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Engineer Research and
Development Center

Ontology for Life-Cycle Modeling of Heating, Ventilating, and Air Conditioning (HVAC) Systems

Experimental Applications Using Revit

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March 2012

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Abstract

The development of an open ontology for the design phase of typical heating, ventilating, and air conditioning (HVAC) systems was documented in ERDC-CERL Contract Report CR-12-2 (March 2012). It was developed following Information Delivery Manual (IDM) and Model View Definition (MVD) procedures defined by the International Organization for Standardization (ISO) and the buildingSMART Alliance. The purpose of the work was to promote consistency and quality of content created for Building Information Models (BIMs) across various disciplines.

The HVAC MVD was then tested in a separate task, as documented in this report, through its implementation in three example BIMs based on experimental architectural models provided by ERDC-CERL. HVAC equipment and systems were added to those architectural models using a commercial off-the-shelf (COTS) modeling package. Industry Foundation Class (IFC) models were then generated using the software's IFC export function and reviewed for compliance with the reference HVAC MVD.

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Preface

This study was conducted for the US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) by Hitchcock Consulting, Kelsey, CA, under Contract W912HZ-09-D-0003 (0761), “Life-Cycle Model of Mission-Ready and Sustainable Facilities—Schedules for Building Space Requirements.” The technical reviewer was Dr. E. William East (CEERD-CF-N), and the Contracting Officer’s Technical Representative was David T. McKay (CEERD-CF-N).

The work was supervised and monitored by the Engineering Processes Branch (CF-N) of the Facilities Division (CF), ERDC-CERL. Dr. East was the Project Manager. At the time of publication, Donald K. Hicks was Chief, CEERD-CF-N; L. Michael Golish was Chief, CEERD-CF; and Martin J. Savoie, CEERD-CV-ZT, was the Technical Director for Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

COL Kevin J. Wilson was the Commander and Executive Director of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	$(F-32)/1.8$	degrees Celsius
feet	0.3048	meters
gallons (US liquid)	3.785412 E-03	cubic meters
horsepower (550 foot-pounds force per second)	745.6999	watts
inches	0.0254	meters
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic inch	2.757990 E+04	kilograms per cubic meter
pounds (mass) per square foot	4.882428	kilograms per square meter
pounds (mass) per square yard	0.542492	kilograms per square meter
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
yards	0.9144	meters

1 Introduction

1.1 Background

The US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) has developed a core life-cycle building information model (BIM) based on three example Army buildings: an Officer Duplex Apartment, a Headquarters Office, and a Clinic. These models were developed inconsistently over time by different modelers, and they reflect different levels of detail and quality of content across disciplines. One cause for these differences is that an ontology describing the requirements for life-cycle modeling has not been identified for the heating, ventilating, and air-conditioning (HVAC) domain. Current efforts at HVAC modeling typically focus only on those hard physical collisions between ductwork and structural or architectural building elements. One of the difficulties of modeling the HVAC system is the complexity of the system itself.

In order to facilitate the life-cycle modeling of HVAC systems using BIM technology, ERDC-CERL has identified and documented all specific data-exchange requirements relevant to the HVAC engineering design practice.¹ That work was executed in conformance with the Information Delivery Manual (IDM) and Model View Definition (MVD) procedures defined by the International Organization for Standardization (ISO) and the buildingSMART International Alliance for Interoperability (e.g., Wix 2007 and Hietanen 2008).

Upon completion of the life-cycle HVAC MVD, it was assessed through implementation in three existing building models using commercially available architectural software. Upon validation of the HVAC MVD, these models can serve as platforms for future experimentation by CERL and other researchers. This report documents the creation of these models.

¹ ERDC-CERL Contract Report CR-12-2, March 2012.

1.2 Objective

The objective of this work was to demonstrate the ERDC-CERL life-cycle HVAC MVD by updating a set of experimental building models representing three types of low-rise facilities commonly built for the US Army.

1.3 Approach

HVAC equipment and systems were added to existing architectural models provided by ERDC-CERL using the life-cycle HVAC ontology documented in ERDC-CERL CR-12-2. Specifically, the ontology was implemented in models of a duplex apartment, an office building, and a clinic representative of such low-rise facilities constructed for the Army. The HVAC equipment and systems are added to the models using Revit, a commercial off-the-shelf (COTS) modeling software package, and a native common object library developed for this project within the software. An IFC-compliant model of each building was then generated using Revit's IFC export capability.

The coordinated IFC models were then reviewed for compliance with the reference MVD using the BimSevices suite of command-line utilities developed by AEC3 for ERDC (AEC3 2010) and other manual checks. Gaps between the IFC models generated by Revit and the reference MVD were identified and resolved where possible. The results of these compliance reviews are included in this report.

To ensure proper bounds on the models created, the following assumptions were made:

1. Thermal Fluid modeling is assumed to be a traditional water-based system comprised of boilers and fan coil units (heating) and chillers and air handling units (cooling).
2. Equipment product specifications will be provided as government furnished information.
3. Thermal Transfer Fluid modeling is assumed to be a traditional air system containing ductwork, diffusers, returns, dampers, and fans.
4. Control system components are not included in this scope of work.
5. Example models have been created at the level of detail required to demonstrate compliance with exchange requirements corresponding to the completion of the design phase as identified in the exchange requirements stage of this project.

2 Experimental Model Plan

This section documents a plan for the design-phase modeling of HVAC systems equipment found in three typical Army facilities: a Duplex Apartment, an Office Building and a Clinic. The goal of this process is to produce model files in native COTS BIM-authoring software, IFC, and COBie formats for the information exchange of HVAC design models that will minimize the requirements on downstream applications that would typically require the manual re-entry of this HVAC-related information. The three example models produced by this process will serve as platforms for future experimentation by ERDC.

The design team selected Revit MEP 2011 as the COTS BIM-authoring software for this project. This allowed the use of the government-furnished Revit architectural, structural, and MEP models as the starting point of our modeling. The government-furnished Revit models contain an initial Common Object Library (COL), consisting of Revit Families, which we plan to use, modify and customize as our modeling work progresses. These models were initially developed by Kristine Fallon Associates, Inc. (KFA) and the MEP models were started using the Revit MEP template file *Template_MEP.rvt*. The models were developed using components included in the Common Object Library, which is initially part of this project template file. The objects are subsequently customized to meet the requirements of this project.

In order to focus on the HVAC aspects of the models, we decided to strip down the existing models to include only the mechanical design. All other non-related information is deleted from the model (sheets, views, schedules, families and groups). Some basic, default, non-mechanical Revit families are not able to be removed and so remain in the project model.

The following sections give details of creating the Revit MEP 2011 mechanical design models, exporting these models to IFC, and transforming the IFC files to COBie. Specific details on the modeling of each building type are given below in separate sections.

2.1 Government-furnished model download and setup

The KFA Revit models for a given building type were downloaded from the ProjNet web site, including Architectural, Structural, and MEP models.

In order to replicate the entire mechanical model from scratch we will use the *Mechanical-Default_Metric.rte* template file. This Mechanical model will be saved as *BuildingType_M CreationDate.rvt*. The architectural model, and structural model when available, will be linked to our new model at import position, 'Auto-Origin to Origin'.

In order to replicate the furnished model in a more efficient manner, the Families of Objects that are present in the furnished model will be saved and inserted into our new mechanical model.

The government furnished Revit models will serve as a 'starting point' for the mechanical HVAC design process. The furnished design of the HVAC systems will be included as part of the model but the generic information that is initially associated with these systems do not represent an actual design, and so must be completed in our modeling process. We also intend to use the Revit families from the government furnished models as the basis for our Common Object Library (COL) and will load these into our new models. Only families that are needed to complete the mechanical design will be copied and loaded into the new model (the terms 'objects' and 'families' refer to the same thing – families are really a collections of objects, the same objects but different sizes/models).

2.2 HVAC design-phase modeling procedure

2.2.1 Pre-modeling engineering

When designing the mechanical HVAC systems for a building, the first things that need to be considered are building size, location and intended use. How big will the building be? How many floors are there? Where will the building be located? How will the building be occupied and used? The answers to all of these questions help the mechanical engineer determine what type(s) of HVAC systems will work best. At this stage in the design, major mechanical equipment items may be generically selected and sized using 'rule-of-thumb' approximations or based on past projects or previous experience. Typically, this step of the design process is not accomplished in a BIM environment. After all, it is unlikely that an architectural

BIM model would be available this early in the design phase to even begin a mechanical BIM model.

2.2.2 Coordinated HVAC engineering modeling

For this modeling effort we are starting at the point of already having Architectural and Structural design models for which we are to develop a coordinated Mechanical model. So, for this project it is assumed that the HVAC systems/arrangements have been previously selected and agreed upon between all parties (owner, architect and engineers) during previous design phases (conceptual and schematic). It is our intent to mirror the HVAC systems in the government-furnished models while developing our HVAC Mechanical model.

2.2.3 Creating a new HVAC model

A new Revit MEP 2011 project will be created using the Mechanical-Default_Metric.rte template file. This creates an MEP template model which is initially blank. The initial set-up is structured to include Mechanical, Electrical, and Plumbing disciplines. All work should be done in its applicable discipline. Any that are not required may be deleted. For this project only a Mechanical model is required, therefore the other two disciplines (Electrical and Plumbing) will be removed. These can be added back to the model at any time.

2.2.4 Linking existing architectural and structural models

Linking to existing models can be accomplished by browsing to where the architectural and structural models have been saved, selecting them and specifying the correct positioning to 'Pin' the linked models in place. This will make it impossible to move the linked models within the new Mechanical model.

2.2.5 Coordinating and matching discipline levels

When more than one discipline is working on a coordinated BIM model (in this case architectural and mechanical disciplines) it is advantageous to constantly 'monitor' the number and location of all the levels in the model. Revit can do this automatically by linking the Levels in the MEP model to the Levels that exist in the architectural model. This is done by using the Copy/Monitor command on the Collaborate tab at the top of the screen. This command is also used to create new or additional Levels that may ex-

ist in the Architectural model but do not yet exist in the Mechanical model. The levels in the Mechanical model now ‘monitor’ the levels in the linked architectural model. If the levels are changed, moved or altered in any way in the Architectural model and saved, these changes are automatically updated in the Mechanical model.

2.2.6 Defining project settings

Before starting work on the Mechanical model, certain settings should be considered. Project Information, Parameters and Units need to be defined. This can be done under the Manage tab at the top of the screen. The Project Information, Project Parameters, Project Units and Shared Parameters menus should all be selected and completed. Thermal properties may be entered here as well under the Building Construction parameter. Project units should already be set to metric units, as that is the template we started this project with.

Project Parameters in our mechanical models will be added and defined to match the Project Parameters in the furnished model. A few of these are categorized as Project Parameters (which are specific to a Project and cannot be shared with other projects), while the majority of them are considered Shared Project Parameters. In addition, these can also be defined as Instance-Type Parameters, meaning they will require definition for each Instance of Objects in the model, or as Family-Type Parameters, meaning they only require defining for each Family Type in the model. These Shared Project Parameters are ‘pulled’ into our new model using the COBieSharedParameters.txt file provided with the government-furnished models. With these Parameters defined, each time an Object is placed in the model, if the Object Category and the Parameter Category match, then that Parameter will be available for the Object.

2.2.7 Defining spaces and rooms

Revit MEP models use both MEP Spaces and Rooms which are very similar Revit objects, but used for different purposes. Spaces contain important MEP properties for analysis, especially HVAC load calculations. The Room object is used to establish containment relationships for mechanical objects in the model.

In order for Revit to perform HVAC load calculations, MEP spaces must be ‘placed’ and defined in the mechanical model. These spaces are not needed

unless Revit will be used to perform thermal load calculations. In order to use the linked architectural model to define these spaces, the 'Room Bounding' option must be checked as a Type Property of the linked model. This allows the software to automatically determine the physical properties of each space (floor space, wall areas, windows, doors, etc.) based on the information in the architectural model.

With Spaces placed in the mechanical model, their names and numbers should be entered to match those in the architectural model. Each space that is placed can have its own properties. Electrical, mechanical, thermal and occupancy properties should be defined for each Space. Space Types should be selected to best match the intended use. These settings will likely be more general at the beginning stages of the design, but will evolve to reflect actual design intent at the completion of the design phase.

Rooms are added to the Mechanical model using the Room command on the Architect tab. The Room name and numbers should be defined to match the name and numbers on the Architectural model and also match Space name and number for consistency. No additional properties need to be defined for Revit Rooms.

Note that there is potentially a conflict that arises from this Space/Room dichotomy. If both Spaces and Rooms are placed in a mechanical model, and these correspond to Spaces in the architectural model, then it is likely that duplicate instances of the IfcSpace class will be exported to IFC. See identified gaps below for more discussion.

2.2.8 Defining zones

Zones must be entered so that the software knows which Spaces are to be served 'together' by an HVAC System. These Zones will be used in the load calculations to determine heating, cooling and air-flow requirement for all the Spaces in that Zone so that the equipment may be sized and selected appropriately. Heating and Cooling Information (set-points and supply air temperatures) may be entered for each Zone.

2.2.9 Setting building construction properties for Revit loads calculations

In order to use the load calculation methods embedded in Revit to determine the required heating (and cooling) loads, certain information is re-

quired about how the structure will be built. What is it made of? What types of insulation are used? What are the thermal properties of walls, windows, doors and roofs? To perform load calculations with Revit, these values must be set in the Building Construction dialog box (click on Manage tab, Project Information, Edit the Energy Settings, Building Construction option). For this project, all default Revit values are used for these properties.

2.2.10 Calculating loads

Heating (and cooling) loads may now be calculated within Revit MEP. A loads report will be displayed when the calculations are complete. A history of the loads reports are saved in the project and are available for review at any time. These loads may also be calculated manually or using a separate calculation method. These results serve as the basis for sizing the mechanical systems and equipment that become part of the mechanical HVAC model.

2.2.11 Creating and using a Common Object Library (COL)

The Revit Common Object Library (COL) is a collection of Revit families. This collection exists within each project model and can be saved in a separate 'folder'. The COL can be edited through the model, or opened directly from the folder where it has been saved. If you open directly from the folder and make changes, these changes are not represented in the model until the edited family has been 'reloaded' into the project. Similarly, if you edit a family within the model, the version that exists in the 'folder' will not be up-to-date until the existing version is overwritten by the changed version in the model. The COL can be delivered either on its own or as part of a model.

For this project, since we have the government furnished model to use and refer to, we will use the mechanical families contained in the furnished model as our initial COL and customize it to meet our needs in modeling the three building types. The intent of creating such a Common Object Library is that it can grow over time as more family objects are defined, and can then be consistently used in future project models. The objects, or families, contained in a COL may be loaded into a project model in one of two ways.

- A Family may be loaded into a model directly through the Family editor. On any tab, the last option is to Load into Project. From here you can select the Project you want to load the Family into. The applicable Project must be opened in Revit for this option.
- Families may also be loaded into a Project from within the Project. On the Insert tab, there is an option call Load Family. Selecting this allows the user to browse to the COL and directly load the applicable Family into the Project.

