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Diagramming Transactive Building Business Cases

Using Principles of e^3 *Value* to Document Valuation Studies

December 2016

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Summary

Energy management in buildings is becoming more transactive. Pacific Northwest National Laboratory and the U.S. Department of Energy Building Technologies Office recently defined innovative use cases wherein market-like mechanisms are used to manage energy within buildings, between buildings, and between buildings and third-party entities, such as power utilities. A next step toward defining a set of transactive use cases in the buildings domain is to carefully diagram the corresponding business cases to capture details of transactions among all stakeholders and their economic value propositions. The principles of e^3-*value* diagramming are applied in this report toward creating business value diagrams. These principles are extended to be consistent with Universal Modeling Language use-case diagrams. Example diagrams are presented for a subset of buildings-domain use cases that were introduced in an earlier Pacific Northwest National Laboratory report.[1] The diagrams are intended to clearly represent an understanding of the transactions through which individual entities accumulate value in their respective use cases, and the diagrams should therefore support economic valuation studies.

The report reviews some of the foundational principles of e^3 *value* and includes authors' insights concerning the formulation of these diagrams using Universal Modeling Language as a more systematic modeling approach.

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[1]Somasundaram S, RG Pratt, BA Akyol, N Fernandez, NAF Foster, S Katipamula, ET Mayhorn, A Somani, AC Steckley, and ZT Taylor. 2014. *Transaction-Based Building Controls Framework, Volume 1: Reference Guide*. PNNL-23302, Pacific Northwest National Laboratory, Richland, WA. Accessed December 14, 2016, at http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23302.pdf,

Acronyms and Abbreviations

AHU	air handling unit
CHP	combined heat and power
EMS	energy management system
HVAC	heating, ventilation, and air conditioning
UML	Unified Modeling Language
VAV	variable air volume

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1.0   Introduction

Transactive building control strategies have gained interest in recent years as a method to achieve aggressive energy efficiency goals for buildings. Some of the control strategies permit the buildings to further respond to power system objectives. Deployment of such control strategies is hypothesized to enable cost-effective market-based transactions between multiple stakeholders and across different domains. However, this hypothesis cannot be verified without valuation studies to make sure that such implementations are cost-effective and that benefits are real and sustainable over time.

The objective of this work is to formulate a systematic business value-diagramming approach that documents economic, environmental, and societal objectives. Development of such business value diagrams will aid in the valuation of existing and new transactive use cases. To achieve this, an existing business modeling approach called e^3 *value* was adopted (e^3 *value* 2016). The inventors of e^3 *value* originally developed it for valuation of e-business ideas, but the framework has been extended to other domains as well. We accept many of the useful concepts of e^3 *value* and its framework, which clearly and elegantly allocate the distribution, exchange, and consumption of economic and other values among stakeholders (i.e., actors). However, we follow the lead of Huemer et al. (2008) by mapping e^3*-value* diagrams into their equivalent Unified Modeling Language (UML) use-case diagrams. UML is used for object-oriented information modeling and has strong standing as an international standard.

A basic model of the valuation process is offered in Figure 1. Entities of a physical system, a transactive building control system, for example, aspire to one or more operational or business objectives. Energy conservation is one such high-level objective. The system conducts one or more *activities* as it strives to achieve the objective. Combinations of objectives and sets of corresponding activities, including those intended to achieve the objectives, are often formalized as *use cases*.

An analyst must define one or more *metrics* to measure the performance of each activity. Some, but not all, these metrics are defined monetarily. A valuation study always entails a comparison, and the differences between the metrics in a test scenario and its corresponding baseline scenario are *impacts* or *benefits*. An analyst employs *models* (e.g., time-series simulations) to represent and predict the activities and thereby quantify the metrics.
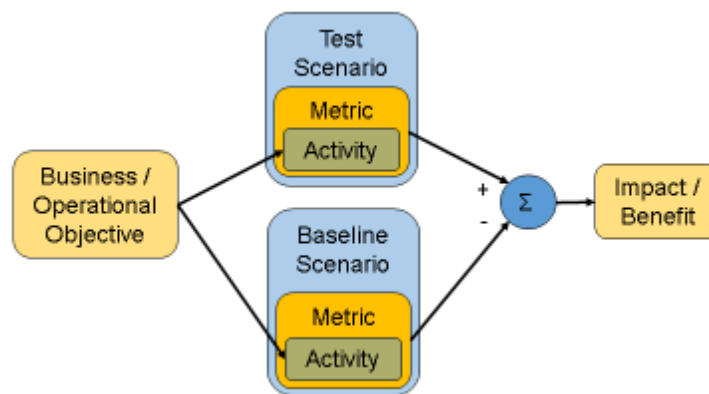
Figure 1. Simple, but Useful Model of the Valuation Process

The business value diagrams to be developed in this report define metrics that are needed to evaluate the performance of transactive building control systems, where value accrues to various stakeholders through defined transactions. However, these diagrams do not define specifically *how* the activities quantify the metrics. A next step, beyond the scope of this report, should be to model the specific process details of the activities toward quantifying the identified metrics. Existing use cases are often found to lack sufficient definition of these activities to complete this next step, so assumptions must be made and documented.

Following a brief review of e^3 *value* and its mapping into UML diagramming, this report includes insights from our experience applying e^3 *value* methodology in the building energy space. A representative subset of use cases defined in Somasundaram et al. (2014) are diagrammed to demonstrate the business value-diagramming method. UML diagrams illustrating actors, activities, objects of value, and value exchanges along with other elements of these diagrams are included.

2.0   Review of the e^3-value Diagramming Tool

Jaap Gordijn and Hans Akkermans developed a compelling conceptual business modeling approach called e^3 value (Gordijn and Akkermans 2001). The approach was originally developed for e-business, but examples have now been formulated in other domains, including the electricity sector. For example, in their 2004 paper, Kartseva et al. applied the e^3-value methodology to the field of distributed power generation. The e^3 value is defined as a methodology that employs conceptual modeling to show "which parties exchange things of economic value with whom and expect what in return" (Kartseva et al. 2004). This methodology provides a framework to structure knowledge concerning how systems distribute, consume, and analyze things of economic value.

The e^3-value methodology relies on the following constructs (Gordijn et al. 2006):

- *Actor*: an economically independent entity in a specific environment.

- *Value object*: a service, good, money, or experience, which is of economic value to at least one *actor*. *Actors* exchange *value objects*.

- *Value port*: a way for actors to provide or request *value objects* to or from other *actors*.

- *Value interface*: grouped *value ports* to illustrate economic reciprocity that relies on exchange of *value objects* between *actors*. An *actor* can have multiple *value interfaces*.

- *Value exchange*: a way to connect two or more *value ports* by trading *value objects*.

- *Value activity*: activities performed by *actors* to yield a profit.

- *Scenario path*: a way to represent dependencies among *actors*, *activities*, and *value exchanges*.

e^3 value provides many strong principles for business modeling and valuation, but among the strongest are these two:

- The most important value objects are themselves metrics that will be used during valuation, especially as we document transactive control systems.

- The sum of value objects sent or received by any given actor in an e^3-value diagram provides for a clear accounting of the business case for that actor.

This report will not provide a complete tutorial on e^3 value, but we provide references that cover the fundamentals. The next sections address some process steps and experiences that might be useful to others as they apply the principles of e^3 value.

2.1   Mapping e^3-value Diagramming into UML Use Cases

In the past decade, another tool, UML, has been extended beyond its intended area (software systems engineering) into business practice representation (UML 2016). UML's ability to embody behavior diagrams (e.g., use-case diagrams) makes it suitable for defining processes and behaviors of objects and systems. The mapping of the e^3-value diagramming process into UML was found suitable in studies conducted by Huemer (Huemer et al. 2008). The authors' conclusion was that the best practice was to convert e^3-value diagrams into their equivalent UML use-case diagram. UML diagrams offer an engineering formalism that could elevate the practice of valuation studies and perhaps enhance the standing of valuation studies' results with their audiences. Minor terminology differences exist. For example, e^3-value *value activities* must be modeled as UML use cases, and *value exchanges* as UML information flows.

The mapping of e^3-*value* notation into equivalent UML notation is presented in Table 1. Minor variations in representation between e^3-*value* notation and UML notation are captured in the side-by-side comparison. While this report draws heavily from the principles of e^3 *value*, UML use-case representations will be used.

Table 1. Mapping of e^3-*value* Symbols to their Equivalent UML Use-Case Symbols

e^3-*value* Element	e^3-*value* Symbol	Equivalent UML Element	Equivalent UML Use-Case Symbol	Comments
Actor		Actor	«actor» Customer / Customer	A UML stick figure actor classifier may be represented by a rectangle to make the representations appear similar.
Value activity		Use case	Use Case	An activity specifies how execution of subordinate behaviors is coordinated.
Value interface		Port	Use Case Port	A value interface, or "port" in UML is an input that provides a value to an action.
Value port		Interface	Use case RequiredInterface ProvidedInterface	A strong principle of e^3 value is that all value ports that share an interface must be active if any one of them becomes active.
Value exchange	Value object	Information flow	Value object	The use of arrows in UML would be redundant because UML interfaces indicate direction of object flow.
Scenario path		Trace	«trace»	In UML, a trace is an "inter-model" relationship for tracking requirements and changes across models.
Start stimulus		Start		Despite using "start" and "stop" stimuli, e^3-*value* scenario paths show grouping, not process. We observe that e^3-*value* scenario paths are infrequently needed while using UML notation because UML facilitates the separation of diagrams into multiple, simpler diagrams, each of which clearly shows logical groupings of value exchanges.
Stop stimulus		Stop		
Join and fork nodes	AND OR	Join and fork nodes		A join node is a control node that synchronizes multiple flows, while a fork node splits the flow into multiple concurrent flows.

Note that the UML diagrams presented in this report do not illustrate scenario paths with start and stop stimuli (details are provided in Section 2.4). Our approach creates simpler diagrams, one for each type of logical grouping of value exchanges. Readers can form an integrated viewpoint of the business case by inspecting all the provided diagrams.

2.2 Activities, Actors, and the Allocation of Activities to Actors

The first questions to answer in order to construct a business model are: (1) who are the actors, (2) which service or product of economic value they are providing, exchanging, and/or consuming, and (3) what activities must be executed to exchange this service or product. After answering these three questions, we can then accurately identify the transactions of *value objects*.

Important activities are derived from use cases. Valuation is necessarily a comparison. Therefore, activities must be defined to facilitate and compare at least two business cases (e.g., a business-as-usual baseline and its alternative). The accumulation of value is expected to differ, of course, between the two alternatives.

Identification of actors, their activities, and their relation to each other is an iterative process and requires good understanding of the business and its objectives. The flowchart below illustrates the iterative process of identifying all necessary actors and activities, starting from the actors that are identified in the use case. In the process of identifying actors and activities, we derive the value objects being transacted or exchanged. Our experience with development of business models has revealed that accurate identification of actors is the first step in advancing the business model and all other constituent parts of it.
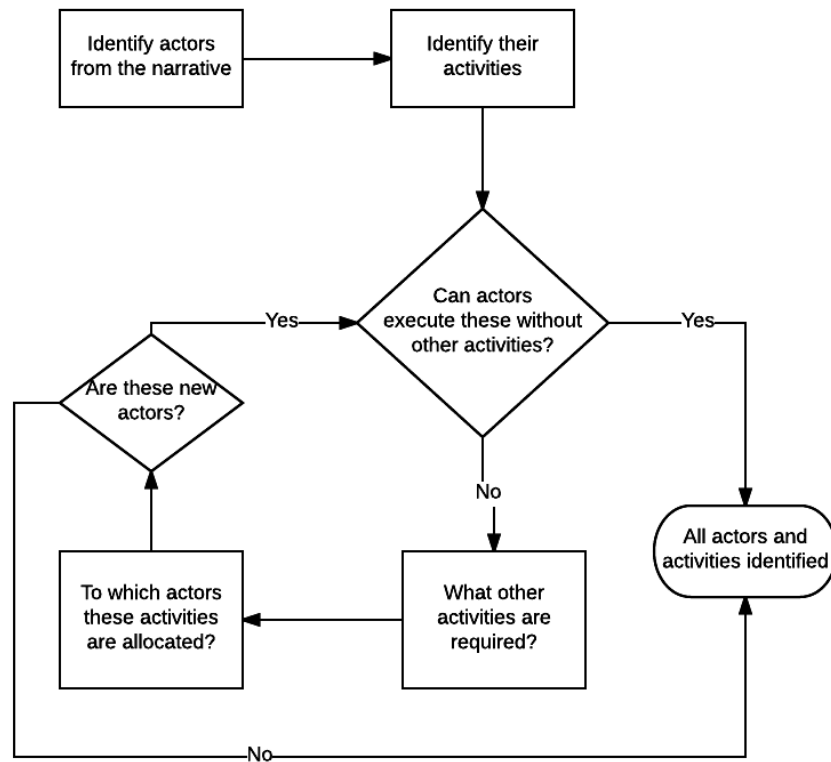

Figure 2. Iterative Process to Identify Actors and Activities

We found this iterative process to be useful. In short, groups of activities must be defined for every scenario path found in use cases. New actors must be defined if, for any scenario path, none of the existing actors can serve as the recipient or supplier of an important transaction.

2.3 Value Comparison Worksheet

The goal of developing business value diagrams is to clearly identify value exchanges. These value exchanges are then the foundation for comparing baseline and test scenarios. A worksheet can be created to support this analysis, following closely the guidance from e^3 *value* for such worksheets.

Table 2 is an example worksheet that suggests the accounting that is facilitated by business value diagrams. This example was derived from a fictitious "Electricity supply diagram," perhaps a UML diagram that defines transactions by which energy is supplied in a use case. Each "Actor" column entry must be one of the actors represented in the diagram. The metrics in the "Metrics" column should include all the value objects that are grouped within an interface for a given actor and diagram. An "Aggregation" states the spatial range or temporal period over which the metrics are aggregated. Paired inflow and outflow columns are provided for each scenario that is to be compared. Finally, the "Impact" column should show the change in the metric between two scenarios, which is presumed to have been caused by the differences between the baseline and test scenarios.

Table 2. Suggested Valuation Worksheet Format

Diagram	Actor	Aggregations	Metric	Units	Baseline Scenario		Test Scenario		Impact
					Inflow	Outflow	Inflow	Outflow	
Electricity supply diagram	One customer	Year 1	Electricity	MWh	13.1		12.6		−0.5
			Fee	$		−1,179		−1,134	45
	All customers	Year 1, Electric utility	Electricity	GWh	144		139		−5
			Fee	$M		−13.0		−12.5	0.5
	Electric utility	Year 1	Electricity	GWh		−144		−139	5
			Sales	$M	13.0		12.5		−0.5

The resultant impacts can be mapped to the system activities and operational and business objectives (as were introduced in Figure 1). Additional columns could be included in the table to keep track of such mappings.

