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Life-Cycle Model of Mission-Ready and Sustainable Facilities—Planning Space Resource Utilization

COBie Representation of Resource Demands for Mission-Ready and Sustainable Facilities

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May 2012

Prepared under Contract W9132T-06-D-0005 (0002)
under the supervision of

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Construction Engineering
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COBie Representation of Resource Demands for Mission-Ready and Sustainable Facilities

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Abstract: This report documents work performed under contract for the US Army Engineer Research and Development Center by researchers at Arizona State University to support the development of technology that can describe the use of a building's space resources. The specific purpose of this work was to create schedules of building space attributes, in the form of tables; and the requirements for different types and combinations of facilities constructed for the Army. Such information can be used to compare real-world facility user behavior with predicted facility resource consumption as part of a methodology for optimizing building space utilization to improve mission readiness and sustainability.

The research addressed the process of using the existing structure of the Construction Operations Building information exchange (COBie) data specification to add information relevant to planning space resource utilization. The example provided was for a standard family housing duplex unit. In addition, the use of COBie as a tool for testing enhancements to the Industry Foundation Class (IFC) schema has been demonstrated.

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Preface

This study was performed by Arizona State University, Tempe, AZ, for the US Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL) under Contract W9132T-06-D-0005 (0002), "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), US Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL). The project manager and technical reviewer was E. William East, CEERD-CF-N. At the time of publication, Donald K. Hicks was Chief, CEERD-CF-N; L. Michael Golish was Chief, CEERD-CF; and Martin J. Savoie 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
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (US liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters

1 Introduction

1.1 Background

The US Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) is conducting research into the Life-Cycle Modeling of Mission-Ready and Sustainable Army Facilities. One thrust of that research is to establish the mechanism to predict the expected use of resources in a facility. The overall purpose of this work was to create schedules (tables) of building space attributes and the requirements (in terms of necessary equipment, electrical power and water) for different types and combinations of Army facilities. With such information, actual user behavior may be compared against this predicted facility resource consumption.

1.2 Objectives

The objective of this research is to create the framework for the delivery of building space attributes related to required heating load, required cooling load, required electrical power, and required water use for Army facilities. Attributes and requirements are checked against the Unified Facility Criteria (UFC), the Uniform Facility Guide Specifications (UFGS) and vendor criteria standards as appropriate when facility components do not have specific guidance. The family housing duplex is used to provide the primary example.

1.3 Approach

The information supplied initially included COBie files and a building information model (BIM) with industry foundation class (IFc) objects . Information regarding resource-consuming devices was taken from these documents and transferred to an excel files for the team's internal use to verify data organization and completeness. After reviewing the information from the documents that were provided, it was discovered that the drawings and COBie information were incomplete with respect to capturing all the resource-consuming devices that should/could be included in the facilities. Additional information was gathered from the following sources: the Unified Facility Criteria (UFC), the Unified Facilities Guide Specifications (UFGS), Energy Star and assumptions as determined by the ASU researchers.

The next step was to find the resource consumption of the devices that were noted and/or determined to be within the duplex. This data was collected through the documents provided and researching products through Energy Star and external websites. Information that was collected was then structured to match the COBie format requirements. Data specification sheets used for references were linked via attachments (hyperlinks) to the various resource components. This step concluded with reviewing the new updated information that was received and inputting it into the COBie data sheets.

The final step consisted of validating the data framework by calculating the water and electricity consumption for an average day (winter and summer separately) at various levels of detail (room, zone, building). The completeness of the representation of the building occupancy was also tested.

1.4 Scope

This report documents the process of using the existing COBie data structure for adding information relevant to planning space resource utilization for a family housing duplex unit, namely data related to heating, cooling, electrical power, and water for any Army facility. In addition, the use of COBie as a tool for testing enhancements to the IFc schema has been demonstrated.

Depending on the stage of completion of a building, the COBie data specification schema may provide over 30 separate data structures (i.e., *worksheets*) in a COBie file [East 2007]. The information relevant to the definition of the facility is the responsibility of the designer and hence will be found in the combined set of Early Design Worksheets, Detailed Design Worksheets and All Phases Worksheets. This combined set is composed of the following worksheets: Facility, Floor, Space, Zone, Type, Component, system, Document, Attribute, Connection, Coordinate and Issue. Note that COBie does not provide a separate data structure (i.e., worksheet) for the occupancy information of the building. However, the data structure is flexible enough to allow the capturing of the building occupancy and resource consumption by using solely the existing data structure. This report discusses the steps involved in capturing the aforementioned information by using the example of a duplex apartment building. All other buildings will follow a similar scenario.

To facilitate the understanding of the approach described in this report, we will follow the common practice of presenting the COBie specification in the form of a spreadsheet (workbook with worksheets). It should be noted that COBie is a data specification schema (i.e., a normalized relational database) and not a functional spreadsheet. The worksheet format is used only because the data structure is easier to present this way. In the early examples in this report we will also point out how the relationships are implicitly represented in the worksheet representation. For the later examples, we will assume that the reader is familiar with the representation and the implied relationships will not be explicitly presented.

The Excel format COBie file (COBie version 2.26) containing the information referred to in this report can be downloaded from the web site of the Building Smart Alliance (NIBS 2012). The building used as an example throughout this report is a duplex apartment building with rooms as presented in Table 1.

Table 1. Rooms and floors for the duplex building used as an example in this report.

Flat	FloorName	(Room)Name	Description
1	Floor_1	F1-101	Lounge in flat 1
		F1-102	Kitchen-Diner
		F1-103	Shower
		F1-104	Entrance
	Floor_2	F2-105	Bedroom 2
		F2-106	Bedroom 1
		F2-107	Bathroom
		F2-108	Hallway
2	Floor_1	F1-201	Lounge in flat 2
		F1-202	Kitchen-Diner
		F1-203	Shower
		F1-204	Entrance
	Floor_2	F2-205	Bedroom1
		F2-206	Bedroom 2
		F2-207	Bathroom
		F2-208	Hallway

Note that Table 1 is the result of merging three of the worksheets in the COBie file: Floor, where Floor_1 and Floor_2 are uniquely defined (see Table 2); Space, where each of the numbered space is uniquely defined, and the floor to which the space belongs is indicated (see Table 3); and Zone, where the flats and their rooms are defined (see Table 4).

Table 2. Excerpt from COBie worksheet Floor for the duplex (not all columns reproduced).

Name	CreatedBy	CreatedOn	Category
Foundations	v..	2..	Site
Floor_1	v..	2..	Floor
Floor_2	v..	2..	Floor
Roof	v..	2..	Roof

Table 3. Excerpt from COBie worksheet Space for the duplex (not all columns reproduced).

Name	CreatedBy	CreatedOn	Category	FloorName	Description	NetArea
F1-101	v..	2..	13-51 24 11: General Residential Space	Floor_1	Lounge in flat 1	27.84
F1-201	v..	2..	13-51 24 11: General Residential Space	Floor_1	Lounge in flat 2	27.84
F1-103	v..	2..	13-41 11 14 14: Shower	Floor_1	Shower	3.28
F1-203	v..	2..	13-41 11 14 14: Shower	Floor_1	Shower	3.28
F1-204	v..	2..	13-85 11 11: Corridor	Floor_1	Entrance	19.72
F1-202	v..	2..	13-11 19 11 11: Kitchen	Floor_1	Kitchen-Diner	13.915
F1-102	v..	2..	13-11 19 11 11: Kitchen	Floor_1	Kitchen-Diner	13.92
F1-104	v..	2..	13-85 11 11: Corridor	Floor_1	Entrance	19.72
F2-207	v..	2..	13-41 11 14 11: Bathroom	Floor_2	Bathroom	6.56
F2-107	v..	2..	13-41 11 14 11: Bathroom	Floor_2	Bathroom	6.56
F2-205	v..	2..	13-51 21 11: Bedroom	Floor_2	Bedroom1	22.62
F2-208	v..	2..	13-85 11 11: Corridor	Floor_2	Hallway	7.445
F2-206	v..	2..	13-51 21 11: Bedroom	Floor_2	Bedroom 2	22.62
F2-106	v..	2..	13-51 21 11: Bedroom	Floor_2	Bedroom 1	22.62
F2-108	v..	2..	13-85 11 11: Corridor	Floor_2	Hallway	7.445
F2-105	v..	2..	13-51 21 11: Bedroom	Floor_2	Bedroom 2	22.62

Table 4. Excerpt from COBie worksheet Zone for the duplex (not all columns reproduced).

Name	CreatedBy	CreatedOn	Category	SpaceNames
Flat_1	v..	2..	Occupancy Zone: Occupancy Zone	F1-101, F1-102, F1-103, F1-104, F2-105, F2-106, F2-107, F2-108,
Flat_2	v..	2..	Occupancy Zone: Occupancy Zone	F1-201, F1-202, F1-203, F1-204, F2-205, F2-206, F2-207, F2-208,

2 Building Occupancy

Predicting, tracking and comparing the resource consumption of built facilities are only meaningful in the context of the intended use of the facility. The expected consumption of resources is a result of the physical characteristics of the facility, the resource-consuming or dispensing devices installed in the facility, and their schedule of operation. The schedule of operation, in turn, is a function of the activities that are taking place in the facility and the facility management policy.

All this information is readily understood at the time when the building program is conceived, but only some of it is explicitly captured. It appears that the level of specification decreases with the "commonness" of the building. For instance, in the current practice, there is no need to detail all the activities that take place in a residential building. Specifying the number of bedrooms and the size of the dwelling unit will provide architects with enough information to generate the first sketches of the building's layout. A medical center will require some specification of the services that will be offered and the number of expected patients or service providers. For more unique facilities, such as a fabricating facility, there will be a higher degree of explicit description of the building users (both people and equipment), their activities and the specific requirements of those users. Many of these requirements are expressed because they require specialized resource delivery systems (such as purified water or air or specialty fluids) and thus require additional consultants on the design team.

