A Framework for
Characterizing Connected Equipment

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Building Technologies Program

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A Framework for Characterizing Connected Equipment

Executive Summary

This characterization framework document proposes a draft plan for how to develop characterization protocols for connected buildings' end-use appliances and equipment. The U.S. Department of Energy (DOE) plans to work with and convene industry and other stakeholders to develop characterization protocols that are uniformly developed, and do not place undue burden on industry, to measure the responses that connected equipment can provide. The main goals of developing this framework are the following:

- Promote innovation among the industry players.
- Help establish a scalable market for connected equipment through developing data and information to inform consumers/building owners, manufacturers, and electric and gas utilities.
- Protect consumer value through quality of service and amenities provided by the equipment and minimize cost of life-cycle operation.
- Protect manufacturers by avoiding damage to equipment, violation of warranty, and consumer dissatisfaction.
- Inform utilities and service providers of the end-user, societal, grid, and energy market services that the connected equipment can deliver, as well as create an opportunity for new services and value streams for the different stakeholders in the future.

At an initial public meeting held on April 30th, 2014 in Golden, CO, (79 FR 19322) there was general support from attendees for DOE's vision for characterization of connected equipment and their role as convener of industry stakeholders to develop the characterization protocols in an open and transparent process, and that DOE is the right entity to develop these resources for the nation. A second public meeting was held on July 11th, 2014 in Washington, D.C. (79 FR 32542), at which structure and content for this draft framework document was presented and the attendees were given the opportunity to provide input and discuss the details of the characterization framework. The framework covers the scope, terminology, and definitions of connected equipment, the details of the characterization protocol framework, and the process for developing the characterization protocols. An example is provided in Appendix A to illustrate the framework of this document with hypothetical data for a connected room air conditioner.

The primary objective of this framework is to describe the characterization protocol structure and performance metrics that stakeholders may use to evaluate the services that connected equipment can deliver. This framework applies to connected buildings' end-use appliances and equipment within residential, commercial, and industrial buildings. The document also described a process for collaborating with industry stakeholders to develop characterization protocols and performance metrics for connected equipment in the future. However, communications and interoperability barriers such as cybersecurity, privacy, message syntax, or signal transmission are not within the scope of this framework document. In addition, DOE is generally aware of several activities ongoing within the industry related to connected appliances and equipment, such as the activities in AHAM, AHRI, ASHRAE, EPA and many other professional societies and trade associations. DOE acknowledges the changing landscape of the industry and is performing due diligence to understand ongoing complementary activities underway by stakeholders.

Across this document, DOE has provided annotations listing important feedback and some of the most frequently raised comments during the two previous public meetings. These notes are marked in ***bold italics***. DOE has also included textboxes with questions that should stimulate discussion and elicit input from the public and stakeholders reviewing this document.

> ***Item 1*** *What reports, studies, activities, or other documents are there that might be useful in the development of characterization protocols for connected equipment?*

1 Introduction

The Department of Energy ("DOE") Office of Energy Efficiency and Renewable Energy ("EERE") recognizes that the market is developing portfolios of clean energy technologies that may require new innovative solutions and implementation techniques to achieve large scale deployment. One set of solutions, given the direction and pace of technological innovation in industry, may include the dynamic management of residential and commercial building end-use loads brought about by the connectivity installed within, or externally controlling the equipment.

As demonstrated by some utilities using innovative technologies from industry, dynamically engaging building end-use loads can enable integration of intermittent renewable resources at scale and enhance grid reliability and resiliency, while unlocking potential new value streams for homeowners and building owners and operators. In support of EERE's objectives to engage industry, the Building Technologies Office ("BTO") is beginning to study how the use of grid-connected appliances and equipment (hereafter "connected equipment") in residential, commercial, or industrial buildings (hereafter "buildings") may provide multiple service benefits for building owners, including cost savings, while enabling the scale integration of variable renewable resources and other national-scale benefits. Therefore, connected equipment may directly benefit consumers as well as provide benefits to the grid.

Industry has traditionally supported these types of benefits made available through the management and control of equipment. Furthermore, many in industry envision a future where connected equipment may provide new value streams through delivery of recognizable services to consumers, building owners, third-party service providers, or electricity providers. To realize this future, characterization protocols and associated metrics may be needed to adequately describe the potential of connected equipment to deliver services that can scale and act as in a trustworthy manner. With respect to this framework, DOE is committed to the core principles of working with and convening industry, minimizing the burden of characterization on stakeholders, separating characterization of connected equipment responses from communications and interoperability, and driving characterization via use cases and known (or potential) services. The purpose of this characterization framework is to engage industry on a voluntary basis.[1]

[1] See the Summary Notes from the April 30th meeting, available from DOE at http://www.regulations.gov/#!documentDetail;D=EERE-2014-BT-NOA-0016-0006

Comments from industry at the April 30th, 2014 public meeting encourage BTO to implement a process for developing this characterization framework that will proceed in an open, transparent, and iterative manner.

To address these comments, DOE convened the July 11th, 2014 public meeting to present and give the public an opportunity to review and comment on a draft characterization protocol and a framework for establishing a process for the protocol content. Understanding the performance envelope and capabilities of connected equipment through characterization is an important step toward evaluating the range of services that may be delivered. DOE proposes that the first step is to work with industry to develop a framework for characterizing connected equipment.

2 Objectives and Scope

2.1 Objectives

The two primary objectives of this framework are to develop with industry:

1. A characterization protocol structure and performance metrics that industry may use to evaluate the services that connected equipment within residential, commercial, or industrial buildings can deliver.

2. A process for collaborating with industry stakeholders to develop characterization protocols and performance metrics for connected equipment.

2.2 Scope

DOE appreciates that *how* connected equipment communicates with other devices, other buildings, third-party service providers, or electricity providers, may be important for realizing benefits to building owners and others. However, *how* connected equipment communicates is not within the scope of this framework. DOE assumes that barriers associated with standards harmonization, communication protocols, interoperability, and signal definition may be addressed by industry or possibly through a collaborative effort between DOE and industry.

As stated by DOE during the April 30th, 2014 public meeting and reiterated at the July 11th, 2014 public meeting,, DOE does not have the authority to promulgate these protocols within the current rulemaking process and no standard will be issued. The *process* DOE uses for equipment and appliance standards development does however, provide a useful model (i.e., open and transparent with public involvement) that can be used for the development of characterization protocols for connected equipment. The voluntary process envisioned for this framework is intended to be more iterative with stakeholders and more flexible than a rulemaking procedure. Underlying this objective is a desire by DOE to promote industry innovation while minimizing burden, help establish a scalable market for connected equipment, protect consumer value, protect manufacturers, and inform utilities and service providers of new value opportunities.

3 Terminology and Elements of Connected Equipment

Participants at the April 30th, 2014 public meeting hosted by BTO at NREL commented that the terms and definitions presented were unclear and needed improvement. Participants

commented that the terms "grid-connected" and "smart" were nearly redundant, that grid-connected should embody smart (i.e., decision logic and intelligence), and that smart should be altogether dropped from the vocabulary. Additional feedback from the July 11th, 2014 public meeting has also been incorporated. This section clarifies a few of the key definitions based on a synthesis of the public comments.

3.1 Terminology

Equipment: Building end-use loads that consume, store, or generate electricity while providing necessary services and amenities within buildings. Examples of equipment include: refrigerators, computers, lighting, HVAC, heat pumps, room AC, vehicle chargers, inverters, or energy storage to name a few. Because equipment varies widely in size and complexity, boundaries delineating what is, and is not considered part of a particular piece of equipment should be clearly defined on an individual basis and may occur during the characterization protocol development process described in Section 5.

