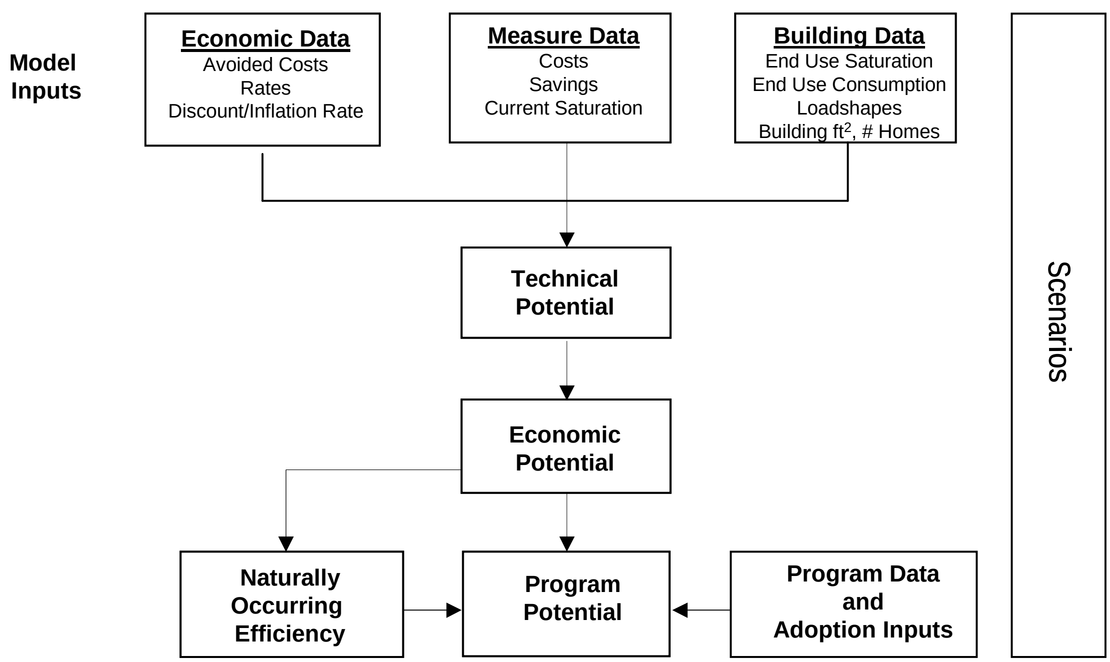
A. Appendix A: Detailed Methodology and Model Description

In this appendix we present and discuss our basic methodology for conducting market potential studies. We also present an overview of DSM ASSYST™, our model used to develop market potential estimates. Information presented here has been extracted from several recent energy efficiency potential reports.

A.1 Overview of DSM Forecasting Method

The crux of any DSM forecasting process involves carrying out a number of systematic analytical steps that are necessary to produce accurate estimates of energy efficiency (EE) effects on system load. A simplified overview of these basic analytical steps is shown in Figure A-1.

Figure A-1
Simplified Conceptual Overview of Modeling Process



Developing a DSM forecast is viewed by KEMA as a five-step process. The steps include:

Step 1: Develop Initial Input Data

- Develop list of EE measure opportunities to include in scope

- Gather and develop technical data (costs and savings) on efficient measure opportunities
- Gather, analyze, and develop information on building characteristics, including total square footage and households, electricity consumption and intensity by end use, end-use consumption load patterns by time of day and year (i.e., load shapes), market shares of key electric consuming equipment, and market shares of EE technologies and practices.

Step 2: Estimate Technical Potential and Develop Supply Curves

- Match and integrate data on efficient measures to data on existing building characteristics to produce estimates of technical potential and EE supply curves.

Step 3: Estimate Economic Potential

- Gather economic input data such as current and forecasted retail electric prices and current and forecasted costs of electricity generation, along with estimates of other potential benefits of reducing supply, such as the value of reducing environmental impacts associated with electricity production
- Match and integrate measure and building data with economic assumptions to produce indicators of costs from different viewpoints (e.g., utility, societal, and consumer)
- Estimate total economic potential using supply curve approach

Step 4: Estimate Achievable Program and Naturally Occurring Potentials

- Gather and develop estimates of program costs (e.g., for administration and marketing) and historic program savings
- Develop estimates of customer adoption of EE measures as a function of the economic attractiveness of the measures, barriers to their adoption, and the effects of program intervention
- Estimate achievable program and naturally occurring potentials; calibrate achievable and naturally occurring potential to recent program and market data
- Develop alternative economic estimates associated with alternative future scenarios

Step 5: Scenario Analyses and Resource Planning Inputs

- Recalculate potentials under alternate economic scenarios and deliver data in format required for resource planning.

Provided below is additional discussion of KEMA’s modeling approaches for technical, economic, and achievable DSM forecasts.

A.1.1 Estimate Technical Potential and Develop Energy-Efficiency Supply Curves

Technical potential refers to the amount of energy savings or peak demand reduction that would occur with the *complete* penetration of all measures analyzed in applications where they were deemed *technically* feasible from an *engineering* perspective. Total technical potential is developed from estimates of the technical potential of individual measures as they are applied to discrete market segments (commercial building types, residential dwelling types, etc.).

A.1.1.1 Core Equation

The core equation used to calculate the energy technical potential for each individual efficiency measure, by market segment, is shown below (using a commercial example):[1]

Technical Potential of Efficient Measure	=	Total Square Feet	×	Base Case Equipment EUI	×	Applicability Factor	×	Not Complete Factor	×	Feasibility Factor	×	Savings Factor

where:

- **Square feet** is the total floor space for all buildings in the market segment. For the residential analysis, the **number of dwelling units** is substituted for square feet.
- **Base-case equipment EUI** is the energy used per square foot by each base-case technology in each market segment. This is the consumption of the energy-using equipment that the efficient technology replaces or affects. For example, if the efficient measure were a CFL, the base EUI would be the annual kWh per square foot of an equivalent incandescent lamp. For the residential analysis, unit energy consumption (UECs), energy used per dwelling, are substituted for EUIs.
- **Applicability factor** is the fraction of the floor space (or dwelling units) that is applicable for the efficient technology in a given market segment; for the example above, the percentage of floor space lit by incandescent bulbs.

[1] Note that stock turnover is not accounted for in our estimates of technical and economic potential, stock turnover *is accounted for* in our estimates of achievable potential. Our definition of technical potential assumes instantaneous replacement of standard-efficiency with high-efficiency measures.

- **Not complete factor** is the fraction of applicable floor space (or dwelling units) that has not yet been converted to the efficient measure; that is, (1 minus the fraction of floor space that already has the EE measure installed).
- **Feasibility factor** is the fraction of the applicable floor space (or dwelling units) that is technically feasible for conversion to the efficient technology from an *engineering* perspective.
- **Savings factor** is the reduction in energy consumption resulting from application of the efficient technology.

Technical potential for peak demand reduction is calculated analogously.

An example of the core equation is shown in Table A-1 for the case of a prototypical 4-lamp 4-foot standard T-8 lighting fixture, which is replaced by a 4-lamp 4-foot premium T-8 fixture in the office segment of a large utility service territory.

Table A-1
Example of Technical Potential Calculation—Replace 4-Lamp 4-Foot Standard T-8s with 4-Lamp 4-Foot Premium T-8s in the Office Segment of a Utility Service Territory
(*Note: Data are illustrative only*)

Technical Potential of Efficient Measure	=	Total square feet	×	Base Case Equipment UEC	×	Applicability Factor	×	Not Complete Factor	×	Feasibility Factor	×	Savings Factor
57 million kWh		195 million		5.74		0.34		0.95		1.00		0.16

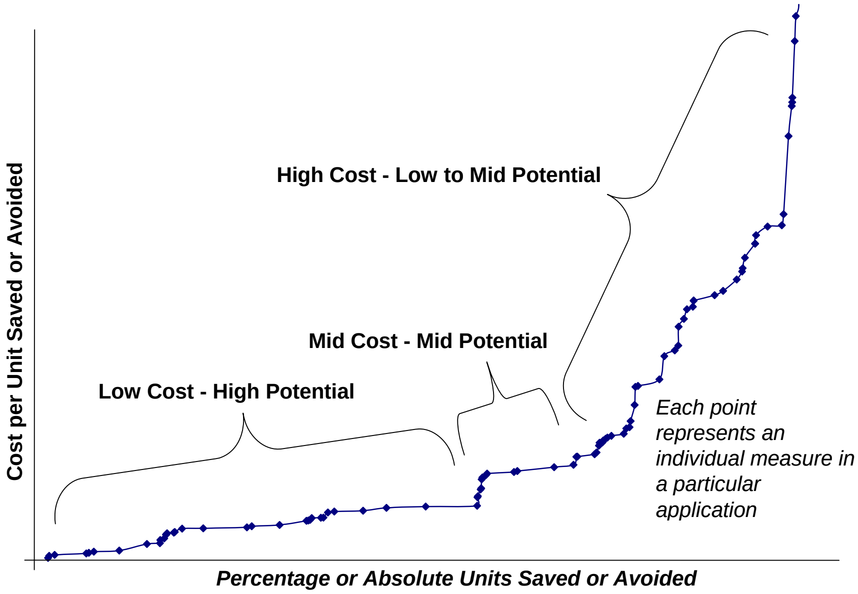
Technical EE potential is calculated in two steps. In the first step, all measures are treated *independently*; that is, the savings of each measure are not marginalized or otherwise adjusted for overlap between competing or synergistic measures. By treating measures independently, their relative economics are analyzed without making assumptions about the order or combinations in which they might be implemented in customer buildings. However, the total technical potential across measures cannot be estimated by summing the individual measure potentials directly. The cumulative savings cannot be estimated by adding the savings from the individual savings estimates because some savings would be double counted. For example, the savings from a measure that reduces heat gain into a building, such as window film, are partially dependent on other measures that affect the efficiency of the system being used to cool the building, such as a high-efficiency chiller; the more efficient the chiller, the less energy saved from the application of the window film.

A.1.1.2 Use of Supply Curves

In the second step, cumulative technical potential is estimated using an EE supply curve approach.[2] This method eliminates the double-counting problem. In Figure A-2, we present a generic example of a supply curve. As shown in the figure, a supply curve typically consists of two axes—one that captures the cost per unit of saving a resource or mitigating an impact (e.g., $/kWh saved or $/ton of carbon avoided) and the other that shows the amount of savings or mitigation that could be achieved at each level of cost. The curve is typically built up across individual measures that are applied to specific base-case practices or technologies by market segment. Savings or mitigation measures are sorted on a least-cost basis, and total savings or impacts mitigated are calculated incrementally with respect to measures that precede them. Supply curves typically, but not always, end up reflecting diminishing returns, i.e., as costs increase rapidly and savings decrease significantly at the end of the curve.

Figure A-2
Generic Illustration of EE Supply Curve

[2] This section describes conservation supply curves as they have been defined and implemented in numerous studies. Readers should note that Stoft 1995 describes several technical errors in the definition and implementation of conservation supply curves in the original and subsequent conservation supply curve studies. Stoft concludes that conservation supply curves are not "true" supply curves in the standard economic sense but can still be useful (albeit with his recommended improvements) for their intended purpose (demonstration of cost-effective conservation opportunities).



As noted above, the cost dimension of most EE supply curves is usually represented in dollars per unit of energy savings. Costs are usually annualized (often referred to as "levelized") in supply curves. For example, EE supply curves usually present levelized costs per kWh or kW saved by multiplying the initial investment in an efficient technology or program by the "capital recovery rate" (CRR):

$$\text{CRR} = \frac{d}{1-(1+d)^{-n}}$$

where d is the real discount rate and n is the number of years over which the investment is written off (i.e., amortized).

Thus,

Levelized Cost per kWh Saved = Initial Cost x CRR/Annual Energy Savings

Levelized Cost per kW Saved = Initial Cost x CRR/Peak Demand Savings

The levelized cost per kWh and kW saved are useful because they allow simple comparison of the characteristics of EE with the characteristics of energy supply technologies. However, the levelized cost per kW saved is a biased indicator of cost-effectiveness because all of the efficiency measure costs are arbitrarily allocated to peak savings.

Returning to the issue of EE supply curves, Table A-2 shows a simplified numeric example of a supply curve calculation for several EE measures applied to commercial lighting for a hypothetical population of buildings. What is important to note is that in an EE supply curve, the measures are sorted by relative cost—from least to most expensive. In addition, the energy consumption of the system being affected by the efficiency measures goes down as each measure is applied. As a result, the savings attributable to each subsequent measure decrease if the measures are interactive. For example, the occupancy sensor measure shown in Table 1-2 would save more at less cost per unit saved if it were applied to the base-case consumption before the T8 lamp and electronic ballast combination. Because the T8 electronic ballast combination is more cost-effective, however, it is applied first, reducing the energy savings potential for the occupancy sensor. Thus, in a typical EE supply curve, the base-case end-use consumption is reduced with each unit of EE that is acquired. Notice in Table 1-2 that the total end-use GWh consumption is recalculated after each measure is implemented, thus reducing the base energy available to be saved by the next measure.

Table A-2 shows an example that would represent measures for one base-case technology in one market segment. These calculations are performed for all of the base-case technologies, market segments, and measure combinations in the scope of a study. The results are then ordered by levelized cost and the individual measure savings are summed to produce the EE potential for the entire sector.

In the next subsection, we discuss how economic potential is estimated as a subset of the technical potential.

Table A-2
Sample Technical Potential Supply Curve Calculation for Commercial Lighting
(*Note: Data are illustrative only*)

Measure	Total End Use Consumption of Population (GWh)	Applicable, Not Complete and Feasible (1000s of ft^2)	Average kWh/ft^2 of population	Savings %	GWh Savings	Levelized Cost ($/kWh saved)
Base Case: T12 lamps with Magnetic Ballast	425	100,000	4.3	N/A	N/A	N/A
1. T8 w. Elec. Ballast	425	100,000	4.3	21%	89	$0.04
2. Occupancy Sensors	336	40,000	3.4	10%	13	$0.11
3. Perimeter Dimming	322	10,000	3.2	45%	14	$0.25
With all measures	309		3.1	27%	116	

A.1.2 Estimation of Economic Potential

Economic potential is typically used to refer to the *technical potential* of those energy conservation measures that are cost effective when compared to either supply-side alternatives or the price of energy. Economic potential takes into account the fact that many EE measures cost more to purchase initially than do their standard-efficiency counterparts. The incremental costs of each efficiency measure are compared to the savings delivered by the measure to produce estimates of energy savings per unit of additional cost. These estimates of EE resource costs can then be compared to estimates of other resources such as building and operating new power plants.

A.1.2.1 Cost Effectiveness Tests

To estimate economic potential, it is necessary to develop a method by which it can be determined that a measure or program is *economic*. There is a large body of literature that debates the merits of different approaches to calculating whether a public purpose investment in EE is cost effective (Chamberlin and Herman 1993, RER 2000, Ruff 1988, Stoft 1995, and Sutherland 2000). We usually utilize the total resource cost (TRC) test to assess cost effectiveness. The TRC is a form of societal benefit-cost test. Other tests that have been used in analyses of program cost-effectiveness by EE analysts include the utility cost, ratepayer impact measure (RIM), and participant tests. These tests are discussed in detail the CASPM.

Before discussing the TRC test and how it is often used in our DSM forecasts, we present below a brief introduction to the basic tests as described in the CASPM:[3]

- **Total Resource Cost Test**—The TRC test measures the net costs of a demand-side management program as a resource option based on the total costs of the program, including both the participants' and the utility's costs. The test is applicable to conservation, load management, and fuel substitution programs. For fuel substitution programs, the test measures the net effect of the impacts from the fuel not chosen versus the impacts from the fuel that is chosen as a result of the program. TRC test results for fuel substitution programs should be viewed as a measure of the economic efficiency implications of the total energy supply system (gas and electric). A variant on the TRC test is the societal test. The societal test differs from the TRC test in that it includes the effects of externalities (e.g. environmental, national security), excludes tax credit benefits, and uses a different (societal) discount rate.

[3] These definitions are direct excerpts from the California Standard Practice Manual, October 2001.