Some principles of balance are evident from the worksheet. First, the example approach is like a double accounting in that both ends of a value exchange must be represented. This facilitates a check that value is neither lost nor magically created during the exercise. In this example, the electrical energies and fees that are exchanged between the electric utility and all its customers are shown to be equal and of opposite sign. Additional rows (not shown) would be included to represent the electricity received by the electric utility from its wholesale suppliers and the fee paid for the electricity, thus completing the balance of energy and energy fee from the perspective of the electric utility.

The worksheet potentially facilitates many interesting aggregations, in addition to that which is directly shown in the table. A very strong guiding principle is that the sum of value exchange at a given actor precisely represents the business case from that actor's perspective. Further post-processing is facilitated by combining the spatial aggregations (e.g., by customer, feeder, substation, utility, etc.) and temporal aggregations (by minute, hour, day, month, year, etc.).

2.4 Scenario Paths

In *e3 value*, a scenario path is defined as "a specific instance of a scenario" to show the coincidence between events. Scenario paths are notated by symbols that were introduced near the bottom of Table 1. The primary purposes of scenario paths are to create a common understanding between stakeholders and to integrate viewpoints[1] (Gordijn 2002). We did not find the definition and use of scenario paths for business value modeling compelling. The notation seems to invite inclusion of transactions and value objects that, while important to process, are not themselves critical valuation metrics.

For example, in a double auction market, the value objects are exchanged between a "buyer" and "seller" for a certain monetary amount, and these are the main elements we model in a business value diagram. However, the market is influenced by how and when the market is cleared. Business value diagrams are not concerned with such activities. In other words, in business value diagramming, we are only interested in answering "who," "what," and "why" questions and do not get into "how" and "when" questions that will ultimately quantify the value objects, or metrics. The latter can be addressed later as the analyst defines the process and sequence of activities.

In our approach of using UML to diagram business cases, we made several modifications that reduced the need for scenario paths even more. UML was found to facilitate the separation of the *e³-value* case diagrams into multiple, simpler diagrams. Instances of, or links to, various actors can easily be represented, as needed, in the multiple, simple diagrams. As a by-product of the separation of diagrams into multiple, simpler ones, each diagram can be made to address no more than one or two scenario paths. We found that the resulting scenario-path notation was then trivial and unnecessary on our UML diagrams.

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[1] There are different viewpoints defined in *e3 value*: *value* viewpoint, *process* viewpoint, and *information system* viewpoint.

3.0   Examples from the Buildings Domain

In April 2014, Pacific Northwest National Laboratory published a reference guide for a transactive building controls framework (Somasundaram et al. 2014). This reference guide proposes a framework concept to achieve the energy efficiency objectives of buildings using the flexibility of buildings in the modern grid. In this transactive framework, mutually beneficial and cost-effective market-based transactions can be enabled between multiple players across different domains. Treatments and interventions are required to enable these transactions. At the building scale, these changes are mostly related to upgrading building control strategies, integration of building sub-metering, and installing an advanced communication network. Other retrofits related to systems (e.g., lighting and heating, ventilation, and air conditioning (HVAC)) or the building envelope may also be required to achieve maximum benefits in terms of occupant comfort while minimizing cost for the building owner.

There are four categories of transactions discussed in the reference guide. These include end-user services, energy market services, grid services, and societal services. End-user services are building-scale transactions performed to enhance occupant comfort while reducing cost. Energy market services are focused on strategies that change consumer behavior to save energy or money (e.g., peak reduction through time-of-use pricing). Grid services cover ancillary or regulatory services, and societal services include cap-and-trade markets for energy and emissions savings using transactive mechanisms. A set of example business cases are described in the reference guide for each category of transactions mentioned. Each transaction has a type categorized as intra-building, building-to-building, building-to-other, or building-to-grid. A summary of these use cases and their types is provided in Table 3.

Table 3. Transactive Building Use Cases Introduced in Somasundaram et al. (2014)

No.	Transactive Use Case	Service Type	Interaction Type
4.1	Third-party energy provider[*]	End-user	Building-to-other
4.2	Efficiency shared savings	End-user	Building-to-other
4.3	Tenant contracts with building owner for energy[*]	End-user	Intra-building
4.4	Transactive control for large commercial building HVAC systems[*]	End-user	Intra-building
4.5	Diagnostic and automated commissioning services[*]	End-user	Building-to-other
4.6	Data centers trade computation jobs	End-user	Service-provider-to-service-provider
4.7	Microgrid coordinating demand response, distributed generation and storage	End-user	Building-to-building
4.8	Trading positions in an electric vehicle charging queue	End-user	Customer-to-customer
5.1	Dynamic rates	Energy-market	Building-to-grid
5.2	Optimize electric vehicle charging for dynamic rates	Energy-market	Building-to-grid
5.3	End-use differentiated dynamic rates	Energy-market	Building-to-grid
5.4	Transactive energy market exchange	Energy-market	Building-to-grid
5.5	Trading efficiency to relieve congestion	Energy-market	Building-to-grid
5.6	Differentiated reliability service	Energy-market	Building-to-grid
6.1	Interruptible service or direct load control	Grid	Building-to-grid
6.2	Transactive retail energy market	Grid	Building-to-grid
6.3	Trading allocated capacity rights[*]	Grid	Building-to-building

No.	Transactive Use Case	Service Type	Interaction Type
6.4	Ancillary services via aggregator	Grid	Building-to-grid
6.5	Transactive acquisition of ancillary services	Grid	Building-to-grid
6.6	Rate dependent priority for cold load pickup	Grid	Building-to-grid
7.1	Emergency power rationing	Societal	Building-to-grid
7.2	Efficiency incentive payment	Societal	Building-to-grid
7.3	Air shed management	Societal	Building-to-other

*Business value diagrams are completed in this report for these use cases.

The true value of each defined business case cannot be well understood without a systematic approach to enable comparison of the economic value of a base case (i.e., current practice) against the proposed business idea. To enable such comparison, a conceptual modeling approach is necessary to capture different actors, activities, and transactions in a business model. Such a conceptual model supports exploration of details of a business idea, communication among stakeholders, identification of *values*, and derivation of a higher fidelity model to support simulation and quantification of values identified.

The following use-case examples are selected from the reference guide use cases and represent different types of the transactions mentioned above. Each use case and its type of transaction are explained in the reference guide, and a short summary is included here.

3.1   Use Case 4.1: Third-Party Energy Provider

In Use Case 4.1 a customer contracts with a third-party energy service provider. The energy service provider installs and operates equipment at the building location. Two quite different energy services are highlighted.

1. If the provided equipment is battery energy storage, thermal energy storage, or a combined-heat-and-power (CHP) system, then the building's access to the thermal and electrical energy that is produced by the equipment must be described.

2. Alternatively, the third-party energy provider controls the equipment that has been installed at the building location to facilitate provision of grid services. In this case, the provision of grid services, such as ancillary services or demand response, to the electric power grid must be described. Any revenues received for performing those grid services are shared between the customer, the energy provider, and perhaps entities in the electric power grid, too.

Figure 3 shows many of the associations between various actors and other items that were inferred from Use Case 4.1. Note that a commercial building owner is a special type of customer for the purposes of this use case.
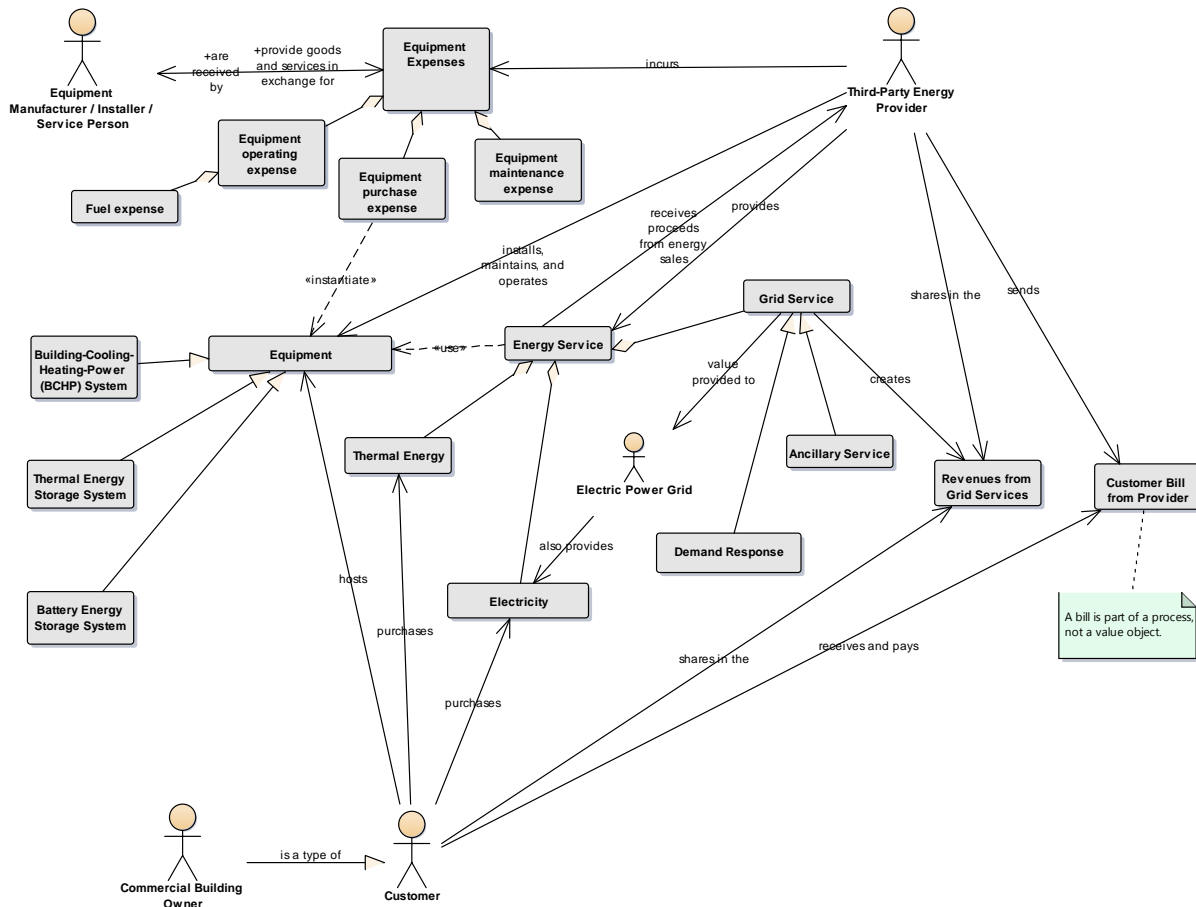
Figure 3. Model for Use Case 4.1

Use Case 4.1 includes provided energy equipment. The expenses of purchasing, installing, maintaining, and operating the equipment and providing the services must be captured during valuation. These expenses are addressed toward the top left of Figure 3. The use case makes it clear that the energy provider alone owns the responsibility to install, maintain, and operate the provided equipment. The precise selection of equipment and the processes by which the equipment is installed, maintained, and operated were not described in the use case, but such costs are critical to whether scenarios will prove economically feasible. The business model needs only a single aggregate actor that can be presumed to sell and install the needed goods and perform the needed labor and services. Figure 4 shows the set of transactions that is needed to account for these expenses and the corresponding goods and services. The aggregate actor in this model is called an "Equipment manufacturer / installer / service person."
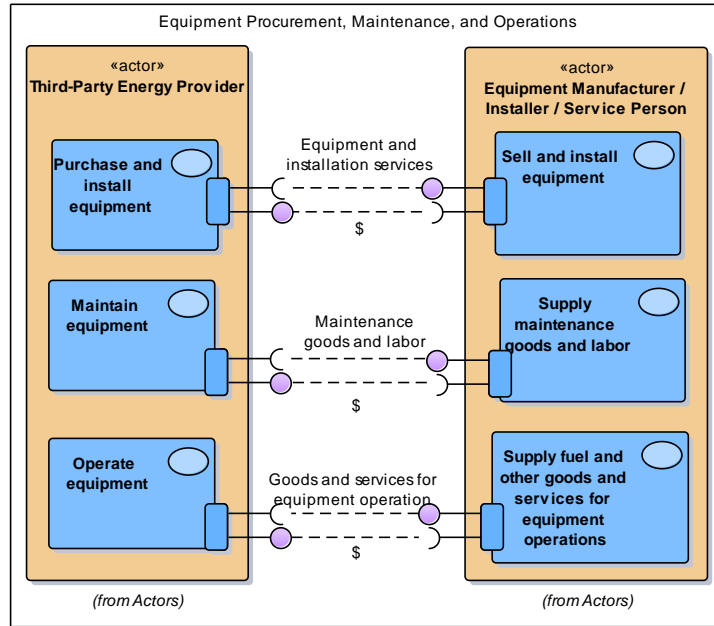
Figure 4. Equipment Purchases, Maintenance, and Operation Expenses in Use Case 4.1

Figure 5 addresses all the purchases and sales of electricity in Use Case 4.1. Three transactions are described. (1) The customer must purchase electricity from the electric power grid (usually represented by a distribution utility) for the loads other than the provided equipment. It is important to capture this transaction because the equipment provided by the energy service provider may affect the electricity consumption of these other customer loads. (2) Because the third-party energy provider accepts all costs of operating provided equipment, the energy provider must pay for any electricity that the provided equipment consumes. (3) Alternatively, when the provided equipment generates more electricity than is needed by the customer, then the surplus electricity might be sold back to the grid by the energy service provider. This third transaction was not directly stated in the use case, but it is sensible and may be necessary to support grid services as described in Use Case 4.1.

