modeling knowledge. This facilitated the review process. The reviewed attributes were then re-organized and categorized according to whether they dealt with type, occurrence or performance history data. The revised spreadsheets were then used as the basis for encoding in EXPRESS. The sizes of the attribute lists were significantly reduced after applying the connectivity model concepts for fluid inlets and outlets. Some commonly used structures were extracted from the attribute lists and used as the basis for new independent entity definitions, such as energy source, water consumption requirements, sound and vibration, etc. To describe the performance of components properly, it is necessary to define component performance curves. These curves typically include exponential functions and polynomials of different order. Component performance is described by linking components to appropriate definitions of such curves or tables that already exist in IFC2*x*.

Table 2 shows sample attribute lists for the boiler and actuator components. A boiler is an energy conversion device that is related to fluid flow and an energy resource. An actuator is a mechanical component related to building automation controls. Each attribute has a name, a definition, a description, and a unit of measure. Attribute definition and unit of measure are omitted from this table for brevity.

On the left side of the table are the attributes defined for a boiler. Under boiler type are attributes related to a certain type of boiler, such as material, weight, and performance curves. There are also multiple type enumerations that are all checked for independence. Note that there are no occurrence attributes for this definition, aside from its unique location in the building as well as its related system components. Under boiler performance history one can find attributes that will change over time, such as working pressure and total efficiency. The efficiency includes efficiency at design phase, at commission phase, or in everyday operation, and is an example of a time series data stream. Fluid connection attributes also include performance history data. All fluid properties are included for each fluid connection using the connectivity model described above. For example, attribute FluidInlet consists of boiler inlet water temperature, pressure, flow rate, etc. All attributes of the boiler's fan and pump are referenced or linked to fan and pump objects in this model. On the right side of the table are attributes defining an actuator, and the grouping of type and performance history is the same as for the boiler.

IFC EXPRESS MODEL

The existing IFC2*x* HVAC component model has a hierarchical structure that contains three levels of abstraction. On top is a generic distribution element which allows the assemblage of distribution systems. On the next hierarchical level below, the model distinguishes among:

- energy conversion devices, used to perform energy conversion or heat transfer
- fluid moving devices, used to distribute, circulate or perform conveyance of fluids
- storage devices, used for temporary storage of a fluid
- treatment devices, used to remove unwanted matter from a fluid
- controlling devices, used to regulate flow through a distribution system

The third level of specialization includes the specification of particular components, such as a chiller, pump, boiler, etc. These concepts are not segregated into the notion of type and occurrence, nor is there a mechanism for inclusion of performance history data across the life-cycle of the component.

Of the components defined in Table 1 above, all but a few were already present in the IFC2*x* data model, so the introduction of the new entities in and of itself was not a significant challenge. However, re-factoring the existing IFC2*x* definitions to accommodate the generic approach for

HVAC components described above, including redeploying attributes and re-architecting the model hierarchy, required substantial effort.

Table 2: Examples of HVAC component attributes lists (Boiler and Actuator)

Boiler		**Actuator**	
Name	**Description**	**Name**	**Description**
Type		**Type**	
TypeEnum	STEAM, WATER	TypeEnum	ELECTRICMOTOR, ELECTRICMAGNETIC, PNEUMATIC,
PressureTypeEnum	LOW, MEDIUM, HIGH	AcuOperationTypeEnum	Positioner, Raiselower
OperatingModeEnum	Fix, TwoStep, Modulate,	MaterialHousing	Link to material ressource
Material	Link to material resource	MaterialStem	Link to material ressource
PrimaryEnergySource	Link to energy source	StemLength	
AuxiliaryEnergySource	Link to elecEnergy source	OperationType	link to act operation type
HeatTransferSurfaceArea		HasPosFeedPotMeter	boolean
PartLoadRatio	Range (maximum,	AmbientPressure	Range (maximum, minimum)
WaterInTempRange	Range (maximum,	AmbientTemperature	Range (maximum, minimum)
ExpansionVessel	Link to tank	AmbientRelativeHumidity	Range (maximum, minimum)
WaterStorage	LINK to tank	AuxilaryEnergySource	link to energy source select
DomWaterStorageCap		TypeEnum	VOLTAGE, CURRENT, PRESSURE, OTHER
Weight		ValueRange	Range (upper, lower)
SoundLevel		Weight	
PartialLoadEfficencyCurves	Link to polynomial	SoundLevel	
EfficiencyTable	Link to table	MinimumPositionChange	
HeatOutputTalbe	Link to table	CharacteristicEnum	LINEAR, EXPONENTIAL, SWITCHABLE
ApplicationEnum	DomWatHeater, Heating	AllowedOrientationEnum	HORIZONTAL, VERTICAL, ANGLE, OTHER
Performance History		AllowedOrientationAngle	
WaterQuality	Link to water material	MaximumHysteresys	
EnergySourceConsumptio	Link to energy source	IsReversable	boolean
Efficiency		OpeningTravelTime	
FullLoadEfficiency		ClosingTravelTime	
CombustionEfficiency		MovementTypeEnum	TRANSLATIONAL, ROTATIONAL
WorkingPressure		MovementRange	Select (MovementRange, RangeAngle)
CombustionTemperature		MoveMentEnum	STEM DOWN, STEM UP,
PartLoadRatio		PositionFeedbackType	Resistance (range), Voltage
Load		FullStemUp(CCW)Input	
EnergyConsumption		FullStemDown(CW)Input	
AuxEnergyConsumption		**Performance History**	
combustionproductMaxLo	link to combustion product	StartPosition	
combproduct60%Load	link to combustion product	EndPosition	
Fluid connections		DemandedPosition	
FluidInlet		ActualPosition	
FluidOutlet		TotalDistanceTraveled	
MakeUpWaterInlet		ControlEleDirectionEnum	FORWARD, REVERSE
CombustionAirInlet		ActualHysteresis	
		Movement	Select (Thrust, Torque)