- **Participant Test**—The participant test is the measure of the quantifiable benefits and costs to the customer due to participation in a program. Since many customers do not base their decision to participate in a program entirely on quantifiable variables, this test cannot be a complete measure of the benefits and costs of a program to a customer.
- **Utility (Program Administrator) Test**—The program administrator cost test measures the net costs of a demand-side management program as a resource option based on the costs incurred by the program administrator (including incentive costs) and excluding any net costs incurred by the participant. The benefits are similar to the TRC benefits. Costs are defined more narrowly.
- **Ratepayer Impact Measure Test**—The ratepayer impact measure (RIM) test measures what happens to customer bills or rates due to changes in utility revenues and operating costs caused by the program. Rates will go down if the change in revenues from the program is greater than the change in utility costs. Conversely, rates or bills will go up if revenues collected after program implementation are less than the total costs incurred by the utility in implementing the program. This test indicates the direction and magnitude of the expected change in customer bills or rate levels.

The key benefits and costs of the various cost-effectiveness tests are summarized in Table A-3.

Table A-3
Summary of Benefits and Costs of California Standard Practice Manual Tests

Test	Benefits	Costs
TRC Test	Generation, transmission and distribution savings Participants avoided equipment costs (fuel switching only)	Generation costs Program costs paid by the administrator Participant measure costs
Participant Test	Bill reductions Incentives Participants avoided equipment costs (fuel switching only)	Bill increases Participant measure costs
Utility (Program Administrator) Test	Generation, transmission and distribution savings	Generation costs Program costs paid by the administrator Incentives
Ratepayer Impact Measure Test	Generation, transmission and distribution savings Revenue gain	Generation costs Revenue loss Program costs paid by the administrator Incentives

Generation, transmission and distribution savings (hereafter, energy benefits) are defined as the economic value of the energy and demand savings stimulated by the interventions being assessed. These benefits are typically measured as induced changes in energy consumption, valued using some mix of avoided costs. Statewide values of avoided costs are prescribed for use in implementing the test. Electricity benefits are valued using three types of avoided electricity costs: avoided distribution costs, avoided transmission costs, and avoided electricity generation costs.

Participant costs are comprised primarily of incremental measure costs. Incremental measure costs are essentially the costs of obtaining EE. In the case of an add-on device (say, an adjustable-speed drive or ceiling insulation), the incremental cost is simply the installed cost of the measure itself. In the case of equipment that is available in various levels of efficiency (e.g., a central air conditioner), the incremental cost is the excess of the cost of the high-efficiency unit over the cost of the base (reference) unit.

Administrative costs encompass the real resource costs of program administration, including the costs of administrative personnel, program promotions, overhead, measurement and evaluation, and shareholder incentives. In this context, administrative costs are not defined to include the costs of various incentives (e.g., customer rebates and salesperson incentives) that may be offered to encourage certain types of behavior. The exclusion of these incentive costs reflects the fact that they are essentially transfer payments. That is, from a societal perspective they involve offsetting costs (to the program administrator) and benefits (to the recipient).

A.1.2.2 Use of the Total Resource Cost to Estimate Economic Potential

We often use the TRC test in two ways in our model. First, we develop an estimate of economic potential by calculating the TRC of individual measures and applying the methodology described below. Second, we develop estimates of whether different program scenarios are cost effective.

Economic potential can be defined either inclusively or exclusively of the costs of programs that are designed to increase the adoption rate of EE measures. *In many of our projects, we define economic potential to* ***exclude*** *program costs*. We do so primarily because program costs are dependent on a number of factors that vary significantly as a function of program delivery strategy. There is no single estimate of program costs that would accurately represent such costs across the wide range of program types and funding levels possible. Once an assumption is made about program costs, one must also link those assumptions to expectations about market response to the types of interventions assumed. Because of this, we believe it is more appropriate to factor program costs into our analysis of *program potential*. Thus, our definition of *economic potential* is that portion of the technical potential that passes our economic screening test (described below) exclusive of program costs. Economic potential, like technical potential, is a theoretical quantity that will exceed the amount of potential we estimate to be achievable through current or more aggressive program activities.

As implied in Table A-3 and defined in the CASPM 2001, the TRC focuses on resource savings and counts benefits as utility-avoided supply costs and costs as participant costs and utility program costs. It ignores any impact on rates. It also treats financial incentives and rebates as transfer payments; i.e., the TRC is not affected by incentives. The somewhat simplified benefit and cost formulas for the TRC are presented in Equations A-1 and A-2 below.

Equation A-1

$$\text{Benefits} = \sum_{t=1}^{N} \frac{\text{Avoided Costs of Supply}_{p,t}}{(1+d)^{t-1}}$$

Equation A-2

$$\text{Costs} = \sum_{t=1}^{N} \frac{\text{Program Cost}_{t} + \text{Participant Cost}_{t}}{(1+d)^{t-1}}$$

Where:

d	= the discount rate
p	= the costing period
t	= time (in years)
n	= 20 years

A nominal discount rate is typically used in the analysis, as inflation is taken into account separately. We use a *normalized* measure life of 20 years to capture the benefit of long-lived measures. Measures with measure lives shorter than 20 years are "re-installed" in our analysis as many times as necessary to reach the normalized 20-year life of the analysis.

The avoided costs of supply are calculated by multiplying measure energy savings and peak demand impacts by per-unit avoided costs by costing period. Energy savings are allocated to costing periods and peak impacts estimated using load shape factors.

As noted previously, in the *measure-level* TRC calculation used to estimate economic potential, program costs are excluded from Equation A-2. Using the supply curve methodology discussed previously, measures are ordered by TRC (highest to lowest) and then the *economic* potential is calculated by summing the energy savings for all of the technologies for which the marginal TRC test is greater than 1.0. In the example in Table A-4, the economic potential would include the savings for measures 1 and 2, but exclude saving for measure 3 because the TRC is less than 1.0 for measure 3. The supply curve methodology, when combined with estimates of the TRC for individual measures, produces estimates of the economic potential of efficiency improvements. By definition and intent, this estimate of economic potential is a theoretical quantity that will exceed the amount of potential we estimate to be achievable through program activities in the final steps of our analyses.

Table A-4
Sample Use of Supply Curve Framework to Estimate Economic Potential
(*Note: Data are illustrative only*)

Measure	Total End Use Consumption of Population (GWh)	Applicable, Not Complete and Feasible Sq.Feet (000s)	Average kWh/ft^2 of population	Savings %	GWh Savings	Total Resource Cost Test	Savings Included in Economic Potential?
Base Case: T12 lamps with Magnetic Ballast	425	100,000	4.3	N/A	N/A	N/A	N/A
1. T8 w. Elec. Ballast	425	100,000	4.3	21%	89	2.5	Yes
2. Occupancy Sensors	336	40,000	3.4	10%	13	1.3	Yes
3. Perimeter Dimming	322	10,000	3.2	45%	14	0.8	No
Technical Potential with all measures				27%	116		
Economic Potential with measures for which TRC Ratio > 1.0				24%	102		

A.1.3 Estimation of Program and Naturally occurring Potentials

In this section we present the method we employ to estimate the fraction of the market that adopts each EE measure in the presence and absence of EE programs. We define:

- **Program potential** as the amount of savings that would occur in response to one or more specific market interventions
- **Naturally occurring potential** as the amount of savings estimated to occur as a result of normal market forces, that is, in the absence of any utility or governmental intervention.

Our estimates of program potential are typically the most important results of the modeling process. Estimating technical and economic potentials are necessary steps in the process from which important information can be obtained; however, the end goal of the process is better understanding how much of the remaining potential can be captured in programs, whether it would be cost-effective to increase program spending, and how program costs may be expected to change in response to measure adoption over time.

A.1.3.1 Adoption Method Overview

We use a method of estimating adoption of EE measures that applies equally to be our program and naturally occurring analyses. Whether as a result of natural market forces or aided by a program intervention, the rate at which measures are adopted is modeled in our method as a function of the following factors:

- The availability of the adoption opportunity as a function of capital equipment turnover rates and changes in building stock over time
- Customer awareness of the efficiency measure
- The cost-effectiveness of the efficiency measure
- Market barriers associated with the efficiency measure.

The method we employ is executed in the measure penetration module of KEMA's DSM ASSYST™ model.

In many of our projects, only measures that pass the measure-level TRC test are put into the penetration module for estimation of customer adoption.

A.1.3.2 Availability

A crucial part of the model is a stock accounting algorithm that handles capital turnover and stock decay over a period of up to 20 years. In the first step of our achievable potential method, we calculate the number of customers for whom each measure will apply. The input to this calculation is the total floor space available for the measure from the technical potential analysis, i.e., the total floor space multiplied by the applicability, not complete, and feasibility factors described previously. We call this the *eligible* stock. The stock algorithm keeps track of the amount of floor space available for each efficiency measure in each year based on the total eligible stock and whether the application is new construction, retrofit, or replace-on-burnout.[4]

Retrofit measures are available for implementation by the entire eligible stock. The eligible stock is reduced over time as a function of adoptions[5] and building decay.[6] Replace-on-burnout measures are available only on an annual basis, approximated as equal to the inverse of the service life.[7] The annual portion of the eligible market that does not accept the replace-on-burnout measure does not have an opportunity again until the end of the service life.

New construction applications are available for implementation in the first year. Those customers that do not accept the measure are given subsequent opportunities corresponding to whether the measure is a replacement or retrofit-type measure.

A.1.3.3 Awareness

In our modeling framework, customers cannot adopt an efficient measure merely because there is stock available for conversion. Before they can make the adoption choice, they must be aware and informed about the efficiency measure. Thus, in the second stage of the process, the model calculates the portion of the available market that is *informed*. An initial user-specified parameter sets the initial level of awareness for all measures. Incremental awareness occurs in the model as a function of the amount of money spent on awareness/information building and how well those information-building resources are directed to target markets. User-defined program characteristics determine how well information-building money is targeted. Well-targeted programs are those for which most of the money is spent informing only those customers that are in a position to implement a particular group of measures. Untargeted programs are those in which advertising cannot be well focused on the portion of the market that is available to implement particular measures. The penetration module in DSM ASSYST has a target effectiveness

[4] Replace-on-burnout measures are defined as the efficiency opportunities that are available only when the base equipment turns over at the end of its service life. For example, a high-efficiency chiller measure is usually only considered at the end of the life of an existing chiller. By contrast, retrofit measures are defined to be constantly available, for example, application of a window film to existing glazing.

[5] That is, each square foot that adopts the retrofit measure is removed from the eligible stock for retrofit in the subsequent year.

[6] Buildings do not last forever. An input to the model is the rate of decay of the existing floor space. Floor space typically decays at a very slow rate.

[7] For example, a base-case technology with a service life of 15 years is only available for replacement to a high-efficiency alternative each year at the rate of 1/15 times the total eligible stock. For example, the fraction of the market that does not adopt the high-efficiency measure in year t will not be available to adopt the efficient alternative again until year $t + 15$.

parameter that is used to adjust for differences in program advertising efficiency associated with alternative program types.

The model also controls for information retention. An information decay parameter in the model is used to control for the percentage of customers that will retain program information from one year to the next. Information retention is based on the characteristics of the target audience and the temporal effectiveness of the marketing techniques employed.

A.1.3.4 Adoption

The portion of the total market this is available and informed can now face the choice of whether or not to adopt a particular measure. Only those customers for whom a measure is available for implementation (stage 1) and, of those customers, only those who have been informed about the program/measure (stage 2), are in a position to make the implementation decision.

In the third stage of our penetration process, the model calculates the fraction of the market that adopts each efficiency measure as a function of the participant test. The participant test is a benefit-cost ratio that is generally calculated as follows:

Equation A-3

$$\text{Benefits} = \sum_{t=1}^{N} \frac{\text{Customer Bill Savings (\$)}_t}{(1+d)^{t-1}}$$

Equation A-4

$$\text{Costs} = \sum_{t=1}^{N} \frac{\text{Participant Costs (\$)}_t}{(1+d)^{t-1}}$$

Where:

d = the discount rate
t = time (in years)
n = 20 years

We use a *normalized* measure life of 20 years in order to capture the benefits associated with long-lived measures. Measures with lives shorter than 20 years are “re-installed” in our analysis as many times as necessary to reach the normalized 20-year life of the analysis.

The bill reductions are calculated by multiplying measure energy savings and customer peak demand impacts by retail energy and demand rates.

The model uses measure implementation curves to estimate the percentage of the informed market that will accept each measure based on the participant’s benefit-cost ratio. The model provides enough flexibility so that each measure in each market segment can have a separate implementation rate curve. The functional form used for the implementation curves is:

$$y = \frac{a}{\left(1 + e^{-\ln \frac{x}{4}}\right) \times \left(1 + e^{-c\ln(bx)}\right)}$$

where:

y = the fraction of the market that installs a measure in a given year from the pool of informed applicable customers;

x = the customer’s benefit-cost ratio for the measure;

a = the maximum annual acceptance rate for the technology;

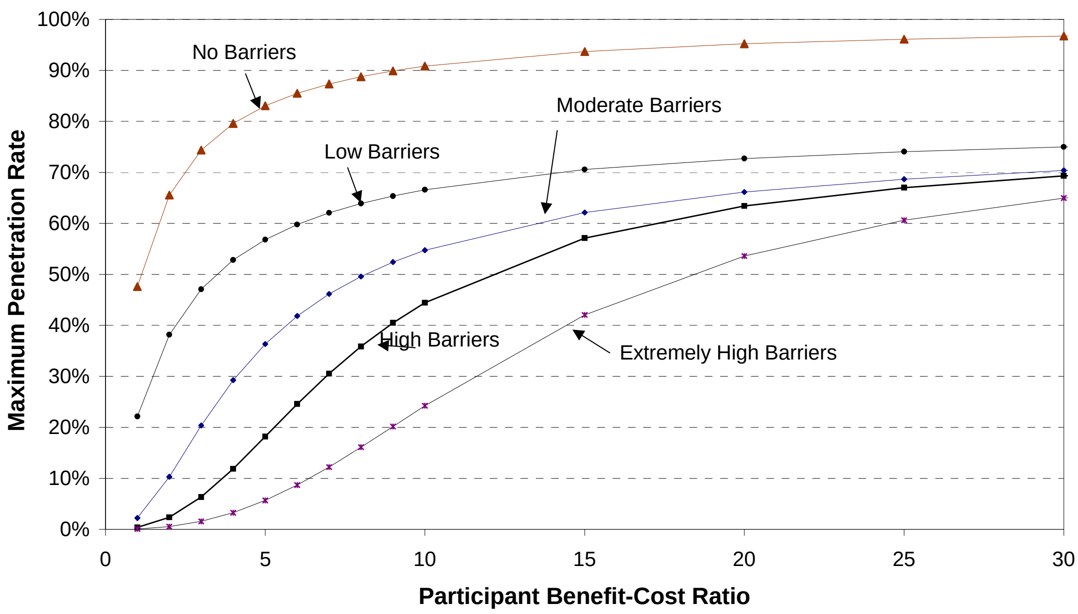
b = the inflection point of the curve. It is generally 1 over the benefit-cost ratio that will give a value of 1/2 the maximum value; and

c = the parameter that determines the general shape (slope) of the curve.

The primary curves utilized in our model are shown in Figure A-3. These curves produce base year program results that are calibrated to actual measure implementation results associated with major IOU commercial efficiency programs over the past several years. Different curves are used to reflect different levels of market barriers for different efficiency measures. A list of market barriers is shown in Table A-5. It is the existence of these barriers that necessitates program interventions to increase the adoption of EE measures.

Figure A-3

Primary Measure Implementation Curves Used in Adoption Model



Note that for the moderate, high barrier, and extremely high curves, the participant benefit-cost ratios have to be very high before significant adoption occurs. This is because the participant benefit-cost ratios are based on a 15-percent discount rate. This discount rate reflects likely adoption if there were no market barriers or market failures, as reflected in the no-barriers curve in the figure. Experience has shown, however, that actual adoption behavior correlates with implicit discount rates several times those that would be expected in a perfect market.[8]

[8] For some, it is easier to consider adoption as a function of simple payback. However, the relationship between payback and the participant benefit-cost ratio varies depending on measure life and discount rate. For a long-lived measure of 15 years with a 15-percent discount rate, the equivalent payback at which half of the market would adopt a measure is roughly 6 months, based on the high barrier curve in Figure 2-3. At a 1-year payback, one-quarter of the market would adopt the measure. Adoption reaches near its maximum at a 3-month payback. The curves reflect the real-world observation that implicit discount rates can average up to 100 percent.

