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Final Report for the Energy Efficient and Affordable Small Commercial and Residential Buildings Research Program –

Project 6.6 - Development of the Assessment Framework

M. Kintner-Meyer
D. Anderson
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June 2003

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

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Richland, Washington 99352

Abstract
This report describes a generic methodology for assessing the impacts of new products that improve the energy efficiency of buildings and reduce electric peak demand. The methodology is illustrated for new products designed for use in commercial buildings in California, but it is general and could be applied to new energy-efficiency products used for these and other purposes in any other geographic region for which the necessary data are available.

Summary

The development of this assessment framework was motivated by the California Energy Commission's need for a consistent methodology that enables its staff to assess the potential impacts of a broad spectrum of new and innovative energy efficiency and electric peak demand reduction products that are expected to emerge from research projects funded by the Public Interest Energy Research (PIER) program. This assessment framework is designed to guide an analyst through the process of estimating impacts and could serve as the basis for a software tool for assessing impact.

The assessment framework is composed of four components that lead to impact estimates. They are: 1) Product Characterization, 2) Market Segmentation, 3) Market Penetration, and 4) Analysis of Impacts. Figure E-1 depicts the simplified view of the overall assessment framework.

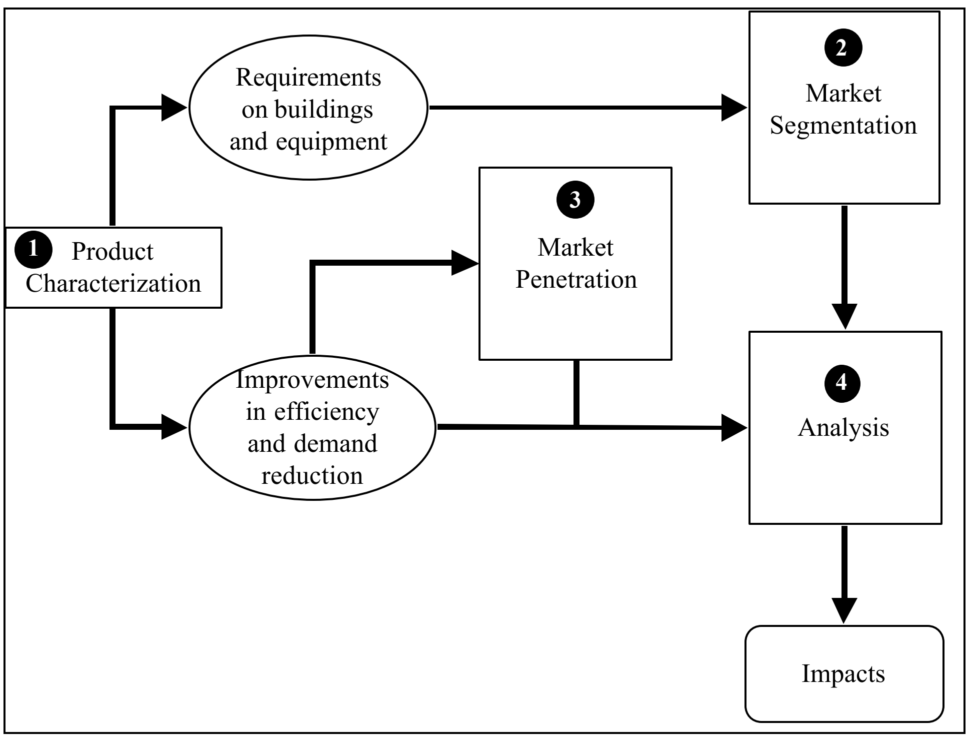

Figure E-1: Overview of the Assessment Framework

Each of the four major components is described and thoroughly discussed using one or more examples to illustrate to the user how the component can be used. The data requirements for each component have been developed with a great emphasis to detail, completeness, and sufficient richness in expressing the necessary characteristics for each evaluation step in this assessment framework. Data models were developed and are described for each component.

Product Characterization

Product characteristics are used for two primary purposes: (1) identification of the buildings on which the products of PIER research could be used (market segmentation) and (2) estimation of improvements likely to result from penetration of the products into those buildings (impact analysis). Characteristics used for market segmentation include features of buildings on which the product could be used, local climate, types of equipment and systems present, size of the building, and other factors that determine the suitability of a building for use of the product. Characteristics for estimating impacts include the technical improvements in electricity consumption and peak power use by the product compared to the product it replaces or by the equipment or system on which the product under analysis is installed.

The assignment of reasonable values for the improvement characteristics of new products is an inherent problem in any impact assessment of new products and technologies that have not yet been validated and tested in the field. This assessment framework is no exception. We recommended using the technology developers as the first source from which to gather information about a new product or practice. In some cases, others with expertise in the applicable market or field of application can supplement information provided by developers, possibly expanding the perspective provided by the developers. Groups of knowledgeable people, such as focus groups, might also be used to comment on the certainty of data used in the assessment and, perhaps, to make some adjustments. Mechanisms for assessing product information include discussions, surveys, and interviews.

Market Segmentation

Market segmentation is the process of determining the potential market for a product (i.e., the product's market segment) by using a set of market attributes to identify the maximum scope of opportunity for application of the product. In the context of this project, segmentation is the process of defining that portion of the total commercial buildings market most likely to be affected by a particular product, standard, guideline, equipment, hardware, software or other tools and then determining the size of that market segment. Rarely will a product apply to the entire marketplace. Therefore, we segment or attempt to determine the maximum specific portion of the market to which the product is expected to apply.

Segmentation combines the analysis of available data characterizing the market and the expertise of analysts familiar with the specific product to determine the widest possible target market without overstating the opportunity. Market segmentation should rely on the best market data available. However, market data types vary. "Hard" data include those sources held generally in high regard by industry analysts, such as buildings databases like the California Commercial End-Use Survey (CEUS) and the Commercial Energy Buildings Energy Consumption Survey (CBECS). Hard data can also include studies that have collected market-size data ranging from a specific segment across a narrow geography to many segments across a wide geography.

Ideally, availability of hard data would not be a limiting factor; however, practice reveals that as the definition of a market segment increases in refinement or narrowness, hard data become increasingly scarce. Lack of hard data increases the need to use expert judgment to determine the target market.

"Soft" data can be provided by technology experts, such as inventors, researchers, or others knowledgeable about a technology or product, who through practice and industry involvement can further provide segmentation information. Soft data include such sources as technology reports, marketing studies, and expert opinion. Often soft data can temper market size estimates in the absence of sufficiently detailed hard data. The segmentation framework combines hard data science and expert judgment to provide flexibility in application.

Once the market segment has been identified, its size must be determined. The size of a commercial buildings market segment can be characterized by measures such as floor space, peak loads, number of buildings, energy expenditures, total energy consumption, and installed base of specific equipment. The report provides mathematical definitions of variables used for expressing the size of a potential segment.

The methodology provides the flexibility to adapt to the types of data available. Examples covering a continuum of available data are provided in the full report to guide users. It should be noted that the assessment framework expects the default data source to be some current or future commercial buildings database characterized by building-level (or more disaggregated) records. To the degree that such hard data do not exist, an assumption-based top-down approach can be used. The market segmentation part of the assessment framework is designed primarily for data-driven analysis.

Market Penetration

Once the market potential has been identified, the next step is to forecast the rate of market penetration. Market penetration is primarily influenced by the marketing effort (e.g., promotion, advertising), product characteristics (e.g., complexity, compatibility), characteristics of potential adopters (e.g., decision making style, innovativeness), and market characteristics (e.g., macroeconomic conditions, competitive conditions). Two basic approaches to estimating market penetration are provided as part of the framework: 1) method based on expert judgment with the penetration curve constrained to a specific functional form and 2) a model-based method which explicitly accounts for competition between products.

The method based on expert judgment relies on the experience and perceptions of forecasters but is constrained to the "S"-shaped, logit function-based market penetration curve. The expert assigns values to the parameters that describe the shape of the "S" curve. This method is called the user-definable market penetration approach in our framework.

The model-based method utilize well-specified algorithms to process and analyze data. Because model-based methods require more quantitative data, are more expensive to develop, and more time-consuming to use, they are not as widely used as methods based on judgment. This framework uses the model developed by Peterka to develop market penetration curves for competing products. The report provides details of the model, which was implemented in software for analysis of examples.

The report provides examples for both methods of generating market penetration curves.

Impact Analysis
Impacts are expressed in terms of:

- size of the market segment targeted by a product,
- market penetration over time,
- cumulative and annual projected reductions in electricity consumption and peak electric demand, and
- savings on electricity expenditures.

Key to estimating these impacts are:

- the results of the market segmentation
- the estimated market penetration curve
- projected technical performance of the product expressed as improvement factors for electricity use and peak electric demand

Equations for estimating impacts are provided in the report.

Representative Results
Example analyses of impacts are given for four example products:

1. A product based on the Whole-Building Diagnostician (WBD) developed by Pacific Northwest National Laboratory for the U.S. Department of Energy and enhanced and demonstrated in this PIER program (Projects 2.6 and 2.4)
2. An automated fault detection and diagnostic system (AFDD1) for retrofit onto package rooftop air-conditioning systems based on technology developed by Purdue University in this PIER program (Project 2.1)
3. An automated fault detection and diagnostic system (AFDD2) for retrofit onto package rooftop air-conditioning systems based on the technology demonstrated by Battelle in this program (Project 2.4)
4. An Enhanced Packaged Rooftop Unit Controller (EPRUC) based on technology developed by Purdue University in this PIER program (Project 3.1).

These products competed against reference cases corresponding to current standard industrial products without enhancements and to existing installed stock of package HVAC equipment.

An example of results is shown in Figures E-2 and E-3 for the WBD-based product with market penetration developed using the user-defined judgment-based approach. Results shown in Figure E-2 include market penetration, electricity savings, savings on expenditures for electricity, and electric peak demand reduction impacts from 2001 through 2030. Figure E-3 shows projected cumulative energy and monetary savings. The report also provides additional detail, numerical results in tables, and tables providing assumptions.

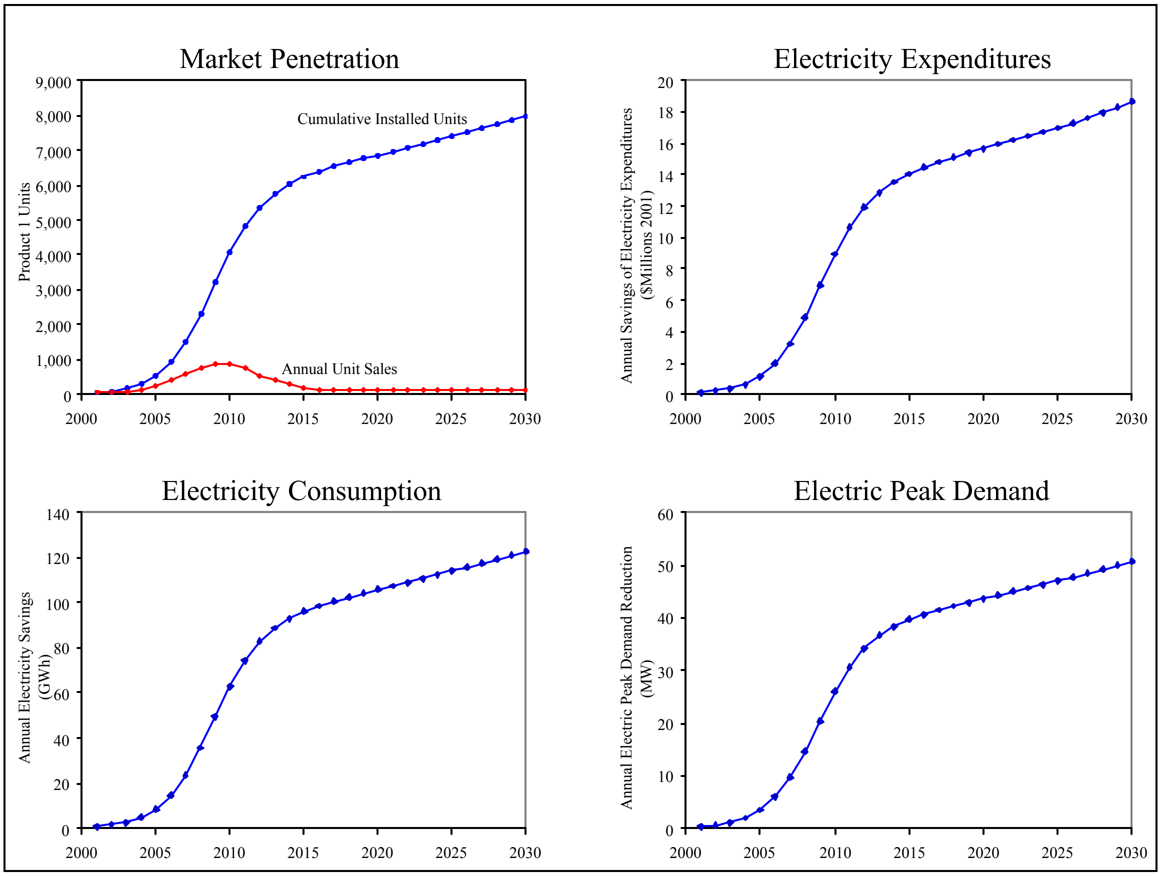

Figure E-2: Annual Impact Estimates for the Whole Building Diagnostician (Product 1)

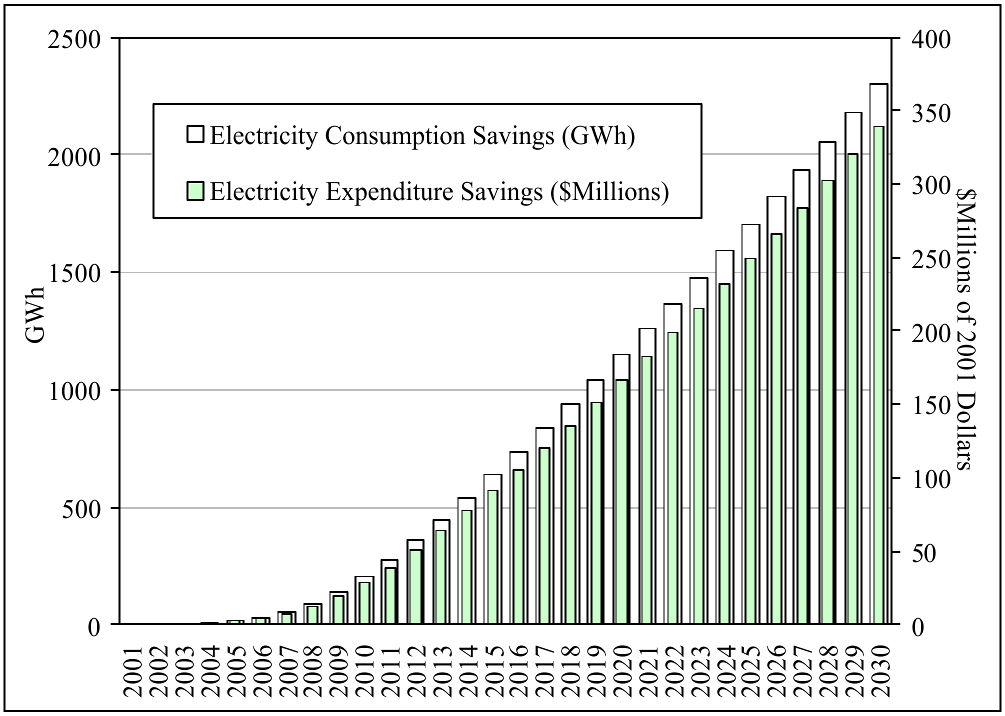

Figure E-3: Cumulative Impact Estimates for the Whole Building Diagnostician (Product 1)

Conclusions

A methodology and framework for assessing the benefits of products that may emerge from the Commission's PIER Program for the commercial buildings sector has been developed and demonstrated. The methodology defines a process that starts with the initial product characterization and identification of the product's market segment, determines the market penetration trajectory as a function of time, and concludes with estimating the impacts on electricity use, electricity demand, and monetary expenditures on electricity.

The key features of the assessment framework are:

- generally applicable to all energy efficiency products for commercial buildings
- choice between two generic approaches to estimating market penetration, a judgment based approach and a model-based approach
- exposure of all assumptions underlying the results.

As with any modeling and analysis framework, careful application of the tools and approaches remains the responsibility of the analyst using the framework. Because most assumptions are made transparent in this process, the users of the assessment framework can check and validate projection assumptions, data, calculations, and impact estimates for agreement with citable sources, industry experience, and analytical intuition.

Recommendations

The framework developed in this project was demonstrated for example products using the PG&E Commercial End-Use Survey as a data source for representing the existing building stock in PG&E's service territory. To broaden the regional representation of the building stock from PG&E's service area to the State of California, Commission staff should consider using the methodology with the results of Commission's own commercial building survey activity when they become available.

Furthermore, the value of this framework would be enhanced if extended to use for the residential and industrial sectors of the electricity market. Commission research is likely to lead to new products that will affect electricity demand for residential and industrial electricity customers (including agriculture), in addition to commercial buildings. Typically, these demands are just as significant as those posed by the commercial sector.

We have provided a prototype spreadsheet to use for exercising the framework. The spreadsheet instrument implements the framework for the example products analyzed in this report. It steps the user through the various modules of the assessment framework and is designed to permit scenario analysis for the specific example products. As a device for demonstration, the spreadsheet currently is set up for use by the investigators of this project. The spreadsheet instrument could be further refined, all steps of the process automated, and the breadth of product characteristics increased to produce a user-friendly tool for use by Commission staff. This would enable Commission staff to conveniently perform impact assessments and scenario analyses of potential impacts of the entire Commission PIER buildings portfolio.

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Acronyms

AC	Air-conditioner
AEC	Architectural Energy Corporation
AFDD	Automated Fault Detection and Diagnostics
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.
CBECS	Commercial Buildings Energy Consumption Survey
CEC	California Energy Commission
CEUS	California Commercial End-Use Survey
COP	Coefficient of Performance
CRT	Cathode Ray Tube
DCV	Demand-controlled ventilation
EER	Energy Efficiency Ratio
EMCS	Energy management and control system
EMS	Energy management system
EPRI	Electric Power Research Institute
EPRUC	Enhanced packaged rooftop unit controller
HID	High Intensity Discharge
HPS	High Pressure Sodium
HVAC	Heating, ventilation, and air-conditioning system
LAN	Local Area Network
LCD	Liquid Crystal Display
OEA	Outdoor-Air Economizer
PDA	Personal Digital Assistant
PG&E	Pacific Gas and Electric Company
PIER	Public Interest Energy Research
PTAC	Packaged Terminal Air-Conditioner
PTHP	Packaged Terminal Heat Pump
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient

WBD	Whole-Building Diagnostician
WBE	Whole-Building Energy module

1 Introduction

In April 2000, the California Energy Commission (CEC) initiated a project with co-funding from the U.S. Department of Energy (DOE) to develop a methodology for assessing the impacts of products that may result from projects performed as part of the California Energy Commission's (Commission's) Public Interest Energy Research (PIER) program, buildings end-use energy efficiency program area. The methodology developed and described in this report is illustrated for new products designed for use in commercial buildings in California, but it is general and could be applied to new energy-efficiency products used for these and other purposes in any other geographic region for which the necessary data are available. We consider a new product any product or service offering that has an energy efficiency improvement feature or component that can be clearly characterized by either a performance metric or an improvement factor that expresses the improvement potential over the best currently available products or the installed base of the same or similar products. New products could include: new equipment in support of heating, ventilation, and air-conditioning (HVAC); lighting; domestic water heating or any other end-uses relevant for commercial buildings; diagnostics, controls, or monitoring service products that either assist in or perform monitoring or control functions of the energy uses or the thermal integrity of the building shell.

The development of this assessment framework was motivated by Commission's perceived need to develop a consistent methodology that enables Commission staff to assess the potential impacts of a broad spectrum of new and innovative energy efficiency and electric peak demand reduction products that are expected to emerge from research projects funded by the PIER program. This assessment framework is designed to guide an analyst through the process of estimating impacts and could serve as the basis for a software tool for assessing impact.

The starting point for the use of this assessment framework is a new product that must be sufficiently defined by cost-performance and use characteristics. The framework is not designed to assess the benefits or impacts of the PIER buildings end-use program as a whole or individual research projects within the program. The distinction of a product impact assessment from an R&D project impact assessment is not always obvious and is sometimes subtle. A product impact assessment is generally smaller in scope. It focuses on one specific product. A project or program impact assessment, in contrast, requires much broader consideration of potential outcomes of the research being conducted. For instance, take a project that improves the accuracy in a simulation of the natural convective ventilation in buildings. It is not quite clear how this improvement in the simulation accuracy ultimately affects the energy efficiency in buildings. Conceivable are many different direct and indirect impact paths. For example, the improvement in the simulation accuracy could lead to improved design tools that the building designer community would adopt over time and, thus, the improved analytical capability could result in buildings designs with higher energy efficiency. Another possible mechanism could be improved simulation accuracy that leads to analytical studies, from which operational guidelines could be developed that would maximize the natural ventilation capabilities in buildings. While this example is rather specific, it, nevertheless, highlights the general dilemma one encounters when attempting to assess the impacts of research that is of enabling nature or character.

This assessment framework avoids the ambivalence and uncertainty associated with postulating future impact paths by requiring the analyst to define specific commercializable products outside the assessment framework. We feel strongly that the product definition should be decoupled from the quantitative impact assessment because it greatly reduces the uncertainties in the quantitative impact estimates. An analyst faced with the task of estimating the potential impacts of a research project would first need to postulate one or more likely products that would likely emerge directly or indirectly as an outcome of the research project. In a second step, the impacts of each product would then be assessed using the framework described in this report.

The remainder of this report describes the assessment framework. First, a general overview of the framework with all contributing components is presented before discussing each element within the framework in detail. Three examples are provided to illuminate the potential use of this assessment framework.

2 Overview of Assessment Process

The assessment framework for the commercial sector is composed of four components that will lead to impact estimates. They are: 1) Product Characterization, 2) Market Segmentation, 3) Market Penetration, and 4) Analysis of Impacts. Figure 2-1 depicts the simplified view of the processes within the assessment framework.

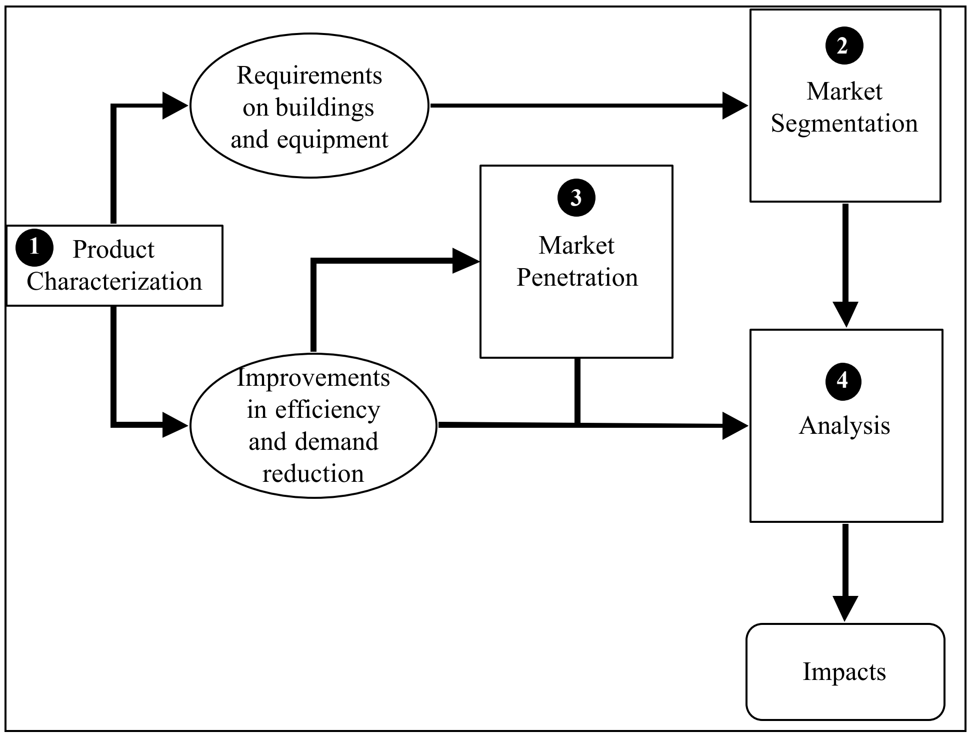

Figure 2-1: Overview of the Assessment Framework

The product characterization provides detailed information about cost and performance characteristics, as well as a set of requirements necessary for the product to be sold and applied. The product characteristics can be grouped into the following major categories:

- Requirements for defining the applicability of the product and its market segment (niche)
- Cost and performance characteristics that describe improvement over existing or standard technologies.

The set of requirements reduces the applicability of the product to a specific market segment. Market segmentation involves identifying and characterizing the size of this market segment. It is defined as the theoretical bound on the size of the market that a product could capture. Market penetration provides projected rates of adoption of a product in the applicable market segment. The impact analysis process utilizes the market penetration projection and the technical-improvement characteristics of a product to estimate the impacts in terms of electricity savings, reduction in peak electric power demand, and savings on energy expenditures.

The remainder of this report discusses each of these processes in more detail. Section 3 discusses product characterization; Section 4 expands on market segmentation; and Section 5 details the market penetration process. Section 6 explains how these other processes come together for the overall impact analysis, and in Section 7, the assessment framework is applied using example products. Conclusions and recommendations are presented in Section 8.

3 Product Characterization

This section provides descriptions of the product characterization process and the uses for which product characteristics are collected. Product characteristics are used for two primary purposes: (1) identification of the buildings on which the products of PIER research could be used (market segmentation) and (2) estimation of improvements likely to result from penetration of the products into those buildings (impact analysis).

The first purpose is market segmentation, where the populations of buildings and equipment that potentially would use a product are identified. The product characterization specifies a set of requirements that must be in place in a building or be met by the building's equipment in order for the product to be implemented.

The second purpose for the product characterization is to provide improvement parameters with which the impacts are estimated. These characteristics define the technical performance of the new product in terms of its energy use, power consumption, other performance attributes such as how it affects the operation or performance of other equipment, and how its performance or the performance of systems in which it is used compares to currently used technology.

3.1 Product Characteristics

The product characteristics needed by this methodology are identified in the two sections that follow, each corresponding to the two purposes identified above: Market Segmentation and Impact Analysis.

3.1.1 Market Segmentation

The product characteristics used for market segmentation are used to define the buildings and equipment on which the product can be used. Candidate product characteristics for market segmentation are shown in Table 3-1 through Table 3-10. Only the characteristics in these tables that are required to identify the buildings and equipment on which the product can be used are needed (i.e., the product may be applicable only to certain types of buildings, located in specific types of climates, and only when certain types of equipment or operating practices are used).

In specifying the product characteristics, the highest-level characteristics (e.g., climate zone, cooling, or ventilation) applicable to the specific product should be considered first. If a high-level variable is not applicable, no deeper examination of it is necessary (e.g., if cooling is not affected by the product, then detailed information on whether the cooling system is central or packaged is irrelevant and need not be examined). If, on the other hand, a high-level characteristic is relevant, then all lower level characteristics must be considered.

Consider, for example, SaveNet, which is a hypothetical product used to monitor the performance of packaged commercial air-conditioners of all types greater than 10 tons capacity. The restrictions to packaged air-conditioners and only to those larger than 10 tons capacity are product characteristics important for market segmentation. Furthermore, in characterizing SaveNet, we also find that it will be deployed only in buildings with a floor area of 50,000 ft^2 or greater. Thus the size of buildings in which SaveNet can be used also becomes a product characteristic used for market segmentation for SaveNet. The complete set of product characteristic for segmenting the market for SaveNet are identified in Table 3-11.

3.1.2 Impact Analysis

Characteristics used in the impact analysis are those that characterize how and to what degree the relevant market segment is impacted. Examples include electricity consumption, peak power demand, and other variables that indicate the size of the market segment and the potential impacts on that segment.

There are two fundamental ways to characterize the improvements provided by a product in the context of this assessment framework:

1. For a product that conforms with the existing HVAC and building systems infrastructure (e.g., envelope, heating, cooling, ventilation, and lighting systems) and can be used as a direct replacement for existing equipment, its impacts can be calculated from the improved performance characteristics, as defined in the same way we characterized existing HVAC or buildings. An example would be a super-high efficiency package air-conditioning unit with an SEER of 20. The impact calculation methodology is described in Section 6.
2. For a product that is an accessory to existing or future buildings or HVAC systems that enhance the performance of the building or HVAC system, an indicator of the improvement to the performance of the equipment on which the product is installed is required. The improvement can be expressed in the form of an improvement factor applied to a specific type of equipment, end-use, or overall building's electricity consumption as it operates currently or in a particular base year. We introduce two specific improvement factors: 1) a factor applied to the electricity consumption and 2) a factor applied to the peak demand. They are listed in Table 3-2 through Table 3-10.

Consider SaveNet as an example again. It increases the energy efficiency of rooftop air-conditioning units by 11% and reduces peak demand by about 8%. Table 3-11 summarizes SaveNet's product characteristics used for analyzing impacts.

3.2 Collecting Product Characteristics

PIER projects often focus on development, testing, or demonstration of a technology or practice. Before evaluating impacts, the products likely to result from the technology or practice need to be identified, because it is the products that compete in the market place, not the underlying technologies. A technology often provides the basis for several different products that have different applications and users. Developers are the first source from which to gather information about a technology or practice because they are the most familiar with it. They likely possess the knowledge to identify specific products that will result from development of these underlying capabilities and their potential performance. In some cases, others with expertise in the applicable market or field of application can supplement information provided by developers, possibly expanding the perspective provided by the developers. Groups of knowledgeable people, such as focus groups, might also be used to identify possible products and their range of applications.

Mechanisms for collecting product information include surveys and interviews. Both must be designed to elicit all products likely to result from a project, the applicability of each variable in Table 3-1 through Table 3-10, and values for each applicable variable. Written surveys are unlikely to provide sufficiently complete information and should be followed up with direct contact with the experts surveyed. Interviews or discussions, when used to collect this information, should be guided by an outline or list of variables to ensure that all required information is collected.

3.3 Use of Product Characteristics

The equations or algorithms in which the product characteristics are used are defined in Section 6 on the analysis processes of the assessment framework.