Note that Use Case 4.1 carries some ambiguity as to whether grid entities will contract with the third-party energy provider or with the customer. Figure 5 presumes that surplus energy from provided equipment is sold back into the electric grid by the energy provider. If it is instead the customer who does so, then the figure must be amended to include that transaction.
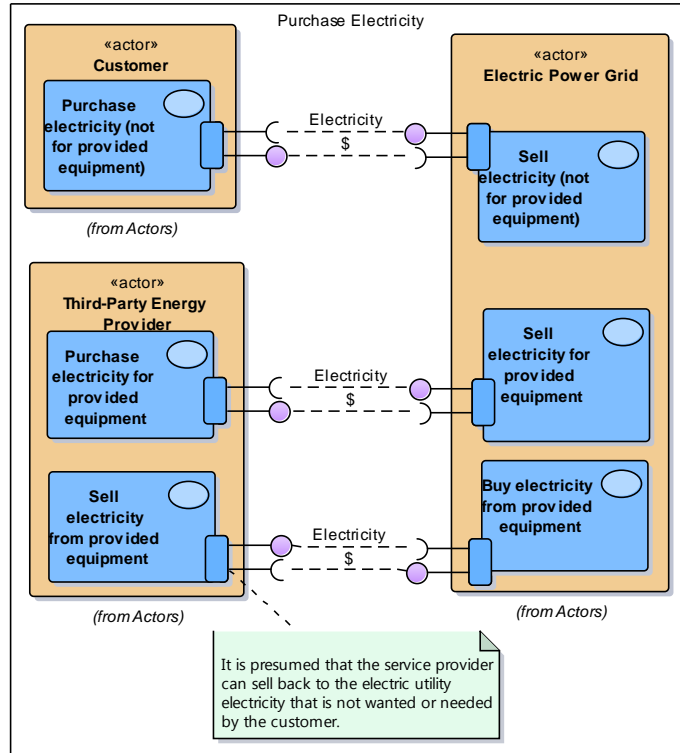
Figure 5. Procurements of Electricity in Use Case 4.1

Figure 6 describes the transactions in which the customer (e.g., a commercial building owner) purchases energy generated by provided equipment. The energy can be in the form of either electricity (e.g., from battery energy storage) or heat (e.g., CHP). According to the use case, the customer may buy generated heat or electricity "if it is advantageous to do so." The meaning of this contingency must be further defined among the process details of the activities. It is the provided equipment that, under the control of the third-party energy provider, generates electricity and heat. The energy provider receives revenue for energy that is provided to the customer. Separate transactions are described for the thermal and electricity energy cases, but the diagram also points out the possible dependency between the sale and production of heat and electricity, as is the case for CHP systems.
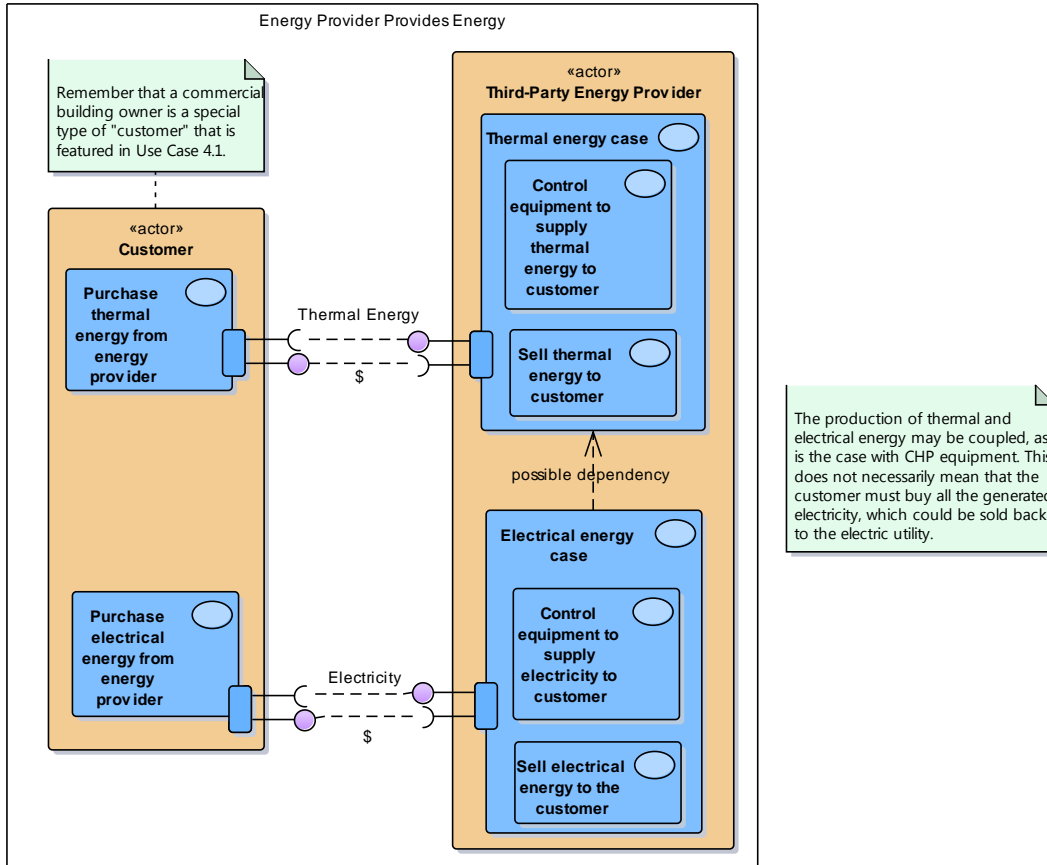
Figure 6. Energy Provider Supplies Heat or Electricity from Provided Equipment in Use Case 4.1

The final business value diagram for Use Case 4.1, Figure 7, shows transactions necessary for the facilitation of grid services. Use Case 4.1 specifically names two example grid services: demand response and ancillary services. Two alternative scenario paths are shown, depending upon whether the electric power grid entity has contracted with the customer or with the energy provider. The energy provider necessarily provides the grid service because it alone controls the provided equipment. But both the customer and the energy provider share in the revenues. If it is the energy provider that has contracted with the grid entity to provide grid services, then the energy provider receives revenues from the grid entity and shares some of them with the customer. If, however, the customer has contracted with the grid entity, then the customer directly receives the revenues. The customer then shares the revenues with the energy provider on a per-occurrence basis or perhaps through periodic (e.g., monthly) billing.

The electric power grid is a boundary of Use Case 4.1 and is therefore an aggregate actor that potentially represents many actors. The customer and the energy provider might directly transact with their distribution utility. However, a distribution utility may not be the originator of the demand-response and ancillary-service objectives and services, and cannot therefore independently quantify incentives for these grid services. This is a possible limitation from a valuation perspective because the use case, as described, lacks a foundation that would tie together the grid services with the monetary incentives for the provision of those grid services. A simplification is accepted in the model. It will be necessary to assume the relationship between grid services and their incentives to move forward. This is an example of one of the most important strengths of modeling; the process can help to identify missing or misaligned incentives.
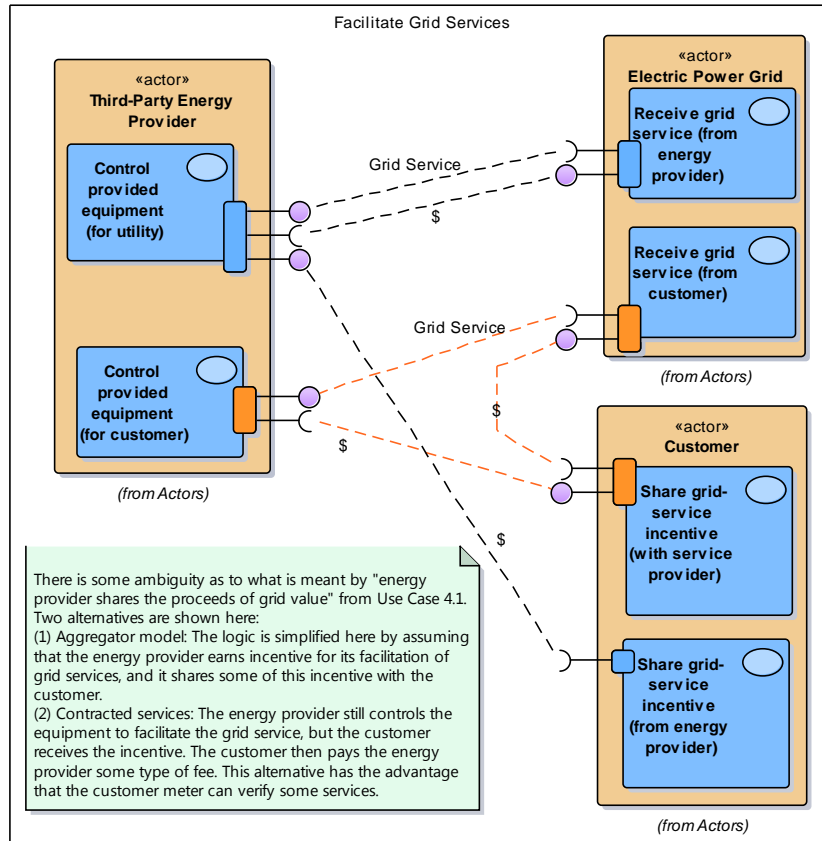
Figure 7. Facilitation of Grid Services in Use Case 4.1

3.2 Use Case 4.4: Transactive Control for Large Commercial Building HVAC Systems

Use Case 4.4 describes a hierarchical control system for a building's HVAC system. Novel pseudo-markets are established at each level of the HVAC system within the building. Each HVAC component then competes in these pseudo-markets for the resources to produce and distribute its energy commodity. The bottom of the hierarchy is driven by building occupants' needs (e.g., comfort, productivity, etc.)

The meaning of "hierarchy" is clarified by the association model for Use Case 4.4 in Figure 8. Only three classes of human actor are shown in this figure, but numerous pseudo-actors have been defined by the levels of the building's HVAC system. The building level hosts the aggregation of electricity and natural gas usage for the entire building. Building lighting, plug loads, banks of cooling towers, and boilers might compete for these energy sources in building-level pseudo-markets—one for natural gas and another for electricity. In turn, the pseudo-markets include the natural gas and electricity utilities as their energy suppliers. There could be markets at the utility levels, but those are beyond the immediate scope of Use Case 4.4. The boiler, which competes for natural gas at the building level, conducts its own pseudo-market for creation and distribution of hot water to the building's radiators and air handling units (AHUs). The radiators and AHUs further conduct their own pseudo-markets, and so on down through the hierarchy.
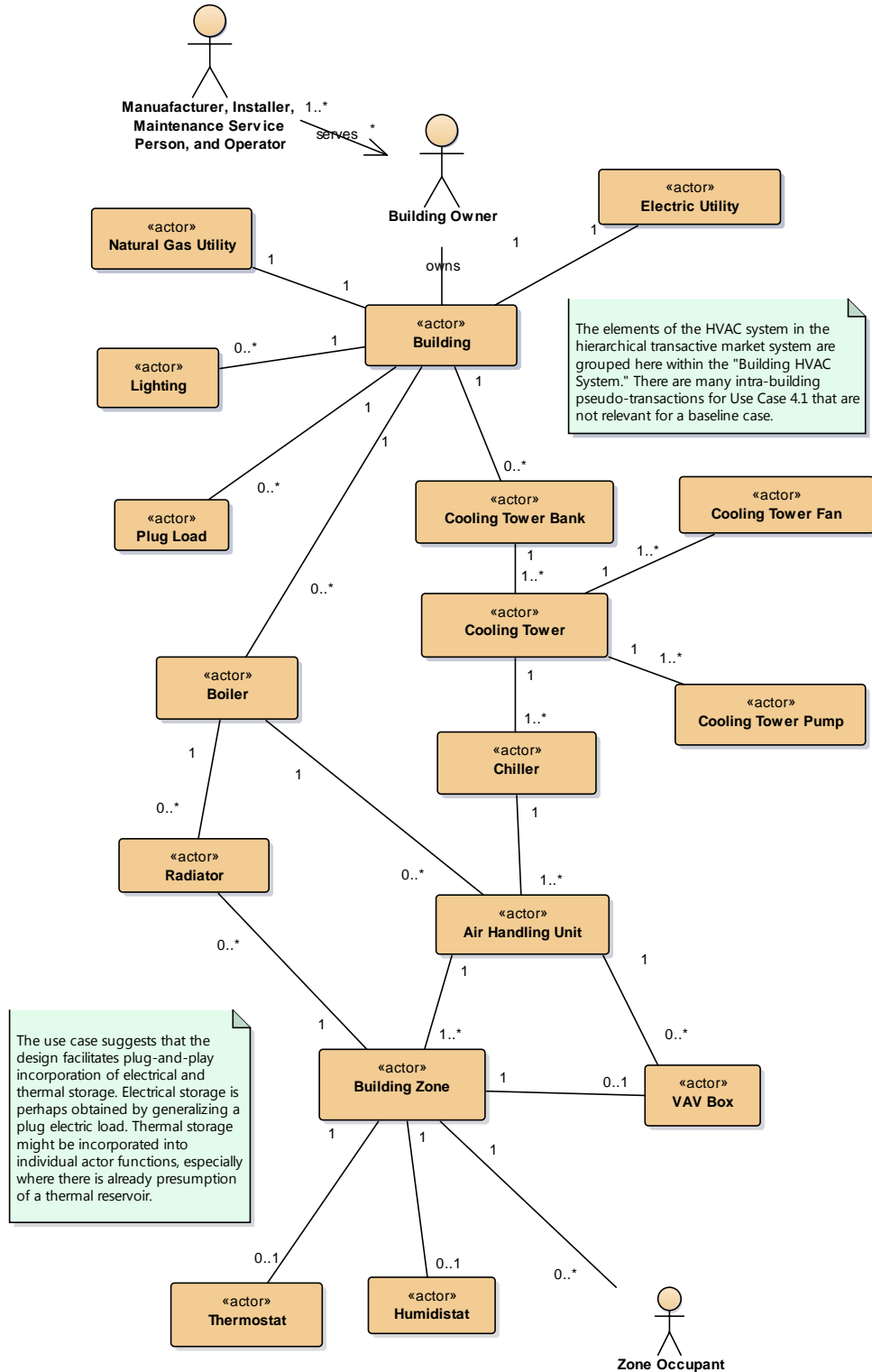
Figure 8. Model of Actors and HVAC "Actors" in Use Case 4.4

Figure 8 is intended to represent nearly all the possible relationships between HVAC system components in building HVAC systems. A specific building may not possess all the components and their

corresponding associations. The indicated multiplicities help identify these options. For example, a building zone (multiplicity "1") is associated with from zero to one VAV box (multiplicity "0..1").

Figure 9 represents all the transactions that are needed to account for the purchase, installation, maintenance, and operation of new equipment that makes this building transactive. Examples might include microprocessor and communication platforms and integration and design costs. This model is not intended to capture the costs of the HVAC components, which are presumed to exist, or which would incur similar lifetimes and upgrades. If any effect on HVAC system lifetime or performance might be hypothesized, then this model and its diagrams must be extended to also represent the purchase, replacement, maintenance, and operations of the HVAC equipment. The details of the activities would also be extended to model HVAC equipment lifetime and maintenance and operation expenses.