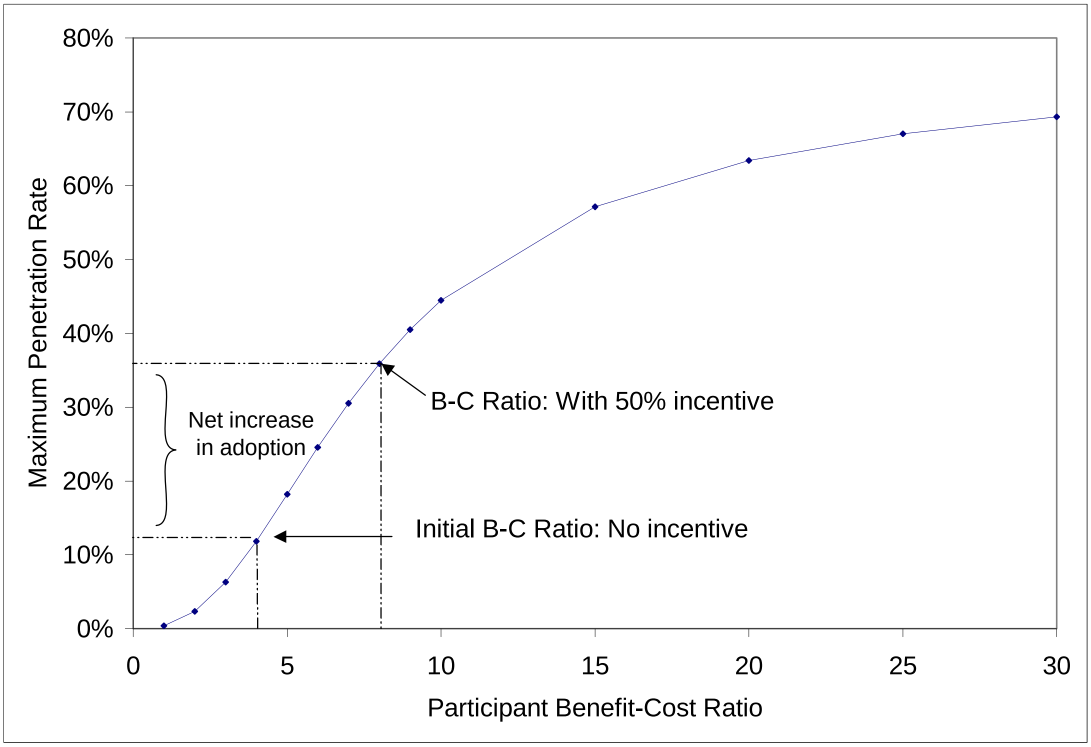
Table A-5

Summary Description of Market Barriers from Eto, Prahl, Schlegel 1997

Barrier	Description
Information or Search Costs	The costs of identifying energy-efficient products or services or of learning about energy-efficient practices, including the value of time spent finding out about or locating a product or service or hiring someone else to do so.
Performance Uncertainties	The difficulties consumers face in evaluating claims about future benefits. Closely related to high search costs, in that acquiring the information needed to evaluate claims regarding future performance is rarely costless.
Asymmetric Information and Opportunism	The tendency of sellers of energy-efficient products or services to have more and better information about their offerings than do consumers, which, combined with potential incentives to mislead, can lead to sub-optimal purchasing behavior.
Hassle or Transaction Costs	The indirect costs of acquiring EE, including the time, materials and labor involved in obtaining or contracting for an energy-efficient product or service. (Distinct from search costs in that it refers to what happens once a product has been located.)
Hidden Costs	Unexpected costs associated with reliance on or operation of energy-efficient products or services - for example, extra operating and maintenance costs.
Access to Financing	The difficulties associated with the lending industry's historic inability to account for the unique features of loans for energy savings products (i.e., that future reductions in utility bills increase the borrower's ability to repay a loan) in underwriting procedures.
Bounded Rationality	The behavior of an individual during the decision-making process that either seems or actually is inconsistent with the individual's goals.
Organization Practices or Customs	Organizational behavior or systems of practice that discourage or inhibit cost-effective EE decisions, for example, procurement rules that make it difficult to act on EE decisions based on economic merit.
Misplaced or Split incentives	Cases in which the incentives of an agent charged with purchasing EE are not aligned with those of the persons who would benefit from the purchase.
Product or Service Unavailability	The failure of manufacturers, distributors or vendors to make a product or service available in a given area or market. May result from collusion, bounded rationality, or supply constraints.
Externalities	Costs that are associated with transactions, but which are not reflected in the price paid in the transaction.
Non-externality Pricing	Factors other than externalities that move prices away from marginal cost. An example arises when utility commodity prices are set using ratemaking practices based on average (rather than marginal) costs.
Inseparability of Product Features	The difficulties consumers sometimes face in acquiring desirable EE features in products without also acquiring (and paying for) additional undesired features that increase the total cost of the product beyond what the consumer is willing to pay.
Irreversibility	The difficulty of reversing a purchase decision in light of new information that may become available, which may deter the initial purchase, for example, if energy prices decline, one cannot resell insulation that has been blown into a wall.

The model estimates adoption under both naturally occurring and program intervention situations. There are only two differences between the naturally occurring and program analyses. First, in any program intervention case in which measure incentives are provided, the participant benefit-cost ratios are adjusted based on the incentives. Thus, if an incentive that pays 50 percent of the incremental measure cost is applied in the program analysis, the participant benefit-cost ratio for that measure will double (since the costs have been halved). The effect on the amount of adoption estimated will depend on where the pre- and post-incentive benefit-cost ratios fall on the curve. This effect is illustrated in Figure A-4.

Figure A-4
Illustration of Effect of Incentives on Adoption Level as Characterized in Implementation Curves



In many of our projects achievable potential EE forecasts are developed for several scenarios, ranging from base levels of program intervention, through moderate levels, up to an aggressive EE acquisition scenario. Uncertainty in rates and avoided costs are often characterized in alternate scenarios. The final results produced are annual streams of achievable program impacts (energy and demand by time-of-use period) and all societal and participant costs (program costs plus end-user costs).

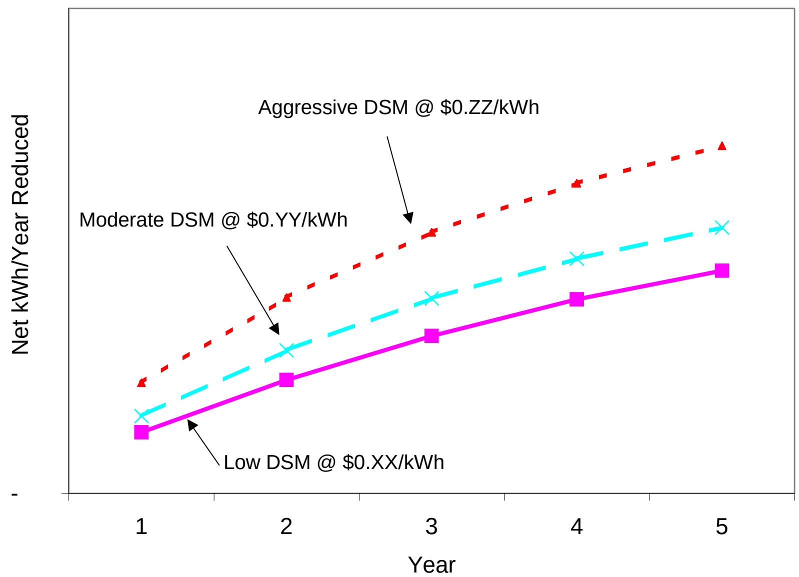
A.1.4 Scenario Analyses

Achievable potential forecasts can be developed for multiple scenarios. For example, program savings can be modeled under low levels of program intervention, through moderate levels, up to an aggressive DSM acquisition scenario. Uncertainty in rates and avoided costs can be characterized in alternate scenarios as well. The final results produced will be annual streams of achievable DSM program impacts (energy and demand by time-of-use period) and all societal and participant costs. An example of the types of outputs that have been produced for similar studies in the past is shown in Table A-6 and Figure A-5.

Table A-6
Example Format of DSM ASSYST Achievable Potential Outputs

DSM ASSYST Program Output	2006	2007	2008	etc.
Annual Energy Savings (kWh)				
Summer Period Energy Savings (kWh)				
Non Summer Period Energy Savings (kWh)				
Net Annual Energy Savings (kWh)				
Summer Period Net Energy Savings (kWh)				
Non Summer Period Net Energy Savings (kWh)				
Peak Demand Savings (kW)				
Net Peak Demand Savings (kW)				
Annual Program Costs				
Supplemental Customer Costs				

Figure A-5
Example of DSM Scenario Outputs



A.1.5 Measure "Bundles" for Complex End Uses

Although potential can be estimated through measure-specific analyses for many sectors and end uses, there are some cases where the measure-specific approach becomes problematic because of the complexity or heterogeneity of the base-case energy systems being addressed. Two key examples are industrial processes and some aspects of residential and commercial new construction.

In the industrial case, there may be dozens or even hundreds of individual measures that can be applied to industrial processes throughout the population of industrial facilities in a service territory; however, analyzing each of these opportunities, though possible, is impractical within a resource and time-constrained study such as this one.

In the case of new construction, the problem is sometimes that an equipment substitution paradigm does not fit the real-world circumstances in which efficiency levels are improved. For example, in commercial lighting, virtually all new buildings tend to have electronic ballasts and T-8 lamps, as well as CFLs, and other high-efficiency components. These high-efficiency components are generally needed to meet Title 24 efficiency requirements; however, the overall lighting system efficiency can often be increased by using these same components in smarter designs configurations or by combining with other features such as daylighting.

For both of these situations, our approach on recent related work has been to bundle multiple individual efficiency measures into somewhat simplified efficiency levels. For example, lighting levels for commercial new construction might be set at 10- and 20-percent improvement over Title 24 standards (as they are often specified in the Savings by Design program planning documents). Similarly, for industrial compressed air systems, we have bundled savings opportunities into three levels where both savings and costs increase with each level. We then estimate an incremental cost for achieving each of the efficiency levels. An example of these results developed in a recent study for industrial motors, compressed air, and processes in California is shown in Table A-7.

Once the levels efficiency are specified in terms of costs and savings, they are run through the modeling system as if they were individual measures. Thus, cost-effectiveness indicators are calculated for each level, those that pass the TRC are included in the achievable potential forecasting, and adoption is modeled using the same process as described above. Although we recommend using this approach for complex end uses in the proposed study because it creates a manageable forecasting process, care must be taken in developing the levels and recognizing that this approach results in some aggregation bias.

A.2 DSM ASSYST™ Model Description

DSM ASSYST™ (Demand-Side Management Technology Assessment System) is a tool developed to assess the technical, economic and market potential of DSM technologies in the residential, commercial and industrial sectors. Based on user-specified information about base technologies, conservation technologies, load shapes, utility avoided costs, utility service rates, and economic parameters, DSM ASSYST yields numeric data for a variety of criteria. The user can then evaluate and compare technologies. DSM ASSYST allows the user to analyze each DSM technology in multiple combinations of building types, market segments, end uses, and vintages both individually and compared to other DSM technology options.

Table A-7

Example of Industrial Efficiency Levels Developed for a Recent California Potential Study

DSM ASSYST ADDITIVE SUPPLY ANALYSIS			Year	2011			
		Vintage: Existing Sector: Industrial Scenario: Base			Levelized Cost per KWh Saved	Levelized Cost per KW Saved	Total Resource Cost Test
End Use	Measure Number	Measure	GWH Savings	MW Savings	$/kWH	$/kW	TRC
Motors	101	Replace 1-5 HP Motor	248.7	34.1	$0.10	$698	0.8
Motors	102	Add 1-5 HP VSD	447.1	61.3	$0.14	$1,019	0.6
Motors	103	Motor Practices Level 1	607.0	83.2	$0.06	$440	1.3
Motors	104	Motor Practices Level 2	539.1	73.9	$0.24	$1,764	0.3
Motors	121	Replace 21-50 HP Motor	78.1	10.7	$0.09	$661	0.9
Motors	122	Add 21-50 HP VSD	319.0	43.7	$0.04	$278	2.1
Motors	123	Motor Practices Level 1	404.3	55.4	$0.03	$211	2.7
Motors	124	Motor Practices Level 2	361.9	49.6	$0.12	$840	0.7
Motors	151	Replace 201-500 HP Motor	143.5	19.7	$0.03	$201	2.8
Motors	152	Add 201-500 HP VSD	516.6	70.8	$0.01	$106	5.4
Motors	153	Motor Practices Level 1	598.6	82.0	$0.02	$152	3.7
Motors	154	Motor Practices Level 2	554.9	76.0	$0.08	$586	1.0
Compressed Air	202	CAS Level 1	433.9	59.5	$0.02	$168	3.4
Compressed Air	203	CAS Level 2	453.6	62.2	$0.05	$362	1.6
Compressed Air	204	CAS Level 3	325.5	44.6	$0.13	$936	0.6
Other Process	301	Process Level 1	1,031.8	141.4	$0.03	$190	3.0
Other Process	302	Process Level 2	1,219.7	167.1	$0.05	$345	1.7
Other Process	303	Process Level 3	767.3	105.1	$0.25	$1,831	0.3

The current version of DSM ASSYST uses a combination of Microsoft Excel spreadsheets and Visual Basic (VB) programming software. All input and output data are stored in spreadsheets. The VB modules read input data from various spreadsheets, perform the various analyses, and store output results into spreadsheets.

There are three major VB analysis modules: Basic, Supply, and Penetration. Figure A-6 provides an overview of the model process and key inputs. Each module is briefly described below.

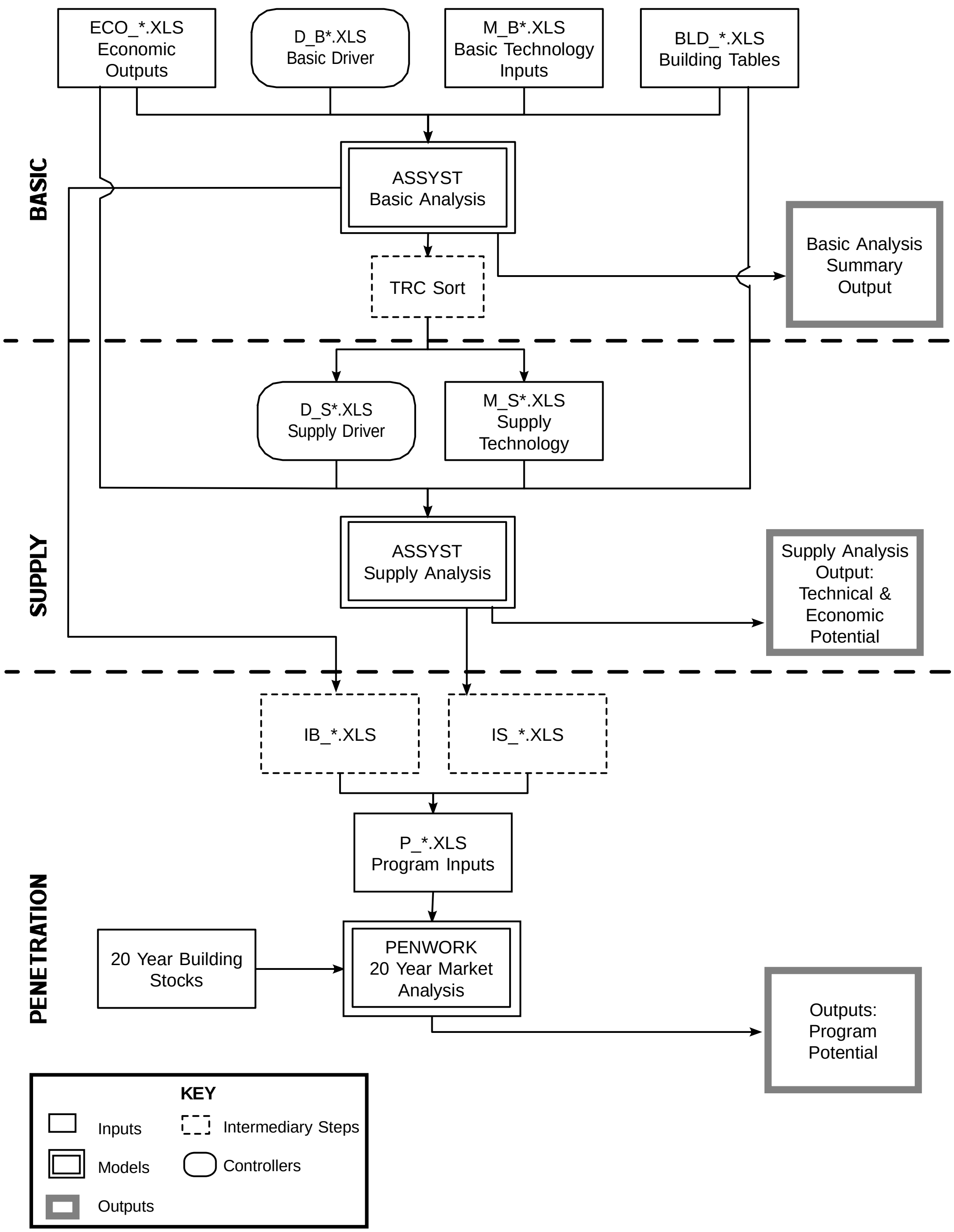
A.2.1 Basic Module

In the Basic module, each technology is assessed individually by comparing it to a base case. Comparisons are made at a high degree of segmentation. The segmentation may include, but is not limited to sector, building type, end use, vintage and geographic area.

