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Development Center

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

Model View Definition

Hitchcock Consulting

*6049 Shoo Fly Road
Kelsey, CA 95667*

March 2012

Prepared under Contract W912HZ-09-D-0003 (0761)
under the supervision of

E. William East, Project Manager (CEERD-CF-N)

*Construction Engineering Research Laboratory
US Army Engineer Research and Development Center
2902 Newmark Drive
Champaign, IL 61822*

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Robert J. Hitchcock

*Hitchcock Consulting
6049 Shoo Fly Road
Kelsey, CA 95667*

Nicholas Nisbet

*AEC3 UK Ltd
46 St Margaret's Grove
Great Kingshill, High Wycombe, Bucks, HP15 6HP, UK*

Christopher Wilkins and Matthew Tanis

*Hallam ICS
38 Eastwood Dr., Suite 200
South Burlington, VT 05403*

Reijo Hänninen and Tuomas Laine

*Olof Granlund Oy
Malminkaari 21
Helsinki, Finland FIN-00701*

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Abstract

In previous work, building information models (BIMs) were developed for three buildings: Duplex Apartment, Office, and Clinic. However, the models were developed inconsistently and contain differing levels of detail and quality of content across disciplines. One reason for these differences was the lack of an ontology that describes the specific requirements for life-cycle modeling for the heating, ventilating, and air conditioning (HVAC) domain. The objective of the work described here was to develop an ontology for the design phase of typical HVAC systems found in low-rise Army facilities.

This report documents the process modeling and data-exchange requirements of HVAC engineering design practice, following Information Delivery Manual (IDM) and Model View Definition (MVD) procedures defined by the International Organization for Standardization (ISO) and the buildingSMART Alliance.

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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 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.

Life-cycle information exchanges have previously been identified in the structural steel domain—an analysis model, a design model, and a detailed model. The analysis model reflects the needs of structural engineers to evaluate the requirements of the building and size the system to meet the facility's requirements. The design model shows sufficient detail to allow construction contractors to bid. The detailed model provides fabrication and erection details required to physically construct and connect the system. A life-cycle model for HVAC systems includes a similar phased set of information needed to effectively support activities over the facility life cycle.

Traditional Army HVAC systems include four major subsystems. The first is the circulation of a thermal fluid, typically water that is heated or cooled, depending on the season. The second is the set of equipment needed to transfer energy from the thermal fluid to a thermal transfer fluid, typically air. The third subsystem is the transport mechanism for the thermal transfer fluid. This thermal transfer fluid is circulated by pressure differentials in the case of ductwork systems, or through convection currents in the case of radiators and fan coil units. The fourth subsystem is the set of sensors that provide a feedback loop to ensure proper delivery of thermal flu-

id, heat-transfer rate of equipment, and adequate distribution of thermal transfer fluid.

The work accomplished in this effort complements efforts being conducted by organizations developing and promoting energy modeling tools. It is intended to establish a common minimum standard framework, used on typical Army facilities, to describe the components and topology of HVAC systems from an HVAC engineering design perspective. This work will help to establish the foundation for the delivery of HVAC models during the design stage, thereby easing the requirements on energy modeling tools that currently force the manual entry of higher-order HVAC information that is not available today.

1.2 Objectives

The objective of this work was to develop and document an ontology addressing the specific requirements for the design-phase of HVAC systems typically found on low-rise Army facilities such as housing, offices, and clinics.

1.3 Approach

The HVAC design process was mapped in order to identify and document all specific data-exchange requirements relevant to the HVAC engineering design practice. This 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).

2 HVAC System Design Process Models

2.1 Overview

The selection, design, and modeling of Heating, Ventilating, and Air-Conditioning (HVAC) domain equipment and systems involve iterative, evolutionary, collaborative processes. The HVAC Designer should be an active member of the design team, ideally beginning in early project planning, interacting with other team members and the Project Owner primarily through the Architect who is coordinating the overall design process.

The process model details in this document focus on the HVAC Designer Activity Tasks and Data Exchanges as part of the overall design process. Activity Tasks and Data Exchanges performed by other design team members are represented here only through interactions and communications with the Architect, without explicit representation of Tasks and Data Exchanges performed by other team members.

2.1.1 HVAC system design phases

The overall design process can be divided into a variety of incremental phases that may vary depending on the project contracting type. The Process Models detailed in this document represent commonly identified phases applicable to most contracting types in the United States. The phases included here are Programming, Concept Design, Schematic Design, Design Development, and Construction Documents production. These combined phases bring a project from early planning to the point of generating design construction documents for bidding the project.

2.1.1.1 Programming and concept HVAC system design

The Programming phase of design focuses on identifying and codifying the requirements for fulfilling the needs and wants of the Owner of a project. These requirements can be referred to as the Owner's Project Requirements (OPR) as defined in the ASHRAE Guideline 0 (ASHRAE, 2005).

From the Architect's perspective, Programming will focus on functional space requirements and budget constraints as well as higher-level objectives such as the Owner's desired level of energy-efficiency and aesthetic

considerations. From the HVAC Designer's perspective, Programming will focus on proposing HVAC-related space requirements and understanding potential impacts of identified OPRs on HVAC-related issues.

The Concept Design phase will begin to develop conceptual design alternatives that meet the identified OPRs. The level of detail developed in Concept Design will vary depending on the project contractual type and agreements. These variations may range from simple overall massing and orientation concepts to relatively complete layout of functional spaces.

The HVAC Designer will work with the level of Concept Design detail provided by the Architect to elaborate HVAC systems as much as possible without performing work that requires additional detailed assumptions that will likely change dramatically as design proceeds. The HVAC Designer will develop early Basis of Design documentation including at least suggested HVAC system types, and propose HVAC-related spatial requirements. The HVAC Designer may also perform preliminary HVAC cost and whole-building energy performance estimations based on available design data, as appropriate for evaluation of Concept Design alternatives.

Ideally, sufficient levels of detail will be modeled using a Building Information Modeling (BIM) tool for sharing amongst Design Team members. An Owner accepted Concept Design BIM will then be passed to the Schematic Design phase for further elaboration.

2.1.1.2 Schematic HVAC system design

The Schematic Design phase will build on the previously developed Concept Design to add significantly more detail to the accepted conceptual design. From the perspective of the HVAC Designer this will include selection and preliminary sizing of main HVAC equipment for the proposed system types; coordination of Mechanical Equipment Room (MER) spaces within a combined architectural, structural, and MEP (mechanical, electrical, and plumbing) design model; zoning of functional spaces into HVAC zones; and estimation of whole-building energy performance and HVAC system construction costs as appropriate given known building information. Sizing, performance, and cost estimates may still be based on simplified functional-area-based methods. Preliminary piping schematics and air-flow diagrams may also be developed at this point.

An Owner accepted Schematic Design BIM will be passed to the Coordinated Design phase for further elaboration.

2.1.1.3 Coordinated HVAC system design

Coordinated Design comprises two phases commonly referred to as Design Development and Construction Documents. Design Development elaborates the accepted Schematic Design to the level of detail required to fully evaluate its acceptability. The production of Construction Documents then generates documentation of the accepted design to support the process of Construction Bidding.

From the perspective of the HVAC Designer, in coordination with the Design Team through the Architect, Design Development finalizes the selection of HVAC equipment and MER layout, adds more complete HVAC distribution system layout, enhances and updates building information required for accurate HVAC-related calculations, finalizes those calculations, and documents as much HVAC information as possible in the coordinated Design Development BIM.