2.2.12 Placing HVAC equipment and distribution elements

With the required COL families loaded into a new model, placement of mechanical equipment, systems and accessories can begin. In order to stay consistent with the furnished models, we will place the same instances of the same families in similar locations as in the furnished models. In addition, we will place all distribution system objects in similar fashion as the furnished models. Ductwork and piping is sized and placed to ensure coordination with the structural model.

2.2.13 Defining equipment type and instance properties

As described, we will use the HVAC load analysis program within Revit to calculate the required heating and cooling loads, airflows, etc. for all Spaces and Zones in the models. The calculated information must be 'transferred' to the equipment that serves those Spaces and Zones.

With all the equipment and system types placed in the model, defining the applicable values for all properties of all instances of each object type is required. For example, VAV boxes, air terminals, air handlers, etc. are initially placed in the model, but there is no 'real' design data associated with any of these objects. Actual manufacturers will be selected for this equipment, engineering calculations will be made to size this equipment appropriately and data will be entered for each instance (where applicable) corresponding to the actual load requirements for the corresponding space, zone and/or building.

Type properties (or parameters) are those that are common to all Instances of that Type that are placed within the model. These are edited by selecting a piece of equipment (e.g., a VAV box) and selecting Edit Type. This only needs to be done once for each Type of equipment. In an actual de-

sign scenario, the Type properties may be defined early but will likely evolve through the design process.

Instance properties are those that are specific to each Instance, or placement, of each object in the model. For example, there will be numerous Supply Air Terminals in a building model. Not all of these air terminals will have the same air flow requirement. They will not all have the same pressure drop. Instance properties such as these are entered by clicking on each instance in the model and filling in the required data. Some of this information is automatically determined by the software and can usually be edited by the user to meet specific project needs. Instance property values are not necessarily needed until the model is near completion as this data is likely to change through the design process so there is no need to spend time on this until the end. With large projects with a vast amount of objects, saving this data entry to the end can save a significant amount of time.

There are times when some equipment does not have all of the properties that a particular engineer would want to specify as part of the BIM model. For instance, the default pump families in Revit do not have a property where the actual design flow-rate was specified. The Family name offers a range of flow-rates for different size pumps, but once inserted into a model, there is nothing to tell the user what the actual flow-rate of that instance should be. Therefore in some cases properties may need to be added to a particular family. To test this and track the result from Revit-to-IFC-to-COBie, a property called 'Flow Rate' can be added to a pump family using the Family Editor as follows:

- Parameter Type: Family Parameter
- Name: Flow Rate
- Discipline: Piping
- Type of Parameter: Flow
- Group Parameter Under: Mechanical

After saving the changes to this family, it must be loaded back into the Revit model so that the changes 'take effect'. Particular attention should be paid to this property through the conversion process to see if it 'behaves' any differently than some of the other default properties.

2.2.14 Defining systems

Multiple air systems and several piping systems can be ‘created’ and defined in a building model. These systems do not exist in the model and are not created or defined until the duct (or pipe) is run to a piece of equipment that has that system defined. For example, the supply air terminal that is part of the model has a single duct connector. This duct connector has a property called ‘System Type’ and is defined as ‘Supply Air’. These systems are created by selecting an air terminal and selecting Supply System at the top of the screen. This creates a ‘Supply Air System #X’ and allows the user to select all other supply air terminals that are to be part of that system (typically all the supply air terminals that serve a single zone would be selected) in addition to the VAV box that serves those air terminal.

2.3 Exporting the Revit model to IFC

Once the Revit MEP model is complete and all data have been entered, an IFC mapping file can be created. By clicking on the main Revit dropdown at the top of the screen, click Export, click Options, and click IFC Options. This opens an IFC Export Classes dialog box. This defines how certain items in the models are mapped to an IFC exported file. An IFC mapping file titled IFC-exportlayers.txt provided along with the government-furnished Revit models is loaded into the project through this dialog box. This IFC mapping file defines how objects within the Revit model are classified when exported to an IFC file.

2.3.1 Customizing Revit IFC export mappings

Revit MEP 2011 has a limited categorization of HVAC-related Types that can be mapped to IFC using the IFC mapping file approach described above. In particular only a single Mechanical Equipment category is available through the mapping file approach, forcing all Types and Instances in this category to be exported to a single IFC Type and Instance class.

In order to further customize the mapping of Revit Types and Instances to the IFC data model upon export to IFC, two so-called shared parameters must be added to each Family in the Revit COL. These parameters are named IfcExportType and IfcExportAs. Each Revit Family requires values for each of these properties that identify the most appropriate mapping to

IFC from a list of Revit supported IFC classes. These mappings will be developed for each equipment Type and Instance in each building model.

See Autodesk WikiHelp (2011) for further information.

http://wikihelp.autodesk.com/Revit/enu/2012/Help/Revit_User%27s_Guide/1394-Documents/2112-Print_Export2113/2150-Exportin2150/2151-Supporte2151

2.4 Transforming the IFC export file to COBie2

Once the IFC files have been exported from Revit, they can be transformed to COBie2 spreadsheet format using the BimServices software (AEC3, 2010). Output from this transformation process will be reviewed for each model and addressed in model modifications.

2.5 Identifying and resolving gaps between Revit, IFC, and COBie

There are likely to be gaps between what this project identifies as exchange requirements information and the information that can currently be modeled in Revit, exported to IFC, and transformed to COBie. These gaps will be identified and documented as the project progresses. Project Team members will endeavor to resolve these gaps through contacts with software developers.

3 Common Object Library

A Revit Common Object Library (COL) is a collection of Revit families. This collection exists within each project model and can be saved in a separate 'folder'. The COL can be edited through the model, or opened directly from the folder where it has been saved. If you open directly from the folder and make changes, these changes are not represented in the model until the edited family has been 'reloaded' into the project. Similarly, if you edit a family within the model, the version that exists in the 'folder' will not be up-to-date until the existing version is overwritten by the changed version in the model.

For this project, since we have the government furnished model to use and refer to, we will use the mechanical families contained in the furnished model as our initial COL and customize it to meet our needs in modeling the three building types. The intent of creating such a Common Object Library is that it can grow over time as more family objects are defined, and can then be consistently used in future project models.

A Revit COL can be delivered either on its own or as part of a model. For each of the example building models delivered as part of this project, the specific project Revit COL is delivered along with these building models. A separate combined Revit COL is also available from ProjNet.

The objects, or families, contained in a Revit COL may be loaded into a project model in one of two ways.

- A Family may be loaded into a model directly through the Family editor. On any tab, the last option is to Load into Project. From here you can select the Project you want to load the Family into. The applicable Project must be opened in Revit for this option.
- Families may also be loaded into a Project from within the Project. On the Insert tab, there is an option call Load Family. Selecting this allows the user to browse to the COL and directly load the applicable Family into the Project.

4 Duplex Apartment Model

4.1 Government-furnished model download and setup

Two Revit models (*Duplex_A.rvt* and *Duplex_MEP.rvt*) were downloaded on May 12, 2011. These files were in a .zip file called *DUPLEX_01Revit_Files_20110505.zip*. Also downloaded on that date were:

- *COL_Revit_Files_20110301.zip* — The KFA Common Object Library (COL) that ‘lives’ in the two Revit models.
- *DUPLEX_02-IFC_Exports_From_Revit_20110505.zip* — This file contains five IFC models (two of the duplex architectural model and two of the duplex MEP model, along with one other).
- *DUPLEX_06_Schedules_20110505.zip* — Spreadsheet files of schedules generated from the Revit models.

To begin using the KFA models as the starting point for our HVAC models, the MEP model was saved as *Duplex_M 08-29-2011.rvt* and the architectural model was saved as *Duplex_A 08-29-2011.rvt* and was linked to our HVAC model at import position, ‘Auto-Origin to Origin’.

In order to focus on the HVAC aspects of the MEP model, we decided to strip down the existing model to include only the Mechanical design. All other non-related information was deleted from the model (sheets, views, schedules, families and groups). Some basic, default, non-mechanical Revit families were not able to be removed and so remain in the project model. Also, the visibility graphics were customized so that the model displayed better for this exercise (line-weights and colors were changed for mechanical/piping objects and equipment).

The submitted Mechanical model files include the following:

- *Duplex_20111024_Revit_Files.zip* — The Revit Mechanical model (*Duplex_M_20111024.rvt*) and its linked Architectural model (*Duplex_A_20111024.rvt*).
- *Duplex_20111024_Revit_COL_Files.zip* — The Common Object Library (COL) files used in the Revit Mechanical model.

- *Duplex_M_20111024_IFC_Exports_From_Revit.zip* – The two versions of IFC models exported from the Revit Mechanical model: *Duplex_M_20111024_ROOMS_ONLY.ifc* and *Duplex_M_20111024_ROOMS_AND_SPACES.ifc*.
- *Duplex_M_20111024_Converted_To_COBie2.zip* – The COBie2 *Duplex_M_20111024_ROOMS_ONLY_asCOBie2.xls* spreadsheet file generated from a BimServices transformation of the Revit exported *Duplex_M_20111024_ROOMS_ONLY.ifc*.

4.2 HVAC design-phase modeling procedure

This section documents the steps needed to complete an HVAC mechanical engineering design using the BIM software, Revit MEP 2011.

4.2.1 Pre-modeling engineering

When designing the mechanical HVAC systems for a building, the first things that need to be considered are building size, location and intended use. How big will the building be? How many floors are there? Where will the building be located? How will the building be occupied and used? The answers to all of these questions help the mechanical engineer determine what type(s) of HVAC systems will work best. At this stage in the design, major mechanical equipment items may be generically selected and sized using ‘rule-of-thumb’ approximations or based on past projects or previous experience. Typically, this step of the design process is not accomplished in a BIM environment. After all, it is unlikely that an architectural BIM model would be available this early in the design phase to even begin a mechanical BIM model. So, for this project it is assumed that the HVAC systems/arrangements have been selected and agreed upon between all parties; owner(s), architect(s) and engineer(s). It is our intent to mirror the HVAC systems in the furnished models for the new mechanical model.

4.2.2 Creating a new HVAC model

When Revit MEP is started, select New Project from the initialization screen. This creates an MEP template model which is currently blank. The project browser will be initially set-up and will be structured to include Electrical, Mechanical and Plumbing disciplines. All work should be done in its applicable discipline. Any that are not required may be deleted. For this project only a Mechanical model is required, therefore the other two

disciplines (Electrical and Plumbing) have been removed. These can be added back to the model at any time.

4.2.3 Linking an existing model

At the very bottom of the project browser, right click on Revit Links and select New Links. Here you browse to where an existing architectural model has been saved, select the appropriate file and before selecting Open, be sure that Auto-Origin to Origin is selected in the Positioning category. There are other options for this linked positioning and each time a model is created, this option should be coordinated with the rest of the design team. In the Duplex Apartment case our architectural model was saved as Duplex_A 08-29-2011.rvt. With this file selected and the correct positioning specified, clicking on Open will then display the architectural model of the building. With the model displayed, click on the linked Revit file and on the Modify tab on the top of the screen, and 'Pin' the link in place. This will make it impossible to move the linked model within the new Mechanical model.

4.2.4 Coordinating and matching discipline levels

When more than one discipline is working on a coordinated BIM model (in this case architectural and mechanical disciplines) it is advantageous to constantly 'monitor' the number and location of all the levels in the model. Revit can do this automatically by linking the Levels in the MEP model to the Levels that exist in the architectural model. This is done by using the Copy/Monitor command on the Collaborate tab at the top of the screen. This command is also used to create new or additional Levels that may exist in the architectural model but do not yet exist in our Mechanical model. In this case, two new levels were created, the Roof (at 6.000m) and the T/FDN (at -1.250m). The levels in the MEP model now 'monitor' the levels in the linked architectural model. If the levels are changed, moved or altered in any way in the architectural model and saved, these changes are automatically updated in the Mechanical model.

4.2.5 Define project settings

Before starting work on the Mechanical model, certain project level settings should be considered. Project Information, Parameters and Units need to be defined. This can be done under the Manage tab at the top of the screen. The Project Information, Project Parameters, Project Units and

Shared Parameters menus should all be selected and completed. Thermal properties may be entered here as well under the Building Construction parameter. Project units should be filled out for all disciplines and should be consistent for all (if SI units are used then all units should be SI). Project units should already be set to metric units in our case, as that is the template we started this project with. Project and Shared Parameters will evolve and grow as the design progresses. In this case, most parameters will be 'loaded' into our model as we use the objects in the furnished model which already have all project and shared parameters defined.

The following 'Energy Setting' parameters were used for the Duplex Apartment model:

- Building Type: Multi Family
- Location: Chicago, Illinois
- Building Service: Central Heating: Radiators
- Building Infiltration Class: Medium

Some other general-type properties used for this model include the following:

- Project Issue Date: Aug. 29, 2011
- Project Status: Designed
- Client Name: US Army
- Project Number: 0001
- Category Description: Duplex

4.2.6 Placing spaces

In order for Revit to perform HVAC load calculations, spaces must be 'placed' and defined in the mechanical model. These spaces are not needed unless Revit will be used to perform thermal load calculations. In order to use the linked architectural model to define these spaces, the 'Room Bounding' option must be checked as a Type Property of the linked model. This is done by right-clicking on the linked model, selecting Type Properties and checking the Room Bounding option. This allows the software to automatically determine the physical properties of each space (floor space, wall areas, windows, doors, etc.) based on the information in the architectural model. To place a Space, select the Analyze tab at the top of the screen and select Space. Hover over a region in the building and click to enter to place the Space.

4.2.6.1 *Note on Revit spaces vs rooms*

In the (DRAFT) document authored by KFA in association with the original government-furnished models, entitled, “Duplex Apartment Model Description’ dated May 27, 2011, the following paragraph is included under the MEP Model heading, “The Revit MEP model uses both Rooms and MEP Spaces which are very similar Revit objects that both export as IfcSpace entities, and are both mapped to the COBie spaces tab by BimServices. In a typical Revit MEP project, Rooms are used to match the Architectural model room layout while Spaces are used for the MEP design, and contain additional MEP properties for analysis. While both Rooms and Spaces export to IFC as IfcSpace entities, only the Room object is used to establish containment relationships for objects in the model.” In our first attempt at IFC export and further conversion to COBie, our Mechanical model only contained Revit Spaces (no Rooms had been defined). The furnished Architectural model does have Revit Rooms defined, but these are only linked into the Mechanical model and therefore are not included in the Mechanical IFC file export. It wasn’t until Rooms were added directly to the Mechanical model that they appeared as part of the IFC file. So, while the statement was made that Rooms and Spaces ‘export as IfcSpace entities’, we were unable to have the Revit Spaces export as such. In fact, checking the furnished text file IFC-exportlayers.txt confirmed that Rooms are mapped to ‘IfcSpace’ entities while Spaces are ‘Not Exported’. These Rooms are added to the Mechanical model using the Room command on the Architect tab. The Room name and numbers were defined to match the name and numbers on the Architectural model and also match Space name and number.

4.2.7 Defining spaces

With the Spaces placed in the mechanical model, names and numbers were entered to match those in the architectural model. The Space name and number can be edited by clicking on each. Each space that is placed can have its own properties (individual properties that relate to specific items in the model are referred to as ‘instance properties’). Electrical, mechanical, thermal and occupancy properties should be defined for each space instance. These settings will likely be more general at the beginning stages of the design, but will evolve to reflect actual design intent at the completion of the design phase.