Nevertheless, in the most common buildings the design program (i.e., a description of the users and their needs) is a document simple enough to not be included in the BIM model. For those buildings, however, there is enough knowledge of the users' behavior to allow bypassing the need of a detailed analysis of the influence of the users' activities on the schedule of the resource-consuming devices. Even for more complex buildings, the design program is usually a spreadsheet describing the rooms, their purpose and adjacency matrix, but rarely the schedule of the activities taking place in them and the specific schedule of the building performance requirements. Such an analysis is possible, as proved by Wiezel and Becker

(1996), but not necessary for assessing the resource needs of a "common" building.

This report focuses on the data required to assess the resource consumption of buildings for which the schedule of the building performance requirements is known. One such schedule for instance is the temperature setting (i.e., requirement) in each of the zones of the building.

For any given location, the resource utilization of a building is primarily driven by the physical characteristics of the building, the building occupancy (defined here as the type and number of the building users, their activities and the duration of those activities) and the facility management policies. These three factors are interrelated, as the facility management policies tend to respond to the needs of the users and to the capacity (or the lack of capacity) of the building to fulfill those needs by natural means. For instance, facility management policies may be set up take advantage of natural lighting where available.

The physical characteristics of the building are usually adequately represented through the IFc. This section refers to the representation of the building occupancy. The representation of the facility management policy will be addressed at a later stage and thus it is not a part of this report.

The occupancy of the building can be captured in the sheet Attribute as shown in Table 5.

Table 5. Occupancy information for a Duplex (excerpt from the sheet Attribute, not all columns reproduced).

Name	CreatedBy	CreatedOn	Category	SheetName	RowName	Value	Unit
OccupancyClassification	a..	2..	Req.	Facility	Duplex Apartment	R-3	n/a
OccupancyNumber	a..	2..	Req.	Zone	Flat_1	4	people
OccupancyNumber	a..	2..	Req.	Zone	Flat_2	4	people
OccupancyNumberPeak	a..	2..	Req.	Zone	Flat_1	7	people
OccupancyNumberPeak	a..	2..	Req.	Zone	Flat_2	7	people
OccupancyDurationPerDay	a..	2..	Req.	Zone	Flat_1	15	hours
OccupancyDurationPerDay	a..	2..	Req.	Zone	Flat_2	15	hours

A first indicator of the building occupancy is the destination of the building (Occupancy Classification). According to the International Building Code (IBC Section 3), the occupancy classification of the duplex is R-3 - Residential: one or two dwelling units.

In terms of data structure, the unique key-field is a combination (concatenation) of the fields Name, SheetName, RowName, and Unit. For instance, the value of this concatenated key filed (the information that appears only once in this worksheet) for row #5 in Table 5 is OccupancyNumberPeak & Zone & Flat_2& People. In plain English, row # 5 in Table 5 means "The maximum occupancy of Flat #2 in the Duplex is 7 people". Note that in this data set there is only one duplex, only one Flat #2 and the information about the maximum occupancy for Flat #2 in the Duplex will appear only once in the whole workbook. The references to each unique instance (DuplexApartment, Flat_2) are normally maintained through the relationships defined in a relational database. As stated before, in the workbook representation of the COBie specification schema, these relationships are only represented implicitly and special care should be taken by the user when defining new entries.

It should be noted that facilities can have several categories of users and thus, there will be more values for each of the parameters described in Table 5. For instance, in a clinic, the types of occupants consist of Patients, Physicians, Dentists, Dental Lab Technicians, X-Ray Technicians, Administrators, Office Personnel, etc. All these users will be included in the worksheet PickLists in column OccupancyUnit. See Chapter 6 and Table 14 for more details. The occupancy information for a medical clinic where the dentistry is placed in (say) zone Occupancy Zone 2A, may look like the one presented in Table 6.

Not each of these users spends the whole specified time in the building. For instance, in the case of the clinic presented in Table 6, the meaning of 72 patients for 10 hours per day is not that each one of the 72 patients spends 10 hours at the clinic but that during 10 hours the clinic receives 72 patients. The duration of each visit is addressed starting in Chapter 7. A stochastic approach may be required for determining the distributing of the resource consumption thought the day. This problem shall be addressed by subsequent efforts.

Table 6. Sample occupancy information for dentistry zone in a medical clinic– Excerpt from the sheet Attribute (not all rows and columns reproduced).

Name	CreatedBy	CreatedOn	Category	SheetName	RowName	Value	Unit
OccupancyNumber	a..	2..	Req..	Zone	Occupancy Zone 2A	2	Dental Lab Technicians
OccupancyNumber	a..	2..	Req..	Zone	Occupancy Zone 2A	3	Dentists
OccupancyNumber	a..	2..	Req..	Zone	Occupancy Zone 2A	72	Patients
OccupancyNumber	a..	2..	Req..	Zone	Occupancy Zone 2A	1	X-Ray Technicians
OccupancyDurationPerDay	a..	2..	Req..	Zone	Occupancy Zone 2A	10	hours

3 Resource-Consuming Devices

Only two types of resources are consumed in the facility used as an example in this report (the building DuplexApartment). Those two resources are water and electricity. Other types of resources, such as natural gas, heating oil, specialty gasses or different qualities of water (such as potable or gray), may be present in other buildings. The representation of the consumption of those resources will follow a similar pattern with the one presented for water and electricity.

The consumption of resources takes place through resource-consuming devices. Most of the resource-consuming devices are readily represented in the COBie files, in the worksheets Type and Component. While there is no explicit indication if a component represents a resource-consuming device (as opposed to being "just a component"), the resource-consuming devices can be easily identified. For instance, for the types of resource-consuming devices (components) that appear in the COBie file for the Duplex are reproduced in Table 7.

Table 7.Types of resource-consuming devices information for a Duplex – Excerpt from the sheet Type (not all columns reproduced).

Name	CreatedBy	CreatedOn	Category
Candelabra_6_lights	v..	2..	23-80 70 11 11: General Luminaries: Non Directional
Combi_Boiler	v..	2..	23-75 10 11 14 17: Finned Water-Tube Boilers
ElectricHandDryer	v..	2..	23-40 20 21 14: Hand and Hair Dryers
Shower_900x900	v..	2..	23-25 40 14 14 14 17: Plastic Shower and Dressing Compartments
Tub_750x1600	v..	2..	23-45 05 14 21: Bathtubs
Wall_light_duo	v..	2..	23-80 70 11 11: General Luminaries: Non Directional
Washbasin_330x450	v..	2..	23-45 05 14 14: Sinks/Lavatories
Washbasin_380dia	v..	2..	23-45 05 14 14: Sinks/Lavatories
WC_370x550	v..	2..	23-45 05 21 11 11: Water Operated Water Closets
Refrigerator	v..	2..	23-40 40 11 11: Refrigerators and Freezers
Range	v..	2..	23-40 40 14 17 17: Ranges
Dishwasher	v..	2..	23-45 30 11 11: Residential Dishwashers

In spreadsheet Type (and in the excerpt presented in Table 7), the column Category refers to the OmniClass [OCCS 2012] of the component. The OmniClass codes can be used to create a dictionary of resource-consuming devices that can be applied for automating the process of identifying the components relevant to resource consumption.

It is worth noting a number of decisions that may not seem intuitive to the casual reader.

a. There are some components that are related to resource consumption but are not real consumers of the resource. Table 8 presents the components purposefully omitted from Table 7. The particular type of radiators presented are circulating hot water, which in turn is heated by the combi boiler. The amount of energy used by the boiler is dependent upon the amount of the water used and the heating load required by the building. This issue is discussed further in Chapter 10 (see Figure 5).

b. It can be argued that the water consumptions of the shower, tub and washbasins are actually taken place at the faucets installed for these components, i.e., at the distribution point. Another argument can be made that the consumption takes place at the collection point (the receptacles or the basin). Since the water distribution system is designed (and hence represented) later in the process, it is more advantageous to link the water consumption to the receptacles.

Table 8. Non-resource-consuming devices that were purposely omitted from Table 6.

Name	CreatedBy	CreatedOn	Category
Radiator_450x1195	v..	2..	23-75 70 17 24: Finned-Tube Radiation
Radiator_500x764	v..	2..	23-75 70 17 24: Finned-Tube Radiation
Thermostat	v..	2..	23-75 65 14 14 11: Temperature Controls

4 Verification of Data Completeness

To ensure a correct evaluation of the resource demands of a building it is important to verify that all the resource-consuming devices have been taken into account. This verification is even more important when COBie is used as the base for evaluating the resource demands. Since COBie is intended to accompany the whole life cycle of the building, beginning with the very early stages of design, it is very probable that, during the design stage, a number of energy-consuming devices are not yet represented in the model, even though there is implicit knowledge about their future existence. It is also possible for the designers / modelers to omit resource-consuming devices either by mistake or because the need for their representation was not specifically required.

Two separate, but interrelated checks need to be performed to identify possible omissions: (a) by device type and (b) by room. Table 9 and Table 10 represent the two checks for the Duplex. The type of resources consumed by these devices is marked with E for electricity and W for water.

Table 9. Resource-consuming devices identified from the COBie file – Verification by device.