An Owner accepted Design Development BIM is then used as the basis for generating Construction Documents.

2.2 Specification of processes

This section of the document contains three Process Map diagrams covering the HVAC design phases of (1) Programming and Concept Design, (2) Schematic Design, and (3) Design Development and Construction Documents production. Immediately following each of the three diagrams below are textural descriptions of the Activities and Events shown in each diagram. Textural descriptions of the combined set of data exchange objects shown in all of the diagrams are given in the Specification of Data Objects section.

2.2.1 Programming and Concept HVAC System Design

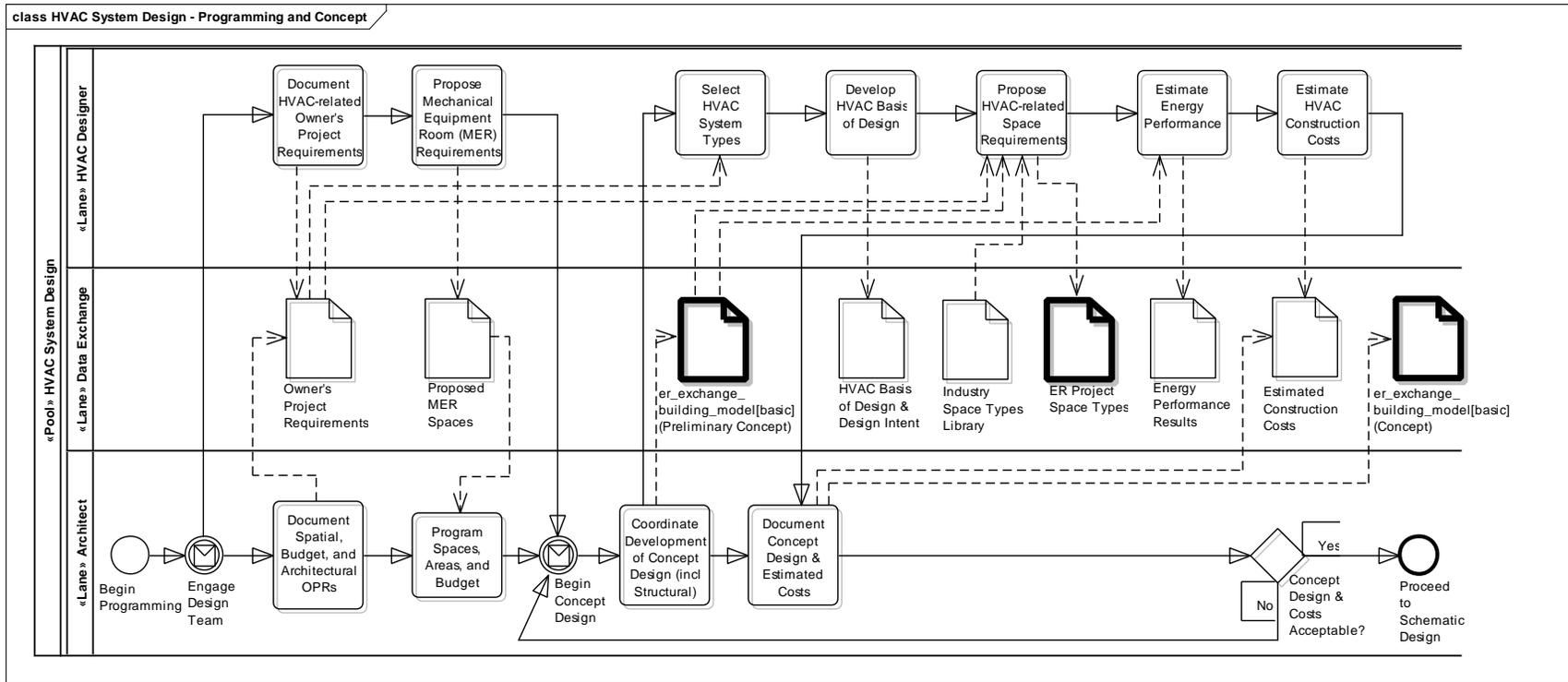


Figure 1. Process map for programming and concept HVAC system design.

Begin programming

Type	Start Event
Actor	Architect
Documentation	This is the start of project planning and design.

Engage design team

Type	Intermediate Event
Actor	Architect
Documentation	The Architect engages all relevant Design Team members in the Programming process.

Document spatial, budget, and architectural OPRs

Type	Task
Actor	Architect
Documentation	The Architect coordinates Programming and documents resulting Owner Project Requirements (OPRs) that focus on functional space requirements and budget constraints as well as higher-level objectives such as the Owner's desired level of energy-efficiency and aesthetic considerations.

Document HVAC-related owner project requirements

Type	Task
Actor	HVAC Designer
Documentation	The HVAC Designer proposes and documents HVAC-related space requirements and provides input on potential impacts of identified OPRs on HVAC-related issues. This information is documented in the Owner Project Requirements (OPRs) report.

Propose Mechanical Equipment Room (MER) requirements

Type	Task
Actor	HVAC Designer
Documentation	The HVAC Designer proposes HVAC-related Mechanical Equipment Room (MER) space requirements to be included in the overall project program. This information is documented in the Proposed MER Spaces report.

Program spaces, areas, and budget

Type	Task
Actor	Architect
Documentation	The Architect coordinates Programming of spaces, areas, and budget for the overall project.

Begin concept design

Type	Intermediate Event
Actor	Architect
Documentation	The Architect initiates the Concept Design phase following initial Programming phase.

Coordinate development of concept design (incl. structural)

Type	Task
Actor	Architect
Documentation	The Architect coordinates the Concept Design phase including all relevant Design Team members, particularly the HVAC and Structural Designers. This task includes an initial creation of the <code>er_exchange_building_model[basic]</code> (Preliminary Concept) that will be referenced by the HVAC Designer. The level of detail made available to the HVAC Designer by the Architect will determine the level to which the HVAC design is developed during Concept Design.

Select HVAC system types

Type	Task
Actor	HVAC Designer
Documentation	The HVAC Designer proposes HVAC System Types based on information established during Programming.

Develop HVAC basis of design

Type	Task
Actor	HVAC Designer
Documentation	The HVAC Designer develops and documents a preliminary HVAC Basis of Design & Design Intent report including thought processes and assumptions behind the design decisions made to date to meet known OPRs. The HVAC Basis of Design & Design Intent documentation will be incrementally updated as design proceeds.

Propose HVAC-related space requirements

Type	Task
Actor	HVAC Designer
Documentation	The HVAC Designer proposes HVAC-related space requirements to meet project OPRs for identified functional space types, based on generalized Industry Space Types Library requirements, and produces a preliminary ER Project Space Types dataset. See ER spatial requirements_aec3_20111109.xlsx and [GSA-005_MVD]_IFC2x3_Concept_Design_BIM_2010_v7.pdf

Estimate energy performance

Type	Task
Actor	HVAC Designer
Documentation	The HVAC Designer estimates the whole-building energy performance of the Concept Design model of the building. Energy performance estimation is not within the scope of this project, but is included in the process map because of its importance in overall design decision making.