The Basic module reads four types of information, contained within four spreadsheet files. These files include:

- **Economic**: containing utility rates paid by customers, discount rates, avoided costs, and other utility-specific economic parameters
- **Building**: containing square footage or number of households and load shape data
- **Measure**: containing technology based inputs for the Basic Analysis
- **Driver**: containing information that drives the analysis process.

Figure A-6
DSM ASSYST Analytic Flow



The output files produced by the Basic module include a Summary Basic Output file that contains an assessment of how much energy and demand each technology will save relative to the base case within each segment. In addition, the summary contains cost data, savings fractions, before and after EUIs or UECs, service life, the levelized costs of implementing the technology, and results of economic tests including the TRC test, participant test, and customer payback.

This module also produces a second file that contains all the measures that were assessed in the Basic Analysis sorted in the highest to lowest TRC order within each market segment and end use. This file serves as an input file for the Supply module.

A.2.2 Supply Module

In the Supply Module each technology, within each market segment, is stacked, or implemented, such that all energy savings are realized from preceding technologies prior to the implementation of all subsequent technologies. The stacking order generally follows the TRC sort order, highest to lowest, resulting from the Basic module.

The Supply module requires two input files: a Driver file and a modified output file from the Basic module. As in the Basic module, the Driver file contains instructions for the analysis process. The output file from the basic analysis must be modified in Excel to address overlapping measures, such as different SEER levels or measures that are direct substitutes for each other.

Output from the Supply module contains the technical and economic potential plus energy and demand supply curves. The Supply module produces measure-level information that can be incorporated into the input file for the Penetration module

A.2.3 Penetration Module

The Penetration (or Program Potential) module of ASSYST is designed to calculate the costs and net energy and demand savings from DSM programs under a variety of marketing scenarios. This module estimates the net impact and cost of a program over time by forecasting the naturally occurring penetration of each measure as well as the penetration of each measure given the program activities (i.e., incentives and awareness building).

Using a stock accounting algorithm over a period of 20 years, this module first calculates the number of customers for whom the measure will apply. Second, the model calculates the number of informed customers based on the amount of money spent on advertising. Third, the model calculates the number of customers who will implement the technology based on their benefit/cost ratio. Finally, the model compares the number of customers that implement the technology due to the program with those who would take the technology anyway (naturally occurring). Per-unit energy and demand savings are applied to the net number of customers (total minus naturally occurring) over the 20-year period. After completing the analysis, the results are automatically summed across measures to provide program-level costs and savings for 20 years, and formatted for input into Integrated Resource Planning models.

A program input file is used to define a program and provide the building stock forecast. The program characterization variables include:

- Incentive Levels
- Incentive Budget Constraints
- Yearly Incentive Adjuster
- Technology Acceptance Curve Parameters
- Administration Budgets
- Advertising Budgets
- Awareness Decay Rate
- Target Effectiveness
- Advertising Effective Ratio.

B. Appendix B: Measure Descriptions

This appendix describes the energy efficiency measures used in the study.

B.1 Residential Electric Measures

This subsection provides brief descriptions of the residential electric measures included in this study. Measures are grouped by end use.

B.1.1 HVAC Equipment

Central Air Conditioner Upgrade: Air conditioner equipment includes a compressor, an air-cooled or evaporatively-cooled condenser (located outdoors), an expansion valve, and an evaporator coil (located in the supply air duct near the supply fan). Cooling efficiencies vary based on the quality of the materials used, the size of equipment, the condenser type, and the configuration of the system. Central air conditioners may be of the unitary variety (all components housed in a factory-built assembly) or be a split system (an outdoor condenser section and an indoor evaporator section connected by refrigerant lines and with the compressor at either the outdoor or indoor location). Efficient air conditioner measures involve the upgrade of a standard efficiency unit (13 SEER) to a higher efficiency unit (14 SEER or higher).

Proper Refrigerant Charging and Air Flow: This measure involves diagnostic and repair services for existing central air conditioners to improve their efficiency. Inspection and services of AC systems involves checking the refrigerant level, cleaning the coils, cleaning the blower, cleaning or replacing filters, and making sure air is flowing properly through the system.

High Efficiency Room Air Conditioner: Window (or wall) mounted room air conditioners are designed to cool individual rooms or spaces. This type of unit incorporates a complete air-cooled refrigeration and air-handling system in an individual package. Cooled air is discharged in response to thermostatic control to meet room requirements. Each unit has a self-contained, air-cooled direct expansion (DX) cooling system and associated controls. Room air conditioners are rated by energy efficiency ration (EER), which is cooling output divided by power consumption. The efficient room air conditioner measure involves the upgrade of a standard efficiency unit (9 EER) to a higher efficiency unit (11.3 EER).

Room Air Conditioner Early Replacement: For this measure we assume replacement of an older room air conditioner (EER 8.5) with a new high-efficiency unit (EER 11.3). Energy savings are diminished to account for the fact that a fraction of the associated energy savings would have been realized at the end of the older unit’s useful life, when a minimum EER unit would have been purchased as a replacement.

Air Source Heat Pump (for space heating): Heat pumps consist of a refrigeration system using a direct expansion cycle. Equipment includes a compressor, an air-cooled or evaporatively-cooled condenser (located outdoors), an expansion valve, an evaporator coil (located in the supply air duct near the supply fan) and a reversing valve to change the DX cycle from cooling to heating when required. The cooling and heating efficiencies vary based on the quality of the materials used, the size of equipment, the condenser type and the configuration of the system. Heat pumps may be of the unitary variety (all components housed in a factory-built assembly) or be a split system (an outdoor condenser section and an indoor evaporator section connected by refrigerant lines and with the compressor at either the outdoor or indoor location).

Ground Source Heat Pump (GSHP) with Desuperheater: Also referred to as geoexchange, geothermal, earth-coupled, or water-source heat pumps, these units operate on the same principle as an air source heat pump, but use ground or groundwater as a heat sink and source instead of air. The earth is a relatively constant year-round temperature a few feet below ground level, and GSHPs capture this energy for heating or cooling by:

- directly circulating refrigerant through copper pipes in the earth ("direct exchange" systems)
- using a heat exchanger to transfer 2-3 gallons/minute/ton of fluid sourced from:
  - a water loop drawn from a well ("open" or "groundwater")
  - polyethylene pipes installed vertically in boreholes that are 200' to 300' deep or laid horizontally a few feet below ground and filled with water or glycol ("closed," or "ground loop")

Desuperheaters are a heat exchanger installed between the compressor and primary condenser providing auxiliary heat for domestic hot water when the unit is running.

High-Efficiency Dehumidifier: ENERGY STAR®-qualified dehumidifiers use less energy to remove moisture from the air on account of more efficient refrigeration coils, fans, and compressors.

Heat Recovery Ventilators (HRV): Typically installed in ducted whole-house mechanical ventilation systems, these heat exchangers use air from return ducts to pre-heat or cool air in the HVAC air handler, thus recovering energy which would ordinarily be exhausted to the atmosphere. If the unit also exchanges moisture between the two airstreams, it is referred to as an energy recovery ventilator (ERV).

Whole House Fans: Whole house fans keep a home cool during the cooling months instead of running the air conditioner. These fans typically consume 0.22kW (1/3 hp), about one-third the consumption of a central air conditioner. These fans pull cool air from the outside, move air through the house, and/or remove hot air through the attic.

Ceiling Fans: ENERGY STAR Ceiling Fans save energy through improved motors and blade designs. Ceiling fans save energy from space conditioning in the summer by creating a wind chill, and during the winter by distributing hot air evenly throughout the room.

Variable Speed Furnace/AC Fans: Air handler models with the lowest electrical use ratings employ electronically commutated motors (ECMs). ECMs, also known as brushless DC motors or variable speed blower motors, have two principal advantages over the typical permanent-magnet split capacitor (PSC) blower motors found in the majority of air handlers. First, ECMs are claimed to be 20% to 30% more efficient than standard blower motors. Second, the typical ECM blower can produce a much wider range of airflow than a PSC blower, which typically has only three or four set speeds over a fairly narrow range. Because power consumption by an air handler rises with the cube of airflow, the ability to reduce airflow when appropriate can dramatically reduce the electrical power draw by the air handler.

Proper Sizing and Quality Install: Most HVAC systems are typically over-sized by contractors for a variety of reasons: as a precaution against peak day temperatures or future problems from duct leaks, improper flow across the coils, and improper charge, or because they replace older systems with the same size (or larger) unit – even though the house may have been made more energy efficient since it was originally constructed (through home improvements, window replacements, insulation, caulking, and so on). Oversized air conditioners will be more expensive and tend to cycle, rather than run continuously, during both typical and peak cooling periods. This more frequent cycling reduces overall operating efficiency and also results in more variable indoor humidity levels. This measure assumes the contractor performs an Air Conditioning Contractors of America (ACCA) Manual J calculation to size the HVAC system and an ACCA Manual D calculation to size the ducts. These calculations take into account climate, house and site characteristics and orientation, air exchange rates, occupancy, and heat-emitting appliances.

Programmable Thermostat: ENERGY STAR® programmable thermostats come pre-programmed with settings intended to deliver energy savings without sacrificing comfort. The settings vary for the cooling and heating months, with specific temperature ranges and setback points for the morning, daytime, evening, and night. Programmable thermostat settings may also be changed to reflect individual schedules and preferences.

B.1.2 Building Envelope

Duct Repair: An ideal duct system would be free of leaks, especially when the ducts are outside the conditioned space. Leakage in unsealed ducts varies considerably with the fabricating machinery used, the methods for assembly, installation workmanship, and age of the ductwork. To seal ducts, a wide variety of sealing methods and products exist. Care should be taken to tape or otherwise seal all joints to minimize leakage in all duct systems and the sealing material should have a projected life of 20 to 30 years. Current duct sealing methods include use of computer-controlled aerosol and pre- and post-sealing duct pressurization testing.

Duct Insulation: Insulation material inhibits the transfer of heat through the air-supply duct. Several types of ducts and duct insulation are available, including flexible duct, pre-insulated flexible duct, duct board, duct wrap, tacked or glued rigid insulation, and water proof hard shell materials for exterior ducts. Duct insulation for existing construction involves wrapping un-insulated ducts with an R-4 insulating material.

Sealed Attic w/Sprayed Foam Insulated Roof Deck: By applying expanding sprayed foam insulation directly to the underside of the roof down to the soffit areas and gable end walls, this measure seals the entire attic space and significantly reduces heat gain from the exterior roof. This effectively brings the duct system into the conditioned space of the house, resulting in reduced attic temperatures and reduced radiative losses in the duct system, as well as reduced humidity and infiltration.

Cool Roof: ENERGY STAR®-qualified roofing shingles and tiles reflect more sunlight and can lower the temperature of a roof considerably, diminishing solar gain. This increases winter heating loads but reduces summer cooling loads, especially peak cooling demand. Consumers frequently prefer colored or dark roofing products, but since the visible spectrum accounts for less than half of the total energy in the sun's rays, substantial amounts of energy can be reflected without even changing the color of the roofing product, and several commercial roofing products have developed in coordination with Lawrence Berkeley National Laboratory to take advantage of this.

Window Film: This measure involves application of a dark-colored film to the existing windows of a home. The film lowers the shading coefficient of a window, reducing the amount of solar heat gain of a building, and thus decreasing the cooling load for the building.

Default Window with Sunscreen: This measure prevents direct sunlight on window surfaces, reducing solar gain and consequent cooling requirements.

Windows - Add Storm Windows: These are installed on the exterior or interior of the primary window and reduce air infiltration by sealing tightly to the window frame. Interior storm windows are typically less costly and easier to install, and also save more energy, because the exterior storm windows require drainage holes to vent excess moisture. Although some models offer multiple glazing and low-e coatings, they are typically cost-comparable with new windows.

ENERGY STAR® Windows: Windows which meet the ENERGY STAR® requirements have U-value and solar heat gain coefficients (SHGC) specified by climate zone, and are certified by the National

Fenestration Rating Council (NFRC). These are modeled as a replace on burnout measure, so the costs are not the full cost of the window and installation, but rather the cost compared to installing a new non-ENERGY STAR® window.

Heat Shrink Wrap Film (1-2 yr measure, window kit): This heavy-duty clear plastic is taped onto the inside of window frames and is heat-activated (typically with a hair dryer) to shrink until it stretches tightly across the frame, thereby reducing air infiltration without impacting visibility. The plastic is usually removed at the end of the heating season and can be re-used.

Comprehensive Shell Air Sealing - Infiltration Reduction: Professional installation of weather stripping, caulking, and expanding foam insulation aided by a blower door test. These measures reduce energy consumption by improving the tightness of the building shell and limiting heat gain and loss.

Self-Install Weatherization: Installation of weather stripping, caulking, and expanding foam insulation from a spray can to fix easily found leaks and reduce air infiltration, completed by the homeowner.

Ceiling and Floor Insulation: Thermal insulation is material or combinations of materials that are used to inhibit the flow of heat energy by conductive, convective, and radiative transfer modes. By inhibiting the flow of heat energy, thermal insulation can conserve energy by reducing heat loss or gain of a structure. An important characteristic of insulating materials is the thermal resistivity, or R-value. The R-value of a material is the reciprocal of the time rate of heat flow through a unit of this material in a direction perpendicular to two areas of different temperatures.

Crawlspace Insulation. As an alternative to floor insulation, crawlspace walls may be insulated. Because an insulated but unheated crawlspace can create moisture problems, the floor of the crawlspace should also be sealed with a vapor barrier. Insulating a crawlspace includes rim joist insulation.

Basement Insulation. Basement walls are typically insulated by constructing a stud wall inside the house foundation, and insulating it as any interior wall. This increases the cost of basement insulation compared to crawlspace insulation (in addition to the taller wall height to be insulated). The cost-effectiveness of basement insulation depends on whether the basement will be conditioned. Basement insulation includes rim joist insulation.

Wall Insulation: For existing construction, this measure involves adding R-13 insulation to un-insulated walls. This is usually accomplished by drilling holes into the building's siding or interior walls and blowing in insulation material.

B.1.3 Lighting

Compact Fluorescent Lighting (CFLs): Compact fluorescent lamps are designed to replace standard incandescent lamps. They are approximately four times more efficient than incandescent light sources. Screw-in modular lamps have reusable ballasts that typically last the life of four lamps. This study takes into account recently enacted Federal standards under the Energy Policy and Conservation Act. The standards mandate an increase in efficiency of approximately 30% for the majority of residential incandescent light bulbs using a phased approach, beginning with 100 watt bulbs in 2012 and ending with 40 watt bulbs in 2014. It was assumed that this would result in a shift to CFL bulbs as a baseline for the specified bulb types.

LED General Purpose Lighting: A light emitting diode (LED) is a solid state lighting (SSL) technology that produces light by passing electrons through a semiconductor material, which is mounted on a heat sink and encased in a lens. Each LED is 7 mm to 9 mm on a side, and typically mounted in arrays on a circuit board, which is in turn mounted on another heat sink and encased in a fixture or bulb. This technology is revolutionizing the field in terms of light quality, energy efficiency, and design. However, poor manufacture has led to a range of problems in early products, notably color degradation and prematurely dimmed diodes from under-performing heat sinks, and “burnt out” diodes from faulty circuit boards. ENERGY STAR provides rigorous standards to certify quality LED lighting fixtures, which are commercially available and currently rebated in numerous energy efficiency programs, and has recently completed an LED bulb specification around which products are being rapidly developed.

Super T-8 Lamps with Electronic Ballast: T-8 lamps are a smaller diameter fluorescent lamp than T-12 lamps. When paired with specially designed electronic ballasts, T-8 lamps provide more lumens per watt, resulting in energy savings. Electronic ballasts replace the standard core and coil technology in magnetic ballasts with solid-state components. This technology allows for more consistent control over ballast output and converts power to higher frequencies, causing the fluorescent lamps to operate more efficiently. For existing first generation T-8 systems, this measure is specified as an upgrade to efficiency levels associated with optimal Super T-8 lamp-ballast combinations on a replace-on-burnout basis.