Connected: The capability of equipment to receive and transmit signals (e.g., to/from equipment, buildings, utilities, or third-party providers), make decisions, and respond accordingly. Connected equipment also includes intelligent features that enable, for example, the projection of future states, measurement and verification (M&V), or maintenance needs. Two simple illustrative examples of connected functionality are as follows: (1) HVAC equipment detects a compressor failure and transmits its condition to a third-party maintenance provider; (2) a refrigerator receives a load curtailment request and then adjusts load and forecasts future availability.

Service: In the context of this framework document, services are energy or power related functions that benefit consumers, building owners, third-party providers, or utilities. For example, a building owner may contract with a third-party provider which provides a service to monitor energy consumption of equipment and to report when consumption drops below a given threshold. Another service may be the offering of equipment by a building owner to participate in peak load reduction programs. Services may be a one-time offering, periodic, or regular in frequency depending on the service contract that has been agreed upon.

Response: Physical or informational actions taken by equipment in reaction to external signals or internally generated information. Examples of physical responses include load reduction or increase, adjustment of set points, short cycle prevention, or scheduling of events. Examples of informational responses include forecasting future conditions, logging data, reporting maintenance issues, or alerting consumers.

Characterization: The measurement and evaluation of physical or informational responses that are possible for connected equipment. Examples of physical measurements include voltage, current, phase angle, or time. Informational measurements may include data files, status, or sensor values. Experimental parameters may include pressure, temperature, or humidity. Characterization may include the evaluation of information oriented characteristics (e.g., forecasting, status, or diagnostics). An example of characterization is an accounting of the presence or absence of given features, such as the ability to schedule future events or alert the owner of excessive energy consumption.

Item 2 *How can these terms be better defined?*

Item 3 *Should additional terms be defined?*

3.2 Elements of Connected Equipment

Figure 3.1 illustrates an example of connected equipment functioning within a commercial building. Each piece of equipment may have the ability to receive and transmit signals, make decisions, and respond accordingly. An illustrative example is given to highlight these important elements of connected equipment. For example, transactions are being negotiated between a local utility and the whole building energy management system (BEMS). The BEMS in turn engages in two-way communication with a roof-top air conditioning unit (RTU) that is capable of receiving and transmitting signals. The RTU then processes the signals and utilizes embedded intelligence and self-awareness to make decisions and determine a response or suite of responses. The RTU responds by adjusting electrical load or sending data. Although this example illustrates a case where decision making is performed exclusively by the equipment, intelligent functions may occur external to the equipment (e.g., by a BEMS or third-party service provider).

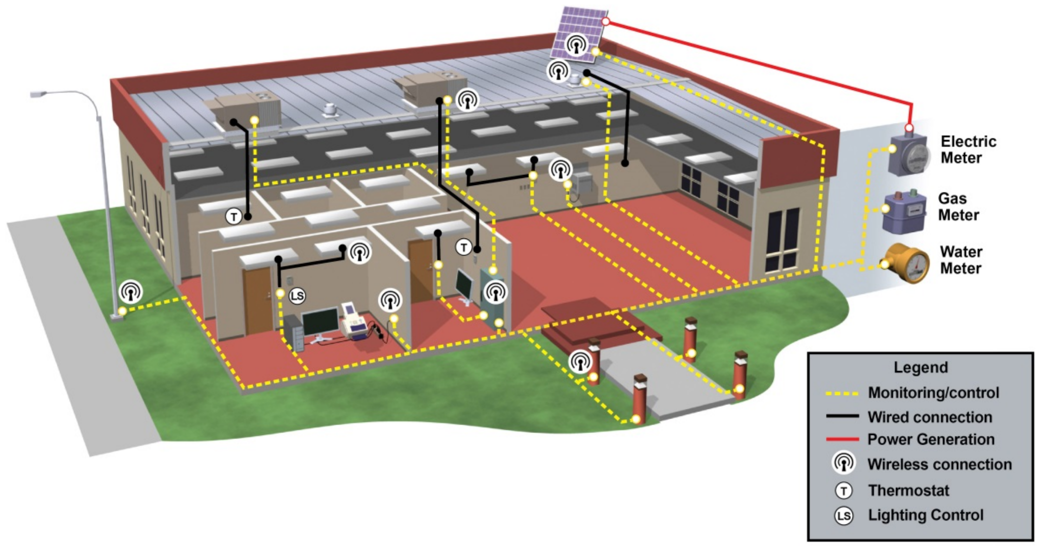

Figure 3.1. Illustrative Elements of Connected Equipment

Public comment received during and after the April 30th, 2014 public meeting expressed the view that interoperability and communications should be developed by DOE and industry independently of this characterization framework (or not at all by DOE).

As noted previously, characterization related to receiving and transmitting signals (i.e., communication protocols and standards, interoperability, or signal definition) along with decision making are <u>beyond the scope of this characterization framework document</u>. This framework covers only the physical and informational responses that connected equipment can render assuming that signals have been properly received and decided upon. DOE seeks to encourage innovation in communications and interoperability and assumes that the marketplace, with possible facilitation by DOE, will adopt/develop technologies suitable for connected equipment. These topics may be covered in future documents, but are not within the scope for this characterization framework

4 Characterization Protocol Framework

Characterization is the evaluation of physical and informational responses that are possible for connected equipment. Characterization is not annual efficiency testing, a label, test procedure development, or any part of the Energy Star program. Characterization is a first step toward mapping equipment responses to services and helping industry to evaluate value and benefit to stakeholders.

Public comment received during the April 30th, 2014 public meeting expressed the view that characterization data and performance metrics should be linked to services. This approach was also suggested at the July 11th, 2014 public meeting.

4.1 Linking Characterization to Services

One of the two primary objectives of this framework is to develop with industry a characterization protocol structure and associated performance metrics that industry may use to evaluate services that connected equipment can deliver. DOE and industry agree that it is imperative that the results from characterization of connected equipment link closely with services of interest to consumers, building owners, third-party service providers, and utilities. In order to make this link between characterization and services (see Figure 4.1), it is important that the salient performance metrics are adequately defined for each service. With the performance metrics defined, characterization data can then be specified for use in the computation of metrics. With the characterization data defined, the characterization sequence (specific to services) can be prescribed. Following this logic, the performance metrics, characterization data, and characterization sequence would be directly linked to services.