Estimate HVAC construction costs

Type	Task
Actor	HVAC Designer
Documentation	The HVAC Designer estimates the construction costs (first cost) of Main HVAC equipment and systems for the Concept Design model. Cost estimation is not within the scope of this project, but is included in the process map because of its importance in overall design decision making.

Document concept design and estimated costs

Type	Task
Actor	Architect
Documentation	<p>The Architect coordinates documentation of a combined er_exchange_building_model[basic](Concept) including input from all relevant Design Team members.</p> <p>The er_exchange_building_model[basic](Concept) should include as much detail as has been established to date regarding the following: Project, Site, Building, Building Stories, Spaces (Functional), Space Types, Building Elements (General).</p>

Proceed to schematic design

Type	Intermediate Event
Actor	Architect
Documentation	Having received approval of Concept Design from the Owner, the Architect directs that the Design Team proceed to Schematic Design.

2.2.2 Schematic HVAC system design

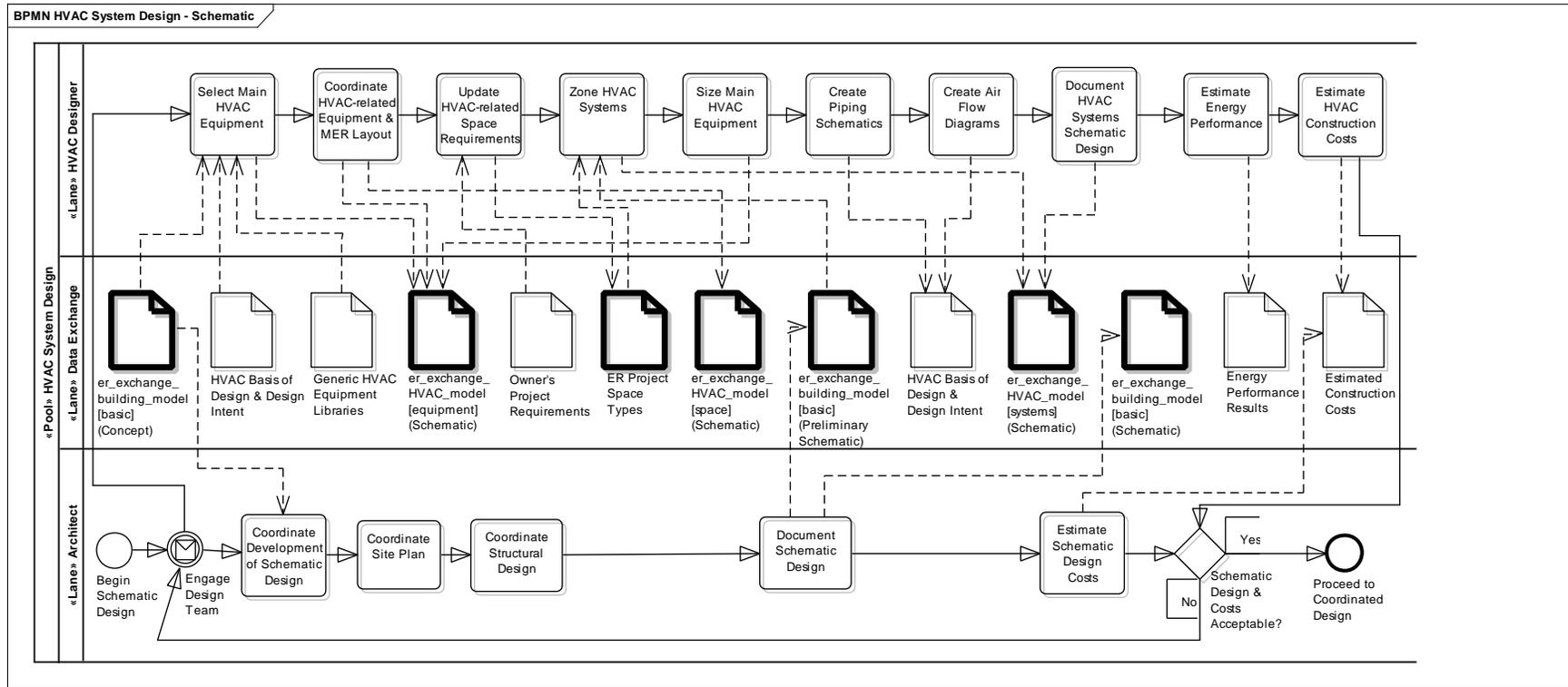


Figure 2. Process map for schematic HVAC system design.

Begin schematic design

Type	Start Event
Actor	Architect
Documentation	This is the start of Schematic design.

Engage design team

Type	Intermediate Event
Actor	Architect
Documentation	The Architect engages all relevant Design Team members in the Schematic design process.

Coordinate development of schematic design

Type	Task
Actor	Architect
Documentation	The Architect coordinates interactions and communications between all relevant Design Team members in the Schematic Design process. This process builds on information documented in the er_exchange_building_model[basic](Concept).

Coordinate site plan

Type	Task
Actor	Architect
Documentation	The Architect coordinates details of the site plan such as overall building orientation and site specifics such as available utilities and relevant codes and standards.

Coordinate structural design

Type	Task
Actor	Architect
Documentation	The Architect coordinates interactions and communications related to the structural design between all relevant Design Team members.

Select main HVAC equipment

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer selects main HVAC equipment based on the identified system type. During Schematic Design these selections are often made from generic HVAC equipment libraries to allow sizing and costing based on generalities and uncertainties in building information at this time.</p> <p>This information is documented in the <code>er_exchange_HVAC_model[equipment]</code> (Schematic).</p>

Coordinate HVAC-related equipment & MER layout

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer preliminarily locates HVAC equipment in the building and updates proposed MER spaces layout.</p> <p>This information is documented in the <code>er_exchange_HVAC_model[space]</code> (Schematic). Technical Space information may be combined into the <code>er_exchange_building_model[basic]</code> (Schematic) if appropriate.</p>

Update HVAC-related space requirements

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer reviews HVAC-related space requirements and updates them to meet currently specified OPRs for identified functional space types.</p> <p>This information is documented in the ER Project Space Types dataset and may be combined into the <code>er_exchange_building_model[basic]</code> (Schematic) through coordination with Architect. See ER spatial requirements_aec3_20111109.xlsx and [GSA-005_MVD]_IFC2x3_Concept_Design_BIM_2010_v7.pdf</p>

Zone HVAC systems

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer groups identified functional space types into appropriate HVAC zones (e.g., thermal zones) for subsequent HVAC-related calculations and design decisions.</p> <p>This information is documented in the <code>er_exchange_HVAC_model[systems]</code> (Schematic).</p>

Size Main HVAC equipment

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer sizes main HVAC equipment based on the preliminary schematic design. At this stage of design, equipment is likely sized based on aggregated functional space area ("per ft²") calculations. More detailed sizing calculations will be used if there is sufficient detail in the preliminary schematic design.</p> <p>This information is documented in the <code>er_exchange_HVAC_model[equipment]</code> (Schematic).</p>

Create piping schematics

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer creates preliminary piping schematics for selected HVAC systems.</p> <p>This information is documented in the HVAC Basis of Design & Design Intent report and may ultimately be documented in the <code>er_exchange_HVAC_model[systems]</code> (Schematic) if there is sufficient confidence that subsequent design changes will not force substantial rework.</p>