B.1.4 Water Heat

Heat Pump Water Heater: Air-to-water heat pump water heaters extract low-grade heat from the air then transfer this heat to the water by means of an immersion coil. This is the most commonly utilized residential heat pump water heater. The air-to-water heat pump unit includes a compressor, air-to-refrigerant evaporator coil, evaporator fan, water circulating pump, refrigerant-to-water condenser coil, expansion valve, and controls. Residential heat pump water heaters replace base electric units with the same tank capacities.

Integrated Heat Pump Water Heater – these are heat pump water heaters designed to be retrofitted onto the top of common electric water heaters.

High Efficiency Water Heater: Higher efficiency water heaters have greater insulation to reduce standby heat loss.

Solar Water Heater: Heat transfer technology that uses the sun's energy to warm water. Solar water heaters preheat water supplied to a conventional domestic hot water heating system. The energy savings for the system depend on solar radiation, air temperatures, water temperatures at the site, and the hot water use pattern.

Tankless Water Heater: Also known as "instant" or "on-demand" water heaters, tankless units function only when a hot water faucet is turned on. There is no energy required to maintain the temperature of the water in a tank, eliminating standby losses.

Ground Source Heat Pump with Desuperheater: See the full measure description under HVAC Equipment. Desuperheaters are a heat exchanger installed between the compressor and primary condenser providing auxiliary heat for domestic hot water when the unit is running.

Drain Water Heat Recovery (GFX): Gravity film exchange (GFX) drain-water heat recovery systems consist of a copper pipe for incoming cold water coiled tightly around a copper drain-water pipe. When water goes down the drain, it doesn't drop straight down as though poured from a spout, but rather falls against the side of the pipe. This phenomenon allows the GFX unit to easily re-capture some of this energy, as heat is transferred through the copper pipes to the incoming water supply going to the water heater.

Low-Flow Showerhead: Many households are still equipped with showerheads using 3+ gallons per minute. Low flow showerheads can significantly reduce water heating energy for a nominal cost. Typical low-flow showerheads use 1.0-2.5 gallons per minute compared to conventional flow rate of 3.5-6.0 gallons per minute. The reduction in shower water use can substantially lower water heating energy use since showering accounts for about one-fourth of total domestic hot water energy use.

Pipe Wrap: Thermal insulation is material or combinations of materials that are used to inhibit the flow of heat energy by conductive, convective, and radiative transfer modes. By inhibiting the flow of heat energy, thermal insulation can conserve energy by reducing heat loss or gain.

Faucet Aerators: Water faucet aerators are threaded screens that attach to existing faucets. They reduce the volume of water coming out of faucets while introducing air into the water stream. A standard non-conserving faucet aerator has a typical flow rate of 3-5 gallons per minute. A water-saving aerator can reduce the flow to 1-2 gallons per minute. The reduction in the flow rate will lower hot water use and save energy (kitchen and bathroom sinks utilize approximately 7 percent of total domestic hot water energy use).

B.1.5 Appliances

High Efficiency Refrigerator: We model both an ENERGY STAR® and a CEE Tier 2 refrigerator. ENERGY STAR® refrigerators must exceed the stringent July 1, 2001 minimum federal standards for refrigerator energy consumption by at least 10%. As specified for this study, the average efficiency improvement is 20% for ENERGY STAR® and 25% for CEE Tier II. An energy efficient refrigerator/freezer is designed by improving the various components of the cabinet and refrigeration system. These component improvements include cabinet insulation, compressor efficiency, evaporator fan efficiency, defrost controls, mullion heaters, oversized condenser coils, and improved door seals.

Refrigerator/Freezer Recycling: For this measure we assume replacement of an older refrigerator (10 years old or more) with a new standard-efficiency refrigerator. The early replacement assumes that the same new refrigerator would have been bought, only six years later. Savings for this measure result for six years because the newer refrigerators, given the stringent efficiency standards implemented in 2001, use much less energy than older units.

High Efficiency Freezer: Stand-alone freezers include either upright or chest models. Efficient freezers should exceed standard efficiencies by 10 percent or more. As specified for this study, the average efficiency improvement is 15 percent.

ENERGY STAR® Dishwasher: ENERGY STAR® labeled dishwashers save by using both improved technology for the primary wash cycle, and by using less hot water to clean. They include more effective washing action, energy efficient motors and other advanced technology such as sensors that determine the length of the wash cycle and the temperature of the water necessary to clean the dishes.

High Efficiency Clothes Washer: A standard clothes washer uses various temperatures, water levels, and cycle durations to wash clothes depending on the clothing type and size of the laundry load. A high-efficiency vertical-axis clothes washer, which eliminates the warm rinse option and utilizes a spray technology to rinse clothes, can significantly reduce washer-related energy. Such machines also utilize a spin cycle that eliminates more water from the clothes than conventional clothes washers and are generally driven by more efficient motors. A horizontal axis clothes washer utilizes a cylinder that rotates horizontally to wash, rinse, and spin the clothes. These types of washing machines can be top loading or front loading, and utilize significantly less water (hot and cold) than the standard vertical axis machines. A vertical axis machine generally fills the tub until all of the clothes are immersed in water. In contrast, the horizontal axis machine only requires about one third of the tub to be full, since the rotation of the drum around its axis forces the clothes into the water and thus can drastically reduce the total energy use for washing. These machines are also easier on clothes and use less detergent.

High Efficiency Clothes Dryer: High efficiency clothes dryers incorporate moisture sensors and prevent the frequency and magnitude of over-drying compared to clothes dryers without moisture sensors. The Federal minimum Energy Factor (pounds of clothing per kilowatt hour) is 3.01, and does not vary widely between models currently on the market.

Heat Pump Clothes Dryer: These clothes dryers are sometimes referred to as "ventless" dryers because the warm, moist process air is passed in a closed-loop cycle from the tumbler through a heat pump. The refrigerant first takes energy out of the process air sufficient to cool it to the ambient dew point in order to condense any water vapor, which is then drained. Then the cycle transfers heat back into the dehumidified process air, which is passed into the clothes tumbler, and the cycle repeats.

B.1.6 Home Electronics

ENERGY STAR® Home Electronics (Televisions, Set-top Boxes, DVD Players, Laptop and Desktop Computers, Air Cleaners, Battery Chargers, Digital to Analog Converters, External Power Adapters, Home Audio Devices, Cordless Phones)**:** All ENERGY STAR® qualified home electronics have off-mode power draws of 1 watt or less. Some home electronic devices spend the vast majority of their time in off-mode but often continue to draw a small "trickle charge" to maintain clock or other memory functions. Reductions in off-mode power draws can thus produce significant reductions in total energy consumption without changing on-mode power consumption characteristics. Savings from ENERGY STAR® home electronics considered in this study were estimated based on reductions in off-mode power draw from standard to ENERGY STAR® levels.

ENERGY STAR® Ventilating Fans: These fans use improved blade design and high performance motors to significantly increase efficiency while decreasing noise. If the fan has a light source, it must be fluorescent or LED.

Smart Power Strip: These power strips use a variety of controls to reduce standby power consumption of home electronics, including timers, occupancy sensors, and secondary outlets which automatically turn off in tandem with a pre-specified outlet.

B.1.7 Whole House Measures

Behavioral Conservation: Indirect feedback approaches utilize energy information report mailers that motivate customers to use less, while direct feedback interventions use in-home energy-use monitors.

Residential New Construction: Both the ENERGY STAR® New Home and Best Practice New Home measures were directly based on BEopt modeling results completed for the Southwest Energy Efficiency Project's (SWEEP) 2007 study "*High Performance Homes in the Southwest: Savings Potential, Cost Effectiveness and Policy Options*."

B.1.8 Other End Uses

High Efficiency Pool Pump and Motor: This measure involves the replacement of a standard-efficiency motor and low volume pump with a smaller high-efficiency motor and a new high-volume pump.

Two Speed Pool Pump: Two speed pool pumps saves energy by reducing the energy used during ongoing pool filtering operation.

Variable-Speed Pool Pump: This measure saves energy much in the same way as two-speed pool pumps, with the exception that variable-speed pumps are able to further optimize pump operation and pool water flows to match the specific needs and requirements of individual owners.

B.2 Commercial Electric Measures

This subsection provides brief descriptions of the commercial measures included in this study.

B.2.1 Lighting

Super T-8 Lamps with Electronic Ballast: T-8 lamps are a smaller diameter fluorescent lamp than T-12 lamps. When paired with specially designed electronic ballasts, T-8 lamps provide more lumens per watt, resulting in energy savings. Electronic ballasts replace the standard core and coil technology in magnetic ballasts with solid-state components. This technology allows for more consistent control over ballast output and converts power to higher frequencies, causing the fluorescent lamps to operate more efficiently. For existing first generation T-8 systems, this measure is specified as an upgrade to efficiency levels associated with optimal Super T-8 lamp-ballast combinations on a replace-on-burnout basis.

T-5 High-Output Lighting with Electronic Ballast: Like T8 lamps, straight tube T5 lamps are available in nominal 2', 3', 4', and 5' lengths. Standard T-5 lamps have light output and efficiency comparable to T-8/electronic ballast systems. High output T-5 lamps have considerably higher light output: a 1-lamp high output T-5 cross-section can replace a 2-lamp T-8 cross-section. The 5/8" bulb diameter of the T-5 lamp lends itself to low profile luminaires well-suited for cove lighting and display case lighting. Its smaller scale allows for sleeker fluorescent indirect and direct/indirect pendants and shallower profile recessed troffer type luminaires. Because of variances in actual lamp lengths and a different socket design, the T-5 lamp cannot easily be retrofitted in existing T-12 and T-8 luminaires. Consequently, use the T-5 lamp to its best advantage in specially designed luminaires.

Induction Lamps: The primary difference between induction lighting and conventional fluorescent lamps is that induction lighting does not have an electrical connection going inside the glass bulb (electrodeless). Instead, energy is transferred wirelessly into the glass envelope via electromagnetic induction. Induction lamps typically take the place of HID lamps. Their advantage is both long life and quick start, which unlike HID lamps, allows them to be turned off and on with the demand. Although induction lamps have a longer service life than other lamp technology they are also more expensive. They are most often used in places where the lamps are difficult to reach and replace. Induction lamps have very long lifetimes (100,000 hours), excellent color rendering, and perform well in a wide temperature range. They have better lumen maintenance than HID lamps. Our study looks at two applications for induction lighting--high bay lighting and streetlighting.

Ceramic Metal Halide Lamps: Metal halide lamps are HID lamps, which are approximately four times more efficacious than incandescent lamps. Metal halide (MH) lamps are a form of high intensity discharge (HID) lighting with good lighting efficiency and excellent color rendition.

Pulse-Start Metal Halide Lamps: Pulse start lamps have a greater light output than standard metal halide, provide a white light and require special ballasts and fixtures for each specific lamp. The pulse start metal halide combined with new, more efficient low current crest factor ballasts using high voltage ignitors provides higher light levels initially (20% more) and significantly more maintained light over time (40% more) than today's standard metal halide.

Compact Fluorescent Lighting (CFLs): Compact fluorescent lamps are designed to replace standard incandescent lamps. They are approximately four times more efficacious than incandescent light sources. Screw-in modular lamps have reusable ballasts that typically last for four lamp lives.

Cold Cathode Fluorescent Lamps: The term cold cathode refers to the fact that the cathode is not independently heated, as it is in conventional fluorescent lamps. Unlike conventional fluorescent lamps, cold cathode lamps reach full brightness instantly, can be operated in rapid on off cycles without degrading the lamp lifetime, and operate in cold ambient temperatures. This makes them appropriate for some applications where a conventional fluorescent lamp would not be appropriate. Cold cathode lamps are significantly more expensive than conventional fluorescents but have a much longer life.

High Pressure Sodium Lamps: In many situations, 400 watt mercury vapor lamps can be replaced by 250 watt high pressure sodium (HPS) lamps. HPS lamps are HID lighting and emit a golden-white or yellow light. The color rendition for HPS lamps is worse than for MV lamps, but the number of lumens per watt, although dependent on the size of the lamps, is much improved over MV lamps.

Reflectors: Optical reflectors are mirrored surfaces installed in fluorescent fixtures to direct light toward a specific area or work surface. By installing optical reflectors, four-lamp and three-lamp fluorescent fixtures can be reduced to two lamp fixtures and still meet the needed lighting levels.

Lighting Control Tune-up: This involves various measures to optimize the customer's current lighting control systems, with measures such as: relocating/tuning occupancy sensors, relocating photocells, optimizing sweep timers, repairing lighting timers, and adjust lighting schedules.

Occupancy Sensors: Occupancy sensors (infrared or ultrasonic motion detection devices) turn lights on upon entry of a person into a room, and then turn the lights off from ½ minute to 20 minutes after they have left. Occupancy sensors require proper installation and calibration. Their savings depend on the mounting type.

Continuous Dimming: (Emerging Technology) Dimming electronic ballasts can be incorporated into a daylighting strategy around the perimeter of office buildings or in areas under skylights. These systems use photocells to reduce power consumption and light output when daylight is available.

Outdoor Lighting Controls (Photocells and Timeclocks): Photocells can be used to automatically control both outdoor lamps and indoor lamps adjacent to skylights and windows. When lights do not need to be on all night, a photocell in series with a time clock provides maximum savings and eliminates the need for manual operation and seasonal time clock adjustments. Time clocks enable users to turn on and off electrical equipment at specific times during the day or week.

LED Lighting: A light emitting diode (LEDs) is a semiconductor light source. They have been use for many years in niche application (such as indicator lights), but it was not until the late 1990's that high-output white LEDs became feasible. Over the last decade, LEDs have begun appearing in a variety of illumination applications. LEDs have the potential to be more efficient than fluorescent lighting, although efficacy varies widely between products (but in general continues to improve). They have long lifetimes (about 50,000 hours), are shock resistant and dimmable, can be cylcled rapidly, and they perform well in low temperatures. The light from LEDs is highly directional, creating challenges for luminaire design, which is reflected in highly variable luminaire performance. This study considers LED lighting as a measures for indoor lighting, outdoor lighting, and streetlighting

LED technology, both in the LEDs themselves and in luminaire design, continues to change rapidly. In certain applications (architectural lighting, undercabinet lighting, streetlighting), highly effective LED products available and competitive on a life-cycle-cost basis with incandescent and fluorescent technologies. In other applications, such as commercial ambient lighting, LED products are not yet competitive on a performance or cost basis. That could easily change in the next few years, given the rapid pace of technological change and innovation.

LED Exit Sign: Exit signs were an early application of LED technology. Since exit signs are typically red or green, colored LEDs couldbe used directly, without the colored filter necessary when using a white light source. LED exit signs require significantly less maintenance than incandescent or CFL exit sign. Even a CFL would need to be replaced every year or two, while an LED sign could go without maintenance for up to 10 years. Because exit signs are operated continuously, the energy savings are significant.

Bi-Level LED Outdoor Lighting: Bi-level lighting is designed to operate at a minimum level of light output until occupancy is detected (e.g. through a motion sensor), then temporarily increase to a higher level of illumination.

Spectrally Enhanced Lighting (Scotopic Lighting): In the last few years, research has shown that photopic lumens, the common metric of efficacy for lighting fixtures, do not correlate perfectly with perceived brightness as evaluated subjectively by human beings. The human eye contains two types of photoreceptors, rods and cones, but the way lumen output is measured only considers the effect of the light on the central part of the retina, which contains only cones (photopic vision). The effect of light on the rods of the eye (scotopic vision) is not measured. Rods and cones differ in their sensitivity to different color temperatures. At higher color temperatures, the rods are more sensitive. The perceived brightness of a high color temperature lamp is higher than the rated (photopic) lumens would suggest. Therefore, by taking into account both photopic and scotopic lumens when choosing lamps, the same perceived brightness and lighting satisfaction can be achieved with an overall lower lumen density

High Performance Lighting Retrofit/Replacement: Because of the interaction between lighting measures (daylighting, controls, etc.), the costs and benefits may not be additive. We allocate a percent of the applicable stock to comprehensive lighting retrofits, at a 25 percent savings level.

B.2.2 Space Cooling

Chiller Efficiency Upgrade: Centrifugal chillers are used in building types which normally use water-based cooling systems and have cooling requirements greater than 200 tons. Centrifugal chillers reject heat through a water cooled condenser or cooling tower. In general, efficiency levels for centrifugal chillers start at 0.80 kW/ton (for older units) and may go as high as 0.4 kW/ton. This measure involves installation of a high-efficiency chiller (0.51 kW per ton) versus a standard unit (0.58 kW per ton). This measure also serves in the potential analysis as a proxy for other non-centrifugal chiller systems.