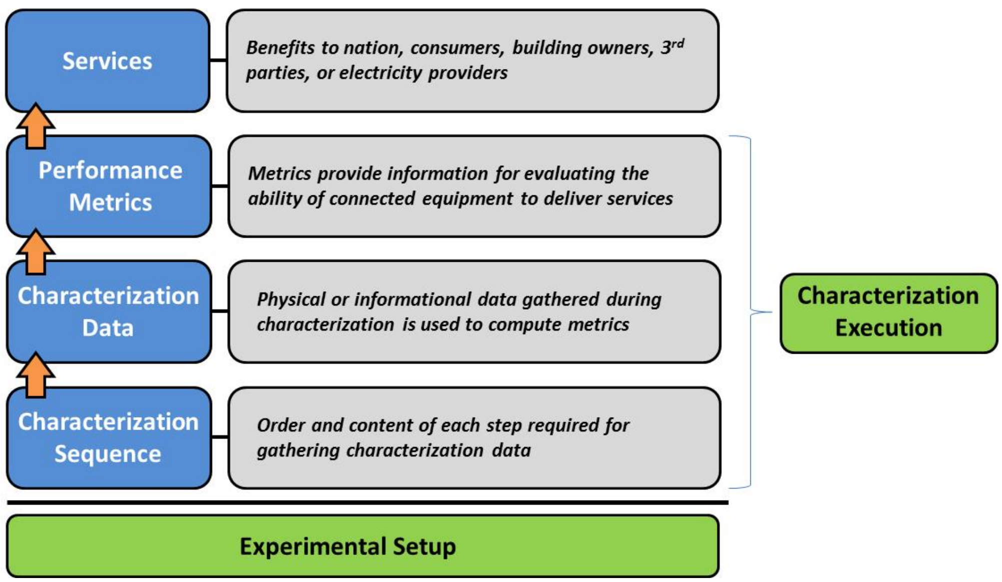

Figure 4.1. Link Between Services, Metrics, Data, and Sequencing

To promote consistency with existing test methods and to leverage industry familiarity, DOE proposes that the characterization protocol framework contains, where possible, elements similar to those found in existing test methods. This may allow for re-use and leveraging of proven approaches from existing test methods when applicable to connected equipment to minimize the burden on industry. The content within the existing test methods is divided into two main categories dealing with the *experimental set-up* and *characterization execution*, as shown in Figure 4.1(highlighted in green).

4.2 Characterization Protocol

Figure 4.2 shows the proposed framework for characterizing connected equipment. In this framework, the protocol elements are divided into two primary categories: the experimental set-up and the characterization execution. These categories allow for the grouping of elements where considerable content from existing test methods (i.e. experimental set-up) can be re-used and where content is most likely to vary for connected equipment (i.e. characterization execution). Note that the performance metrics, characterization data, and characterization sequence elements shown in Figure 4.1 map directly into the characterization execution category in Figure 4.2.

A review of the structure used for many existing test methods shows, in general, that seven common elements encompass the bulk of the information found in experimental setup and characterization execution. The seven elements are: Global Definitions, Boundary Conditions, Equipment Installation, Instrumentation, Characterization Sequence, Characterization Data and Performance Metrics. For consistency and leveraging purposes, these seven elements can be incorporated into a characterization protocol for connected equipment as shown in Figure 4.2.

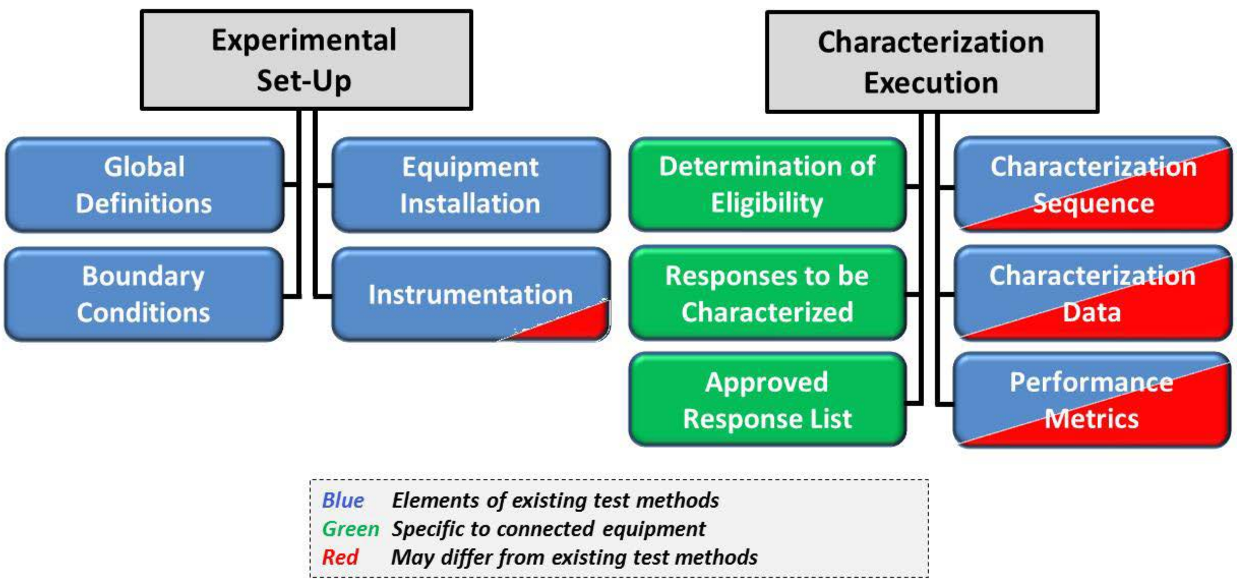

Figure 4.2. Characterization Protocol Framework

The seven elements being leveraged from existing test methods are shown fully or partially colored in blue. At this stage, DOE anticipates that elements marked in solid blue may not differ substantially for connected equipment compared to their non-connected counterparts. For example, the mechanical installation of a refrigerator into a characterization facility may not differ between connected and non-connected models. However, elements in Figure 4.2 marked with the color red may differ for connected equipment. For example, characterization sequencing for a room air conditioner undergoing short term cycling may differ from traditional test methods. As such, only partial leveraging may be possible for blue/red elements. Elements marked in green are not found in existing test methods and are specific to connected equipment.

4.3 Experimental Set-Up

Although very important to the overall characterization protocol framework, DOE does not anticipate that the experimental set-up will be substantially different for connected equipment compared to non-connected equipment in terms of measuring the physical responses. The exception here would be instrumentation, where some differences may occur due to the nature of characterizing information responses. Because only minor differences are anticipated, the structure of the experimental set-up is captured in this framework but further elaboration is not given other than a brief description of each element.

Global Definitions: Contains definitions of terms and data variables that are used globally throughout the characterization protocol.

Boundary Conditions: Prescribes the environmental conditions to ensure control and repeatability of the characterization. Example boundary conditions include ambient temperature, pressure, humidity, or air flow rate.

Installation: Contains instructions for the mechanical and electrical set-up of the equipment within a characterization facility. Examples include mechanical attachments, ducting, plumbing, electrical hook-up, assembly hardware, or supporting equipment such as pumps or fans.

Instrumentation: Prescribes the type, location, calibration or accuracy of measurement sensors, such as thermocouples, voltage and current transducers, or flow meters. Also includes equipment, such as power supplies, data acquisition, meters or computing resources.

Item 4 *Are there other aspects of the experimental set-up that should be considered for connected equipment?*

4.4 Characterization Execution

Elements within the characterization execution, shown in Figure 4.2, are important for the characterization of connected equipment. DOE anticipates that the performance metrics, characterization data, and characterization sequence elements will likely be different for connected equipment compared to non-connected equipment. Elements for determination of eligibility, responses to be characterized, and an approved response list may be altogether new. As a result, new approaches may need to be developed in order to characterize connected equipment. A description of each element within characterization execution is given below.

4.4.1 Determination of Eligibility

In this initial step, the manufacturer submits an application asserting that the equipment has minimum features in order to be eligible for characterization as connected equipment.

Eligibility may be granted by validating claimed capabilities against a checklist or by experimental methods. Example minimum features may include the ability to perform two-way digital communication, offer load management functions, execute diagnostic functions, or communicate status or alert consumers to performance deviations.