Create air flow diagrams

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer creates air flow diagrams for selected HVAC systems.</p> <p>This information is documented in the HVAC Basis of Design & Design Intent report and may ultimately be documented in the er_exchange_HVAC_model[systems] (Schematic) if there is sufficient confidence that subsequent design changes will not force substantial rework.</p>

Document HVAC systems schematic design

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer documents HVAC systems information generated in the previous tasks, for which there is sufficient confidence that subsequent design changes will not force substantial rework, in the er_exchange_HVAC_model[systems] (Schematic) for coordination with Architect.</p>

Estimate energy performance

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer estimates the whole-building energy performance of the preliminary schematic design of the building.</p> <p>Energy performance estimation is not within the scope of this project, but is included in the process map because of its importance in overall design decision making.</p>

Estimate HVAC system costs

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer estimates the construction costs (first cost) of procuring and installing the selected Main HVAC equipment and designed systems for the Schematic Design model.</p> <p>Cost estimation is not within the scope of this project, but is included in the process map because of its importance in overall design decision making.</p>

Document schematic design

Type	Task
Actor	Architect
Documentation	<p>The Architect coordinates documentation of a combined er_exchange_building_model[basic] (Schematic) including input from all relevant Design Team members.</p> <p>The er_exchange_building_model[basic] (Schematic) should include the following: Project, Site, Building, Building Stories, Spaces, Space Types, and Building Elements.</p>

Estimate schematic design costs

Type	Task
Actor	Architect
Documentation	<p>The Architect coordinates estimation of construction costs (first cost) and life-cycle costs as needed for evaluation of the schematic design before moving on to coordinated design.</p> <p>Cost estimation is not within the scope of this project, but is included in the process map because of its importance in overall design decision making.</p>

Proceed to coordinated design

Type	Task
Actor	Architect
Documentation	Having received approval of Schematic Design from the Owner, the Architect directs that the Design Team proceed to Coordinated Design.

2.2.3 Coordinated HVAC system design

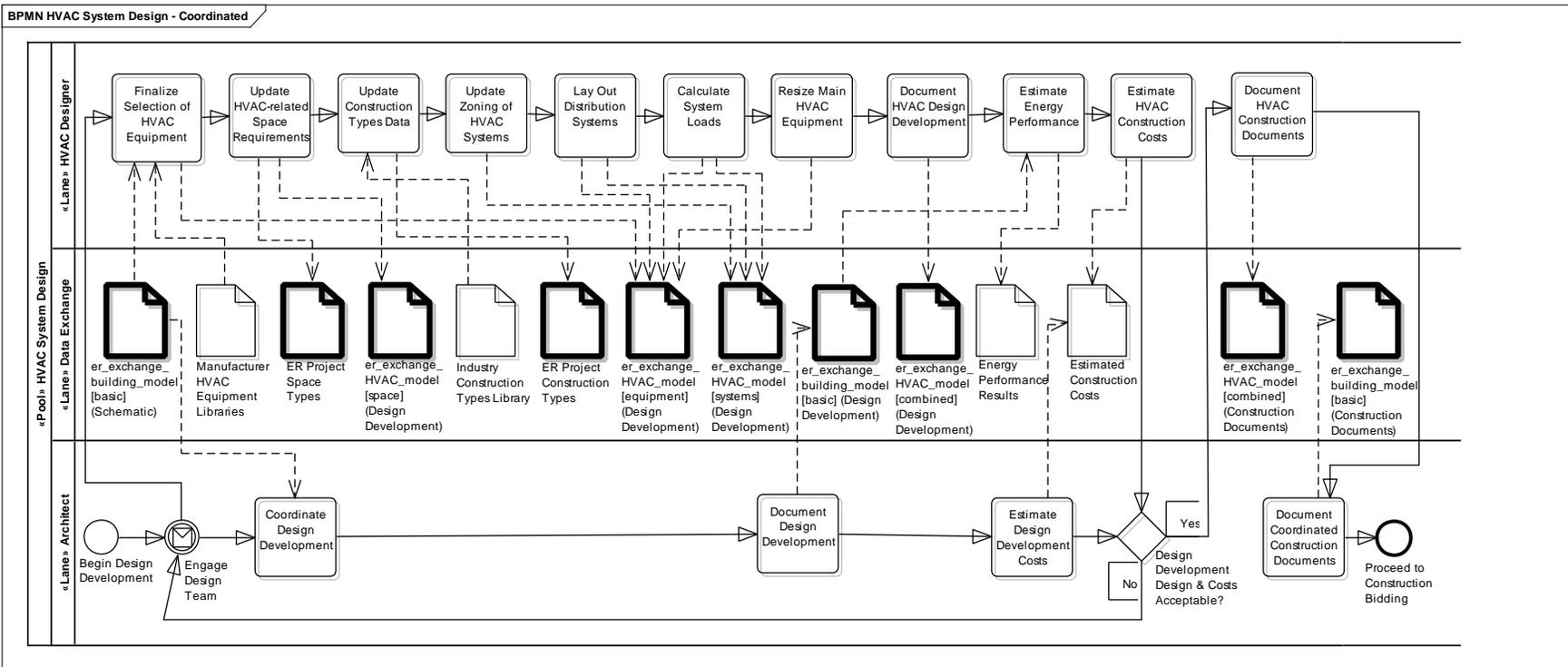


Figure 3. Process map for coordinated HVAC system design.

Begin design development

Type	Start Event
Actor	Architect
Documentation	<p>It is assumed at this point that the Design Team has completed an <code>er_exchange_building_model[basic]</code> (Schematic) that includes building elements and space objects, and that this design has successfully passed Schematic Design evaluation. This design provides at least a partial proposed building layout including space configuration and placement of other geometric elements.</p> <p>HVAC-related spaces such as Mechanical Equipment Room (MER) technical spaces and chases may not yet be defined by space objects.</p>

Engage design team

Type	Intermediate Event
Actor	Architect
Documentation	The Architect engages all relevant Design Team members in the Design Development process.

Coordinate design development

Type	Task
Actor	Architect
Documentation	The Architect coordinates interactions and communications between all relevant Design Team members in the Design Development process.

Finalize selection of HVAC equipment

Type	Task
Actor	HVAC Designer
Documentation	The HVAC Designer checks generic HVAC equipment specified in the <code>er_exchange_building_model[basic]</code> (Schematic) and finalizes specification based on Manufacturer HVAC Equipment Libraries. This information is documented in the <code>er_exchange_HVAC_model[equipment]</code> (Design Development).

Update HVAC-related space requirements

Type	Task
Actor	HVAC Designer
Documentation	The HVAC Designer checks HVAC-related Space Requirements such as thermal conditioning set points and updates information in the ER Project Space Types for Space Types specific to this project. See ER spatial requirements_aec3_20111109.xlsx and [GSA-005_MVD]_IFC2x3_Concept_Design_BIM_2010_v7.pdf

Update construction types data

Type	Task
Actor	HVAC Designer
Documentation	The HVAC Designer checks HVAC-related Industry Construction Types Library data and updates information in the ER Project Construction Types for Building Elements specific to this project. See [GSA-005_MVD]_IFC2x3_Concept_Design_BIM_2010_v7.pdf

Update zoning of HVAC systems

Type	Task
Actor	HVAC Designer
Documentation	The HVAC Designer checks previous groupings of Spaces into Thermal Zones and updates as appropriate. This information is documented in the er_exchange_HVAC_model[systems] (Design Development).