High-Efficiency Chiller Motors: This measure involves replacement of standard efficiency motors that power compressor systems on chillers. High-efficiency chiller motors have typically have efficiencies exceeding 90% and are typically electronically-commutated motors, which produce higher average operating efficiencies at partial loads compared to standard efficiency, brushed DC compressor motors.

VSD – Cooling Circulation Pumps: Variable speed drives installed on chilled water pumps can reduce energy use by varying the pump speed according to the building's demand for cooling. There is also a reduction in piping losses associated with this measure, which can have a major impact on the heating loads and energy use for a building. Pump speeds, however, can generally only be reduced to a minimum specified rate, because chillers and the control valves may require a minimum flow rate to operate.

VSD – Cooling Tower Fans: Energy usage in cooling tower fans can be reduced by installing electronic variable speed drives (VSDs). VSDs are a far more efficient method of regulating speed or torque than other control mechanisms. Energy required to operate a fan motor can be reduced significantly during reduced load conditions by installing a VSD.

Chiller Tune-up/Diagnostics: In addition to some of the activities conducted in a DX tune-up, an optimization of the chilled water plant can include activities such as: optimizing CW/CHW setpoints, improving chiller staging, trimming pump impellers, resetting chilled water supply temperature, and staging cooling tower fan operation.

Energy Management System: The term Energy Management System (EMS) refers to a complete building control system which usually can include controls for both lighting and HVAC systems. The HVAC control system may include on\off scheduling and warm-up routines. The complete lighting and HVAC control systems are generally integrated using a personal computer and control system software.

EMS Optimization: Energy management systems are frequently underutilized and have hundreds of minor inefficiencies throughout the system. Optimization of the existing system frequently results in substantial savings to the measures controlled by the EMS (e.g. lighting, HVAC) by minimizing waste. Improvements can include: building start-up schedule adjustments, improving integrated sequence of operations, calibration of sensors, and relocation of OA sensors.

Cool Roof: The color and material of a building structure surface will determine the amount of solar radiation absorbed by that surface. By using an appropriate reflective material to coat the roof, the roof will absorb less solar radiation and consequently reduce the cooling load.

DX Packaged System Efficiency Upgrade: A single-package A/C unit consists of a single package (or cabinet housing) containing a condensing unit, a compressor, and an indoor fan/coil. An additional benefit of package units is that there is no need for field-installed refrigerant piping, thus minimizing labor costs and the possibility of contaminating the system with dirt, metal, oxides or non-condensing gases. We look at two efficiency levels, an EER 10.9 and an EER 13.4, compared to a base case unit with EER=10.3.

Tune up/Advanced Diagnostics: The assumed tune-up includes cleaning the condenser and evaporator coils, establishing optimal refrigerant levels, and purging refrigerant loops of entrained air. The qualifying relative performance range for a tune-up is between 60 and 85 percent of the rated efficiency of the unit. Includes fresh air economizer controls providing demand control ventilation and consisting of a logic module, enthalpy sensor(s), and CO2 sensors in appropriate applications.

Window Film: Reflective window film is an effective way to reduce solar energy gains, thus reducing mechanical cooling energy consumption. Windows affect building energy use through thermal heat transfer (U-value), solar heat gains (shading coefficient), daylighting (visible light transmittance), and air leakage.

Evaporative Pre-cooler: (Emerging Technology) Evaporative pre-cooler pre-cools outdoor air through an air-to-water heat exchanger so that the outdoor supply air is sensibly cooled and humidity is not raised. This process is designed to reduce the need for mechanical cooling by providing a cooler than ambient source of supply outdoor air. The effectiveness of this measure is highly dependent on the characteristics of the outdoor and the cooling requirements of the building.

Programmable Thermostat: Setback programmable thermostats are appropriate controls for HVAC equipment that serve spaces with regular occupied and unoccupied periods, resulting in long periods of time when heating and cooling setpoints can be adjusted.

Roof / Ceiling Insulation: Thermal insulation is material or combinations of materials that are used to inhibit the flow of heat energy by conductive, convective, and radiative transfer modes. By inhibiting the flow of heat energy, thermal insulation can conserve energy by reducing heat loss or gain of a structure. An important characteristic of insulating materials is the thermal resistance, or R-value. The R-value of a material is the reciprocal of the time rate of heat flow through a unit of this material in a direction perpendicular to two areas of different temperatures.

Installation of Air-Side Economizers: Air-side economizers reduce the energy consumption associated with cooling by providing access to outside air – when temperatures permit – in lieu of using mechanical cooling of recirculated indoor air.

Duct Insulation. Insulation material inhibits the transfer of heat through air supply ducts or hot water pipes. Several types of ducts and duct insulation are available, including flexible duct, pre-insulated flexible duct, duct board, duct wrap, tacked or glued rigid insulation, and water proof hard shell materials for exterior ducts.

Duct Repair and Sealing. An ideal duct system would be free of leaks, especially when the ducts are outside the conditioned space. Leakage in unsealed ducts varies considerably with the fabricating machinery used, the methods for assembly, installation workmanship, and age of the ductwork. To seal ducts, a wide variety of sealing methods and products exist. Care should be taken to tape or otherwise seal all joints to minimize leakage in all duct systems and the sealing material should have a projected life of 20-30 years. Current duct sealing methods include use of computer-controlled aerosol and pre- and post-sealing duct pressurization testing.

DX Coil cleaning: A dirty coil cannot supply proper heat transfer, leading to higher energy consumption and reduced cooling capacity. Coil cleaning should be a routine maintenance measure, but in practice many systems operate with fouled coils.

Geothermal heat pump: A geothermal, or ground-source, heat pump, operates on the same principle as more common air-source heat pumps. But unlike ir-source heat pumps, which transfers heat to or from the outside air, geothermal heat pumps exchange heat with the ground. Underground temperatures maintain a relatively constant temperature throughout the year, especially compared to air temperatures, which increases the system efficiency compared to an air-source heat pump. Because the system relies on extensive subterranean piping for heat exchange, geothermal heat pumps are expensive to install, and installation opportunities in existing buildings are limited.

B.2.3 Ventilation

Motor Efficiency Upgrade: Premium-efficiency motors use additional copper to reduce electrical losses and better magnetic materials to reduce core losses, and are generally built to more precise tolerances. Consequently, such motors are more reliable, resulting in reduced downtime and replacement costs. Premium-efficiency motors may also carry longer manufacturer's warranties.

VFD on Motor Installation: Energy usage in HVAC systems can be reduced by installing electronic variable frequency drives (VFDs) on ventilation fans. VFDs are a far more efficient method of regulating speed or torque than throttling valves, inlet vanes and fan dampers. Energy required to operate a fan motor can be reduced as much as 85% during reduced load conditions by installing a VFD.

Installation of Demand-Controlled Ventilation (via Occupancy Sensors, CO2 Sensors, Etc.): Often, usage of a building's ventilation control goes beyond what is necessary to maintain a healthy and comfortable environment. A variety of controls can save energy by limiting the use of the ventilation system to minimum amount necessary. Sensors that detect critical contaminants activate ventilations systems only when necessary. Occupancy sensors limit the operation ventilation systems to periods when the building is in use.

Air Handler Optimization: Optimization of a building's air-handling system is concerned principally with the proper sizing and configuration of its HVAC units. Energy savings can result from a variety of improvements, including reduced equipment loads and better functionality of existing equipment.

Electronically Commutated Motors (ECM) on air-handler unit: Air handler models with the lowest electrical use ratings employ ECMs. ECMs, also known as brushless DC motors or variable speed blower motors, have two principal advantages over the typical permanent magnet split capacitor (PSC) blower motors found in the majority of air handlers. First, ECMs are claimed to be 20% to 30% more efficient than standard blower motors. Second, the typical ECM blower can produce a much wider range of airflow than a PSC blower, which typically has only three or four set speeds over a narrow range. Because power consumption by an air handler rises with the cube of airflow, the ability to reduce airflow when appropriate can dramatically reduce the electrical power draw by the air handler.

Energy Recovery Ventilation: These systems provide a controlled way of ventilating a building while minimizing energy loss. Heating energy requirements are reduced during the winter season by transferring heat from the warm inside air being exhausted to the fresh (but cold) supply air. Similarly, in the summer, the inside air being exhausted cools the warmer supply air and reduces cooling energy requirements.

Separate Makeup Air/Exhaust Hoods: Ventilation requirements in restaurants and grocery stores are driven both by occupancy and by the need to exhaust fumes from food preparation activities. Standard ventilation and exhaust systems operate at constant speeds that are most often matched to maximum ventilation requirements. Systems that modulate both exhaust and make-up air flow rates in response to measurements of "smoke" and temperature in the exhaust hood reduce exhaust and make-up air flow rates when full exhaust capacity is not required, and can thereby produce significant reduction in fan power and space conditioning energy use.

B.2.4 Refrigeration

Motor Efficiency Upgrade for Fans and Compressors: In addition to saving energy, premium-efficiency motors are more reliable, resulting in reduced downtime and replacement costs.

Strip Curtains: Installing strip curtains on doorways to walk-in boxes and refrigerated warehouses can produce energy savings due to decreased infiltration of outside air into the refrigerated space. Although refrigerated spaces have doors, these doors are often left open, for example during product delivery and store stocking activities.

Night Covers: Installing film or blanket type night covers on display cases can significantly reduce the infiltration of warm ambient air into the refrigerated space. This reduction in display case loads in turn reduces the electric use of the central plant, including compressors and condensers, thus saving energy. The target market for this measure is small, independently owned grocery stores and other stores that are typically closed at night and restock their shelves during the day. The target cases are vertical displays, with a single- or double-air curtain, and tub (coffin) type cases.

Evaporator Fan Controller for Medium Temperature Walk-Ins: In response to the temperature setpoint being satisfied in a medium temperature walk-in cooler, evaporator fans are cycled to maintain minimum necessary air flow, which prevents ice build-up on the evaporator coils. In conventional systems, fans run constantly whether the temperature setpoint is satisfied or not.

Variable Speed Compressor Retrofit: A variable speed compressor is a screw or reciprocating compressor whose current is modulated by a frequency inverter. A controller senses the compressor suction pressure and modulates the current and therefore the motor speed in response to changes in this pressure. When low load conditions exist, the current to the compressor motor is decreased, decreasing the compressor work done on the refrigerant.

Floating Head Pressure Controls: Floating head pressure controls allow a refrigeration system to operate under lower condensing temperature and pressure settings, where compressor operation is most efficient, working against a relatively low head pressure. The condensing temperature is allowed to float below the design setpoint of, say, 95 deg. F under lower outdoor temperatures, which in-turn lowers the condensate pressure. In a conventional system a higher fixed condensing temperature setpoint is used which results in a lowered capacity for the system, requires extra power, and may overload the compressor motor. Energy savings can be realized if the refrigeration system head pressure is allowed to float during periods of low ambient temperature, when the condensing temperature can be dramatically reduced.

Refrigeration Commissioning: Refrigeration commissioning refers to a process whereby refrigeration systems are subject to inspection on a variety of criteria to ensure efficiency. The commissioning process can involve tests that cover a system’s controls for humidity and temperature, anti-condensation, and heat recovery, among others.

Demand Defrost: Defrost of a refrigeration system is critical to its efficient operation. Demand defrost uses a pressure-sensing device to activate the defrost cycle when it detects a significant drop in pressure of the air across the refrigeration coil. Because load during defrost can be three times that of normal operation, defrosting on demand only – not when an individual operator deems it necessary – can save energy by minimizing the amount of time spent on defrosting.

Humidistat Controls: A humidistat control is a control device to turn refrigeration display case anti-sweat heaters off when ambient relative humidity is low enough that sweating will not occur. Anti-sweat heaters evaporate moisture by heating the door rails, case frame and glass of display cases. Savings result from reducing the operating hours of the anti-sweat heaters, which without a humidistat control generally run continuously. There are various types of control strategies including cycling on a fixed schedule.

LED Display lighting: This measure involves the replacement of standard fluorescent tube lighting fixtures within medium and low-temperature display cases with LED fixtures. The higher luminous efficacy of LED lamps compared to T-8 and T-5 fluorescent lamps delivers significant energy savings and also results in lower heat gains inside refrigerator and freezer cases, which in turn reduces the effective load served by the compressor. LED fixtures also exhibit much longer service lives compared to T-8 or T-5 fixtures and very little maintenance requirements.

Fiber Optic display lighting: Fiber optics can be used to distribute light from a single light source located outside the refrigerator system to multiple display cases. Lighting energy use is reduced, because a single high efficiency light source (e.g. metal halide) serves multiple cases. But the bigger savings are in the refrigeration: by taking the light source outside the refrigerated space, it reduces the load on the compressor. While this technology has been used in demonstration projects, it is not a mature technology.

High R-Value Glass Doors: This measure involves the replacement of standard glass doors on refrigerated display cases with advanced glass doors that incorporate heat-reflective treated glass and/or low-conductivity gas fills between panes to produce high R-values. The greater insulation properties of the insulated glass doors reduce condensation buildup and reduce or eliminate the need for anti-sweat heaters.

Multiplex Compressor Systems: Multiplex refrigeration systems involve the use of multiple compressors in parallel, rather than single compressors, to serve specific refrigeration loads. Multiplex systems are designed so that compressors can be selectively selected and cycled in order to better match changes in refrigeration load dynamically and increase the overall operational efficiency of the compressors.

Oversized Air Cooled Condenser: The use of oversized condensers can provide additional "natural sub-cooling" of the condensed refrigerant, which results in lower-temperature refrigerant liquid in the system, lower evaporator temperatures, and reduced load on the compressor.

Freezer/Cooler Replacement Gaskets: Worn out freezer/cooler door gaskets can result in significant leakage and increased cooling energy consumption. Regular replacement of worn door gaskets reduces unnecessary air leaks and can lead to significant refrigeration energy savings.

B.2.5 Office Equipment

Power Management Enabling: Most PCs, monitors, printers and copiers have the capability of entering a low-power "sleep" mode when idle. However devices may come with this feature disabled or users may disable it for a variety of reasons. Enabling power management reduces energy use when devices are left idle during the day, or when a device is left on overnight. Most savings occur off-peak. This measure can be applied to PCs, PC monitors, printers and copiers.

Energy Star or Better Office Equipment. For many years, virtually all PCs and monitors met the Energy Star efficiency requirements, which required only that devices be capable of entering a low-power "sleep" mode after a period of inactivity. The Environmental Protection Agency (EPA) has tightened its requirements, adding active-mode power requirements to the specifications. Choosing Energy Star PCs, monitors, copiers and printers can reduce energy use both in all power modes.

Data Center Energy Efficiency: Data centers are facilities that are densely packed with electronic equipment for data processing, data storage, and networking. Ranging from a server closet in a small building to building that provide remote data operations to multiple clients, data centers are extremely energy intensive, both for the information architecture and the for cooling required to support it. We analyze three scenarios for reduce energy use in data centers, taken from a 2007 EPA report:[9] (1) Improved operations focuses on operational improvements with little or no capital investment. (1) Best Practices assumes the adoption of practices and technologies used in the most energy-efficient of today's data centers. (3) State of the Art Practices represents the maximum efficiency achievable using available technologies.

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[9] EPA, 2007. *Report to Congress on Server and Data Center Energy Efficiency, Public Law 109-431.* Available at: http://www.energystar.gov/ia/partners/prod_development/downloads/EPA_Datacenter_Report_Congress_Final1.pdf

B.2.6 Water Heating

High Efficiency Water Heater: Higher efficiency water heater have greater insulation to reduce standby heat loss. For this study, efficiency of the base unit (measured as the Energy Factor) is specified as 0.88, whereas the efficiency of the high efficiency electric water heater is specified as 0.93.

Heat Pump Water Heater: Air-to-water heat pump water heaters extract low-grade heat from the air then transfer this heat to the water by means of an immersion coil. This is the most commonly utilized residential heat pump water heater. The air-to-water heat pump unit includes a compressor, air-to-refrigerant evaporator coil, evaporator fan, water circulating pump, refrigerant-to-water condenser coil, expansion valve, and controls. Residential heat pump water heaters replace base electric units with the same tank capacities. For this study, efficiency of the base unit (measured as the Energy Factor) is specified as 0.88, whereas the efficiency of the heat pump water heater is specified as 2.9.

Solar Water Heater: Heat transfer technology that uses the sun's energy to warm water. Solar water heaters preheat water supplied to a conventional domestic hot water heating system. The energy savings for the system depend on solar radiation, air temperatures, water temperatures at the site, and the hot water use pattern.