Item 5 *Should there be a step to determine eligibility for characterization as connected equipment?*

Item 6 *If so, what are examples of minimum features in order to become eligible?*

4.4.2 Responses to be Characterized

Once eligibility has been determined, the equipment would qualify for characterization as connected equipment. As part of a characterization application process, a manufacturer would identify equipment responses, from a list of approved responses (described next), for which the physical and informational responses of the equipment are to be characterized. The physical and information response categories could be further broken down in the following manner.

Example physical responses include:

Load	Electrical load up/down, event scheduling and delay
Consumer	Thresholds and limits
Equipment	Short cycling and overload prevention

Example informational responses include:

Reporting	Alert, history, mode, status, availability
Applications	Forecasting, diagnostics, M&V

Item 7 *What are examples of responses that should be characterized for connected equipment?*

4.4.3 Approved Response List

DOE proposes the use of an approved response list to assure stakeholders that equipment responses measured during characterization reflect useful services. Figure 4.3 shows an illustrative approved list which contains the physical and informational responses that can be characterized for connected equipment (i.e. if it is not on the list, then there is no characterization protocol available). Responsibility for developing and maintaining the approved list may reside with some entity as described in Section 5. Marketplace innovation would lead to updating the list to include responses with consensus value. This list should not limit opportunities; rather, DOE envisions multiple lists that each maintaining group will regularly update in response to industry innovation.

Figure 4.3. Illustrative Approved Response List

Item 8 *Should there be an approved list of responses available for characterization? What organizations, entities or groups would be likely candidates to maintain lists of approved responses? Is it ok if multiple lists exist?*

4.4.4 Characterization Sequence

This is a step-by-step sequence of instructions describing how to conduct the characterization. The sequence may include controlling profiles (e.g. resource draws, temperature ramps or changes in electrical load), timing of data collection (e.g. sampling intervals or timing of modes) switching of operating modes (e.g. slow/fast or high/low) or activation of informational responses (e.g. low refrigerant alert or query of stored data). It is within this element where knowledge of the service to be provided is translated into a relevant characterization sequence such that subsequent characterization data and performance metrics can be directly linked to services. DOE acknowledges that characterization sequencing for informational responses such as forecasting, M&V, diagnostics or historical data are challenging and is seeking guidance in this area. While the characterization sequence may depend on equipment type, it is desirable to generalize the characterization sequence as much as possible to minimize the burden on industry.

Item 9 *How does characterization sequence depend on equipment type?*

Item 10 *What should be included in a characterization sequence for connected equipment?*

4.4.5 Characterization Data

This category defines the data to be measured for a given response from the approved list. Physical data may include parameters such as voltage, current, time, temperature or pressure. Informational data may include set points, lock out delay, disallowed state transitions or data files. DOE acknowledges that characterization data related to informational responses can vary widely and is seeking guidance in this area. Table 4.1 gives illustrative examples of physical and informational data that can be collected. The “other” category of data would include any other data that may need to be collected.

Table 4.1. Illustrative Physical and Informational Data to be Collected

Physical	Informational	Other
• Voltage • Current • Phase angle • Time • Response duration • Response time • Recovery time • Experimental parameters • # of cycles	• Presence/absence • Modes • States • Sensor values • Set points • Lock out • Failures • Confirmation • Data files	• DOE seeking input

Item 11 *What data should be collected for physical, informational, or other responses?*

4.4.6 Performance Metrics

This category defines the metrics calculated using the characterization data as inputs. These metrics could be used by industry to evaluate the ability of connected equipment to deliver services. Example metrics include percent of baseline energy consumption, response time, or pass/fail. The "other" category of metrics would include any other metrics that may need to be computed.

Table 4.2. Illustrative Physical and Informational Metrics to be Computed

Physical	Informational	Other
• kW, kWh, kVAR • Energy consumption as % of baseline • Power reduction or increase as % of baseline • Length of response • Availability • Recovery time	• Present/absent • Correct/incorrect • Time lag	• DOE seeking input

Item 12 *What metrics should be computed for physical, informational, or other responses?*

Although this characterization protocol provides a structured *framework* for characterizing connected equipment, the *technical content* may vary depending on the specific connected equipment being characterized. For example, the installation hardware for an RTU may be substantially different from that of a clothes dryer. Likewise, the characterization sequence for peak load shifting of a refrigerator may be very different from a forecasting application. This framework allows for characterization protocols to be developed for both physical *and* informational responses.

Item 13 *Are there other aspects of the characterization execution that should be considered for connected equipment?*

An additional layer of complexity arises when connected equipment has characteristics that introduce differences in their potential operating modes (i.e. more than simple on/off). For example, equipment may have either multi-speed or more advanced variable speed drive compressors and fans. In addition, multiple load consuming functions may also be present, such as in a refrigerator/freezer where chilled air, defrost, and ice making are possible. As a result of the differences described above, it will be necessary, as part of the characterization protocol development process, to populate the red and green elements in Figure 3 with content appropriate for the specific connected equipment being characterized. Other features that add complexity are solid state devices which exhibit almost binary operating states compared to resistive types of equipment that operate on a continuum. In addition, this framework can accommodate other complexities, through the process described in Section 5, that have yet to be envisioned.

Public comment received during the April 30th, 2014 public meeting expressed the view that data and performance metrics collected and computed during characterization should contain information that is useful to electricity providers and original equipment manufacturers and should align with services. DOE was also encouraged to keep the characterization simple with electrical load magnitude and duration as the key measurements. The notion of availability (e.g. whether or not the device is able to act if called upon) was also requested to be included in the list of metrics. Comments at the July 11th, 2014 public meeting requested that characterization be high level such that equipment determines an optimal response.

The characterization data and performance metrics are intended to provide consumers, manufacturers, building owners, third-party service providers, utilities and the nation as a whole, with information needed to evaluate the ability of connected equipment to deliver services. For example, consumers and building owners may be concerned with impacts on energy consumption and maintaining comfort while keeping costs down. Utilities may be interested in load response magnitude and duration, availability, and recovery time. Third-party service providers may be interested in maintenance and diagnostic features. Manufacturers may place importance on consumer impact (e.g., clothes take longer to dry than usual) and number of cycles that the appliance or equipment may encounter.

A notional and illustrative example of how the framework might be implemented and connected equipment characterized using the example of a connected room air conditioner (RAC) is provided in Appendix A of this document.

5 Process for Developing Characterization Protocols

Comments during the April 30th, 2014 public meeting and re-enforced during the July 11th public meeting expressed a strong desire for DOE to proceed with development of characterization protocols for connected equipment in an open and transparent manner. More frequent industry engagement was requested in contrast to that allowed in the formal rulemaking process.

DOE is committed to developing these characterization protocols via a process that is public, transparent, and iterative with stakeholders. As a convener of industry and other stakeholders, DOE intends to work with interested parties by hosting public meetings such as those held on April 30th and July 11th of 2014. As part of the open process, DOE will post presentations and documents for public review and comments, and will solicit oral and written public comments on these materials.

One approach would be for DOE to develop a draft characterization protocol for a particular type of connected equipment that would include the scope of coverage, definitions, experimental set-up and characterization sequence, and performance metrics. This draft characterization protocol would then be released and circulated for public review and comments. Following public meetings and an extensive public comment period, DOE would, for example, address and respond to the comments, explain the basis for the new revised protocol, and eventually release the final characterization protocol through publication in the Federal Register.