Lay out distribution systems

Type	Task
Actor	HVAC Designer
Documentation	The HVAC Designer formally models the layout of the HVAC distribution systems and component equipment. This information is documented in er_exchange_HVAC_model[systems] (Design Development) and er_exchange_HVAC_model[equipment] (Design Development).

Calculate system loads

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer calculates the nominal (or design) requirements for the maximum thermal power addition or extraction required to maintain specified conditions in all thermal zone Spaces in the building under suitably chosen assumptions for weather and operation (the design conditions). These values are termed system loads.</p> <p>This information is documented in er_exchange_HVAC_model[systems] (Design Development) and er_exchange_HVAC_model[equipment] (Design Development).</p>

Resize main HVAC equipment

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer recalculates the size of main HVAC plant equipment required to meet the calculated system loads.</p> <p>This information is documented in the er_exchange_HVAC_model[equipment] (Design Development).</p>

Document HVAC design development

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer documents HVAC-related Space, Equipment, and Systems information generated during Design Development in er_exchange_HVAC_model[combined] (Design Development), which is the combined set of er_exchange_HVAC_model[space] (Design Development), er_exchange_HVAC_model[equipment] (Design Development) and er_exchange_HVAC_model[systems] (Design Development)</p>

Estimate energy performance

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer estimates the whole-building energy performance of the Design Development model of the building.</p> <p>This task is not within the scope of this project, but is included in the process map because of its importance in overall design decision making.</p>

Estimate HVAC system costs

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer estimates the construction costs (first cost) of procuring and installing the selected Main HVAC equipment and designed systems for the Design Development model.</p> <p>Cost estimation is not within the scope of this project, but is included in the process map because of its importance in overall design decision making.</p>

Document design development

Type	Task
Actor	Architect
Documentation	<p>The Architect coordinates documentation of a combined er_exchange_building_model[basic] (Design Development) and er_exchange_HVAC_model[combined] (Design Development) including input from all relevant Design Team members and should include the following: Project, Site, Building, Building Stories, Spaces (including MER and chases), Space Types, Building Elements, HVAC Equipment with Location, HVAC Systems.</p>

Estimate design development costs

Type	Task
Actor	Architect
Documentation	<p>The Architect coordinates estimation of construction and life-cycle costs as needed for evaluation of the building design before moving on to finalization during production of Construction Documents.</p> <p>Cost estimation is not within the scope of this project, but is included in the process map because of its importance in overall design decision making.</p>

Document HVAC construction documents

Type	Task
Actor	HVAC Designer
Documentation	<p>The HVAC Designer documents Construction Documents for HVAC-related Space, Equipment, and Systems information in er_exchange_HVAC_model[combined] (Construction Documents).</p>

Document coordinated construction documents

Type	Task
Actor	Architect
Documentation	<p>The Architect coordinates documentation of a combined er_exchange_building_model[basic] (Construction Documents) and er_exchange_HVAC_model[combined] (Construction Documents) including input from all relevant Design Team members and should include the following: Project, Site, Building, Building Stories, Spaces (including MER and chases), Space Types, Building Elements, HVAC Equipment with Location, HVAC Systems.</p>

Proceed to construction bidding

Type	Intermediate Event
Actor	Owner
Documentation	<p>The Owner directs that the project proceed to construction bidding.</p>

2.3 Specification of data objects

Data Objects described in this section are less formally detailed than Exchange Requirements in the following section. These Data Objects represent either reference materials used by Actors, or reports generated by Actors to document information not formally detailed in Exchange Requirements. These Data Objects are important to capture in the Process Maps, but are not the focus of subsequent elaboration of Exchange Requirements into a Model View Definition (MVD) for these HVAC Design processes.

Energy performance results

Type	Data Object
Documentation	<p>The results of energy performance analysis of a building design used in evaluating Project objectives such as energy-efficiency and life-cycle costs.</p> <p>Energy Performance Analyses are not within the scope of this project, but are included in the process maps because of their importance in overall design decision making.</p>

Estimated construction costs

Type	Data Object
Documentation	<p>The estimated construction costs (first cost) of the building design.</p> <p>Cost Estimation Analyses are not within the scope of this project, but are included in the process maps because of their importance in overall design decision making.</p>

Generic HVAC equipment libraries

Type	Data Object
Documentation	<p>A library of generic HVAC equipment with properties from which the HVAC Designer can select in specifying project equipment.</p>

HVAC Basis of design & design intent

Type	Data Object
Documentation	<p>The HVAC Basis of Design & Design Intent includes narrative descriptions of the thought processes and assumptions behind HVAC-related design decisions. The purpose of this documentation is to provide all parties involved, not only in Design, but in eventual Operations and Management of the facility, with an understanding of the thinking behind the selection, design, and intended operation of HVAC components, assemblies, and systems for a given project. See also ASHRAE Guideline 0 (ASHRAE, 2005).</p> <p>The HVAC Basis of Design & Design Intent documentation will be incrementally updated as design proceeds.</p>

Industry construction types library

Type	Data Object
Documentation	<p>A library of common industry construction and material type performance data used in HVAC-related calculations keyed to accepted categorization schemes from sources such as ASHRAE 90.1 or CA Title 24.</p>

Industry space types library

Type	Data Object
Documentation	<p>A library of industry Space Type requirements used in HVAC-related calculations keyed to an accepted Space Type categorization scheme from sources such as ASHRAE 90.1, CA Title 24, or the GSA.</p> <p>HVAC-related Space Type requirements include: thermal conditioning, occupancy, installed lighting, installed equipment, and associated schedules.</p>

Manufacturer HVAC equipment libraries

Type	Data Object
Documentation	<p>A library of manufactured HVAC equipment with properties from which the HVAC Designer can select in specifying project equipment.</p>

Owner's project requirements

Type	Data Object
Documentation	Documentation of Owner's Project Requirements (OPR). The OPR should detail the functional requirements of a project and the expectations of the building's use and operation of its systems. From an HVAC Designer perspective the OPR may address: Owner and User Requirements, Environmental and Sustainability Goals, Energy Efficiency Goals, Indoor Environmental Quality Requirements, Equipment and System Expectations, and Building Occupant and O&M Personnel Requirements. See also ASHRAE Guideline 0 (ASHRAE, 2005).

Proposed MER spaces

Type	Data Object
Documentation	Documentation of the HVAC-related Technical Mechanical Equipment Room (MER) Spaces that should be accounted for in the project design.