Model Architecture

The entity definitions described above were re-factored to incorporate a lightweight super-type for capturing type definitions. A precedent for this had been introduced in IFC2*x* for doors and windows.

The type definition hierarchy was fully elaborated to incorporate all the required entity definitions. Each type entity now has a single attribute that contains an enumeration identifying major classes of each type. However, the occurrence hierarchy was purposely truncated at the level immediately below IfcFlowDistributionElement because there was no substantial need for further subtypes. A generalized entity for capturing performance history data was added.

Property Sets

It was concluded that only those enumerations that define a specific type needed to be formalized as an entity attribute within the model. The remaining attributes can be catalogued into property sets. A property set is a simple attribute-value pair, although there is a significant amount of flexibility on whether the value is scalar, a pair of scalars, a table, etc. Additionally, there is significant opportunity for using complex units of measure. A few shortcomings within the existing IfcPropertyResource schema had to be resolved, including the need to extend the property types to include time series data streams and lists of scalars that could facilitate polynomial definitions. Towards this end, new subtypes of IfcProperty were defined to add a list type and reference time series definitions defined above; these were added into a new resource schema.

Using property sets to catalogue attributes allows flexibility that cannot be accomplished if all attributes are defined explicitly within the IFC data model. This flexibility accommodates local variations and allows for future extensions. Accordingly, the existing attributes defined for the IFC2*x* components, with the exception of type enumerations, are being demoted into property sets. It was determined that this methodology also suited the needs of other building services related projects under consideration for the next IFC release.

IMPLEMENTATION AND TESTING

Testing of the new IFC HVAC schemata will take several forms. The first will be the implementation of the new schemata in software that deals with HVAC definitions. The next level will be testing by developers of schemata and models that build on top of these HVAC definitions. One such effort will be by ePlanCheck, the codes and standard element of the CORENET project in Singapore [Mok 2002].

The first software implementation project involves three applications that are already IFC compatible: BS Pro COM server from Olof Granlund OY in Finland, EnergyPlus simulation engine from LBNL and other collaborators in the US, and MagiCAD, and HVAC and ducting design application from Progman in Finland. The implementation of the new IFC HVAC extension schemata in these software products will permit direct data exchange between HVAC design and simulation software. Making this environment operational in a professional setting is subjecting the new schemata to a serious test.

The new IFC HVAC extension schemata are in the process of being integrated with IFC schemata from other projects and with the "core" of the IFC data model. This integration will result in a new release of the IFC model, IFC2*x* Second Edition, expected in early 2003.

CONCLUSIONS

A major extension to the HVAC part of the IAI's IFC data model has been defined, reviewed and implemented. This extension will facilitate interoperability between energy simulation programs, such as EnergyPlus, and other software used in the design and operation of HVAC systems, including CAD programs and fault detection and diagnosis tools. The work has included the development of a generic model structure that provides for both product types, as defined in manufacturers' catalogs, and individual instances of those types, each of which has unique placement, connections and performance history. A time series model has been defined to support both the performance histories of individual components and the various boundary conditions – weather data, occupancy schedules etc – required by simulation tools. Prototype implementations of parts of the model are being developed at the time of writing. These implementations will be used both to test the extensions to the IFC data model and to demonstrate the potential advantages of software interoperability for HVAC system design and operation to designers, equipment manufacturers and those concerned with the commissioning and operation of HVAC systems in buildings.

ACKNOWLEDGMENTS

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REFERENCES

Bazjanac, V. 2001. Acquisition of Building Geometry in the Simulation of Energy Performance. In R. Lamberts et al. (eds), *Building Simulation 2001, Proc. intern. conf., Rio de Janeiro,* Vol. 1: 305-311. ISBN 85-901939-2-6.

Building Lifecycle Interoperable Software (BLIS) 2000. http://www.blis-project.org.

International Alliance for Interoperability (IAI). 1995. http://www.iai-international.org.

International Alliance for Interoperability (IAI). 1998. BS-7 project. http://cic.vtt.fi/niai/technical/ifc_3/R3_BS7.html

International Alliance for Interoperability (IAI). 2000. http://iaiweb.lbl.gov.

International Alliance for Interoperability (IAI). 2002. Release 2x of the IFC data model, http://cig.bre.co.uk/iai_international/Technical_Documents/iai_documents.html

Mok, J. 2002. Joint IT Effort between Government and Industry: A Unique Experience, http://cic.vtt.fi/niai/IAI_Summit_2002.htm.

U.S. Department of Energy (US-DOE). 2002. EnergyPlus, http://www.eren.doe.gov/buildings/energy_tools/energyplus/