Table 3-1: Product Characteristics

No.	Description	Data Class	Units
2	Building floor area		ft^2
3	Building total electric peak demand		kW
4	Building vintage		year
5	Ownership		
5.1	Private		Yes/No
5.2	Federal		Yes/No
5.3	State		Yes/No
5.4	Municipal/local		Yes/No
6	Zip code		
7	Climate zone		
7.1	North Coast		Yes/No
7.2	North Coast Ranges		Yes/No
7.3	Bay Area		Yes/No
7.4	Central Coast Ranges		Yes/No
7.5	Central Coast		Yes/No
7.6	Southern Coast		Yes/No
7.7	San Diego Coast		Yes/No
7.8	Santa Ana		Yes/No
7.9	Los Angeles Basin		Yes/No
7.10	Inland Empire		Yes/No

No.	Description	Data Class	Units
7.11	Northern Central Valley		Yes/No
7.12	Central Valley		Yes/No
7.13	Southern Central Valley		Yes/No
7.14	Deserts		Yes/No
7.15	Imperial		Yes/No
7.16	Mountains		Yes/No
	END-USE		
8	Cooling		
8.1	Central System		
8.1.1	Refrigeration cycle/compressor		
8.1.1.1	Rotary	Cooler[1]	
8.1.1.2	Reciprocating	Cooler	
8.1.1.3	Absorption	Cooler	
8.1.1.4	Centrifugal	Cooler	
8.1.2	Auxiliary systems		
8.1.2.1	Chilled water pump	Pump[2]	
8.1.2.2	Condenser water pump	Pump	
8.1.2.3	Cooling tower fan	Fan[3]	
8.2	Packaged		
8.2.1	Heat pump	Cooler	
8.2.2	Packaged AC	Cooler	
8.2.3	Residential AC	Cooler	
8.3	Individual		
8.3.1	PTAC	Cooler	
8.3.2	Water Loop Heat Pump	Cooler	
8.3.3	PTHP	Cooler	
8.3.4	Room AC	Cooler	
9	Evaporative pre-cooling		
9.1	Direct	Cooler	
9.2	Indirect	Cooler	
9.3	Direct/Indirect	Cooler	
10	Ventilation		
10.1	Supply fan	Fan	
10.2	Return fan	Fan	
10.3	Terminal box fan	Fan	
10.4	Fan coil unit fan	Fan	
11	Heating		

[1] See data definition in Table 3-2
[2] See data definition in Table 3-3
[3] See data definition in Table 3-4

No.	Description	Data Class	Units
11.1	Heating system		
11.1.1	Central system		
11.1.1.1	Boiler	Heater[4]	
11.1.1.2	District heating	Heater	
11.1.2	Packaged		
11.1.2.1	Heat pump	Heater	
11.1.2.2	Package unit furnace	Heater	
11.1.3	Individual heater		
11.1.3.1	PTAC	Heater	
11.1.3.2	Water loop heat pump	Heater	
11.1.3.3	Baseboard	Heater	
11.1.3.4	Unit heater	Heater	
11.1.3.5	Furnace	Heater	
11.2	Auxiliary system		
11.2.1	Boiler feed water	Pump	
11.2.2	Boiler condenser water	Pump	
12	Domestic hot water		
12.1	Boiler system		
12.1.1	Boiler (electric)	Heater	
12.1.2	Boiler (natural gas)	Heater	
12.1.3	Boiler (oil)	Heater	
12.2	Auxiliary system		
12.2.1	Hot water pump	Pump	
13	Commercial refrigeration		
13.1	Supermarkets, medium temperature	Cooler	
13.2	Supermarkets, low temperature	Cooler	
13.3	Walk-ins	Cooler	
13.4	Beverage merchandiser	Cooler	
13.5	Reach-in freezers	Cooler	
13.6	Reach-in refrigerators	Cooler	
13.7	Refrigerated vending machines	Cooler	
13.8	Ice machines	Cooler	
13.9	Other	Cooler	
14	Indoor lighting		
14.1	Incandescent	Lamp[5]	
14.2	High intensity discharge (HPS)	Lamp	
14.3	High intensity discharge (HV)	Lamp	

[4] See data definition in Table 3-5
[5] See data definition in Table 3-6

No.	Description	Data Class	Units
14.4	Compact fluorescent	Lamp	
14.5	Standard fluorescent		
14.5.1	T8, electric ballast, 4’ fixture	Lamp	
14.5.2	T8, electric. ballast, 8’ fixture	Lamp	
14.5.3	T12, electric. ballast, 4’ fixture	Lamp	
14.5.4	T12, electric. ballast, 8’ fixture	Lamp	
14.5.5	T12, magnetic. ballast, 4’ fixture	Lamp	
14.5.6	T12, magnetic ballast, 8’ fixture	Lamp	
15	Outdoor lighting		
15.1	Incandescent	Lamp	
15.2	High intensity discharge (HID)	Lamp	
15.3	Compact fluorescent	Lamp	
16	Office equipment		
16.1	Laser printer	Equip[6]	
16.2	Fax machines	Equip	
16.3	PC	Equip	
16.4	PC monitors, CRT	Equip	
16.5	PC monitors, LCD	Equip	
16.6	Minicomputer	Equip	
16.7	Mainframe	Equip	
16.8	Network servers for LAN	Equip	
16.9	Photocopier	Equip	
17	Cooking		
17.1	Electric under-fired broiler	Heater	
17.2	Electric open deep fat fryer	Heater	
17.3	Electric range top	Heater	
17.4	Electric griddle	Heater	
17.5	Electric convection oven	Heater	
17.6	Electric steam kettle	Heater	
	BUILDING SHELL		
18	Exterior opaque walls		
18.1	Wood frame	Wall[7]	
18.2	Metal frame	Wall	
18.3	Structural masonry	Wall	
19	Roof		
19.1	Pitched joist/rafter/truss, wood, insulated	Roof[8]	
19.2	Pitched joist/rafter/truss, wood, not-insulated	Roof	

[6] See data definition in Table 3-7
[7] See data definition in Table 3-8
[8] See data definition in Table 3-9

No.	Description	Data Class	Units
19.3	Pitched joist/rafter/truss, metal, insulated	Roof	
19.4	Pitched joist/rafter/truss, metal, not-insulated	Roof	
19.5	Flat structural concrete	Roof	
20	Windows		
20.1	Single pane	Window[9]	
20.2	Double pane	Window	
20.3	Triple pane	Window	
21	Conservation features		
21.1	Operable windows		Yes/No
21.2	Operable skylights		Yes/No
21.3	Number of floors		Number
21.4	Footprint area		ft2
	BUILDING OPERATION		
22	Schedule		
22.1	24h/7d		Yes/No
22.2	24h/weekdays		Yes/No
22.3	Daytime/7d		Yes/No
22.4	Daytime/weekdays		Yes/No
23	Principal activity		
23.1	Office <30,000 ft^2		Yes/No
23.2	Office >30,000 ft^2		Yes/No
23.3	Restaurants		Yes/No
23.4	Health care		Yes/No
23.5	Lodging		Yes/No
23.6	Mercantile, retail (other than mall)		Yes/No
23.7	Mercantile, enclosed and strip malls		Yes/No
23.8	Food/liquor sales		Yes/No
23.9	Warehouses		Yes/No
23.10	Refrigerated warehouses		Yes/No
23.11	Schools		Yes/No
23.12	Colleges/trades		Yes/No
23.13	Miscellaneous		Yes/No
24	Vacant		-
25	Controls		
25.1	EMCS		Yes/No
25.2	Lighting control		Yes/No
25.3	Daylighting controls		Yes/No
25.4	Automated HVAC equipment diagnostics		Yes/No

[9] see data definition in Table 3-10

No.	Description	Data Class	Units
25.5	Direct load control		Yes/No
	COST AND AVAILABILITY		
26	Cost		$
27	Year of commercial availability		Year

Table 3-2: Attributes of a Cooler

No.	Attributes	Units	To determine market segment	To determine impacts
x.1	Size	ton	X	
x.2	EER	BTU/Wh	X	X
x.3	SEER	BTU/Wh	X	X
x.4	Year installed	Year	X	
x.5	Annual consumption electricity	KWh	X	
x.6	Annual consumption natural gas	MMBTU	X	
x.7	Improvement factor for peak demand	-		X
x.8	Improvement factor for energy	-		X

Table 3-3: Attributes of a Pump

No.	Attributes	Units	To determine market segment	To determine impacts
x.1	Size	HP	X	
x.2	Efficiency		X	X
x.3	Year installed	Year	X	
x.4	Annual consumption	KWh	X	
x.5	Improvement factor for peak demand	-		X
x.6	Improvement factor for energy	-		X

Table 3-4: Attributes of a Fan

No.	Attributes	Units	To determine market segment	To determine impacts
x.1	Size	HP	X	
x.2	Efficiency		X	X
x.3	Year installed	Year	X	
x.4	Annual consumption	KWh	X	
x.5	Improvement factor for peak demand	-		X
x.6	Improvement factor for energy	-		X

Table 3-5: Attributes of a Heater

No.	Attributes	Units	To determine market segment	To determine impacts
x.1	Size	BTU/h	X	
x.2	Efficiency		X	X
x.3	Year installed	Year	X	
x.4	Annual consumption electricity	KWh	X	
x.5	Annual consumption Natural Gas	MMBTU	X	
x.6	Annual consumption Fuel Oil	MMBTU	X	
x.7	Annual consumption Coal	MMBTU	X	
x.8	Improvement factor for peak demand	-		X
x.9	Improvement factor for energy	-		X

Table 3-6: Attributes of a Lamp

No.	Attributes	Units	To determine market segment	To determine impacts
x.1	Wattage	W	X	X
x.2	Year installed	Year	X	
x.3	Annual consumption	kWh	X	
x.4	Improvement factor for peak demand	-		X
x.5	Improvement factor for energy	-		X

Table 3-7: Attributes of Other Equipment

No.	Attributes	Units	To determine market segment	To determine impacts
x.1	Wattage	W	X	X
x.2	Year installed	Year	X	
x.3	Annual consumption	kWh	X	
x.4	Improvement factor for peak demand	-		X
x.5	Improvement factor for energy	-		X

Table 3-8: Attributes of a Wall

No.	Attributes	Units	To determine market segment	To determine impacts
x.1	Area	ft^2	X	
x.2	U-factor	BTU/ft^2/R	X	X
x.3	Heat capacity	BTU/ft/R	X	X
x.4	Improvement factor for peak demand	-		X
x.5	Improvement factor for energy	-		X

Table 3-9: Attributes of a Roof

No.	Attributes	Units	To determine market segment	To determine impacts
x.1	Area	ft^2	X	
x.2	U-factor	BTU/ft^2/R	X	X
x.3	Color		X	
x.4	Azimuth angle	degrees	X	
x.5	Pitch angle	degrees	X	
x.6	Year installed	Year	X	
x.7	Improvement factor for peak demand	-		X
x.8	Improvement factor for energy	-		X

Table 3-10: Attributes of a Window

No.	Attributes	Units	To determine market segment	To determine impacts
x.1	Area	ft^2	X	
x.2	U-factor	BTU/ft^2/R	X	X
x.3	Solar heat gain coefficient (SHGC)		X	X
x.4	Clear glass	Yes/no	X	
x.5	Tinted glass	Yes/no	X	
x.6	reflective glass	Yes/no	X	
x.7	Year installed	Year	X	
x.8	Improvement factor for peak demand	-		X
x.9	Improvement factor for energy	-		X

Using the example of the SaveNet product we can generate a product characteristic table, as shown below. Table 3-11 represents a compressed form of Table 3-1 through Table 3-10 showing only the non-blank product characteristics.

Table 3-11: Product Characteristics for Market Segmentation for Analyzing the Impacts of SaveNet.

No.	Description	Data Class	Units	Values	To determine market segment	To determine impacts
2	Building floor area		ft^2	≥50,000	X	
8	Cooling					
8.2	Packaged					
8.2.2	Packaged AC	Cooler				
8.2.2.1	Size		ton	≥10 tons	X	
8.2.2.4	Year installed		year	1982	X	
8.2.2.5	Annual consumption electricity		KWh	>0	X	
8.2.2.7	Improvement factor for peak demand		-	0.08		X
8.2.2.8	Improvement factor for energy		-	0.1		X

4 Market Segmentation

Market segmentation is the practice of determining the potential market for a product (i.e., the product's market segment) by using a set of market attributes to identify the maximum scope of opportunity for the application of the product. In the context of this project, segmentation is the process of defining that portion of the total commercial buildings market most likely to be affected by a particular product, standard, guideline, equipment, hardware, software or other tools developed in the PIER program of the Commission or likely to emerge as a result of work done in the program. Rarely will a program or product apply to the entire marketplace. Therefore, we segment or attempt to determine the maximum specific portion of the market to which the product is expected to apply.

Segmentation combines the analysis of available data characterizing the market and the expertise of analysts familiar with the specific program or product to determine the widest possible target market without overstating the opportunity. Market segmentation should rely on the best market data available. However, market data types vary. "Hard" data include those sources held in generally high regard by industry analysts, such as buildings databases like the California Commercial End-Use Survey (CEUS) or the Commercial Energy Buildings Energy Consumption Survey (CBECS). Hard data can also include studies that have collected market-size data ranging from a specific segment across a narrow geography to many segments across a wide geography. Commission publications and other research reports that present compilations and aggregated analyses of hard data sources may represent the only source of certain market information. The framework needs to be responsive to both the data intensive case, where segmentation relies directly on analyzing database extracts, and the aggregate data case, where inference can only be made from a roll-up table with highly aggregated information.

Ideally, availability of hard data would not be a limiting factor; however, practice reveals that as the definition of a market segment increases in refinement or narrowness, hard data become increasingly scarce. Lack of hard data increases the need to use expert judgment to determine the target market.

"Soft" data can be provided by technology experts, such as inventors, researchers, or others knowledgeable about a technology or product, who through practice and industry involvement can further provide segmentation information. Soft data include such sources as technology reports, marketing studies, and expert opinion. Often soft data can temper market size estimates in the absence of sufficiently detailed hard data. The ideal commercial buildings segmentation framework needs to combine the best of hard data science and expert judgment to provide total flexibility in application.

The size of a commercial buildings market and its segments can be characterized by measures such as floor space, peak loads, number of buildings, energy expenditures, total energy consumption, and installed base of specific equipment. These variables are mathematically described below, and are the terms used for expressing the size of a potential segment. Market segments can be very large or very small depending on the number and types of attributes or descriptors used to define them. Market attributes for the commercial sector can include end-use splits, equipment types, window types, heating energy source, or equipment-size class, among many others. The more that is known about a potential product, standard, guideline, or technology, the more attributes are likely to be defined for identifying the market segment (i.e. the resolution of the market segment is increased). The more accurate the market segmentation, the more reliable will be the eventual assessment of potential energy savings and other benefits associated with the product, whether it is a standard, guideline, equipment, or tool.

4.1 Identifying the Market Segment

Identifying the market segment most applicable to a specific product requires an initial characterization of the features of the product. Product variables include general building descriptors, end-use information, building construction details, and building operation. Once key features of the product are known, these attributes can be used to query data sources to select the relevant population of buildings or equipment. This population defines the market segment for the product. The complete listing of variables available for use in establishing selection criteria for commercial-building market segments in this methodology is provided in Section 3.

4.2 Size of the Market Segment

Market segments are generally characterized by their size once they have been identified. For assessing the electricity use and peak demand impacts of products resulting from the PIER program, we have selected six variables to characterize the market segment size:

1. Number of buildings in the market segment,
2. Floor space of buildings in the market segment,
3. Installed base of specific equipment units in the market segment (e.g., total number of packaged rooftop air-conditioning units on buildings in the market segment),
4. Electricity consumption of the market segment,
5. Peak electric demand of the market segment,
6. Expenditures on electric energy used by commercial buildings in the market segment, including both consumption and peak demand charges.

The first three variables are used, in some cases, to estimate the impact variables. The last three variables are the energy, load and expenditure characteristics that are used in evaluating impacts. All of these market-size variables can be evaluated (i.e., assigned values) at any point in time, and the values will most likely vary with time.

The variables can be evaluated as follows:

The number of buildings in the market segment $N(t)$ at year t is

$$N(t) = \sum_{i=1}^{n} \left(\alpha_i (t, x_s) \right) \quad (4\text{-}1)$$

where:

t represents a year counter,

x_s is a segmentation vector (fully specified in Section 2). The segmentation vector, x_s, is the set of binary variables, each binary variable corresponding to satisfaction of a specific market-segment-selection criterion for this particular market segment. These variables take values of unity when the criterion is satisfied and zero when it is not. For example, if three criterion (x_1, x_2 and x_3) are used to define the market segment, then building i must have $x_s = (x_1, x_2, x_3) = (1, 1, 1)$ to be included in the market segment. If any of the segmentation variables for this market segment is zero, the building is not included in the market segment.

α_i is a binary variable for building i, which takes values of unity when all conditions of x_s are satisfied; otherwise α_i is zero. For example, if $x_s = (x_1, x_2, x_3) = (1, 1, 1)$, then $\alpha_i = 1$; otherwise, $\alpha_i = 0$. In other words $\alpha_i = 1$ if building i is a member of the market segment and is zero otherwise. As a result, α_i can be considered a variable indicating membership in the market segment.

n is the number of all buildings in a specific population. In this methodology, n is all buildings in California. If we were working with a different geographic area, such as the entire U.S., n would be the number of buildings in the U.S.

The total floor space in the market segment *A(t)* in year *t* is given by:

$$A(t) = \sum_{i=1}^{n} \left(\alpha_i (t, x_s) a_i \right), \quad (4\text{-}2)$$

where a_i is the floor space of building i, (e.g., in ft^2).

The consumption of electricity by the market segment *E(t)* in year *t* is

$$E(t) = \sum_{i=1}^{n} \left(\alpha_i (t, x_s) E_i(t) \right) \quad (4\text{-}3)$$

where $E_i(t)$ is the electric energy consumption of building i in year t (e.g., in kWh).

Electric peak demand *D(t)* in year *t* is given by the relation:

$$D(t) = \sum_{i=1}^{n} \left(\alpha_i (t, x_s) d_i \right), \quad (4\text{-}4)$$

where d_i represents the electric peak demand of building i in year t, (e.g., in kW).

The cost $C(t)$ associated with the electricity consumption $E(t)$ and electric peak demand $D(t)$ is given by the relation:

$$C(t) = \sum_{i=1}^{n} (\alpha_i(t, x_s))(E_i(t)P_i(t) + D_i(t)dc_i(t)) \tag{4-5}$$

$$= E(t)P(t) + D(t)dc(t), \text{ for } P_i(t) = P(t) \text{ and } dc_i(t) = dc(t) \text{ for all } i, \tag{4-6}$$

where $dc(t)$ is the demand charge applied to the peak demand $D(t)$, expressed in \$/kW.

The first term $(E(t)\ P(t))$ on the right hand side is the cost associated with the quantity of electricity consumed and the second term $(D(t)\ dc(t))$ is the demand charges for peak power consumption.

The installed base of specific equipment j ($Q_j(t)$) in year t is given by:

$$Q_j(t) = \sum_{i=1}^{n} (\alpha_i(t, x_s) q_{j,i}(t)) \tag{4-7}$$

where $q_{j,i}(t)$ represents the number of pieces of equipment j in building i in year t.

Any analysis of market data must consider the vintage of those data in the ultimate estimate of current market size. For example, if data collected in 1998 were the most recent available for an assessment being conducted in 2002, results obtained from those data should be benchmarked to 2002. In addition, product assessments typically require development of information about the potential market size at the end of some defined projection period. For this reason it is essential to the assessment that results from market segmentation are reliably projected to the year of the analysis to reflect an accurate baseline and projection. Section 4.3 provides specific examples of these concepts.

4.3 Segmentation Examples

We have developed four specific hypothetical examples to demonstrate how our methodology for market segmentation would be applied given different data types. The examples cover a continuum of data availability potentially affecting product impact assessments. Table 4-1 identifies the mapping of examples across data availability and data completeness. The assessment framework covers the entire range of data availability, while the examples cover the extremes. It should be noted that the assessment framework expects the default data source to be some current or future commercial buildings database characterized by building-level (or more disaggregated) records. To the degree that such hard data do not exist, an assumption-based, top-down, approach will be required. The market segmentation part of the assessment framework is designed primarily for data-driven analysis.

Table 4-1: Coverage of Segmentation Example Cases

		Resolution of Data	
		Detailed Data	**Aggregate Data**
Completeness of Data	**Census of Buildings**	Example 1: Detailed Data on Every Building Available	Example 3: Variable Aggregation in the Building Census
	Sample of Buildings	Example 2: Detailed Data for a Sample of Buildings. Extrapolating from Sample to the Entire Market Segment Required	Example 4: Variable Aggregation for a Sample of Buildings. Need to Extrapolate from Sample to the Entire Market Segment

In some cases, no actual building data may be available for a sample of buildings or the census of buildings. Only aggregate estimates of important factors (e.g., total electricity consumption) may be available. In these cases, a "top-down" approach to market segmentation must be used. This approach is illustrated in Example 4.

4.3.1 Description of the Example Product

All examples feature segmentation of the same hypothetical product to maintain consistency. The hypothetical product is arbitrarily defined as an on-board, energy-efficiency monitoring tool for rooftop air-conditioning (AC) units. It is packaged as a box including electronics and communications hardware with sensors attached. For sake of example, it is designed to function on packaged units having at least a 10-ton capacity and installed on buildings of greater than 50,000 square feet of floor area. The device would permit online monitoring of equipment from the remote location of a service company. As performance issues arise, the service company dispatches technicians to tune or repair the problem system. This on-time servicing reduces wasted service calls when no problems exist and ensures that equipment gets serviced as soon as required in case of failure or performance degradation. For referencing purposes in this document, we will call the product "SaveNet." In all cases, we assume that the ultimate goal of the assessment is to quantify the electricity savings impacts of the tool for the Pacific Gas and Electric (PG&E) service territory. Table 4-2 summarizes the distinguishing product characteristics, which come from the product characterization. All other market-segment identification variables can take any of the available values.

Table 4-2: Distinguishing product characteristics for the example product

Product Characteristic Variable	Acceptable Values for Market Segment	Variable Number in Table 2-1[10]
Zip code	All zip codes in the PG&E service territory	6
Building floor area	Greater than 50,000 square feet	2
Building vintage	New and existing buildings	4
Cooling	Packaged AC	8.2.2
Cooling size	Equal to or greater than 10 ton	8.2.2.1
Cooler annual consumption of electricity	All values greater than zero (or some threshold)	8.2.2.5
Cooler annual consumption of gas	Zero	8.2.2.6

4.3.2 Segmentation Example 1: Data Not an Issue

In this example, data on all buildings are available at the necessary granularity from a census of buildings. Data for all segmentation variables identified in Table 3-1 populate records in a database. In addition, data for all six market-segment size variables are included in the database. In this case, the market-segment size is estimated by selecting those buildings in the database that satisfy the criteria in Table 4-2 and then determining the market-segment size by applying Equations (4-1) through (4-7) to the selected building set. Because the data are based on a census of all buildings, the selected buildings represent all buildings in the market segment. The electricity consumption of the market segment is determined using Equation (4-3), where the values of E_i are obtained directly from the database for each building within the selected building set. Other size variables can be determined using Equations (4-1), (4-2), and (4-4) through (4-7).

Market size must then be benchmarked from the year of data collection to the year (or first year) of analysis. If the impact estimate extends over a period of time, e.g., to the year 2020, the market size also must be projected out to each year in the time horizon. These adjustments are described and illustrated below. The market-segment sizes would then be used in estimating the savings impact of the technology later in the Analysis step of the assessment process (see Figure 2-1).

To illustrate how to determine the market size for this example, consider the following hypothetical building census provided in Table 4-3. It is assumed that a hypothetical population of 20 commercial buildings had a census performed in 1996. Table 4-3 is a subset of Table 3-1, containing only relevant and non-blank entries.

There are four steps involved in determining the market size:

1) select buildings that meet the example product (SaveNet) requirements,

[10] See Table 3-1.

2) determine the total market size defined by Equations (4-1) through (4-7),
3) benchmark the 1996 data to an analysis base year, and
4) project the market segment size through an analysis period (2002-2030).

Data in Table 4-3 are most conveniently stored in a database to provide easy querying and reporting services. Therefore, we will refer to the Table 4-3 as a database on which queries are performed.

4.3.2.1 Building Selection

To determine the applicable market segment, analysts query this example census to select individual building records that match the criteria for which the SaveNet product would apply, based on information gathered from preliminary characterization. Such a query to specify the segmentation vector based on Table 4-2 above could be generically structured as follows:

Select census records where:

[6.0 Zip Code] is in the PG&E Service Territory,
AND
[2.0 Building Floor Area] equal to or greater than 50,000
AND
[8.2.2.X.1 Packaged AC (tons)] equal to or greater than 10,
AND
[8.2.2.X.5 Packaged AC (Annual kWh)] greater than 0,
AND
[8.2.2.X.6 Packaged AC (Annual MMBTU of Gas)] equal to 0.

Such a query will result in the segment of the population of commercial buildings having the requisite equipment installed for application of the SaveNet product. From the example database the query would return 11 records (Building IDs 2, 3, 5, 7, 9, 11, 13, 15-17, and 20).

Table 4-3: Hypothetical Example Buildings Census with Qualifying Records Identified By Shaded Column Headings

Building ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Census	Selection
2.0 Building floor area (000 ft^2)	80.7	86	73.9	108.7	96.4	945	93.1	93.7	61.2	99.7	80.7	66.2	83.8	23.2	53.1	51.6	68.6	34.6	34.5	86.8	**2321.5**	**835.2**
3.0 Building total electric peak demand (kW)	414.6	362.3	311.3	707.3	594.2	3980.7	392.2	394.7	257.8	420.0	339.9	278.9	353.0	97.7	223.7	217.4	289.0	145.7	236.3	365.6	**10,382**	**3,706**
4.0 Building vintage (Year)	79	96	95	62	74	93	88	85	85	86	87	88	87	89	89	95	96	94	71	80		
5.0 Ownership	1	1	4	1	1	1	1	1	1	1	1	1	1	3	2	2	1	1	1	1		
6.0 Zip Code	95838	95062	94105	94607	93721	90012	95030	92101	95501	96101	95630	92501	95928	95688	95340	94612	94103	95206	92311	94101		
7.0 Climate zone	12	3	3	3	13	9	3	7	1	16	12	10	11	3	13	3	3	12	14	3		
8.0 Cooling	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**20**	**11**
8.1 Central System	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**	**0**
8.2 Packaged	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**18**	**11**
8.2.1 Heat pump	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
8.2.2 Packaged AC	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**18**	**11**
8.2.2.1.1 Packaged AC (Units)	4	2	3		5		4	5	3	3	4	4	4	2	2	6	4	3	2	2	**62**	**37**
8.2.2.1.2 Packaged AC (Tons)	20	5	20		20		20	20	20	5	20	10	20	10	20	10	10	5	5	10	**910**	**630**
8.2.2.1.3 Packaged AC (EER)								10		7												
8.2.2.1.4 Packaged AC (SEER)	10	12	11		8		11		12		11	12	11	9	11	12	11	11	8	8		
8.2.2.1.5 Packaged AC (Year)	91	96	95		88		88	85	94	86	87	96	87	89	89	95	96	94	86	95		
8.2.2.1.6 Packaged AC (Annual kWh)	314,730	39,290	236,332		451,152		297,734	299,653	195,718	50,343	258,079	141,138	267,992	74,194	169,814	165,017	146,255	110,651	59,800	69,397	**3,347,287**	**2,257,489**
8.2.2.1.7 Packaged AC (Annual MMBTU)																						**0**
8.2.2.2.1 Packaged AC (Units)		1								3				1				3	2		**10**	**1**
8.2.2.2.2 Packaged AC (Tons)		20								20				20				20	10		**180**	**20**
8.2.2.2.3 Packaged AC (EER)																						
8.2.2.2.4 Packaged AC (SEER)		12								10				11				8	8			
8.2.2.2.5 Packaged AC (Year)		96								86				96				95	86			
8.2.2.2.6 Packaged AC (Annual KWh)		73,128								201,373				70,569				208,190	67,124		**620,384**	**73,128**
8.2.2.2.7 Packaged AC (Annual MMBTU)																						**0**
8.2.2.3.1 Packaged AC (Units)		3																	1		**4**	**3**
8.2.2.3.2 Packaged AC (Tons)		20																	20		**80**	**60**
8.2.2.3.3 Packaged AC (EER)																						
8.2.2.3.4 Packaged AC (SEER)		12																	7			
8.2.2.3.5 Packaged AC (Year)		96																	86			
8.2.2.3.6 Packaged AC (Annual KWh)		235,738																	119,600		**355,338**	**235,738**
8.2.2.3.7 Packaged AC (Annual MMBTU)																						**0**
8.2.3 Residential AC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
8.3 Individual	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**

(Sizes of census and building characteristics are arbitrarily chosen and only the applicable subset of fields are displayed)

4.3.2.2 Market-Segment Size Determination

With the market segment selected from the census of buildings, the analyst now aggregates the query to determine the six measures of market segment size using Equations (4-1) through (4-7). Table 4-4 illustrates the resulting market segment size across the six measures.

Table 4-4: Example 1996 Market Segment Size for Hypothetical "SaveNet" Product

Equation	Measure	Units	Segment Size (1996)
4-1	Number of buildings	buildings	11
4-2	Floor space of buildings	square feet	835,200
4-3	Electricity consumption of packaged AC units	kWh	2,566,355
4-4	Peak electric demand	kW	3,706
4-6	Expenditures on cooling electric energy*	current dollars	247,791
4-7	Packaged AC units (PAC)	units	41

* Assumes $0.085/kWh electricity price and $8/kW demand charge for example purposes.

4.3.2.3 Benchmarking

Benchmarking is the process of adjusting data representing one period to accurately reflect a different period. In this example, the market segment size values need to be benchmarked from 1996 to the period of analysis. For purposes of this report, the analysis period runs from 2002 to 2020. Incumbent upon any benchmarking exercise is the need to provide clear documentation of the approach and the requisite assumptions used. Any number of forecasting techniques may be acceptable, provided that the foundation material permits the methods to be reconstructed for review by others.