4.2.8 Setting building construction properties for Revit loads calculations

In order to use the load calculation methods embedded in Revit to determine the required heating (and cooling) loads, certain information is required about how the structure will be built. What is it made of? What types of insulation are used? What are the thermal properties of walls, windows, doors and roofs? To perform load calculations with Revit, these values must be set in the Building Construction dialog box (click on Manage tab, Project Information, Edit the Energy Settings, Building Construction option). For this exercise, all default Revit values were used for these properties with the exception of Ceilings, which was changed to 'Ceiling below joists, R-10 board insulation' to better match the intended construction of this building type.

4.2.9 Calculating loads

Heating (and cooling) loads may now be calculated within Revit MEP. This is done by selecting the Heating and Cooling Loads option on the Analyze tab. This will display a shell of the model and will highlight all the defined spaces in the building. If a space is missing, or if there are some errors regarding any of the spaces, they will appear here. Changes to any of the Space settings can also be made through this dialog box. There is a Parameter in this dialog box called Report Type where the engineer may select a Simple, Standard or Detailed load report. Pressing the Calculate button will initiate the load calculation. A loads report will be displayed when the calculations are complete. A history of the loads reports are saved in the project and are available for review at any time (any particular report may be deleted at any time). These can be found in the Project Browser. These loads may also be calculated manually as would be done in a 'non-BIM environment'. For the Duplex Apartment model, heating loads were calculated using the Revit MEP load software and serve as the basis for sizing the mechanical systems and equipment that become part of the mechanical HVAC model.

4.2.10 Creating and using a Common Object Library (COL)

The Revit Common Object Library (COL) is a collection of Revit families. This collection exists within each project model and can be saved in a separate 'folder'. The COL can be edited through the model, or opened directly from the folder where it has been saved. If you open directly from the

folder and make changes, these changes are not represented in the model until the edited family has been 'reloaded' into the project. Similarly, if you edit a family within the model, the version that exists in the 'folder' will not be up-to-date until the existing version is overwritten by the changed version in the model. The COL can be delivered either on its own or as part of a model.

For this project, since we have the government furnished model to use and refer to, we used the mechanical families contained in the furnished model as our initial COL. In order to create our COL, the furnished model was opened and the library of families was navigated to. Right-clicking on a particular family in the existing library allows the engineer to 'edit the family'. This opens up the family object in its own editor and allows the user to make changes. From here, these families may be saved in their own folder creating a separate Common Object Library that can be used in other projects. The intent of creating such a Common Object Library is that it can grow over time as more family objects are defined, and can then be consistently used in future project models. The Duplex Apartment model contains only a few COL families that need to be loaded into our new model. The objects, or families, contained in our COL may be loaded into a project model in one of two ways.

- A family may be loaded into a model directly through the family editor. On any tab, the last option is to Load into Project. From here you can select the Project you want to load the family into. The applicable Project must be opened in Revit for this option.
- Families may also be loaded into a Project from within the Project. On the Insert tab, there is an option call Load Family. Selecting this allows the user to browse to the COL and directly load the applicable Family into the Project.

4.2.11 Placing HVAC equipment and distribution elements

With the required COL families loaded into our new model, placement of mechanical equipment, systems and accessories can begin. In order to stay consistent with the furnished model, we placed the same instances of the same families in similar locations as in the furnished model. In addition, we placed all distribution piping in similar fashion as the furnished model.

In some cases for the Duplex Apartment, extra heating elements (radiators and associated distribution piping) were added to the new model in order

to meet calculated peak heating load requirements for each space. Another option would have been to insert a higher heating capacity radiator able to meet the calculated load. This would have added an additional ‘type’ or model of radiator to the project and the COL.

4.2.12 Defining equipment type and instance properties

Both Revit and IFC include the concept of equipment Type and Instance. An equipment Type contains information that is common to all occurrences of a family of equipment (e.g., manufacturer). Each individual occurrence of that Type is referred to as an Instance and contains information unique to that occurrence (e.g., location). A Common Object Library should contain complete information for each Type in the library. However, while the additional properties of Instances of that Type may also be defined in the COL, the values for these Instance properties may not be correctly populated until an occurrence is created within a project model.

Many equipment Types were already defined in the COL of the government-furnished models, however appropriate values for all Type and Instance properties were not always populated. For example, a hot water radiator was placed in each foyer Space in the Duplex Apartment model, but there was only generic, or no, information assigned to that Instance’s properties. As part of our modeling effort, actual manufacturers were selected for each equipment Type, and engineering calculations were made to size this equipment appropriately and data was entered for each Instance based on the actual load requirements for each Space.

Type properties can be edited by selecting a piece of equipment (e.g., a radiator) and selecting Edit Type (this can be done on the tab at the top of the screen or by a link on the properties dialog box). This only needs to be done once for each Type of equipment. In an actual design scenario, the Type properties may be defined early, but will likely evolve throughout the design process.

Instance properties are those that are specific to each occurrence, or placement, of each equipment object in the model. For example, there are numerous radiators in the Duplex model. Not all of these radiators will need the same hot water requirement. They will not all have the same pressure drop or provide the same amounts of heat to a particular space. They will all be at different positions and in different rooms. These are all examples of Instance properties, which are entered by clicking on each In-

stance in the model and filling in the required data. Some of this information is automatically determined by the software and can usually be edited by the user to meet specific project needs. Instance properties are not necessarily needed until the model is near completion as this data is likely to change over the course of the design process, so there is no need to spend time on this until the end. With large projects with a vast amount of objects, saving this data entry to the end can save a significant amount of rework time.

There are times when some equipment does not have all of the Parameters or Properties that a particular engineer would want to specify as part of the BIM model. For instance, there are two Hot Water Pumps used in the Duplex model, one for each unit. But the Pump family that was furnished (and the default pump families in Revit) did not have a Parameter/Property where the actual design flow-rate was specified. The Family name offered a range of flow-rates for different size pumps, but once inserted into the model, there was nothing to tell the user what the actual flow-rate of that instance should be. Therefore in some cases Parameters may need to be added to a particular family. To test this and track the result from Revit-to-IFC-to-COBie, a Parameter called 'Flow Rate' was added to the M_Inline Pump – Circulator family that is present in the Duplex model. This Parameter was added to this family using the Family Editor as is specified as follows:

- Parameter Type: Family Parameter
- Name: Flow Rate
- Discipline: Piping
- Type of Parameter: Flow
- Group Parameter Under: Mechanical

After saving the changes to this family, it must be loaded back into the Duplex model so that the changes 'take effect'. Particular attention should be paid to this Parameter through the conversion process to see if it 'behaves' any differently than some of the other default Parameters.

Note two additional items regarding the properties and values in our HVAC model:

- The properties for each family type contain very specific dimensional properties that were not changed in our HVAC model or COL. This

- would have involved unproductive time to gather information not yet readily available from manufacturers. General dimensions (NominalHeight, NominalWidth and NominalLength) for each family type were input as placeholders. Ideally, in the future this information will come from manufacturers' catalogs of their equipment.
- All pricing information (Cost and ReplacementCost) have similarly been approximated.

4.2.13 Defining systems

Several piping systems and two duct systems were created in the government-furnished Duplex model. These systems do not exist in the model until a pipe (or duct) is run to a piece of equipment that has that system defined. For example, the boiler that is part of the model has pipe connections with System Types specified as Hydronic Supply, Hydronic Return and Other (used for Natural Gas). The available System Types within Revit are predefined and are specified through the Family Editor. The Systems and System Names are not created until the user places an instance of equipment and makes its piping connections. With an object instance placed, clicking on it will display at the top of the screen a prompt to Create 'X' System, with the 'X' being whichever systems are associated with that object. After defining the System (selecting all parts associated with the given System), the System is created and the actual System Name may be customized through the System Browser. The default names are created by Trade / System Type / Numerical Order. For example, the first System created in the mechanical model associated with a Radiator with a pipe connection specified as Hot Water Supply, would be named "Mechanical Hot Water Supply 1".

Note that Revit Systems only have a Name property associated with them. No additional properties such as overall system fluid flow rate or pressure drop are associated with these Systems.

4.2.14 Exporting to IFC

Once the model is complete and all data have been entered, an IFC mapping file can be created. By clicking on the main Revit dropdown at the top of the screen, click Export, click Options, and click IFC Options. This opens an IFC Export Classes dialog box. This defines how certain items in the models are mapped to an IFC exported file. An IFC mapping file titled IFC-exportlayers.txt was provided along with the government-furnished

Revit models and was loaded into the project through this dialog box. After selecting Okay, proceed back to the Export option and select IFC. In the Export IFC dialog box, specify the location and name of the IFC file and the Type of File required (in this case we have used the IFC 2x3 (*.ifc) type). Click on Save and the IFC file is generated.

4.2.15 Customizing Revit IFC export mappings

Revit MEP 2011 has a limited categorization of HVAC-related Types that can be mapped to IFC using the IFC mapping file approach described above. In particular only a single Mechanical Equipment category is available through the mapping file approach, forcing all Types and Instances in this category to be exported to a single IFC Type and Instance class.

In order to further customize the mapping of Revit Types and Instances to the IFC data model upon export to IFC, two so-called shared parameters must be added to each Family in the Revit COL. These parameters are named IfcExportType and IfcExportAs. Each Revit Family requires values for each of these properties that identify the most appropriate mapping to IFC from a list of Revit supported IFC classes. See Autodesk WikiHelp (2011) for further information.

http://wikihelp.autodesk.com/Revit/enu/2012/Help/Revit_User%27s_Guide/1394-Documents/2112-Print_Export2113/2150-Exportin2150/2151-Supporte2151

Table 4-1. Duplex apartment mechanical equipment IFC export parameters.

Revit object	IFCExportType	IFCExportAs
Radiator	Radiator	IfcSpaceHeaterType
Pump	Circulator	IfcPumpType
Boiler	Water	IfcBoilerType
Fan	VaneAxial	IfcFanType
Backflow Preventer	DoubleCheck	IfcValveType
Ball Valve	Isolating	IfcValveType

Table 4-1 shows the shared parameter values used in the Duplex mechanical model. IFCExportAs nominates the IFC type object (e.g., IfcSpaceHeaterType). Where there is doubt IfcBuildingElementProxyType can be used. The values for IFCExportAs are selected from the set of IFC equipment sub-types of IfcDistributionFlowElementType that are shown as being supported by Revit on the above web site. IFCExportType nomi-

nates the `PredefinedType` attribute (e.g., Radiator) which is chosen from the type object enumeration (e.g., `IfcSpaceHeaterTypeEnum`). Where there is uncertainty `NotDefined` can be used.

7.5.1.28 `IfcSpaceHeaterTypeEnum`

Enumeration defining the functional type of space heater. The `IfcSpaceHeaterTypeEnum` contains the following:

- **CONVECTOR**: A heat-distributing unit that operates with gravity-circulated air.
- **RADIATOR**: A heat-distributing unit that operates with thermal radiation.
- **USERDEFINED**: User-defined space heater type.
- **NOTDEFINED**: Undefined space heater type.

NOTE: This enumeration was revised in IFC 2x4 and was renamed from `IfcHydronicHeaterTypeEnum` in IFC R2x.

HISTORY: [New enumeration in IFC R2x.](#)

EXPRESS specification:

```
TYPE IfcSpaceHeaterTypeEnum = ENUMERATION OF (
    CONVECTOR,
    RADIATOR,
    USERDEFINED,
    NOTDEFINED);
END_TYPE;
```

Figure 4-1. IFC example documentation of predefined type values for equipment types.

4.2.15.1 Note on IFC export of radiator equipment type `IfcSpaceHeaterType`

We have been unable to map Duplex Apartment Radiator instances to the desired IFC `PredefinedType` of “Radiator”. We set the shared parameters as shown in Table 4-1. While the `IfcSpaceHeaterType` is correctly exported, its `PredefinedType` is listed in the IFC file as “UserDefined”. Each other equipment type (e.g., `IfcPumpType`) correctly exports with the `PredefinedType` shown in Table 4-1 (e.g., Circulator). This is a puzzling exception to our customized mapping.

4.2.15.2 Note on IFC export of Revit rooms and spaces issue

Both Revit Rooms and Revit Spaces can be exported to IFC as `IfcSpace` instances. As mentioned above, Revit Spaces contain information needed for mechanical load calculations while Revit Rooms contain equipment location information (i.e., which room contains which equipment instances). Exporting both Rooms and Spaces to IFC results in duplicate `IfcSpace` Name instances in the IFC file and in the resulting COBie transformation spreadsheet. This is a gap that should be addressed within the Revit IFC export utility.

Using the government furnished IFC-exportlayers.txt file, the initial IFC file seemed to export correctly. All Revit Objects in the model were listed under (or within) their relevant Revit Room in the IFC hierarchy. Howev-

er, it was determined that only Revit Rooms were designated to export as IfcSpace, while Revit Spaces were not exported. In order to export Revit Spaces to IFC format, changes were made to the IFC-exportlayers.txt. Revit Spaces were designated as 'IfcSpace' in this file (rather than 'Not Exported'). At the same time the Revit Rooms were designated as 'Not Exported' so the changes to the IFC file could be readily determined. The resulting IFC file had all Revit Objects listed, but the Objects were no longer associated (or tied) to a particular Space (or Room) in the model. Each Object type was listed under its own Name in the IFC hierarchy. A third IFC file was created that had both Revit Rooms and Spaces designated to export as IfcSpaces. This resulted in duplicate Space entries in the IFC file, with the remaining Revit Objects listed under the Revit Room IFC object. Ideally, Revit Spaces should export to IFC in the same manner as Revit Rooms, that is to say keeping the spatial relationship with all other Objects in the model. The Revit Spaces have important engineering information that Revit Rooms do not, including HVAC load results, designated airflows, electrical and lighting information and more. For our first submission we have decided to keep the spatial relationship between the Revit Rooms and the mechanical Objects in the model and to avoid having duplicate Space entries in the resulting IFC file. For this reason, we have gone back to the original IFC-exportlayers.txt file which only exports the Revit Rooms.

For this project it was determined that equipment location information was of more importance and so only Revit Rooms were exported to the IFC file subsequently used for COBie transformation. We also exported IFC files containing both Revit Room and Space objects to capture all information associated with these two similar object types.

4.3 Mechanical and ventilation equipment and systems details

The following tables list the mechanical and ventilation equipment and systems that are present in the Duplex Apartment Revit Mechanical model. At least two instances of each of these objects are present in the Duplex Apartment model.

As with any COTS BIM software, each object will have Type and Instance Properties associated with it (the property names may be called something different in other software applications).

An understanding of how these properties are defined, managed and mapped from the Revit model to an IFC model and ultimately to a COBie file is critical.

Refer to Appendix A for lists of Revit properties for each type of Object in the Duplex Apartment model. Also, refer to Appendix B for tables of key HVAC properties for all example models.

Table 4-2. Duplex apartment mechanical equipment.

Mechanical Equipment - Duplex Apartment		
Item	Revit Object Family Name	Revit Object Type
Pump	M_Inline Pump - Circulator	3.9 LPS - 0.8 Meter Head
Radiator	M_Radiator - Hosted	25
Boiler	M_Hot Water Boiler - 59-440 kW	147 kW
Fan	M_Centrifugal Fan - Rooftop - Upblast	991-1905 LPS

Table 4-3. Duplex apartment piping equipment.