TypeName	Resource	Flat	Space	RoomType	Name_In_COBie
Candelabra_6_lights	E	1	F1-101	Lounge in flat 1	Candelabra_6_lights.F1-101
			F2-105	Bedroom 2	Candelabra_6_lights.F2-105
			F2-106	Bedroom 1	Candelabra_6_lights.F2-106
		2	F1-201	Lounge in flat 2	Candelabra_6_lights.F1-201
			F2-205	Bedroom1	Candelabra_6_lights.F2-205
			F2-206	Bedroom 2	Candelabra_6_lights.F2-206
Combi_Boiler	E	1	F2-107	Bathroom	CombiBoiler.F2-107
		2	F2-207	Bathroom	CombiBoiler.F2-207
Dishwasher	E, W	1	F1-102	Kitchen-Diner	Dishwasher_F1-102
		2	F1-202	Kitchen-Diner	Dishwasher_F1-202
ElectricHandDryer	E	1	F1-103	Shower	ElectricHandDryer.F1-103
		2	F1-203	Shower	ElectricHandDryer.F1-203
Range	E	1	F1-102	Kitchen-Diner	Range_F1-102
		2	F1-202	Kitchen-Diner	Range_F1-202
Refrigerator	E	1	F1-102	Kitchen-Diner	Refrigerator_F1-102
		2	F1-202	Kitchen-Diner	Refrigerator_F1-202
Shower_900x900	W	1	F1-103	Shower	Shower_103.F1-103
		2	F1-203	Shower	Shower_203.F1-203
Tub_750x1600	W	1	F2-107	Bathroom	Tub_107.F2-107

TypeName	Resource	Flat	Space	RoomType	Name_In_COBie
		2	F2-207	Bathroom	Tub_207.F2-207
Wall_light_duo	E	1	F1-104	Entrance	Wall_light_duo.F1-104
			F2-107	Bathroom	Wall_light_duo.F2-107
		2	F1-204	Entrance	Wall_light_duo.F1-204
			F2-207	Bathroom	Wall_light_duo.F2-207
Washbasin_330x450	W	1	F1-103	Shower	Washbasin_103.F1-103
		2	F1-203	Shower	Washbasin_203.F1-203
Washbasin_380dia	W	1	F2-107	Bathroom	Washbasin_1071.F2-107
			F2-107	Bathroom	Washbasin_1072.F2-107
		2	F2-207	Bathroom	Washbasin_2071.F2-207
			F2-207	Bathroom	Washbasin_2072.F2-207
WC_370x550	W	1	F1-103	Shower	WC_103.F1-103
			F2-107	Bathroom	WC_107.F2-107
		2	F1-203	Shower	WC_203.F1-203
			F2-207	Bathroom	WC_207.F2-207

Note that the resource used by each type of device (electricity or water) is only marked for the purpose of the completeness verification and there is no need to represent the resource in COBie. The types or resources used by each component are indicated in COBie through the consumption rates. For more details see Chapter 7.

Table 10. Resource-consuming devices identified from the COBie file – Verification by room.

Flat	Space	RoomType	TypeName	Name_In_COBie
1	F1-101	Lounge in flat 1	Candelabra_6_lights	Candelabra_6_lights.F1-101
	F1-102	Kitchen-Diner	Dishwasher	Dishwasher_F1-102
			Range	Range_F1-102
			Refrigerator	Refrigerator_F1-102
	F1-103	Shower	ElectricHandDryer	ElectricHandDryer.F1-103
			Shower_900x900	Shower_103.F1-103
			Washbasin_330x450	Washbasin_103.F1-103
			WC_370x550	WC_103.F1-103
	F1-104	Entrance	Wall_light_duo	Wall_light_duo.F1-104
	F2-105	Bedroom 2	Candelabra_6_lights	Candelabra_6_lights.F2-105
	F2-106	Bedroom 1	Candelabra_6_lights	Candelabra_6_lights.F2-106
	F2-107	Bathroom	Combi_Boiler	CombiBoiler.F2-107
			Tub_750x1600	Tub_107.F2-107
			Wall_light_duo	Wall_light_duo.F2-107
			Washbasin_380dia	Washbasin_1071.F2-107
			Washbasin_380dia	Washbasin_1072.F2-107
			WC_370x551	WC_107.F2-107
2	F1-201	Lounge in flat 2	Candelabra_6_lights	Candelabra_6_lights.F1-201

Flat	Space	RoomType	TypeName	Name_In_COBie
	F1-202	Kitchen-Diner	Dishwasher	Dishwasher_F1-202
			Range	Range_F1-202
			Refrigerator	Refrigerator_F1-202
	F1-203	Shower	ElectricHandDryer	ElectricHandDryer.F1-203
			Shower_900x901	Shower_203.F1-203
			Washbasin_330x451	Washbasin_203.F1-203
			WC_370x552	WC_203.F1-203
	F1-204	Entrance	Wall_light_duo	Wall_light_duo.F1-204
	F2-205	Bedroom1	Candelabra_6_lights	Candelabra_6_lights.F2-205
	F2-206	Bedroom 2	Candelabra_6_lights	Candelabra_6_lights.F2-206
	F2-207	Bathroom	Combi_Boiler	CombiBoiler.F2-207
			Tub_750x1601	Tub_207.F2-207
			Wall_light_duo	Wall_light_duo.F2-207
			Washbasin_380dia	Washbasin_2071.F2-207
			Washbasin_380dia	Washbasin_2072.F2-207
			WC_370x553	WC_207.F2-207

The only device consuming both electricity and water in Table 9 is the Dishwasher (Dishwasher_F1-102 and Dishwasher_F1-202). The Combi Boilers (CombiBoiler.F2-207 and CombiBoiler.F2-107) use only electric energy (E) because they only heat the water but they are not water-consuming devices. The energy the boiler uses to heat the water is proportional with the hot water used by the other devices. The data used for calculation of the electric energy for water heating is presented in Chapter 7.

From Table 10 one can notice that the kitchen sink in each Kitchen-Diner (F1-102 and F1-202) was omitted. The kitchen sink (a hot and cold water-consuming device) will be used as an example of how omitted resource-consuming devices (components) can be added manually to the COBie file.

Additional resource-consuming devices that need to be added for a complete assessment of the resource consumption are lighting in kitchen and shower and user furnished devices (TVs, computers, toasters, etc.). Since the purpose of this report is to present the data structure for the representation of resource demands, rather than calculating the demands themselves, we will use the kitchen sink as the only example of missing devices. All other additional devices will follow a similar path.

5 Adding Devices in COBie

The steps to follow when adding a new device to the COBie data file are described below. Note that special care should be taken to maintain the compatibility of the data with the data structure.

Also note that since the data is added manually, in every worksheet where links to external references are required the newly added data vector (the row where the data is entered) data will contain the value n/a in columns ExtSystem, ExtObject and ExtIdentifier.

1. In the Contact worksheet, add email and personal information about the individual performing the operation.
2. In the worksheet Type, add the device type. In the case presented here the Kitchen_Sink was added to the worksheet Type, as shown in Table 11.

Table 11. Adding a new resource type to the worksheet Type (not all columns and rows reproduced).

Name	CreatedBy	CreatedOn	Category	Description	AssetType	...	ExtSystem	ExtObject	ExtIdentifier
Kitchen_Sink	a..	2..	23-45 05 14 14: Sinks/Lavatories	Kitchen Sink	Fixed		n/a	n/a	n/a

3. Add the component instances to the Component sheet. In our example the kitchen sink should have been present in rooms 102 and 202 (one kitchen in each of the two apartments), so we add Kitchen_Sink.F1-102 and Kitchen_Sink.F1-202, as shown in Table 12.

Table 12. Adding a new Components the worksheet Component
(not all columns and rows reproduced).

Name	CreatedBy	CreatedOn	TypeName	Space	Description	ExtSystem	ExtObject	ExtIdentifier
Kitchen_Sink. F1-102	a..	a..	Kitchen_Sink	F1-102	Kitchen Sink	n/a	n/a	n/a
Kitchen_Sink. F1-202	a..	a..	Kitchen_Sink	F1-202	Kitchen Sink	n/a	n/a	n/a

4. On worksheet System add the component instances to list of the components in each of the systems that the new component belongs to. In our example these systems are Flat_1_Plumbing and Flat_2_Plumbing respectively. Note for instance how in column ComponentNames the Flat_1_Plumbing (system) contains the Kitchen_Sink.F1-102 at the end of the list: Shower_103.F1-103, Tub_107.F2-107, WC_103.F1-103, WC_107.F2-107, Washbasin_103.F1-103, Washbasin_1071.F2-107, Washbasin_1072.F2-107, **Kitchen_Sink.F1-102**. See Table 13.

Table 13. Adding a new Components the worksheet System
(not all columns and rows reproduced).

Name	CreatedBy	CreatedOn	Category	ComponentNames
Flat_1_Plumbing	a..	2..	21-51 31 11: Water for Single Facility	Shower_103.F1-103, Tub_107.F2-107, WC_103.F1-103, WC_107.F2-107, Washbasin_103.F1-103, Washbasin_1071.F2-107, Washbasin_1072.F2-107, **Kitchen_Sink.F1-102**
Flat_2_Plumbing	a..	2..	21-51 31 11: Water for Single Facility	Shower_203.F1-203, Tub_207.F2-207, WC_203.F1-203, WC_207.F2-207, Washbasin_203.F1-203, Washbasin_2071.F2-207, Washbasin_2072.F2-207, **Kitchen_Sink.F1-202**

6 Additional PickLists.

A number of measuring units need to be added to the COBie file to represent the parameters of resource consumption. The type of measuring units and their denominations are presented in Table 14. Note that each column in the worksheet PickLists is a named range and is used as a list for data validation (any unit used in the COBie file can be found in the worksheet PickList). This requirement is necessary for ensuring consistency among the values and to allow an automatic conversion of the data.

For instance, referring to the first column in Table 14 , FlowRateUnit will be not only the heading of the column, but also the name of the range defined by the whole column. Assuming that the column FlowRateUnit is in the Excel column AW, the definition of the range FlowRateUnit will be =PickLists!$AW:$AW. The reason behind defining the named range as the whole column rather than only cells that contain data (for instance the first three rows for FlowRateUnit=PickLists!$AW$1:$AW$3), is to ensure that all the units that are later defined are automatically included in the pick list.