Benchmarking from a census provides the ideal situation. By definition, census data reflect the total measurement of the population, and are typically the source of most forecasts. Usually, forecasts will project commercial floor space, end-use consumption, and other principal measures needed to determine future electricity demand. It is less likely that regular forecasts will be available for narrowly defined segments. One approach to benchmark the 1996 market segment size to 2002 relies on simple scaling of market segment values by published forecasts using scaling factors such as those shown in the equations below.

The total commercial floor space scaling factor S_A in year t, where t_0 is the reference year (1996 for this example), is given by:

$$\text{Scaling Factor} = S_A = \frac{A_t}{A_0}, \qquad (4\text{-}8)$$

where t = 2002, A_t = total commercial floor space in 2002, and A_0 = total commercial floor space in 1996.

The total segment floor space in arbitrary year t (a_t) can then be expressed as:

$$a_t = a_0 S_A, \tag{4-9}$$

where a = segment floor space and a_0 is the segment floor space in the initial year, which in this example is 2002. Equation (4-9) is based on the assumption that

$$A_t / A_0 \cong a_t / a_0 .$$

Using example numbers from the database, where A_0 = 2,321,500 ft^2, and (from a hypothetical state floor space forecast) A_t = 2,555,000 ft^2, and a_0 = 835,200 ft^2:

$$S_A = \frac{2{,}555{,}000\, ft^2}{2{,}321{,}500\, ft^2} = 1.101.$$

Then, multiplying S_A by a_0,

$$a_t = a_{2002} = a_0 S_A = 835{,}200\, ft^2 \times 1.101 = 919{,}555 \text{ ft}^2.$$

This value represents an estimate of the market segment size expressed in floor space in 2002. The benchmarking approach is identical for the other measures, each in its own unit context. To further illustrate, we consider electricity consumption.

4.3.2.3.1 Electricity Consumption

The total commercial packaged AC electricity scaling factor S in year t, where t_0 = the reference year (1996) is given by:

$$\text{Scaling Factor} = S_E = \frac{E_t}{E_0}, \tag{4-10}$$

where t = 2002, and E = total commercial packaged AC electricity consumption.

The calculation results in the estimated market segment size (electricity consumption by the market segment) in 2002:

$$e_t = e_{2002} = e_0 S_E, \tag{4-11}$$

where e = segment electricity consumption.

4.3.2.3.2 Number of Buildings

The scaling factor S_N in year t for total number of buildings, where t_0 = the reference year (1996), is given by:

$$\text{Scaling Factor} = S_N = \frac{N_t}{N_0}, \qquad (4\text{-}12)$$

where N = total commercial buildings in the specified year.

The market segment size in year t is then given by:

$$n_t = n_0 S_A, \qquad (4\text{-}13)$$

where n = number of buildings in the market segment in the specified year.

4.3.2.3.3 Equipment Installed Base

Continuing with the example approach to benchmarking, analysts might have access to a forecast of packaged AC units. Ideally, the forecast would call out specific equipment characteristics (i.e., rated capacity, SEER, etc.), and be focused on the PG&E service territory. In that case, the forecast would simply supercede the census. If the same forecast were at the California State level, a simple conversion of the state-forecasted segment size could be obtained by multiplying the value (number of units) by the PG&E share of state package AC units, packaged AC consumption, number of buildings, etc. Without a forecast of specific equipment, the analyst must develop a reasonable set of assumptions to benchmark the number of pieces of specific equipment or decide whether other measures of market size might be more reliable or more appropriate and document them so others can evaluate the reasonableness of the assumptions.

4.3.2.4 Caveats to Benchmarking

- **Snapshot Data:** Analysts need to recognize that census data represent a snapshot taken at a point in time (e.g., a specific year) – 1996 in this hypothetical case. Therefore, if the census were conducted in a relatively recessionary year, the snapshot would likely reflect artificially high vacancy rates as demand for commercial space slows. Data collected in very healthy economic times might have unrepresentatively low vacancy rates as commercial space becomes scarcer. The vacancy example indicates that caution should be used when benchmarking proportions using data from one specific year, especially when economic conditions were unusual such as a recessionary year or one with high-growth. This applies to all relationships used for benchmarking.
- **Target Market:** Because census data do not include changing trends for system or equipment conversion over time, defining the market based on current installed base might not include all important factors and underestimate the market. On the other hand, defining the market based on a projection of the potential population of buildings

that could use the product if that population converted systems might overestimate the market segment size. In this case, as the scope of the analysis is defined, the characterization of the market needs to specify realistic limits to the potential market segment using best professional judgment.

- **Structural Change:** The linear adjustments defined in Equations (4-8) through (4-13) neglect potential structural changes in the market. For instance, a building might convert from one without AC services to one with AC services. Another example is a potential trend toward replacing central systems with a greater number of packaged units. These structural changes alter the proportions found in the census data, and these changes in proportions could grow over time since the census was conducted. In cases where significant time has passed since the last census, benchmarking must use information from other studies that document trends and changes in the market observed in the intervening years to help adjust for changes between the time of the census and the year for which the market size is estimated.

4.3.2.5 Extrapolation to 2030

Once the segment size has been estimated from the census and benchmarked to the first year of analysis, it must be projected over the analysis period (2002 to 2030 for the example) to facilitate the estimation of energy savings and other impacts over this period. The simplest method for accomplishing this relies on extending the linear projections used for benchmarking from 1996 to 2002, out to 2030, using the annual rate of change implicit in the scaling factors developed in Section 4.3.2.3. However, published forecasts used in the development of the original scaling factors (for benchmarking from 1996 to 2002) might extend out further – perhaps as far as 2030. In that case, the applicable scaling factors can simply be calculated for each year of the study period and applied to the previous year's estimated segment size. Table 4-5 illustrates scaling using an annual scaling factor based on forecasts of California Packaged AC electricity use from 1996 through 2030. A scaling factor for each year based on the electricity use by packaged AC units is used to scale all measures of size of the SaveNet market segment (electricity consumption, number of buildings, number of packaged AC units, peak demand and electricity expenditures). Note that this approach of scaling based on annual changes in forecast values is analogous to scaling based on applying a constant market share to all forecast values or applying a set of inflators to a base-year benchmark.

Table 4-5: Example Market Segment Size Forecast for Hypothetical "SaveNet" Product

Year	California Packaged AC Electricity (kWh)	Scaling Factor (E_t/E_0)	SaveNet Market Segment Size*					
			Electricity Consumption (kWh)	Number of Buildings	Floor Space (ft^2)	Packaged AC Units	Peak Demand (kW)	Electricity Expenditures ($ Current)
1996	4,323,010		2,391,759	11	835,200	41	3,706	247,791
2002	5,555,068	1.285	3,073,410	14	1,073,232	53	4,762	318,411
2003	5,749,495	1.330	3,181,039	15	1,110,816	55	4,929	329,562
2004	5,950,728	1.377	3,293,452	15	1,150,070	56	5,103	341,208
2005	6,147,102	1.422	3,401,081	16	1,187,654	58	5,270	352,359
2006	6,343,809	1.467	3,508,710	16	1,225,238	60	5,437	363,509
2007	6,534,123	1.511	3,613,948	17	1,261,987	62	5,600	374,412
2008	6,730,147	1.557	3,723,969	17	1,300,406	64	5,770	385,811
2009	6,932,051	1.604	3,836,381	18	1,339,661	66	5,944	397,457
2010	7,140,013	1.652	3,951,186	18	1,379,750	68	6,122	409,351
2011	7,347,073	1.700	4,065,990	19	1,419,840	70	6,300	421,245
2012	7,552,791	1.747	4,178,403	19	1,459,094	72	6,474	432,891
2013	7,749,164	1.793	4,288,424	20	1,497,514	74	6,645	444,289
2014	7,942,893	1.837	4,393,661	20	1,534,262	75	6,808	455,192
2015	8,133,522	1.881	4,498,899	21	1,571,011	77	6,971	466,095
2016	8,320,593	1.925	4,604,136	21	1,607,760	79	7,134	476,998
2017	8,495,326	1.965	4,699,806	22	1,641,168	81	7,282	486,909
2018	8,665,232	2.004	4,793,085	22	1,673,741	82	7,427	496,573
2019	8,829,872	2.043	4,886,364	22	1,706,314	84	7,571	506,237
2020	8,988,809	2.079	4,972,467	23	1,736,381	85	7,705	515,157
2021	9,132,630	2.113	5,053,787	23	1,764,778	87	7,831	523,582
2022	9,269,620	2.144	5,127,931	24	1,790,669	88	7,946	531,264
2023	9,399,394	2.174	5,199,684	24	1,815,725	89	8,057	538,698
2024	9,521,587	2.203	5,269,045	24	1,839,946	90	8,164	545,884
2025	9,626,324	2.227	5,326,447	24	1,859,990	91	8,253	551,831
2026	9,722,587	2.249	5,379,066	25	1,878,365	92	8,335	557,282
2027	9,810,090	2.269	5,426,901	25	1,895,069	93	8,409	562,238
2028	9,888,571	2.287	5,469,953	25	1,910,102	94	8,476	566,698
2029	9,947,903	2.301	5,503,437	25	1,921,795	94	8,528	570,167
2030	9,997,642	2.313	5,532,139	25	1,931,818	95	8,572	573,141

*All values are contrived, rounded, and presented for hypothetical example purposes only.

Consider the hypothetical example forecast of state-level packaged AC electric energy consumption depicted in Figure 4-1. This contrived example shows the typical shape of energy forecasts. Long-term energy forecasts are rarely projected linearly. Generally, they feature a shape characterized by more rapid growth in the near term followed by slower growth in the long term. For example purposes, we have contrived this forecast to fit the shape most often seen in projections, however, the same scaling principles apply for any forecast shape. In this example, the market segment size is scaled based on the diminishing annual inflator embodied in the hypothetical forecast provided in Table 4-5.

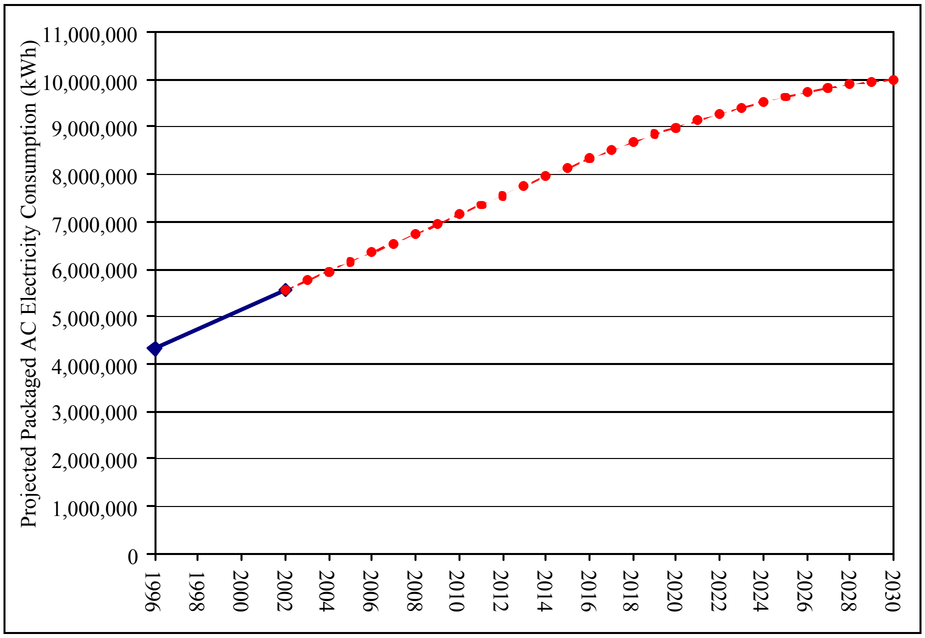

Figure 4-1: Hypothetical Statewide Forecast of Packaged AC Electricity Consumption

4.3.2.6 Additional Considerations

Several complicating factors need explaining. The simple example shown above relies on the forecast of packaged AC electricity consumption as the basis for a scaling factor to be applied to all measures of market size. This implies that the proportions of floor space, buildings, peak demand, and expenditures, to packaged AC electricity consumption remain constant over the 2002-2030 period. This may be inappropriate or over-simplified. In reality, the analyst should choose the most appropriate measure of market size and the corresponding best forecast depending on the analysis to be done. For assessment of electricity savings impacts, it might be more important to characterize market segment size by electricity use (in kWh). To identify the potential installations of the product, it may be more important to characterize the size of the market segment in terms of numbers of packaged AC units or numbers of buildings.

Long-term energy demand forecasts generally take into consideration the likelihood of structural changes in the economy and how these projected changes manifest themselves in the commercial buildings sector. Reputable forecasts can be assumed to account for both a "status quo" or "business as usual" case, reflecting an extension of current trends, and a "conservation" or "technology" case, reflecting reasonable adoption of energy-saving practices. When characterizing the example SaveNet product, it should be determined which forecast most closely pertains to the example product and that forecast should be used for projecting market size over the study period.

4.3.3 Segmentation Example 2: Complete Data for a Sample of Buildings - Extrapolating from a Sample to the Full Market Segment

In this example, data are available at the necessary granularity but only for a sample of buildings in the target population. Data for all segmentation variables identified in Table 3-1 populate records in a database, including data for all six market-segment-size variables. The market size is estimated by selecting those buildings in the database that satisfy the criteria in Table 4-2, determining the sizes of the market-segment sample (in this case the electricity consumption), and then extrapolating from the sample to the entire market segment to estimate the size of the segment. To determine the electricity consumption of the market-segment sample, Equation (4-3) is applied to the values of E_i in the database for each building identified as satisfying the criteria for belong to the market segment for the example SaveNet product. Other size variables for the market-segment sample can be determined using Equations (4-1), (4-2) and (4-4) through (4-7).

Extrapolation of the market-segment-sample size to the entire market-segment size depends on the method used to sample the population of buildings. Samples are generally designed to provide data that represent the population, while keeping costs associated with data collection to a minimum. Many different sampling strategies are common, e.g., random, stratified, cluster, and multi-stage sampling. The particular sampling method determines the relationship between sample statistics and estimators for the size of the entire population; however, in general, the size (M) for the entire market segment can be estimated from the size (M_{sample}) of the sample using the relation

$$M = S \times M_{sample}, \tag{4-14}$$

where S is a scaling factor estimated from other indicators of the ratio of the size of the full population of buildings to the sample size. For example, S might be estimated by

$$S = n/n_{sample}, \tag{4-15}$$

where n is the total number of buildings in the region surveyed (e.g., the State of California) and n_{sample} is the size of the full sample of buildings upon which the database is based (not the market-segment).

For this example, consider the hypothetical 1996 database presented in Table 4-3 as a representative 10 percent sample of the population of commercial buildings in California, rather than a complete commercial buildings census. The approach to determine the market segment size is identical to that of Example 1, with the additional step of extrapolating from sample values to population values. Therefore, considering Table 4-4 to be sample values rather than population values would imply that the values in Table 4-4 should be multiplied by 10 to approximate the population values or actual market segment size. This is shown explicitly in Table 4-6.

Table 4-6: Example 1996 Market Segment Size for Hypothetical "SaveNet" Product

Equation	Measure	Units	Sample Segment Size (1996)	Population Segment Size (1996)
4-1	Number of buildings	buildings	11	110
4-2	Floor space of buildings	ft^2	835,200	8,352,000
4-3	Electricity consumption of PAC	kWh	2,566,355	25,663,550
4-4	Peak electric demand	kW	3,706	37,060
4-6	Expenditures on cooling electric energy*	$ (current)	247,791	2,477,910
4-7	Packaged AC units (PAC)	units	41	410

* Assumes $0.085/kWh electricity price and $8/kW demand charge.

As in Example 1, the market-segment size must then be benchmarked from the year of data collection to the year (or first year) of analysis. If the impact estimate extends over a period of time, the market-segment size also must be projected out to each year in the time horizon. Following the approach presented in Example 1, Whenever possible, the analyst should attempt to develop scaling factors based on actual observed population numbers. For example, if the 1996 sample claimed to be a representative 10 percent sample of the population of commercial buildings, hindsight can be employed to check the actual number of commercial buildings in California in 1996. Because the actual number of commercial buildings in California in 1996 probably could not be absolutely verified at the time of data collection, the sample will probably turn out to be different than a true 10 percent. Correcting small errors in the early portion of a forecast can help prevent the magnification of the errors at the end of the forecast resulting from compounding.

Analysts should note that the uncertainty is greater in estimates of impacts made from samples of populations than estimates made from census of populations. This is inherent in estimates based on any sample of a population. As a result, the projections of market-segment size in Table 4-7 (Example 2) are less certain than those in Table 4-5 (Example 1).

Table 4-7 illustrates the benchmarked and projected market segment size, based on the extrapolated sample of commercial buildings data presented in
Table 4-6.

Whenever possible, the analyst should attempt to develop scaling factors based on actual observed population numbers. For example, if the 1996 sample claimed to be a representative 10 percent sample of the population of commercial buildings, hindsight can be employed to check the actual number of commercial buildings in California in 1996. Because the actual number of commercial buildings in California in 1996 probably could not be absolutely verified at the time of data collection, the sample will probably turn out to be different than a true 10 percent. Correcting small errors in the early portion of a forecast can help prevent the magnification of the errors at the end of the forecast resulting from compounding.

Analysts should note that the uncertainty is greater in estimates of impacts made from samples of populations than estimates made from census of populations. This is inherent in estimates based on any sample of a population. As a result, the projections of market-segment size in Table 4-7 (Example 2) are less certain than those in Table 4-5 (Example 1).

Table 4-7: Extrapolation of Market Segment Size to 2030

Year	California Packaged AC Electricity (kWh)	Scaling Factor (E_t/E_0)	SaveNet Market Segment Size*					
			Electricity Consumption (kWh)	Number of Buildings	Floor Space (ft^2)	Packaged AC Units	Peak Demand (kW)	Electricity Expenditures ($ Current)
1996	43,230,100		23,917,590	110	8,352,000	410	37,060	2,477,910
2002	55,550,679	1.285	30,734,103	141	10,732,320	527	47,622	3,184,114
2003	57,494,952	1.330	31,810,395	146	11,108,160	545	49,290	3,295,620
2004	59,507,276	1.377	32,934,521	151	11,500,704	565	51,032	3,412,082
2005	61,471,016	1.422	34,010,813	156	11,876,544	583	52,699	3,523,588
2006	63,438,088	1.467	35,087,105	161	12,252,384	601	54,367	3,635,094
2007	65,341,231	1.511	36,139,478	166	12,619,872	620	55,998	3,744,122
2008	67,301,468	1.557	37,239,688	171	13,004,064	638	57,702	3,858,106
2009	69,320,512	1.604	38,363,814	176	13,396,608	658	59,444	3,974,568
2010	71,400,127	1.652	39,511,859	182	13,797,504	677	61,223	4,093,507
2011	73,470,731	1.700	40,659,903	187	14,198,400	697	63,002	4,212,447
2012	75,527,911	1.747	41,784,030	192	14,590,944	716	64,744	4,328,909
2013	77,491,637	1.793	42,884,239	197	14,975,136	735	66,449	4,442,893
2014	79,428,928	1.837	43,936,613	202	15,342,624	753	68,079	4,551,921
2015	81,335,222	1.881	44,988,987	207	15,710,112	771	69,710	4,660,949
2016	83,205,932	1.925	46,041,361	212	16,077,600	789	71,341	4,769,977
2017	84,953,257	1.965	46,998,064	216	16,411,680	806	72,823	4,869,093
2018	86,652,322	2.004	47,930,850	220	16,737,408	822	74,268	4,965,732
2019	88,298,716	2.043	48,863,636	225	17,063,136	838	75,714	5,062,370
2020	89,888,093	2.079	49,724,670	229	17,363,808	852	77,048	5,151,575
2021	91,326,302	2.113	50,537,868	232	17,647,776	866	78,308	5,235,824
2022	92,696,197	2.144	51,279,313	236	17,906,688	879	79,457	5,312,639
2023	93,993,944	2.174	51,996,841	239	18,157,248	891	80,568	5,386,976
2024	95,215,865	2.203	52,690,451	242	18,399,456	903	81,643	5,458,836
2025	96,263,240	2.227	53,264,473	245	18,599,904	913	82,533	5,518,306
2026	97,225,872	2.249	53,790,660	247	18,783,648	922	83,348	5,572,820
2027	98,100,905	2.269	54,269,012	250	18,950,688	930	84,089	5,622,378
2028	98,885,712	2.287	54,699,528	252	19,101,024	938	84,756	5,666,980
2029	99,479,026	2.301	55,034,375	253	19,217,952	943	85,275	5,701,671
2030	99,976,421	2.313	55,321,386	254	19,318,176	948	85,720	5,731,406

*All values are contrived, rounded, and presented for hypothetical example purposes only.

4.3.4 Segmentation Example 3: Variable Aggregation in Census Data

In this example, data on all buildings are available from a census of all buildings in the population but with variables at a lower level of granularity than designated in Table 3-1. Data for some segmentation variables are available at the desired granularity in the database, but other variables are aggregated compared to the variables identified in Table 3-1. Data for all six market-segment size variables are included in the database. Because the data are based on a census of all buildings, the selected buildings represent all buildings in the market segment.

Table 4-8 presents the hypothetical census database being described. Table 4-8 corresponds to Table 4-3 presented in Example 1. The difference in this example is that there is not an identical one-to-one mapping of fields in Table 4-8 to fields in Table 3-1 (as there is for Table 4-3). The problem compared to Example 1 is that some of the data are aggregated compared to our ideal data source (Table 3-1). In this case, to select the buildings in the market segment for our example product, we must first "approximately disaggregate" for any variables not at the required granularity. This can only be done based on experience, familiarity with the building stock, and "soft data" (i.e., estimates not based on direct quantitative evidence).

In this example, we assume that the database does not have fields indicating the size class of the rooftop units and the end-use electricity consumption for air conditioning for each building. Instead, total electricity use is given for each building. Assumptions are required to estimate the required AC portion of the load and the share of units that are of at least 10-ton capacity for each building. The key to data-limited segmentation is to develop a strong basis for any assumptions needed to fill in missing information, to record the assumptions, and to record any facts that support the assumptions. In this case, the fraction of total electric load represented by air conditioning for a portion of the population for which it is known or for another location for which it is known might be used as estimators of this fraction. For example, the average across all buildings in the State might be used, the average for another state with similar weather for which data are available might be used, or a national average might be used if available. A similar approach might be used for estimating the number and size of the units for each building. In this case, the required data could be constructed from the hypothetical example database using the relationships:

$$E_{AC,\,i}(t) = F_{AC} \quad E_i(t) \tag{4-16}$$

and

$$q_{PAC>10,i}(t) = F_{AC>10} \;\; q_{PAC,i}(t), \tag{4-17}$$

where

$E_{AC,\,i}(t)$ is the electricity consumption for air conditioning of building i in year t,
F_{AC} is an estimate of the fraction of electricity consumption attributable to air conditioning, (15.4% for a contrived example);
$q_{PAC>10,i}(t)$ is the number of packaged air-conditioning units with capacities greater than 10 tons on building i in year t, and
$F_{AC>10}$ is an estimate of the average fraction of packaged AC units on a building of greater than 50,000 square feet that are greater than 10 tons (85% for a contrived example).

To reiterate, F_{AC} and $F_{AC>10}$ must be estimated. The assumptions and supporting evidence upon which their estimates are based should be recorded and presented along with any results derived from them. For purposes of example, we cite hypothetical studies in the notes to Table 4-8 to illustrate the indication of the basis for the assumptions. The resulting estimates were added to the database as constructed values of $E_{AC,\,i}(t)$ and $q_{PAC>10,i}(t)$ for each building (the yellow highlighted rows at the bottom of Table 4-8). Having the constructed values, the electricity consumption for the market segment can be estimated using Equation (4-3). The other market-segment-size variables can be estimated in a similar way using Equations (4-2) and (4-4) through (7-7), but relying on constructed fields in the data.

To determine the applicable market segment, analysts query this example census to select individual building records that match the criteria for which the SaveNet product would apply, based on information gathered from preliminary product characterization. In the aggregated data case, such a query to specify the segmentation vector based on Table 4-8 could be generically structured as follows:

Select census records where:
[6.0 Zip Code] is in the PG&E Service Territory,
AND
[2.0 Building Floor Area] equal to or greater than 50,000
AND
[Estimated Packaged AC Units >= 10 tons] greater than 0.

Such a query will result in all members of the population of commercial buildings estimated to have the requisite equipment already installed for application of the SaveNet product. From the example database the query would return 11 records (Building IDs 2-3, 5, 7, 9, 11, 13, 15-17, and 20).

The market size then can be determined using an approach analogous to that of Example 1. With the market segment selected from the census of buildings, the analyst now aggregates the query to determine the six measures of market segment size using Equations (4-1) through (4-7). Table 4-9 illustrates the resulting market segment size across the six measures, based on the estimated fields in Table 4-8.

Table 4-8: Hypothetical Example Buildings Census with the Column Headings of Qualifying Records Shaded Green and "constructed" data for $E_{AC,\,i}(t)$ and $q_{PAC>10,i}(t)$ for each building shown in the yellow highlighted rows.

Building ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Sample**	**Selection**
2.0 Building floor area (000 FT2)	80.7	86	73.9	108.7	96.4	945	93.1	93.7	61.2	99.7	80.7	66.2	83.8	23.2	53.1	51.6	68.6	34.6	34.5	86.8	2321.5	835.2
3.0 Building total electric peak demand	415	362	311	707	594	3,981	392	395	258	420	340	279	353	98	224	217	289	146	236	366	10,382	3,706
Building Electricity Consumption (KWh)	2,043,701	1,785,896	1,534,625	2,065,300	2,929,558	11,623,500	1,933,336	1,945,796	1,270,894	2,070,394	1,675,835	1,374,725	1,740,210	481,777	1,102,687	1,071,538	1,424,564	718,512	1,164,935	1,802,509	41,760,291	18,271,652
4.0 Building vintage (Year)	79	96	95	62	74	93	88	85	85	86	87	88	87	89	89	95	96	94	71	80	1719	972
5.0 Ownership	1	1	4	1	1	1	1	1	1	1	1	1	1	3	2	2	1	1	1	1	27	16
6.0 Zip Code	95838	95062	94105	94607	93721	90012	95030	92101	95501	96101	95630	92501	95928	95688	95340	94612	94103	95206	92311	94101		569911
7.0 Climate zone	12	3	3	3	13	9	3	7	1	16	12	10	11	3	13	3	3	12	14	3	154	68
8.0 Cooling	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20	11
8.1 Central System	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
8.2 Packaged	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18	11
8.2.1 Heat pump	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.2.2 Packaged AC	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18	11
8.2.2.1 Packaged AC (Units)	4	5	3	0	5	0	4	5	3	8	4	5	4	2	2	6	5	3	3	5	76	46
Estimated Packaged AC Units >= 10 Tons (1)	3	4	3	0	4	0	3	4	3	7	3	4	3	2	2	5	4	3	3	4	64	38
Estimated AC Electricity Consumption (2)	314,730	275,028	236,332	0	451,152	0	297,734	299,653	195,718	318,841	258,079	211,708	267,992	74,194	169,814	165,017	219,383	110,651	179,400	277,586	4,323,010	2,391,759

Notes:

Hypothetical 1998 CA-based study of packaged AC adoption in the commercial sector indicates that 85% of all units installed are >= 10 tons.
Units rounded to whole units at the building level.
Hypothetical 1999 CA-based study estimates that air conditioning makes up 15.4% of the statewide commercial electricity consumption.
PG&E service territory is assumed to be large enough and diverse enough in climate to apply the statewide average.

Table 4-9: Example 1996 Market Segment Size for Hypothetical "SaveNet" Product

Equation	Measure	Units	Segment Size (1996)
4-1	Number of buildings	Buildings	11
4-2	Floor space of buildings	Square Feet	835,200
4-3	Electricity consumption of PAC	kWh	2,391,759
4-4	Peak electric demand	kW	3,706
4-6	Expenditures on cooling electric energy*	Current Dollars	232,948
4-7	Packaged AC units (PAC)	Units	38

* Assumes $0.085/kWh electricity price and $8/kW demand charge.

As with Examples 1 and 2, the market-segment sizes must then be benchmarked from the year of data collection to the year (or first year) of analysis. If the impact estimate extends over a period of time, the market-segment sizes also must be projected out to each year in the time horizon. The market-segment sizes would then be used in estimating the savings impact of the technology later in the Analysis step of the assessment process (see Figure 2-1). See Example 1 to review the detailed approach.

Following the approach presented in Example 1, the use of assumptions to resolve the data-aggregation problem resulted in outyear results that differ slightly from those produced using the fully disaggregated example building concus. Compared to the results for Example 1 where complete data were available, the market segment size for 2030 was underestimated by 7.4 percent in kWh and number-of-units.

Table 4-10 illustrates the benchmarked and projected market segment size, based on the aggregated census data on commercial buildings presented in Table 4-9.

The use of assumptions to resolve the data-aggregation problem resulted in outyear results that differ slightly from those produced using the fully disaggregated example buildings census. Compared to the results for Example 1 where complete data were available, the market segment size for 2030 was underestimated by 7.4 percent in kWh and number-of-units.