2.4 Specification of exchange requirements

The exchange requirements described in this section are the focus of subsequent elaboration into a Model View Definition (MVD) supporting the HVAC Design processes mapped above.

er_exchange_building_model[basic] (Preliminary concept)

Type	Exchange Requirements Data Object
Name	er_exchange_building_model[basic] (Preliminary Concept)
Documentation	Early Concept Design building information created by the Architect based on the results of Programming. Focus is on Spaces including their Space Type, expected size and shape, and floor plan layout if known at this stage. Programming information may not be documented in a BIM at all, but rather in less formal textual documents. There will be considerable tentative information in the er_exchange_building_model[basic] (Preliminary Concept).

er_exchange_building_model[basic] (Concept)

Type	Exchange Requirements Data Object
Name	er_exchange_building_model[basic] (Concept)
Documentation	<p>Concept Design building information. This exchange requirement is coordinated by the Architect with input from the Design Team members including at least the HVAC Designer and the Structural Designer. This exchange is intended to provide Design Team members with as much information as is known at the completion of Concept Design.</p> <p>Ideally the er_exchange_building_model[basic] (Concept) will fulfill the GSA Concept Design BIM 2010 Spatial Program Validation requirements (GSA, 2007 and IFC Solutions Factory, 2011).</p> <p>There will still be tentative information in the er_exchange_building_model[basic] (Concept).</p> <p>The following exchange requirements should be met: Project, Site, Building, Building Stories, Spaces (Functional), Space Types, Building Elements (General).</p>

er_exchange_building_model[basic] (Preliminary schematic)

Type	Exchange Requirements Data Object
Name	er_exchange_building_model[basic] (Preliminary Schematic)
Documentation	<p>Exchange of Preliminary Schematic Design building information. This exchange requirement is coordinated by the Architect and will basically consist of an updated Concept Design BIM fulfilling the GSA Concept Design BIM 2010 Spatial Program Validation requirements (GSA, 2007 and IFC Solutions Factory, 2011).</p> <p>This information will be referenced by the HVAC Designer in performing HVAC-related design decisions such as thermal zoning, main equipment sizing, and initial HVAC system schematics.</p> <p>The er_exchange_building_model[basic] (Preliminary Schematic) should include the following (subject to modifications over the course of Schematic Design):</p> <ul style="list-style-type: none"> o site and building location o building orientation o site and building elevation o building story information o 3D geometry of the building, including walls (exterior/interior), curtain walls, roofs, floors/slabs, ceilings, windows/skylights, doors, and shading devices o space objects o ER Project Space Types o space boundaries o structural type <p>The following exchange requirements should be met: Project, Site, Building, Building Stories, Spaces (Functional), Space Types, Building Elements (General), and Space Boundaries.</p>

er_exchange_building_model[basic] (Schematic)

Type	Exchange Requirements Data Object
Name	er_exchange_building_model[basic] (Schematic)
Documentation	<p>Exchange of combined Schematic Design building information. This exchange requirement is coordinated by the Architect with input from the Design Team members including at least the HVAC Designer and the Structural Designer.</p> <p>The er_exchange_building_model[basic] (Schematic) should include the following (subject to modifications over the course of Coordinated Design):</p> <ul style="list-style-type: none"> o site and building location o building orientation o site and building elevation o building story information o 3D geometry of the building, including walls (exterior/interior), curtain walls, roofs, floors/slabs, ceilings, windows/skylights, doors, and shading devices o space objects o ER Project Space Types o structural type o ER HVAC Equipment & Systems (Schematic) <p>The following exchange requirements should be met: Project, Site, Building, Building Stories, Spaces (Functional & Technical), Space Types, and Building Elements.</p> <p>This information should be coordinated with er_exchange_HVAC_model[space, equipment, systems] (Schematic), which will cover HVAC Spaces, Equipment & Systems (General).</p>

er_exchange_building_model[basic] (Design development)

Type	Exchange Requirements Data Object
Name	er_exchange_building_model[basic] (Design Development)
Documentation	<p>Exchange of Design Development building information. This exchange requirement is coordinated by the Architect with input from the Design Team members including at least the HVAC Designer and the Structural Designer.</p> <p>This should be a complete collection of building information ready for finalization during production of Construction Documents.</p> <p>The er_exchange_building_model[basic] (Design Development) should be coordinated with the HVAC-related Exchange Requirements generated during Design Development and should include the following (subject to finalization during the production of Construction Documents):</p> <ul style="list-style-type: none"> o site and building location o building orientation o site and building elevation o building story information o 3D geometry of the building, including walls (exterior/interior), curtain walls, roofs, floors/slabs, ceilings, windows/skylights, doors, and shading devices o ER Project Construction Types o space objects o ER Project Space Types o structural detail <p>The following exchange requirements should be met: Project, Site, Building, Building Stories, Spaces (Functional & Technical), Space Types, Building Elements, and Construction Types.</p> <p>This information should be coordinated with er_exchange_HVAC_model[combined] (Design Development), which will cover HVAC Equipment & Systems (Specific).</p>

er_exchange_building_model[basic] (Construction documents)

Type	Exchange Requirements Data Object
Name	er_exchange_building_model[basic] (Construction Documents)
Documentation	<p>Exchange of Construction Documents building information. This exchange requirement is coordinated by the Architect with input from all Design Team members.</p> <p>This should be a complete and finalized collection of building information ready for Construction Bidding.</p> <p>The er_exchange_building_model[basic] (Construction Documents) should include the following:</p> <ul style="list-style-type: none"> o site and building location o building orientation o site and building elevation o building story information o 3D geometry of the building, including walls (exterior/interior), curtain walls, roofs, floors/slabs, ceilings, windows/skylights, doors, and shading devices o ER Project Construction Types o space objects o ER Project Space Types o structural detail <p>The following exchange requirements should be met: Project, Site, Building, Building Stories, Spaces (Functional & Technical), Space Types, Building Elements, and Construction Types.</p> <p>This information should be coordinated with er_exchange_HVAC_model[combined] (Construction Documents), which will cover HVAC Equipment & Systems (Specific).</p>

er_exchange_HVAC_model[] (Schematic)*

Type	Exchange Requirements Data Object
Name	er_exchange_HVAC_model[*] (Schematic)
Documentation	<p>Exchange of the HVAC-related information at the Schematic design phase.</p> <p>This information is contained in three related exchange requirements for space, equipment, and systems as represented by the bracketed asterisk in the exchange requirement name:</p> <ul style="list-style-type: none"> o er_exchange_HVAC_model[space] o er_exchange_HVAC_model[equipment] o er_exchange_HVAC_model[systems] <p>The following exchange requirements should be met: Spaces (Technical MER), HVAC Zones, Main HVAC Equipment (Generic), and Preliminary Equipment Sizing.</p> <p>The following exchange requirements may be partially met: Preliminary Piping Schematics.</p>

er_exchange_HVAC_model[] (Design development)*

Type	Exchange Requirements Data Object
Name	er_exchange_HVAC_model[*] (Design Development)
Documentation	<p>Exchange of the HVAC-related information at the Design Development design phase.</p> <p>This information is contained in three related exchange requirements for space, equipment, and systems as represented by the bracketed asterisk in the exchange requirement name:</p> <ul style="list-style-type: none"> o er_exchange_HVAC_model[space] o er_exchange_HVAC_model[equipment] o er_exchange_HVAC_model[systems] <p>The following exchange requirements should be met: Spaces (Technical MER and chases), HVAC Zones, Main HVAC Equipment (Specific) with Location, Equipment Sizing, Distribution System Layout, and System Sizing.</p>

er_exchange_HVAC_model[] (Construction documents)*

Type	Exchange Requirements Data Object
Name	er_exchange_HVAC_model[*] (Construction Documents)

Documentation	<p>Exchange of the HVAC-related information at the Construction Documents design phase.</p> <p>This information is contained in three related exchange requirements for space, equipment, and systems as represented by the bracketed asterisk in the exchange requirement name:</p> <ul style="list-style-type: none"> o er_exchange_HVAC_model[space] o er_exchange_HVAC_model[equipment] o er_exchange_HVAC_model[systems] <p>The following exchange requirements should be met: Spaces (Technical MER and chases), HVAC Zones, Main HVAC Equipment (Specific) with Location, Equipment Sizing, Distribution System Layout, and System Sizing.</p>
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ER project construction types

Type	Exchange Requirements Data Object
Name	ER Project Construction Types
Documentation	<p>Exchange of Construction Types requirements specific to this Project.</p> <p>HVAC-related Construction Type requirements include: thermal and optical properties of associated Building Element construction materials and material layer sets.</p> <p>See [GSA-005_MVD]_IFC2x3_Concept_Design_BIM_2010_v7.pdf for Exchange Requirement specifications for Building Elements</p>

ER project space types

Type	Exchange Requirements Data Object
Name	ER Project Space Types Library
Documentation	<p>Exchange of Space Types requirements specific to this Project.</p> <p>HVAC-related Space Type requirements include: thermal conditioning, occupancy, installed lighting, installed equipment, and associated schedules.</p> <p>See ER spatial requirements_aec3_20111109.xlsx and [GSA-005_MVD]_IFC2x3_Concept_Design_BIM_2010_v7.pdf for Exchange Requirement specifications for Space</p>

2.5 Specification of decision point gateways

Concept design & costs acceptable?