As was the case for Use Case 4.1, an aggregate actor has been defined ("Manufacturer, Installer, Maintenance Service Person, and Operator") to represent any of the actors who might receive payments for supplying goods and services toward the procurement, installation, maintenance, and operation of the transactive system and its components. It is assumed in this model that the building owner bears all these expenses. The model must be revised if actors other than the building owner bear the expenses. For example, distribution utilities might provide and maintain equipment during pilot-scale demonstrations.
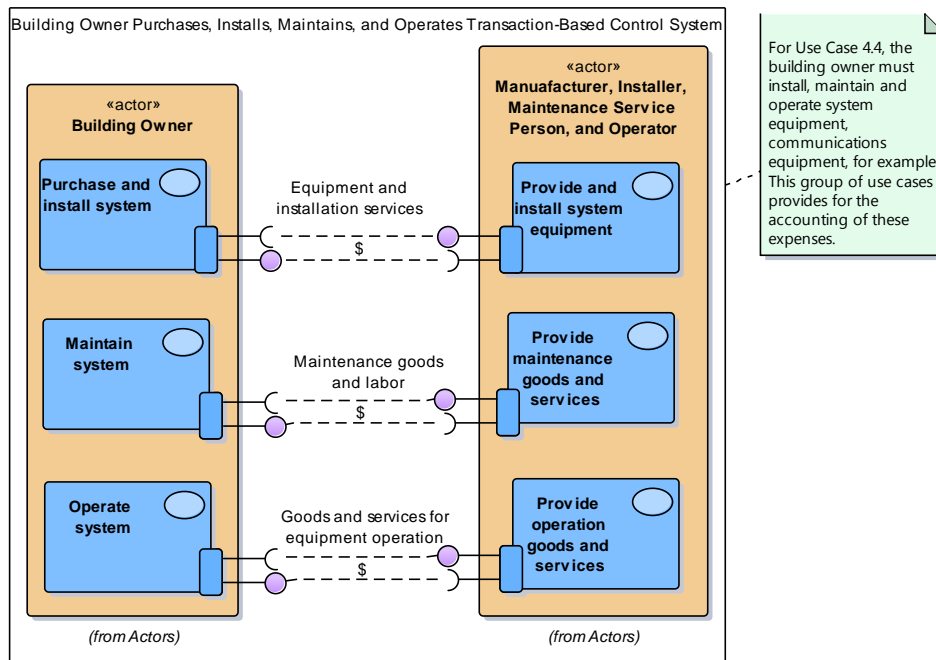

Figure 9. Transactive Control System Equipment Purchase, Maintenance, and Operation Expenses in Use Case 4.4

Diagrams will now be presented for each of the building levels that may host pseudo-markets. The order of the diagrams will proceed from the top of Figure 8 downward.

Two pseudo-markets are hosted at the building level for the building's total electricity and natural gas usages. Figure 10 shows the transactions for electricity distribution in the building. The building actor purchases electricity supply from the electric distribution utility and "sells" the electricity to all the various electric loads in the building. The electric utility could be, but is probably not, an active bidder in this pseudo-market.

The word "Sells" is placed in quotation marks here because the exchange of money between the HVAC control system levels is, or is not, real, depending on the detailed design of the pseudo-market activities. Use Case 4.4 suggests some design alternatives, including auction mechanisms. It is conceivable that building occupants would receive either tokens or real money with which they could make their bids and drive the hierarchical markets.

There are many HVAC levels that require electricity and therefore might participate in this pseudo-market and "buy" electricity. While the HVAC components are quite diverse, the means by which they "buy" electricity in the pseudo-market are expected to be very similar. Each activity is an instance of a common defined activity. Seven such instances are shown. Five of the seven are owned by components of the HVAC system, but the electricity pseudo-market is also shown to possibly include electrical plug loads and building lighting.

Several sub-activities or actions are notated nested within the building's activity "operate transactive market." These steps would be included in the more detailed behavioral modeling of the activity to which they belong.
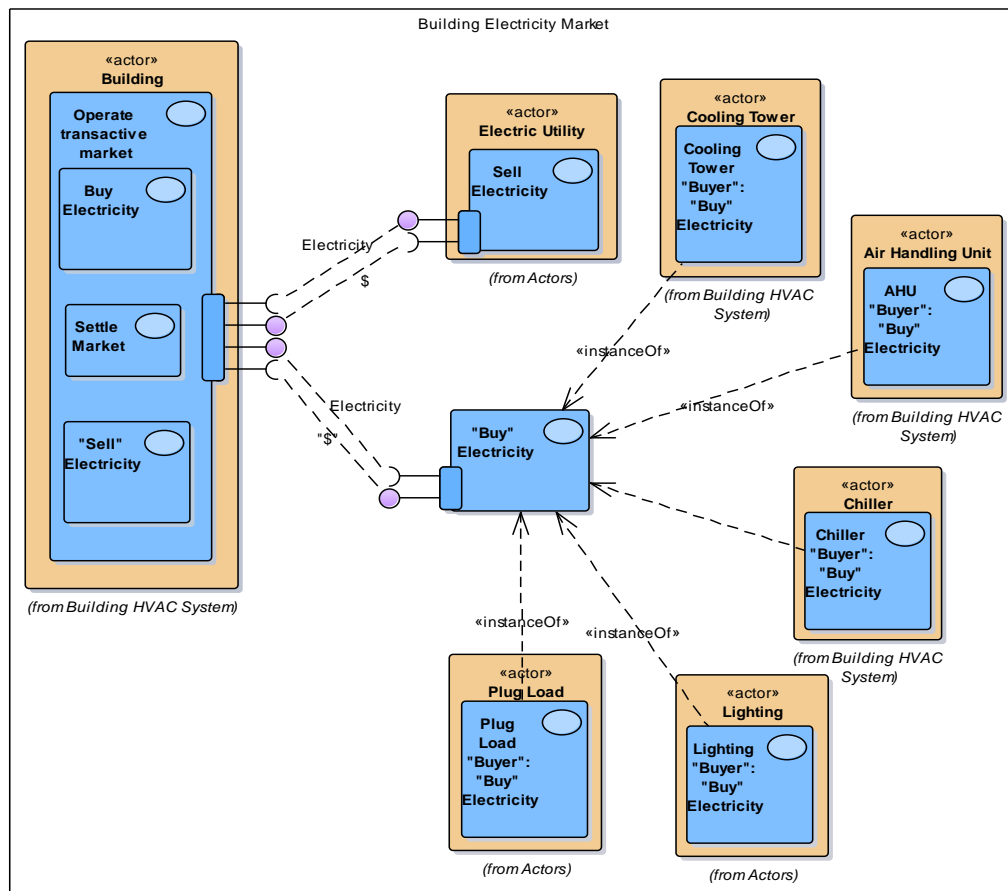

Figure 10. Building Electricity Pseudo-Market in Use Case 4.4¶Many HVAC system components need and could compete for electricity at the building level. VAV is variable air volume.

The building level also hosts the simpler natural gas pseudo-market shown in Figure 11. The building boilers appear to be the only "buyers" in this market. If the supply were to become constrained, the market should select the most cost-efficient boilers for producing the hot-water commodity and its building uses. Even if the supply is unconstrained, the users of boiler water in the building should elect to

use the most efficient boilers first and thereby improve the effective efficiency of natural gas consumption by the boilers.

The building purchases its natural gas supply from its gas utility. Again, the natural gas utility could be an active participant in the building pseudo-market, but it is probably not. Instead, it might provide a relatively static natural gas price and a virtually unconstrained supply. In the absence of active participation, the best practice is to accurately reflect the dynamics (if any) of the existing transactions.
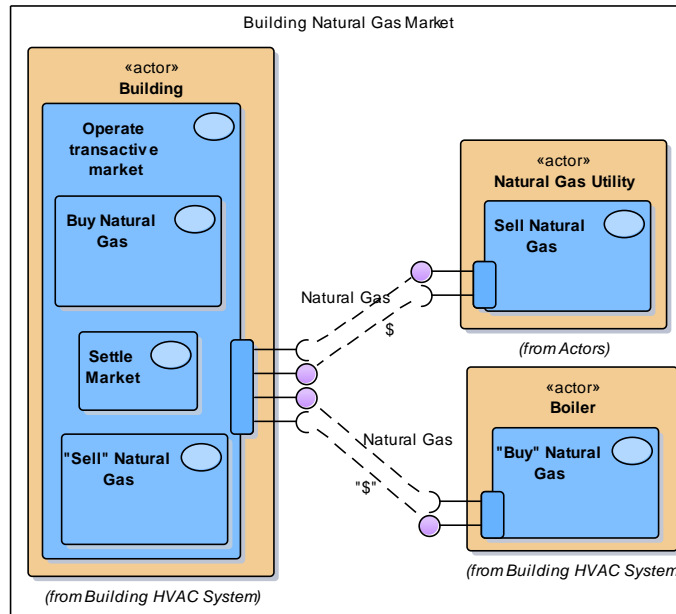

Figure 11. Natural Gas Pseudo-Market in Use Case 4.4

The hierarchy of HVAC pseudo-markets has a cooling branch and a heating branch. We will trace the cooling branch first. No market diagram will be presented for a bank of cooling towers, which is intended to represent aggregations of cooling towers on the building premises. We will jump instead to the diagram of Figure 12 that represents a pseudo-market from the perspective of a single cooling tower. The cooling tower is relevant only during cooling mode. A cooling tower possesses fans and pumps that help it transfer heat out of circulating water into the ambient air. No transaction has been shown for the expulsion of the heat because there appears to be no cost or incentive for doing so. The cooling tower must procure a supply of electricity to operate its pumps and fans.

Chillers compete in this pseudo-market and "buy" the cooling tower's service of removing heat from the circulating water.
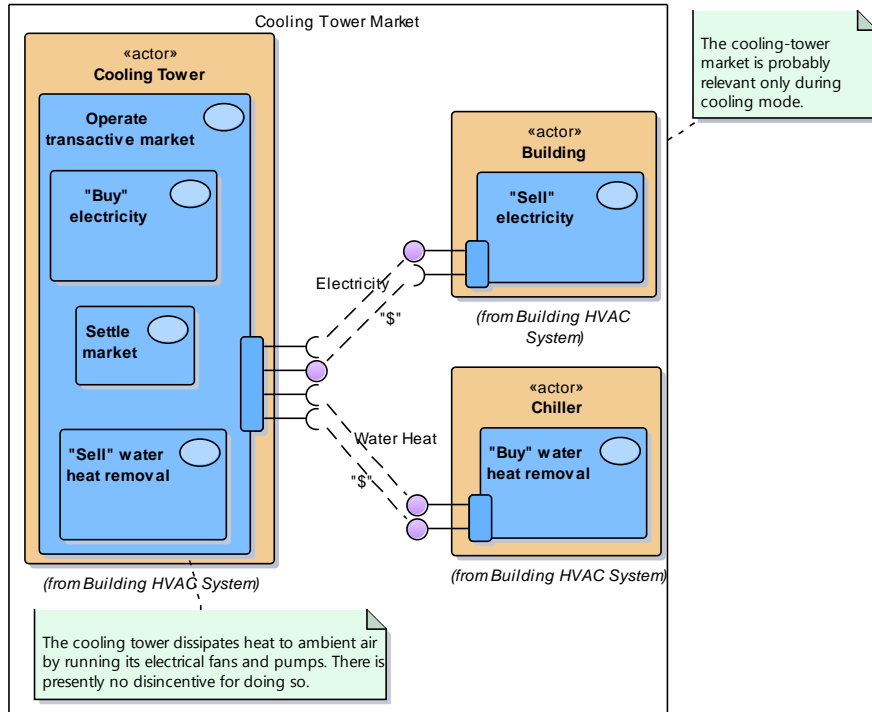
Figure 12. Cooling Tower Pseudo-Market in Use Case 4.4

In many buildings, a chiller expels heat to a cooling tower and, in turn, provides cooling services to AHUs. A pseudo-market at this level of the HVAC system might be represented by Figure 13. The chiller requires electricity to move the heat from an air handler to a cooling tower, so it is shown as also participating in the building-level electricity pseudo-market.
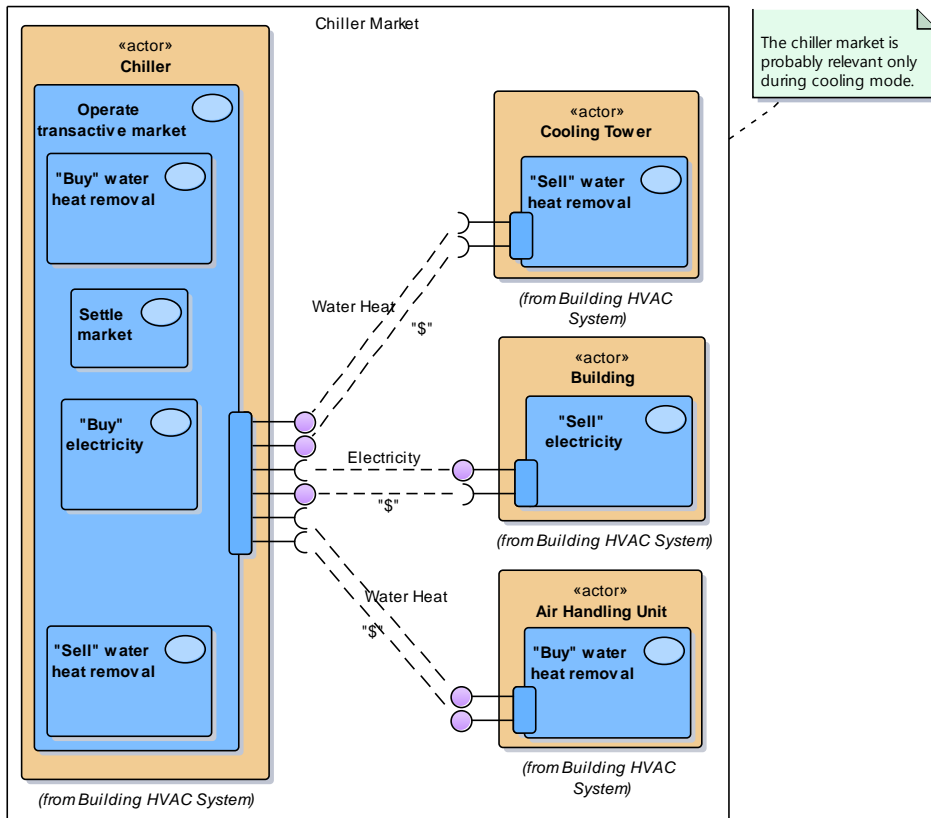
Figure 13. Chiller Pseudo-Market for Cooled Water in Use Case 4.4

The heating-mode path down the hierarchy might include a pseudo-market at the boiler level (see Figure 14). The boiler consumes natural gas to heat water. The boilers compete to "buy" natural gas and "sell" the heat to air handlers or radiators. The air handlers and radiators are presumed to compete similarly in the market.