Table 4-10: Extrapolation of Market Segment Size to 2030 based on Aggregated Data

Year	California Packaged AC Electricity (kWh)	Scaling Factor (E_t/E_0)	SaveNet Market Segment Size*					
			Electricity Consumption (kWh)	Number of Buildings	Floor Space (ft^2)	Packaged AC Units	Peak Demand (kW)	Electricity Expenditures ($ Current)
1996	43,230,100		2,391,759	11	835,200	38	3,706	232,948
2002	55,550,679	1.285	3,073,410	14	1,073,232	49	4,762	299,338
2003	57,494,952	1.330	3,181,039	15	1,110,816	51	4,929	309,821
2004	59,507,276	1.377	3,293,452	15	1,150,070	52	5,103	320,769
2005	61,471,016	1.422	3,401,081	16	1,187,654	54	5,270	331,252
2006	63,438,088	1.467	3,508,710	16	1,225,238	56	5,437	341,735
2007	65,341,231	1.511	3,613,948	17	1,261,987	57	5,600	351,984
2008	67,301,468	1.557	3,723,969	17	1,300,406	59	5,770	362,700
2009	69,320,512	1.604	3,836,381	18	1,339,661	61	5,944	373,649
2010	71,400,127	1.652	3,951,186	18	1,379,750	63	6,122	384,830
2011	73,470,731	1.700	4,065,990	19	1,419,840	65	6,300	396,012
2012	75,527,911	1.747	4,178,403	19	1,459,094	66	6,474	406,960
2013	77,491,637	1.793	4,288,424	20	1,497,514	68	6,645	417,676
2014	79,428,928	1.837	4,393,661	20	1,534,262	70	6,808	427,925
2015	81,335,222	1.881	4,498,899	21	1,571,011	71	6,971	438,175
2016	83,205,932	1.925	4,604,136	21	1,607,760	73	7,134	448,425
2017	84,953,257	1.965	4,699,806	22	1,641,168	75	7,282	457,743
2018	86,652,322	2.004	4,793,085	22	1,673,741	76	7,427	466,828
2019	88,298,716	2.043	4,886,364	22	1,706,314	78	7,571	475,913
2020	89,888,093	2.079	4,972,467	23	1,736,381	79	7,705	484,299
2021	91,326,302	2.113	5,053,787	23	1,764,778	80	7,831	492,219
2022	92,696,197	2.144	5,127,931	24	1,790,669	81	7,946	499,441
2023	93,993,944	2.174	5,199,684	24	1,815,725	83	8,057	506,429
2024	95,215,865	2.203	5,269,045	24	1,839,946	84	8,164	513,184
2025	96,263,240	2.227	5,326,447	24	1,859,990	85	8,253	518,775
2026	97,225,872	2.249	5,379,066	25	1,878,365	85	8,335	523,900
2027	98,100,905	2.269	5,426,901	25	1,895,069	86	8,409	528,559
2028	98,885,712	2.287	5,469,953	25	1,910,102	87	8,476	532,752
2029	99,479,026	2.301	5,503,437	25	1,921,795	87	8,528	536,013
2030	99,976,421	2.313	5,532,139	25	1,931,818	88	8,572	538,809

*All values are contrived, rounded, and presented for hypothetical example purposes only.

4.3.5 Segmentation Example 4: Top-Down Market Segment Size Estimation

Although the framework is designed to be data driven, with that data being highly granular, we recognize that there will be occasions where only highly aggregated data will be available to analyze the impacts of a product. These data may just be statewide consumption totals by sector or end-use. For this example, we will assume that the analyst has "hard" data for annual commercial-building electricity consumption in California. A set of assumptions must be made to segment the market for the example product from such a highly aggregated number.

For this example, given the commercial-building electricity consumption for California ($E_{total,CA}$), values are estimated for the following fractions:

- Fraction of total commercial-building electricity consumption used for air conditioning (E_{AC}/E_{total}),
- Fraction of air-conditioning electricity usage consumed by packaged units (E_{PAC}/E_{AC}),
- Fraction of packaged unit electricity consumption consumed by units larger than 10 tons ($E_{PAC>10}/E_{PAC}$),
- Fraction of commercial-building electricity consumption in buildings greater than 50,000 square feet ($E_{>50,000\ sq\ ft}/E_{total}$), which is used as an estimate of the fraction of electricity consumption of package units larger than 10 tons that are on buildings larger than 50,000 square feet ($E_{PAC>10,\ >50,000\ sq\ ft}/E_{PAC>10}$), and
- Fraction of California's commercial electricity consumption that is consumed in the PG&E service territory ($E(t)/E_{total,CA}$).

The electricity consumption of the market segment for our example product is then estimated by

$$E(t) = E_{PAC>10,\ >50,000\ sq\ ft} = E_{total,CA}\ (E_{total}(t)/E_{total,CA})(E_{AC}/E_{total})(E_{PAC}/E_{AC})(E_{PAC>10}/E_{PAC})(E_{>50,000\ sq\ ft}/E_{total}) \tag{4-18}$$

We start by defining the assumptions needed (example assumptions – hypothetical source material). As presented in Example 3, the fraction of total commercial-building electricity consumption used for air conditioning was assumed to be 15.4 percent based on a hypothetical 1999 California-based study. The PG&E service territory is assumed to be large enough and diverse enough in climate to apply the statewide average. Example 3 also referenced a hypothetical 1999 study on packaged AC adoption that indicated that the fraction of air-conditioning electricity usage consumed by packaged units was 66 percent statewide. That same hypothetical report indicated that 85 percent of all commercial packaged units installed were at least 10-ton units. A hypothetical National Laboratory report on California floor space trends indicates that the fraction of commercial-building electricity consumption in buildings greater than 50,000 square feet is 74.4 percent. Finally, a state energy agency report hypothetically indicates that in 1996, PG&E's service territory accounted for 44 percent of all commercial energy consumption in California. We also know, for sake of hypothetical example that California statewide commercial electricity consumption amounted to 80,000,000 kWh in 1996.

Table 4-11 illustrates the accounting used to derive the top-down estimate of the SaveNet market segment size.

Table 4-11: Top-Down Calculation of Market Segment Size Using Hypothetical Data

Segmentation Steps	Adjustments	kWh
1996 California Electricity Consumption		80,000,000
PG&E Proportion	44.0%	35,200,000
AC Proportion	15.4%	5.420,800
Packaged AC Proportion	66.0%	3,577,728
≥ 10-ton Proportion	85.0%	3,041,069
≥ 50,000 ft^2 Proportion	74.4%	2,262,555
SaveNet Market Segment Size		2,262,555

Other indicators of market-segment size can be estimated from aggregated data using similar assumptions. Market size must then be benchmarked from the reporting year of the data to the year (or first year) of analysis. If the impact estimate extends over a period of time, the market size also must be projected out to each year in the time horizon. The market-segment sizes estimated using this top-down approach would then be used as inputs to the analysis step of the assessment process (see Figure 2-1), just as the market-segment sizes obtained using data-driven approaches (Examples 1, 2 and 3) are when detailed data are available. Table 4-12 illustrates the benchmarking and extrapolating of the 1996 top-down estimate of market segment size.

Our example construct began with a hypothetical buildings census matching the granularity specified in Table 3-1, as illustrated in Example 1. Example 4 represents a significant departure from the data-driven case of Example 1. If we allow Example 1 to represent the true 1996 population of commercial buildings, then the hypothetical 2030 market segment size in energy consumption terms would be 5,532,139 kWh. The error introduced through application of the top-down approach resulted in the 2030 estimated market segment size being 5,233,290 kWh, or 5.4 percent below what resulted from the hypothetical census data analysis in Example 1.

The point is that as assumptions are used to replace observed data that may not be available, the degree of introduced error increases. The top-down approach should only be used when detailed building stock data are not available. When they are used, all assumptions and supporting information should be documented and included in the reporting of final impact assessment results.

Table 4-12: Extrapolation of Market Segment Size to 2030 for Top-Down Estimates

Year	California Electricity Demand (kWh)	Scaling Factor (E_t/E_0)	SaveNet Market Segment Size (kWh)
1996	80,000,000		2,262,555
2002	102,800,000	1.285	2,907,383
2003	106,400,000	1.330	3,009,198
2004	110,160,000	1.377	3,115,538
2005	113,760,000	1.422	3,217,353
2006	117,360,000	1.467	3,319,168
2007	120,880,000	1.511	3,418,721
2008	124,560,000	1.557	3,522,798
2009	128,320,000	1.604	3,629,138
2010	132,160,000	1.652	3,737,741
2011	136,000,000	1.700	3,846,344
2012	139,760,000	1.747	3,952,684
2013	143,440,000	1.793	4,056,761
2014	146,960,000	1.837	4,156,314
2015	150,480,000	1.881	4,255,866
2016	154,000,000	1.925	4,355,418
2017	157,200,000	1.965	4,445,921
2018	160,320,000	2.004	4,534,160
2019	163,440,000	2.043	4,622,400
2020	166,320,000	2.079	4,703,852
2021	169,040,000	2.113	4,780,779
2022	171,520,000	2.144	4,850,918
2023	173,920,000	2.174	4,918,795
2024	176,240,000	2.203	4,984,409
2025	178,160,000	2.227	5,038,710
2026	179,920,000	2.249	5,088,486
2027	181,520,000	2.269	5,133,737
2028	182,960,000	2.287	5,174,463
2029	184,080,000	2.301	5,206,139
2030	185,040,000	2.313	5,233,290

5 Market Penetration

Once the market potential has been identified, as discussed in the previous section, the next step is to forecast the rate of market penetration. Since the 1960s, many market penetration theories have been researched with the object of projecting the impact of the market adoption of a new technology. The Electric Power Research Institute (EPRI 1991) provides an overview of market penetration approaches. The EPRI report states that the rate of market penetration is primarily influenced by the marketing effort (e.g., promotion, advertising), product characteristics (e.g., complexity, compatibility), characteristics of potential adopters (e.g., decision making style, innovativeness), and market characteristics (e.g., macroeconomic conditions, competitive conditions).

5.1 Judgmental Methods

Judgmental methods don't require mathematical models or computations; instead, they rely on the experience and perceptions of the forecaster. Often the experience of experts is formulized in some relatively simple mathematical framework, such as the "S"-shaped market penetration curve. The expert may be asked to assign values to a few parameters that describe the shape of the "S" curve. Because these methods take less time to develop, rely on qualitative data, and require less technical skill to implement and interpret, they tend to be used more often than model-based methods (EPRI 1991). However, judgmental methods are more difficult to use for sensitivity analysis and are generally difficult for others to reproduce because they are not based on well-specified algorithms. A few researchers have explored judgmental methods (Armstrong 1985, Dalkey 1969, Thomas 1985).

This report will present a judgmental method that we will describe and demonstrate with an example product. This method will be called the user-definable market penetration approach using the logit function model. The logit function provides the mathematical representation of the generic "S"-shaped penetration curve.

5.2 Model-Based Methods

Contrary to judgmental methods, model-based methods utilize well-specified algorithms to process and analyze data, and generally allow cause-effect relationships to be described, which is conducive to performing sensitivity analyses. Because they tend to require more quantitative data, are more expensive to develop, and more time-consuming, they tend not to be used as widely as judgmental methods (EPRI 1991). Model-based methods can be divided into two primary categories: adoption process models and diffusion models.

Adoption process models assume that customers go through stages of awareness of a product, beginning with unawareness and ending with the decision to adopt or reject (Rogers 1983, EPRI 1982, Choffray and Lilien 1980, Nasbeth and Ray 1974). Adoption process models usually take the form of micro-simulation or discrete simulation. The advantages of micro-simulation include realism within the system and compatibility with direct segment and sensitivity analysis; the advantages of discrete simulation include modeling dynamic systems with abruptly changing variables at each adoption stage and that the effects of interventions can be included and controlled (PG&E 2001). Both forms suffer from the need that many parameters must be calibrated through judgmental or data-oriented methods, which can be more expensive (EPRI 1991).

Market penetration models assume that a product's market penetration will follow a characteristic time path. While penetration models are most appropriately applied to analyses involving new technologies, they are difficult to calibrate (Bernhardt and Mackenzie 1972, Heeler and Hustad 1980). The primary criticism of diffusion models is that they tend to be simplistic in describing complex behavioral and economic decision-making that determines the rate of market diffusion. Additionally, diffusion models are technically applicable only to those products that do not involve repeat purchases, replacements, or multiple purchases (Mahajan and Wind 1986). The remainder of Section 5 focuses on diffusion models and their application to the Commission's PIER program.

5.3 User-Definable Market Penetration Using the Logit-Function Approach

Figure 5-1 illustrates market penetration as a function of time typically observed for new products. This characteristic "S" curve (logit function) originates from the single-competition model by Fisher-Pry (Fisher and Pry 1971). Likewise, the mixed-influence model developed by Bass (Bass 1969) has an "S"-shaped market penetration solution, provided the estimation parameters in the model are chosen appropriately. We will show below the equivalence of the Bass model solution with that of the Fisher-Pry for a set of "S"-shaped solutions.

5.3.1 Overview of Fisher-Pry Model

The Fisher-Pry model defines a symmetric "S"-shaped curve as a general form of market penetration. In the original formulation, Fisher and Pry postulated a two-parameter model of the following form:

$$M(t) = \frac{1}{1 + e^{-c(t - t_h)}}, \qquad (5\text{-}1)$$

where

$M(t)$ is the fraction of market penetration at time t,
t is the time indexed in years,
t_h is the time at which half of the market is penetrated, and
c is the parameter determining the rate of penetration.

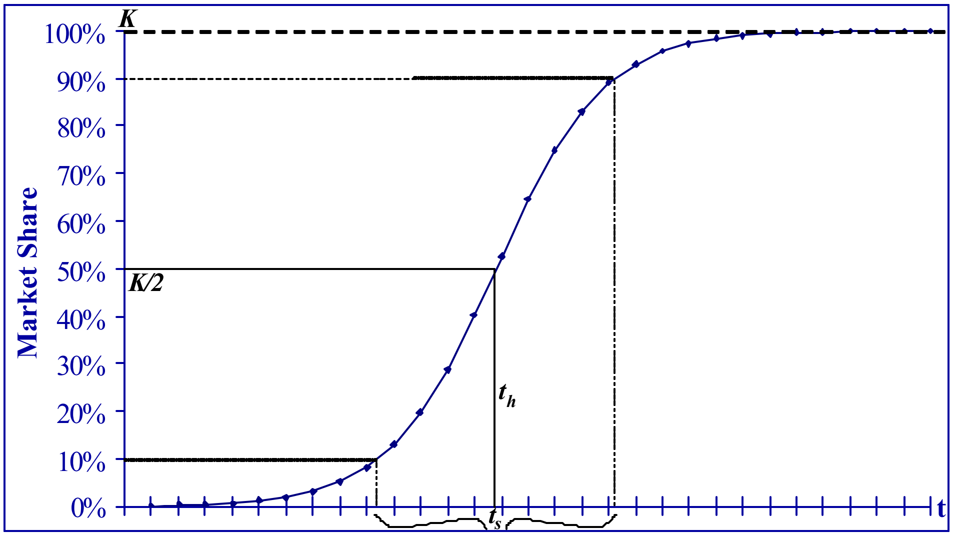

Figure 5-1: Hypothetical Example of a Single-Product, User-Defined, Market Penetration Function Based on the Logit Model, where K=100% of the Market.

A special solution of the Fisher-Pry model specifies the time period t_s required for the product to go from penetrating 10% to 90% of maximum penetration. In addition, a variable expressing the total potential market share κ is defined that constitutes the asymptotic limit as t goes to infinity, $M(t \to \infty)$. The specific solution can be written as:

$$M(t) = \frac{\kappa}{1 + e^{-\left(\frac{\ln(81)}{t_s}\right)(t - t_h)}}, \qquad (5\text{-}2)$$

where

κ is the total potential market penetration,

t is the time indexed in years,

t_h is the time at which half of the market is penetrated, and

t_s is the time period required to transition from F=0.1 to F=0.9.

The results of Equation (5-2) are shown in Figure 5-1. The market penetration $M(t)$ as a function of κ, t_h, and t_s is very intuitive and lends itself well for use in a tool with which to elicit expert judgment about plausible market penetration scenarios of new energy efficient products. An example of a potential use is discussed for the hypothetical product SaveNet.

Use of expert opinion to supply this model with the necessary parameters requires that the experts be sufficiently well informed about the market segment in question. How information about a market segment gets presented to experts greatly affects their ability to judge the information and suggest parameter values for the model. Just as for any modeling exercise, experts should have detailed information about the product's cost and performance characteristics, and should be expert in the domain of the potential market segment. This includes understanding of the competitiveness of the market place, future growth potential and customers' acceptance to new products. The analysts must strike a balance between potential bias that could be introduced to experts through the elicitation process and bias that could result from not framing the elicitation tightly enough to have confidence in the responses.

5.3.2 Example Application of the User-Defined Market Penetration Model

The intent of the user-defined penetration modeling approach is to facilitate the efficient gathering of necessary penetration model parameters through expert judgment or opinion. Many potential energy efficient products are efficiently and often reasonably well characterized using the advice and judgment of recognized experts having the specialized industry or technology knowledge – especially when the product is relatively novel or the market is very specialized.

By consulting such experts, analysts can develop estimates of the potential market share (κ) for some hypothetical future product, the takeover time (t_s) as the product catches on in the market and approaches its maximum penetration, and the amount of time it will take to reach half of its maximum market share (t_h). Plugging these three parameters into a spreadsheet application of the single-product Fisher-Pry specification in Equation (5-2) results in the logistic penetration curve from which the actual number of product unit adoptions can be estimated.

To employ this user-defined model, a simple spreadsheet tool can be developed. With the Fisher-Pry diffusion equation provided, the analyst needs estimates of only the three parameters, κ, $t_{s,}$ and t_h, to generate custom penetration functions for any product. For this example, we use the hypothetical SaveNet product.

The steps in the application are:

- The expert needs to define the analysis horizon (time horizon). We assume that we are looking at the 2002-2020 time period for impact analysis.
- Next, the expert needs to specify the maximum target market share κ the product is likely to penetrate (parameter 1). This market share is relative to the total market segment that was identified earlier in the assessment framework. For this example, we will say that by 2020 the expert determined that the SaveNet product will capture 60 percent of its target market. Assume, for example, that hypothetically the applicable market in California for SaveNet amounted to 100,000 packaged AC units in 2020, thus 60% of the 100,000 packaged AC units or 60,000 units would have SaveNet installed on them in 2020.
- Next, the expert defines the length of time required to meet half of the goal of 60 percent of the market, t_h (parameter 2). This parameter sets the inflection point of

the penetration function. Based on hypothetical expert input, assume that it will take 7 years for SaveNet to reach half of its 2020 target market, or 30,000 units.

- Finally, the expert estimates the time period t_s, which the product will require to transition from a 10% to a 90% of maximum market share (parameter 3). For example, we assume that the product will spend 5 years between 10% and 90% of the total 60% penetration goal.

The input parameters for the example product are summarized in Table 5-1.

Table 5-1: Input Parameters for the Fisher-Pry Model with example values.

Description	**Value**
Time horizon	2002-2020
Parameter 1, κ	60%
Parameter 2, t_h	7 years
Parameter 3, t_s	5 years

For this hypothetical example, the set of input parameters presented in Table 5-1 yields the SaveNet market penetration curve illustrated in Figure 5-2.

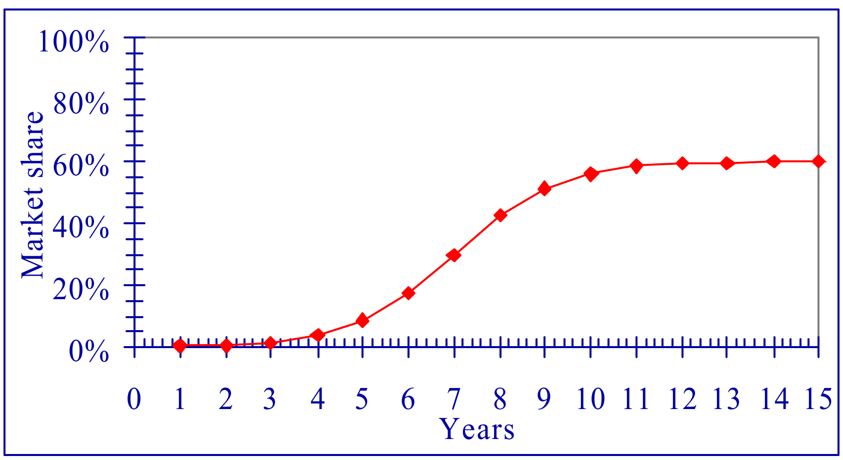

Figure 5-2: Hypothetical Example of a Single-Product, User-Defined, Market Penetration Function for the SaveNet Example Product

Under this formulation, the diffusion of SaveNet units into the market follows the schedule indicated in Table 5-2.

Table 5-2: Hypothetical Example Market Penetration of SaveNet Example Product Based on User-Defined Specification (and the Curve in Figure 5-2)

Year	Market Share	SaveNet Units
2002	0.0025	250
2003	0.0063	630
2004	0.0153	1,530
2005	0.0367	3,670
2006	0.0835	8,350
2007	0.1721	17,210
2008	0.3000	30,000
2009	0.4279	42,790
2010	0.5165	51,650
2011	0.5633	56,330
2012	0.5847	58,470
2013	0.5938	59,380
2014	0.5975	59,750
2015	0.5990	59,900
2016	0.5996	59,960
2017	0.5998	59,980
2018	0.5999	59,990
2019	0.6000	60,000

5.3.3 Delphi Approach for Obtaining User-Definable Market Penetration Curves

To obtain an estimate for a market penetration curve of a particular product, a group of experts could be asked to select the three parameters of the logit function (κ, t_h, t_s) to generate an "S"-shaped penetration curve. The experts are given an spreadsheet with an implemented logit function model and the graphing capabilities. Each expert chooses an initial set of κ, t_h, t_s parameters and adjusts the values until the "S" shape looks reasonable according to their understanding of the industry.

The final penetration curve could be obtained by utilizing an averaging scheme (such as a geometric mean) to determine the final three logit-model parameters.

5.4 Market Penetration with Multi-Product Competition

The interactions between multiple products are often viewed from the perspective of a new product competing with the mature product that it is targeting, often referred to as technological substitution between consecutive generations (Foster 1986). Bayus et al. (2000) contend that interactions are potentially much broader than simple technological substitution arguments suggest (see also Ratneshwar et al. 1997, Dickson 1992). Instead, products are often viewed by the consumer as a bundle of benefits and costs; different products can become substitutes because they provide similar benefits to the specific consumer. Therefore, the market success of a product may be assisted by what is happening with another product.

Despite the fact that multiple product relationships are important and have been recognized for some time (see Kerin et al. 1990, Czepiel 1992, Farrell 1993), multiple product interaction models have received relatively little attention in the marketing literature. Bayus et al. (2000) classify the existing literature into two categories: 1) research that extends single-product diffusion models to account for possible multiple product interactions, and 2) models that concentrate on the diffusion of successive product generations.

Extensions of the single-product models began with Peterka (1977), who built on the original work of Fisher and Pry (1971) by proposing a system of diffusion equations for different types of inter-product relationships. This model has been applied to estimate the substitution of wood- and coal-fired electricity generation technologies by modern fossil fueled (oil and natural gas) and nuclear generation technologies.

5.4.1 Multiple Product Competition

The introduction of competitive new products to the framework increases the complexity of impact analysis significantly. In the single-product case, we postulated that a new product was unique and novel enough that no direct competitors exist. In that case, we have the logit function model to determine a product's penetration to some maximum market share. Experts supply key parameters to estimate the shape of the diffusion function. For multiple product competition, we consider the case when several new products resulting from the efforts of the PIER program enter the market as competitors to established products.

Often these two cases are observed in sequence whereby a single novel product creates a new market with no competition. The product enters the market as a sole product until competitors emerge with similar products. An example of this sequential market behavior is the web browser technology. Once protocols like http were established for transmitting rich content embodied in text code over internet networks, a market for web browser software was created where no market existed previously. The initial product offering was the Mosaic browser (the forerunner of today's Netscape). The diffusion of web browser software into this new market followed the classic logit function. Several other minor players entered and exited this market – remaining essentially on the periphery of a market dominated by Netscape. Microsoft entered the browser market about 2 years behind Netscape and immediately began to compete and win market share until it surpassed Netscape in 1998 at around 45% of the installed base. Currently, trends have slowed and Microsoft enjoys about an 80-20 advantage in market share – not counting other niche players that make up a minor portion of the market. This 12-year story can be viewed graphically in Figure 5-3.

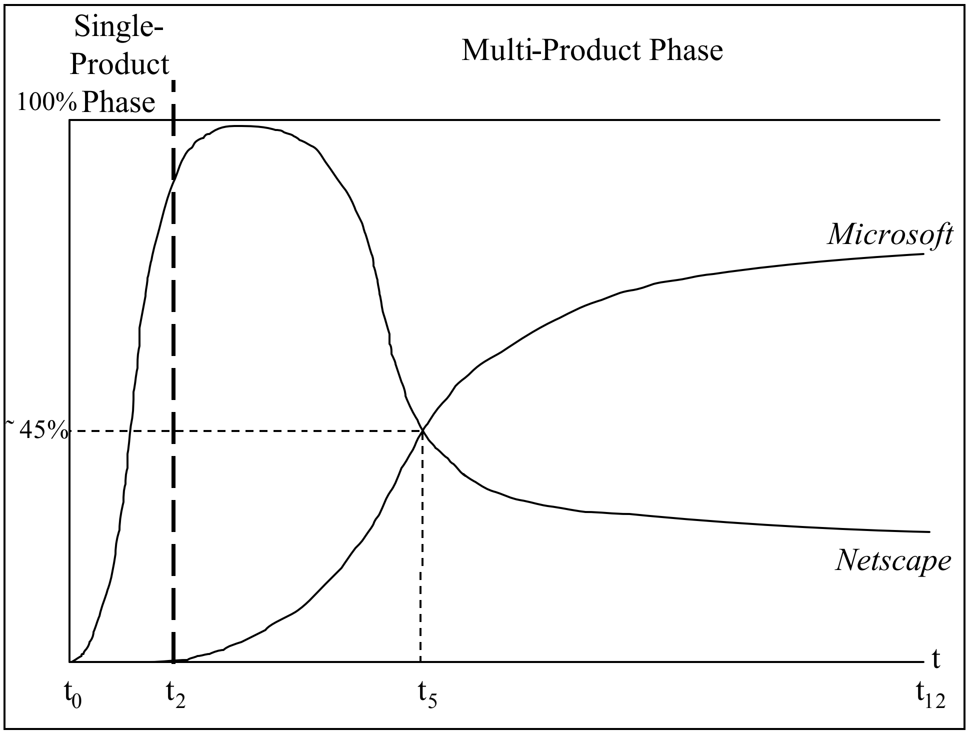

Figure 5-3: Simplified Example of Web Browser Market Penetration in Competition

One new product successfully may penetrate a newly identified market and become the *de facto* market leader. Economic theory suggests that other market actors would perceive the opportunity being harvested by the first product and quickly act to compete for that market segment. At the point where the first competitors enter the market, the multi-product competition begins. The methodological approach representing the multi-product competition is modeled using the Peterka market penetration model. Figure 5-4 illustrates the market share trajectory for a two-product competition whereby the new market entrant takes over almost the entire market.

In this hypothetical example, F_i represents the market penetration (as a fraction of the maximum penetration) of product *i* over time. At the point when *i* is established in the market place, product *j* enters the market as a competitor to *i*. The function F_j depicts the capture of market share away from *i* to product *j* – reflective of the market perceiving some level of cost-per-performance superiority in product *j*. This implies that consumers make rational decisions in choosing between these two products. For example, consumers will choose the product if performance increases for the same unit cost, or if unit cost decreases for the same performance – exclusive of other attributes.

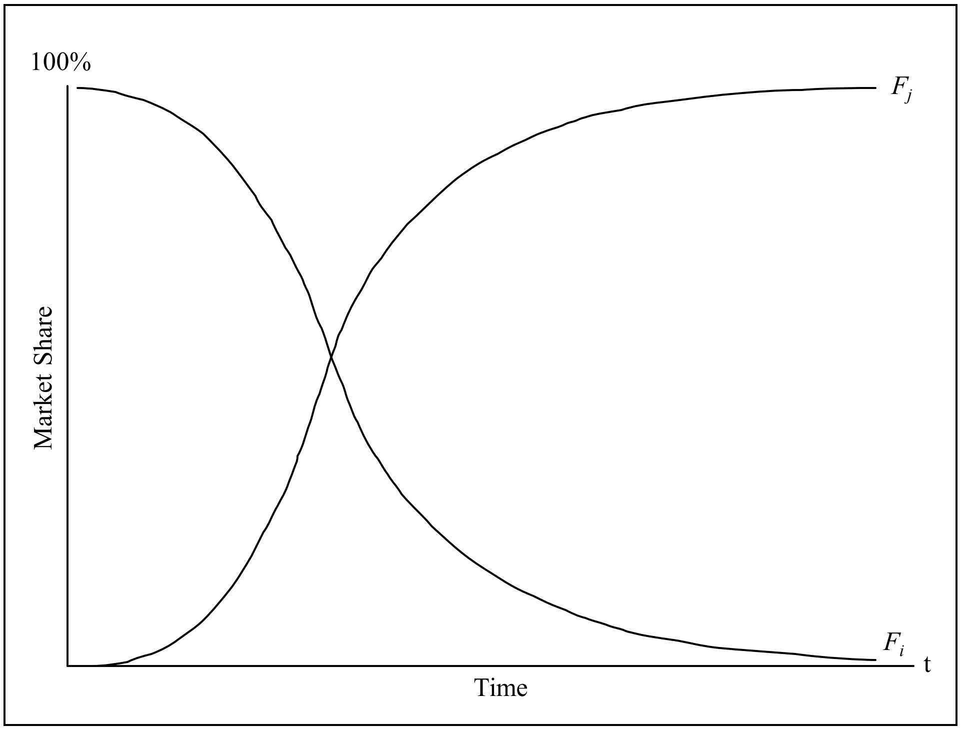

Figure 5-4: Approach to Modeling Market Penetration in the Case of Multi-Product Competition

Figure 5-4 depicts the extreme case where product *i* eventually is completely displaced by product *j*. Certainly, many outcomes are possible and have been observed in reality. These outcomes range from each product capturing a relatively stable niche market share (web browsers) to one product eventually driving another product out of the market (color televisions replaced black and white).

Introducing multiple competing products to the market requires an extension of the Fisher-Pry approach. Peterka (1977) developed such an approach and reduced it to application in computer code. The model forecasts the penetration function of multiple products in competition against each other. Section 5.4.2 provides an overview of that approach.

5.4.2 Overview of the Peterka Model

5.4.2.1 Mathematical Derivation of Model

The algorithm used to simulate market penetration under competition resulted from Peterka's 1977 analysis of fuel use from the time of wood (1850s) to nuclear power (1970s) (Peterka, 1977). This analysis found that the determining factors in market penetration of competing fuels were the specific investment, production cost, and initial market share of competing products.

Peterka's basic approach to his model included the definition of two cost items that need to balance. They are:

1. the investment over a finite period Δt to increase production of a commodity,

$$a_i \left(P_i(t+\Delta t) - P_i(t) \right) , \tag{5-3}$$

where

α_i is the specific investment of production in the ith competing technology and
$P_i(t)$ is the production of the ith competing technology in time t.

and

2. revenue covering the investment is expressed as:

$$\int_t^{t+\Delta t} P_i(t) \left[p(t) - c_i \right] dt , \tag{5-4}$$

where

c_i is the specific production cost of the ith technology,
$p(t)$ is the market price of the commodity the competing technologies produce.