An alternate approach might be through a consensus-like process where DOE and stakeholder representatives meet as a committee to compile, in a shorter timeframe, the text of a draft characterization protocol for a given equipment type.[2] The goal of the consensus would be for the committee to reach agreement on the draft text, which DOE could then publish in the Federal Register and invite public comments. This method may allow the protocols to be developed more quickly. The joint committee or subcommittees may also be responsible for:

- Creating and maintaining an approved list of equipment responses.
- Identifying services to which the characterization protocol is applied.

Item 14 *Which of these two options for establishing the characterization protocols best addresses industry needs and minimizes industry burdens?*

Item 15 *Are there other options that DOE might pursue for establishing characterization protocols?*

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[2] This would be similar in approach, but not outcome, to the consensus process used by DOE's Equipment and Appliance Standards Program.

APPENDIX A – LIST OF ITEMS FOR COMMENT

APPENDIX B – NOTIONAL AND ILLUSTRATIVE EXAMPLE: ROOM AIR CONDITIONER

Illustrative, notional, and fictitcious example.

B.1 Intent

This section provides an illustrative example of how the framework might be implemented and connected equipment characterized. This example involves a connected room air conditioner (RAC).

[This example is entirely fictitious and is not intended as the basis for characterization. Rather, it is provided to form a tangible use case to clarify the proposed framework and the general nature of what is meant by characterization of connected equipment. The intent is to spur a deeper understanding on the part of the reader, for the purpose of discussion and comment on the process, and to provide a glimpse of some of the issues involved in developing a characterization protocol that will ultimately need to be addressed. A thermostatically controlled RAC was chosen for this illustration because it is a relatively simple piece of equipment to characterize compared to, for example, a dishwasher with its many operating modes and cycles. Yet it also brings forth some of the complexity of characterizing many types of equipment where the “balance-of-system” – in this case the cooling load of the space being conditioned – is an important determinant of its performance in some respects. It lies intermediate between equipment such as a refrigerator, which is essentially self-contained with its own controls, and equipment such as a chiller or air handling unit that only performs its function as part of a larger system controlled by a building management system].

B.2 Illustrative Use Case – Characterizing a Room Air Conditioner

Scenario: In this hypothetical use case, ACME Equipment, Inc., a RAC manufacturer, approaches a Wiley Electric Company (an electric utility) with a proposition to supply connected RACs to its customers to supply certain grid services in one of Wiley Electric’s demand response programs. Wiley Electric signals its interest to ACME and informs them that it requires characterization of such equipment’s ability to respond to demand response signals before they are eligible to participate in their program. In response, ACME submits its RAC to Connected Certification Labs (CCL – a third-party certification laboratory) so it can be characterized using a protocol developed jointly by DOE and industry stakeholders, and its performance as “connected equipment” independently certified.

Determination of Eligibility and Responses to be Characterized: To initiate the characterization process for its connected RAC, ACME fills out a form indicating the basis for its eligibility and the connected features it wants certified, and provides the form to CCL along with a sample of the product to be characterized. The form as completed by ACME is shown in Table B.1.

Table B.1. Application for Characterization of Connected Equipment Submitted by ACME, Inc.

Application for Characterization of Connected Equipment

Applicant:	ACME Equipment, Inc.
Equipment Type:	Room air conditioner with thermostat
Model:	RAC-XYZ123

Eligibility Requirements	Details Provided (check all that apply)		Explanation
[X] Two-way Communications	Transport Media		
		[X] WiFi	
		[ ] Ethernet	
		[ ] Bluetooth	
		[ ] Homeplug	
		⋮	
		[ ] Other (explain):	
	Information Protocol		
		[X] SEP 2.0	
		[ ] Open ADR	
		[ ] …	
		[ ] Other (explain):	
[X] Automated Response(s)	Physical responses to be characterized		
	Load	[x] Electrical load up	thermostat moves up 5°F when issued <SEP 2.0 command>
		[x] Electrical load down	returns thermostat to original setting when issued <SEP 2.0 command>
		[ ] Schedule Event	
		[ ] Delay event	
	Consumer	[x] Thresholds	load management mode must be enabled by user (button on interface)
		[x] Limits	5-hour time limit on the load-down mode
	Equipment	[x] Prevent short cycling	operating mode persists for minimum of 2 minutes
		[ ] Prevent overload	
	Informational responses tio be characterized		
	Reporting	[ ] Alert	
		[ ] History	
		[x] Mode	reports operating modes (on/off plus normal/load down) <SEP 2.0 command>
		[ ] Status	
		[ ] Availability	
	Applications	[x] Forecast	estimates remaining on/off-time after a load up/down command <SEP 2.0 command>
		[x] Diagnostics	warning for low refrigerant charge <SEP 2.0 command>
		[ ] M&V	

Illustrative Only

ACME indicates that the RAC is controlled by an integral thermostat. By checking boxes in the leftmost column, it specifies that the RAC meets the minimum eligibility features (for example, two-way communications and some form of automated response). It checks boxes to provide details on the transport media and information protocol the RAC uses to receive and send information from among standards supported by the characterization protocol rig. In this example, ACME indicates the RAC communicates via WiFi and the SEP 2.0 protocol. [Note the characterization framework does not currently address the communication system itself as to its interoperability, which may be the subject of a future DOE effort, but this information is required for the protocol rig to operate the RAC through its various modes to implement the characterization protocol. In addition, the examples of WiFi and SEP 2.0 are purely for illustrative purposes only].

As a final step, ACME checks boxes indicating the automated responses it wants characterized from among those supported by the characterization protocol approved list. In this example, ACME indicates the RAC can respond to load commands by adjusting the thermostat up 5^{o}F when a specified load-down command is received, and returns the thermostat to its original position when another specified load-up command is received. ACME indicates the RAC has consumer protection threshold (a button on the user interface enabling/disabling the load management features described above), and a 5-hour time limit on the load-down mode (after which the original thermostat setpoint is restored). The RAC also has an equipment protection feature that prevents it from short cycling, in that it will not automatically change its operating mode within a two-minute interval from the previous mode change.

ACME further indicates the RAC responds to several requests for information. It can report its current operating mode and lists those modes. It can provide a forecast of the remaining off-time when in the load-down mode, or the remaining on time when in the load-up mode. It also provides a diagnostic service, indicating a warning for low refrigerant charge. All of these informational responses are activated by a specified SEP 2.0 command.[3]

Characterization Sequence. The certification laboratory (CCL) takes the information provided by ACME and proceeds to characterize its connected functionality using a protocol established by collaboration between industry and DOE. In this illustrative example, physical responses of connected equipment are characterized by a sequence of three characterization protocols.

The first is a basic characterization of the electrical response of the RAC to variations in the voltage and frequency of electric power. The RAC is placed in an environmental chamber and operated in the “on” mode until steady state is achieved under each combination of voltage and frequency, which are individually varied from the base case of 115V and 60 Hz power in the range from 110V to 120V and 59 Hz to 61 Hz. Real and reactive power input and thermal output are measured as shown in Figure B.1. This provides information about the RACs effect on the electric power grid when operating under a broad range of conditions. This is shown in the form of plots of real power input and power factor as a function of voltage and frequency as shown in Figure B.2 and Figure B.3. Characterization using this protocol also provides the RAC’s steady-state thermal performance in the form of its energy output/input ratio as a function of voltage and frequency as shown in Figure B.4.

Note that these and all subsequent “results” are purely fictitious and for illustrative purposes only.

Note this is for illustrative purposes only, SEP 2.0 may or may not support any such requests or commands.

[3] Note this is for illustrative purposes only, SEP 2.0 may or may not support any such requests or commands.