If the building heating system includes radiators, then a pseudo-market would be defined at each radiator (not shown). Each radiator would "buy" heat from the boiler and "sell" the heat to its building zone.
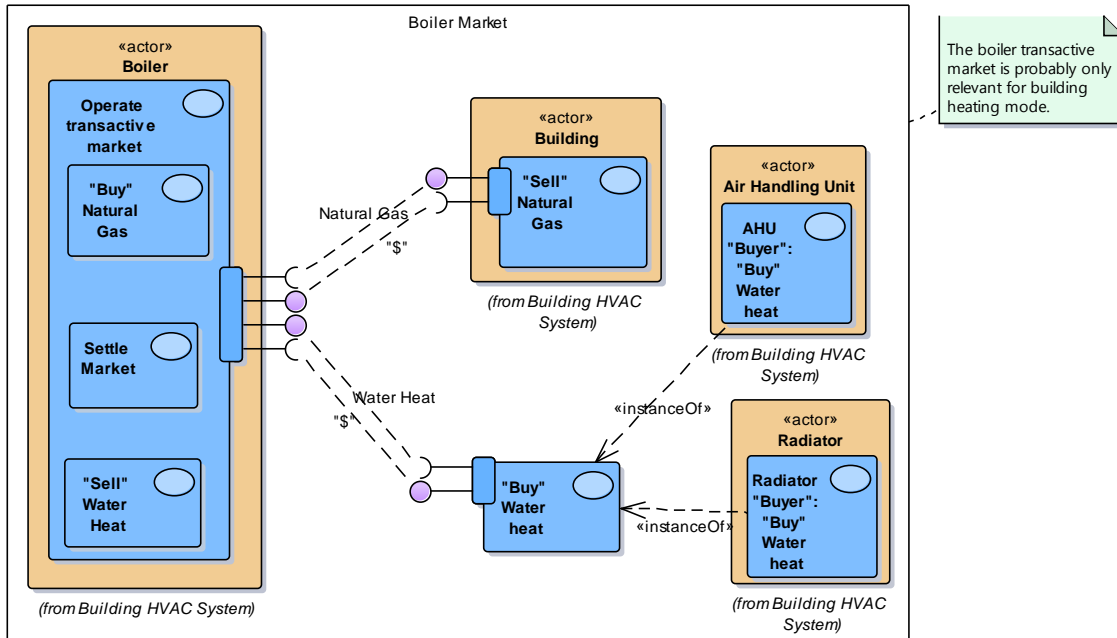
Figure 14. Boiler Pseudo-Market in Use Case 4.4¶AHUs and radiators can compete for the hot water from the boiler.

The cooling- and heating-mode paths rejoin at an AHU, which may participate in both cooling and heating modes. The cooling mode pseudo-market at an AHU is shown in Figure 15. In cooling mode, a chiller "sells" its service of heat removal into the AHU pseudo-market. The building zones or their VAV boxes "buy" the heat-removal service. Some electricity must also be procured from the building level electricity pseudo-market to operate the AHU's fan or fans.

This may be the first diagram in which both the commodity and the payment flow the same direction. Both water heat and payment are shown to flow from the AHU to the chiller, for example. This is a result of the way the value object has been defined, and it is intentional. We have elected to define the commodity as heat, a measure of energy, where the service of cooling is the removal of heat. The AHU therefore pays for the removal of heat, and both value objects flow in the same direction. Another advantage of this convention is that both heating and cooling modes can be defined through the exchange of the same value object—heat energy.
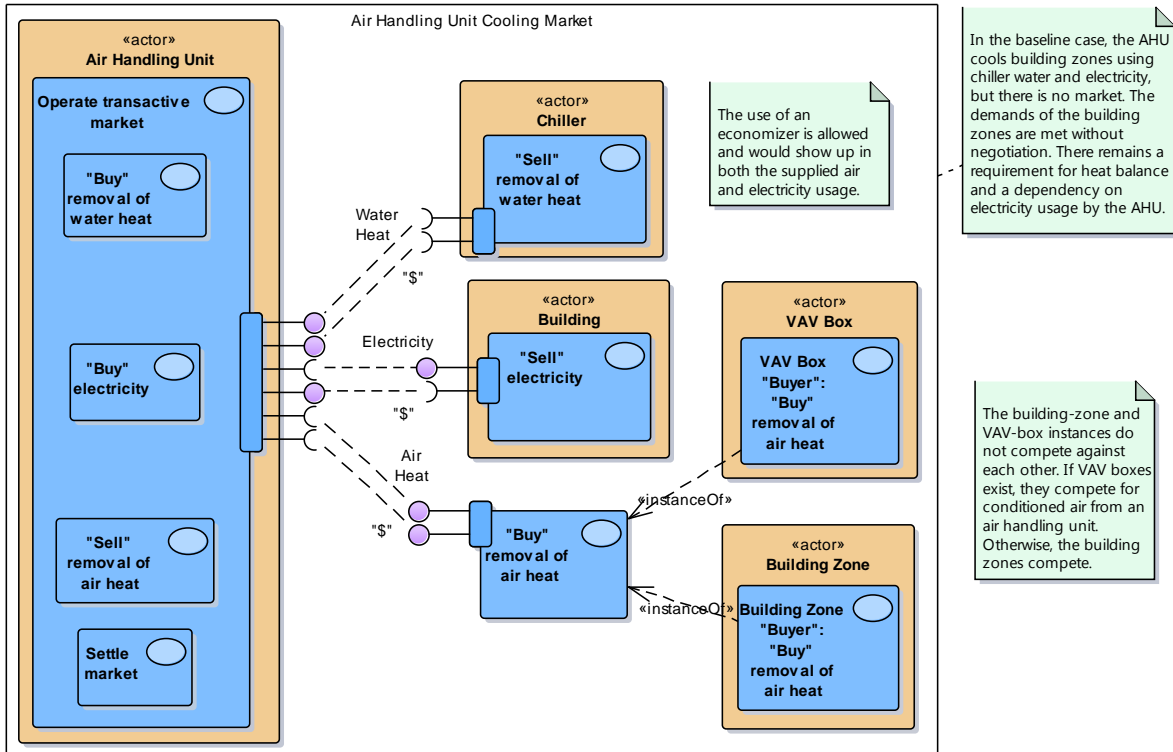
Figure 15. Air-Handling-Unit Pseudo-Market, Heating Mode, in Use Case 4.4

Alternatively, in heating mode an AHU must "buy" heat from a boiler and can "sell" the heat to the building zones or their VAV boxes. As was the case for cooling mode, electricity must be "purchased" to run the AHU's fan or fans.
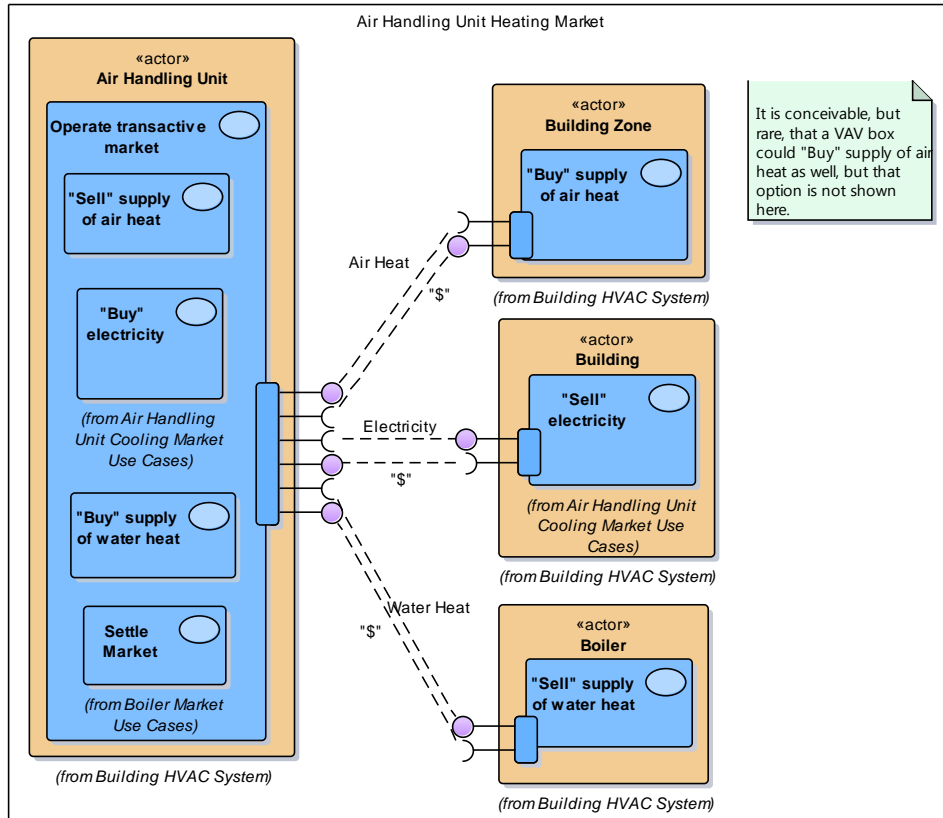
Figure 16. Air-Handling-Unit Pseudo-Market, Heating Mode, in Use Case 4.4

Some building zones may be served by VAV boxes that manage the amount of conditioned air that is delivered to the building zone. Where a VAV box is used, a pseudo-market may be established, as shown in Figure 17. The VAV boxes are shown to "buy" cooled air from their AHU. The conditioned air is then competitively "sold" to the building zones.
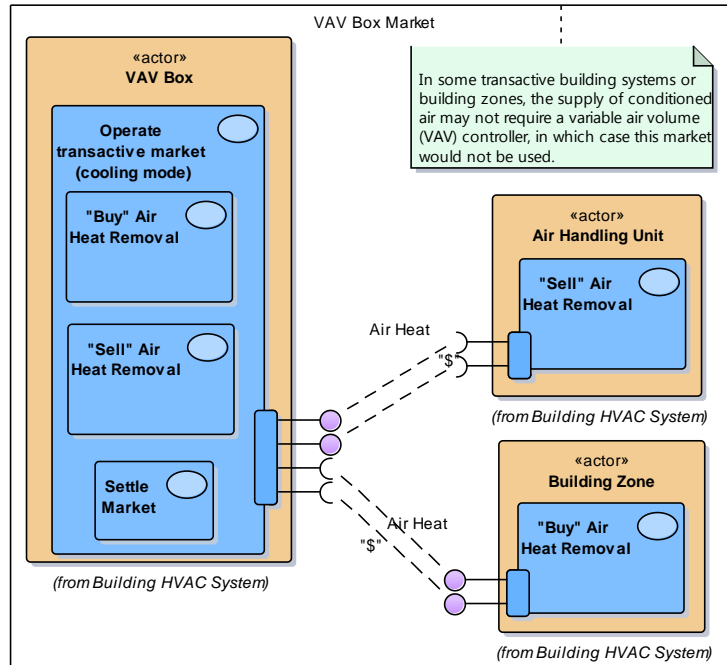
Figure 17. VAV Box Pseudo-Market in Use Case 4.4¶Separate cases are defined here for heating and cooling modes.
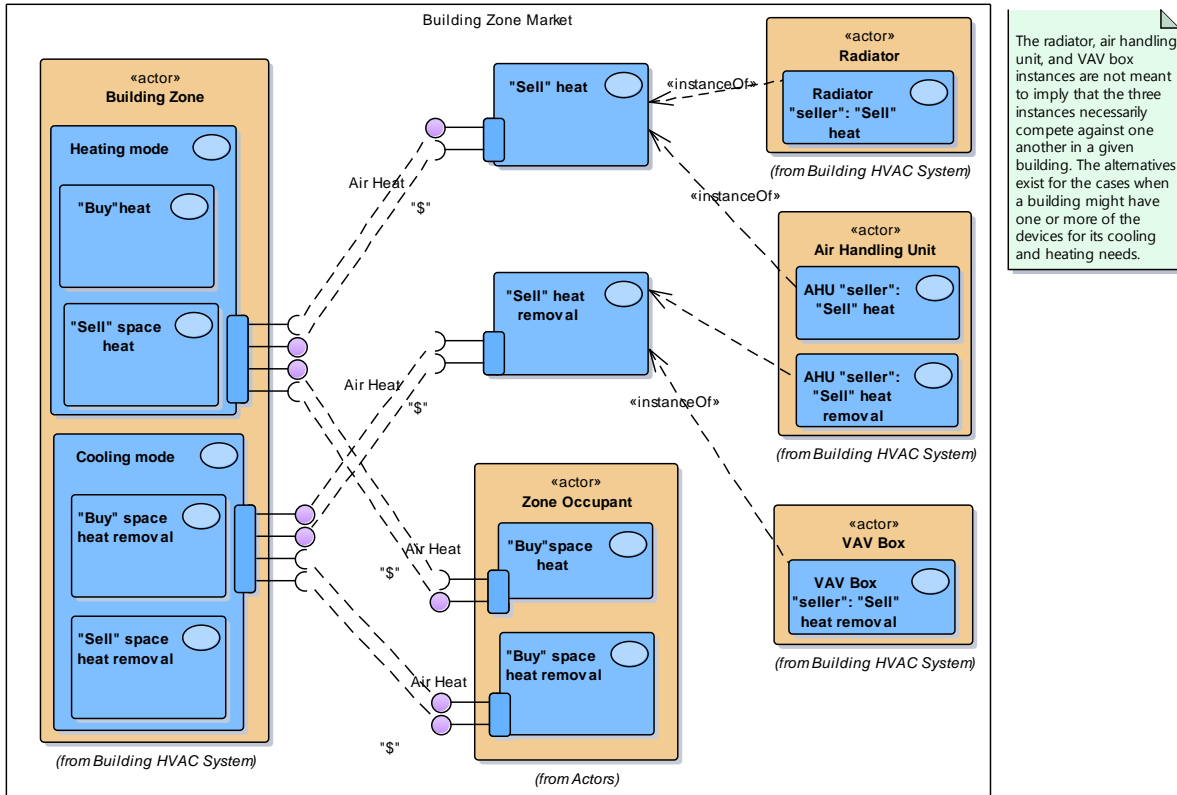
In the final diagram of Use Case 4.4, Figure 18 shows a building-zone pseudo-market. Two scenarios are shown, one for cooling mode and another for heating mode. In heating mode, the building zone "buys" heat from the zone's radiators or AHUs. These sources do not necessarily coexist in a given building. The ones that exist employ similar instances of the activity through which they "sell" heat into the building-zone pseudo-market.