Type	Decision Gateway
Documentation	The Owner and Architect must decide whether the project concept design performance and costs are acceptable before proceeding to the next stage.

Schematic design & costs acceptable?

Type	Decision Gateway
Documentation	The Owner and Architect must decide whether the project schematic design performance and costs are acceptable before proceeding to the next stage.

Design Development design & costs acceptable?

Type	Decision Gateway
Documentation	The Owner and Architect must decide whether the project design performance and costs are acceptable before proceeding to the next stage.

3 Exchange Requirements and Functional Parts

This section provides a more detailed overview of each of the exchange requirements identified above and their related functional parts. Further details, including tabular listings of objects and properties within each exchange requirement are given in separate documents adhering to the Information Delivery Manual (IDM) formats. Compressed archives of each exchange requirement and its related functional parts are listed below.

3.1 er_exchange_building_model[basic].doc

A basic building model is defined as ‘the set of information that provides both a graphical representation of the design of a building and key pieces of information about the building that can be further used to analyze building performance’ (from

http://www3.autodesk.com/apac_sapac_main/files/4525079_BIM_A_Key_to_Performance-Based_Design.pdf)

The purpose of exchanging a basic building model is to provide information about a building that enables downstream analyses (structural, thermal, lighting, acoustic etc.) to be undertaken, and that supports facility management activities in the occupied building. The basic building model provides information about the building, the layout of spaces within it and the main building elements from which it is to be constructed

Particular information that is required with the basic building model includes:

- the name of the project (for identification purposes) and the units generally used throughout the project; additionally, the current phase of the project may be given but this is not mandatory
- configuration of a site on which a building is located including the geographical location (latitude, longitude and elevation above sea level for the site datum) and shape layout
- further information about a site may be provided including land title number and local address

- location of a building in connection with a site or external space on which it is located
- overall shape of a building with its plan shape at various heights and elevation shape at various orientations so that building areas, height, volume and building mass can be established
- configuration of levels or storeys within a building with their plan shape and height so that areas and volumes can be established
- configuration of spaces within a building or building storey, including both partial and complete/room spaces and the association between partial and complete spaces, with their plan shape and height so that areas and volumes can be established; this allows for the definition of atrium spaces that span more than one storey of a building
- spaces should have a name and a type that specifies their function (for later use in analysis)
- dimensional information concerning spaces should enable calculation of areas and volume and include length, width and height information and the plan shape of the room.
- the elevation of spaces above the building reference should be given.
- one or more 3 dimensional shape representations should be defined for the space including at least a 'bounding box' representation (the box that contains the space shape) and probably a more detailed 3 dimensional representation of the boundaries of the space.
- arrangement of major building elements within a building and within the storeys of a building with their shape so their typical length, width, height dimensions can be established; major building elements being defined as walls, floors, roofs, ceilings
- shape representations of building elements should be defined including their 2D profile, bounding box and 3 dimensional representation of their boundaries.
- type or style definitions should be given where a given type or style of building element will be used many times; each occurrence of a building element will be designated as being of a particular type
- provision of openings within buildings elements within which further building elements can be constructed to fill the openings (referred to as 'filling' elements)
- provision of filling elements with their shape so that their typical length and height dimensions can be established; filling elements being defined as doors, windows, skylights/rooflights

- shape representations of filling elements should be defined including their 2D profile, bounding box and 3 dimensional representation of their boundaries.
- type or style definitions should be given where a given type or style of filling element will be used many times; each occurrence of a filling element will be designated as being of a particular type
- relationships between openings and major elements and between openings and filling elements so that the identity of particular filling elements within particular major elements can be determined
- Optional information that may be required with the basic building model includes:
 - material from which a building element or filling element is constructed
 - classification of spaces, building elements and filling elements according to particular classification systems and tables
 - connection relationships between major building elements

For a complete specification of this exchange requirement and its related functional parts see ERDC_er_exchange_building_model[*basic*].zip

3.2 er_exchange_HVAC_model[*space*].doc

The scope of this exchange requirement is the exchange of information to enable provision of technical spaces that have as their primary purpose the housing of HVAC or other technical equipment. The purpose of the exchange requirement is to enable coordination of HVAC systems space requirements with other technical systems requirements (notably electrical and piping systems) and with building design with regard to the provision of space for the technical systems.

This exchange requirement allows for the provision of information at various stages during the design process including outline conceptual or sketch design, full conceptual design and coordinated design. The information provided at each stage is essentially the same. However, the level of certainty regarding equipment and components used will increase at each stage allowing greater certainty in space provision.

It is assumed that the information provisions outlined in the exchange requirement er_exchange_building_model[*basic*] have been satisfied for the project stage concerned. This provides an initial assessment of spaces from the perspective of building design and project details.

Information provided through this exchange requirement includes:

- Proposed technical space specification with area, configuration and height. At earlier stages of design, area and height only may be given; later stages of design may also propose a space configuration.

For a complete specification of this exchange requirement and its related functional parts see ERDC_er_exchange_HVAC_model[space].zip

3.3 er_exchange_HVAC_model[equipment].doc

The scope of this exchange requirement is the exchange of information to enable coordination of HVAC Equipment with other technical design roles, building design and structural design. It includes the need for shape, size and location of components and also for weight, as well as other equipment properties to be included.

This exchange requirement allows for the provision of information at various stages during the design process including outline conceptual or sketch design, full conceptual design and coordinated design. The information provided at each stage is essentially the same. However, the level of certainty and specificity regarding equipment and components will increase at each stage allowing greater certainty in space provision. Additionally, equipment and components may still be specified at a generic level at the end of design, with specification of manufactured equipment and components coming during procurement and construction.

It is assumed that the information provisions outlined in the exchange requirement er_exchange_HVAC_model [space] have been satisfied. This provides an initial assessment of spaces from the perspective of building design and HVAC design as well as project details.

Information provided through this exchange requirement includes:

- HVAC equipment component type and size
- Shape representation of component type
- Weight of component type
- Location and orientation of occurrences of component type
- Properties of the equipment types and occurrences required for HVAC design process

For a complete specification of this exchange requirement and its related functional parts see ERDC_er_exchange_HVAC_model[equipment].zip

3.4 er_exchange_HVAC_model[systems].doc

This exchange requirement describes the information to be provided about duct and pipe HVAC systems. It allows for the provision of information at various stages during the design process including:

- Representation of components and their relation to spatial structures (sites, buildings and spaces) without connection to systems
- Line based representations at early design stages that enable routing, terminal location and main plant location information to be exchanged;
- Full 3D shape representations at detailed design stages that enable coordination between different building services systems, between services and structure and between services and the building construction elements.