The values in the picklist (gpm ,liter/min and gal/day for the FlowRateUnit in Table 14) prevent arbitrary use of synonyms. For instance, the unit liter/minute could have been also defined as l/min, or lpmin or lpm. Other units such as m^3/h, can be added later if needed. Once the uniqueness of each unit has been insured, the conversion of the values can be performed automatically by searching all the values measured by the measuring unit to be converted. Consider for instance the daily water consumption of 5.8 gal/day for the Dishwasher_F1-102 (Table 21, row 4). Converting the units to the metric system will consist of applying the conversion factor of 1 gal/day = 0.00378541178 m^3/day, so the 5.8 gal/day will become 0.021955388324 m^3/day.

Table 14. Additional measuring units in worksheet PickLists.

FlowRateUnit	OccupancyUnit	TemperatureUnit	EnergyUnit	PowerUnit	Ratio
gpm	people	°F	KWh	KW	%
liter/min	Administrators	°C	BTU	HP	Ratio
gal/day	Dental Lab Technicians		Joules	KWh/day	
m^3/day	Dentists				
	Office Personnel				
	Patients				
	Physicians				
	X-Ray Technicians				

As stated in Chapter 2, some facilities may have several categories of users. For those buildings the column OccupancyUnit will include the description of each type of user. For instance, in a medical clinic, the users may be Patients, Physicians, Dentists, Dental Lab Technicians, X-Ray Technicians, Administrators, Office Personnel, etc. This differentiation of the types of users is required for calculating the effect of occupancy changes in the building. For instance, the calculation of the number of uses per day for an X-Ray machine is dependent on the duration of an X-Ray test, the number available X-Ray machines, number of patients and the number of X-Ray technicians available. While COBie is not intended to provide of store the calculation formulas, COBie is required to store the data required for such calculations.

This section will present the COBie data structure for each of the 8 categories of resource-consuming devices presented in Chapter 7.

All the consumption data is added to the worksheet Attribute. The unique key for the added data (i.e., the information that appears only once in the worksheet) is the concatenation of the fields Name and RowName.

7 Parameters for Resource Consumption

When considering the risk of overload on the service interruption, consumable resources fall into one of the following two categories: high and low. For instance, if all the high consumption electric devices are turned on simultaneously, there is a chance of surpassing the capacity of the system and triggering the overload protection (breaker). In this case all the electricity-consuming devices in the affected system would be shut down. To predict / avoid such situation, the capturing of the electricity consumption data needs to have a temporal component, i.e., when during the day is the electricity consumption taken place.

On the other hand, if water-consuming devices are all turned on simultaneously, the effect will be a reduction of the water pressure, but not all the water-consuming devices in that system will be automatically shut down. For these devices, the representation of the time interval when the actual consumption takes place is not as critical.

In the next sections we will present first the resources that are not time-critical (water), then the ones that are time-critical (electricity). The data structure for capturing this information will be provided in section 8.

7.1 Water consumption

For each water-consuming device, the water consumption depends on the activities of the occupants, the number of occupants of the zone, the duration of the occupancy and the number of available similar devices in the zone (apartment). For instance, if we consider that a person visits (uses) the toilet 6 times per day, but occupies the apartment only 15 hours per day, we can assume that in a given apartment there will be 4 visits to the toilet per person per day. If we have 3 people in the apartment and two available toilets, the number of visits (uses) per toilet per day will be: 4 x 3 / 2 = 6. Showers and sinks are treated in a similar way, except that for them the duration of each visit is also a variable. Also, if some dissimilar devices may perform similar functions (such as tub and shower, or different types of sinks), they are treated as similar. Note that this calculation and reasoning is performed outside the COBie data structure and only the results of the calculations are represented in the data exchange files.

Below are the tables of the water-consuming devices, examples of calculation and the data that needs to be included in the COBie files.

7.1.1 Parameters for water-consuming devices with consumption independent of the duration of each use

Water-consuming devices with consumption independent of the duration of each use are presented in Table 15. In this case it was assumed that, for sanitary reasons, the family occupying the apartment will use the dishwasher at the end of the day, whether there is a full load or not. For higher occupancy there may be more than one load of dishes per day.

As shown in Table 9, the dishwasher is a consumer of water and electricity. The electricity consumption of the dishwasher is shown separately in Table 17.

Table 15. Water-consuming devices with consumption semi-dependent on the occupancy

Parameter	Instance 1	Instance 2
Type	Dishwasher	WC_370x550
DailyWaterUsage	5.8 gal	19 gal
DailyHotWaterUsage	5.8 gal	0 gal
UsersPerZone	4 people	4 people
DevicesPerZone	1	2
UsersPerDevice	4	2
DailyVisitsPerUser	1	6
DailyUses	1	12
HotWaterInMix	100%	0%
VisitWaterUsage	5.8 gal	1.6 gal
Documents	UFGS 2.1.17 pg. 9	UFGS 2.4.3 pg. 34

Note that the water (and electricity) consumption per load of the Dishwasher is a constant. This type of resource-consuming device will be referred to as “consuming device with consumption independent of the duration of each visit.”

7.1.2 Parameters for water-consuming devices with consumption dependent on the duration of the visit

A second type of water-consuming devices consists of the devices whose consumption is dependent on the duration of the visit. Information relative to the duration of the visit and the water flow rate has to be provided.

See Table 16 for the water-consuming devices with consumption depending on the duration of each visit in the duplex.

Table 16. Water-consuming devices with consumption depending on the duration of each visit.

Parameter	Instance 1	Instance 2	Instance 3	Instance 4	Instance 5
Type	Kitchen_ Sink	Shower_ 900x900	Tub_ 750x 1600	Washbasin_ 330x450	Washbasin_ 380dia
DailyWaterUsage	24 gal	40 gal	40 gal	10 gal	10 gal
DailyHotWaterUsage	12 gal	20 gal	20 gal	5 gal	5 gal
UsersPerZone	4 people	4 people	4 people	4 people	4 people
DevicesPerZone	1	2	2	2	2
UsersPerDevice	4	2	2	2	2
DailyUses	12	2	2	2	2
DailyVisitsPerUser	3	1	1	1	1
HotWaterInMix	0.5	50%	50%	50%	50%
VisitWaterUsage	2 gal	20 gal	20 gal	5 gal	5 gal
VisitDuration	2 min	10 min	10 min	2 min	2 min
WaterFlowRate	1 gpm	2 gpm	2 gpm	1 gpm	1 gpm
Documents	UFGS 2.4.12 pg. 37	UFGS 2.4.16 pg. 38	UFGS 2.4.16 pg. 38	UFGS 2.4.11 pg. 37	UFGS 2.4.11 pg. 37

7.2 Electricity consumption

Similar to water-consuming devices, electricity-consuming devices can fall in one of several categories. Whether a specific electricity-consuming device falls in one category or another is a function of the facility management policy. For the duplex, the policy is implicitly set by the living habits of the occupants. For facilities that are professionally managed (by facility managers), those policies may be explicitly set. These policies may include lighting, heating and cooling distribution of services in the facilities in case of underutilization, etc.

One simple example of such a facility management policy was already presented for the dishwasher, in section 7.1.1: “the family occupying the apartment will use the dishwasher at the end of the day, whether there is a full load or not.” Time wise, this policy translates into operating the dishwasher once every day, between the hours on 7:00 pm (19:00 hours in military time) and 9:00 pm (21:00 hours in military time).

7.2.1 Parameters for electricity-consuming devices with consumption

dependent on the occupancy

The Dishwasher, together with the Cooking Range and Refrigerator, fall into the category of electricity-consuming devices for which it is practically impossible to predict exactly when during the day the electricity consumption will take place. Each of these devices is governed by an internal thermostat, and hence the exact time when the device is using electricity needs to be simulated stochastically. The data required for storing the daily electricity consumption (usage) and the data needed for stochastic calculations of electricity peaks is presented in Table 17. Note that the correlation between the daily electricity usage and the number of persons per device is not linear. For instance, the dishwasher will be most probably operated only once a day whether there are 3 or 4 members in the family. Due to the non-linearity of the relationship between the daily electricity use and the number of occupants, this particular category of devices does not have a parameter representing the number of visits (uses) per day. While there certainly is a connection between the electricity consumption and the number of times a refrigerator door is opened, this relationship is not part of the scope of the COBie representation.

Table 17. Electricity-consuming devices with consumption dependent on occupancy.

Parameter	Instance 1	Instance 2	Instance 3
Type	Dishwasher	Range	Refrigerator
DailyElectricityUsageSummer	1 kwh	2 kwh	1.3 kwh
DailyElectricityUsageWinter	1 kwh	2 kwh	1.1 kwh
UsersPerZone	4 people	4 people	4 people
DevicesPerZone	1	1	1
UsersPerDevice	4 people	4 people	4 people
ElectricPowerAverage	1 kw	1.5 kw	0.5 kw
ElectricPowerAverageDuration	0.5 hrs	1 hr	0.3 hrs
ElectricPowerPeak	1.5 kw	11 kw	0.7 kw
ElectricPowerPeakDuration	0.5 hrs	0.1 hrs	0.01 hr
ElectricityNeedStartTime	19:00	6:00	0:00
ElectricityNeedEndTime	21:00	21:00	23:59

7.2.2 Parameters for electricity-consuming devices with consumption dependent on the number of uses per day

Another category of electricity-consuming devices are the ones that have the consumption linearly dependent on the number of uses. For these consuming devices the number of uses per person is an important parameter.

Table 18 shows the data for electricity consumption that is depend on the number of uses per day.

Table 18. Electricity-consuming devices with consumption dependent on the number of uses per day.