Peterka equates the investment given by Equation (5-3) with the revenue given by Equation (5-4), which is equivalent to requiring that the revenue equal the investment for any time period Δt. The resulting relation is:

$$\int_t^{t+\Delta t} \left\{ \alpha_i \dot{P}_i(t) - P_i(t) \left[p(t) - c_i \right] \right\} dt = 0 \tag{5-5}$$

Because the integral in Equation (5-5) is equal to zero for any t and Δt, the following differential equations for n technologies must hold:

$$\alpha_i \dot{P}_i(t) = P_i(t) \left[p(t) - c_i \right] \qquad \text{for all } i = 1, 2, 3, \ldots, n \tag{5-6}$$

The same equation can be written for the technology indexed by j. When subtracting that equation from equation (5-6) and introducing the fractional market share,

$$f_i = \frac{P_i}{P} , \tag{5-7}$$

where P is the total production of competing technologies, we establish the set of differential equations:

$$\dot{f}_i + f_i \frac{\sum_{j=1}^{n} c_{i,j} f_j}{\sum_{j=1}^{n} a_{i,j} f_j} = 0 \qquad i=1,2,3,\ldots,n \tag{5-8}$$

where

$$a_{i,j} = \frac{\alpha_i}{\alpha_j} \;, \tag{5-9}$$

$$c_{i,j} = \frac{\alpha_i}{\alpha_j}\left(\frac{c_i}{\alpha_i} + \rho\right) - \left(\frac{c_j}{\alpha_j} + \rho\right) \;, \tag{5-10}$$

and ρ is the rate of growth for total production of all products.

Relationship (5-9) provides a set of (n-1) simultaneous equations. To solve the system of differential equations for n technologies we need one additional equation, which we obtain from the requirement that the sum of all fractional market shares must be unity, i.e.,

$$\sum_{i=1}^{n} f_i = 1 \;. \tag{5-11}$$

We implemented and solved Equations (5-8) through (5-11) in a Matlab program. Peterka also provided an iterative solution method implemented in FORTRAN code. Peterka's program is provided in the documentation for this method (Peterka 1977) and was also implemented for this project. We tested both implementations and found that the solution method based on solving the set of ordinary differential equation is more robust, particularly when the incremental investment cost c_i is small and approaches zero. This is the case for analyzing retrofit technologies, where the cost of the reference technology (i.e., the prevailing technology with no retrofit) is zero. The iterative solution method aborted for values of c_i not far from zero.

5.4.2.2 Considerations for Using the Model

The modeler must supply the model with specific investment, production cost, and initial market shares for each competitor, plus the production growth rate. Specific investment is the capital required to increase production by one unit (fixed cost). Production cost reflects all of the operation and maintenance expenses connected with a unit of production (variable cost). The modeler must also provide the initial market share for each competing product, and the sum must equal 1. This means that for new products, some existing reference product must be characterized as one of the competitors (i.e., there must be an existing product). This also means that for an entirely new product that provides a service that did not exist previously (e.g., radio), the Peterka model cannot be applied. It requires a minimum of two competitors. The production growth rate is the rate of growth of the total production of all competing products.

With the competitors fully specified, the model can be used to calculate the unit cost differentials between the competitors and the reference product. These differentials represent the cost-per-performance measure alluded to earlier. Essentially, the model uses the cost inputs, growth rates, and initial market shares to develop the cost differential of each product as a function of time. For example, we know that compact fluorescent lamps (CFLs) compete directly with incandescent lamps. Because incandescent lamps are a well-established product, consumers have an expectation of the cost per lumen that they understand as the price of a light bulb. CFLs have the advantage of producing the same illumination for a reduced amount of electricity (and therefore reduced cost), and they last several years per unit. CFLs have a significantly higher per unit cost to the consumer than incandescent bulbs. In this example, the model places the two products on a consistent economic footing by converting the cost information into a cost per lumen (unit of illumination) over the product lifecycle.

These consistent per unit cost functions are presented to the maximum likelihood estimation module to forecast market penetration. The principal assumption of the model is that the decision between the competing products is made based on lowest cost per unit of efficacy (for example, the cost per lumen of a bulb). Given that market share passes from the product of highest cost-per-performance to that of the lowest, the rate of market share change is determined based on the maximum likelihood estimation, which defines a probability function for the change in market share for a given unit cost differential. The output of the Peterka model is the market share vector $M_i(t)$ for each product.

Peterka provides the full documentation of this approach and fully derives the theorems governing its application (Peterka 1977). The Peterka Model relies on initial specifications of product cost as the foundation for consumer response in the market. The results are only as good as the quality and completeness of the underlying specification of product costs. Costs are specified in monetary terms, but must be as indicative as possible of the actual decision facing the consumer. Returning to the CFL example, research typically suggests that based on a cost-per-performance comparison, consumers should be flocking to CFLs as replacements for incandescent bulbs more rapidly than what is being observed. When this has been investigated, other factors emerge as barriers to adoption by consumers. These typically are differences in characteristics and performance, including the delay in the CFL turning on, color temperature differences, differences in bulb size and shape, etc. To have the penetration models represent consumer behavior (e.g., choosing a CFL product over an incandescent), these barriers need to be reflected in the per-unit cost of the CFL presented to the model. This is one of the major difficulties with market penetration modeling approaches in general and the Peterka model is no exception.

5.4.3 Caveats to Market Penetration Modeling

A major challenge for the Commission in using the Peterka model is the choice of a reasonable and plausible investment and production cost for a future product. The product may not be clearly defined at the time when the R&D is still under way. Furthermore, it is difficult to estimate a unit cost of a future product not knowing the means by which it will be mass-produced and distributed.

The Peterka model exhibits a methodological caveat. The fundamental assumption of the model is that the cost of a product is constant. The cost of a new product at the point of first market introduction is generally high and tends to decrease as the production of the product improves and becomes more efficient. This cost reduction relation is commonly defined as the learning curve of production and relates the cost as a function of sold products (e.g., Hirschmann 1964).

The impacts of a simplified single cost model as opposed to a model with a learning curve representation are difficult to quantify. Because there are high uncertainties inherent in determining the cost for any future products, it appears that omission of additional complexity may be more advantageous than limiting.

5.5 Market Competition Data Model

This section describes the data model resulting from application of the market penetration portion of the assessment framework. Sections 5.3 and 5.4 documented the recommended approach for modeling the market penetration of new products. These include both a user-definable approach for single products and a competition model for multiple competing products.

The point is to explicitly declare the inputs and outputs that apply to any market penetration modeling scenario, whether single-product or competing products. Table 5-3 and Table 5-4 outline the set of input variables for the user-definable and Peterka model approaches, respectively. Table 5-5 shows the output data of the penetration model.

Table 5-3: Variables for Input to the User-Definable Market Penetration Model

Field Number	Description	Units
1	Model ID	-
2	Product ID	-
3	Time horizon for market penetration	year
4	Estimated maximum market share (κ)	-
5	Estimated time half of maximum market share (t_h)	years
6	Estimated time to transition from 10% to 90% of market share (t_s)	years

Table 5-4: Variables for Input to the Peterka Market Penetration Model

Field Number	**Description**	**Units**
1	Model ID	-
2	Product ID	-
3	Time horizon for market penetration	year
4	Production growth rate	-
5	Number of competing products	-
6.1	Specific investment of product 1	$\$/kW_{th}$
6.2	Production costs of product 1	$\$/kW_{th}$
6.3	Initial market share of product 1	-
7.1	Specific investment of product 2	$\$/kW_{th}$
7.2	Production costs of product 2	$\$/kW_{th}$
7.3	Initial market share of product 2	-
	……………………………….	
8.1	Specific investment of product n	$\$/kW_{th}$
8.2	Production costs of product n	$\$/kW_{th}$
8.3	Initial market share of product n	-

Table 5-5: Output of Market Penetration Model

Field Number	**Description**	**Units**
1	Model ID	-
2	Product ID	-
3	Year index	-
4	Market share of product 1, $M_1(t)$	-
5	Market share of product 2, $M_2(t)$	-
	………………………………..	
6	Market share of product n, $M_n(t)$	-

6 Equations to Calculate Impacts

This section summarizes the mathematical formulae and equations to calculate impact estimates of products resulting from projects performed as part of the California Energy Commission's PIER program. The equations relate the impact estimates to a set of variables that were defined and discussed in previous sections. The primary variables include:

- size of a market segment targeted by a product
- potential reduction of energy consumption and peak electric demand
- product market penetration over time.

6.1 Major Variables for Calculating Impact Estimates

We use the following constituents for the impact estimation:

- Size of market segment,
- Technical improvement characteristics, and
- Market penetration vector.

Each of these primary variables are discussed more fully below.

6.1.1 Size of Market Segment

In Section 4, we defined the market size in terms of electricity consumption and peak demand for electricity.

The electricity consumption of the market segment can be expressed as [see Equation (4-3)]:

$$E(t) = \sum_{i=1}^{n} \left(\alpha_i (t, x_s) \, E_i (t) \right) \qquad (6\text{-}1)$$

where

t represents a year counter,

n is the total number of buildings in a data set

x_s is a segmentation vector (fully specified in Section 3 on the data model of market segments). The segmentation vector, x_s, is the set of binary variables, each binary variable corresponding to satisfaction of a specific market-segment-selection criterion for this particular market segment. These variables take values of unity when the criterion is satisfied and zero when it is not. For example, if three criterion (x_1, x_2 and x_3) are used to define the market segment, then building i must have $x_s = (x_1, x_2, x_3) = (1,1,1)$ to be included in the market segment. If any of the segmentation variables for this market segment is zero, the building is not included in the market segment.

α_i is a binary variable for building i, which takes values of unity when all conditions of x_s are satisfied; otherwise α_i is zero. For example, if $x_s = (x_1, x_2, x_3) = (1,1,1)$, then $\alpha_i = 1$; otherwise, $\alpha_i = 0$. In other words $\alpha_i = 1$ if building i is a member of the market segment and is zero otherwise. As a result, α_i can be considered a variable indicating membership in the market segment.

$E_i(t)$ is the electric energy consumption of building i in year t (e.g., in kWh). It represents the sum of all electricity consumed by equipment and end-uses in a building.

b) the peak demand for electricity (electric peak demand) is given by the relation (see Equation (4-4):

$$D(t) = \sum_{i=1}^{n} \left(\alpha_i(t, x_s) D_i(t) \right) \tag{6-2}$$

where D_i represents the electric peak demand of building i in year t, (e.g., in kW).

6.1.2 Technical-Improvement Characteristics

In Section 3, we define two technical improvement factors for each equipment class j. The first improvement factor is applied to the electricity consumption; the second factor is applied to the peak demand. We define the following variables for the improvement characteristics of a new product:

IE_j, the improvement factor applied to electric energy consumption of equipment class j, and
ID_j, the improvement factor applied to peak electric demand of equipment class j.

The equipment class j has the following constituents: cooler, pump, fan, heater, lamp, other equipment, wall, roof, and window (see Table 3-2 through Table 3-10).

6.1.3 Market Penetration Vector

In Section 5 on market penetration, we described the market penetration methodology, which leads to the definition of a vector $M(t)$ as the fractional share of the total market segment in year t captured by a new product. Market share vector $M(t)$ was defined in Equation (5-2) for the user-definable approach and described in Table 5-5 for the Peterka model.

6.2 Calculation of Impact Estimates

6.2.1 Disaggregation of Electricity Consumption and Electric Demand

The energy consumption $E_i(t)$ and the peak demand $D_i(t)$ for building i were defined as annual values. Because the improvement factors IE_j and ID_j are specified by equipment class j (i.e., a product may have different improvement factors, for instance, for a cooler than for a heater), we disaggregate $E_i(t)$ and $D_i(t)$ into equipment class *j* as well. $E_i(t)$ is disaggregated into $E_{i,j}(t)$ and $D_i(t)$ is disaggregated into $D_{i,j}(t)$. Equations (5-1) and (5-2) can then be rewritten as:

$$E(t) = \sum_{j=1}^{m}\left[\sum_{i=1}^{n}\left(\alpha_i(t,x_s)\,E_{i,j}(t)\right)\right] = \sum_{j=1}^{m} E_j(t) \text{ and} \qquad (6\text{-}3)$$

$$D(t) = \sum_{j=1}^{m}\left[\sum_{i=1}^{n}\left(\alpha_i(t,x_s)\cdot D_{i,j}(t)\right)\right] = \sum_{j=1}^{m} D_j(t)\ , \qquad (6\text{-}4)$$

where

m represents the total number of equipment classes,

$E_{i,j}(t)$ represents the electric energy consumption of building *i* and equipment class *j* in year *t* (e.g., in kWh),

$E_j(t)$ represents the electric energy consumption of equipment class *j* in year *t* summed over all *n* buildings (e.g., in kWh),

$D_{i,j}$ represents the electric peak demand of building *i* and equipment class *j* in year *t*, (e.g., in kW),

D_i represents the electric peak demand of equipment class *j* in year *t* summed over all *n* buildings, (e.g., in kW).

6.2.2 Impact Estimates for Energy Consumption

Given the constituents discussed above, the impacts of a new product on electricity consumption can be defined as:

$$SE(t) = \sum_{j=1}^{m}\left(E_j(t)\cdot IE_j\cdot M(t)\right), \qquad (6\text{-}5)$$

where

$SE(t)$ represents the savings on electric energy in year *t* (in kWh) and

$E_j(t)$ represents the total electricity consumption of the market segment consumed by equipment class *j* in year *t*.

The cumulative energy savings over the time horizon of the project (commercialization year to 2030) can be expressed as:

$$TSE = \sum_{t=T_c}^{T_e} SE(t), \qquad (6\text{-}6)$$

where

T_e represents the end year of the time horizon and

T_c represents the year of commercialization.

6.2.3 Impact Estimates for Peak Demand

The impacts on the peak demand are defined as:

$$SD(t) = \sum_{j=1}^{m} \left(D_j(t) \cdot ID_j \cdot M(t) \right) \tag{6-7}$$

where

SD(t) represent the savings of electric peak demand in year *t* (in kW) and
$D_j(t)$ represents the total electric peak demand of the market segment attributable to equipment class *j* in year *t*.

6.2.4 Impact Estimates for Expenditures

The impacts on electricity expenditures are defined as yearly savings on expenditures for electricity resulting from electricity savings in year *t* [*CE (t)*] and are given by

$$CE(t) = SE(t)\ PE(t) \text{, and} \tag{6-8}$$

the yearly savings on expenditures due to peak demand reductions in year *t* [*CD(t)*] are given by

$$CD(t) = SD(t)\ PD(t), \tag{6-9}$$

where

PE(t) represents the price of electricity projected for year *t*, and
PD(t) represents the demand charge projected for year *t*.

The choice for *PE(t)* can be based on the report titled "2002 – 2012 Electricity Outlook Report" published by the Commission, which provides commercial electric rate projections to the year 2012 (CEC 1). For projections beyond 2012, the analyst needs to extend the Commission projections. It is recommended that similar growth assumptions as the Commission has used up to the year 2030 be used for the extension beyond 2012.

The cumulative expenditure savings associated with reductions in electricity use over the time horizon of the project (commercialization year to 2030) can be expressed as:

$$TCE = \sum_{t=T_c}^{T_e} CE(t) \tag{6-10}$$

The cumulative expenditure savings resulting from peak demand reductions over the time horizon of the project (commercialization year to 2030) can be expressed as:

$$TCD = \sum_{t=T_c}^{T_e} CD(t) \qquad (6\text{-}11)$$

To be able to sum the terms *CE(t)* and *CD(t)* in Equations (6-10) and (6-11), the terms must be expressed in constant dollars.

6.3 Data Model for Integrated Electric Energy/Power Impact Calculation Methodology

Section 6.2 documented the equations for calculating impact estimates of new products. This section describes the data model for the integrated energy and power impact calculations. The data model specifies the variables in which the impact estimates are expressed (see Table 6-1).

Table 6-1: Variables for Impact Estimates

Field Number	Description	Units
1	Model ID	-
2	Product ID	-
3	Starting Year	-
4	Estimate for electricity savings per year, *SE(t)*	kWh/y
5	Estimate for peak demand reduction per year, *SD(t)*	kW
6	Estimate for expenditure savings on electricity per year, *CE(t)*	$
7	Estimate for expenditure savings on peak demand per year, *CD(t)*	$
8	Estimate for total energy savings over study horizon in constant dollars, *TSE*	kWh
9	Estimate for total expenditure savings on energy over study horizon in constant dollars, *TCE*	$
10	Estimate for total expenditure savings on peak demand over study horizon in constant dollars, *TCD*	$

6.4 Summary

In this section, we have described the basic equations for calculating impact estimates. The equations are based on constituents discussed in earlier sections. In the next section, we will exercise the assessment framework for three examples utilizing the equations discussed previously.

7 Exercising the Assessment Framework Using Example Products

7.1 Introduction

As described in Section 2 and shown in Figure 2-1, the assessment framework consists of four individual steps. In this section, we discuss each step for three individual scenarios that utilize different methods for market penetration. Selected were six example products for which we illustrate the assessment framework. The example products are briefly introduced below with more detailed information in Appendix A. To provide a roadmap for the exercise, we outline the four steps as follows:

- **Step 1:** Product characterization. Product characterization defines the product with respect to its applicability or deployment requirements, which determine the market segment, and its cost-performance or improvement characteristics. The applicability specifics of a product are key input for identifying the applicable market segment. The cost-performance characteristics describe the product's performance and as a result its competitiveness among other competing products. The performance or improvement capabilities are used in the final impact analysis.
- **Step 2:** Market segmentation. Given the deployment requirements from Step 1, and data that describe the current building stock, the market segment for the new product can be determined, and the corresponding market size can be estimated. It is common that several data sources are required to fully and adequately estimate all indicators of market size of interest. For the exercise of this assessment framework, we show how to benchmark (or calibrate) the measures of impact for a common base year. Once all market size measures are established for the base year, they need to be projected into the future (in our assessment we chose to project to 2030).
- **Step 3:** Market penetration. Two market penetration approaches are discussed: 1) the user-defined method using a logit function and expert judgment, and 2) a model-based method that explicitly models market competition of multiple competing products (the Peterka model). The model-based method uses the cost-performance characteristics from Step 1.
- **Step 4:** Analysis. This final step of the assessment framework uses the projections of market size (Step 2), the estimates of market penetration (Step 3), and the performance characteristics (Step 1), to estimate impacts.

The ensuing discussion leads the reader from Step 1 through Step 4 for the six example products.

7.2 STEP 1: Product Characterization of Example Products

7.2.1 Rationale for Selecting the Example Products

All products selected for exercising the assessment framework were chosen from projects that are part of Architectural Energy Corporation's (AEC's) research program. This allowed us easy access to the principal investigators and the assurance of their collaborations in characterizing potential commercial products as an outcome of their research project.

To demonstrate the user-defined market penetration approach using the logit function and expert judgment, we needed one single product that currently does not have any competitor in the market place. As discussed in Section 5.3, the user-definable approach using the logit function model is appropriate for the impact assessment of brand-new products that do not yet have a market competitor. We chose the Whole-Building Diagnostician (WBD) as a unique and novel diagnostic tool for that purpose.

To illustrate market penetration under competition with multiple players, we selected two scenarios that demonstrate somewhat different uses of the Peterka model and the impact analysis. The first scenario represents a retrofit case in which the competing products are considered retrofitable accessories to existing HVAC equipment. The two products chosen are: 1) an add-on product that is based on Purdue University's vapor compression diagnostics tool (from Project 2.1) and 2) an add-on product that is based on the outdoor-air economizer diagnostician developed by Battelle (studied in Project 2.4).

The second scenario illuminates the use of the assessment framework for products that are likely to be deployed in new equipment. We defined a product that is based on Purdue University's demand-controlled ventilation research (from Project 3.1). We assumed the technology would be embedded in the controller of new packaged HVAC units. The competing technology is today's best conventional packaged HVAC unit without the demand-control ventilation feature.

The sections that follow provide an overview of six example products. They are grouped according to how their impacts are estimated using the assessment framework.

7.2.2 Product 1: WBD

The Whole-Building Diagnostician (WBD) is a modular diagnostic software system that provides detection and diagnosis of common problems associated with the operation of heating, ventilating, and air-conditioning (HVAC) systems in commercial buildings. The WBD tracks overall building energy use, monitors the performance of air-handling units, and detects problems with outside-air control. The WBD consists of two primary diagnostic modules, the Whole-Building Energy (WBE) module and the Outdoor-Air Economizer diagnostician (OAE). The WBE tracks the energy consumption of the whole-building and its major systems (e.g., chillers or packaged units), identifies when consumption anomalies occur, and alerts the user (e.g., a building operator) to these anomalies. The OAE module monitors the performance of air handlers, detects faults in air-handling performance, and then provides information on likely causes of the faults and potential solutions.

Energy savings are difficult to attribute directly to the WBE module; however, air-handling problems fixed because the OAE has detected them and provided information to building staff can be attributed to it. Most problems detected by the OAE go undetected when they occur during ordinary operation. This is substantiated by testing of this tool in the field and years of field observations by many different investigators. The information provided by the OAE diagnostician should alert building staff to problems they would otherwise not detect and provide information to enable the staff to fix these problems.

In this characterization, we only estimate savings for the OAE module of the WBD. Although, studies show that monitoring energy use does inspire savings, data available at this time are too sketchy for us to attribute savings directly to the WBE module. As a result, savings from use of the WBD are likely to exceed our estimates and paybacks are likely to be shorter.

The WBD software operates on a PC that is used as part of a building automation system. The WBD can be used on buildings of all sizes, all vintages, and at essentially all locations in California.

More detailed characterization data of the WBD can be found in Appendix: Definition of Example Products.

7.2.3 Market Penetration Modeling: Retrofit Case

7.2.3.1 Product 2: AFDD1

The AFDD1 system is an automated fault detection and diagnostic system (AFDD) for retrofit onto package rooftop air-conditioning systems. AFDD1 is based on technology developed by Purdue University under Project 2.1. It provides monitoring capabilities and detection and diagnosis of air-side and refrigerant-side problems. These problems include both control problems (e.g., incorrect set points and incorrectly implemented economizing strategies) and hardware faults (e.g., stuck dampers, low or high compressor charge, and failed fans). The system continuously monitors sensors at various points on a packaged unit and provides alarms and diagnoses when problems are detected. Reports can be provided online on a website (to the building owner, building operator, or a central service provider) if the system is connected to a network or to a technician using a local interface (e.g., a PDA). The product includes all necessary components of measurements, diagnostics, monitoring, and alarm notification. The results are reported to building operation staff or service companies through a networked computer.

Because the AFDD1 detects problems and provides that information to operation staff, the resulting problem fixing and associated savings can be attributed to it. Most problems detected by the AFDD1 go undetected until periodic service by a technician (if done regularly). This is substantiated by evidence of these faults in the field by many different investigators. The information provided by the AFDD1 should alert building operation staff or service providers to problems they likely otherwise would not detect and troubleshoot until the unit is inspected by a technician.

This characterization applies to the AFDD1 used in an on-line manner with results provided in real time to an on-site or off-site computer. The AFDD1 can be used on packaged units of any size and any vintage, buildings of all sizes, all vintages, and at essentially all locations in California. More detailed characterization data of the AFDD1 product can be found in Appendix: Definition of Example Products.

7.2.3.2 Product 3: AFDD2

The AFDD2 is an automated fault detection and diagnostic system for retrofit onto package rooftop air-conditioning systems. AFDD2 is based on the technology demonstrated by Battelle under Project 2.4. It provides monitoring capabilities and detection and diagnosis of air-side problems with unit operation. These problems include both control problems (e.g., incorrect set points, incorrectly implemented economizing strategies, and bad schedules) and hardware faults (e.g., failed sensors, stuck dampers, and failed fans). The system continuously monitors sensors at various points on a packaged unit and provides alarms and diagnoses when problems are found. The product includes all necessary components for measurements, diagnostics, monitoring, and alarm notification. The results are reported to an on-site computer through a serial or network connection.

Because the AFDD2 detects problems and provides that information to building staff, the resulting problem fixing and associated savings can be attributed to it. Most problems detected by the AFDD2 go undetected until periodic servicing by a technician (if done regularly or at all). This is substantiated by evidence of these faults in the field by many different investigators. The information provided by the AFDD2 should alert building staff to problems they likely otherwise would not detect and troubleshoot until the unit is inspected by a technician.

This characterization applies to the AFDD2 used in an on-line manner with results provided in real time to building operation staff. The AFDD2 can be used on packaged units of any size and any vintage, buildings of all sizes, all vintages, and at essentially all locations in California where air-conditioning is used. More detailed characterization data of the AFDD2 product can be found in Appendix: Definition of Example Products.

7.2.3.3 Product 4: Reference Technology

The market penetration model requires a reference technology, which was defined as a representative packaged rooftop HVAC unit as it exists in the current stock without these fault detection and diagnostic capabilities.

7.2.4 Market Penetration Modeling: New-Equipment Case

7.2.4.1 Product 5: EPRUC

EPRUC (Enhanced Packaged Rooftop Unit Controller) is based on Purdue University's Project 3.1. The EPRUC is a new controller for rooftop packaged air-conditioning units that provides for demand-control ventilation (DCV). This controller is a direct replacement for package-unit controllers commonly installed today during manufacture of rooftop units. The new controller will determine the necessary ventilation rates, which prevents over ventilation. The EPRUC enables use of DCV based on CO_2 sensors in the zones that the package unit serves.

This characterization applies to the EPRUC used on new rooftop package air-conditioning units. The controller is not intended for retrofit applications. The EPRUC can be used on packaged units of any size installed on buildings of all sizes, all vintages, and at essentially all locations in California where air-conditioning is used. The new controller affects cooling and electric-heating consumptions. More detailed characterization data of the EPRUC product can be found in Appendix: Definition of Example Products.

To model the competitiveness of the EPRUC product for new-equipment applications, we selected a commonly used 25-ton packaged HVAC unit as the host equipment. The size of the host equipment has an impact on competitiveness of this product and will be discussed later in Section 7.4.

7.2.4.2 Product 6: Reference Model

The market penetration model requires a reference technology, which represents today's best available technology for a package HVAC unit of the same size (25 tons) without the EPRUC technology. More detailed information on the reference model is provided in Appendix: Definition of Example Products.

7.3 STEP 2: Estimate Market Segment Size

7.3.1 Data Source and Assumptions

Pacific Gas and Electric Company's (PG&E) service territory was selected as the geographic market for these examples. PG&E's service territory was selected primarily because high-resolution survey data on commercial end-uses was available in electronic format. While the examples are specific to PG&E's data set, a similar analysis of market size for a particular product could be performed using data from any highly disaggregated commercial end-use database for any geographic region. We anticipate that the Commission will utilize data from the statewide commercial end-use database that is currently under development for such assessments in the future.

7.3.1.1 PG&E CEUS Database

In 1996 and 1997, PG&E collected commercial building data using an on-site survey of almost 1,000 commercial customers chosen to represent the population of commercial buildings in the PG&E electric service territory. This survey collected data on the building structures, business operations, equipment types, fuel choices, and operating schedules (PG&E 1999). This survey results were compiled in a database using SAS (SAS 2003) and later translated to Microsoft Access (Microsoft 2003a).

To project from the survey sample to the total population of commercial customers two statistical weights are used. One sample weight was used to estimate the total number of premises and other information solely related to the number of premises in the population. Another sample weight was used to estimate energy consumption for the entire population of facilities. These weights are simply factors by which to multiply individual survey responses to estimate population-level results. They represent the fraction of the population represented by an individual survey response. Both weights were established in the analysis of the 1996 CEUS data by PG&E (PG&E 1999).

The market for Product 1 is defined as any electrical HVAC system with controls. The sample from the CEUS database included all facilities that had electrical cooling or heating loads with a preexisting control system.

The query extracted all qualifying individual facility records from the database. To represent the relationship of a particular facility record to the entire population of facilities in the PG&E service area, survey-sample weights must be applied. Each record contains relevant information used for estimating the market size, as shown in Table 7-1.

Table 7-1: Data Available in CEUS Relevant for Estimating Total Potential Market Size

Characteristic	Description
Number of buildings	total number of buildings at the facility
Facility area	total square footage of facility
Total cooling capacity	sum of cooling capacity of all individual HVAC units at the facility
Total number of HVAC units	total number of HVAC units at the facility
Annual energy consumption	total annual electricity consumption (in kWh) at the facility
Facility type	specified as one of nine building types: office, restaurant, retail, food store, warehouse, school, college, hospital, hotel, or miscellaneous
Sampling weight	Multipliers that permit the survey responses to be scaled to values approximating values for the population of buildings.

The detailed sequence of the SQL queries for extracting facilities meeting the criteria for the market segment for Product 1 is listed in Kintner-Meyer et al. 2003.

7.3.1.2 Assumptions for the Use of CEUS

Many assumptions were made about the data in the CEUS database. Assumptions were necessary to deal with missing or inconsistent data in the database. For example, respondents sometimes fail to answer all relevant questions on the survey, or they provide answers that are not consistent with either the characteristics of their building or other related answers. However, because of the small individual impact of each assumption and the large number of them, we only supply a couple examples of the technical assumptions here. The details of how incomplete data records were eliminated are illustrated in the supplemental report titled "Supplement to Final Report on Project 6.6 – Development of Assessment Framework" (Kintner-Meyer et al. 2003).

The CEUS surveyed customers by facility. Facilities are made up of one or more buildings. Customers varied widely in their responses – some choosing to respond at the facility level and others choosing to respond at the building level or some mix of these levels. We used the most detailed data available for each facility.

A number of the responses had detailed descriptions of chiller size and schedule but listed the number of units as zero. In these cases, we assumed a value of one for the number of units.

In some cases, respondents did not provide building types for each building in a facility, but rather assigned building type descriptions to floor areas at the facility level. In such cases, the entire facility was classified as the building type with the largest floor area. If building-type data were not provided at the facility level, then the facility was assumed to be the same type as the first building record found to have a building type within the facility. Further detail on value range testing can be found in Kintner-Meyer et al. 2003.

7.3.1.3 Analyze the Data Gaps

Six pieces of information are required for the impact estimates for a product. These six items are listed in Table 7-2 along with the data that are available directly from the CEUS database.