Pipe Accessories - Duplex Apartment		
Item	Revit Object Family/Instance Name	Revit Object Type
Backflow Preventer	M_Backflow Preventer_DCW to Hydronic Supply_15-50 mm_	25 mm
Ball Valve	M_Ball Valve - 50-150 mm	50 mm

Table 4-4. Duplex apartment piping systems.

Pipe Systems - Duplex Apartment		
Item	Revit Object Family/Instance Name	Revit Object Type
Piping System	Unit A Hydronic Return	n/a
Piping System	Unit A Hydronic Supply In	n/a
Piping System	Unit A Hydronic Supply Out	n/a
Piping System	Unit A Natural Gas	n/a
Piping System	Unit B Hydronic Return	n/a
Piping System	Unit B Hydronic Supply In	n/a
Piping System	Unit B Hydronic Supply Out	n/a
Piping System	Unit B Natural Gas	n/a

Table 4-5. Duplex apartment duct systems.

Duct Systems - Duplex Apartment		
Item	Revit Object Family/Instance Name	Revit Object Type
Duct System	Unit A Mechanical Exhaust Air	n/a
Duct System	Unit B Mechanical Exhaust Air	n/a

4.4 Exporting to COBie

The AEC3 BimServices Transform1 application was configured with the latest current version of “asCOBie.xml.xsl” transformation specification (2011-10-18). The transformation was run with the setting to include non-asset Types and Components.

Initially the presence of a System object named “<unnamed>” caused disruption to the transformation process, which is XML based, due to the angle bracket special characters used in the name. This is a default name within Revit for System objects that have not been instantiated by making at least one connection to an instance of equipment. In this case, this System object relates to electrical connections that have not been modeled in our purely mechanical model of the Duplex, and would ideally be ignored by the transformation. The transformation was upgraded to handle the presence of angle brackets. In general, naming policies should be used that avoid punctuation and exotic characters.

4.4.1 Automatic quality checking

The resulting COBie file was assessed and the following issues were detected automatically.

Type (Types of IfcTypeProduct)

Identifier : Type	Description :	Status :	Qualifier :
Unique names for Asset Types	Quality and Compliance Assessment of Unique names for Asset Types (5/13) Percent indicating the ease of management of the clearly named asset types.	NON COMPLIANT	38.5 Percent

Contact (IfcOwnerHistory) : 1

Identifier : Contact	Description :	Status :	Qualifier :
Contact mandatory data (3)	Telephone Numbers is mandatory but n/a is insufficient for Contact mjt@unknown.com	ADEQUATE COMPLIANCE	Data requirements
	Contact Role is mandatory but n/a is insufficient for Contact mjt@unknown.com		
	Organization Identification is mandatory but n/a is insufficient for Contact mjt@unknown.com		

Facility (IfcBuilding) : 1

Identifier : Facility	Description :	Status :	Qualifier :

Floor (IfcBuildingStorey) : 3

Identifier : Floor	Description :	Status :	Qualifier :
Floor mandatory data (3)	Classification Name is mandatory but n/a is insufficient for Floor Level 1	ADEQUATE COMPLIANCE	Data requirements
	Classification Name is mandatory but n/a is insufficient for Floor Level 2		
	Classification Name is mandatory but n/a is insufficient for Floor Roof		

Space (IfcSpace) : 19

Identifier : Space	Description :	Status :	Qualifier :
Space mandatory data (19)	Classification Name is mandatory but n/a is insufficient for Space B101	ADEQUATE COMPLIANCE	Data requirements

Type (Types of IfcTypeProduct) : 11

Identifier : Type	Description :	Status :	Qualifier :
Type mandatory data (3)	Classification Name is mandatory but n/a is insufficient for Type Pipe Type: Mechanical Pipe:540160	ADEQUATE COMPLIANCE	Data requirements
	Classification Name is mandatory but n/a is insufficient for Type Round Duct:Tap:557534		
	Classification Name is mandatory but n/a is insufficient for Type Pipe Type: Hot Water:583610		

Attribute (IfcPropertySingleValue) : 33780

Identifier : Attribute	Description :	Status :	Qualifier :
Attribute mandatory data (161)	Property Value is mandatory but n/a is insufficient for Attribute Reference	ADEQUATE COMPLIANCE	Data requirements

Figure 4-2: Typical Issues detected using automatic checking and quality reports.

The duplication of type names is severe, with only 5 out of the 13 names being unique in the IFC model. This is however masked by the transformation which reports only the first type definition encountered. Similarly, documentation, spares sets and preventative maintenance is suggested for only the first of the duplicated types.

There is no classification information found on any of the Spaces or Types. Revit does not support a classification model but may allow controlled picklists to be associated to the AssemblyCode and Omniclass properties. If these properties had been supplied, they would have been detected and transferred. There is no classification found for floors, but these can be manually corrected to one of 'Floor', 'Roof' or 'Site'.

Lastly there are 141 attributes (listed in the full report) which have been given a blank of 'n/a' value. Other 'n/a' values are found on the Contact details. There is limited ability to specify the user in the Revit interface so only a provisional email address can be obtained.

4.4.2 Review of COBie

The main Contact, Facility, Levels and Spaces were all documented successfully. Spaces were reported with their Gross Areas in square meters. Eleven types were found (including six for non-asset types such as Pipe and Duct Segments and Fittings). About half of the non-asset Components were not assigned to Spaces. All of the asset Components were assigned to Spaces.

Asset Types and Components had a good population of common and type specific attributes.

No Zones were found, but a good selection of Systems was declared. Systems held both asset and non-asset Components.

A total of 30000 attributes were extracted. Many were internal Revit parameters that could best have been omitted. Some common Type properties were additionally reported from the Component occurrences.

5 Office Building and Medical Clinic Models

The Office Building and Medical Clinic models are successively more complex than the residential Duplex Apartment building model. This chapter documents the steps needed to complete mechanical engineering design models for these building types using the BIM software, Autodesk Revit MEP 2011. These steps include, but are not limited to, how to: link architectural and structural models to the mechanical model, set up mechanical spaces and zones, calculate heating and ventilation loads, load custom Revit families into the model, place and define equipment and systems, insert and define parameters for all equipment that is part of each mechanical model, export an IFC file of the Revit model, and transform the IFC model to COBie.

5.1 Government-furnished models download and setup

Three Office Revit models (*Office_A.rvt*, *Office_S.rvt* and *Office_MEP.rvt*) and three Clinic Revit models (*Clinic_A.rvt*, *Clinic_S.rvt* and *Clinic_MEP.rvt*) were downloaded from the ProjNet site.

In order to replicate the entire mechanical models from scratch we used the *Mechanical-Default_Metric.rte* template file. The Mechanical models were then saved as *Office_M.rvt* and *Clinic_M.rvt* with appropriate creation dates appended to the names. The architectural and structural models were linked to our new models at import position, 'Auto-Origin to Origin'.

In order to replicate the furnished models in a more efficient manner, the Families of Objects that are present in each furnished model were saved and inserted into our new mechanical models.

The government furnished Revit models served as a 'starting point' for the mechanical HVAC design process. The HVAC systems were included as part of the model but it appeared that the information associated with these systems were generic in nature and did not represent an actual design. We intend to use the Revit families from the government furnished models as the basis for our Common Object Library and will load these into our new model. Only families that are needed to complete the mechanical design will be copied and loaded into the new model.

5.2 HVAC design-phase modeling procedure

5.2.1 Pre-modeling engineering

When designing the mechanical HVAC systems for a building, the first things that need to be considered are building size, location and intended use. How big will the building be? How many floors are there? Where will the building be located? How will the building be occupied and used? The answers to all of these questions help the mechanical engineer determine what type(s) of HVAC systems will work best. At this stage in the design, major mechanical equipment items may be generically selected and sized using 'rule-of-thumb' approximations or based on past projects or previous experience. Typically, this step of the design process is not accomplished in a BIM environment. After all, it is unlikely that an architectural BIM model would be available this early in the design phase to even begin a mechanical BIM model.

5.2.2 Coordinated HVAC engineering modeling

For this modeling effort we are starting at the point of already having Architectural and Structural design models for which we are to develop a coordinated Mechanical model. So, for this project it is assumed that the HVAC systems/arrangements have been previously selected and agreed upon between all parties (owner, architect and engineers) during previous design phases (conceptual and schematic). It is our intent to mirror the HVAC systems in the government-furnished models while developing our HVAC Mechanical model.

5.2.3 Creating a new HVAC model

When Revit MEP is started, go to the Revit symbol in the upper left corner of the screen, select the dropdown, and go to the New dropdown and select Project. From here you can browse to the Mechanical-Default_Metric.rte template file. This creates a blank MEP template model, set up defaulting to metric units. The project browser will be initially set-up and will be structured to include Electrical, Mechanical and Plumbing disciplines. All work should be done in its applicable discipline. Any that are not required may be deleted. For this project only a Mechanical model is required, therefore the other two disciplines (Electrical and Plumbing) have been removed. These can be added back to the model at any time.

5.2.4 Linking the existing architectural and structural models

At the very bottom of the project browser, right click on Revit Links and select New Links. Here you browse to where the architectural and structural models have been saved, select the appropriate file(s) and before selecting Open, be sure that Auto-Origin to Origin is selected in the Positioning category (there are other options for this linked positioning and each time a model is created, this option should be coordinated with the rest of the design team). With the appropriate files selected and the correct positioning specified, clicking on Open will then display the architectural and structural model of the building. With the model displayed, click on the linked Revit files and on the Modify tab on the top of the screen, 'Pin' the link in place. This will make it impossible to move the linked model within the new Mechanical model.

5.2.5 Coordinating and matching discipline levels

When more than one discipline is working on a coordinated BIM model (in this case architectural and mechanical disciplines) it is advantageous to constantly 'monitor' the number and location of all the levels in the model. Revit can do this automatically by linking the Levels in the MEP model to the Levels that exist in the architectural model. This is done by using the Copy/Monitor command on the Collaborate tab at the top of the screen. This command is also used to create new or additional Levels that may exist in the Architectural model but do not yet exist in the Mechanical model. The levels in the Mechanical model now 'monitor' the levels in the linked architectural model. If the levels are changed, moved or altered in any way in the Architectural model and saved, these changes are automatically updated in the Mechanical model.

5.2.6 Define project settings

Before starting work on the Mechanical model, certain settings should be considered. Project Information, Parameters and Units need to be defined. This can be done under the Manage tab at the top of the screen. The Project Information, Project Parameters, Project Units and Shared Parameters menus should all be selected and completed. Thermal properties may be entered here as well under the Building Construction parameter. Project units should already be set to metric units, as that is the template we started this project with.

Project Parameters were added and defined to match the Project Parameters in the furnished model. A few of these are categorized as Project Parameters (which are specific to a Project and cannot be shared with other projects), while the majority of them are considered Shared Project Parameters. In addition, these can also be defined as Instance-Type Parameters, meaning they will require definition for each Instance of Objects in the model, or as Family-Type Parameters, meaning they only require defining for each Family Type in the model. These Shared Project Parameters were 'pulled' into our new model using the COBieSharedParameters.txt file provided with the Duplex model. Once the Parameter is selected the corresponding Categories for which that Parameter shall be available must be determined. With these Parameters now defined, each time an Object is placed in the model, if the Object Category and the Parameter Category match, then that Parameter will be available for the Object. We did find some inconsistencies between the Project Parameters in the furnished Office model and the Project Parameters available in the COBieSharedParameters.txt file (this file was furnished with the Duplex model, so perhaps these 'other' Parameters were not needed or required in the Duplex model).

The following is a list of Parameters that were included in the furnished Office model but not in the COBieSharedParameters.txt file:

- VentilationZoneName
- OccupancyZoneName
- CirculationZoneName
- ClassificationCode
- ClassificationDescription
- ConstructionType
- RoomTag
- FireAlarmZoneName
- FireRating
- HistoricPreservationZoneName
- LightingZoneName
- ModelLabel

The following 'Energy Setting' parameters were used for the Office Building model:

- Building Type: Office

- Location: Chicago, Illinois
- Building Service: Central Heating: VAV – Single Duct
- Building Infiltration Class: Medium

Some other general-type properties used for this model include the following:

- Project Issue Date: September 30, 2011
- Project Status: HVAC Design Complete
- Client Name: US Army
- Project Number: 123456789
- Category Description: OmniClass Table 11 Code

5.2.7 Placing spaces

In order for Revit to perform HVAC load calculations, spaces must be ‘placed’ and defined in the mechanical model. These spaces are not needed unless Revit will be used to perform thermal load calculations. In order to use the linked Architectural model to define these spaces, the ‘Room Bounding’ option must be checked as a Type Property of the linked model. This is done by right-clicking on the linked model, selecting Type Properties and checking the Room Bounding option. This allows the software to automatically determine the physical properties of each space (floor space, wall areas, windows, doors, etc.) based on the information in the Architectural model. To place a Space, select the Analyze tab at the top of the screen and select Space. Hover over a region in the building and click to enter to place the Space. The Space name and number can be edited by clicking on each.

5.2.8 Placing rooms

Refer to the Rooms discussion in the Duplex Model Description on why these are required for IFC exporting. Rooms are added to the Mechanical model using the Room command on the Architect tab. The Room name and numbers were defined to match the name and numbers on the Architectural model and also match Space names and numbers.

Because the Office Air-Cooler Chiller is placed outside, its location was not being assigned to a Space or a Room. Consequently, a Room was created in the Mechanical model so that the chiller’s referenced location would be carried through the transformation process from Revit to IFC to COBie. A

Revit Room was created by drawing Room Separation Lines (on the Architect tab under the Room dropdown) to define a chiller pad area. A Revit Room was then created and is referenced as Chiller Pad, S100.

5.2.9 Defining spaces and rooms

NOTE: See Lessons Learned below for more details on this topic.

With the Spaces placed in the Mechanical model, names and numbers were entered to match those in the Architectural model. The Space name and number can be edited by clicking on each. Each space that is placed can have its own properties (individual properties that relate to specific items in the model are referred to as 'instance properties'). Electrical, mechanical, thermal and occupancy properties should be defined for each Space instance. Space Types were selected to best match the intended use (based solely on the Space Name). These settings will likely be more general at the beginning stages of the design, but will evolve to reflect actual design intent at the completion of the design phase. For the Office model Spaces, the Condition Type was maintained as 'Heated and Cooled' for most Spaces. The following Spaces were specified for ventilation only, based on typical engineering practice:

- Mechanical Equipment Room(s)
- Janitor's Closet(s)
- Elevator Machine Room / Elevator Shaft

A Space was entered at the Roof level (to incorporate the 'attic' space) and was defined as an Unconditioned Space.

There are no Parameters that need to be defined for Revit Rooms, unless the Project and Shared Parameters are defined to include Rooms. For this Project several Parameters were defined as such, but have not been completed (this model is a Mechanical model only and much of the information required to complete these parameters is not known). Some examples of the Parameters are Occupancy, Department, Base Finish, Ceiling Finish, Wall Finish, Floor Finish, CeilingCovering, etc.