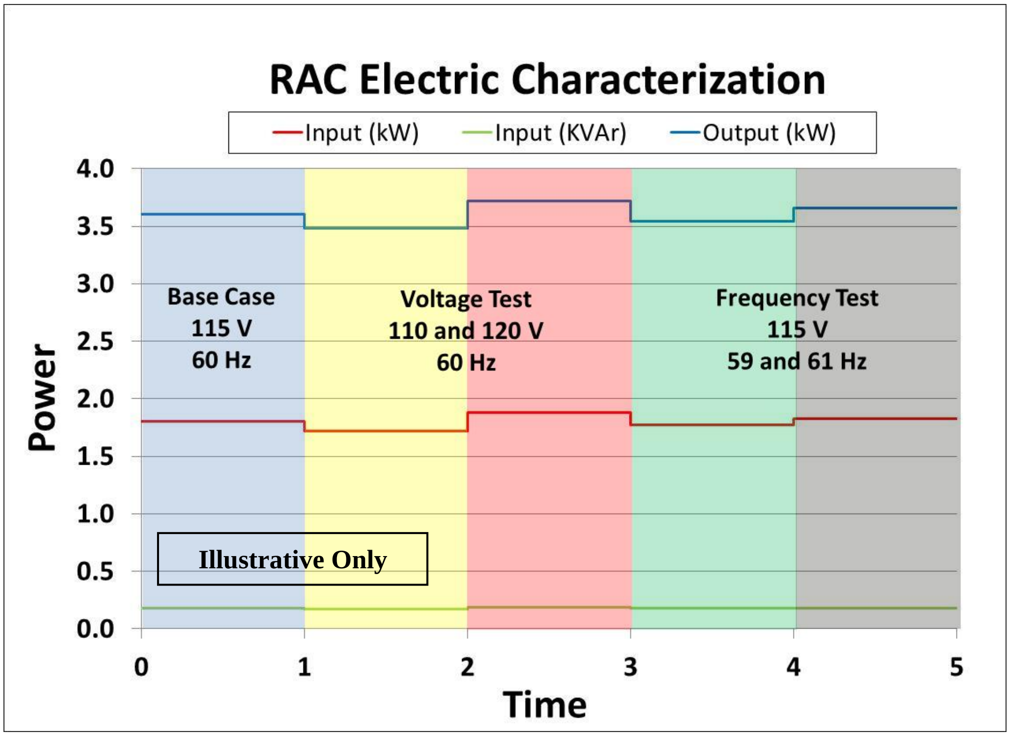

Figure B.1. Results from Electrical Characterization Protocol

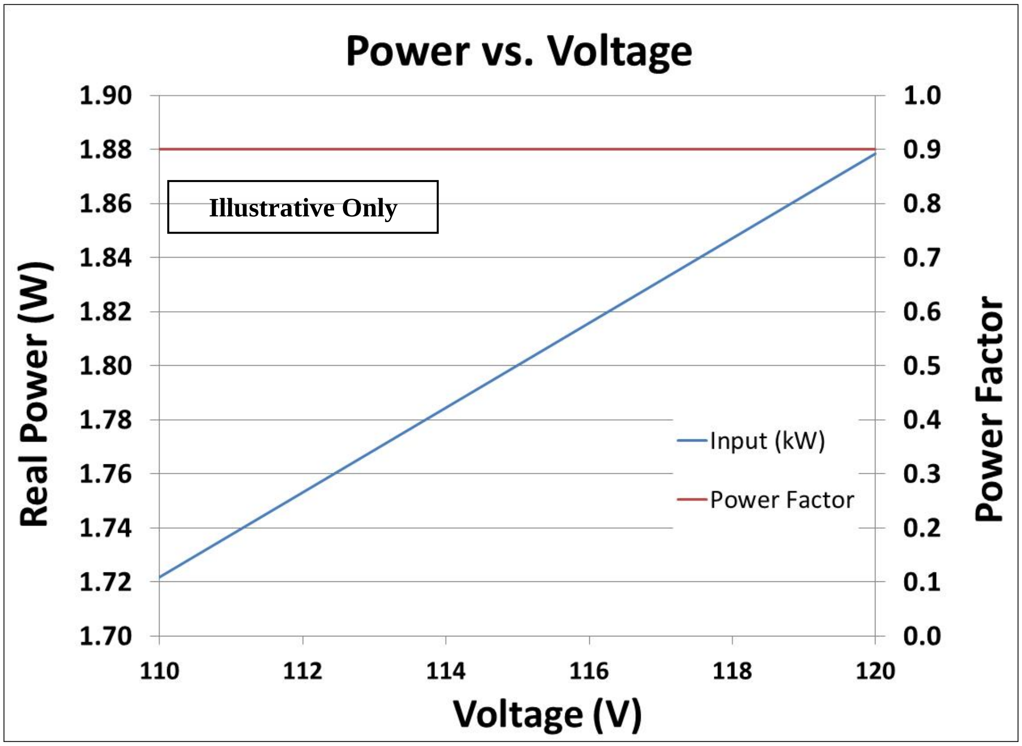

Figure B.2. Power vs. Voltage

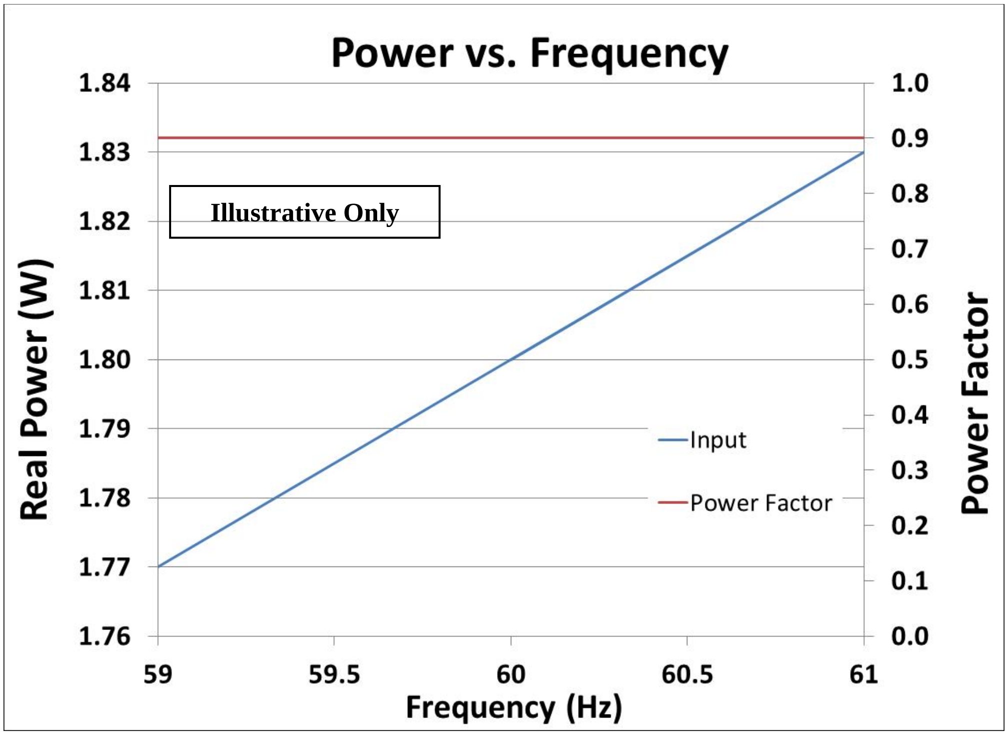

Figure B.3. Power vs. Frequency

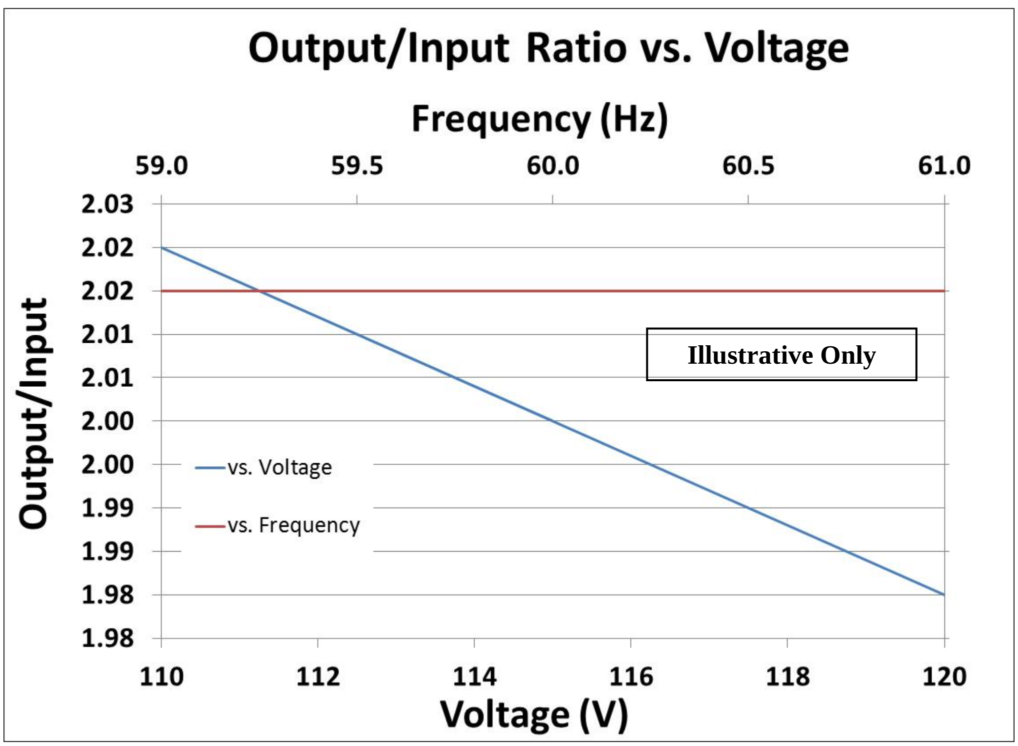

Figure B.4. Output/Input Ratio vs. Voltage and Frequency

A second protocol is then used to characterize the RAC's load curtailment responses. The results might be as illustrated in Figure B.5 and Figure B.6. Figure B.5 shows the first 1.5 hours of the sequence. A 50% duty cycle with a 15-minute periodicity is established by manipulating the temperature of the environmental chamber, mimicking the room air temperature fluctuating within the deadband of the thermostat, to represent the initial steady-state thermal load placed on the RAC by the space to be conditioned, the relative size of the RAC output to the load, and the thermal mass of the space. (A