In cooling mode, the building-zone pseudo-market "buys" the removal of heat (also known as cooling) from AHUs and VAV boxes that can serve the building zone. The "sale" of heat removal into this pseudo-market is expected to be similar regardless of whether it is performed by AHUs or by VAV boxes.

Zone occupants "buy" either heat or the removal of heat. This transaction is important because it is at the bottom of the hierarchy for Use Case 4.4 and creates the currency that drives all the other pseudo-markets. Use Case 4.4 did not state exactly the source of money or pseudo-money that would be used, but there are alternatives. At one extreme of the spectrum, building occupants might bid real dollars into the control system to make themselves comfortable. One could also conceive of the building owner paying tenant occupants a share of the predicted space conditioning budget that the tenants could either spend toward their comfort or keep. The monetary impacts become less tangible as we imagine token-like systems that do not employ real money. For example, an HVAC control system might represent the occupants' presumed needs without necessarily even having their representation or input. The Use Case 4.4 diagrams in this report have been made general and inclusive of all these alternatives.

There are many process details that have been deferred in these diagrams, but which could be specified using these diagrams as their starting points. For example, Figure 18 does not attempt to define *how* the zone occupants "buy" their space conditioning. Human occupants are unlikely to be able to engage continuously in pseudo-markets, so agents and automation will likely be required to represent the needs and interests of the occupants in their respective pseudo-markets. An agent (e.g., a smart thermostat) might "bid" on behalf of its occupant and also estimate the energy costs of its occupant's preferences.

Alternatively, occupants might "vote" their space conditioning preferences into their building zone, with each occupant's vote weighted by their reserve of tokens.

Figure 18. Building Zone Market.¶This is the interface to the comfort of the zone occupants.[1]

3.3 Use Case 4.3: Tenant Contracts with Building Owner for Energy

In Case 4.3, a building owner engages tenants and business divisions in conserving energy, managing peak loads and responding to dynamic rates following a contract agreement (Somasundaram et al. 2014).

Figure 19 presents the actor associations, emphasizing the intra-building dependencies. The main actors are the building owner and the tenants. Two additional actors were found to be necessary but were not discussed by the use case:

- An electric power utility actor sells electricity to building owner.

- A facility manager actor provides the building owner with a means to modify the building's electric load and enables the tenants to make informed decisions on how to utilize their loads via a building automation system (or energy management system (EMS)).

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[1] This diagram addresses only the heating and cooling needs. The diagram must be revised if the use case is understood to include additional building-zone objectives like ventilation and humidity control.
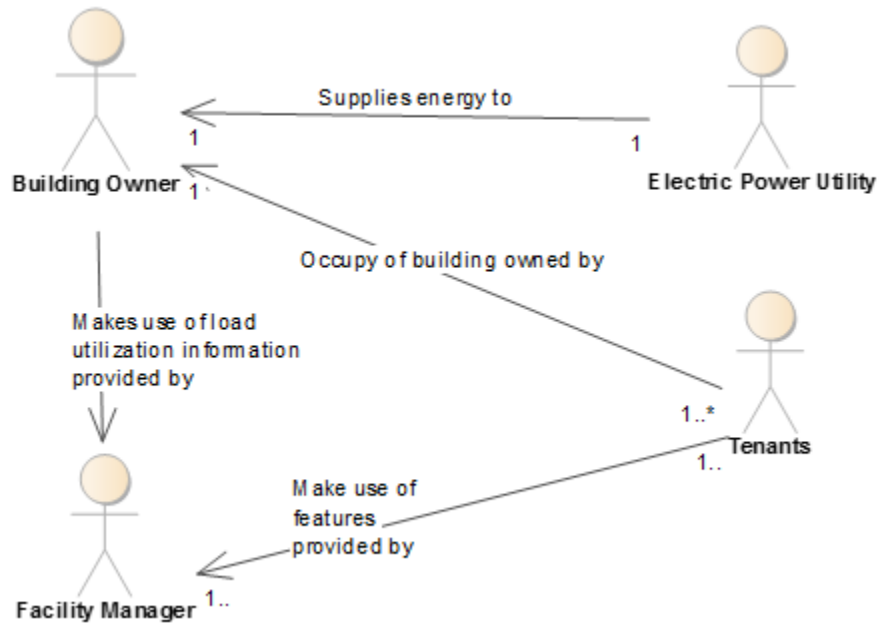
Figure 19. Actor Associations in Use Case 4.3

As part of the lease agreement, the building owner sets monthly allowances for energy use, peak demand charges, and dynamic prices and gives rebates and penalties when the tenant's energy consumption is below or exceeds the monthly allowance, respectively. The building owner relies on sub-metering or nonintrusive load monitoring to get the time-series data for billing purposes. A description of the allowance mechanisms is presented in Figure 20. Note that the real-time allocation is presented as an alternative and drawn in orange.
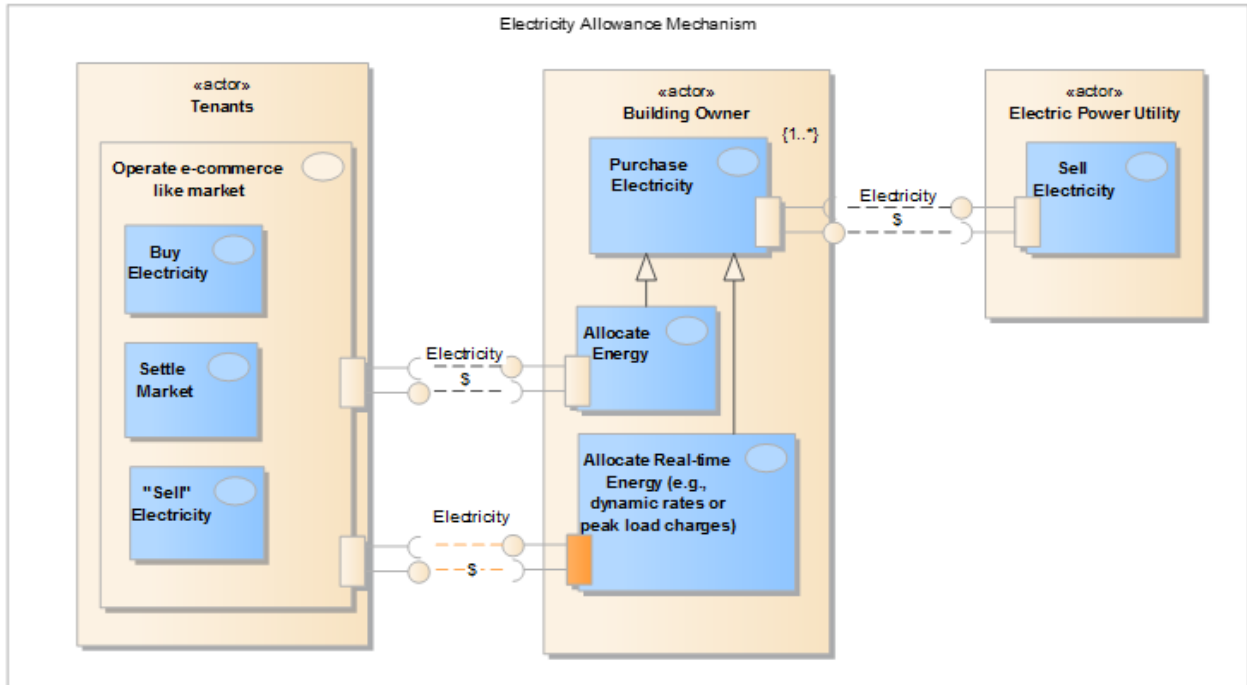
Figure 20. Energy Allowance Mechanism

Tenants can sell excess allowance with others tenants that are in deficit at a mutually agreed-upon price. The building owner sends each tenant the same dynamic rate that it receives to enable the tenants to make informed decisions on how to utilize their loads via a building automation system or EMS. A graphic representation of this trading is presented in Figure 21.
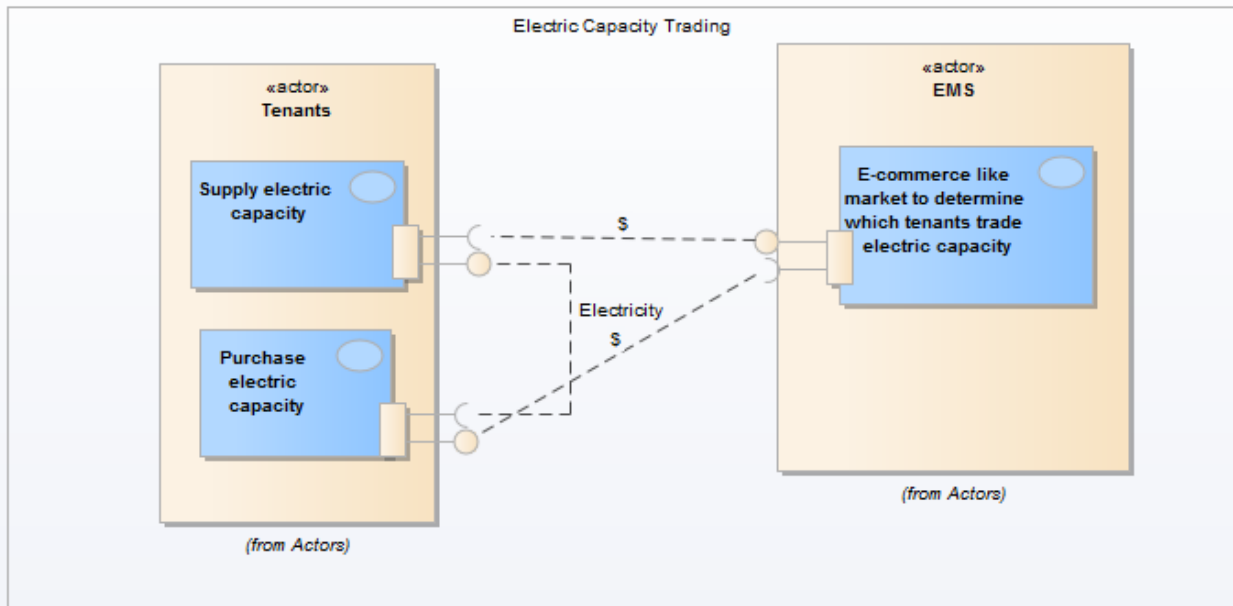

Figure 21. Electric Capacity Trading Illustration

3.4 Use Case 4.5: Diagnostic and Automated Commissioning Services

This is an example of the "building to other" transaction type. Use Case 4.5 describes an "automated diagnostic and commissioning service" offered by a service provider. The customer signs up with the service provider to receive the automated diagnostic and commissioning service. To achieve this, real-time data is collected from the building using the building EMS. The service provider applies data analytics including fault detection methods to generate diagnostic or commissioning information. This information is sent back to the customer via the internet and over an interface (e.g., web application). The customer pays for the service provided based on the contract, e.g., payment per fault detected or a fixed monthly charge for the service regardless of whether a fault is detected.

According to Use Case 4.5, there are two primary actors: the consumer (i.e., building owner or operator) and the service provider. However, in the process of developing the business model, we realized there are more actors or stakeholders necessary to this transactive use case. Following the approach of Figure 2, we identified all actors and activities required to model and implement this use case. The primary service or product being exchanged is denoted in the use case as the automated fault detection service. Identification of other activities is a by-product of identifying (1) initial actors' objectives, and (2) additional required actors and services.

From Use Case 4.5, it is clear that the customer pays a fee for remote diagnostic and automated commissioning services, either as a fixed monthly payment (i.e., insurance contract) or based on the number and magnitude of faults detected. However, it is not specified who is responsible for retrofitting the building EMS, including sensors to collect all data required at a proper granularity. Here, we assume the building owner and facility managers are responsible to deal with EMS services based on their coordination with the service provider.

Figure 22, Figure 23, Figure 24, and Figure 25 represent activities involved in Use Case 4.5. The use case specifies the objectives of the customer to minimize energy bills and improve comfort from enhanced building operation. Hence, energy transaction services are modeled (Figure 22) to capture customer energy savings observed after participating in automated diagnostic services. Quantifying the economic value of comfort is a challenging task since the customer is paying for it through energy bills. Therefore, we assume, building managers maintain the building at optimum indoor air conditions and quality, and cost of comfort is reflected in the cost of operation. Objectives such as reduced number of maintenance activities and repairs and increased life of equipment are not pointed out in the use case. However, they should be considered in quantification of value and profit for the customer and overall impact of this transactive use case.