Demand-Controlled Circulating Systems: Hot water circulation systems are designed to maintain water in hot water pipes at a pre-determined temperature and prevent excess water demand (and associated water heating energy) from waiting for hot water to arrive from the water heater. Demand-controlled circulating systems provide additional savings by optimizing pumping energy requirements to only specific moments of hot water demand. This is achieved through the integration of an electronic controller on the circulation pump that is triggered by a switch engaged by the consumer at the point of hot water demand.

Heat Recovery Units: This measure is heat transfer strategy that uses the heat rejected during the refrigerant cycle on air conditioning units to heat water.

Pipe Wrap: Thermal insulation is material or combinations of materials that are used to inhibit the flow of heat energy by conductive, convective, and radiative transfer modes. By inhibiting the flow of heat energy, thermal insulation can conserve energy by reducing heat loss or gain.

Heat Trap: Heat traps are valves or loops of pipe, which allow water to flow into the water heater tank but prevent unwanted hot-water flow out of the tank that would otherwise occur due to convection.

Tankless Water Heater. Tankless water heaters eliminate the standby tank (and associated losses) of a standard water heater. The water is heated instantaneously by a high energy heat source that can be either gas or electric.

B.2.7 Cooking

Convection Oven. Convection ovens use a small fan to circulate hot air within the oven cavity. Circulating air can heat food more efficiently than the still air found in conventional ovens. The hot air in the oven can be heated by gas or electricity. In general, a convection oven will save 30% of the energy used by an oven. These savings result from burners cycling off for a longer period.

Energy Star Fryer. Fryers cook foods by submerging them in hot animal or vegetable oils, and utilize a range of different burner types. In order to qualify as ENERGY STAR, electric fryers must meet a minimum cooking efficiency 80 percent while also meeting a maximum idle energy rate of 1,000 watts. Energy efficient fryers offer shorter cook times and higher production rates through advanced burner and heat exchanger designs. Frypot insulation reduces standby losses resulting in a lower idle energy rate.

Energy Star Steamer. Commercial steam cookers are versatile appliances which can be used to quickly prepare any foods that do not require a crust. Steamers come in a variety of configurations but generally resemble an oven, with between one and four gasketed and windowless compartments. The stacked compartments typically accommodate a standard 12 by 20-inch hotel pan. Pressure steamers have an external boiler that produces potable steam under pressure, and atmospheric steamers have a steam generator located directly below the compartments. Both require a water line and drain hookup. In contrast, the connectionless steamer is a closed loop system with a reservoir that is periodically drained and refilled. Significant improvements in water- and energy- efficiency are achieved because no steam is allowed to escape down the condensate drain.

Energy Star Hot Food Holding Cabinet. Hot food holding cabinets mainain heated foods at a safe temperature for commercial food service. ENERGY STAR units use 65 percent less energy than standard models. ENERGY STAR units must meet a maximum idle energy rate of 40 watts/ft3. Models that meet this requirement incorporate better insulation to reduce heat loss. Other energy-saving features, such as magnetic door gaskets, auto-door closures, and dutch doors, may also be incorporated.

Vending Misers. The Vending Miser is an after-market energy control technology for refrigerated vending machines. It incorporates an occupancy sensor, thermostat, and timer to power down the vending maching for extended period, while periodically repowering the device to ensure that the product stays cold.

B.3 Industrial Electric Measures

This subsection provides brief descriptions of the industrial measures included in this study. First measures that cut across industries are described, followed by descriptions of industry-specific measures.

B.3.1 Cross-Cutting Electricity Efficiency Measures

Replace motors: This measure refers to the replacement of existing motors with high-efficiency motors. High-efficiency motors reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, high-efficiency motors can run cooler than standard motors and can consequently have higher service factors, longer bearing life, longer insulation life, and less vibration.

Adjustable speed drives (ASDs): Adjustable speed drives better match motor speed to load and can therefore lead to significant energy savings compared to constant speed motors. Typical energy savings associated with ASDs range from 7-60%.

Motor practices: This measure refers to proper motor maintenance. The purposes of motor maintenance are to prolong motor life and to foresee a motor failure. Motor maintenance measures can be categorized as either preventive or predictive. Preventive measures, whose purpose is to prevent unexpected downtime of motors, include electrical consideration, voltage imbalance minimization, motor ventilation, alignment, and lubrication, and load consideration. The purpose of predictive motor maintenance is to observe ongoing motor temperature, vibration, and other operating data to identify when it becomes necessary to overhaul or replace a motor before failure occurs. The savings associated with ongoing motor maintenance could range from 2-30% of total motor system energy use.

Compressed air - operation and maintenance (O&M): Inadequate maintenance can lower compression efficiency and increase air leakage or pressure variability, as well as lead to increased operating temperatures, poor moisture control, and excessive contamination. Improved maintenance will reduce these problems and save energy. Proper maintenance includes regular motor lubrication, replacement of air lubricant separators, fan and pump inspection, and filter replacement.

Compressed air – controls: The objective of any control strategy is to shut off unneeded compressors or delay bringing on additional compressors until needed. Energy savings for sophisticated controls have been around 12% annually. Available controls for compressed air systems include start/stop, load/unload, throttling, multi-step, variable speed, and network controls.

Compressed air - system optimization: This is a general measure that refers to compressed air system improvements (besides sizing, controls, and maintenance) that allow it to perform at maximum energy efficiency. Such improvements could include reducing leaks, better load management, minimizing pressure drops throughout the system, reducing air inlet temperatures, and recovering waste compressor heat for other facility applications.

Compressed air – sizing: This measure refers to the proper sizing of compressors, regulators, and distribution pipes. Oversizing of compressors can result in wasted energy. By properly sizing regulators, compressed air will be saved that is otherwise wasted as excess air. Pipes must be sized correctly for optimal performance or resized to fit the current compressor system. Increasing pipe diameters typically reduces annual energy consumption by 3%.

Pumps - operation and maintenance (O&M): Inadequate maintenance can lower pump system efficiency, cause pumps to wear out more quickly, and increase costs. Better maintenance will reduce these problems and also save energy. Proper pump system maintenance includes bearing inspection and repair, bearing lubrication, replacement of worn impellers, and inspection and replacement of mechanical seals.

Pumps – controls: The objective of pump control strategies is to shut off unneeded pumps or, alternatively, to reduce pump load until needed. In addition to energy savings, proper pump control can lead to reduced maintenance costs and increased pump life.

Pumps - system optimization: This is a general measure that refers to pump system improvements (besides sizing, controls, and maintenance) that allow it to perform at maximum energy efficiency. Such improvements could include pump demand reduction, high-efficiency pumps, impeller trimming, and installing multiple pumps for variable loads.

Pumps – sizing: Pumps that are sized inappropriately result in unnecessary losses. Where peak loads can be reduced, pump size can also be reduced. Replacing oversized pumps with pumps that are properly sized can save 15-25% of the electricity consumption of a pumping system (on average for U.S. industry).

Fans - operation and maintenance (O&M): This measure refers to the improvement of general O&M practice for fans, such as tightening belts, cleaning fans, and changing filters regularly.

Fans – controls: The objective of fan control strategies is to shut off unneeded fans or, alternatively, to reduce fan load until needed. In addition to energy savings, proper fan control can lead to reduced maintenance costs and increased pump life.

Fans - system optimization: This measure refers to general strategies for optimizing fans from a systems perspective, and includes such actions as better inlet and outlet design and reduction of fan sizing, where appropriate.

Fans - improve components: This measure refers to the improvement of fan components, such as replacing standard v-belts with cog v-belts and upgrading to the most energy efficient motors possible.

Replace T-12 by T-8 and electronic ballasts: T-12 tubes consume significant amounts of electricity, and also have extremely poor efficacy, lamp life, lumen depreciation, and color rendering index. Replacing T-12 lamps with T-8 lamps (smaller diameter) approximately doubles the efficacy of the former. Electronic ballasts save 12-30% power over their magnetic predecessors; typical energy savings associated with replacing magnetic ballasts by electronic ballasts are estimated to be roughly 25%.

Metal halides/fluorescents: Metal halide lamps can replace mercury or fluorescent lamps with energy savings of 50%. For even further savings, high-intensity fluorescent lamps can be installed, which can yield 50% electricity savings over standard metal halide (high-intensity discharge) systems.

Compact Fluorescent Lighting (CFLs): Compact fluorescent lighting fixtures are designed to replace standard incandescent lighting fixtures. They are approximately four times more efficacious than incandescent light sources.

Controls/sensors: Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors, which turn off lights when a space becomes unoccupied. Manual controls can also be used in addition to automatic controls to save additional energy in small areas.

Chiller Efficiency Upgrade: Centrifugal chillers are used in building types which normally use water-based cooling systems and have cooling requirements greater than 200 tons. Centrifugal chillers reject heat through a water cooled condenser or cooling tower. In general, efficiency levels for centrifugal chillers start at 0.80 kW/ton (for older units) and may go as high as 0.4 kW/ton. This measure involves installation of a high-efficiency chiller (0.51 kW per ton) versus a standard unit (0.58 kW per ton). This measure also serves in the potential analysis as a proxy for other non-centrifugal chiller systems.

HVAC management system: An energy monitoring and control system supports the efficient operation of HVAC systems by monitoring, controlling, and tracking system energy consumption. Such systems continuously manage and optimize HVAC system energy consumption while also providing building engineers and energy managers with a valuable diagnostic tool for tracking energy consumption and identifying potential HVAC system problems.

Cooling circulation pumps – variable speed drives (VSDs): Variable speed drives better match motor speed to load and can therefore lead to significant energy savings compared to constant speed drives. This measure considers the installation of VSDs on cooling circulation pumps.

DX tune up/advanced diagnostics: The tune-up includes cleaning the condenser and evaporator coils, establishing optimal refrigerant levels, and purging refrigerant loops of entrained air. The qualifying relative performance range for a tune-up is between 60 and 85 percent of the rated efficiency of the unit. Includes fresh air economizer controls providing demand control ventilation and consisting of a logic module, enthalpy sensor(s), and CO^2 sensors in appropriate applications.

DX packaged system, EER=10.9, 10 tons: A single-package A/C unit consists of a single package (or cabinet housing) containing a condensing unit, a compressor, and an indoor fan/coil. An additional benefit of package units is that there is no need for field-installed refrigerant piping, thus minimizing labor costs and the possibility of contaminating the system with dirt, metal, oxides or non-condensing gases. This measure involves installation of a TIER 2 high-efficiency unit (EER=10.9) versus a standard unit (EER=10.3.

Window film: Low-emittance windows are an effective strategy for improving building insulation. Low-emittance windows can lower the heat transmitted into a building and therefore increase its insulating ability. There are two types of Low-E glass, high solar transmitting (for regions with higher winter utility bills) and low solar transmitting (for regions with higher summer utility bills).

Programmable thermostat: A programmable thermostat allows to control temperature settings of space heating and cooling, and optimizing settings based on occupancy and use of the building. This will reduce unnecessary heating and cooling outside hours of building use. It may also help in building cooling using nighttime cooling.

Chiller O&M/tune up: This measure refers to the proper inspection and maintenance of chilled water systems. This can include setting correct head pressure, maintaining correct levels of refrigerant, and selecting and running appropriate compressors for part load. Energy saving can also be achieved by cleaning the condensers and evaporators to prevent scale buildup.

Cool Roof: The color and material of a building structure surface will determine the amount of solar radiation absorbed by that surface. By using an appropriate reflective material to coat the roof, the roof will absorb less solar radiation and consequently reduce the cooling load.

Replace v-belts: Inventory data suggest that 4% of pumps have V-belt drives, many of which can be replaced with direct couplings to save energy. Based on assessments in several industries, the savings associated with V-belt replacement are estimated at 4%.

B.3.2 Sector-Specific Efficiency Measures (Electricity)

B.3.2.1 NAICS 311: Food Manufacturing
NAICS 312: Beverage and Tobacco Product Manufacturing

Efficient refrigeration – operations: Refrigeration is an important energy user in the food industries. Operations of refrigeration systems can be improved by applying appropriate settings, opening refrigerated space as short as possible, reducing leakage by controlling doorways, making sure that refrigerated space is used optimally, optimization of defrosting cycle, as well as other small operational changes.

Optimization refrigeration: The refrigeration system can be optimized by improving the operation of the compressors, selecting cooling systems with high COP values, reducing losses in the coolant distribution system, improved insulation of the cooled space, variable speed drives on cooling system, and optimizing the temperature setting of the cooling system.

Bakery – process: Process improvements in the bakery can reduce electricity consumption through selection of energy-efficient equipment for the different processes, optimization of electric ovens, and good housekeeping (e.g. switching equipment off when not in use).

Bakery – process (mixing): About 35% of electricity in bakeries is used to mix and knead the dough. When selecting equipment electricity use should be one of the considerations as energy is the largest cost on a life-cycle basis. Today, energy use is not a criterion. High-efficiency motors, speed control and other measures may reduce electricity consumption.

B.3.2.2 NAICS 313: Textile Mills
NAICS 314: Textile Product Mills
NAICS 315: Textile Product Mills
NAICS 316: Leather and Allied Product Manufacturing

Drying (UV/IR): This measure refers to the use of direct heating methods, such as infrared dryers. Direct heating provides significant energy savings because it eliminates the inefficiency of transferring heat to air and from the air to the wet material. The energy efficiency of direct heating is about 90%.

Membranes for wastewater: Membrane technologies focus on separating the water from the contaminants using semi-permeable membranes and applied pressure differentials. Membrane filtration of wastewater is typically more energy efficient than evaporation methods, and can lead to significant reductions in facility freshwater intake.

O&M/drives spinning machines: Electric motors are the single largest electricity user in spinning mills. Optimization of motor use, proper maintenance procedures (e.g. preventative maintenance), use of new high-efficiency motors instead of re-winding, switching off equipment when not in use can help improve energy efficiency.

B.3.2.3 NAICS 321: Wood Product Manufacturing NAICS 337: Household and Institutional Furniture and Kitchen Cabinet Manufacturing

Air conveying systems: Pneumatic or air conveying systems are used to transport material (e.g. sawdust, fibers) in the lumber industry. Energy efficiency improvement is feasible by optimizing the lay-out of the systems, reducing leakages, reducing bends in the system, and improving compressor operations (see also with compressed air systems).

Optimize drying processes: This is a general measure, which refers to the optimization of drying systems through such actions as the use of controls, heat recovery, insulation, and good housekeeping/maintenance.

Heat pumps – drying: This measure refers to the recovery of low grade heat from the drying process via a heat pump, where cost effective.

B.3.2.4 NAICS 322: Paper Manufacturing

Gap forming paper machine: The gap former produces a paper of equal and uniform quality at a higher rate of speed. Coupling the former with a press section rebuild or an improvement in the drying capacity increases production capacity by as much as 30%. Energy savings from gap formers come from reduced electricity consumption per ton of product produced.

High consistency forming: In high consistency forming, the furnish (process pulp) which enters at the forming stage has more than double the consistency (3%) than normal furnish. This measure increases forming speed, and reduces dewatering and vacuum power requirements. Application of this technology is limited to specific paper grades, especially low-basis weight grades such as tissue, toweling, and newsprint. Electricity savings are estimated at 8%.

Optimization control PM: Large electric motors are used to run the paper machine. Optimization of the paper machine will reduce electricity use of the drives. Improved control strategies will improve throughput, reduce breakage and downtime, improving the energy efficiency per unit of throughput. Variable speed drives may help to optimize the energy use in water pumps in the paper machine.

B.3.2.5 NAICS 323: Printing and Related Support Activities

Efficient practices printing press: Optimizing the use of the printing press by reducing production losses, switching off of the press when not in use and other improved operational practices.

Efficient printing press (fewer cylinders): New printing press designs allow the use of fewer cylinders (or rollers). This reduces the electricity use to drive the printing machine.

Light cylinders: Reducing the weight of the cylinders (or rollers) in the printing machine will reduce the power needed to drive the machine. Using lightweight materials for cylinders has been demonstrated in Europe.

B.3.2.6 NAICS 324: Petroleum and Coal Products

Process controls (batch + site): This is a general measure to implement computer-based process controls, where applicable, to monitor and optimize various processes from an energy consumption perspective. In general, by monitoring key process parameters, processes can be fine tuned to minimize energy consumption while still meeting quality and productivity requirements. Control systems can also reduce the time required to perform complex tasks and can often improve product quality and consistency while optimizing process operations. This measure could include the installation of controls based on neural networks, knowledge based systems, or improved sensor technology.