The Office model, therefore, has both Spaces and Rooms that on the surface seem to define the same parametric areas within the model. In a large model such as this, having duplicate information can be confusing and challenging. In addition, if the Architectural model also contains Revit

Spaces and or Rooms, this duplication is compounded. This is an issue needing resolution in the Revit IFC export procedure.

5.2.10 Defining zones

NOTE: See Lessons Learned below for more details on this topic.

Because the Mechanical system type for this Office Building is defined as a VAV – Single Duct, and due to the size and number of spaces, Zones must be entered so that the software knows which Spaces are to be served ‘together’ from a single (or multiple) VAV box. These Zones will be used in the load calculations to determine heating, cooling and air-flow requirements for all the Spaces in each Zone so that the equipment may be sized and selected appropriately. This is where Heating and Cooling Information (set-points and supply air temperatures) may be entered and specified for each Zone. These values were not changed from the default Revit values and represent typical engineering practice. They are as follows:

- Heating Information – 21.11°C (70°F) Set-point, 32.22°C (90°F) Supply Air Temperature
- Cooling Information – 23.33°C (74°F) Set-point, 12.22°C (54°F) Supply Air Temperature

It should be noted that the zoning in the new model varies slightly with the zoning as defined in the furnished models. These changes were based solely on engineering design experience and common practices.

5.2.11 Setting building construction properties for Revit loads calculations

In order to use the load calculation methods embedded in Revit to determine the required heating and cooling loads, certain information is required about how the structure will be built. What is it made of? What types of insulation are used? What are the thermal properties of walls, windows, doors and roofs? To perform load calculations within Revit, these values must be set in the Building Construction dialog box (click on Manage tab, Project Information, Edit the Energy Settings, Building Construction option). For this exercise, all default Revit values were used for these properties.

5.2.12 Calculating loads

Heating and cooling loads may now be calculated within Revit MEP. This is done by selecting the Heating and Cooling Loads option on the Analyze tab. This will display a shell of the model and will highlight all the defined spaces in the building. If a space is missing, or if there are some errors regarding any of the spaces, they will appear here. Changes to any of the Space settings can also be made through this dialog box. There is a Parameter in this dialog box called Report Type where the engineer may select a Simple, Standard or Detailed load report. Pressing the Calculate button will initiate the load calculation. A loads report will be displayed when the calculations are complete. A history of the loads reports are saved in the project and are available for review at any time (any particular report may be deleted at any time). These can be found in the Project Browser.

The heating and cooling loads may also be calculated manually as would be done in a 'non-BIM environment', or using some other loads calculation software. For the Office Building model, loads were calculated using the Revit MEP load software and serve as the basis for sizing the mechanical systems and equipment that become part of the Mechanical HVAC model.

If the Project has been organized and defined correctly, the resulting load calculations will now 'populate' the Revit Spaces and Zones accordingly. For instance, when clicking on the Space or Zone, all the calculated engineering information is available and visible.

5.2.13 Creating and using a Common Object Library (COL)

The Revit Common Object Library (COL) is a collection of Revit families. This collection exists within each project model and can be saved in a separate 'folder'. The COL can be edited through the model, or opened directly from the folder where it has been saved. If you open directly from the folder and make changes, these changes are not represented in the model until the edited family has been 'reloaded' into the project. Similarly, if you edit a family within the model, the version that exists in the 'folder' will not be up-to-date until the existing version is overwritten by the changed version in the model. The COL can be delivered either on its own or as part of a model.

For this project, since we had the government furnished model to refer to, we used the mechanical families contained in the furnished model as our

initial COL. In order to create our COL, the furnished model was opened and the library of families was navigated to. Right-clicking on a particular family in the existing library allows the engineer to 'edit the family'. This opens up the family object in its own editor and allows the user to make changes. From here, these families may be saved in their own folder creating a separate Common Object Library that can be used in other projects. The intent of creating such a Common Object Library is that it can grow over time as more family objects are defined, and can then be consistently used in future project models. The objects, or families, contained in our COL may be loaded into a project model in one of two ways.

- A family may be loaded into a model directly through the family editor. On any tab, the last option is to Load into Project. From here you can select the Project you want to load the family into. The applicable Project must be opened in Revit for this option.
- Families may also be loaded into a Project from within the Project. On the Insert tab, there is an option call Load Family. Selecting this allows the user to browse to the COL and directly load the applicable Family into the Project.

The Office Building model contains approximately eight (8) families that required loading into our new model. A list of these families can be seen in the subsequent section.

5.2.14 Placing HVAC equipment and distribution elements

With the required COL families loaded into our Mechanical model, placement of mechanical equipment, systems and accessories can begin. In order to stay consistent with the furnished model, we placed the same instances of the same families in similar locations as in the furnished model. In addition, we placed all distribution piping in similar fashion as the furnished model.

Ductwork was sized and placed to ensure coordination with the Architectural and Structural models and may deviate from the furnished model. We did place the supply and return hydronic piping from the Chiller to the air handlers in similar fashion as the furnished model (the furnished model did not have the second floor air handler connected to the hydronic piping – this was completed in our model).

For simplicity, only one Type (or model size) was used for all supply, return and exhaust air terminals. In a typical design, there would likely be various types used, but because the furnished model was provided this way the decision was made to continue this practice. In fact the only Family that has various Types in this model is the family of VAV boxes. Different zones with different airflows require smaller/larger VAV boxes in order to operate properly.

Note our discussion of issues related to Space containment (location) of equipment instances under Lessons Learned below.

5.2.15 Defining equipment type and instance properties

As described, we used the HVAC load analysis program within Revit to calculate the required heating and cooling loads, airflows, etc. for all Spaces and Zones in the model. Now this information must be 'transferred' to the equipment that serves those Spaces and Zones. For airflow requirements, this all starts at the air terminals in each Space. For example, if the load analysis determines that a Space requires 100 L/s of air to meet peak cooling requirements, and that Space has two supply air terminals and one return air terminal, the two supply air terminals must be specified for 50 L/s each and the single return air terminal for 100 L/s. As the ductwork distribution is completed, these airflows are 'carried over' to all other items and equipment upstream of the VAV boxes (the software automatically determines how much air is required in each section of ductwork and each piece of equipment based on all the items located downstream of that piece of ductwork or equipment, however, this only happens when the ductwork systems are placed and completed correctly – all end-of-duct runs must be 'capped' to avoid an open duct). This works similarly for return and exhaust systems.

With all the equipment and system types now defined in the model, defining the applicable values for all instances of each object type was required. For example, VAV boxes, air terminals, air handlers, etc. were placed in the model, but there was no 'real' data associated with any of these objects. Actual manufacturers were selected for this equipment, engineering calculations were made to size this equipment appropriately and data was entered for each Instance (where applicable) corresponding to the actual load requirements for the corresponding space, zone and/or building.

Type Parameters are those that are common to all Instances of that type that are placed within the model. These are edited by selecting a piece of equipment (e.g., a VAV box) and selecting Edit Type (this can be done on the tab at the top of the screen or by a link on the properties dialog box). This only needs to be done once for each Type of equipment. In an actual design scenario, the Type Parameters may be defined early but will likely evolve through the design process.

Instance Parameters are those that are specific to each Instance, or placement, of each object in the model. For example, there are numerous Supply Air Terminals in the Office Building model. Not all of these air terminals will have the same air flow requirement. They will not all have the same pressure drop. They will all be at different positions and may be in different rooms. Instance Parameters such as these are entered by clicking on each instance in the model and filling in the required data. Some of this information is automatically determined by the software and can usually be edited by the user to meet specific project needs. Instance Parameters are not necessarily needed until the model is near completion as this data is likely to change through the design process so there is no need to spend time on this until the end. With large projects with a vast amount of objects, saving this data entry to the end can save a significant amount of time.

5.2.16 Defining systems

Multiple air systems and several piping Systems were ‘created’ and defined in the Office Building model. These Systems do not actually exist in the Revit model (i.e., they are not created or defined) until a duct (or pipe) is run to a piece of equipment that can be associated with a system. For example, a supply air terminal that is part of the model has a single duct connector. This duct connector has a Parameter called ‘System Type’ and is defined as ‘Supply Air’. A System is thus created by selecting an instantiated air terminal and selecting Supply System at the top of the screen. This creates a ‘Supply Air System #X’ and allows the user to select all other supply air terminals that are to be part of that system (typically all the supply air terminals that serve a single zone would be selected) in addition to the VAV box that serves those air terminal.

5.2.17 Exporting to IFC

NOTE: See Lessons Learned below for more details on this topic.

Once the model is complete and all data have been entered, an IFC file can be exported. By clicking on the main Revit dropdown at the top of the screen, click Export, click Options, and click IFC Options. This opens an IFC Export Classes dialog box where definitions for how certain items in the models are mapped to an IFC exported file. An IFC mapping file titled IFC-exportlayers.txt was provided along with the government-furnished Revit models and was loaded into the project through this dialog box. After selecting Okay, proceed back to the Export option and select IFC. In the Export IFC dialog box, specify the location and name of the IFC file and the Type of File required (in this case we have used the IFC 2x3 (*.ifc) type). Click on Save and the IFC file is generated. The IFC file created for this Office Building Mechanical model was saved as Office_M_20111122.ifc.

5.2.18 Customizing Revit IFC export mappings

Revit MEP 2011 has a limited categorization of HVAC-related Types that can be mapped to IFC using the IFC mapping file approach described above. In particular only a single Mechanical Equipment category is available through the mapping file approach, forcing all Types and Instances in this category to be exported to a single IFC Type and Instance class.

In order to further customize the mapping of Revit Types and Instances to the IFC data model upon export to IFC, two so-called shared parameters must be added to each Family in the Revit COL. These parameters are named IfcExportType and IfcExportAs. Each Revit Family requires values for each of these properties that identify the most appropriate mapping to IFC from a list of Revit supported IFC classes. Table 5-1 shows the values for these parameters entered in the Office Mechanical model. See the discussion in the Lessons Learned section for more discussion on these Parameters.

See Autodesk WikiHelp (2011) for further information:

http://wikiphelp.autodesk.com/Revit/enu/2012/Help/Revit_User%27s_Guide/1394-Documents/2112-Print_Export2113/2150-Exportin2150/2151-Supporte2151

Table 5-1. Office building mechanical equipment IFC export parameters.

Revit object	IFCExportType	IFCExportAs
Supply Diffuser	Diffuser	IfcAirTerminalType
Return Diffuser	Diffuser	IfcAirTerminalType
Exhaust Register	Grille	IfcAirTerminalType
Cabinet Exhaust Fan	CentrifugalForwardCurved	IfcFanType
Rooftop Exhaust Fan	VaneAxial	IfcFanType
Air Handler	SplitSystem	IfcUnitaryEquipmentType
Chiller	AirCooled	IfcChillerType
VAV Box	VariableFlowPressureDependant	IfcAirTerminalBoxType

5.3 Mechanical and ventilation equipment and systems details

The following tables list the mechanical and ventilation equipment and systems that are present in the Office Building Revit Mechanical model.

Refer to Appendix B for tables of key HVAC properties for all example models.

Table 5-2. Office building mechanical equipment.

Air Terminals – Office Building		
Item	Revit Object Family Name	Revit Object Type
Exhaust Register	M_Exhaust Register	ER-600x600 Face 300x300 Connection
Return Diffuser	M_Return Diffuser	RR-600x600 Face 300x300 Connection
Supply Diffuser	M_Supply Diffuser	SD-600x600 Face 300x300 Connection

Mechanical Equipment – Office Building		
Item	Revit Object Family/Instance Name	Revit Object Type
Air Handler	M_Air Handling Unit – Split System - Horizontal	63300000 J
Exhaust Fan	M_Centrifugal Fan – Rooftop - Upblast	991-1905 LPS
Exhaust Fan	M_Exhaust Unit with Cabinet – Round Connection – Ceiling Mounted	47-84 LPS
Chiller	M_Screw Chiller – Air Cooled – 281-1231 kW	633-703 kW
VAV Box	M_VAV Unit – Single Duct	150 mm, 200 mm, 250 mm, 300 mm, 350 mm, 400 mm

Table 5-3. Office building piping systems.

Pipe Systems - Office Building		
Item	Revit Object Family/Instance Name	Revit Object Type
Piping System	Hydronic Supply 1	n/a
Piping System	Hydronic Return 1	n/a

Table 5-4. Office building duct systems.

Duct Systems - Office Building		
Item	Revit Object Family/Instance Name	Revit Object Type
Duct System	Supply Air *	n/a
Duct System	Return Air*	n/a
Duct System	Exhaust Air*	n/a

* More than one of these systems exists in the model. For instance, an HVAC zone contains multiple spaces but is served from a single VAV box. The air terminals connected to the VAV discharge are considered one Supply Air System. In this model, there are 31 VAV boxes scattered throughout the building. All 31 of these VAV boxes and their corresponding air terminals are assigned to different Supply Air Systems. Similarly, all VAV box inlet connections must be 'tied' to the air handling unit discharge. This also creates an independent Supply Air System. Return and Exhaust Air Systems are created in a similar fashion.

5.4 Lessons learned

5.4.1 Project, shared and IFC parameters

Early attempts were made to customize each family of Objects by adding these Parameters to each Object directly through the Family Editor, rather than through the Project and Shared Parameter dialog boxes in the model. This led to poor IFC results. It was determined through some trial and error that it was much easier and less time consuming to add these Parameters to the model (and all Objects used in the model) through the Project Parameters dialog. Contradicting this notion, it was determined that our IFC and COBie results were greatly improved when the two IFC Shared Parameters (IfcExportType and IfcExportAs) were added to each Family of Objects through the Family Editor, but not defined here. With the two IFC Parameters added to an Object, that Object should first be loaded into the Project. Once an instance of that Object is placed in the model, these Parameters should be defined using the Type Editor in the model.

5.4.2 Duplicate family type names

The IFC and COBie files can provide some misleading results if more than one Family Type has the same name. For example, in the Office model, three types of air terminals were used; M_Exhaust Register, M_Return Diffuser and M_Supply Diffuser. The Type Name for all three that were placed in the model was "600 x 600 Face 300 x 300 Connection". Because this Type Name was the same, only one Type showed up on the Type Tab on the COBie file (it appeared as though the rest of the COBie classifications were correct). When these Type Names were 'customized' to 'ER - 600 x 600 Face 300 x 300 Connection', 'RR- 600 x 600 Face 300 x 300

Connection' and 'SD - 600 x 600 Face 300 x 300 Connection' each air terminal was correctly classified as its own Type in the COBie file.

5.4.3 Incomplete furnished model

In duplicating the government-furnished Office Building model, it became apparent that there were several features missing that would typically be included in the complete HVAC design. These features are:

- No outdoor air. Code typically requires a minimum amount of outdoor air for ventilation purposes. With the type(s) of mechanical systems installed in this model, this would typically be accomplished by placing an outdoor air louver in the mechanical room exterior wall and ducting outdoor air to mix with return air at the air handler's return air plenum (or mixing box). This would also be installed in tandem with an exhaust duct and louver to control building pressurization. This was not part of the furnished model and was not added to our replicate model.
- No heating medium. While the furnished model did include an exterior, air-cooled chiller with piping run to the 1st floor air handler, there was no heating medium included with this model. The model that was downloaded did have a small, domestic-style water heater, with a small amount of piping, which was assumed to be part of an unfinished plumbing system. No heating system was added to our replicate model due to lack of available information or intent.
- No exhaust system(s). Code typically requires that restrooms are exhausted rather than have return air circulate restroom air throughout other parts of the building. No such systems were present in the furnished model for either sets of common-use restrooms on the first and second floors, or for the private-style bathroom in the Commander's Office area. A rooftop exhaust fan (similar to the exhaust fan in the Duplex Apartment model) was added to our replicate model to serve the common-style restrooms. In addition, a small, cabinet-style, ceiling-mounted exhaust fan was placed to serve the Commander's restroom. Neither of these systems existed in the furnished model.