The use case specifies two other possible transactions or alternatives. One is that the service provider may also offer repair services when a fault is detected. So the alternatives are (1) the building owner conducts repairs, or (2) the service provider has partners to provide corrective services. Both are shown in the business models presented here (Figure 25). The other transaction mentioned in the use case is that energy savings may be transacted with a utility or aggregator to help meet regulatory requirements for efficiency or carbon tax benefits. The latter is shown in Figure 22 as an example of a credit or incentive. These are part of environmental values, which are monetized and transacted among actors.
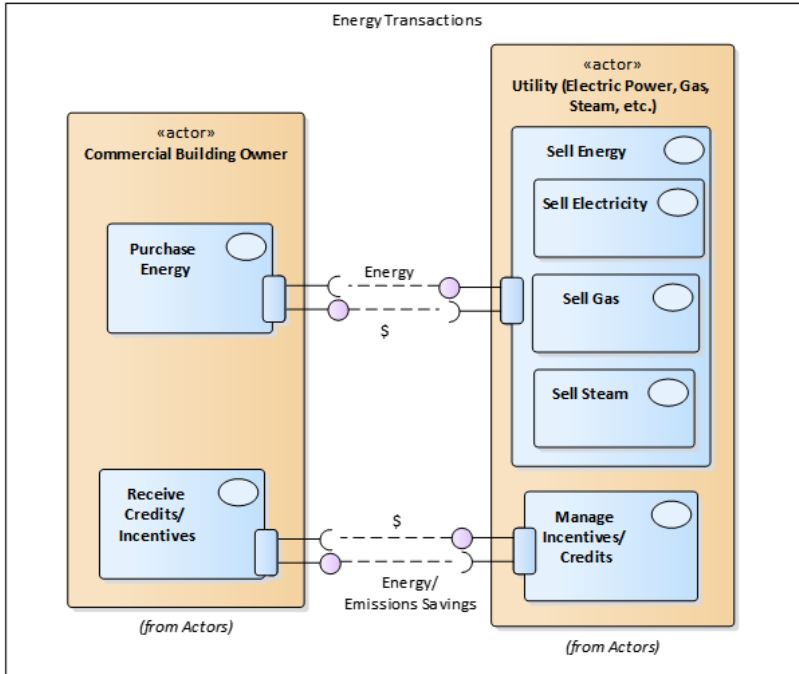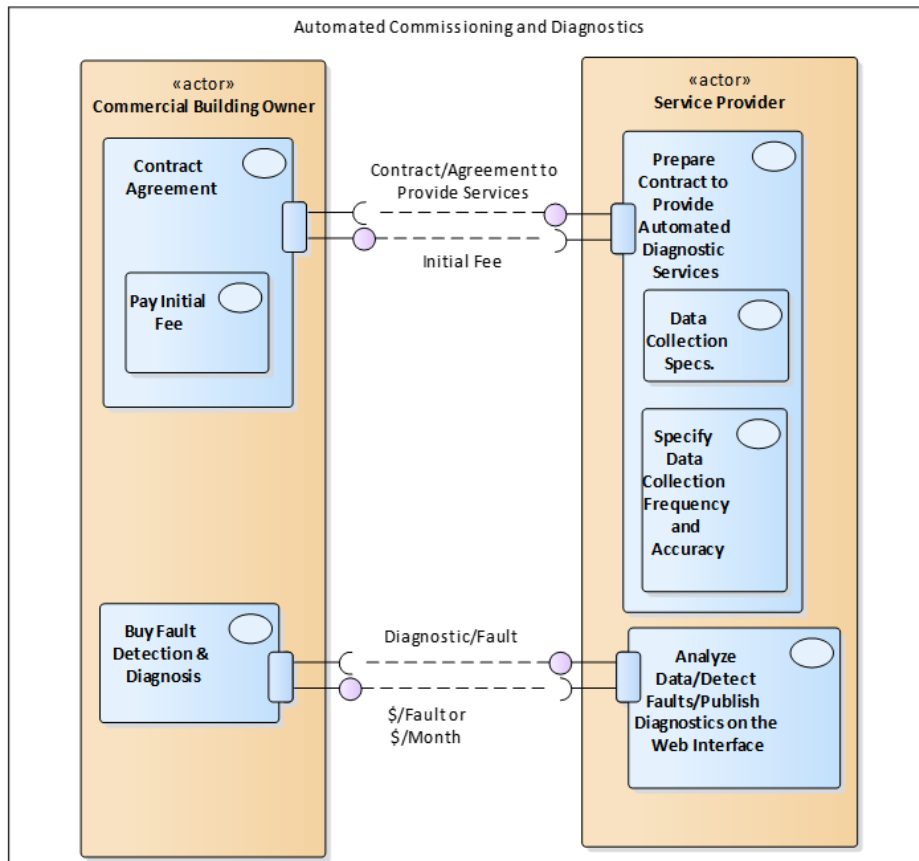
Figure 22. Energy Transaction Activities

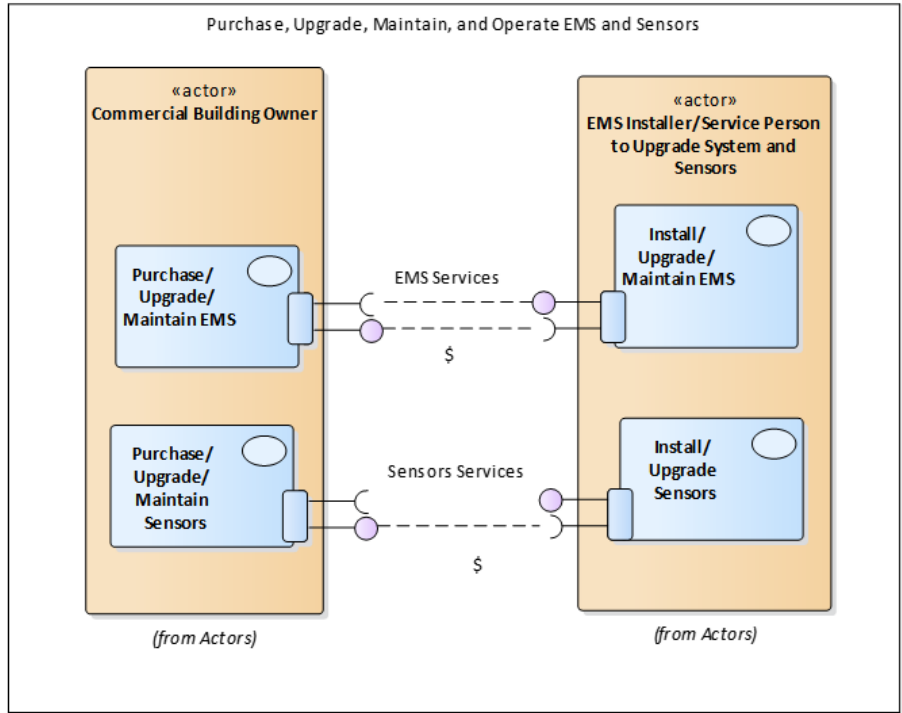**Figure 23**. Automated Commissioning and Diagnostic Activities

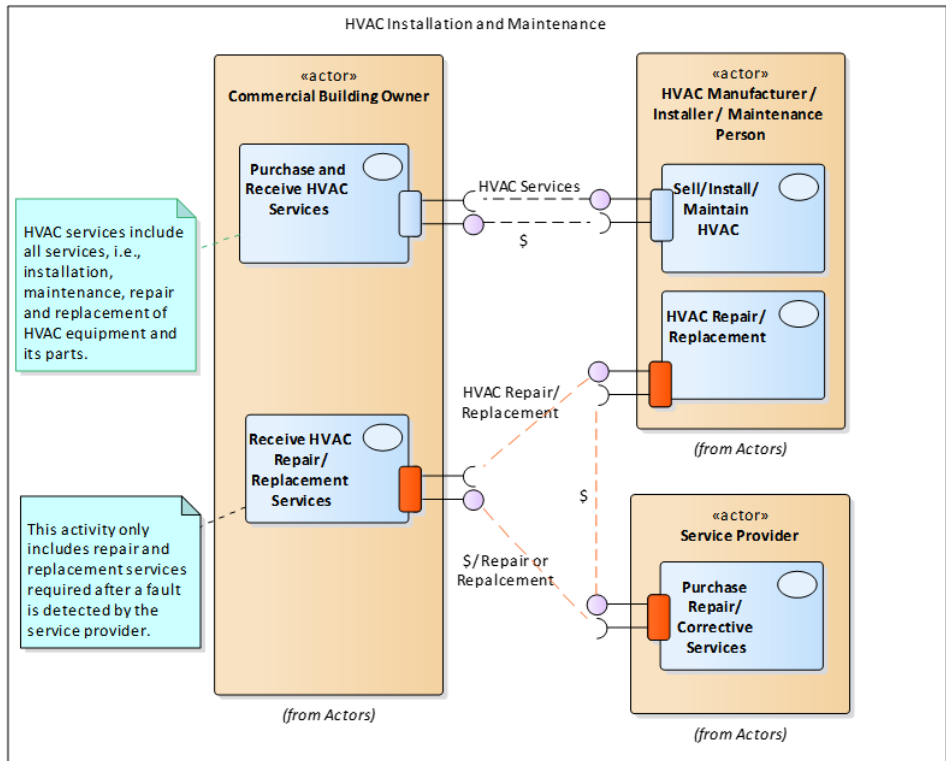**Figure 24**. Purchase, Upgrade, Maintain, and Operate EMS and Sensors Activities

Figure 25. HVAC Installation and Maintenance Activities

This business idea has several benefits for the building, such as reduced utility bills derived from improved building energy efficiency, enhanced comfort and environmental services to occupants, and

reduced cost of building operation and maintenance, all achieved by reducing faults in the system. As was mentioned, not all of these factors have a direct economic value. For instance, the cost of energy is easily captured from utility bills, but determining the cost of comfort is not as straightforward, and an analyst should dig into occupants' productivity and indoor air quality to estimate the cost of reduced occupant comfort. Here, we assume "comfort" is only correlated with space temperature. Hence, an occupant is considered to be comfortable as long as the indoor air temperature setpoint is maintained.

3.5   Use Case 6.3: Trading Allocated Capacity Rights

Use Case 6.3 addresses the trading or allocation of capacity rights via either of two major alternatives: (1) the consumers buy or compete for shares of a capacity allocation, presumably through a transactive market, or (2) an entity, which we will call the allocating or issuing entity, directly allocates capacity rights. As a special case, the consumers may exchange their allocations among themselves.

Many actors are introduced in Use Case 6.3, making it at first seem much more complex than necessary. A relational diagram of all these introduced actors is shown in Figure 26. Despite the many actors, there appear to be only four critical roles that are assumed by the various actors: consumer, electricity provider, allocating or issuing entity, and, in the cases having transactive markets, a market maker. The words *consumer* and *customer* appear to be synonymous. The consumer is alternatively referred to as a building owner or ratepayer, depending on the perspective that is being assumed.

Many actors can assume the role of electricity provider in Use Case 6.3, including a third-party energy provider, independent system operator or regional transmission organization (ISO/RTO), retail load-serving entity, service provider, third-party aggregator, or third-party distributed asset owner. A microgrid operator could provide electricity in a microgrid setting.

The entity that has the authority to allocate or issue capacity rights might be a utility, retail service provider, aggregator, or third-party asset owner, according to Use Case 6.3. Additional actors might also assume this role. A special type of allocating or issuing entity exists where the allocation occurs through a transactive market, and these actors are alternatively called the market maker or market operator.
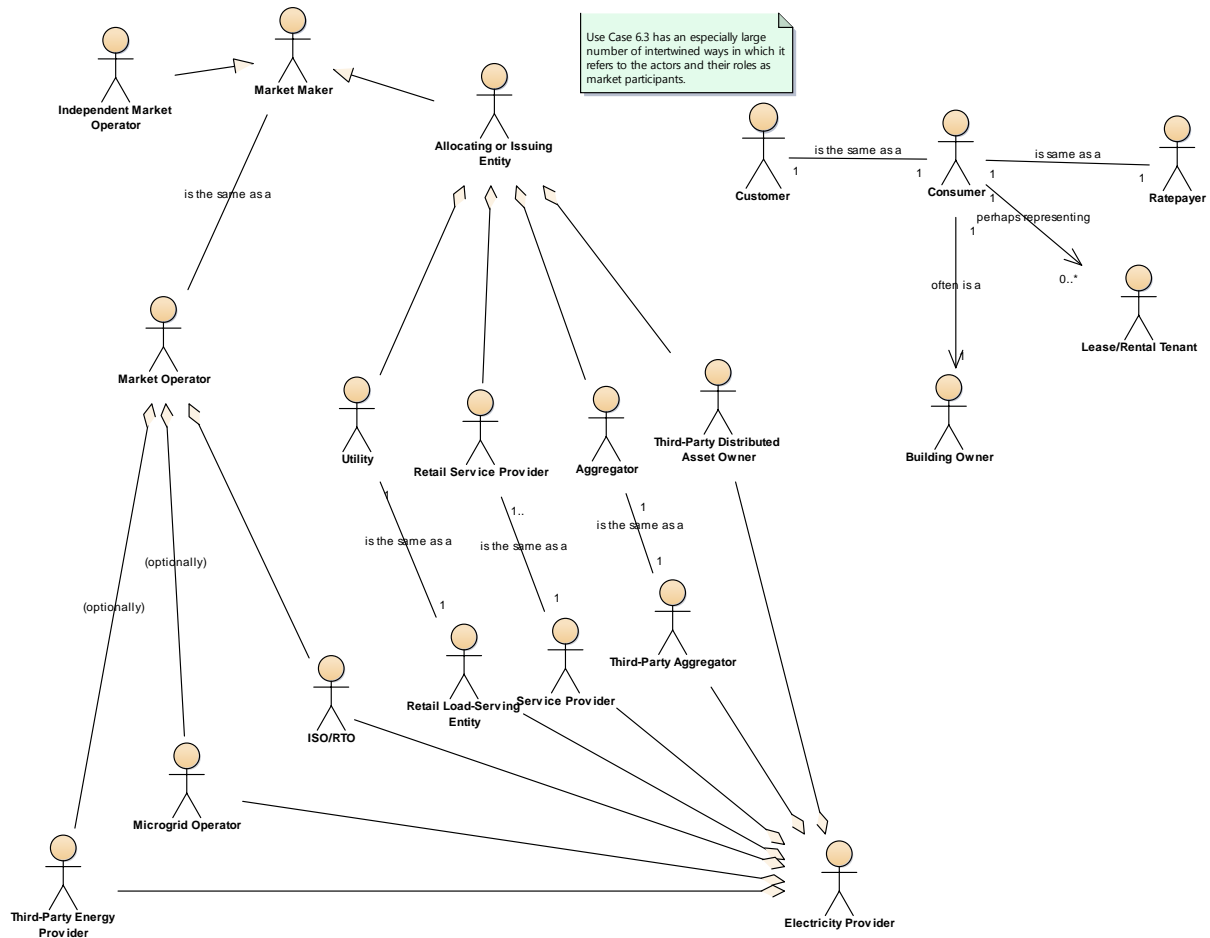
Figure 26. Actor Associations in Use Case 6.3¶Many actors were introduced, but the critical actors appear to be consumers, electricity providers, allocating or issuing entities (of capacity rights), and market makers.