Parameter	Instance 1
Type	Electric Hand Dryer
DailyElectricityUsageSummer	0.22 kwh
DailyElectricityUsageWinter	0.22 kwh
UsersPerZone	4 people
DevicesPerZone	1
UsersPerDevice	4 people
DailyVisitsPerUser	3
DailyUses	12
ElectricPowerAverage	2.2 kw
ElectricPowerAverageDuration	0.06 hrs
ElectricPowerPeak	2.3 kw
ElectricPowerPeakDuration	0.01 hrs
ElectricityNeedStartTime	06:00
ElectricityNeedEndTime	22:00

The following two groups of electricity-consuming devices are strongly governed by the facility management policies, specifically by the schedule of their operation. These groups are HVAC (heating, ventilation, and air conditioning), lighting and production-related equipment.

7.2.3 Parameters for HVAC

The only consumption parameter controllable by the user / facility manager for the HVAC system is the temperature setting. Currently the most advanced temperature settings are controlled by the Energy Star Programmable thermostats that divide each day of the week into four parts (morning / wake, day, evening and night / sleep). Increasing the level of detail of the control schedule will not have any influence on the energy consumption, since there needs to be a duration of at least 6 hours for the advantages of a temperature setback to be translated into energy savings. The parameters of the HVAC temperature control are a combination of heating / cooling, the day of the week, part of the day, and start time and temperature. The components of the HVAC control parameters (settings) are reproduced in Table 19.

Table 19. Components of the HVAC control parameters.

Heating / Cooling	Day	Part of Day	Start Time / Temperature.
Heating	Monday	Morning	StartTime
Cooling	Tuesday	Day	Temperature
	Wednesday	Evening	
	Thursday	Night	
	Friday		
	Saturday		
	Sunday		

There are a total of 2x7x4x2 = 112 combinations, such as: CoolingMondayDayStartTime or CoolingMondayDayTemperature. An example of implementation is given in Table 26.

Note the heating of the duplex used as an example in this report is ensured through a combi boiler, with two functions: (1) provide hot water for the radiators in the rooms and (2) heat water for domestic consumption. Specialized programs need to be used to calculate the electricity consumption of the combo boiler. The electricity consumption for heating the rooms (facility) will be dependent on the outdoor temperature, the thermal characteristics of the facility, and the temperature settings in each zone. For the domestic hot water, the calculations can be performed based on the quantity of hot water used by summing all the values for DailyHotWaterUsage for each water-consuming device in the specific system (i.e., all the water-consuming devices that are linked to the particular combi boiler for which the calculation is performed). See Tables 13 and 15 for examples and typical values. The calculations of the hot water consumption are shown in Chapter 10.

7.2.4 Parameters for lighting

The electricity consumed for general lighting (i.e., not local, work-point lighting) is independent of the number of occupants of the room. Similarly to the HVAC settings, the lights follow a certain pre-set schedule. The difference between the HVAC schedule and the lighting schedule is that lights can be either on or off and hence, the schedule is less detailed. Another difference is that, while the HVAC is usually pre-programmed and then actuated by the thermostat, in case of the duplex, the light schedule is not pre-programmed (i.e., it is implicit knowledge) and it is actuated by the occupants. Due to this difference, it is impractical to require the same five-parts-of-the-day schedule that is normally used for ENERGY STAR Programmable Thermostats. It was found that a two-parts-of-the day sched-

ule is sufficient to describe the status of the lighting. Combined with the two seasons definition needed for calculating the energy consumption on a yearly base, the time settings for lighting are a combination of the values represented in Table 20.

Table 20. Lighting schedule parameters.

Season	Day of Week	AM/PM	Start/Stop
Summer	Monday	Morning	StartTime
Winter	Tuesday	Evening	EndTime
	Wednesday		
	Thursday		
	Friday		
	Saturday		
	Sunday		

There are a total of 2x7x2x2 = 56 combinations, such as: SummerMondayMorningStartTime or WinterSundayNightEndTime. An example of implementation is given in Table 27.

8 Adding Consumption Data to Devices in COBie.

This section focuses solely on the addition of consumption data to resource-consuming devices in COBie. All the data presented in this section will be appended to the worksheet Attribute in the COBie file. It is assumed that all the resource-consuming devices themselves have been added to the COBie file either automatically, from the IFC files, or manually as presented in Chapter 5. It is also assumed that all the additional units have been added to the worksheet PickLists, as shown in Chapter 6.

Note that for each resource-consuming device (such as for instanceDishwasher_F1-102) the consumption parameters are stored in the same worksheet, but at two hierarchical levels: the Type level and the Component level. For instance, line #4 in Table 21, indicates that all the devices identified as Dishwasher in the building have a WaterUsagePerVisit of 5.8 gallons. Individual devices (such as Dishwasher_F1-102) can have different schedules of operations and different number of users, hence those parameters, as well as the individual resource consumptions, are stored at the level of the individual device. For more complex buildings there may be cases when particular devices can have more than one type of user. For instance, the toilets in the dentistry zone of a medical clinic may be shared by the dentists, dental lab technicians and the X-Ray technicians (see Table 6 for the COBie location of this information). In this case, the Attribute worksheet will have four lines with the parameter UserType for the specific toilet, one for each possible user.

8.1 Water consumption data in COBie

8.1.1 COBie representation of water-consuming devices with consumption independent of the duration of each visit

For a description of the parameters of the water-consuming devices with consumption independent of the duration of each visit see section 7.1.1 on page 19.

Note that the dishwashers in the duplex are both water and electricity-consuming devices (see Table 9). The user (occupancy) information for these devices is shared by both water and electricity consumption, hence it

is impractical to separate them in the presentation of the data. Only the data for one of the two dishwashers is presented. The component parameters for the second dishwasher (Dishwash-er_F1-202)are similar.

Table 21. Water- and electricity-consuming devices (consumption independent on the duration of the visit).

Name	...	SheetName	RowName	Value	Unit	...
ElectricPowerAverage	...	Type	Dishwasher	1	kw	...
ElectricPowerPeak	...	Type	Dishwasher	1.5	kw	...
HotWaterInMix	...	Type	Dishwasher	100	%	...
WaterUsagePerVisit	...	Type	Dishwasher	5.8	gallons	...
DailyElectricityUsageSummer	...	Component	Dishwasher_F1-102	1	kwh	...
DailyElectricityUsageWinter	...	Component	Dishwasher_F1-102	1	kwh	...
DailyHotWaterUsage	...	Component	Dishwasher_F1-102	5.8	gallons / day	...
DailyWaterUsage	...	Component	Dishwasher_F1-102	5.8	gallons / day	...
ElectricityNeedEndTime	...	Component	Dishwasher_F1-102	21:00	n/a	...
ElectricityNeedStartTime	...	Component	Dishwasher_F1-102	19:00	n/a	...
UsersPerZone	...	Component	Dishwasher_F1-102	4	people	...
DevicesPerZone	...	Component	Dishwasher_F1-102	1	n/a	...
UsersPerDevice	...	Component	Dishwasher_F1-102	4	people	...
DailyUses	...	Component	Dishwasher_F1-102	1	n/a	...

Another type of water-consuming devices that are independent of the duration of each visit are the toilets.

Table 22. Water-consuming devices with consumption independent of the duration of each visit.

Name	...	SheetName	RowName	Value	Unit	...
DailyUses	...	Type	WC_370x550	12	n/a	...
DailyVisitsPerUser	...	Type	WC_370x550	6	n/a	...
DevicesPerZone	...	Type	WC_370x550	2	n/a	...
HotWaterInMix	...	Type	WC_370x550	0	%	...
UsersPerZone	...	Type	WC_370x550	4	people	...
VisitWaterUsage	...	Type	WC_370x550	1.6	gallons	...
DailyHotWaterUsage	...	Component	WC_207.F2-207	0	gal/day	...

Name	...	SheetName	RowName	Value	Unit	...
DailyWaterUsage	...	Component	WC_207.F2-207	19	gal/day	...
UsersPerDevice	...	Component	WC_207.F2-207	2	people	...
DailyHotWaterUsage	...	Component	WC_203.F1-203	0	gal/day	...
DailyWaterUsage	...	Component	WC_203.F1-203	19	gal/day	...
UsersPerDevice	...	Component	WC_203.F1-203	2	people	...
DailyHotWaterUsage	...	Component	WC_107.F2-107	0	gal/day	...
DailyWaterUsage	...	Component	WC_107.F2-107	19	gal/day	...
UsersPerDevice	...	Component	WC_107.F2-107	2	people	...
DailyHotWaterUsage	...	Component	WC_103.F1-103	0	gal/day	...
DailyWaterUsage	...	Component	WC_103.F1-103	19	gal/day	...
UsersPerDevice	...	Component	WC_103.F1-103	2	people	...

8.1.2 COBie representation of water-consuming devices with consumption dependent on the duration of the visit

This section presents only the data for one of the several water-consuming devices with consumption dependent on the duration presented in section 7.1.2 on page 19. All the other devices presented in section 7.1.2 will follow the same pattern. Note that not all the columns in worksheet Attribute have been represented.

Table 23. Examples of water-consuming devices with consumption dependent on the duration of the visit.

Name	...	SheetName	RowName	Value	Unit	...
DailyVisitsPerUser	...	Type	Shower_900x900	1	n/a	...
HotWaterInMix	...	Type	Shower_900x900	50	%	...
VisitWaterUsage	...	Type	Shower_900x900	20	gallons	...
VisitDuration	...	Type	Shower_900x900	10	minutes	...
WaterFlowRate	...	Type	Shower_900x900	2	gpm	...
DailyWaterUsage	...	Component	Shower_103.F1-103	40	gal/day	...
DailyHotWaterUsage	...	Component	Shower_103.F1-103	20	gal/day	...
UsersPerDevice	...	Component	Shower_103.F1-103	2	people	...
DailyWaterUsage	...	Component	Shower_203.F1-203	40	gal/day	...
DailyHotWaterUsage	...	Component	Shower_203.F1-203	20	gal/day	...