simple first order thermal model was used to create the "data" used in this example.) A load-down curtailment request is issued to the RAC during an "on" cycle, and the RAC responds two minutes later by turning off 100% of its steady-state power consumption (1.8 kW).

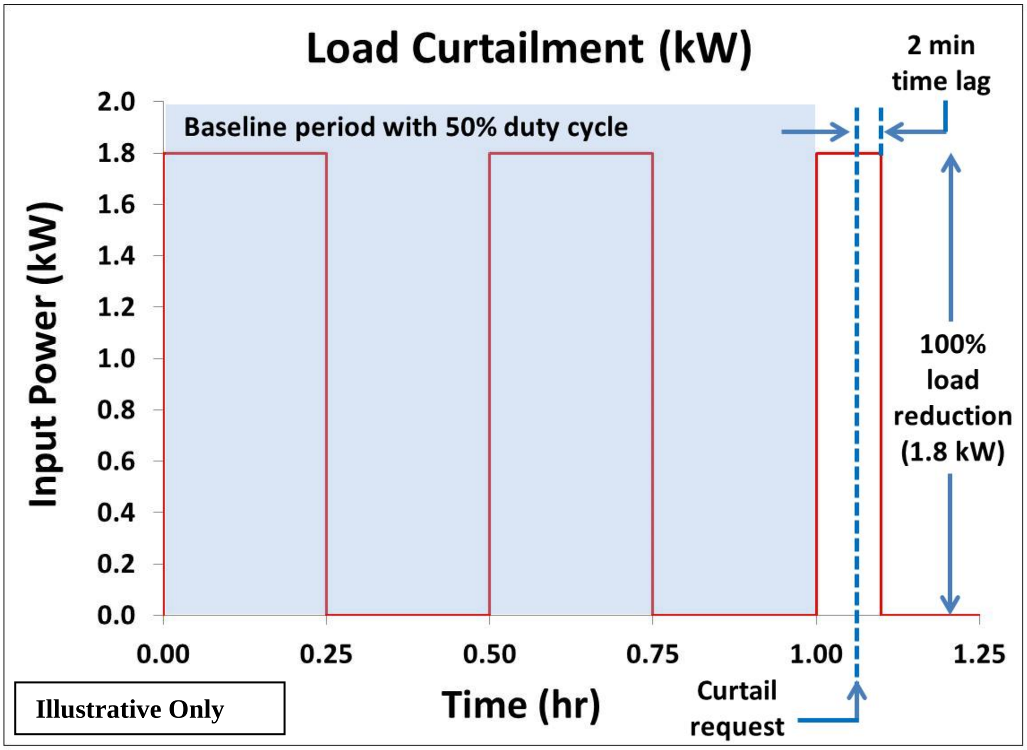

Figure B.5. Load Curtailment Characterization

A third protocol is then used to characterize the RAC as shown in Figure B.6 (note the x-axis scale has changed to accommodate the full 5-hour time span). For illustrative purposes, the room temperature (i.e., that of the environmental chamber) is gradually increased over a period of time until the RAC comes back on. The room temperature at which this occurs is noted to be 5°F higher than the upper end of the thermostat deadband, as specified by ACME. The room temperature is then reduced at the same rate until a 50% duty cycle has been reestablished, restoring the RAC to steady-state operation.