New equipment and systems must be purchased, installed, maintained, and operated to realize Use Case 6.3. Use Case 6.3 is silent concerning exactly what system components will be needed and who is responsible to establish and pay for the system. These responsibilities might differ for the various alternatives that are suggested. Figure 27 therefore includes nearly all permutations of the responsibilities. There are nine possible transactions shown. Not all the transactions will be relevant for a given alternative. An aggregate actor has been defined to provide all the goods and installation, maintenance, and operation services.
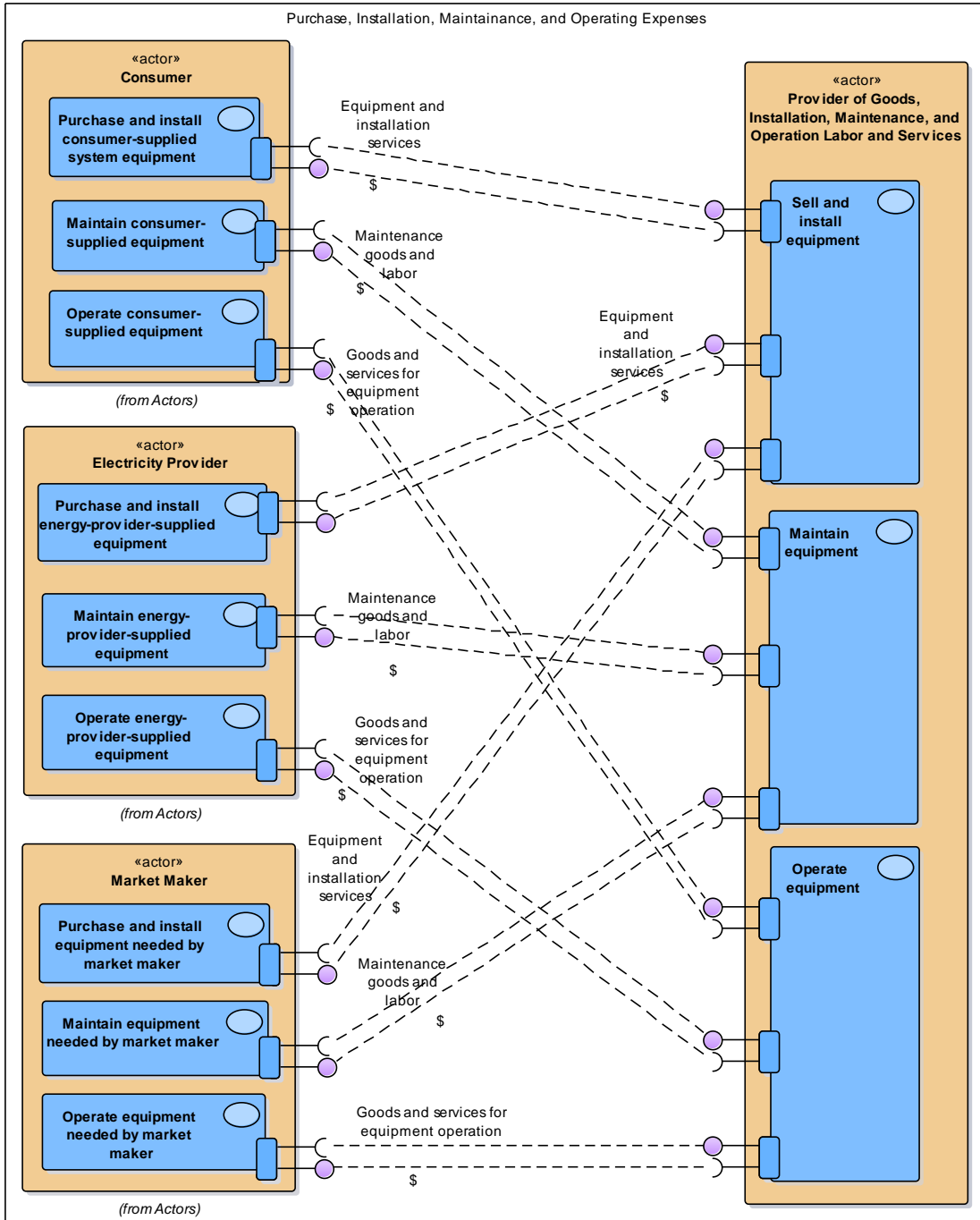
Figure 27. Accounting for the Purchase, Installation, Maintenance, and Operations Expenses in Use Case 6.3

In one of the two major alternative sub-cases given for Use Case 6.3, the allocation of capacity rights is competed for and paid for in a transactive marketplace—an auction, for example. The transactions for this alternative are shown in Figure 28. While the processes for the transactions in such a market might be complex and might differ for each of the alternative transactive mechanisms that could be used, the diagram of the transactions that would be used for valuation is quite simple. The end result of any

transaction is that a consumer obtains electricity and money passes from the consumer to an electricity provider via the market, which is represented by the market maker.
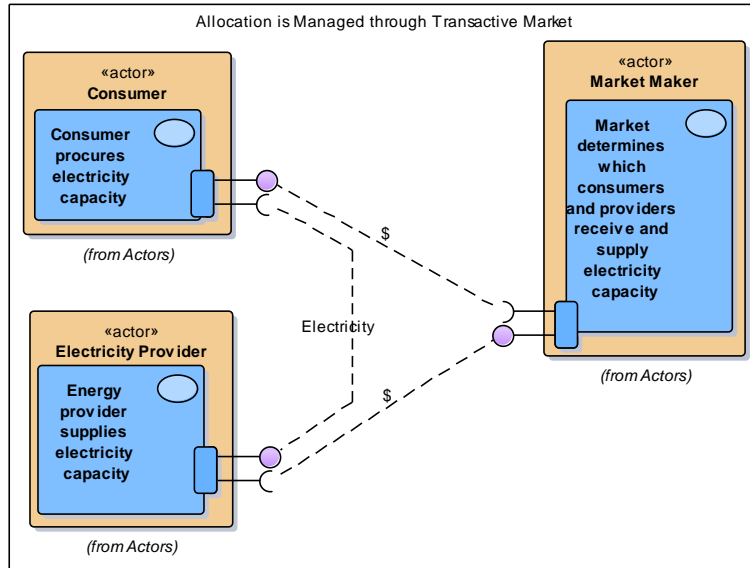

Figure 28. Sub-Case 1 of Use Case 6.3, where Allocation of Electricity Capacity is Managed through a Transactive Market

In the other major alternative sub-case of Use Case 6.3, an entity more directly allocates a share of total capacity rights to a consumer. The meaning of this alternative is not entirely clear from the use case, but we interpret it to entail the transactions of Figure 29. It is clear that the consumer is granted a share of capacity rights. The provision of capacity rights is probably not separable from the provision of electricity, so both the capacity rights and electricity are included in the value exchange to the consumer. The consumer pays for these objects.

The capacity and electricity, however, must come from an electricity provider if this transaction is to be complete, as is shown in Figure 29. An interesting by-product of this modeled transaction is that the allocating or issuing entity necessarily takes a risk in matching the diversity of customer (consumer) loads and the diversity of the electricity supply. It is usually a safe bet that consumer peak loads will be only partially coincident, but the coincidence and lack of coincidence can only be known probabilistically.

The details of the activities in this diagram would necessarily address special cases where customers exceed their capacity allocations and where electricity providers fail to provide their promised energy supplies. The use case was silent on this detail, and such details likely differ from one system design to another. Additional diagrams or activities could certainly be added once such details are known.
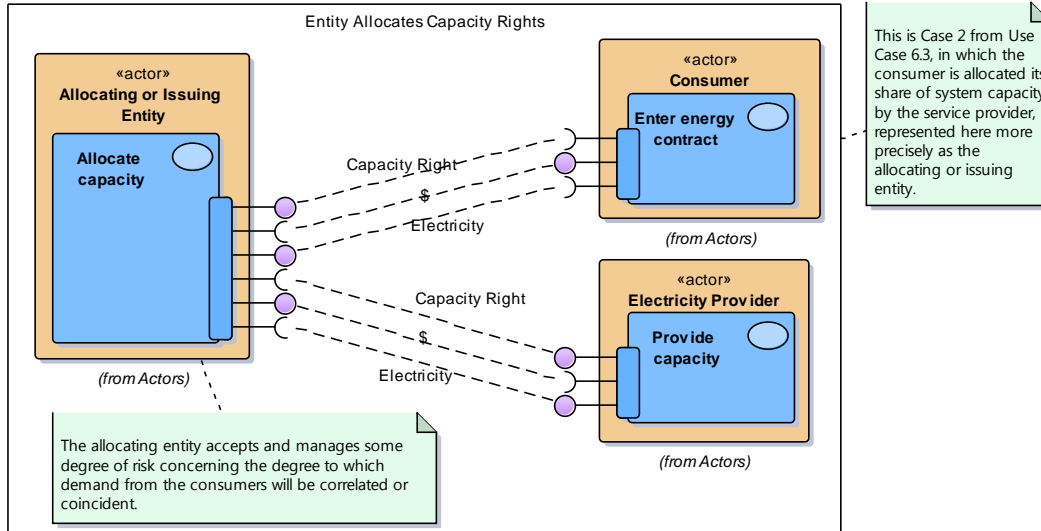
Figure 29. Sub-Case 2 of Use Case 6.3, in which Shares of Capacity Rights are Allocated by Service Providers

Figure 30 addresses a special case where consumers are allowed to exchange their existing capacity allocations with other consumers. From the perspective of valuation, we could have simply shown consumers to transfer the existing capacity right for a fee. We chose in this case to include an important regulatory role, wherein an entity (probably the allocating or issuing entity again) has a responsibility to either permit or deny the exchange of capacity rights. This is important, for example, should the transaction potentially move load to a place where it cannot be supplied by available distribution or transmission infrastructure. This detail could have been deferred to the process details of this transaction since it addresses how the transaction occurs (or not) beyond the model of transacting actors and the transacted value objects.

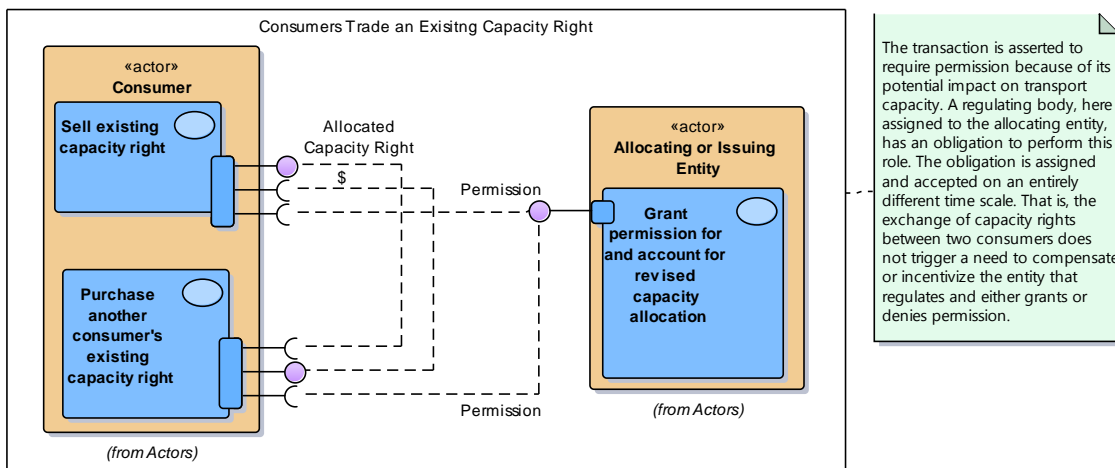
Figure 30. Consumers Trade Existing Capacity Rights in Use Case 6.3¶We presume permission is always required by the allocating entity to make sure that the exchange can be accommodated by transmission or distribution transport infrastructure.

4.0   Insights and Conclusions

This report applies e^3-*value* business value diagramming to transactive building systems. These diagrams should be routinely appended to valuation studies to transparently share an understanding of where value is created, exchanged, and consumed within a use case. The resulting business value diagrams show a static view of the actors, activities, and value objects, and the pathways through which value objects may be exchanged. This report also discusses the conversion of an e^3-*value* diagram into its equivalent UML use-case diagram, which, unlike e^3*value,* is recognized as an international standard.

Others have applied e^3 *value* to energy systems, but applications in this domain are relatively new. This report takes steps toward producing better, clearer business value diagrams, but it perhaps does so by reducing the scope that others had attempted to include in their diagrams. The originators of e^3 *value* clearly state that their diagramming exercise does not include behavioral processes. We wholeheartedly agree with that principle, but we have perhaps further expunged behavioral processes, thus producing even clearer and simpler diagrams.

The use of UML was found to further simplify our diagrams because it allowed for the separation of the diagrams into multiple, simpler diagrams. Each UML diagram then represents at most one or two scenario paths, thus reducing or entirely eliminating the need to explicitly show e^3-*value* scenario paths. The use of e^3-*value* scenario paths seems to invite the inclusion of process detail and nonmonetary value objects that, while important to behavioral processes, are not themselves valuation metrics.

Most of the transactions in our business value diagrams were found to include monetary, or pseudo-monetary, value exchanges. In fact, our hypothesis is now that a scenario path that is intended to support a valuation study must include money as a value object somewhere among its included value exchanges. Nonmonetary value objects were found to be necessary, however, at interfaces to customer endpoints, where objects like comfort were found to initiate and drive a set of associated value exchanges.

This work was tied to a simple model of the valuation process. The model recognizes activities as having been derived from operational or business objectives. Metrics are then chosen to track the performance of these activities, and the differences between these metrics for alternative use cases are the impacts and benefits that eventually become reported by the valuation study. The elegance of this model of the valuation process is that its valuation metrics are precisely the value objects that are being exchanged among actors in the business value diagram. The simple valuation model therefore supports a clear mapping between impacts, metrics, and the system's activities and objectives. The results of a valuation study can be tabulated in a worksheet, an example of which was given in this report (Table 2).

An especially compelling strength of e^3 *value* and business value diagramming is the principle that an actor's business case is fully defined upon accounting for all the actor's diagrammed value exchanges. If the corresponding value objects can be quantified, the perspective of the actor can be estimated.

The authors diagrammed business cases for five transactive building control system use cases that had been proposed in a 2014 report by Pacific Northwest National Laboratory (Somasundaram et al. 2014). The process of developing the diagrams quickly pointed out shortcomings of the use cases, which were sometimes inadequately specified for the purposes of identifying all the value exchanges. The task was made more challenging by references in the use cases to multiple alternatives. The challenge will be even greater during future steps, as process detail must be specified to later quantify the value objects. A methodical approach was found helpful for identifying missing activities, value objects, and actors. For example, principles of balance suggest that an actor cannot expend energy unless energy is also received. Something is wrong in a diagram if all the money flows into an actor and there is no corresponding value

exchange in which money flows outward. An actor might be missing if no actor yet exists to host a system activity that will be important for valuation.

After completing business value diagrams for transactive building control systems, the next step is to document the behavioral process details. The modeled details must include at least the actors, activities, and value exchanges that are interconnected in the scenario path (or in the same UML diagram). The process models must explain how the value objects are derived and thus quantify the value objects, most of which are also valuation metrics. But the process models will further break the activities from our diagrams into smaller steps; they may require actors that are not in the original business value diagram, and may introduce new objects to be exchanged as part of the process. If done correctly, the process models should resemble and emulate the system's actual behaviors and might even be used by future system designers and in future simulations.

A couple of this report's business value diagrams included an exchange of "permission," for example. The diagram's notes explained that permission was not a valuation metric, but it was a critical part of the valuation process. A regulatory body either permits or denies the exchange of a capacity right between two customers. The permission itself is not valuable to possess, but the process of permitting or denying various exchanges between the customers over time plays an important role toward quantifying the customers' access to power and corresponding costs of acquiring that power.

Business value diagrams are potentially useful for documenting use cases, and they should be included as transparent documentation in valuation studies. We were mostly successful in documenting transactive building control system use cases in this report, but we anticipate further improvements may continue to evolve as more analysts investigate and apply this skill. It is our hope that others will find our experience, insight, and examples useful.

5.0   References

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