Name	...	SheetName	RowName	Value	Unit	...
UsersPerDevice	...	Component	Shower_203.F1-203	2	people	...
UsersPerZone	...	Component	Shower_103.F1-103	4	people	...
DevicesPerZone	...	Component	Shower_103.F1-103	2	n/a	...
DailyUses	...	Component	Shower_103.F1-103	2	n/a	...
UsersPerZone	...	Component	Shower_203.F1-203	4	people	...
DevicesPerZone	...	Component	Shower_203.F1-203	2	n/a	...
DailyUses	...	Component	Shower_203.F1-203	2	n/a	...

8.2 Electricity consumption data in COBie

Following an approach similar to presenting the parameters of water-consuming devices, this section presents the electricity-consuming devices according to their specific characteristics. As with water-consuming devices, the parameters that are common to all the devices (components) are represented at the Type level. The parameters that are dependent on the use of each particular device are represented at the level of that electricity-consuming device.

8.2.1 COBie representation of electricity-consuming devices with consumption dependent on the occupancy

As explained in section 7.2.1, the main difference between electricity-consuming devices with consumption dependent on occupancy and the next category (see section 8.2.2) is the fact that for the devices presented in this section the exact number of times when the electric consumption is actuated is impossible to calculate and is not a major factor in the consumption. The relationship between the number of occupants and the electricity consumption of these devices is not linear.

Table 24. Electricity-consuming devices with consumption dependent on occupancy—example of COBie implementation.

Name	:	Category	SheetName	RowName	Value	Unit
ElectricPowerAverage	..	req..	Type	Refrigerator	0.5	kw
ElectricPowerAverageDuration	..	req..	Type	Refrigerator	0.3	hour
ElectricPowerPeak	..	req..	Type	Refrigerator	0.7	kw
ElectricPowerPeakDuration	..	req..	Type	Refrigerator	0.01	hour
DailyElectricityUsageSummer	..	req..	Component	Refrigerator_F1-102	1.3	KWh/day
DailyElectricityUsageWinter	..	req..	Component	Refrigerator_F1-102	1.1	KWh/day
DevicesPerZone	..	req..	Component	Refrigerator_F1-102	1	n/a
ElectricityNeedEndTime	..	req..	Component	Refrigerator_F1-102	23:59	n/a
ElectricityNeedStartTime	..	req..	Component	Refrigerator_F1-102	00:00	n/a
UsersPerDevice	..	req..	Component	Refrigerator_F1-102	4	people
UsersPerZone	..	req..	Component	Refrigerator_F1-102	4	people
DailyElectricityUsageSummer	..	req..	Component	Refrigerator_F1-202	1.3	KWh/day
DailyElectricityUsageWinter	..	req..	Component	Refrigerator_F1-202	1.1	KWh/day
DevicesPerZone	..	req..	Component	Refrigerator_F1-202	1	n/a
ElectricityNeedEndTime	..	req..	Component	Refrigerator_F1-202	23:59	n/a
ElectricityNeedStartTime	..	req..	Component	Refrigerator_F1-202	00:00	n/a
UsersPerDevice	..	req..	Component	Refrigerator_F1-202	4	people
UsersPerZone	..	req..	Component	Refrigerator_F1-202	4	people

8.2.2 COBie representation of electricity-consuming devices with consumption dependent on the number of uses per day

The main difference between the electricity-consuming devices with consumption dependent on the number of uses per day include (presented in this section) and the electricity ones presented in the previous section is the fact that the consumption of these devices (presented here) is proportional with (i.e., linearly dependent on) the number of daily uses. These devices were introduced in section 7.2.2.

Table 25. Electricity-consuming devices with consumption dependent on the number of uses per day—example of COBie implementation.

Name	...	Category	SheetName	RowName	Value	Unit
DailyVisitsPerUser	...	Requirement	Type	ElectricHandDryer	3	n/a
ElectricPowerAverage	...	Requirement	Type	ElectricHandDryer	2.2	kw
ElectricPowerAverageDuration	...	Requirement	Type	ElectricHandDryer	0.058	hour
ElectricPowerPeak	...	Requirement	Type	ElectricHandDryer	2.3	kw
ElectricPowerPeakDuration	...	Requirement	Type	ElectricHandDryer	0.0083	hour
DailyElectricityUsageSummer	...	Requirement	Component	ElectricHandDryer.F1-103	0.22	KWh/day
DailyElectricityUsageWinter	...	Requirement	Component	ElectricHandDryer.F1-103	0.22	KWh/day
DailyUses	...	Requirement	Component	ElectricHandDryer.F1-103	12	n/a
DevicesPerZone	...	Requirement	Component	ElectricHandDryer.F1-103	1	n/a
ElectricityNeedEndTime	...	Requirement	Component	ElectricHandDryer.F1-103	22:00	n/a
ElectricityNeedStratTime	...	Requirement	Component	ElectricHandDryer.F1-103	06:00	n/a
UsersPerDevice	...	Requirement	Component	ElectricHandDryer.F1-103	4	people
UsersPerZone	...	Requirement	Component	ElectricHandDryer.F1-103	4	people
DailyElectricityUsageSummer	...	Requirement	Component	ElectricHandDryer.F1-203	0.22	KWh/day
DailyElectricityUsageWinter	...	Requirement	Component	ElectricHandDryer.F1-203	0.22	KWh/day
DailyUses	...	Requirement	Component	ElectricHandDryer.F1-203	12	n/a
DevicesPerZone	...	Requirement	Component	ElectricHandDryer.F1-203	1	n/a
ElectricityNeedEndTime	...	Requirement	Component	ElectricHandDryer.F1-203	22:00	n/a
ElectricityNeedStratTime	...	Requirement	Component	ElectricHandDryer.F1-203	06:00	n/a
UsersPerDevice	...	Requirement	Component	ElectricHandDryer.F1-203	4	people
UsersPerZone	...	Requirement	Component	ElectricHandDryer.F1-203	4	people

8.2.3 COBie representation of HVAC

As stated in section 7.2.3, the only consumption parameter controllable by the user / facility manager for the HVAC system is the temperature setting. Technical characteristics, such as SEER or maximum electricity consumption, are stored in the same manner as the other technical parameters of electrical consumers. These parameters are defined at the Type level.

The only new type of parameter in the case of the HVAC system is the thermostat setting. Table 26 presents an excerpt of the COBie implementation of the Energy Star heating and cooling schedule.

Table 26. Excerpt from COBie worksheet Attribute—thermostat settings (not all rows and columns reproduced).

Name	SheetName	RowName	Value	Unit
HeatingMondayMorningStartTime	Component	Thermostat_F2-208	06:00	n/a
HeatingMondayMorningTemperature	Component	Thermostat_F2-208	70	°F
HeatingMondayDayStartTime	Component	Thermostat_F2-208	08:00	n/a
HeatingMondayDayTemperature	Component	Thermostat_F2-208	62	°F
HeatingMondayEveningStartTime	Component	Thermostat_F2-208	18:00	n/a
HeatingMondayEveningTemperature	Component	Thermostat_F2-208	70	°F
HeatingMondayNightStartTime	Component	Thermostat_F2-208	22:00	n/a
HeatingMondayNightTemperature	Component	Thermostat_F2-208	62	°F
CoolingMondayMorningStartTime	Component	Thermostat_F2-208	06:00	n/a
CoolingMondayMorningTemperature	Component	Thermostat_F2-208	78	°F
CoolingMondayDayStartTime	Component	Thermostat_F2-208	08:00	n/a
CoolingMondayDayTemperature	Component	Thermostat_F2-208	85	°F
CoolingMondayEveningStartTime	Component	Thermostat_F2-208	18:00	n/a
CoolingMondayEveningTemperature	Component	Thermostat_F2-208	78	°F
CoolingMondayNightStartTime	Component	Thermostat_F2-208	22:00	n/a
CoolingMondayNightTemperature	Component	Thermostat_F2-208	82	°F

8.2.4 COBie representation of lighting

Lighting is linearly dependent on the installed power of the lighting fixtures and the lighting schedule. For actively managed facilities (such as a medical clinic or an office building), the lighting schedule is part of the facility management policy. In facilities where no such formal policy exists, the lighting schedule can be determined through observations. An example for the lighting schedule of a room (Room F1-101 in the duplex) is presented in Table 1. The information in this table is used to calculate the total hours in the day (summer / winter) when the lights are on. This duration is then multiplied by the ElectricPowerAverage consumption of the type of lighting fixture installed in the room (in this case a Candelabra_6_lights). As with the other resource-consuming devices, the ElectricPowerAverage consumption is captured in the worksheet Attribute. See Table 27.

Table 27.Excerpt from COBie worksheet Attribute—lighting settings (not all rows and columns reproduced).

Name	SheetName	RowName	Value	Unit
WinterMondayMorningStartTime	Component	Candelabra_6_lights.F1-101	06:00	n/a
WinterMondayMorningEndTime	Component	Candelabra_6_lights.F1-101	08:00	n/a
WinterMondayEveningStartTime	Component	Candelabra_6_lights.F1-101	17:00	n/a
WinterMondayEveningEndTime	Component	Candelabra_6_lights.F1-101	21:00	n/a
SummerMondayMorningStartTime	Component	Candelabra_6_lights.F1-101	06:00	n/a
SummerMondayMorningEndTime	Component	Candelabra_6_lights.F1-101	07:00	n/a
SummerMondayEveningStartTime	Component	Candelabra_6_lights.F1-101	19:00	n/a
SummerMondayEveningEndTime	Component	Candelabra_6_lights.F1-101	21:00	n/a

Table 28. Power parameters for a light fixture.

Name	...	SheetName	RowName	Value	Unit	...
ElectricPowerAverage	...	Type	Candelabra_6_lights	0.36	kw	...
ElectricPowerPeak	...	Type	Candelabra_6_lights	0.6	kw	...