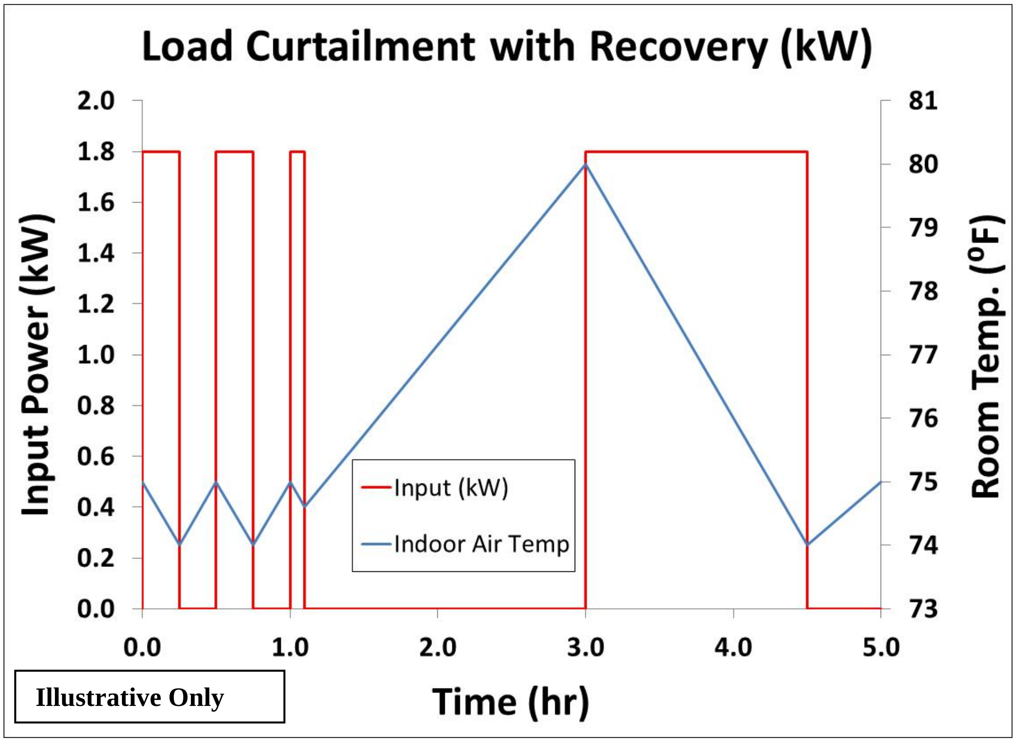

Figure B.6. Load Curtailment Characterization (cont.)

Examples of metrics that may result from these characterization protocols could include:

- absolute power reduction (kW)
- relative power reduction (% of steady-state "on")
- time lag from request to curtailment
- 92% of deferred energy supplied during recovery (hypothetically, in this example less than 100% because the room air temperature rose slightly, and the long steady run during recovery provides a higher part-load ratio during that period)
- 5^{o}F temp. rise limit (verified)
- 5-hr mode time limit (verified, but not shown).

An additional hypothetical characterization indicative of the RAC's ability to operate in a load following mode is illustrated in Figure B.7. It verifies the ability of connected equipment to increase and decrease load in fairly rapid succession, which could be used to supply certain grid services important to the integration of renewable generation resources into grid operations. Again a 50% duty cycle is established to initialize the protocol. Then the thermostat is raised to the mid-point of the 5^{o}F range of the RAC's load curtailment thermostat change, i.e. 2.5^{o}F higher than the original set-point. Then, a sequence of increasingly frequent load-up and load-down requests are sent to the RAC and its response measured. The RAC successfully responds to the first pair of requests that are 8 minutes apart. The time interval is halved to four minutes in the next pair of events, again halved to 2 minutes in the next pair of events, and so forth until the RAC fails to follow the command. In this illustrative example, this occurs when one-minute intervals are tried (as expected, in this case, since ACME restricts mode changes less than two minutes apart).

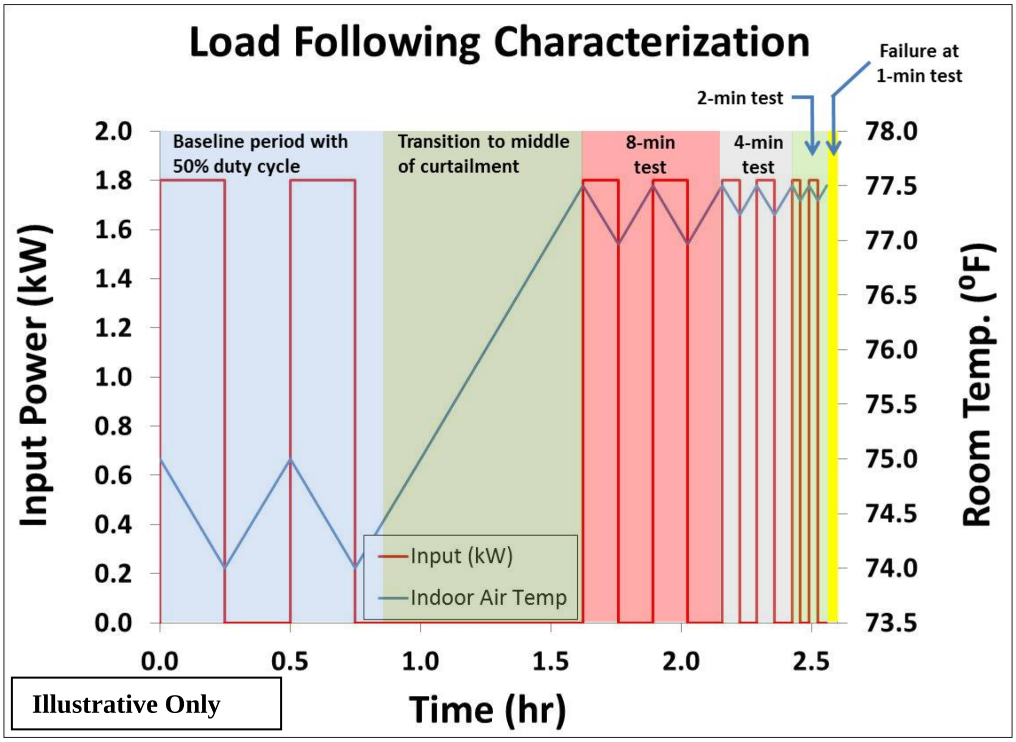

Figure B.7. Load Following Protocol

Metrics for the load following protocol could include:

- 104% recovery energy (not shown)
- 100% load following ability, down to 2-minute intervals
- Short cycle limit (2-minute minimum).

Finally, this example does not illustrate the informational responses indicated in ACME's request for characterizing its RAC. While reporting of its operating mode might be straightforward, and useful for the characterization itself, DOE has not attempted to portray what characterizing such equipment might look like for informational responses such as forecasting or diagnostics. It is not even clear if such responses can be independently characterized at reasonable cost or if doing so would provide meaningful information beyond manufacturer's advertised capability. These are topics for future discussion with manufacturers and industry. DOE assumes that barriers associated with standards harmonization, communication protocols, interoperability, and signal definition may be addressed by industry or possibly through a collaborative effort between DOE and industry.

Connected Equipment is Already on the Way! The reality of such a scenario is not too far away. Just recently, an article in the press from June 24th 2014 says "ConEd will help NY city residents connect their air conditioner to their iPhone for free," where the New York utility ConEd is offering customers a free outlet adapter that turns a standard window-mounted air conditioner into a WiFi-connected unit that can be controlled from an iPhone[4]. As part of the

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[4] Tiffany Nesbit, *Smart Kit Helps New Yorkers Control Old ACs with Their Phones*, PSFK Labs, June 27, 2014, http://www.psfk.com/2014/06/con-ed-coolnyc-air-conditioners.html#!bp763x.

program, customers can sign up to receive up to five free kits, normally retailing for $120 each, that plug in between the wall outlet and window unit thus connecting the unit to the cloud and enabling remote control using a companion app.

Item 16 *Would it be useful to have illustrative examples like this in the framework document?*

Item 17 *After seeing this illustrative example, does the framework need additional steps or further revision?*

Public Meeting on Characterizing Connected Equipment. [DOE posed the following questions at the July 11th, 2014 public meeting for comment and received oral responses saying that they were mostly supportive of this example as a useful one to help illustrate the characterization protocol framework. Hence, it is included in this document for illustrative purposes. Some of the attendees also indicated that a "systems level" example might be needed to help illustrate an HVAC system in a commercial building and how that would be characterized using the protocol framework].