Information items that may be required about HVAC duct systems include:

- System name
- Terminal type, size, location, orientation, airflow rate, discharge velocity, pressure drop; supply air temperature may also be included for supply air systems.
- Duct section size, shape, location, flow rate, air velocity, pressure drop
- Duct fitting type, size, location, pressure drop
- Equipment type, size, location, pressure drop
- Shape of elements
- Connections between elements in the ductwork system
- Material from which elements are constructed
- Classification of elements

Constraints that have been applied during the design of the duct systems to limit or control duct sizing or equipment selection may also be included as part of the exchange requirement. These should be identified as a requirement by the user. Particular constraints considered include:

- Limiting pressure drop in a ductwork section
- Limiting velocity in a ductwork section

- Limiting dimensions for a ductwork section (height, width, diameter)
- Ductwork construction standard
- Duct sizing method

Information items that may be required about piping systems include:

- System name
- Terminal type, size, location, orientation, fluid flow rate, pressure drop.
- Pipe section size, shape, location, fluid flow rate, fluid flow velocity, pressure drop
- Pipe fitting type, size, location, pressure drop
- Equipment type, size, location, pressure drop
- Shape of elements
- Connections between elements in the piping system
- Material from which elements are constructed
- Classification of elements

Constraints that have been applied during the design of the pipe systems to limit or control pipe sizing or equipment selection may also be included as part of the exchange requirement. These should be identified as a requirement by the user. Particular constraints considered include:

- Limiting pressure drop in a pipe section
- Limiting velocity in a pipe section

Note that as of IFC2x4 a specialization of System (`ifcDistributionSystem`) has been added to capture the concepts of a distribution system in a new element. The distribution system has predefined types for various heating, cooling, ventilation, plumbing, security and electrical systems.

Information provided through this exchange requirement also includes:

- Grouping of spaces into zones served by an identified system

For a complete specification of this exchange requirement and its related functional parts see `ERDC_er_exchange_HVAC_model[systems].zip`

3.5 ER Project construction types

See GSA Concept Design BIM 2010, Building Elements exchange requirement specifications. [GSA-005_MVD]_IFC2x3_Concept_Design_BIM_2010_v7.pdf

3.6 ER Project space types

See ER spatial requirements_aec3_20111109.xlsx, Space exchange requirement specifications.

Also see GSA Concept Design BIM 2010, Space exchange requirement specifications. [GSA-005_MVD]_IFC2x3_Concept_Design_BIM_2010_v7.pdf

4 Model View Definition

This section formalizes the combined information delivery requirement arising from the exchanges required based on the process maps. This section summarizes the necessary content which is available as a complete Express sub-schema and associated documentation produced to the ISO/buildingSMART international standard.

4.1 Inputs to a HVAC MVD

The following considerations have been derived from the Process map and Exchange requirements above, from the practical considerations discovered in modeling the three building types and from consideration of the two primary MVD definitions that support the design and documentation of HVAC systems.

4.2 buildingSMART Coordination Model View Definition 2.0

Design and documentation of HVAC systems must be conducted in the context of a detailed description of the architectural fabric and spatial requirements of the facility.

In particular the HVAC subset of the Coordination view allows for the use of the critical connectivity port objects and relationships:

- IfcPort and IfcDistributionPort
- IfcRelConnectsPortToElement and IfcRelConnectsPorts

4.3 buildingSMART FM-10 Handover Model View Definition

It is also central to an integrated working method that the design and documentation of HVAC systems deliver information appropriate to and useful for the handover process, thereby supporting the owner/operators specific use cases:

- Registration of assets including spaces and equipment
- Use of the facility and effective utilization.
- Operations and Maintenance of the systems
- Refurbishment and replacement of equipment
- Tracking of cost and environmental impacts

- Security and safety during use.

In summary, the COBie Handover view includes business rules that require:

- Every occurrence, space, type, zone and system being uniquely named. This also applies to the project, site, building, building floor.
- Every occurrence having an associated uniquely named type.
- Every occurrence being related to a space.

4.4 Other considerations

Whilst these two MVDs actually support the required data, practical experience gained in this project in the areas of design checking and validations suggests that further additional business rules are needed to enforce the use of available objects. These rules include both practical (and universal) rules and rules

4.5 Connectivity

Additional rules are defined to ensure that full connected systems are created.

- All 'Ifc Flow Segments' relating to HVAC distribution ('Ifc Duct Segment Type') to have exactly 2 'Ifc Distribution Port's.
- All 'Ifc Distribution Port's to be paired by a connecting relationship with no sink-to-sink nor source-to-source connections.

Other objects including IfcFlowTerminals may or may not have ports, depending on whether they are part of the HVAC systems.

4.6 Analysis

Although not central to the scope of this project, the HVAC MVD should demand inclusion of the associated property sets for spaces and HVAC systems relating to

- Demand-side design (cooling load and heating load for each space based on outside air, ground, solar, occupancy)
- Supply-side design (temperature and pressure drops along ductwork)

- Equipment selection (boilers, chillers, air handlers, cooling towers, etc.)
- Load simulation
- Performance data, balancing.

These requirements may be developed further to reflect the US ASHRAE guidance.

ASHRAE, 2005. ASHRAE Guideline 0 -2005: The Commissioning Process, *Informative Annex J – Owner’s Project Requirements*.

ASHRAE, 2005. ASHRAE Guideline 0 -2005: The Commissioning Process, *Informative Annex K – Basis of Design*.

4.7 Classification

Analysis and reporting demand that the spaces, systems and objects with the model should be correctly classified.

- A library of common industry construction and material type performance data used in HVAC-related calculations keyed to accepted categorization schemes from sources such as ASHRAE 90.1, CA Title 24, or Omniclass Tables 21 and 23
- A library of industry Space Type requirements used in HVAC-related calculations keyed to an accepted Space Type categorization scheme from sources such as ASHRAE 90.1, CA Title 24, GSA, or Omniclass Tables 11 and 13.

It is not clear yet how far the encoded business rules can express this requirement, but the rules include:

- The classification shall be to Omniclass 2010 Tables.
- Buildings shall be classified to Omniclass 2010 Table 11
- The Spaces (and Zones) shall be classified to Omniclass 2010 Table 13
- The Systems shall be classified to Omniclass 2010 Table 21
- The Types and Materials shall be classified to Omniclass 2010 Table 23

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14. ABSTRACT <p>In previous work, building information models (BIMs) were developed for three buildings: Duplex Apartment, Office, and Clinic. However, the models were developed inconsistently and contain differing levels of detail and quality of content across disciplines. One reason for these differences was the lack of an ontology that describes the specific requirements for life-cycle modeling for the heating, ventilating, and air conditioning (HVAC) domain. The objective of the work described here was to develop an ontology for the design phase of typical HVAC systems found in low-rise Army facilities.</p> <p>This report documents the process modeling and data-exchange requirements of HVAC engineering design practice, following Information Delivery Manual (IDM) and Model View Definition (MVD) procedures defined by the International Organization for Standardization (ISO) and the buildingSMART Alliance.</p>					
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