Table 7-2: Comparison of Data Needed for the Assessment and Data Available in CEUS

No.	Data Needed (for market segment)	Data available from CEUS (for buildings in the survey)	Methods to fill data gaps
1	Number of buildings	Directly available from CEUS	Not needed.
2	Floor space of buildings	Directly available from CEUS	Not needed
3	Installed units of specified equipment	Directly available from CEUS	Not needed.
4	Electricity consumption by specified end-use(s) (e.g., cooling)	Electricity consumption [kWh] by whole building or facility	Attribute total facility consumption to end-uses according to data provided by the Commission (CEC 2000)
5	Peak electric demand by specified end-use(s) (e.g., cooling)	Electricity consumption [kWh] by whole building or facility	1st, attribute total energy to end-uses as for no. 4; 2nd, determine peak coincidence factors according to Xenergy (2002)
6	Expenditures on electricity	Not available	PG&E-specific retail commercial rates provided by the Commission. Expenditures determined by multiplying rates by consumption.

Note: CEUS differentiates between facilities and buildings. Facilities are aggregations of buildings. Buildings are described in great detail in terms of HVAC infrastructure, while facilities are described by aggregated measures such as total electricity consumption and total floor area.

7.3.1.4 Options to Fill Data Gaps

7.3.1.4.1 Cooling and heating energy consumption

The Commission provided Nexant with a spreadsheet that breaks down annual statewide energy consumption by end-use and building type (CEC 2000). These factors are provided by building type to maintain consistency with the way the data are collected in the CEUS and used by the Commission. The list includes values for both cooling and heating for each building type, which can be used to determine an average end-use energy factor, or the fraction of a building type's overall energy use that goes to each end-use. These factors are shown in the Table 7-3.

Table 7-3: Statewide Annual Energy End-Use Factors

Building Type	Ventilation	Cooling
Large Offices	0.1319	0.1847
Restaurants	0.1237	0.1076
Retail Stores	0.0939	0.1261
Food Stores	0.0690	0.0559
Warehouses	0.0590	0.0426
Schools	0.1185	0.1155
Colleges	0.1543	0.2263
Health Care	0.0729	0.2222
Hotels/Motels	0.0712	0.1867
Misc.	0.1280	0.2103

These end-use energy factors can be used to estimate annual consumption by end-use, E_u, as follows:

$$E_{u,i} = \alpha_{u,i} \; E_i \; , \qquad (7\text{-}1)$$

where

$E_{u,i}$ is the annual electricity consumed by end-use u in all buildings of type i,
$\alpha_{u,i}$ is the energy factor, which is the average fraction of total annual electricity consumed by end-use u in all buildings of type i (from Table 7-3),
E_i is the total annual electricity consumed by all buildings of type i (e.g., offices),
u is the end-use (e.g., cooling),
i is the building type (e.g., all offices within the population).

7.3.1.4.2 Electric Peak Demand for Cooling and Heating

We estimate the electric peak demand using an approach outlined in the *California Statewide Commercial Sector Energy Efficiency Potential Study* prepared by Xenergy for PG&E (Xenergy 2002). This study provides a summer peak-load ratio for commercial end-uses. The ratio represents the fraction of the total annual energy consumption by the end-use that occurs during the peak period. The ratio is used to estimate the average summer peak-period consumption from the annual end-use electricity consumption. This average peak consumption can then be divided by the number of peak hours, 722 for the study cited, to yield an average peak demand.

Values of these ratios are provided by end-use and building type statewide for California. The values for cooling and ventilation are shown in the Table 7-4.

Table 7-4: Statewide Summer Peak Load Ratio

Building Type	Ventilation	Cooling
Large offices	0.1463	0.5093
Restaurants	0.1405	0.2776
Retail stores	0.1624	0.4070
Food stores	0.0984	0.2892
Warehouses	0.1547	0.3973
Schools	0.1720	0.6345
Colleges	0.1292	0.4817
Health care	0.1446	0.4393
Hotels/motels	0.1072	0.5467
Misc.	0.1230	0.4445

Electric demand can be estimated from annual electricity consumption using the end-use energy factor and the load shape factor as follows:

$$P_{u,i} = \frac{(\alpha_{u,i}\ \beta_{u,i}\ E_i)}{h}\ , \qquad (7\text{-}2)$$

where

$P_{u,i}$ is the electric peak demand of end-use u in all buildings of type i,
E_i is the annual electricity consumed in buildings of type i,
$\alpha_{u,i}$ is the average fraction of electricity consumed annually by end-use u in buildings of type i,
$\beta_{u,i}$ is the average fraction of the annual end-use energy consumption that occurs during the summer peak period by end-use u in buildings of type i (i.e., the summer peak load ratio for end-use u in buildings of type i; see Table 7-4),
h is number of hours in the summer peak period, 722 summer peak hours as reported in CEC 2000 – this assumes that the statewide average applies to the PG&E service territory in the absence of a PG&E-specific number,
u is the end-use (e.g., cooling),
i is the building type (e.g., all offices within the selected population).

For example, to find the peak demand for office buildings associated with cooling services, we assume that, based on state averages and preliminary analysis of CEUS data:

1. $\alpha_{cooling,\ office}$ = 0.18
2. $\beta_{cooling,office}$ = 0.51
3. $E_{cooling,office}$ = 8.0 x 10^6 MWh (rounded from CEUS Data)
4. h = 722 hours.

Then,

$$P_{(\text{cooling, office})} = \frac{8\times10^6\, MWh \times 0.18 \times 0.51}{722\, h} = 1017\, MW.$$

The total applicable peak cooling demand of each building type can be estimated in this way and summed to the total commercial peak load associated with cooling using the equation:

$$P_u = \sum_i P_{u,i}\ , \qquad (7\text{-}3)$$

where

$P_{u,i}$ is the total electric peak demand of end-use u,
$P_{u,i}$ is the electric peak demand of end-use u in buildings of type i, and
i is the building type (e.g., all offices within the selected population).

7.3.1.5 Caveats

Benefits of using these energy factors for this analysis include easy availability and they do not require manipulation or additional assumptions to be used. The principal drawback to using these factors is that they are highly aggregated numbers and may not be as representative of some of the smaller populations we are analyzing (e.g., only buildings with energy management controls). We are applying statewide factors to a PG&E subgroup, which does not cover all climate zones and has different distributions of buildings by climate zone than the state as a whole. The factors apply to all cooling types while in some cases we are analyzing just packaged units. These assumptions are required to assess impacts using the limited data available today, but as more detailed data become available in the future, such assumptions can be replaced by real data.

7.3.1.6 Expenditures on Electricity

Although data on the consumption of electricity was collected in the CEUS, expenditures for electricity were not collected. To estimate expenditures for electricity attributable to the buildings of survey participants requires the application of 1996 commercial rates for the PG&E service area, which are available from the Commission. The measured monthly electricity usage can be multiplied by the average commercial rate to approximate expenditures on electricity during the study period (1996). Similarly, we estimate the demand charges applicable for commercial customers.

7.3.2 Market Segment Size for Product 1

Using PG&E's commercial end-use survey (CEUS) database and the methodology described in the previous sections, we estimated measures of the size of the market segment at a point-in-time (1996) for each of the example products. Once the market segment size has been determined for 1996, it must be projected over the analysis projection period. This generally requires a two-step approach, where first the 1996 data are projected forward in time to a base year and to benchmark with some more recent data (if available). Then, they are projected from the base year (2001) to each year in the study out to the end of the forecasting horizon (2030).

After calibrating the 1996 CEUS data to the base year, 2001, the market segment size was forecasted to the year 2030 for each measure of market size. The process of market forecasting beyond the base year used growth rates for energy price, demand charges, and commercial floor space, which were obtained from the Commission. The growth rate for commercial floor space was used as a estimate of the growth rates for the number of buildings and the number of packaged units, assuming no structural changes in the size distribution of new buildings and the relation of commercial floor space to packaged units servicing the floor area would occur.

Table 7-5 provides the historic market size data as extracted from CEUS for 1996 and the projection to 2030 for Product 1.

Table 7-5: Estimated Market Segment Size for Product 1 for 1996-2030.

Year	Electricity Consumption (GWh)	Electric Peak Demand (MW)	Electricity Cost ($Million)	Affected Floor Area (ft^2)	Affected HVAC Units	Affected Buildings
1996	3,033.3	1,250.7	310.0	566,305	14,838	7,864
1997	3,063.7	1,263.2	305.5	571,968	14,986	7,943
1998	3,094.3	1,275.9	306.4	577,688	15,136	8,022
1999	3,140.7	1,295.0	311.0	586,353	15,363	8,142
2000	3,187.8	1,314.4	315.7	595,148	15,594	8,265
2001	3,235.7	1,334.1	516.9	604,076	15,828	8,389
2002	3,284.2	1,354.2	539.3	613,137	16,065	8,514
2003	3,333.4	1,374.5	504.7	622,334	16,306	8,642
2004	3,383.5	1,395.1	472.3	631,669	16,551	8,772
2005	3,434.2	1,416.0	494.3	641,144	16,799	8,903
2006	3,485.7	1,437.3	517.2	650,761	17,051	9,037
2007	3,538.0	1,458.8	541.3	660,522	17,307	9,172
2008	3,591.1	1,480.7	566.4	670,430	17,566	9,310
2009	3,644.9	1,502.9	592.7	680,487	17,830	9,450
2010	3,699.6	1,525.5	620.3	690,694	18,097	9,591
2011	3,755.1	1,548.3	649.1	701,054	18,369	9,735
2012	3,811.4	1,571.6	679.2	711,570	18,644	9,881
2013	3,868.6	1,595.1	710.8	722,244	18,924	10,029
2014	3,926.6	1,619.1	743.8	733,077	19,208	10,180
2015	3,985.5	1,643.3	778.4	744,074	19,496	10,333
2016	4,045.3	1,668.0	814.6	755,235	19,788	10,488
2017	4,106.0	1,693.0	852.4	766,563	20,085	10,645
2018	4,167.6	1,718.4	892.0	778,062	20,386	10,805
2019	4,230.1	1,744.2	933.5	789,733	20,692	10,967
2020	4,293.6	1,770.3	976.8	801,579	21,003	11,131
2021	4,358.0	1,796.9	1,022.2	813,602	21,318	11,298
2022	4,423.3	1,823.9	1,069.7	825,806	21,637	11,468
2023	4,489.7	1,851.2	1,119.4	838,193	21,962	11,640
2024	4,557.0	1,879.0	1,171.4	850,766	22,291	11,814
2025	4,625.4	1,907.2	1,225.9	863,528	22,626	11,991
2026	4,694.8	1,935.8	1,282.8	876,481	22,965	12,171
2027	4,765.2	1,964.8	1,342.4	889,628	23,310	12,354
2028	4,836.7	1,994.3	1,404.8	902,972	23,659	12,539
2029	4,909.2	2,024.2	1,470.1	916,517	24,014	12,727
2030	4,982.8	2,054.6	1,538.4	930,265	24,374	12,918

7.3.3 Market Segment Size for Retrofit Products (Products 2 and 3)

Products 2 and 3 are applicable to any packaged unit (with and without EMCS) and require a CEUS query that extracts all records corresponding to facilities with packaged-unit HVAC systems. A query that extracted these records was developed and is described in Kintner-Meyer et al. 2003. The market size data for 1996 extracted from the

CEUS database were then benchmarked to the base year 2001 and then projected to 2030. The results are shown in Table 7-6.

Table 7-6: Projected Market Segment Size for Products 2 and 3 for 1996-2030.

Year	Electricity Consumption (GWh)	Electric Peak Demand (MW)	Electricity Cost ($Million)	Affected Floor Area (ft^2)	Affected HVAC Units	Affected Buildings
1996	4,355.3	1,916.2	445.9	1,209,943	197,530	168,195
1997	4,398.9	1,935.3	450.7	1,222,042	199,505	169,877
1998	4,442.9	1,954.7	452.4	1,234,263	201,500	171,576
1999	4,509.5	1,984.0	459.6	1,252,777	204,523	174,149
2000	4,577.2	2,013.8	466.9	1,271,568	207,591	176,762
2001	4,645.8	2,044.0	756.3	1,290,642	210,705	179,413
2002	4,715.5	2,074.6	789.2	1,310,002	213,865	182,104
2003	4,786.2	2,105.7	740.2	1,329,652	217,073	184,836
2004	4,858.0	2,137.3	694.4	1,349,596	220,329	187,608
2005	4,930.9	2,169.4	724.9	1,369,840	223,634	190,422
2006	5,004.9	2,201.9	757.0	1,390,388	226,989	193,279
2007	5,079.9	2,235.0	790.7	1,411,244	230,393	196,178
2008	5,156.1	2,268.5	827.4	1,432,412	233,849	199,121
2009	5,233.5	2,302.5	865.8	1,453,899	237,357	202,107
2010	5,312.0	2,337.1	906.0	1,475,707	240,917	205,139
2011	5,391.7	2,372.1	948.1	1,497,843	244,531	208,216
2012	5,472.5	2,407.7	992.2	1,520,310	248,199	211,339
2013	5,554.6	2,443.8	1,038.2	1,543,115	251,922	214,509
2014	5,637.9	2,480.5	1,086.5	1,566,262	255,701	217,727
2015	5,722.5	2,517.7	1,136.9	1,589,756	259,537	220,993
2016	5,808.4	2,555.4	1,189.7	1,613,602	263,430	224,308
2018	5,983.9	2,632.7	1,302.8	1,662,373	271,392	231,088
2019	6,073.7	2,672.2	1,363.3	1,687,309	275,463	234,554
2020	6,164.8	2,712.2	1,426.7	1,712,618	279,595	238,072
2021	6,257.2	2,752.9	1,492.9	1,738,308	283,788	241,643
2022	6,351.1	2,794.2	1,562.3	1,764,382	288,045	245,268
2023	6,446.4	2,836.1	1,634.8	1,790,848	292,366	248,947
2024	6,543.1	2,878.7	1,710.8	1,817,711	296,751	252,681
2025	6,641.2	2,921.9	1,790.2	1,844,976	301,203	256,471
2026	6,740.8	2,965.7	1,873.4	1,872,651	305,721	260,318
2027	6,841.9	3,010.2	1,960.4	1,900,741	310,307	264,223
2028	6,944.6	3,055.3	2,051.5	1,929,252	314,961	268,187
2029	7,048.7	3,101.2	2,146.8	1,958,191	319,686	272,209
2030	7,154.5	3,147.7	2,246.5	1,987,563	324,481	276,293

7.3.4 Market Segment Size for New-Equipment Products (5 and 6)

Products 5 and 6 apply to any installation of a new packaged unit that includes an economizer. Current non-residential energy efficiency standards (CEC 2001) include economizer cycles on all HVAC systems over 6 tons as a prescriptive option to meeting the standards. New standards will be set in July 2003 to take effect in 2005. Our analysis assumes these new standards will be as strict, if not stricter, regarding efficiency improvements from economizers. It can be assumed that the majority - if not all - of the new installations of packaged units will have economizer cycles to be compliant with the standards. For the new-equipment scenario, we have assumed that all new packaged units will have economizers and could potentially host Product 5 (EPRUC).

Thus the annual potential market for products under the new-equipment scenario in any given year is all new packaged units being installed in that year. This includes units installed in new construction as well as all units replaced in the existing building stock of the defined market segment in that year. To determine the market for Products 5 and 6, the results of the retrofit scenario products query, which includes all buildings with package units, is multiplied by the replacement factor to obtain the number of units replaced each year. In addition, we estimated the market segment of new construction for each year using the Commission's demand forecast.

The replacement factor is the fraction of facilities in which existing packaged units are replaced in a given year. In our analysis, we specify a 15-year life cycle, based on ASHRAE estimates of average service life (ASHRAE 1999). The new construction contribution to the market segment is based on annual growth factors from the Commission demand forecast for the period 2000 to 2010. For the years 2010 to 2030, we assume continuing growth at the same rate (1.5% per year) as the Commission forecast for the year 2010.

The potential annual market size for Products 5 and 6 is determined using:

$$AM_t = TU_t * (NCF_t + RF_t)\,, \tag{7-4}$$

where

AM_t	is the annual market in year t,
TU_t	is the number of packaged units in the facilities in year t,
NCF_t	is the new construction factor in year t,
RF_t	is the replacement factor in year t, and
t	is the year

Table 7-7 shows annual market size for the year 1996 as obtained from the CEUS database and projections through 2030. We assume for the year 1996 that new construction is implicit in the CEUS 1996 survey.

Table 7-7: Projected Market Segment Size for Products 5 and 6 for 1996-2030.

Year	Electricity Consumption (GWh)	Electric Peak Demand (MW)	Electricity Cost ($Million)	Affected Floor Area (ft^2)	Affected HVAC Units	Affected Buildings
1996	1,563.9	688.1	160.1	99,215	16,197	13,792
1997	1,579.5	694.9	161.8	100,207	16,359	13,930
1998	1,595.3	701.9	162.5	101,209	16,523	14,069
1999	1,619.3	712.4	165.0	102,727	16,770	14,280
2000	1,643.6	723.1	167.6	104,268	17,022	14,494
2001	1,668.2	733.9	271.6	105,832	17,277	14,712
2002	1,693.2	745.0	283.4	107,420	17,536	14,933
2003	1,718.6	756.1	265.8	109,031	17,799	15,157
2004	1,744.4	767.5	249.3	110,667	18,066	15,384
2005	1,770.6	779.0	260.3	112,327	18,337	15,615
2006	1,797.1	790.7	271.8	114,011	18,613	15,849
2007	1,824.1	802.5	283.9	115,722	18,892	16,087
2008	1,851.5	814.6	297.1	117,457	19,175	16,328
2009	1,879.2	826.8	310.9	119,219	19,463	16,573
2010	1,907.4	839.2	325.3	121,008	19,755	16,821
2011	1,936.0	851.8	340.5	122,823	20,051	17,074
2012	1,965.1	864.5	356.3	124,665	20,352	17,330
2013	1,994.5	877.5	372.8	126,535	20,657	17,590
2014	2,024.5	890.7	390.1	128,433	20,967	17,854
2015	2,054.8	904.0	408.2	130,360	21,281	18,121
2016	2,085.7	917.6	427.2	132,315	21,601	18,393
2017	2,116.9	931.4	447.1	134,300	21,925	18,669
2018	2,148.7	945.3	467.8	136,314	22,253	18,949
2019	2,180.9	959.5	489.5	138,359	22,587	19,233
2020	2,213.6	973.9	512.3	140,434	22,926	19,522
2021	2,246.8	988.5	536.1	142,541	23,270	19,815
2022	2,280.5	1,003.3	561.0	144,679	23,619	20,112
2023	2,314.7	1,018.4	587.0	146,849	23,973	20,414
2024	2,349.5	1,033.7	614.3	149,052	24,333	20,720
2025	2,384.7	1,049.2	642.8	151,288	24,698	21,031
2026	2,420.5	1,064.9	672.7	153,557	25,068	21,346
2027	2,456.8	1,080.9	703.9	155,860	25,444	21,666
2028	2,493.6	1,097.1	736.6	158,198	25,826	21,991
2029	2,531.0	1,113.6	770.9	160,571	26,213	22,321
2030	2,569.0	1,130.3	806.7	162,980	26,607	22,656

7.4 STEP 3: Market Penetration

7.4.1 Expert Opinion Using the Logit Function Model for Product 1

Knowing the market segment size (8642 buildings in 2003; see Table 7-5) and the product characteristics, market experts can postulate a market penetration trajectory based on their judgments. The experts must consider the features and benefits of the WBD compared to the likely costs and other trade-offs in specifying the three parameters of the logit function. Table 7-8 provides hypothetical expert opinion about penetration of the WBD as an on-line tool (product 1).

Table 7-8: Hypothetical Expert Estimates of Market Potential for the WBD in the PG&E service territory

Expert	Likely Maximum Market Share ***K***	Time to Half of Maximum Market Share Δt	Time Between 10% and 90% of Maximum Market Share t_m
Expert 1	60%	5 yrs	7 yrs
Expert 2	75%	8 yrs	9 yrs
Expert 3	50%	9 yrs	10 yrs

Using the values of Table 7-8, penetration curves can be graphed, as shown in Figure 7-1.

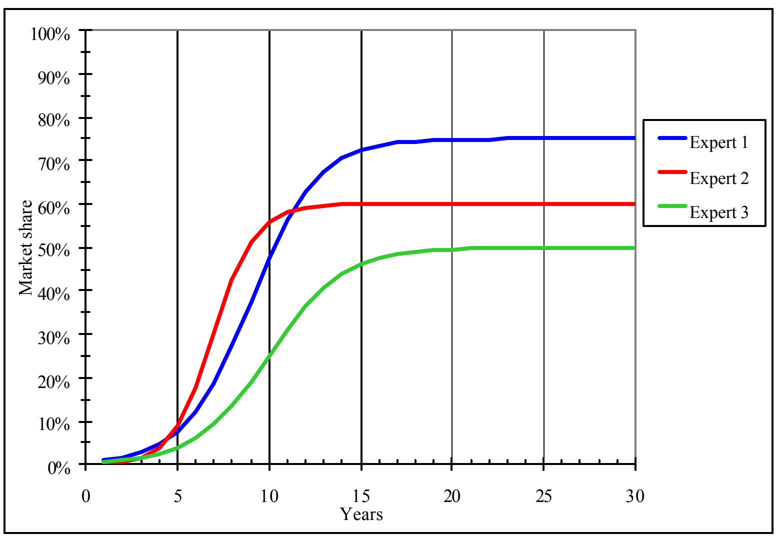

Figure 7-1: Logit Functions Resulting from the parameter estimates in Table 7-8.

Figure 7-1 illustrates three alternative hypothetical views of the WBD's market penetration. The expert opinions bound the maximum market share between 50 and 75 percent of the identified market segment. They differ on the path of market penetration, indicated by the shape of the alternative "S" curves, characterized by their judgments regarding the variables.

In this case of hypothetical expert opinion, several options for interpretation are available to the analyst. The analyst can pick one of the "expert" opinions based on experience and market knowledge. The analyst could construct a fourth penetration function based on choosing selected parameters provided by each of the experts. The analyst might instead construct a composite "S" curve reflecting the average of the parameters supplied by the three experts. For example, this last approach can be performed by taking the averages ($\overline{\kappa}, \overline{\Delta t}, \overline{t_m}$) of the experts' parameter estimates to create the composite function shown in Figure 7-2 by the "Analyst" curve.

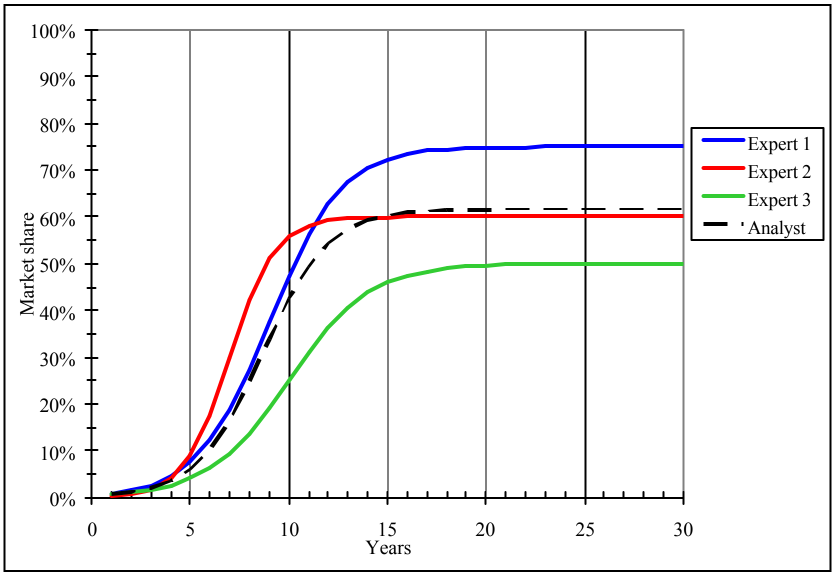

Figure 7-2: Penetration Functions based on Expert Opinion with the Expert Composite Average Function Overlaid (labeled "Analyst").

7.4.2 Peterka Model

As noted in Section 5.4, the Peterka model requires three inputs for each competitor. Peterka defines them as: (1) specific investment, (2) specific production cost, and (3) initial market share. A fourth parameter, production growth rate, uniformly applies to all competitors. For the purpose of this example, we rename the input parameters to be more intuitive for the example products and applications discussed in this report. *Specific investment* is the *specific capital cost* of a piece of equipment or product normalized by the size of the equipment, expressed in tons of refrigeration or kW. The *specific production cost* is the *annual operation and maintenance (O&M) cost* associated with providing a year's worth of service from that same piece of equipment also normalized by the size of the equipment. The sum of the initial market share across the competing products must equal unity. This means that for new products, some existing reference product must also be characterized as one of the competitors.

7.4.3 Development of Model Parameters

Specific capital costs are those costs associated with acquiring the example products normalized by the size of the host equipment. For the purpose of this example, we use a gas and electric rooftop unit with an arbitrary cooling capacity of 25 tons of refrigeration as the host equipment. We will discuss later, for the retrofit products, that the size of the host equipment is crucial for determining the market penetration.

Annual O&M cost represents all cost associated with the operation of a piece of equipment over a 1-year period. The calculation of O&M costs requires several pieces of exogenous information and assumptions including: operational schedules, system energy efficiencies, and cost of energy used to deliver the service.

Table 7-9 lists the exogenous variables required for the computation of the Peterka model input parameters. The first section characterizes the host equipment for the products. For the purpose of this example, we use a gas and electric rooftop unit with an arbitrarily-selected cooling capacity of 25 tons of refrigeration. The incremental cost of rooftop units is estimated to be approximately $1000/ton. Other size and performance parameters chosen in Table 7-9 are typical for 25-ton rooftop units with gas heaters.

To calculate the annual operating cost, we chose operating schedules that are representative of interior climates. The electricity rate applied in this example is an average rate of PG&E's Schedule E-19S, Medium General Demand-Metered Time-Of-Use Service (PG&E 2002a) secondary service for customers exceeding 499 kW in electric demand. We used the mean between the summer peak rate of 8.77 cents/kWh and the summer off-peak rate of 5.81 cents/kWh, which is 7.3 cents/kWh. The summer demand charge is $13.35 per kW based on the maximal 30-minute demand during the peak period (noon through 6:00 p.m.). To quantify the benefit of the EPRUC product (see Appendix: Definition of Example Products, Product 5) during the heating season, we considered the cost savings on the gas bill as well. We selected the Schedule G-NR1, Gas Service to Small Commercial Customers (PG&E 2002b), and applied the winter rate of $0.7/therm.

Table 7-9 also presents intermediate results of the cost computations to provide the analyst with an opportunity to verify the plausibility of the assumptions made.

The model requires the analyst to specify initial market shares for each product. It should be noted that the initial market share must be non-zero and small for new products. The penetration model results are sensitive to the initial market share of a new product. The smaller the initial market share, the longer the delay until a competitive product generates market penetration momentum and gains market share. Decreasing the initial market share results in shifts in the penetration function along the time axis, rather than changes in the function shape. For instance, in a scenario with two competitors, a change in market share for the new product from 10^{-3} to 10^{-6} results in market penetration curve that is delayed by approximately 10 years, while the shape of the curve remains unchanged.

Table 7-9: Example Input Data for the Peterka Model for New-Equipment Products (5 and 6)

			Worksheet for Peterka Market Penetration Model			
			Descriptor	**Units**	**Existing Packaged HVAC**	**EPRUC**
User Input	Host Equipment Characteristics		Capital cost	$/equipment	25,000	26,700
			Cooling capacity	ton	25	25
			Cooling performance	EER ((BTU/h)/W)	10	11
			Heating capacity	BTU/h	400,000	400,000
			Annual fuel utilization efficiency	$(BTU/h)_{out}/(BTU/h)_{in}$	0.80	0.88
			Lifetime*	years	15	15
	Operating Characteristics	Cooling	Cooling runtime per day	hours/day	12	12
			# days per week operating	days/week	6	6
			# months per year operating	month/year	6	6
			Average annual part load	-	0.8	0.8
		Heating	Heating runtime per day	hours/day	12	12
			# days per week operating	days/week	6	6
			# months per year operating	month/year	4	4
			Average annual part load	-	0.5	0.5
	Peterka User Input		Initial market share	fraction	0.0095	0.005
	Cost of Energy	NG	Cost of natural gas	$/therm	0.7	0.7
Linked Data from Other Sheets		Elec-tricity	Energy charge	cents/kWh	7.3	7.3
			Demand charge	$/kW	13	13
	Product Definition	Cooling	Improvement factor for peak demand			0.05
			Improvement factor for energy			0.1
		Heating	Improvement factor for peak demand			0.05
			Improvement factor for energy			0.1
			Capital cost of product	$		2000
Intermediate Results		Cooling	Annual cooling hours	hours/year	2016	2016
			Cooling COP	-	2.64	2.90
			Cooling energy consumption	kWh/year (thermal)	141,805	141,805
			Electric energy consumption	kWh/year	53,775	48,887
			Electric demand	kW	33.34	31.68
			Annual electricity cost	$/year	6,526	6,039
		Heating	Annual heating hours	hours/year	288	288
			Heating energy consumption	MMBTU/year	72	65
			Annual heating operating cost	$/year	504	458
		Total	Annual operating cost	$/year	7,030	6,498
Peterka Input			Specific investment	$/kW	$284.33	$303.67
			Specific O&M cost	$/kW per year	$92.78	$85.86
			Initial market share	fraction	0.0095	0.005
			Production growth rate	1/yr	0.02	0.02

We suggest using a default initial market share for new products between 0.001 and 0.005. Care must be exercised in the selection of values for this parameter to assure that when the share is multiplied by the baseline number of units, the initial market entry seems plausible. For example, setting the parameter to a share of 0.001 for analysis of a market segment having a million installed units, means that 1,000 units will enter the market in the first year. That result must be evaluated for its plausibility with respect to any known production constraints and adjusted accordingly. This effect of initial market share also may indicate that any program the Commission could undertake for the promotion of initial market introduction of new energy-efficient products would potentially have a significant impact on the rate at which this technology would penetrate the market. Early intervention in the market appears to be extremely important, possibly reducing the time to significant penetration by many years.

The market segment growth rate parameter should be determined by analysts familiar with the market segment under study and should be consistent with Commission growth projected for the particular market. For the purpose of this example, we use an annual growth rate of 2 percent. The model results are very insensitive to wide variations in growth rate.