5.4.4 IFC export with architectural and structural model binding

After some initial IFC export testing, it was determined that the best way to export the Mechanical model to IFC format was to 'bind' the linked Architectural and Structural models with the Mechanical model. Doing this creates a much larger IFC file, but the entire process runs much smoother

and the results were more encouraging than when these linked models were not bound.

5.4.5 IFC export and mechanical equipment-space containment

It was determined that the hung ceilings present in the Architectural model were creating mechanical equipment containment problems in the resulting IFC file. It appeared as though all IFC Spaces stopped at the ceiling height level, even though in Revit these Spaces were defined as extending to the bottom-of-slab of the level above. Furthermore, any Revit Object that was inserted at an elevation above the ceiling was not properly 'contained' in that Space in the IFC file. It was discovered that the 'Room Bounding' option was checked for all ceilings in the Architectural model. By definition, this would prevent any Revit Room or Space from extending above the hung ceiling elevation. The Room Bounding option must be 'unchecked' for all instances of ceilings in the Architectural model.

5.4.6 Revit rooms vs spaces and duplication across disciplines

As mentioned previously in this report, the Mechanical model was populated with both Revit Spaces and Revit Rooms. The Rooms were initially inserted directly into the model to support proper equipment location (containment) in the resulting IFC export. However, with the Architectural model 'bound' to the Mechanical model, and Revit Rooms already existing in the Architectural model, there is no need to duplicate them in the combined bound model. However, it is critical to ensure that all Rooms are defined correctly in the Architectural model before binding it to the mechanical model as discussed above.

A related question is what is to become of the Revit Spaces that were entered in the Mechanical model. Recall that Revit Spaces were required to perform the embedded Revit HVAC load analysis for the building. All heating and cooling loads, airflows, set-points, etc. are properties of these Spaces and as such should likely be included in any comprehensive BIM-export procedure.

However, both Revit Rooms and Revit Spaces export to IFC as instances of IfcSpace. We performed several trials of IFC exporting, setting both Rooms and Spaces to export as IfcSpace and the results generated duplicate IfcSpace entries in the IFC file, as expected. One IfcSpace was clearly the Revit Space and had all the HVAC load properties but no 'containment'

of other Revit Objects. The duplicate IfcSpace was a result of the Revit Room exporting as an IfcSpace and correctly 'contained' all Revit Objects that were located within that Revit Room.

For our final IFC export for this project, we did not export the Revit Spaces so as not to have duplicate IfcSpace entries in the IFC file and ultimately in the transformed COBie file. This means that the HVAC load analysis information associated with the Revit Spaces will not be available in the resulting IFC and COBie files. This is an issue that needs to be resolved by the Revit IFC export.

5.4.7 Revit zones

Revit HVAC Zones are a collection of Revit Spaces that are typically served by a single thermostat. These Zones are defined and modeled in Revit and have important mechanical properties associated with them used in calculating heating and cooling loads as discussed above. It appears that Revit does not currently support the IfcZone class for export to IFC format. We have been experimenting with several work-around procedures to have this information included, but have decided to use another IFC-compliant tool for this purpose.

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Appendix A: Duplex Apartment–Revit Family Instance Properties and Values

This Appendix lists Revit properties for each type of Object in the Duplex Apartment model. This information will not be duplicated for the other models as this information is 'built' into the Revit models themselves. This information is included here for reference only and as examples of how information is organized, entered and ultimately flows from one type of export process to another (i.e., Revit-to-IFC-to-COBie files).

The following tables include:

- Revit values entered for each Family Type (Type properties) along with the values entered for a single instance of that Family (Instance properties).
- Comments regarding each objects' Type and Instance properties
- Units of each property whether they are defined or not
- Properties of importance to HVAC Design are emphasized using ***bold italics***

Table A1. Duplex radiator family type properties.

Group	Parameter	Revit Value	Comment
Constraints	Default Elevation	0.1016	Units of meters
Mechanical Loads	<i>BtuPerFt</i>	<i>1530</i>	<i>entered based on actual data - this parameter name does not correspond with SI units</i>
Dimensions	Height	0.3556	value is based on the actual height of the Radiator
	Connector	12.5	Based on the radius of the pipe connector, in this case 12.5 millimeters
Identity Data	URL	none	User entered
	Type Comments	none	User entered
	<i>Model</i>	<i>JVB</i>	<i>User entered</i>
	<i>Manufacturer</i>	<i>Sterling</i>	<i>User entered</i>
	Keynote	15700	Heating, Ventilating, and Air Conditioning Equipment
	Description	Sloped Style FTR	User entered
	Cost	65.00	Will vary with element length, should be \$65.00/foot
	Assembly Code	D3090900	Selected from a list of Unifomat Classifications
	Assembly Description	Misc. Other HVAC Systems & Equipment	Defaults to what is selected in Assembly Code

	Type Mark	n/a	User entered
	OmniClassNumber	23.75.70.17.11	This is defined in the Family Category and Parameters - selected from a list 'OmniClass Table 23 Product Classification'
	OmniClassTitle	Radiators	Defaults to 'Radiators' based on the OmniClassNumber
IFC Parameters	IFCExportType	Radiator	User created, defined and entered
	IFCExportAs	IfcSpaceHeaterType	User created, defined and entered
Other	ModelNumber	JVB	User entered.
	ExpectedLife	5 years	
	ReplacementCost	\$30/foot	
	AssetAccountingType	FIXED	
	AccessibilityPerformance	n/a	
	CodePerformance	15700	
	Color	White	
	Constituents	n/a	
	Features	2.67 fins per inch	
	Finish	Baked Enamel	
	Grade	A	
	Material	Aluminum	
	ModelReference	JVB	
	NominalHeight	14 inches	
	NominalLength	see plans	
	NominalWidth	5-5/16"	
	ProductionYear	2011	
	Reference	Internet	
	Shape	Rectangular	
	Size	25mm	
SustainabilityPerformance	n/a		
WarrantyDescription	tbd		
WarrantyDurationLabor	tbd		
WarrantyDurationParts	tbd		
WarrantyGuarantorLabor	tbd		
WarrantyGuarantorParts	tbd		

Table A2. Duplex radiator instance properties.

Group	Parameter	Revit Value	Comment
Constraints	Host	Linked Revit Model : Duplex_A 08-29-2011.rvt	The radiator instances are placed on a wall that is part of the Architectural Revit model. As such, this entry displays the name of that linked model.
	Elevation	0.1016	Displays the elevation (+/-) that the instance is placed in reference to the Level in which it is placed. Units of meters.

Group	Parameter	Revit Value	Comment
	Offset	-0.0000	This refers to the horizontal offset, +/-, from a vertical wall, that the instance is placed.
Electrical Loads	Panel		These properties are not required for hot water Radiators.
	Circuit Number		
Mechanical	Pressure Drop	904.87 Pa	User entered based on pressure loss through the heating element, in this case through 1.0 meters of piping
	Flow	0.06 L/s	User entered based on the heating load in the space
	System Type	Hydronic Supply	These are automatically generated in Revit based on how the piping connectors are defined within the Family.
	System Name	Default Hydronic Supply (mjt)	
Mechanical - Loads	Power	5019.69	This value is calculated as = BtuPerFt * Length / 304.8. Length appears to be converted from (m) to (mm). Units appear to be (W).
Dimensions	Length	1.0000	User entered - units of meters.
Identity Data	Comments	Added unit	User entered
	Mark	Foyer B2	
Phasing	Phase Created	New Construction	
	Phase Demolished	None	
Other	Schedule Level	Level 1	
	TagNumber	Foyer B2	
	InstallationDate	Aug. 29, 2011	
	SerialNumber	123456789	
	WarrantyStartDate	Aug. 29, 2011	
	BarCode	123456789	
	AssetIdentifier	None	

Table A3. Duplex pump family type properties.

Group	Parameter	Revit Value	Comment
Materials and Finishes	Pump Material	<By Category>	Default Revit value
Electrical	Voltage	115.00 V	User entered
	Number of Poles	1	User entered
	Load Classification	Appliance - Dwelling Unit	User entered - selected from a list
Electrical - Loads	Apparent Load	542.00 VA	User entered
Dimensions	Suction Outside Radius	26.3 mm	These values are either entered directly or calculated based on an entered value. These dimensions reflect the actual size of the object placed in the Revit model. These can be changed to suit a particular manufactured item, but was not done so for this project. The values that do not specify units are in units of meters (m).
	Suction Outside Diameter	52.5 mm	
	Suction Nominal Radius	20.0 mm	

Group	Parameter	Revit Value	Comment
	Suction Nominal Diameter	40.0 mm	
	Outside Diameter 4	0.0621	
	Outside Diameter 2	0.1710	
	Outside Diameter 1	0.1840	
	Length 3	0.0621	
	Length 2	0.3448	
	Length 1	0.4310	
	Housing Width	0.1520	
	Flange Height	0.1300	
	Flange Diameter	0.1020	
	Discharge Nominal Radius	20.0 mm	
	Discharge Nominal Diameter	40.0 mm	
Identity Data	Manufacturer	TACO	User entered
	Assembly Code	D3040400	Selected from a list of Unifomat Classifications
	Keynote	15700	Heating, Ventilating, and Air Conditioning Equipment
	Model	0014	User entered
	Type Comments	Cartridge Circulator	User entered
	URL	None	User entered
	Description	Medium Flow Circulator	User entered
	Assembly Description	Hot Water Distribution	Defaults to what is selected in Assembly Code
	Type Mark	None	User entered
	Cost	300.00	User entered
	OmniClassNumber	23.60.30.21	This is defined in the Family Category and Parameters - selected from a list 'OmniClass Table 23 Product Classification'
	OmniClassTitle	Pumps	Defaults to 'Pumps' based on the OmniClassNumber
IFC Parameters	IFCExportType	Circulator	User created, defined and entered
	IFCExportAs	IfcPumpType	User created, defined and entered
Other	Radius 3	0.0564	These values are either entered directly or calculated based on an entered value. These dimensions reflect the actual size of the object placed in the Revit model. These can be changed to suit a particular manufactured item, but was not done so for this project. These values are all in units of meters (m).
	Radius 2	0.0728	
	Radius 1	0.0792	
	Outside Radius 4	0.031	
	Outside Radius 2	0.0855	

Group	Parameter	Revit Value	Comment
	Outside Radius 1	0.092	
	Length 4	0.0213	
	Flange Radius	0.051	
	ModelNumber	0014	User entered.
	ExpectedLife	10 years	
	ReplacementCost	\$300	
	AssetAccountingType	FIXED	
	AccessibilityPerformance	n/a	
	CodePerformance	15700	
	Color	Green	
	Constituents	n/a	
	Features	Compact, self-lubricating	
	Finish	Cast Iron	
	Grade	A	
	Material	Cast Iron	
	ModelReference	0014	
	NominalHeight	184 mm	
	NominalLength	165 mm	
	NominalWidth	137 mm	
	ProductionYear	2011	
	Reference	Internet	
	Shape	Odd	
	Size	0014	
	SustainabilityPerformance	n/a	
	WarrantyDescription	tbd	
	WarrantyDurationLabor	tbd	
	WarrantyDurationParts	tbd	
	WarrantyGuarantorLabor	tbd	
	WarrantyGuarantorParts	tbd	

Table A4. Duplex pump instance properties.

Group	Parameter	Revit Value	Comment
Constraints	Level	Level 2	User defined based on what Level in the model the instance is placed.
	Host	Level: Level 2	This pump is inserted in space on Level 2, it is not attached to a wall that is part of a linked file like the radiator instances.

Group	Parameter	Revit Value	Comment
	Offset	0.0886	This refers to the vertical offset, +/-, from the specified Level at which the instance is placed.
Electrical Loads	Panel		<i>This project does not include an electrical model. As such, these properties/parameters are not available and this not defined here.</i>
	Circuit Number		
Mechanical	RPM	3250.000000	<i>User entered</i>
	Flow Rate	1.0 L/S	<i>User entered - This property has been moved to this family of Pump!</i>
	System Type	Undefined, Power	These are automatically generated in Revit based on how the piping and electrical connector(s) are defined within the Family.
	System Name	Unit A Hydronic Supply In	
Identity Data	Comments	Unit A Circ Pump	User entered
	Mark	P1A	
Phasing	Phase Created	New Construction	
	Phase Demolished	None	
Other	TagNumber	P1A	
	InstallationDate	Aug. 29, 2011	
	SerialNumber	123456789	
	WarrantyStartDate	Aug. 29, 2011	
	BarCode	123456789	
	AssetIdentifier	None	

Table A5. Duplex boiler family type properties.

Group	Parameter	Revit Value	Comment
Materials and Finishes	Boiler Material	<By Category>	Default Revit value
Electrical	Voltage	208.00 V	<i>User entered</i>
	Number of Poles	3	<i>User entered</i>
	Load Classification	Heating	User entered - selected from a list
Electrical - Loads	Apparent Load	146000.00 VA	<i>User entered</i>
Dimensions	Vent Radius	125.00	These values are either entered directly or calculated based on an entered value. These dimensions reflect the actual size of the object placed in the Revit model. These can be changed to suit a particular manufactured item, but was not done so for this project. The values that do not specify units are in units of meters (m).
	Vent Diameter	250.00	
	Vent Box Height	0.1020	
	Vent Box Diameter	0.2540	
	Hot Water Radius	20.0 mm	
	Hot Water Diameter	40.0 mm	
	Gas Radius	12.5 mm	
	Gas Diameter	25.0 mm	
	Electrical Box Width	0.0940	
	Electrical Box Length	0.2030	
	Electrical Box Height	0.2030	

Group	Parameter	Revit Value	Comment
	Cold Water Radius	20.0 mm	
	Cold Water Diameter	40.0 mm	
	Boiler Top Diameter	0.5600	
	Boiler Height	0.9650	
	Boiler Diameter	0.6100	
Identity Data	URL	n/a	User entered
	Type Comments	none	User entered
	Model	Ultra 155	User entered
	Manufacturer	Weil-McLain	User entered
	Keynote	15500	Heat-Generation Equipment
	Description	Condensing Gas Boiler	User entered
	Cost	4000.00	User entered
	Assembly Code	D3020100	Selected from a list of Unifomat Classifications
	Assembly Description	Boilers	Defaults to what is selected in Assembly Code
	Type Mark	none	User entered
	OmniClassNumber	23.75.10.11.14	This is defined in the Family Category and Parameters - selected from a list 'OmniClass Table 23 Product Classification'
	OmniClassTitle	Hot Water Heat Generators	Defaults to 'Hot Water Heat Generators' based on the OmniClassNumber
IFC Parameters	IFCExportType	Water	User created, defined and entered
	IFCExportAs	lfcBoilerType	User created, defined and entered
Other	Vent Box Radius	0.1270	These values are either entered directly or calculated based on an entered value. These dimensions reflect the actual size of the object placed in the Revit model. These can be changed to suit a particular manufactured item, but was not done so for this project. These values are all in units of meters (m).
	Radius 1	0.2288	
	Boiler Top Radius	0.2800	
	Boiler Radius	0.3050	
	Model Number	Ultra 155	User Entered
	ExpectedLife	20 years	
	ReplacementCost	\$4,000	
	AssetAccountingType	FIXED	
	AccessibilityPerformance	n/a	

Group	Parameter	Revit Value	Comment
	CodePerformance	15500	
	Color	White	
	Constituents	n/a	
	Features	Cast Aluminum Block	
	Finish	Shell	
	Grade	A	
	Material	Various	
	ModelReference	Ultra 155	
	NominalHeight	1092 mm	
	NominalLength	584 mm	
	NominalWidth	559 mm	
	ProductionYear	2011	
	Reference	Internet	
	Shape	Rectangular	
	Size	155	
	SustainabilityPerformance	n/a	
	WarrantyDescription	tbd	
	WarrantyDurationLabor	tbd	
	WarrantyDurationParts	tbd	
WarrantyGuarantorLabor	tbd		
WarrantyGuarantorParts	tbd		

Table A6. Duplex boiler instance properties.