The difference between ElectricPowerPeak and ElectricPowerAverage in Table 28 stems from the ability of the occupant to replace the light bulbs, for instance from 100W bulbs to 60W bulbs.

9 Capturing the Technical Legitimacy of the Consumption Parameters

The sources of information for the values of the parameters should be captured in the worksheet Documents, under the category Guide Specifications. The file names in column File are hyperlinked to the file containing the information about the particular device. The files should either be globally accessible (i.e., addressed with an internet URL) or they can be stored locally, in a subdirectory to the location of the COBie file. The name of the directory is captured in the column Directory. Examples of guide specifications are given in Table 29.

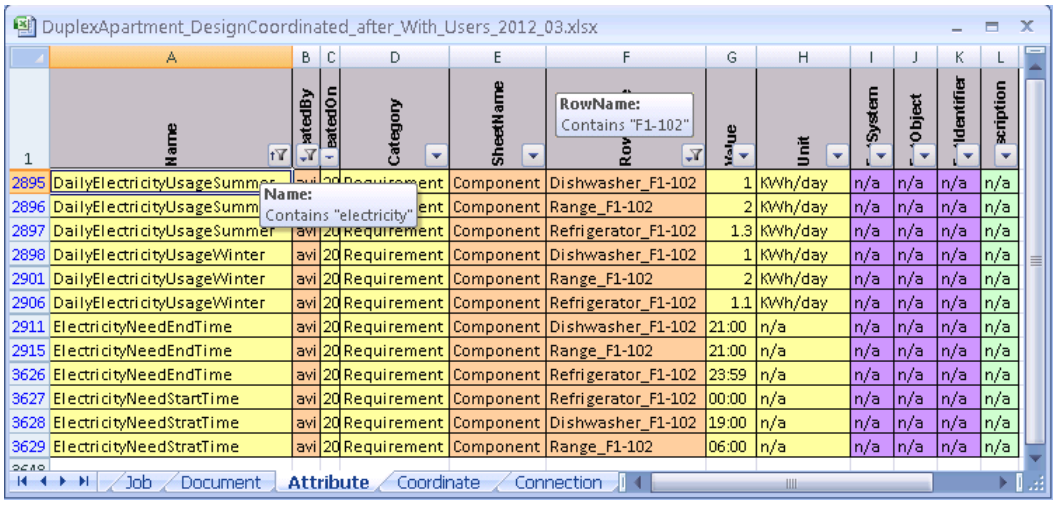
Table 29. Specification source for each type of resource-consuming device.

Name	...	Category	ApprovalBy	Stage	SheetName	RowName	Directory	File
Shower_900x900 Guide Specifications	...	Guide Specifications	Information Only	Req..	Type	Shower_900x900	..\Duplex...	2.4.16_Shower.pdf
Tub_750x1600 Guide Specifications	...	Guide Specifications	Information Only	Req..	Type	Tub_750x1600	..\Duplex...	2.4.16_Shower.pdf
Washbasin_330x450 Guide Specifications	...	Guide Specifications	Information Only	Req..	Type	Washbasin_330x450	..\Duplex...	2.4.11-2.4.12_Sinks.pdf
Washbasin_380dia Guide Specifications	...	Guide Specifications	Information Only	Req..	Type	Washbasin_380dia	..\Duplex...	2.4.11-2.4.12_Sinks.pdf
Kitchen_Sink Guide Specifications	...	Guide Specifications	Information Only	Req..	Type	Kitchen_Sink	..\Duplex...	2.4.11-2.4.12_Sinks.pdf
WC_370x550 Guide Specifications	...	Guide Specifications	Information Only	Req..	Type	WC_370x550	..\Duplex...	2.4.3_WC.pdf

10 Extracting Resource Consumption Data from COBie

With all the data stored in the COBie file as described in the previous sections, it is possible to extract all the information needed for assessing the resource utilization for the facility represented in COBie.

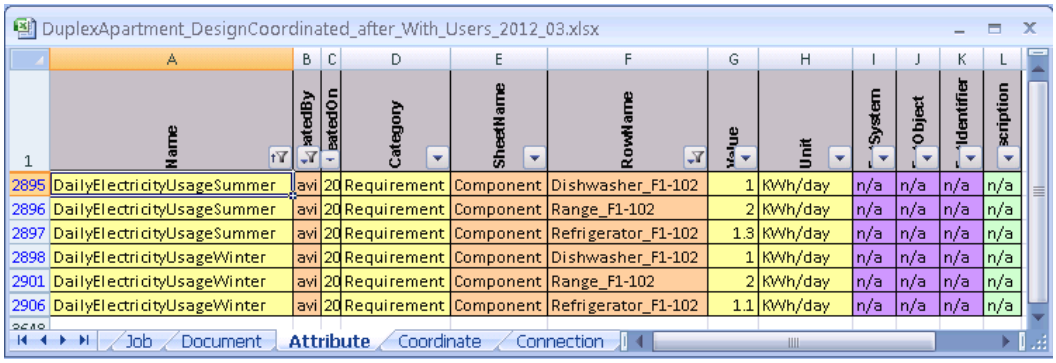
The queries for resource utilization can be done by space, zone, system, and user for each resource. All the resource use information is contained in the worksheet Attribute. For instance, to calculate the amount of electric energy used in the kitchen-diner of Apartment #1 in the duplex (space F1-102), one only needs to place a filter for F1-102 on column RowName and another filter for Electricity on column Name. Figure 1 presents a screen capture of the COBie file with the two filters enabled.



	Name	CreatedBy	CreatedOn	Category	SheetName	RowName	Value	Unit	ExtSystem	ExtObject	ExtIdentifier	Description
2895	DailyElectricityUsageSummer	avi	20	Requirement	Component	Dishwasher_F1-102	1	KWh/day	n/a	n/a	n/a	n/a
2896	DailyElectricityUsageSumm	avi	20	Requirement	Component	Range_F1-102	2	KWh/day	n/a	n/a	n/a	n/a
2897	DailyElectricityUsageSummer	avi	20	Requirement	Component	Refrigerator_F1-102	1.3	KWh/day	n/a	n/a	n/a	n/a
2898	DailyElectricityUsageWinter	avi	20	Requirement	Component	Dishwasher_F1-102	1	KWh/day	n/a	n/a	n/a	n/a
2901	DailyElectricityUsageWinter	avi	20	Requirement	Component	Range_F1-102	2	KWh/day	n/a	n/a	n/a	n/a
2906	DailyElectricityUsageWinter	avi	20	Requirement	Component	Refrigerator_F1-102	1.1	KWh/day	n/a	n/a	n/a	n/a
2911	ElectricityNeedEndTime	avi	20	Requirement	Component	Dishwasher_F1-102	21:00	n/a	n/a	n/a	n/a	n/a
2915	ElectricityNeedEndTime	avi	20	Requirement	Component	Range_F1-102	21:00	n/a	n/a	n/a	n/a	n/a
3626	ElectricityNeedEndTime	avi	20	Requirement	Component	Refrigerator_F1-102	23:59	n/a	n/a	n/a	n/a	n/a
3627	ElectricityNeedStartTime	avi	20	Requirement	Component	Refrigerator_F1-102	00:00	n/a	n/a	n/a	n/a	n/a
3628	ElectricityNeedStratTime	avi	20	Requirement	Component	Dishwasher_F1-102	19:00	n/a	n/a	n/a	n/a	n/a
3629	ElectricityNeedStratTime	avi	20	Requirement	Component	Range_F1-102	06:00	n/a	n/a	n/a	n/a	n/a

Figure 1. Example of data filtering for assessing the electricity use in a room (worksheet Attribute, all data shown).

Figure 2 presents the same data as Figure 1, except that the filter on column Name has been changed from Electricity to DailyElectricity. By adding the daily usage for each electricity-consuming device we conclude that the total expected daily electricity usage in room F2-102 in the summer is 4.3 KWh/day and 4.1 KHh/day in the winter. The difference in daily usage comes from the refrigerator.



DuplexApartment_DesignCoordinated_after_With_Users_2012_03.xlsx

	A	B	C	D	E	F	G	H	I	J	K	L
1	Name	atedBy	eatedOn	Category	SheetName	RowName	alue	Unit	System	Object	Identifier	scription
2895	DailyElectricityUsageSummer	avi	20	Requirement	Component	Dishwasher_F1-102	1	KWh/day	n/a	n/a	n/a	n/a
2896	DailyElectricityUsageSummer	avi	20	Requirement	Component	Range_F1-102	2	KWh/day	n/a	n/a	n/a	n/a
2897	DailyElectricityUsageSummer	avi	20	Requirement	Component	Refrigerator_F1-102	1.3	KWh/day	n/a	n/a	n/a	n/a
2898	DailyElectricityUsageWinter	avi	20	Requirement	Component	Dishwasher_F1-102	1	KWh/day	n/a	n/a	n/a	n/a
2901	DailyElectricityUsageWinter	avi	20	Requirement	Component	Range_F1-102	2	KWh/day	n/a	n/a	n/a	n/a
2906	DailyElectricityUsageWinter	avi	20	Requirement	Component	Refrigerator_F1-102	1.1	KWh/day	n/a	n/a	n/a	n/a

Job Document Attribute Coordinate Connection

Figure 2. Room F1-102 daily electricity usage.

For calculating the resource needs for a zone or by system, the data filters for rooms or components will be more extensive than the case presented in Figure 1 and Figure 2. For instance, to calculate the total electricity consumption in the summer for apartment #1 in the duplex, one will have to create an OR concatenation filter for all the consumers in Apartment 1. This information is presented in Table 10 on page 12. Note that there is no need to separate the devices by type of resource consumption. The filtering on column Name will ensure that only devices consuming electricity will be selected. An alternative way of selecting all the devices in a specific zone can be used if the space naming convention allows selecting the zone from the space name. For instance, in the naming convention of the components in the duplex, the zone number is always the fifth character from the right.