The calculations for the capital cost and O&M cost for the competing products, as well as the Peterka model itself, are implemented in a Microsoft Excel spreadsheet (Microsoft 2003b). We used the spreadsheet instrument to automate the analytical processes of impact assessment for the example products. All input parameters for the Peterka model and key exogenous variables needed to compute them are shown in Table 7-9. The application of the Peterka model for two specific sets of competing products is discussed in Sections 7.4.4 and 7.4.5 below.

7.4.4 Market Penetration Results for the EPRUC Product Using the Peterka Model

The characterization of the EPRUC product specified new packaged HVAC equipment as a target market. The investment for a customer who acquires the EPRUC product is the cost of the entire HVAC equipment including additional cost for the EPRUC technology. We selected a 25-ton packaged rooftop unit as the host equipment for the EPRUC and assigned an operating schedule representative of inland climates.

Table 7-9 provides the relevant information needed to supply the Peterka model with input parameters for simulating the market competition between a 25-ton packaged rooftop unit with the EPRUC product versus the best 25-ton technology available today.

The results from the Peterka model using the inputs from Table 7-9 are shown in Figure 7-3. The performance improvements impact both the heating and cooling end-uses, reducing O&M costs for the EPRUC product compared to those for the competing product. These improvements in operating costs, however, are offset by the relatively high annualized capital cost. As a result, very little penetration of the EPRUC technology occurs during the analysis period.

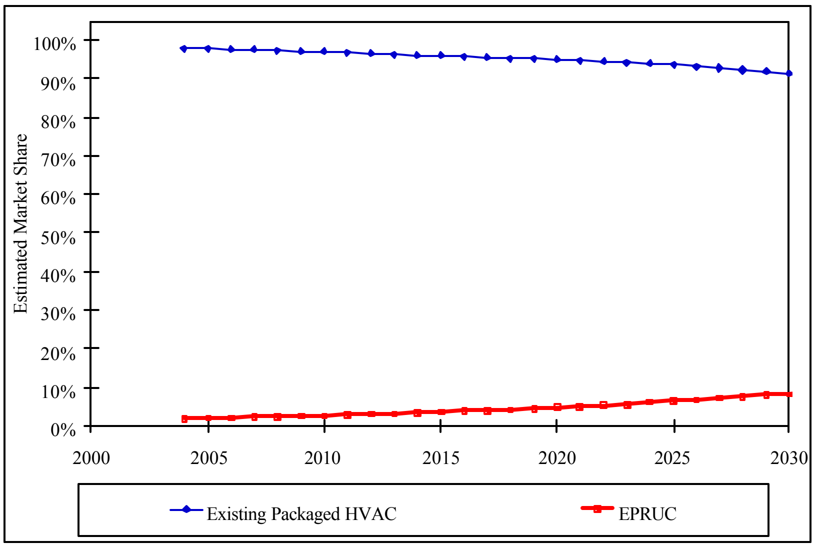

Figure 7-3: Penetration Results for the EPRUC Given Inputs from Table 7-9

Figure 7-4 through Figure 7-7 illustrate the sensitivity in the Peterka model results to changes is key parameters. By altering the initial market share, increasing the price of electricity, increasing improvement factors, and varying product introduction scenarios, the effects compared with the base case illustrated in Figure 7-3, can be seen.

Figure 7-4 shows the impacts of increase initial market share, which models the impact of a public program aimed at stimulating early introduction of energy efficient products into the market. The initial market share was raised from the original value of 0.005 to 0.02. The model indicates more market penetration momentum when the initial market introduction increases. Penetration in 2030 is nearly doubled (compare Figure 7-4 and Figure 7-3).

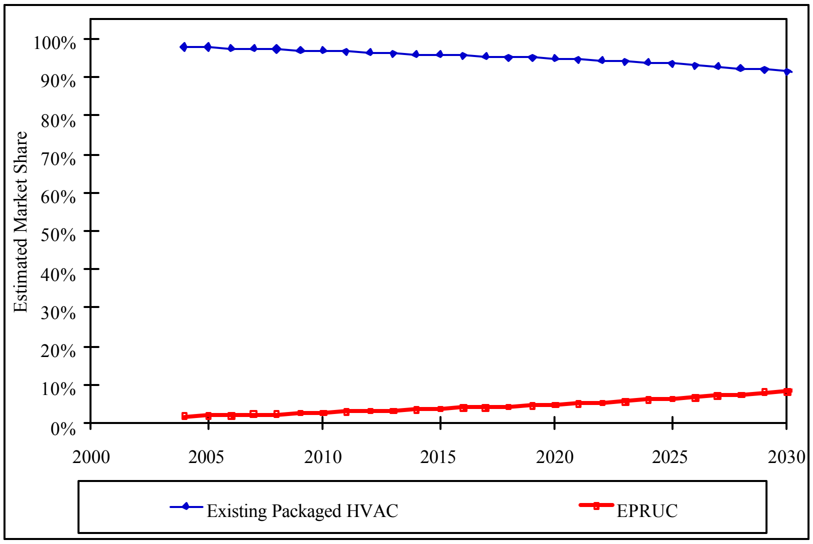

Figure 7-4: Market Penetration Curves with Initial Market Shares of 0.02, increased from 0.005

Modeling these products under the electric rate of 15¢/kWh (raised from the original 7.3¢/kWh), results in roughly the same effect as increasing the initial market share parameter. The higher the average electricity price used or the higher the demand charge, the faster the more efficient product gains market share.

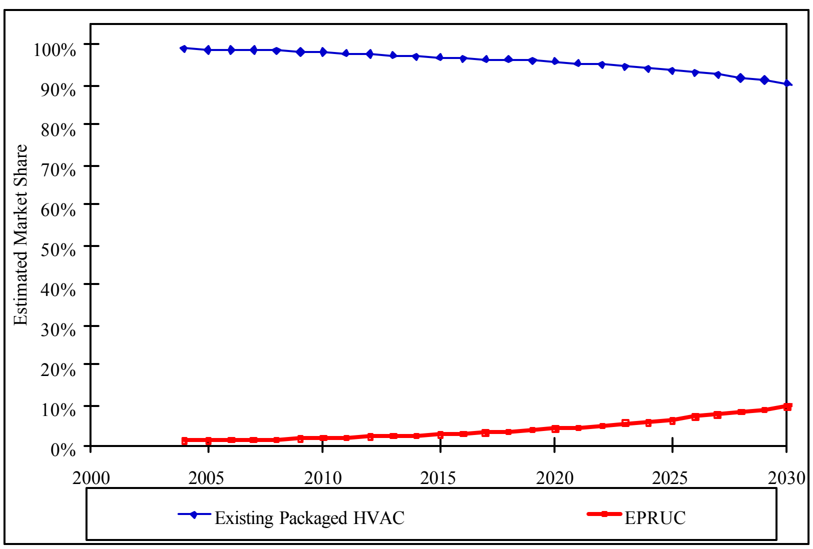

Figure 7-5: Market Penetration Curves Given Table 7-9 Inputs, but with Electricity Rate of 15¢/kWh

Figure 7-6 illustrates the effect of increasing the performance improvement of the while keeping all other inputs as specified in Table 7-9. Raising the improvement from 10% to 20% for energy consumption and 5% to 10% for peak demand accelerates penetration of EPRUC significantly so that it reaches a penetration of about 15% in 2030. This example

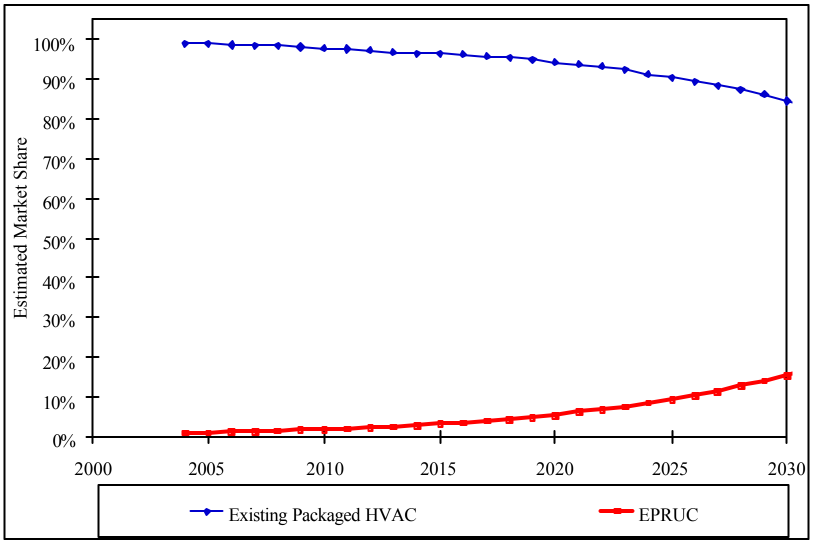

Figure 7-6: Market Penetration Curves Given Table 7-9 Inputs, but Changing the Performance Improvement to 20% for Electricity Consumption and to 10% for Electric Peak Demand (holding all else constant).

shows the impact of uncertainty in the technical performance of new products on predictions of their market penetration.

Carrying this example further in Figure 7-7, all of the various changes mentioned thus far are applied. The initial market share, electricity price, and performance characteristics were all increased. Under this scenario, the EPRUC product achieves significant market share during the analysis period, eventually overtaking existing packaged HVAC as the market leader around 2027.

These examples illustrate the ability to explore different scenarios with the models. Scenarios are helpful in determining the necessary conditions for penetrating a market segment, as well as how energy prices, policy actions, and other changes might affect energy-efficient product penetration. They can illuminate the strengths and the limitations of new or emerging products and help guide their development and deployment.

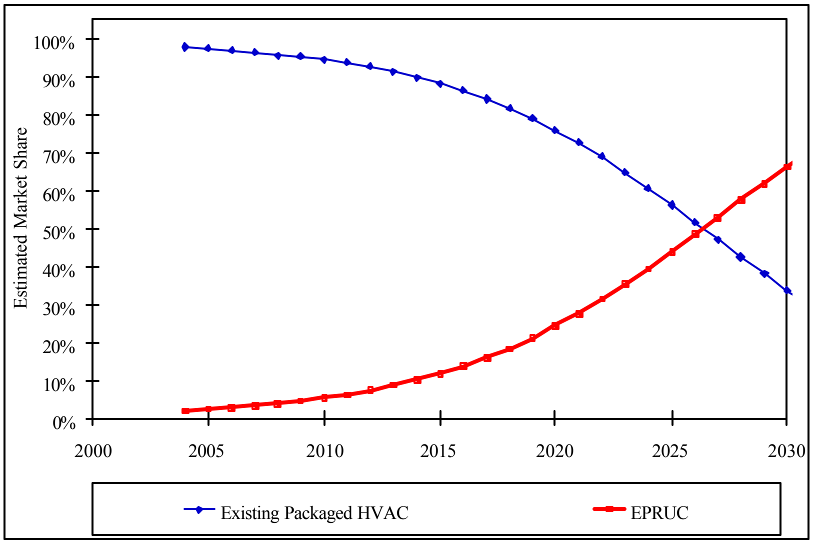

Figure 7-7: Market Penetration for the EPRUC Given Table 7-9 Inputs, but with Alternative Market Introductions of the New Product Coupled with Greater Performance Improvements.

7.4.5 Market Penetration Results for Retrofit Products AFDD1 and AFDD2 Using the Peterka Model

This scenario considers two new products competing to capture the existing market for packaged rooftop AC systems currently without fault detection and diagnostic capabilities. As for the scenario in Section 7.4.4, a 25-ton packaged unit is assumed the host equipment for the diagnostic add-on products. The market penetration modeled in this section represents the competition among: (1) a packaged air-conditioning unit representative of installed units found in the existing building stock, (2) the same packaged air-conditioning unit with the AFDD1, and (3) the existing unit but with the AFDD2. Table 7-10 presents all of the input data for these three products.

Table 7-10: Data Inputs for the Peterka Model for Retrofit Products AFDD1 and AFDD2

			Worksheet for Peterka Market Penetration Model				
			Descriptor	**Units**	**Existing Packaged HVAC**	**AFDD1**	**AFDD2**
User Input	Host Equipment Characteristics		Capital cost	\$/equipment		1,700	1,600
			Cooling capacity	Ton	25	25	25
			Cooling performance	EER ((BTU/h)/W)	9	9.63	9.45
			Heating capacity	BTU/h	400,000	400,000	400,000
			Annual fuel utilization efficiency	$(BTU/h)_{out}/(BTU/h)_{in}$	0.80	0.8	0.8
			Lifetime*	Years	15	15	15
	Operating Characteristics	Cooling	Cooling runtime per day	Hours/day	14	14	14
			# days per week operating	days/week	6	6	6
			# months per year operating	month/year	6	6	6
			Average annual part load	-	0.8	0.8	0.8
		Heating	Heating runtime per day	Hours/day	0	0	0
			# days per week operating	days/week	0	0	0
			# months per year operating	month/year	0	0	0
			Average annual part load	-	0	0	0
	Peterka User Input		Initial market share	fraction	0.99	0.005	0.005
	Cost of Energy	NG	Cost of natural gas	\$/Therm	0.7	0.7	0
Linked Data from Other Sheets		Elec-tricity	Energy charge	cents/kWh	7.3	7.3	7.3
			Demand charge	\$/kW	13.35	13.35	13.35
	Product Definition	Cooling	Improvement factor for peak demand			0.05	0.04
			Improvement factor for energy			0.07	0.05
		Heating	Improvement factor for peak demand			0	0
			Improvement factor for energy			0	0
			Capital cost of product	\$		1700	1600
Intermediate Results		Cooling	Annual cooling hours	Hours/year	2016	2016	2016
			Cooling COP	-	2.64	2.82	2.77
			Cooling energy consumption	kWh/year (thermal)	141,805	141,805	141,805
			Electric energy consumption	kWh/year	53,775	50,257	51,215
			Electric demand	kW	33.34	31.68	32.01
			Annual electricity cost	\$/year	6,596	6,206	6,303
		Heating	Annual heating hours	Hours/year	-	-	-
			Heating energy consumption	MMBTU/year	-	-	-
			Annual heating operating cost	\$/year	0	0	0
		Total	Annual operating cost	\$/year	6,596	6,206	6,303
Peterka Input			Specific investment	\$/kW	\$0	\$19.33	\$18.20
			Specific O&M cost	\$/kW per year	\$93.78	\$88.23	\$89.60
			Initial market share	fraction	0.99	0.005	0.005
			Production growth rate	1/yr	0.02	0.02	0.02

Based on this characterization of the AFDD1 and AFDD2 products, the Peterka model estimates individual penetration curves, as depicted in Figure 7-8. The figure shows that given the inputs provided, AFDD1 and AFDD2 products combine to eventually saturate the market. Holding all else constant, air-conditioning units with the AFDD1 product would surpass the market share of existing HVAC units around 2020.

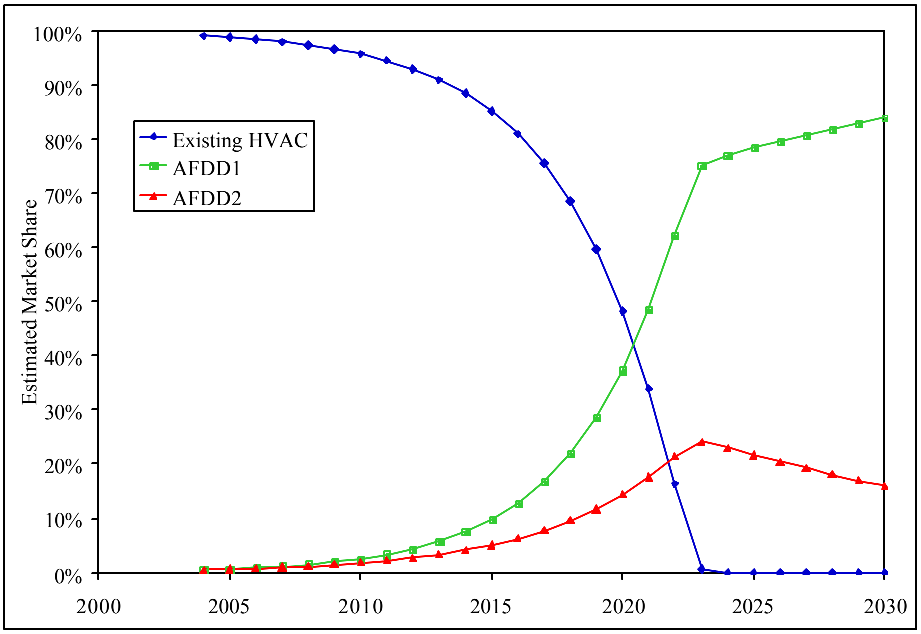

Figure 7-8: Market Penetration Curves Given Inputs in Table 7-10

Figure 7-9 shows the effects of varying the host equipment size. These results indicate that as size of unit increases, the more energy-efficient units succeed in the market sooner. This also suggests that it would be more advantageous to target application of the AFDD1 and AFDD2 products to the larger-sized packaged units, for which the savings per AFDD unit (and per unit of capital cost) are greater.

The results in Figure 7-9 also tend to indicate that better estimates of the penetration of air-conditioning units with diagnostic technology on board would be estimated better by dividing the population of units into size categories, projecting penetration for each size category separately, and adding the impacts of the various size categories to get the total impacts of the technology. This, however, would require knowledge of the distribution of rooftop air-conditioning units by size.

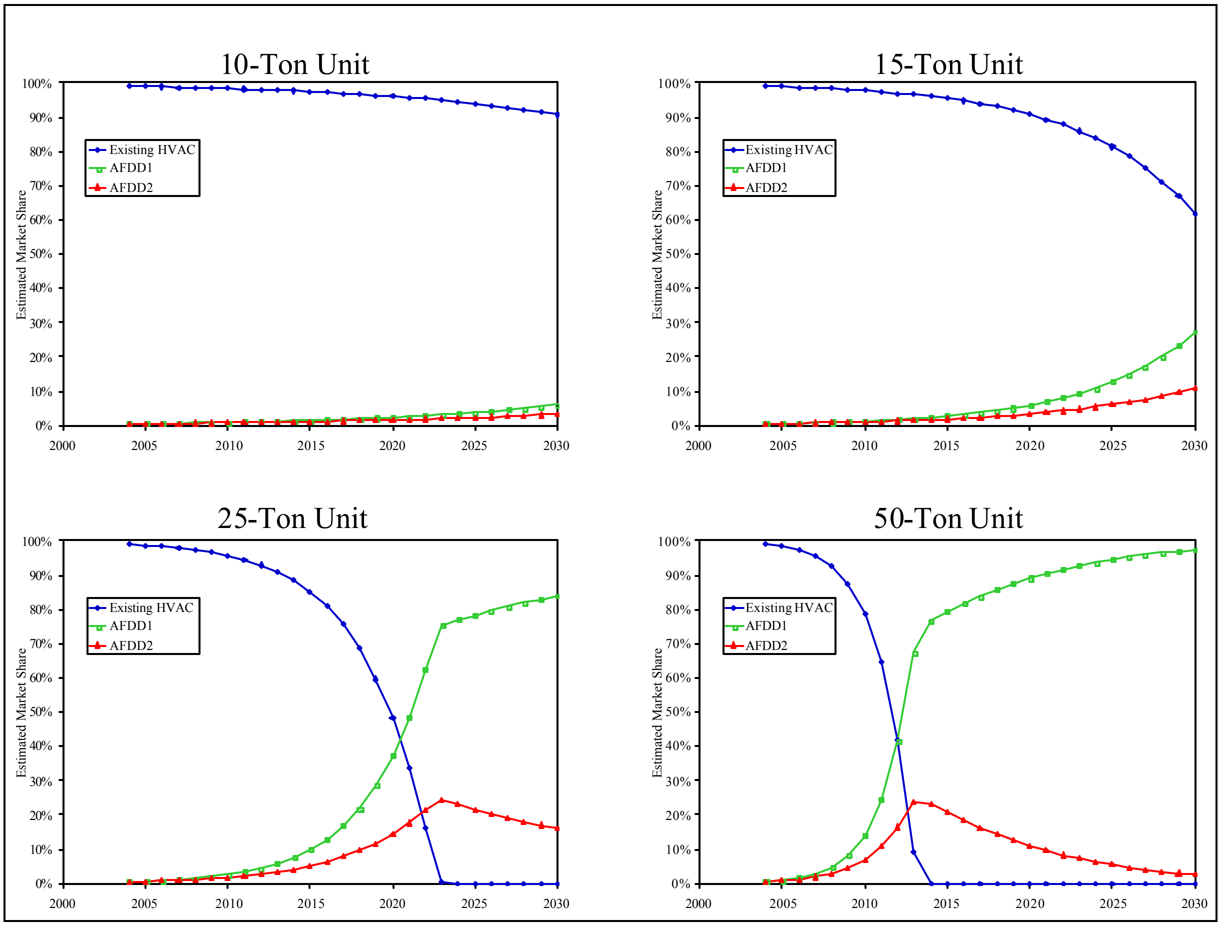

Figure 7-9: Market Penetration Curves for Various Packaged Unit Sizes.

7.4.6 Considerations of Market Penetration Results

The projected market penetration expressed in the chosen unit of measure must be judged by the analyst/modeler for plausibility and realism. Any model should be calibrated to the analyst's understanding of the subject matter and domain. The importance of focusing analyst attention on the development of model inputs cannot be over stressed.

The analyst must ask several questions of the forecasted market penetration:

- Do the market ramp-ups implied by the shape of the "S" curves seem likely, possible, or are they overly optimistic?
- If results seem optimistic or counter intuitive, are all of the model inputs expressed as completely and accurately as possible?
- What other factors (regulations, standards, market conditions, etc.) might also affect the penetration scenarios under consideration? Has the analyst accounted for the influences of such factors explicitly?

The analyst might also want to produce results for ranges of inputs especially when there is significant uncertainty in the values of inputs.

Previous sections have illustrated the important role of assumptions at all points in the application of the assessment framework. Model results will only be as good as the validity of the assumptions used in modeling. In the examples provided for market penetration, the results are quite sensitive to the specific assumptions and values input for electricity prices, improvement factors, market introduction timing, and initial market share. It is incumbent upon users of the framework to research the appropriate assumptions and values for inputs and develop values and assumptions in reasonable ranges. Investing the effort required to develop good assumptions and inputs to the model will result in reasonable forecasts.

Analysts must be aware of the caveats that apply to market penetration modeling. The product development cycle in a market economy seeks to correct perceived inefficiencies as they become apparent. This happens by customers demanding new and better products (demand pull) or by technology development that makes customers aware of new and better products (technology push). This process is continual and dynamic; however, market penetration models typically consider new product competition in isolation from this process. For example, we have demonstrated scenarios facing the packaged HVAC market. The model does not consider that several other product development efforts may be attempting to compete for the same market segment with products that compete with those modeled in our examples.

Carrying this further, the penetration functions imply that perhaps the energy cost savings offered by some new products may cause a shift from an existing product to a new product, and that in out years of the forecast, penetration will remain stable. Out-year stability implied by visually inspecting the penetration functions cannot be assumed. Market dynamics will cause subsequent products to be developed and compete for the same market segments modeled in these scenarios. Thus, the models become valuable for illustrating a product's market potential, but should not suggest that a product will remain at its maximum market share indefinitely. As more efficient products are developed, it seems plausible that future products competing for the same market segment will likely be more efficient than their predecessor products and capture market share from them.

7.5 STEP 4: Estimating Impacts

After having fully characterized the example products, defined their individual market segments, and projected the size of those segments over the analysis period, we estimate the impacts each product may have on the PG&E service territory. Impacts are estimated for electricity consumption, electric peak demand, and expenditures on electricity.

To estimate impacts of the example products, we forecasted the market penetration of each product into its respective market segment using either an expert opinion-based logic function or market penetration based on the Peterka model for products assumed to be in competition for the same market segment.

Figure 7-10 illustrates the impacts of Product 1. The top left graph of Figure 7-10 (labeled "Market Penetration") provides a cumulative count of the market penetration shown Figure 7-2. The largest rate of increase in the market share occurs after 10 years of product introduction (largest slope in Figure 7-2) and reaches constant market share in year 15. From that time forward, the increasing market penetration in terms of units sold is the result of replacements and new constructions. Based on the "Analyst" market penetration curve in Figure 7-2, Product 1 is likely to result in annual savings of about 120 GWh in electricity consumption, 50 MW of peak demand, and $18 million (constant 2001 dollars) in electricity expenditures by 2030. Over the analysis period, these annual impacts accumulate to savings of about 2,400 GWh and $340 million (2001) of electricity expenditures (see Figure 7-11).

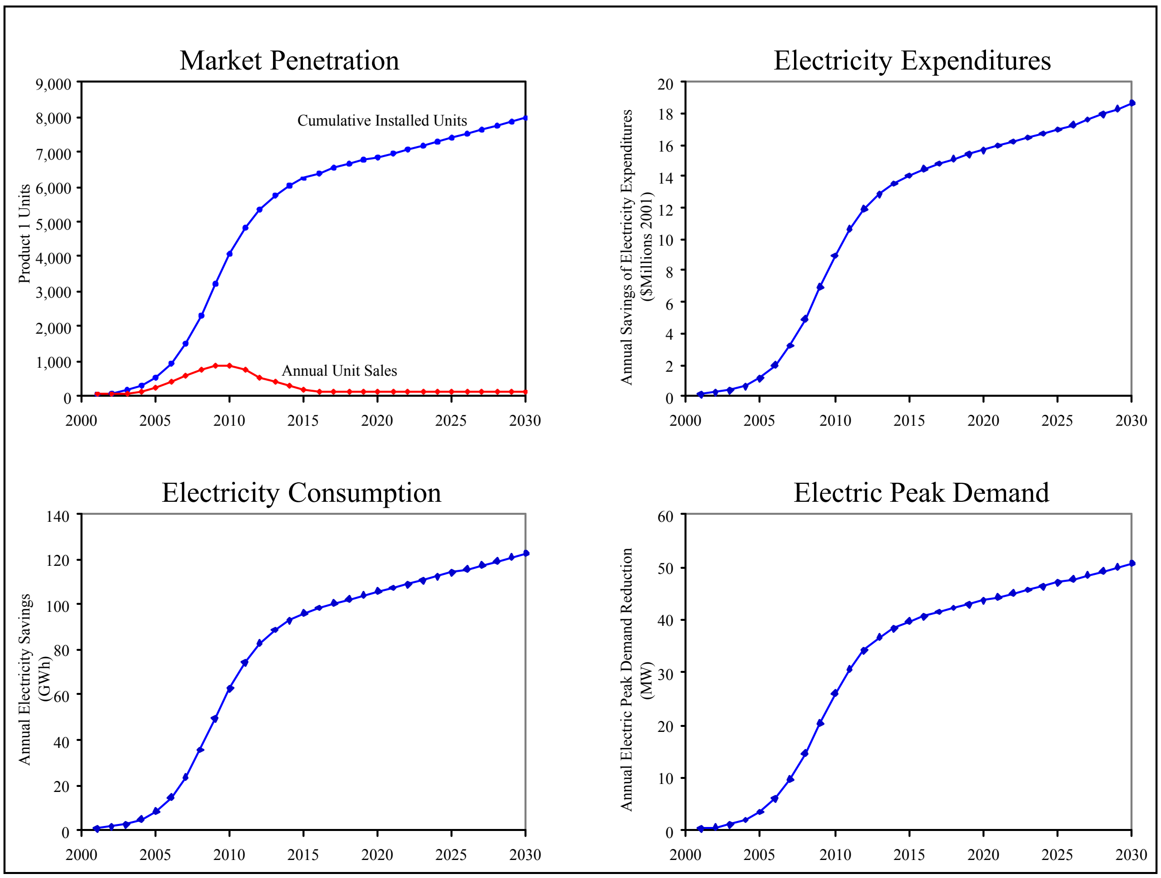

Figure 7-10: Annual Impact Estimates for Product 1

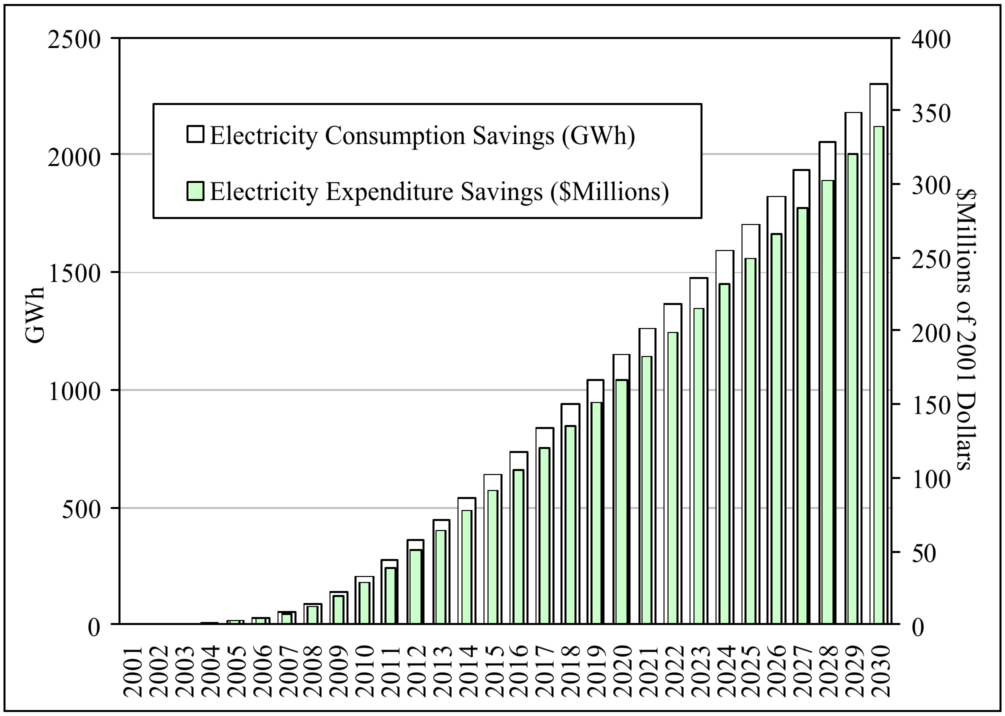

Figure 7-11: Cumulative Impact Estimates for Product 1

In the retrofit scenario, the AFDD1 and AFDD2 products are in competition with each other for application as retrofits to existing packaged 25-ton HVAC units. Although they are in competition, impacts are estimated based on the presence of both in the market during the analysis period because both compete well against the case of doing nothing. Using the market penetration results of Figure 7-8, the estimated combined impact for the retrofit products is illustrated in Figure 7-12. The kink in the market penetration curve occurs at the time when the existing technology is entirely displaced. The additional gains in market share by AFDD1 come from market-share losses of AFDD2.