Group	Parameter	Revit Value	Comment
Constraints	Level	Level 2	User defined based on what Level in the model the instance is placed.
	Host	Level: Level 2	This pump is inserted in space on Level 2, it is not attached to a wall that is part of a linked file like the radiator instances.
	Offset	0.0190	This refers to the vertical offset, +/-, from the specified Level at which the instance is placed.
Electrical Loads	Panel		<i>This project does not include an electrical model. As such, these properties/parameters are not available and this not defined here.</i>
	Circuit Number	<unnamed>	
Mechanical	Water Pressure Drop	13800.00 Pa	<i>User entered, units of Pascals</i>

Group	Parameter	Revit Value	Comment
	Water Flow	0.72 L/s	User entered, units of L/s
	Output Heat	32210.00	User entered, should default to units of W
	Input Heat	45400.00 W	User entered, units of W
	Gas Flow	0.44 L/s	User entered, data is approximate
	Exhaust Air Pressure Drop	1700.00 Pa	User entered, data is approximate
	Exhaust Air Flow	4.00 L/s	User entered, data is approximate
	System Type	Hydronic Supply, Hydronic Return, Other, Power, Exhaust Air	These are automatically generated in Revit based on how the piping and electrical connector(s) are defined within the Family.
	System Name	Unit A Hydronic Supply In, Unit A Hydronic Return, Unit A Natural Gas, Unit A Mechanical Exhaust Air	
Identity Data	Comments	Gas and Exhaust flow data is approximate	User entered
	Mark	B 1A	
Phasing	Phase Created	New Construction	
	Phase Demolished	None	
Other	TagNumber	B 1A	
	InstallationDate	Aug. 29, 2011	
	SerialNumber	123456789	
	WarrantyStartDate	Aug. 29, 2011	
	BarCode	123456789	
	AssetIdentifier	None	

Table A7. Duplex fan family type properties.

Group	Parameter	Revit Value	Comment
Constraints	Default Elevation	1.2000	
Materials and Finishes	Fan Material	<By Category>	Default Revit value
Electrical	Voltage	208.00 V	User entered
	Load Classification	HVAC	User entered - selected from a list
	Number of Poles	3	User entered
Electrical - Loads	Apparent Load	480.00 VA	User entered
Mechanical	RPM	1050.000000	User entered
Dimensions	Overall Height	0.3000	These values are either entered di-

Group	Parameter	Revit Value	Comment
	Fan Radius	0.2000	rectly or calculated based on an entered value. These dimensions reflect the actual size of the object placed in the Revit model. These can be changed to suit a particular manufactured item, but was not done so for this project. All values are in units of meters (m) except for the Outlet Width and Outlet Height, which are in units of millimeters (mm).
	Fan Height	0.2000	
	Fan Diameter	0.4000	
	Outlet Width	250.0	
	Outlet Height	250.0	
	Cap Radius	0.1400	
	Cap Diameter	0.2800	
	Base Width	0.4000	
Identity Data	Manufacturer	Greenheck	User entered
	Assembly Code	D3040200	Selected from a list of Unifomat Classifications
	Keynote	15700	Heating, Ventilating, and Air Conditioning Equipment
	Model	CUE 060-E	User entered
	Type Comments	Direct Drive	User entered
	URL	n/a	User entered
	Description	Rooftop Upblast Fan	User entered
	Assembly Description	Exhaust Ventilation System	Defaults to what is selected in Assembly Code
	Type Mark	none	User entered
	Cost	1500.00	User entered
	OmniClassNumber	23.75.35.17.27	This is defined in the Family Category and Parameters - selected from a list 'OmniClass Table 23 Product Classification'
	OmniClassTitle	Centrifugal Fans	Defaults to 'Centrifugal Fans' based on the OmniClassNumber
IFC Parameters	IFCExportType	VaneAxial	User created, defined and entered
	IFCExportAs	IfcFanType	User created, defined and entered
Other	Radius 1	0.1500	These values are either entered directly or calculated based on an entered value. These dimensions reflect the actual size of the object placed in the Revit model. These can be changed to suit a particular manufactured item, but was not done so for this project. These values are all in units of meters (m).
	Radius 2	0.1600	
	Half Outlet Radius	0.1250	
	Half Exhaust Inlet Height	0.1250	
	Diameter 2	0.3200	
	Diameter 1	0.3000	
	ModelNumber	CUE 060-E	User entered
	ExpectedLife	10 years	
	ReplacementCost	\$1,500	
	AssetAccountingType	FIXED	
	AccessibilityPerformance	n/a	
	CodePerformance	15700	
	Color	Grey	
	Constituents	n/a	
Features	Backdraft Damper		
Finish	Milled		

Group	Parameter	Revit Value	Comment
	Grade	A	
	Material	Aluminum	
	ModelReference	CUE 060-E	
	NominalHeight	387 mm	
	NominalLength	467 mm	
	NominalWidth	467 mm	
	ProductionYear	2011	
	Reference	Internet	
	Shape	Odd	
	Size	060-E	
	SustainabilityPerformance	n/a	
	WarrantyDescription	tbd	
	WarrantyDurationLabor	tbd	
	WarrantyDurationParts	tbd	
	WarrantyGuarantorLabor	tbd	
WarrantyGuarantorParts	tbd		

Table A8. Duplex fan instance properties.

Group	Parameter	Revit Value	Comment
Constraints	Host	Linked Revit Model : Duplex_A 08-29-2011.rvt	The fan instances are placed on the Roof that is part of the Architectural Revit model. As such, this entry displays the name of that linked model.
	Elevation	0.4570	This refers to the vertical offset, +/-, from the specified Level at which the instance is placed.
Electrical Loads	Panel		This project does not include an electrical model. As such, these properties/parameters are not available and this not defined here.
	Circuit Number	<unnamed>	
Mechanical	External Static Pressure	30.00 Pa	User entered, units of Pascals
	System Type	Exhaust Air, Power	These are automatically generated in Revit based on how the piping and electrical connector(s) are defined within the Family.
	System Name	Unit B Mechanical Exhaust Air	
Mechanical - Air-flow	Air Flow	38.00 L/s	User entered, units of L/s
Identity Data	Comments	Boiler Exhaust Fan	User entered
	Mark	F 1B	
Phasing	Phase Created	New Construction	
	Phase Demolished	None	
Other	Schedule Level	Roof	
	TagNumber	F 1B	
	InstallationDate	Aug. 29, 2011	
	SerialNumber	123456789	
	WarrantyStartDate	Aug. 29, 2011	

Group	Parameter	Revit Value	Comment
	BarCode	123456789	
	AssetIdentifier	None	

Table A9. Duplex valve family type properties.

Group	Parameter	Revit Value	Comment
Materials and Finishes	Valve Material	<By Category>	Default Revit value
Mechanical	Loss Method	Not Defined	User entered
	K Coefficient Table	Ball Valve Full Port Full Open	User entered - selected from a list
	K Coefficient	0.350000	User entered
Dimensions	Stem Radius	0.0050	These values are either entered directly or calculated based on an entered value. These dimensions reflect the actual size of the object placed in the Revit model. These can be changed to suit a particular manufactured item, but was not done so for this project. The values that do not specify units are in unit of meters (m).
	Stem Height	0.0275	
	Stem Diameter	0.0100	
	Seal Length	0.0445	
	Nut Radius	0.0075	
	Nut Height	0.0165	
	Nut Diameter	0.0150	
	Nominal Radius	20.0 mm	
	Nominal Diameter	50.0 mm	
	Handle Width	0.0250	
	Handle Length	0.1270	
	Handle Height	0.2290	
	Body Radius	0.0275	
	Body Length	0.1780	
	Body Height	0.0715	
	Body Diameter	0.0550	
Adapter Radius	0.0400		
Adapter Length	0.0178		
Adapted Diameter	0.0800		
Identity Data	URL	n/a	User entered
	Type Comments	Solder End Bronze Valve	User entered
	Model	32-208	User entered
	Manufacturer	Apollo	User entered
	Keynote	15200	Process Piping
	Description	Solder End Bronze Valve	User entered
	Cost	50.00	User entered
	Assembly Code	D3040400	Selected from a list of Unifomat Classifications
	Assembly Description	Hot Water Distribution	Defaults to what is selected in Assembly Code

Group	Parameter	Revit Value	Comment
	Type Mark	none	User entered
	OmniClassNumber	23.65.55.14.17	This is defined in the Family Category and Parameters - selected from a list 'OmniClass Table 23 Product Classification'
	OmniClassTitle	Adjusting/Controlling Valves for Liquid Services	Defaults to 'Adjusting/Controlling Valves for Liquid Services' based on the OmniClassNumber
IFC Parameters	IFCExportType	Isolating	User created, defined and entered
	IFCExportAs	IfcValveType	User created, defined and entered
Other	Radius	0.0920	These values are either entered directly or calculated based on an entered value. These dimensions reflect the actual size of the object placed in the Revit model. These can be changed to suit a particular manufactured item, but was not done so for this project. These values are all in units of meters (m).
	Length 2	0.0445	
	Length 1	0.1424	
	Half Nut Height	0.0083	User entered
	ModelNumber	32-208	
	ExpectedLife	20 years	
	ReplacementCost	\$50	
	AssetAccountingType	FIXED	
	AccessibilityPerformance	n/a	
	CodePerformance	15200	
	Color	Bronze	
	Constituents	n/a	
	Features	Chromium Plated Ball	
	Finish	Bronze Body	
	Grade	A	
	Material	Bronze	
	ModelReference	32-208	
	NominalHeight	89 mm	
	NominalLength	165 mm	
	NominalWidth	63.5 mm	
	ProductionYear	2011	
Reference	Internet		
Shape	Odd		
Size	50 mm		
SustainabilityPerformance	n/a		
WarrantyDescription	tbd		

Group	Parameter	Revit Value	Comment
	WarrantyDurationLabor	tbd	
	WarrantyDurationParts	tbd	
	WarrantyGuarantorLabor	tbd	
	WarrantyGuarantorParts	tbd	

Table A10. Duplex valve instance properties.

Group	Parameter	Revit Value	Comment
Constraints	Level	Level 2	User defined based on what Level in the model the instance is placed.
	Host	Level: Level 2	This valve is inserted in space on Level 2, it is not attached to a wall that is part of a linked file like the radiator instances.
	Offset	-0.0820	This refers to the vertical offset, +/-, from the specified Level at which the instance is placed.
Graphics	Use Annotation Scale	√	User can check or uncheck this box
Mechanical	System Type	Hydronic Supply	These are automatically generated in Revit based on how the piping and electrical connector(s) are defined within the Family.
	System Name	Unit B Hydronic Supply In	
	Loss Method	K Coefficient from Table	User entered - selected from a pulldown menu
	<i>K Coefficient Table</i>	<i>Ball Valve Full Port Open</i>	<i>User entered - selected from a pulldown menu</i>
	<i>K Coefficient</i>		<i>Greyed out - cannot edit - Apparently this is not related to the same parameters listed under the Family Type Properties</i>
Dimensions	Size	50 mmØ-50 mmØ	Greyed out - cannot change
Identity Data	Comments	Inline Ball Valve	User entered
	Mark	V B1	
Phasing	Phase Created	New Construction	
	Phase Demolished	None	
Other	TagNumber	V B1	
	InstallationDate	Aug. 29, 2011	
	SerialNumber	123456789	
	WarrantyStartDate	Aug. 29, 2011	
	BarCode	123456789	
	AssetIdentifier	None	

Appendix B: Key HVAC Properties of Mechanical Equipment

The following tables represent the properties present within the example models and common object library that are of specific interest to HVAC modeling for all mechanical equipment. Most of the properties are default Revit properties. If a property was added to a family as part of this project, it has been noted.