The results of filtering the electricity consumers for the apartment 1 in the duplex are shown in Figure 3 and Figure 4. The expected daily electricity consumption for the apartment 1 (when inhabited by 4 people, who use the apartment according to the schedules presented), is 20.9 KWh. In the winter the expected daily electricity consumption is 45 KWh. The difference come mainly from the longer hours of lighting and the electricity used for heating (combi boiler)

	A	B	C	D	E	F	G	H	I	J	K	L
1	Name	CreatedBy	CreatedOn	Category	SheetName	RowName	Value	Unit	ExtSystem	ExtObject	ExtIdentifier	Description
2	DailyElectricityUsageSummer	av	2(	Requ	Component	Candelabra_6_lights.F1-101	1.8	KWh/day	n/a	n/a	n/a	n/a
3	DailyElectricityUsageSummer	av	2(	Requ	Component	Dishwasher_F1-102	1	KWh/day	n/a	n/a	n/a	n/a
4	DailyElectricityUsageSummer	av	2(	Requ	Component	Range_F1-102	2	KWh/day	n/a	n/a	n/a	n/a
5	DailyElectricityUsageSummer	av	2(	Requ	Component	Refrigerator_F1-102	1.3	KWh/day	n/a	n/a	n/a	n/a
6	DailyElectricityUsageSummer	av	2(	Requ	Component	ElectricHandDryer.F1-103	0.22	KWh/day	n/a	n/a	n/a	n/a
7	DailyElectricityUsageSummer	av	2(	Requ	Component	Candelabra_6_lights.F1-105	1.8	KWh/day	n/a	n/a	n/a	n/a
8	DailyElectricityUsageSummer	av	2(	Requ	Component	Candelabra_6_lights.F1-106	1.8	KWh/day	n/a	n/a	n/a	n/a
9	DailyElectricityUsageSummer	av	2(	Requ	Component	CombiBoiler.F2-107	11	KWh/day	n/a	n/a	n/a	n/a

Figure 3. Apartment 1 summer electricity consumption.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Name	CreatedBy	CreatedOn	Category	SheetName	RowName	Value	Unit	ExtSystem	ExtObject	ExtIdentifier	Description
2	DailyElectricityUsageWinter	av	2(	Requ	Component	Candelabra_6_lights.F1-101	2.88	KWh/day	n/a	n/a	n/a	n/a
3	DailyElectricityUsageWinter	av	2(	Requ	Component	Dishwasher_F1-102	1	KWh/day	n/a	n/a	n/a	n/a
4	DailyElectricityUsageWinter	av	2(	Requ	Component	Range_F1-102	2	KWh/day	n/a	n/a	n/a	n/a
5	DailyElectricityUsageWinter	av	2(	Requ	Component	Refrigerator_F1-102	1.1	KWh/day	n/a	n/a	n/a	n/a
6	DailyElectricityUsageWinter	av	2(	Requ	Component	ElectricHandDryer.F1-103	0.22	KWh/day	n/a	n/a	n/a	n/a
7	DailyElectricityUsageWinter	av	2(	Requ	Component	Candelabra_6_lights.F1-105	2.88	KWh/day	n/a	n/a	n/a	n/a
8	DailyElectricityUsageWinter	av	2(	Requ	Component	Candelabra_6_lights.F1-106	2.88	KWh/day	n/a	n/a	n/a	n/a
9	DailyElectricityUsageWinter	av	2(	Requ	Component	CombiBoiler.F2-107	32	KWh/day	n/a	n/a	n/a	n/a

Figure 4. Apartment 1 winter electricity consumption.

The expected daily electricity consumption of the combi-boiler is calculated as the sum of the two functions it (the combi-boiler) fulfils: heating and water heating. As explained in section 7.2.3, the energy needed for heating the apartment is calculated outside the COBie file. The energy used for water-heating is proportional with the temperature difference and the quantity of the hot water consumed. This later parameter (quantity of hot water consumed) can be extracted from the COBie file in a fashion similar to the way electricity consumption is extracted. Figure 5 presents the data for hot water consumption in Apartment #1 in the duplex (72.8 gal/day).

	A	B	C	D	E	F	G	H	I	J	K	L
1	Name	CreatedBy	CreatedOn	Category	SheetName	RowName	Value	Unit	ExtSystem	ExtObject	ExtIdentifier	Description
2	DailyHotWaterUsage	av	2(	Requ	Component	Dishwasher_F1-102	5.8	gal/day	n/a	n/a	n/a	n/a
3	DailyHotWaterUsage	av	2(	Requ	Component	Kitchen_Sink.F1-102	12	gal/day	n/a	n/a	n/a	n/a
4	DailyHotWaterUsage	av	2(	Requ	Component	Shower_103.F1-103	20	gal/day	n/a	n/a	n/a	n/a
5	DailyHotWaterUsage	av	2(	Requ	Component	Tub_107.F2-107	20	gal/day	n/a	n/a	n/a	n/a
6	DailyHotWaterUsage	av	2(	Requ	Component	Washbasin_103.F1-103	5	gal/day	n/a	n/a	n/a	n/a
7	DailyHotWaterUsage	av	2(	Requ	Component	Washbasin_1071.F2-107	5	gal/day	n/a	n/a	n/a	n/a
8	DailyHotWaterUsage	av	2(	Requ	Component	Washbasin_1072.F2-107	5	gal/day	n/a	n/a	n/a	n/a
9	DailyHotWaterUsage	av	2(	Requ	Component	WC_103.F1-103	0	gal/day	n/a	n/a	n/a	n/a
10	DailyHotWaterUsage	av	2(	Requ	Component	WC_107.F2-107	0	gal/day	n/a	n/a	n/a	n/a

Figure 5. Apartment 1 hot water consumption.

11 Conclusions

Through its fundamental requirement of being human-readable, the Construction Operations Building Information Exchange (COBie) standard allows end-users of building information models (BIM) to develop and test additional functions (attributes) that need to be represented in the BIM programs. The result of such development and testing is a proposal for adding new attributes to existing objects in the set of industry foundation classes (IFc).

This report focuses on the attributes (parameters) required for representing the occupancy and resource demands of built facilities. The attributes required for such a representation are presented in tables 30 to 33 below. Two additional tables, Table 19 (see page 22) and Table 20 (see page 24) complete the parameters required

Table 30. Occupancy related parameters.

Attribute Name	On Sheet	Example of Object	Example of Value	Example of Unit
OccupancyType	Facility	DuplexApartment	R-3	n/a
OccupancyNumber	Zone	Flat_1	4	people
OccupancyNumberPeak	Zone	Flat_1	7	people
DailyOccupancyDuration	Zone	Flat_1	15	hours

Table 31. Parameters common to resource-consuming devices (electricity and water).

Attribute Name	On Sheet	Example of Object	Example of Value	Example of Unit
Guide Specifications	Document	Shower_900x900	..\Duplex_ Linked Files	2.4.16_ Shower.pdf
DailyVisitsPerUser	Type	Shower_900x900	1	n/a
VisitDuration	Type	Shower_900x900	10	minutes
DevicesPerZone	Component	Shower_103.F1-103	2	n/a
UsersPerZone	Component	Shower_103.F1-103	4	people
UsersPerDevice	Component	Shower_103.F1-103	2	people
DailyUses	Component	Shower_103.F1-103	2	n/a

Table 32. Parameters for water-consuming devices.

Attribute Name	On Sheet	Example of Object	Example of Value	Example of Unit
WaterFlowRate	Type	Shower_900x900	2	gpm
VisitWaterUsage	Type	Shower_900x900	20	gallons
HotWaterInMix	Type	Shower_900x900	50	%
DailyWaterUsage	Component	Shower_203.F1-203	40	gal/day
DailyHotWaterUsage	Component	Shower_203.F1-203	20	gal/day

Table 33. Parameters for electricity-consuming devices.

Attribute Name	On Sheet	Example of Object	Example of Value	Example of Unit
ElectricPowerAverage	Type	Wall_light_duo	0.12	kw
ElectricPowerAverageDuration	Type	Refrigerator	0.3	hour
ElectricPowerPeak	Type	Refrigerator	0.7	kw
ElectricPowerPeakDuration	Type	Refrigerator	0.01	hour
ElectricityNeedStartTime	Component	Dishwasher_ F1-202	19:00	n/a
ElectricityNeedEndTime	Component	Dishwasher_ F1-202	21:00	n/a
DailyElectricityUsageSummer	Component	Refrigerator_ F1-102	1.3	KWh/day
DailyElectricityUsageWinter	Component	Refrigerator_ F1-102	1.1	KWh/day

To be considered standardization, these parameters need to be reviewed and vetted by the buildingSMART International organization (buildingsmart-tech.org/).

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14. ABSTRACT

This report documents work performed under contract for the US Army Engineer Research and Development Center by researchers at Arizona State University to support the development of technology that can describe the use of a building's space resources. The specific purpose of this work was to create schedules of building space attributes, in the form of tables; and the requirements for different types and combinations of facilities constructed for the Army. Such information can be used to compare real-world facility user behavior with predicted facility resource consumption as part of a methodology for optimizing building space utilization to improve mission readiness and sustainability.

The research addressed the process of using the existing structure of the Construction Operations Building information exchange (COBie) data specification to add information relevant to planning space resource utilization. The example provided was for a standard family housing duplex unit. In addition, the use of COBie as a tool for testing enhancements to the Industry Foundation Class (IFC) schema has been demonstrated.

15. SUBJECT TERMS
space utilization, sustainability, facility resource consumption, Construction Operations Building information exchange (COBie), Building Information Modeling (BIM)

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