Cumulative impacts are shown in Figure 7-13. These products successfully penetrate the packaged HVAC market and reach saturation by 2024. The AFDD1 product out competes the AFDD2 product by offering a relatively higher performance improvement per incremental capital investment.

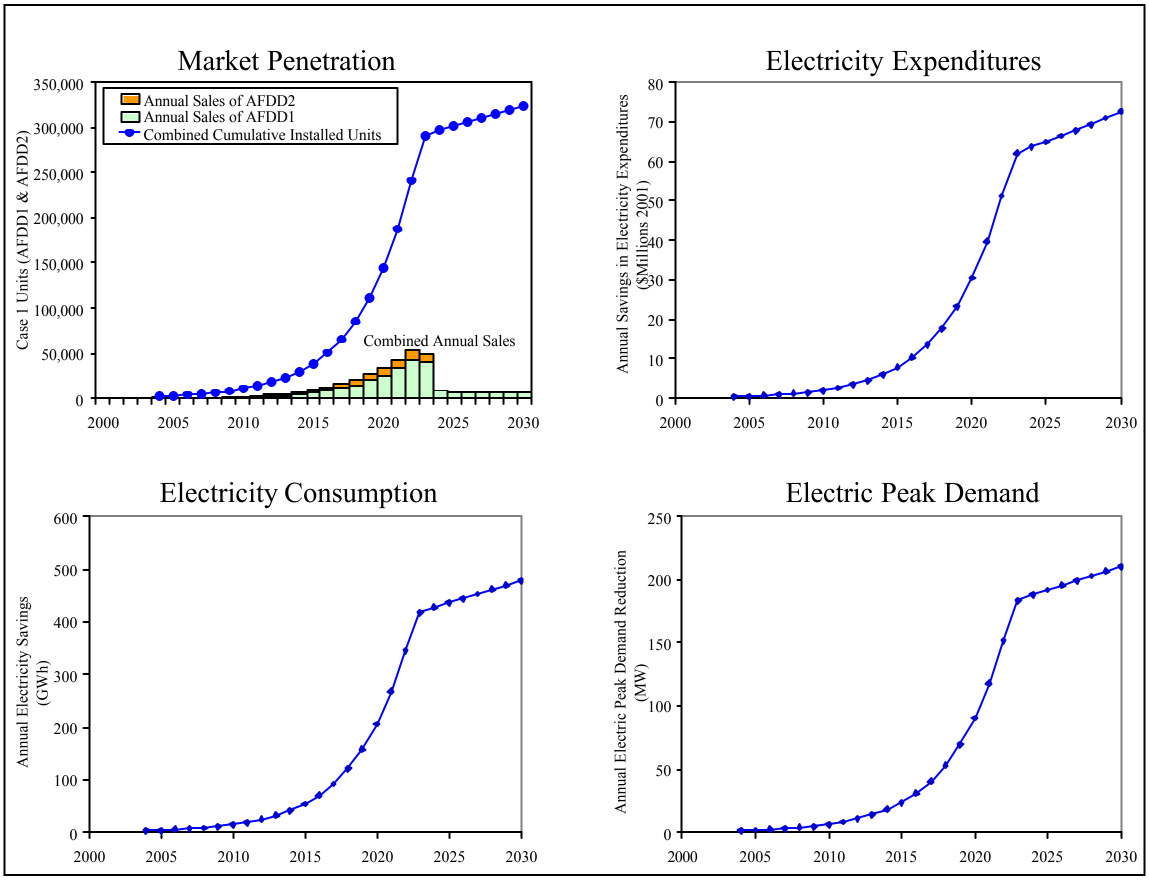

Figure 7-12: Annual Impact Estimates for Retrofit Scenario (Products 2-4)

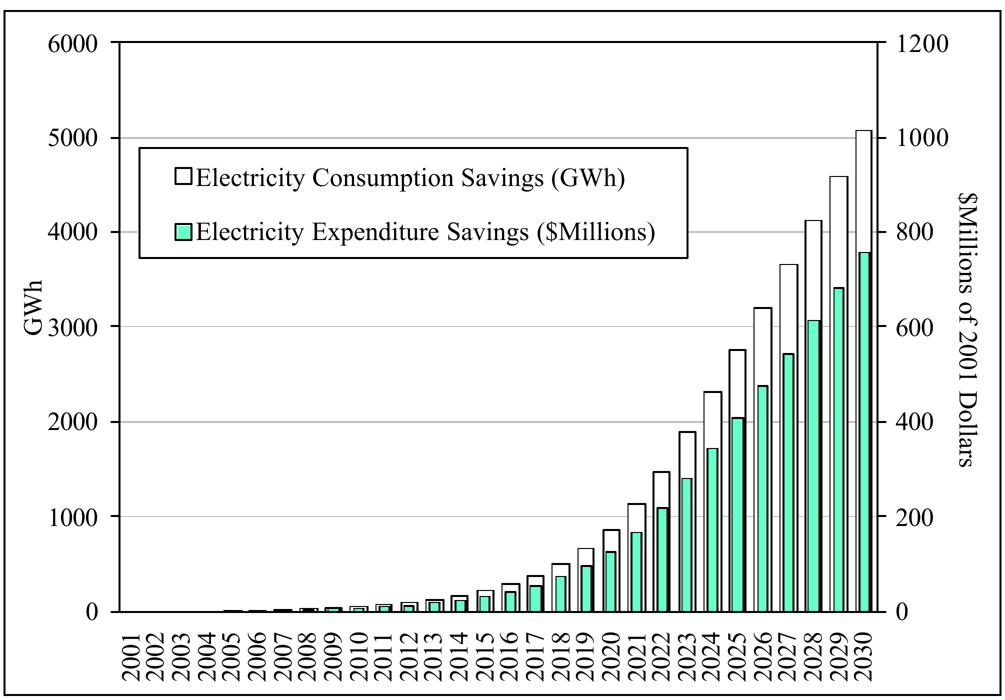

Figure 7-13: Cumulative Impact Estimates for Retrofit Scenario (Products 2-4)

In the new-equipment scenario, the EPRUC-equipped units compete against conventional new 25-ton packaged HVAC units. The EPRUC-equipped units achieve only slight penetration into the new equipment market compared to the AFDD1 or AFDD2 products sold as "add-ons." The difference in impacts can be traced to three factors. The market for the EPRUC is only new units sold each year, while the market for the AFDD products includes both new units sold each year plus all existing units already installed on buildings. The existing unit population, which can be retrofitted, is an order of magnitude larger than the number of sales each year. In addition, the magnitude of capital investment required for EPRUC-equipped new units is much larger than the cost of buying and installing a retrofit box. Furthermore, improvement factors from the EPRUC product are lower than those for the AFDD products, also contributing to lower penetration estimates. Figure 7-14 illustrates the impacts projected for the EPRUC product. Figure 7-15 provides the cumulative impacts.

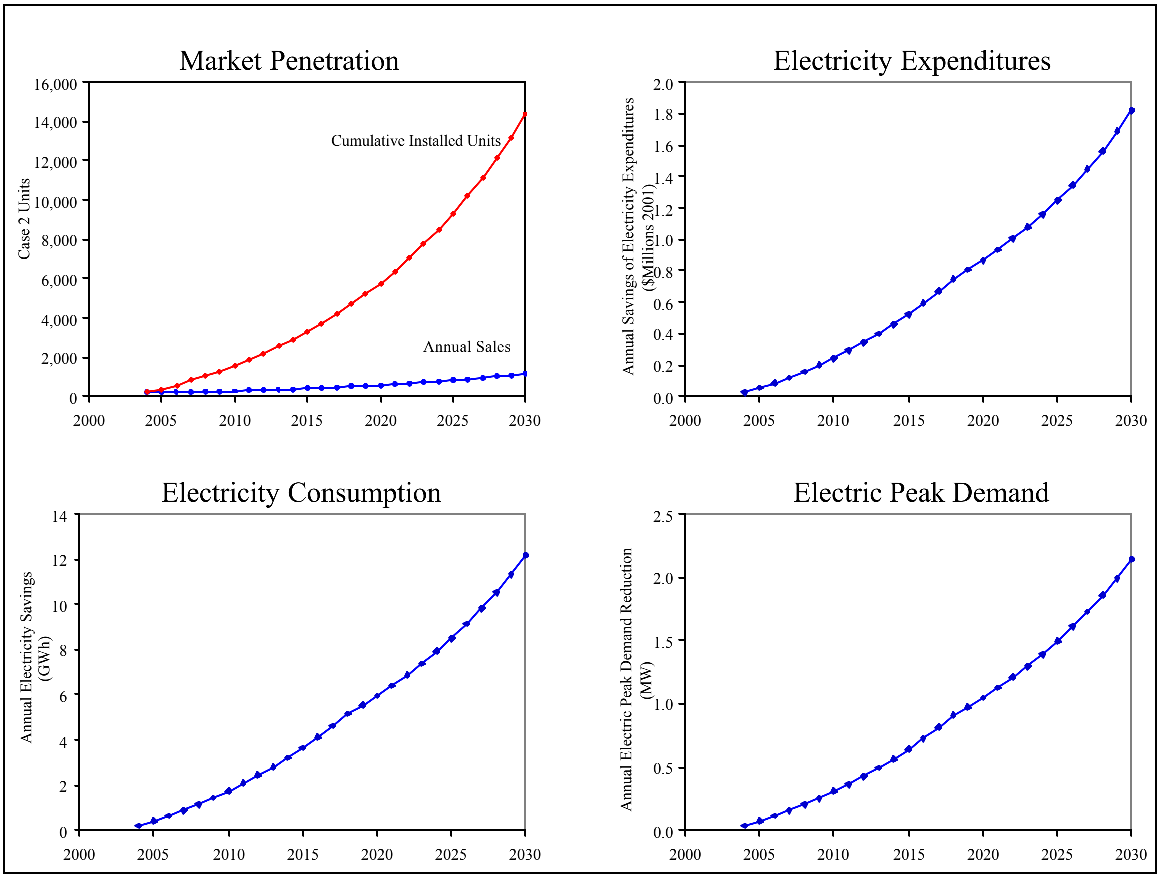

Figure 7-14: Annual Impact Estimates for New-Equipment Scenario (Products 5-6)

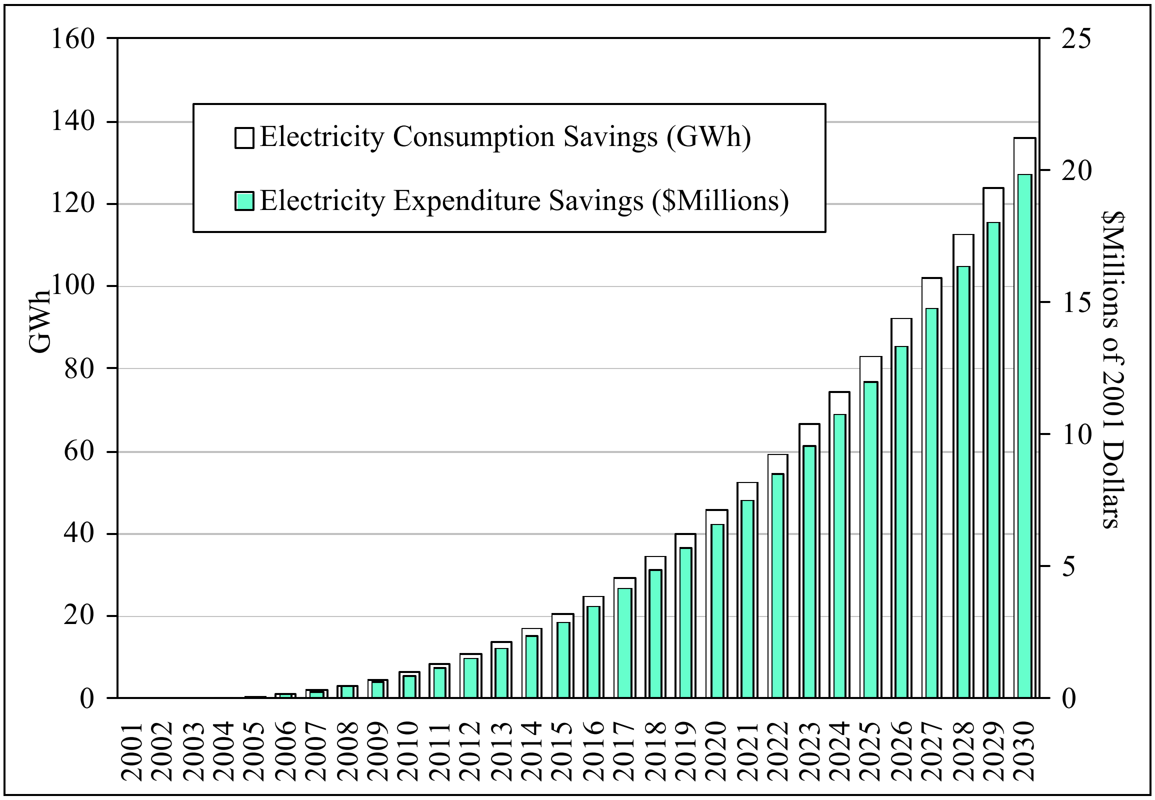

Figure 7-15: Cumulative Impact Estimates for New-Equipment Scenario (Products 5-6)

8 Summary

This report describes a methodology and framework for assessing the benefits of products that may emerge from the Commission's PIER Program research for the commercial buildings sector. The methodology defines a process that starts with the initial product characterization and identification of the product's market segment, determines the market penetration trajectory as a function of time, and concludes with estimating the impacts on electricity use, electricity demand, and monetary expenditures on electricity.

The key features of the assessment framework are, in summary:

- General applicability to all energy efficiency products for commercial buildings. The framework has been developed specifically for analyzing impacts of energy efficiency products relevant for the commercial buildings sector in California. It provides a generic product characterization schema that allows the user to adjust the level of specificity of the product characterization based on the current level to which the characteristics of future energy efficiency products are known. During the development of the product characterization schema, much effort was devoted to designing sufficient flexibility into the schema that products at quite differing stages of development and specificity to which characteristics are known could be analyzed. This enables the user to analyze very specific products such as a 25-ton high energy efficient air-conditioner system on the one hand, as well as a less defined product such as, advanced controls software that will enable utilization of natural ventilation systems in buildings.
- Market penetration models. We described two approaches for estimating market penetration of new products. The first approach requires expert judgment applied to a generic "S"-shaped market penetration model to achieve a specific "S"-shaped market penetration trajectory. This approach is recommended for estimating impacts of single products or a set of aggregated products for which competing technologies either do not exist or are difficult to characterize. The second market penetration approach uses the Peterka multi-competitor market penetration model to explicitly model market competition. It requires estimates of specific capital cost and O&M costs for the new products competing in the same marketplace. It is often difficult to assign values of cost to future products that currently do not exist. The uncertainties associated with this may be high and, thus, the user should be aware of the inherent uncertainties of the input data to the penetration model and then judge the output of the model accordingly. The largest value of this market penetration model, perhaps, lies in its use as an instrument to gain insights into the market dynamics by conducting sensitivity analyses and evaluating relative competitiveness between competing products.
- Exposure of Assumptions. The guiding principal in designing the assessment framework was to provide transparency of all assumptions made during the assessment process. Several assumptions are generally employed for postulating future growth trajectories for prices, energy consumption, building stock, and other trends that impact the results of an assessment. To this end, we designed the framework such that it exposes key variables explicitly rather than aggregating and

lumping them together to represent many mechanisms. As a result, this method requires the user to explicitly assign values to variables and be prepared to substantiate them through defensible sources and logical arguments, so that they can be reviewed by peers.

We exercised the framework to illustrate some of its behavior and to demonstrate how Commission staff may use the framework in the future. The example products for this exercise were chosen from two key research areas of the AEC PIER research program, automated diagnostics and advanced controls for commercial HVAC systems. We chose a set of products that could be retrofitted to existing HVAC systems to illustrate the impact assessment process for this category of energy efficiency products. To contrast the use of the framework for retrofitable products, we also demonstrated the assessment process for new products that can be used in new equipment that is installed in new construction or as replacements for old and retired equipment.

As with any modeling and analysis framework, careful application of the tools and approaches remains the responsibility of the analyst using the framework. Because most assumptions are made transparent in this process, the users of the assessment framework can check and validate projection assumptions, data, calculations, and impact estimates for agreement with citable sources, industry experience, and analytical intuition.

8.1 Recommendations

We demonstrated the framework by using the PG&E Commercial End-Use Survey as a data source for representing the existing building stock in PG&E's service territory. To broaden the regional representation of the building stock from PG&E's service area to the State of California, Commission staff should consider using the methodology with the results of Commission's own commercial building survey activity when they become available.

Furthermore, the value of this framework would be enhanced if extended to use for the residential and industrial sectors of the electricity market. Commission research is likely to lead to new products that will affect electricity demand for residential and industrial electricity customers (including agriculture), in addition to commercial buildings. Typically, these demands are just as significant as those posed by the commercial sector.

We have provided a prototype spreadsheet to use for exercising the framework. The spreadsheet instrument implements the framework for the example products analyzed in this report. It steps the user through the various modules of the assessment framework and is designed to permit scenario analysis for the specific example products. As a device for demonstration, the spreadsheet currently is set up for use by the investigators of this project. The spreadsheet instrument could be further refined, all steps of the process automated, and the breadth of product characteristics increased to produce a user-friendly tool for use by Commission staff. This would enable Commission staff to perform impact assessments and scenario analyses of potential impacts of the entire Commission PIER buildings portfolio.

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Appendix A

Definitions of Example Products

Appendix: Definition of Example Products

A.1 Product 1: WBD as an On-Line Tool

A.1.1 Product Description

The Whole-Building Diagnostician (WBD) is a modular diagnostic software system that provides detection and diagnosis of common problems associated with the operation of heating, ventilating, and air-conditioning (HVAC) systems in buildings. The WBD tracks overall building energy use, monitors the performance of air-handling units, and detects problems with outside-air control. The WBD consists of two primary diagnostic modules, the Whole-Building Energy (WBE) module and the Outdoor-Air/Economizer diagnostician (OAE). The WBE tracks the energy consumption of the whole-building and its major systems (e.g., chillers or packaged units), identifies when consumption anomalies occur and alerts the user (e.g., a building operator) to these anomalies. The OAE module monitors the performance of air handling, detects faults in air handling performance, and then provides information on likely causes of the faults and potential solutions.

A.1.2 Determinants of Market Segmentation

The WBD software as an on-line tool operates on a personal computer (PC) that is part of a building automation system. The WBD can be used on buildings of all sizes, all vintages, and at essentially all locations in California.

A.1.3 Improvements

Energy savings are difficult to attribute directly to the WBE module; however, air-handling problems fixed because the OAE has detected them and provided information to building staff can be attributed to it. Most problems detected by the OAE go undetected when they occur. This is substantiated by testing of this tool in the field and years of field observations by many different investigators. The information provided by the OAE diagnostician should alert building staff to problems they would otherwise not detect and provide information to enable the staff to fix these problems.

In this characterization, we only estimate savings for the OAE module of the WBD. Although, studies show that monitoring energy use does inspire savings, data available at this time are too sketchy for us to attribute savings directly to the WBE module. As a result, savings from use of the WBD are likely to exceed our estimates and paybacks are likely to be shorter.

Electricity savings and reductions in peak power use for both cooling and heating are estimated. Whether savings result from reductions in ventilation fan use is not clear at this time, and therefore not included. On average, we estimate that use of the WBD will reduce electricity consumption by about 4% and peak electric power demand by about 2% for both cooling and heating. Product characterization data are provided in the table that follows.

Table A-0-1: Product Characteristics for Market Segmentation and for Analyzing the Impacts of the WBD Used as an On-Line Tool.

No.	Description	Data Class	Units	Values	To determine market segment	To determine impacts
25	**Controls**		Yes/No	Yes	X	
8	**Cooling**					
8.2	Packaged					
8.2.2	Packaged AC	Cooler				
8.2.2.2	Size		ton	>0		X
8.2.2.6	Annual consumption of electricity		kWh	>0		X
8.2.2.8	Improvement factor for peak demand		-	0.02		X
8.2.2.9	Improvement factor for electricity use		-	0.04		X
8	**Cooling**					
8.1	Central System	Cooler				
8.1.x.2	Size		ton	>0		X
8.1.x.6	Annual consumption of electricity		kWh	>0		X
8.1.x.8	Improvement factor for peak demand		-	0.02		X
8.1.x.9	Improvement factor for electricity use		-	0.04		X
11	**Heati ng**					
11.1	Heating System	Heater				
11.1.x.x.1	Size		BTU/h	>0		X
11.1.x.x.4	Annual consumption of electricity		kWh	>0		X
11.1.x.x.8	Improvement factor for peak demand		-	0.02		X
11.1.x.x.9	Improvement factor for electricity use		-	0.04		X
26	Cost of Product		$	1000		X
27	Year of commercial availability		year	2004		X

A.2 Product 2: AFDD1

A.2.1 Product Description

The AFDD1 system is an automated fault detection and diagnostic system (AFDD) for retrofit onto package rooftop air-conditioning systems. AFDD1 is based on technology developed by Purdue University under Project 2.1. It provides detection and diagnosis of air-side and refrigerant-side problems and monitoring capabilities to facility operators. These problems include both control problems (e.g., incorrect set points, incorrectly implemented economizing strategies) and hardware faults (e.g., stuck dampers, low or high compressor charge, failed fan). The system continuously monitors sensors at various points on a packaged unit and provides alarms and diagnoses when problems are detected. Reports can be provided online within a website (to the building owner, building operator, or a central service provider) if the system is connected to a network or to a technician using a local interface (e.g., a PDA). The product includes all necessary components for measurements, diagnostics, monitoring, and alarm notification.

Because the AFDD1 detects problems and provides that information to operation staff, the resulting problem fixing and associated savings can be attributed to it. Most problems detected by the AFDD1 go undetected until periodic services by a technician (if done regularly). This is substantiated by evidence of these faults in the field by many different investigators. The information provided by the AFDD1 should alert building operation staff or service providers to problems they likely otherwise would not detect and troubleshoot until the unit is inspected carefully by a technician.

A.2.2 Determinants of market segmentation

This characterization applies to the AFDD1 used in an on-line manner with results provided in real-time to an on-site or off-site computer. The AFDD1 can be used on packaged units of any size and any vintage, buildings of all sizes, all vintages, and at essentially all locations in California.

A.2.3 Improvements

Electricity savings and reductions in peak-power use are estimated for cooling only. The major mechanism for electricity and peak power savings is associated with ensuring proper operation and maintenance of packaged rooftop units. Hence, the improvements occur at the end-use level. On average, we estimate that use of the AFDD1 will reduce electricity consumption by about 5% and peak electric power demand by about 4% for electricity consumption for cooling. Product characterization data are provided in Table A-0-2, which follows.

Table A-0-2: Product Characteristics for Market Segmentation and for Analyzing the Impacts of AFDD1

No.	Description	Data Class	Units	Values	To determine market segment	To determine impacts
8	Cooling					
8.2	Packaged				X	
8.2.2	Packaged AC	Cooler			X	
8.2.2.2	Size		ton	>0	X	X
8.2.2.6	Annual consumption of electricity		kWh	>0		X
8.2.2.8	Improvement factor for peak demand		-	0.05		X
8.2.2.9	Improvement factor for electricity use		-	0.07		X
26	Product Cost		$/unit	1700		X
27	Year of commercial availability		year	2004		X

A.3 Product 3: AFDD2

A.3.1 Product Description:

The AFDD2 is an automated fault detection and diagnostic system for retrofit onto package rooftop air conditioning systems. AFDD2 is based on the technology developed by Battelle under Project 2.4. It provides detection and diagnosis of air-side problems with unit operation and monitoring capabilities for facility operators. These problems include both control problems (e.g., incorrect set points, incorrectly implemented economizing strategies, bad schedule) and hardware faults (e.g., failed sensors, stuck dampers, failed fan). The system continuously monitors sensors at various points on a packaged unit and provides alarms and diagnoses when problems are found. The product includes all necessary components of measurements, diagnostics, monitoring, and alarm notifications. The results are reported to an on-site computer through a serial or network connection or offsite service provider via the Internet.

Because the AFDD2 detects problems and provides that information to building staff, the resulting problem fixing and associated savings can be attributed to it. Most problems detected by the AFDD2 go undetected until periodic servicing by a technician (if done regularly or at all). This is substantiated by evidence of these faults in the field by many different investigators. The information provided by the AFDD2 should alert building staff to problems they likely otherwise would not detect and troubleshoot until the unit is inspected carefully by a technician.

A.3.2 Determinants of Market Segmentation

This characterization applies to the AFDD2 used in an on-line manner with results provided in real-time to building operation staff. The AFDD2 can be used on packaged units of any size and any vintage, buildings of all sizes, all vintages, and at essentially all locations in California where air-conditioning is used.

A.3.3 Improvements

Electricity savings and reductions in peak-power use are estimated for cooling only. The major mechanism for electricity and peak power savings is associated with ensuring proper operation and maintenance of packaged rooftop units. Hence, the improvements occur at the end-use level. On average, we estimate that use of the AFDD2 will reduce electricity consumption by about 4% and peak electric power demand by about 2% for electricity consumption for cooling. Product characterization data are provided in Table A-0-3, which follows.

Table A-0-3: Product characteristics for market segmentation and for analyzing the impacts of AFDD2

No.	Description	Data Class	Units	Values	To determine market segment	To determine impacts
8	**Cooling**					
8.2	Packaged				X	
8.2.2	Packaged AC	Cooler			X	
8.2.2.2	Size		ton	>0	X	X
8.2.2.6	Annual consumption of electricity		KWh	>0		X
8.2.2.8	Improvement factor for peak demand		-	0.04		X
8.2.2.9	Improvement factor for electricity use		-	0.05		X
26	Product Cost		$/unit	1600		X
27	Year of commercial availability		year	2004		X

A.4 Product 4: Reference Product

The reference product serves as representation of the existing packaged unit stock. The representation of the current market is required for the market penetration model. Characteristics of the reference product are shown in Table A-0-4.

Table A-0-4: Product Characteristics for Market Segmentation and for Analyzing Impacts of the Reference Product

No.	Description	Data Class	Units	Values	To determine market segment	To determine impacts
8	**Cooling**					
8.2	Packaged				X	
8.2.2	Packaged AC	Cooler			X	
8.2.2.2	Size		ton	>0	X	X
8.2.2.6	Annual consumption of electricity		kWh	>0		X
8.2.2.8	Improvement factor for peak demand		-	0		X
8.2.2.9	Improvement factor for electricity use		-	0		X
26	Product Cost		$/unit			X
27	Year of commercial availability		year	Already available		X

A.5 Product 5: EPRUC

A.5.1 Product Description:

EPRUC (Enhanced Packaged Rooftop Unit Controller) is based on Purdue University's Project 3.1. The EPRUC is a new controller for rooftop packaged air-conditioning units that provides for demand-control ventilation (DCV). This controller is a direct replacement for package-unit controllers commonly installed today during manufacture of rooftop units. The new controller will determine the necessary ventilation rates that prevent over-ventilation. The EPRUC enables use of DCV based on CO_2 sensors in the zones that the package unit serves.

A.5.2 Determinants of market segmentation:

This characterization applies to the EPRUC used on new rooftop package air-conditioning units. The controller is not intended for retrofit applications. The EPRUC can be used on packaged units of any size installed on buildings of all sizes, all vintages, and at essentially all locations in California where air-conditioning is used. The new controller affects both cooling and electric-heating consumption.

A.5.3 Improvements:

Electricity savings and reductions in peak-power use are estimated for cooling and heating. The major mechanism for electricity and peak-power savings is associated with providing only the necessary ventilation based on occupancy and no more. It is assumed that the savings due to reduction of fan power are negligible. Savings are assumed to be primarily attributable to the avoidance of over-ventilation resulting in reduced cooling loads during the cooling seasons and electric heating during winter periods. Although, not quantitatively evaluated in this assessment, the controller should also improve indoor air quality. Hence, the improvements occur at the end-use level. On average, we estimate that use of the EPRUC will reduce electricity consumption by about 5% and peak electric power demand by about 2% for cooling. Product characterization data are provided in Table A-0-5, which follows.

Table A-0-5: Product Characteristics for Market Segmentation and for Analyzing the Impacts of EPRUC

No.	Description	Data Class	Units	Values	To determine market segment	To determine impacts
8	**Cooling**					
8.2	Packaged				X	
8.2.2	Packaged AC	Cooler			X	
8.2.2.2	Size		ton	>0	X	X
8.2.2.6	Annual consumption of electricity		kWh	>0		X
8.2.2.8	Improvement factor for peak demand		-	0.02		X
8.2.2.9	Improvement factor for electricity use		-	0.05		X
11	**Heating**					
11.1	Heating System	Heater			X	
11.1.x.x.1	Size		BTU/h	>0		X
11.1.x.x.4	Annual consumption of electricity		kwh	>0	X	X
11.1.x.x.8	Improvement factor for peak demand		-	0.05		X
11.1.x.x.9	Improvement factor for electricity use		-	0.10		X
26	Product Cost		$/unit	2000		X
27	Year of commercial availability		year	2004		X

A.6 Product 6: Reference Technology

Product 6 represents today's best available packaged HVAC unit without demand-controlled ventilation technology as characterized below.

Table A-0-6: Product Characteristics for Market Segmentation and for Analyzing Impacts for Reference Model

No.	Description	Data Class	Units	Values	To determine market segment	To determine impacts
8	**Cooling**					
8.2	Packaged				X	
8.2.2	Packaged AC	Cooler			X	
8.2.2.2	Size		ton	>0	X	X
8.2.2.6	Annual consumption of electricity		kWh	>0		X
8.2.2.8	Improvement factor for peak demand		-	0		X
8.2.2.9	Improvement factor for electricity use		-	0		X
26	Product Cost		$/unit			X
27	Year of commercial availability		year	Already available		X

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