Family Type Properties			
Family: M_Radiator - Hosted			
Type: 25			
Group	Parameter	Revit Value	Comment
Mechanical Loads	BtuPerFt	1530	Entered based on actual data - this parameter name does not correspond with SI units.
	Model	JVB	User entered
Identity Data	Manufacturer	Sterling	User entered
	Cost	65.00	Will vary with element length, should be \$65.00/foot
Instance Type Properties			
Family: M_Radiator - Hosted			
Type: 25			
Group	Parameter	Revit Value	Comment
Electrical Loads	Panel		These properties are not required for hot water Radiators.
	Circuit Number		
Mechanical	Pressure Drop	904.87 Pa	User entered based on pressure loss through the heating element, in this case through 1.0 meter of pipe
	Flow	0.06 L/s	User entered based on the heating load and temperature difference in the space
Mechanical - Loads	Power	5019.69	This value is calculated as = BtuPerFt * Length / 304.8. Length appears to be converted from (m) to (mm). Units appear to be (W).
Dimensions	Length	1.0000	User entered - units of meters.
Family Type Properties			
Family: M_Inline Pump - Circulator			
Type: 3.9 LPS - 0.8 Meter Head			
Group	Parameter	Revit Value	Comment
Electrical	Voltage	115.00 V	User entered
	Number of Poles	1	User entered
Electrical - Loads	Apparent Load	542.00 VA	User entered
Dimensions	Suction Nominal Radius	20.0 mm	
	Suction Nominal Diameter	40.0 mm	
	Discharge Nominal Radius	20.0 mm	
	Discharge Nominal Diameter	40.0 mm	
Identity Data	Manufacturer	TACO	User entered
	Model	0014	User entered
	Cost	300.00	User entered
Instance Type Properties			
Family: M_Inline Pump - Circulator			
Type: 3.9 LPS - 0.8 Meter Head			
Group	Parameter	Revit Value	Comment
Electrical Loads	Panel		
	Circuit Number		
Mechanical	RPM	3250.000000	User entered
	Flow Rate	1.0 L/S	Custom Parameter - User Entered

Family Type Properties			
Family: M_Hot Water Boiler - 59-440 kW			
Type: 147 kW			
Group	Parameter	Revit Value	Comment
Electrical	Voltage	208.00 V	User entered
	Number of Poles	3	User entered
Electrical - Loads	Apparent Load	146000.00 VA	User entered
Dimensions	Vent Radius	125.00	These values are either entered directly or calculated based on an entered value. These dimensions reflect the actual size of the object placed in the Revit model. These can be changed to suit a particular manufactured item, but was not done so for this project. The values that do not specify units are in units of meters (m).
	Vent Diameter	250.00	
	Hot Water Diameter	40.0 mm	
	Gas Radius	12.5 mm	
	Gas Diameter	25.0 mm	
	Cold Water Radius	20.0 mm	
	Cold Water Diameter	40.0 mm	
	Boiler Height	0.9650	
Identity Data	Boiler Diameter	0.6100	
	Model	Ultra 155	User entered
	Manufacturer	Weil-McLain	User entered
	Cost	4000.00	User entered
Instance Type Properties			
Family: M_Hot Water Boiler - 59-440 kW			
Type: 147 kW			
Group	Parameter	Revit Value	Comment
Electrical Loads	Panel		This project does not include an electrical model. As such, these properties/parameters are not available and this not defined here.
	Circuit Number	<unnamed>	
Mechanical	Water Pressure Drop	13800.00 Pa	User entered, units of Pascals
	Water Flow	0.72 L/s	User entered, units of L/s
	Output Heat	32210.00	User entered, should default to units of W
	Input Heat	45400.00 W	User entered, units of W
	Gas Flow	0.44 L/s	User entered, data is approximate
	Exhaust Air Pressure Drop	1700.00 Pa	User entered, data is approximate
	Exhaust Air Flow	4.00 L/s	User entered, data is approximate
Family Type Properties			
Family: M_Centrifugal Fan - Rooftop - Upblast			
Type: 991-1905 LPS			
Group	Parameter	Revit Value	Comment
Electrical	Voltage	208.00 V	User entered
	Number of Poles	3	User entered
Electrical - Loads	Apparent Load	480.00 VA	User entered
Mechanical	RPM	1050.000000	User entered
Dimensions	Fan Radius	0.2000	
	Fan Diameter	0.4000	
Identity Data	Manufacturer	Greenheck	User entered
	Model	CUE 060-E	User entered
	Cost	1500.00	User entered
Instance Type Properties			
Family: M_Centrifugal Fan - Rooftop - Upblast			
Type: 991-1905 LPS			
Group	Parameter	Revit Value	Comment
Electrical Loads	Panel		This project does not include an electrical model. As such, these properties/parameters are not available and this not defined here.
	Circuit Number	<unnamed>	
Mechanical	External Static Pressure	30.00 Pa	User entered, units of Pascals
Mechanical - Airflow	Air Flow	38.00 L/s	User entered, units of L/s

Family Type Properties			
Family: M_Ball Valve - 50-150 mm			
Type: 50 mm			
Group	Parameter	Revit Value	Comment
Mechanical	K Coefficient Table	Ball Valve Full Port Full Open	User entered - selected from a list
	K Coefficient	0.350000	User entered
Dimensions	Nominal Radius	20.0 mm	
	Nominal Diameter	50.0 mm	
Identity Data	Model	32-208	User entered
	Manufacturer	Apollo	User entered
	Cost	50.00	User entered
Instance Type Properties			
Family: M_Ball Valve - 50-150 mm			
Type: 50 mm			
Group	Parameter	Revit Value	Comment
Mechanical	K Coefficient Table	Ball Valve Full Port Open	User entered - selected from a pulldown menu
	K Coefficient		Greyed out - cannot edit - Apparently this is not related to the same parameters listed under the Family Type Properties
Family Type Properties			
Family: M_Backflow Preventer_DCW to Hydronic Supply_15-50mm_			
Type: 25 mm			
Group	Parameter	Revit Value	Comment
Mechanical	K Coefficient Table	Swing Check Valve Threaded	User entered - selected from a list
	K Coefficient		User entered
Dimensions	Nominal Radius	12.5 mm	
	Nominal Diameter	25.0 mm	
Identity Data	Model	DCLF40	User entered
	Manufacturer	Apollo	User entered
	Cost	150.00	User entered
Instance Type Properties			
Family: M_Backflow Preventer_DCW to Hydronic Supply_15-50mm_			
Type: 25 mm			
Group	Parameter	Revit Value	Comment
Mechanical	Pressure Drop	6900.00 Pa	User entered, units of Pascals
	Loss Method	K Coefficient from Table	User entered - selected from a pulldown menu
	K Coefficient Table	Swing Check Valve Threaded	User entered - selected from a pulldown menu
	K Coefficient		Greyed out - cannot edit - Apparently this is not related to the same parameters listed under the Family Type Properties
Family Type Properties			
Family: M_VAV Unit - Single Duct			
Type: 250 mm			
Group	Parameter	Revit Value	Comment
Dimensions	Overall Length	0.3050 m	User entered
	Supply Air Outlet Width	350.0 mm	
	Supply Air Outlet Height	300.0 mm	
	Supply Air Inlet Radius	125.0 mm	
	Supply Air Inlet Diameter	250.0 mm	
Identity Data	Manufacturer	Tuttle & Bailey	User entered
	Model	SDV 10	User entered
	Cost	550	User entered
Instance Type Properties			
Family: M_VAV Unit - Single Duct			
Type: 250 mm			
Group	Parameter	Revit Value	Comment
Electrical - Loads	Panel		No electrical on this project, typically would be assigned a panel.
	Circuit Number		No electrical on this project, typically would be assigned a circuit.
Mechanical	Supply Air Pressure	0.00250 kPa	User Entered
	System Type	Supply Air	default
	System Name	Mechanical Supply Air 16, Mechanical Supply Air 1	These get assigned when creating the System(s), the names are customizable.
Mechanical - Airflow	Air Flow	508.409 L/s	User entered, set to airflow required for space heating/cooling.
Identity Data	Comments		User entered
	Mark	Z2	User entered - must be unique

Family Type Properties			
Family: M_Supply Diffuser			
Type: SD - 600 x 600 Face 300 x 300 Connection			
Group	Parameter	Revit Value	Comment
Mechanical - Airflow	Max Flow	330.00 L/s	User entered
	Min Flow	0.000 L/s	User entered
Dimensions	Duct Width	300.0 mm	User entered
	Duct Height	300.0 mm	
	Diffuser Width	0.6000 m	
	Diffuser Height	0.6000 m	
Identity Data	Manufacturer	MetalAire	User entered
	Model	DCD 5000-6	User entered
	Cost	80.00	User entered
	Description	Aluminum, T-Bar, Directional Ceiling Diffuser	User entered
Instance Type Properties			
Family: M_Supply Diffuser			
Type: SD - 600 x 600 Face 300 x 300 Connection			
Group	Parameter	Revit Value	Comment
Mechanical - Airflow	Pressure Drop	0.01400 kPa	User entered
	Flow	235.00 L/s	User entered
Identity Data	Comments		User entered
	Mark	9	User entered - must be unique

Family Type Properties			
Family: M_Return Diffuser			
Type: RR - 600 x 600 Face 300 x 300 Connection			
Group	Parameter	Revit Value	Comment
Mechanical - Airflow	Max Flow	330.00 L/s	User entered
	Min Flow	0.000 L/s	User entered
Dimensions	Duct Width	300.0 mm	User entered
	Duct Height	300.0 mm	
	Diffuser Width	0.6000 m	
	Diffuser Height	0.6000 m	
Identity Data	Manufacturer	MetalAire	User entered
	Model	7550R-6	User entered
	Cost	80.00	User entered
	Description	Lay-In, T-Bar Return Register	User entered

Instance Type Properties			
Family: M_Return Diffuser			
Type: RR - 600 x 600 Face 300 x 300 Connection			
Group	Parameter	Revit Value	Comment
Mechanical - Airflow	Pressure Drop	0.01400 kPa	User entered
	Flow	126.60 L/s	User entered
Identity Data	Comments		User entered
	Mark	17	User entered - must be unique

Family Type Properties			
Family: M_Exhaust Register			
Type: ER - 600 x 600 Face 300 x 300 Connection			
Group	Parameter	Revit Value	Comment
Mechanical - Airflow	Max Flow	330.00 L/s	User entered
	Min Flow	0.000 L/s	User entered
Dimensions	Duct Width	300.0 mm	User entered
	Duct Height	300.0 mm	
	Diffuser Width	0.6000 m	
	Diffuser Height	0.6000 m	
Identity Data	Manufacturer	MetalAire	User entered
	Model	7550R-6	User entered
	Cost	80.00	User entered
	Description	Lay-In T-Bar, Exhaust Register	User entered

Instance Type Properties			
Family: M_Exhaust Register			
Type: ER - 600 x 600 Face 300 x 300 Connection			
Group	Parameter	Revit Value	Comment
Mechanical - Airflow	Pressure Drop	0.01400 kPa	User entered
	Flow	71.000 L/s	User entered
Identity Data	Comments		User entered
	Mark	73	User entered - must be unique

Family Type Properties			
Family: M_Screw Chiller - Air Cooled - 281-1231 kW			
Type: 633-703 kW			
Group	Parameter	Revit Value	Comment
Electrical	Voltage	208.00 V	User entered
	Load Classification	Cooling	User entered
	Number of Poles	3	User entered
Dimensions	Chilled Water Supply Radius	75.0	These dimensions reflect the actual size of the object placed in the Revit model. These can be changed to suit a particular manufactured item, but was not done so for this project. The values that do not specify units are in units of meters (m).
	Chilled Water Supply Diameter	150.00	
	Chilled Water Return Radius	74.6	
	Chilled Water Return Diameter	149.2	
	Chiller Length	7.1680 m	
Identity Data	Manufacturer	Ultra 155	User entered
	Model	Weil-Mclain	User entered
	Cost	4000.00	User entered
Other	Number of Fans	12	User entered
	NominalHeight	2.375m	User entered
	NominalLength	5.715m	User entered
	NominalWidth	2.25m	User entered

Instance Type Properties			
Family: M_Screw Chiller - Air Cooled - 281-1231 kW			
Type: 633-703 kW			
Group	Parameter	Revit Value	Comment
Electrical Loads	Apparent Load	217200.00 VA	User entered
	Panel		This project does not include an electrical model. As such, these properties/parameters are not available.
	Circuit Number		
Mechanical	Chilled Water Pressure Drop	46.05700 kPa	User entered
	Drain Flow	0.000	This is a plumbing property, not defined here.
	Chilled Water Flow	29.000 L/s	User entered, should match the chilled water flow for the building
	Cold Capacity	681672.00 W	User entered
Identity Data	Comments		User entered
	Mark	CH-1	User entered, must be unique

Family Type Properties			
Family: M_Centrifugal Fan - Rooftop - Upblast			
Type: 991-1905 LPS			
Group	Parameter	Revit Value	Comment
Electrical	Voltage	208.00 V	User entered
	Number of Poles	3	User entered
Electrical - Loads	Apparent Load	480.00 VA	User entered
Mechanical	RPM	1050.000000	User entered
Dimensions	Fan Radius	0.2000	
	Fan Diameter	0.4000	
Identity Data	Manufacturer	Greenheck	User entered
	Model	CUBE 141HP-7	User entered
	Cost	1500.00	User entered

Instance Type Properties			
Family: M_Centrifugal Fan - Rooftop - Upblast			
Type: 991-1905 LPS			
Group	Parameter	Revit Value	Comment
Electrical Loads	Panel		This project does not include an electrical model. As such, these properties/parameters are not available and this not defined here.
	Circuit Number		
Mechanical	External Static Pressure	10.30000 kPa	User entered
Mechanical - Airflow	Air Flow	570.00 L/s	User entered, should match the exhaust flow from the building
Identity Data	Comments		User entered
	Mark	EF-1	User entered, must be unique

Family Type Properties			
Family: M_ Exhaust Unit with Cabinet - Round Connection - Ceiling Mounted			
Type: 47-84 LPS			
Group	Parameter	Revit Value	Comment
Electrical	Voltage	120.00 V	User entered
	Number of Poles	1	User entered
Dimensions	Fan Width	0.3110 m	User entered
	Fan Length	0.3110 m	
	Fan Height	0.3000 m	
	Duct Radius	75.0 mm	
	Duct Diameter	150.0 mm	
	Diffuser Width	0.3560 m	
Identity Data	Diffuser Length	0.3560 m	User entered
	Manufacturer	Panasonic	
	Model	FV-13-VKM3	
	Cost	150.00	User entered

Instance Type Properties			
Family: M_ Exhaust Unit with Cabinet - Round Connection - Ceiling Mounted			
Type: 47-84 LPS			
Group	Parameter	Revit Value	Comment
Electrical Loads	Panel		This project does not include an electrical model. As such, these properties/parameters are not available and this not defined here.
	Circuit Number		
Mechanical	External Static Pressure	0.00000 kPa	User entered
Mechanical - Airflow	Air Flow	10.000 L/s	User entered, should match the exhaust flow from the room
Identity Data	Comments		User entered
	Mark	EF-2	User entered, must be unique

Family Type Properties			
Family: M_Air Handling Unit - Split System - Horizontal			
Type: 63300000 J			
Group	Parameter	Revit Value	Comment
Electrical	Voltage	208.00 V	User entered
	Number of Poles	3	
Electrical - Loads	Apparent Load	1040.00 VA	User entered
Dimensions	Width	2.5000 m	User entered, values without units are in (mm)
	Length	4.5000 m	
	Height	1.8000 m	
	Condensate Radius	10.0	
	Condensate Diameter	20.0	
Identity Data	Manufacturer	Carrier	User entered
	Model	39MN-17	User entered
	Description	Split System Air Handler	User entered
	Cost	10000.00	User entered

Instance Type Properties			
Family: M_Air Handling Unit - Split System - Horizontal			
Type: 63300000 J			
Group	Parameter	Revit Value	Comment
Electrical Loads	Panel		This project does not include an electrical model. As such, these properties/parameters are not available and this not defined here.
	Circuit Number		
Mechanical	External Static Pressure	17.24000 kPa	User entered
Mechanical - Airflow	Supply Airflow	4253.909 L/s	Revit calculated based on total connected cfm
	Return Airflow	3917.709 L/s	Revit calculated based on total connected cfm
Identity Data	Comments		User entered
	Mark	AHU-1	User entered, must be unique

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14. ABSTRACT <p>The development of an open ontology for the design phase of typical heating, ventilating, and air conditioning (HVAC) systems was documented in ERDC-CERL Contract Report CR-12-2 (March 2012). It was developed following Information Delivery Manual (IDM) and Model View Definition (MVD) procedures defined by the International Organization for Standardization (ISO) and the buildingSMART Alliance. The purpose of the work was to promote consistency and quality of content created for Building Information Models (BIMs) across various disciplines.</p> <p>The HVAC MVD was tested in a separate task, as documented in this report, through its implementation in three example BIMs based on experimental architectural models provided by ERDC-CERL. HVAC equipment and systems were added to those architectural models using a commercial off-the-shelf (COTS) modeling package. Industry Foundation Class (IFC) models were then generated using the software's IFC export function and reviewed for compliance with the reference HVAC MVD.</p>					
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