Power recovery: Various processes run at elevated pressures, enabling the opportunity for power recovery from the pressure in the flue gas. The major application for power recovery in the petroleum refinery is the fluid catalytic cracker (FCC). However, power recovery can also be applied to hydrocrackers or other equipment operated at elevated pressures. A power recovery turbine or turbo expander is used to recover energy from the pressure. The recovered energy can be used to drive the FCC compressor or to generate power.

Efficient desalter: Alternative designs for desalting include multi-stage desalters and a combination of AC and DC fields. These alternative designs may lead to increased efficiency and lower energy consumption.

B.3.2.7 NAICS 325: Chemical Manufacturing

Clean room – controls: Reduced recirculation air change rates, while still meeting quality control and regulatory standards can reduce energy use, optimized chilled water systems, reduction of cleanroom exhaust, and, occasionally, a cleanroom is classified at a higher cleanliness level than is necessary for its current use, and by declassifying energy can be saved.

Clean room – new designs: When designing a clean room, energy use should be a primary consideration. Benchmarking tools and design tools are being developed to help improve the energy efficiency of new cleanroom systems. Furthermore, in the design phase the system can be optimized for improved air filtration quality and efficiency, and the use of cooling towers in lieu of water chillers.

Process controls (batch + site): See discussion for NAICS 324.

B.3.2.8 NAICS 326: Plastics and Rubber Products Manufacturing

O&M – extruders/injection molding: Improved operation and maintenance procedures of extruders, optimization of extruder settings, optimization of the extruder screw shape, optimization of the shape/thickness of the product, and reduction of standby time.

Extruders/injection molding – multipump: The use of multiple pumps and an appropriate control system allow to reduce energy use of the extruder when not working at full capacity, only using the pump(s) needed.

Direct drive extruders: Use of a direct drive, instead of a gearbox or belt, will reduce the losses by approximately 15% in extruders.

Injection molding – impulse cooling: Impulse cooling regulates the cooling water use increasing the cooling rate and reducing productivity (and downtime).

Injection molding – direct drive: Use of a direct drive, instead of a gearbox or belt, will reduce the losses by approximately 20% in injection molding machines.

NAICS 327: Nonmetallic Mineral Product Manufacturing

Efficient grinding: This is a general measure that refers to efficient grinding technologies, which can include the use of high-efficiency classifiers or separators.

Process controls: See discussion for NAICS 324.

Autoclave optimization: In various processes autoclaves are used to press materials. Multiple autoclaves are used. By synchronizing the time of the use of the individual autoclaves, energy can be reduced by re-using the output of one to operate the other autoclave.

Top-heating (glass): Most electric furnaces use electrodes in the batch to melt the raw materials into glass. Newer designs with top-mounted electrodes can improve and maintain product quality, and obtain a higher share of salable glass, which leads to lower energy intensities (energy per kg of glass produced).

B.3.2.9 NAICS 331: Primary Metal Manufacturing

Process controls: See discussion for NAICS 324.

Efficient electric melting: Electric arc furnaces are used in the steel industry to melt scrap. Only one minimill is operating in California. Multiple options are available to reduce the electricity consumption of the furnace, e.g. foamy slag, oxy-fuel injection, improved transformers, eccentric bottom tapping (EBT), as well as scrap preheating.

Near net shape casting: Near net shape casting is the direct casting of the metal into very nearly the final shape, thereby eliminating other processing steps such as hot rolling, which can lead to significant energy savings.

B.3.2.10 NAICS 332: Fabricated Metal Products
NAICS 333: Machinery Manufacturing
NAICS 336: Transportation Equipment

Optimization process (M&T): This is a general measure for optimizing the efficiency of painting processes, via such actions as the use of process controls, proper maintenance, and reducing the airflow rates in paint booths.

Scheduling: Optimization of the scheduling of various pieces of equipment can reduce downtime and hence save energy. Furthermore, improved control strategies can reduce standby energy use of equipment as part of an optimized scheduling system.

Efficient curing ovens: Efficiency options for curing ovens include the optimization of oven insulation, the use of heat recovery techniques, and the use of direct heating methods, such as infrared heating, microwave heating, and ultraviolet heating.

Machinery: Many machines (e.g. metal processing) use electricity or compressed air to drive the equipment. The use of compressed air systems should be minimized and replaced by direct drive systems, because of the low efficiency of the compressed air supply. Furthermore, many machines do not use high-efficiency motors or speed controls.

B.3.2.11 NAICS 334: Computers and Electronic Products

B.3.2.12 NAICS 335: Electrical Equipment, Appliance, and Component Manufacturing

Scheduling: See previous subsection.

Efficient curing ovens: See previous subsection.

Machinery: See previous subsection.

Efficient processes (welding, etc.): New more power efficient welding technology is developed. For welding robots, new servo-based systems reduce energy use. See also new transformers welding (see section 1.1).

B.3.2.13 NAICS 339: Miscellaneous Manufacturing

Scheduling: See discussion for SIC 34.

Efficient Machinery: See discussion for SIC 34.

Process heating: Induction furnaces are often used for electric process heating. Improved operation and maintenance can reduce part-load operation, downtime and tap-to-tap time. Furthermore, high-frequency induction furnaces improve energy use.

Process controls: See discussion for NAICS 324.

B.3.2.14 NAICS 212: Mining

Process controls: See discussion for NAICS 324.

Efficient Grinding: See discussion for NAICS 327.

Process Optimization: See discussion for NAICS 327.

Efficient Machinery: See discussion for NAICS 332.

B.3.2.15 Water/Wastewater

Efficient Machinery: See discussion for NAICS 332.

B.4 Residential Gas Measures

This subsection provides descriptions of the residential gas measures included in this study.

B.4.1 Space Heating

High Efficiency Furnace. High efficiency furnaces have annual fuel use efficiencies (AFUEs) of 90 percent or higher, compared to standard efficiency furnaces with AFUEs of around 80 percent. Efficiencies above 90% can be achieved with a number of technologies, such as pulse combustion or condensing furnaces. Efficiency is dependent on vent type, burner type and heat transfer surface. Condensing furnaces derive useful heat from condensing vaporized by-products of combustion by exchanging this heat with the circulating indoor air stream.

Duct Repair and Sealing. An ideal duct system would be free of leaks, especially when the ducts are outside the conditioned space. Leakage in unsealed ducts varies considerably with the fabricating machinery used, the methods for assembly, installation workmanship, and age of the ductwork. To seal ducts, a wide variety of sealing methods and products exist. Care should be taken to tape or otherwise seal all joints to minimize leakage in all duct systems and the sealing material should have a projected life of 20-30 years. Current duct sealing methods include use of computer-controlled aerosol and pre- and post-sealing duct pressurization testing. The measure is assumed to save both electricity and natural gas and is modeled for electrically cooled and heated homes and for electrically cooled and gas heated homes.

Duct Insulation. Insulation material inhibits the transfer of heat through the air-supply duct. Several types of ducts and duct insulation are available, including flexible duct, pre-insulated flexible duct, duct board, duct wrap, tacked or glued rigid insulation, and water proof hard shell materials for exterior ducts. Duct insulation for existing construction involves wrapping un-insulated ducts with an R-4 or better insulating material.

Furnace Maintenance. Furnace adjustments increase efficiency by insuring that the furnace fan stays on as long as there is heat in the exchanger. Fan Off control is adjusted to maximize efficiency. Other steps include: inspecting thermostat for proper operation; inspecting the filter and changing or cleaning as needed; checking all electrical components and controls; oiling motors as needed; inspecting the heat exchanger for possible cracks; and checking air fuel mixture, where appropriate.

High Efficiency Boiler. This measure involves installation of a high efficiency gas boiler (95 percent efficiency) instead of a standard 82 percent efficient boiler. Condensing boilers are available which operate with thermal efficiencies of 95% or higher. These condensing units achieve their high efficiency by operating with stack gas temperatures around 100°F. At this low stack temperature the water vapor in the products of combustion is condensed. When the water vapor is condensed, its latent heat from the phase change is recovered, resulting in very high efficiencies.

Boiler Controls. Controllers optimize the performance of a boiler by learning the daily demand pattern of domestic hot water and adjusting the water supply accordingly. The controllers usually have the ability to automatically lower water temperatures during low use periods.

Boiler Diagnostic Testing and Maintenance. A high-efficiency boiler tune-up performed by a properly trained technician can improve average combustion efficiency by 10 percent. To ensure that the boiler tune-up is a success, the tune-up technician should use an electronic flue-gas analyzer that is capable of continuously monitoring stack temperature, oxygen (O2 in percent), and carbon monoxide (CO in ppm). In addition, the technician should determine the boiler's actual gas input rate (cubic feet per minute).

Stack Damper. During periods of furnace and boiler standby operation, warm room air is drawn through the stack via the draft hood or dilution air inlet. Air is also drawn through the vent immediately after the appliance shuts off and the flue is still hot. A vent damper, when closed, can prevent residual heat from being drawn up the warm vent.

Pipe Insulation. Thermal insulation is material or combinations of materials that are used to inhibit the flow of heat energy by conductive, convective, and radiative transfer modes. By inhibiting the flow of heat energy, thermal insulation can conserve energy by reducing heat loss or gain.

High Efficiency Gas Room Heater. Gas room heaters are typically less efficient than central furnaces, with minimum efficiencies of 65 AFUE for smaller and 70 AFUE for large units, although typical efficiencies are in the mid-70s for higher output devices. Efficient sealed-combustion heaters are available with efficiencies up to 83 percent.

Room Heater Maintenance. Room heater adjustments increase efficiency by insuring that the furnace fan stays on as long as there is heat in the exchanger. Fan Off control is adjusted to maximize efficiency. Other steps include: inspecting thermostat for proper operation; inspecting the filter and changing or cleaning as needed; checking all electrical components and controls; oiling motors as needed; inspecting the heat exchanger for possible cracks; and checking air fuel mixture, where appropriate.

Programmable Thermostat: ENERGY STAR® programmable thermostats come pre-programmed with settings intended to deliver energy savings without sacrificing comfort. The settings vary for the cooling and heating months, with specific temperature ranges and setback points for the morning, daytime, evening, and night. Programmable thermostat settings may also be changed to reflect individual schedules and preferences.

B.4.2 Building Shell

Ceiling Insulation. Insulation material inhibits the transfer of heat through the roof, wall, or floor structure. Because there are a variety of structure types, the choice of insulation materials will also vary. Typical insulating materials include loose-fill (blown) cellulose, loose-fill (blown) fiberglass, batts of fiberglass, rigid polystyrene, and sprayed foam.

Floor Insulation. Floor insulation involves adding R-19 insulation to raised floors in existing homes. This measure does not apply to homes constructed on slab foundations.

Crawlspace Insulation. As an alternative to floor insulation, crawlspace walls may be insulated. Because an insulated but unheated crawlspace can create moisture problems, the floor of the crawlspace should also be sealed with a vapor barrier. Insulating a crawlspace includes rim joist insulation.

Basement Insulation. Basement walls are typically insulated by constructing a stud wall inside the house foundation, and insulating it as any interior wall. This increases the cost of basement insulation compared to crawlspace insulation (in addition to the taller wall height to be insulated). The cost-effectiveness of basement insulation depends on whether the basement will be conditioned. Basement insulation includes rim joist insulation.

Slab Insulation. A substantial amount of heat is lost through an uninsulated slab, resulting in cold, uncomfortable floors. Insulating the exterior edge of the slab can reduce heating bills by 10-20%. Retrofit slab insulation involves installing rigid insulation directly against the exterior of the slab and footing. The keys to an effective slab foundation are: moisture control—using a water-managed foundation system to drain rainwater and groundwater away from the foundation; airtight construction—sealing interfaces between the slab foundation and the exterior wall to reduce infiltration into the house; and Complete insulation coverage—properly installing the correct insulation levels and making sure the insulation coverage is continuous and complete.

Wall Insulation. For existing construction, this measure involves adding R-11 or greater insulation to uninsulated walls. This is usually accomplished by drilling holes into the building's siding or interior walls and blowing in a loose-fill insulation material.

Comprehensive Shell Air Sealing - Infiltration Reduction: Professional installation of weather stripping, caulking, and expanding foam insulation aided by a blower door test. These measures reduce energy consumption by improving the tightness of the building shell and limiting heat gain and loss.

Self-Install Weatherization: Installation of weather stripping, caulking, and expanding foam insulation from a spray can to fix easily found leaks and reduce air infiltration, completed by the homeowner.

Storm Windows: These are installed on the exterior or interior of the primary window and reduce air infiltration by sealing tightly to the window frame. Interior storm windows are typically less costly and easier to install, and also save more energy, because the exterior storm windows require drainage holes to vent excess moisture. Although some models offer multiple glazing and low-e coatings, they are typically cost-comparable with new windows.

ENERGY STAR® Windows: Windows affect building energy use through thermal heat transfer (U-value), solar heat gains (shading coefficient), daylighting (visible light transmittance), and air leakage. The performance of a window is determined by the type of glass, the number of panes, the solar transmittance, the thickness of, and the gas type used in the gap between panes (for multi-pane windows). This measure meets the ENERGY STAR® requirements for U-value and solar heat gain coefficients (SHGC) specified by climate zone, and are certified by the National Fenestration Rating Council (NFRC). This is modeled as a replace on burnout measure, so the costs are not the full cost of the window and installation, but rather the cost compared to installing a new non-ENERGY STAR® window.

Heat Shrink Wrap Film (1-2 yr measure, window kit): This heavy-duty clear plastic is taped onto the inside of window frames and is heat-activated (typically with a hair dryer) to shrink until it stretches tightly across the frame, thereby reducing air infiltration without impacting visibility. The plastic is usually removed at the end of the heating season and can be re-used.

Storm Windows. Adding storm windows to single- or dual-pane windows can reduce the flow of outside air into the home. The airspace between the storm window and your existing window works as an added insulation factor, further improving thermal performance.

B.4.3 Water Heating

High Efficiency Water Heater. This measure involves substitution of a standard efficiency water heater with a high efficiency unit. For gas water heaters, this involves moving from a base Energy Factor (EF) of 0.63 to an EF of 0.71. Energy factors are a measure of water heater efficiency that combines recovery efficiency with standby losses.

Condensing Gas Storage Water Heater (0.86 EF): Condensing gas water heaters capture additional heat by circulating the flue gas through a heat exchanger in the tank. As the flue gas cools, water vapor and vaporized by-products of combustion condense and are drained.

Solar Water Heater: Heat transfer technology that uses the sun's energy to warm water. Solar water heaters preheat water supplied to a conventional domestic hot water heating system. The energy savings for the system depend on the collector technology (flat plate or glass tubes), solar radiation, air temperatures, water temperatures at the site, and the hot water use pattern.

Tankless Water Heater. Tankless or "on demand" water heaters eliminate the standby tank (and associated losses) of a standard water heater, as the water is heated instantaneously. However, energy savings relative to a tank-based system can not be calculated by comparing their respective energy factors. In addition to the standby losses, the recovery efficiency of the tank-based system must be compared to the tankless heating element's "cold" and "hot" efficiency in the context of the number of hot water draws and total daily hot water demand.

Low Flow Showerhead. Current federal standards mandate that low flow showerheads have a maximum flow rate of 2.5 gallons per minute. Many low flow showerheads use 1.0-2.5 gallons per minute compared to this 2.5 gallons per minute. The reduction in shower water use can substantially lower water heating energy use since showering accounts for about one-fourth of total domestic hot water energy use.

Faucet Aerators. Water faucet aerators are threaded screens that attach to existing faucets. They reduce the volume of water coming out of faucets while introducing air into the water stream. A standard non-conserving faucet aerator has a typical flow rate of 3-5 gallons per minute. A water-saving aerator can reduce the flow to 1-2 gallons per minute. The reduction in the flow rate will lower hot water use and save energy (kitchen and bathroom sinks account for approximately 7% of total domestic hot water energy use).

Pipe Wrap. Thermal insulation is material or combinations of materials that are used to inhibit the flow of heat energy by conductive, convective, and radiative transfer modes. By inhibiting the flow of heat energy, thermal insulation can conserve energy by reducing heat loss or gain. Insulation material inhibits the transfer of heat through the hot water tanks and hot water pipe. In residential applications, usually the first five feet of pipe closest to the domestic water heater is insulated. Small pipes are insulated with cylindrical half-sections of insulation with factory-applied jackets that form a hinge-and-lap or with flexible closed cell material.

ENERGY STAR® Clothes Washers. A standard clothes washer uses various temperatures, water levels, and cycle durations to wash clothes depending on the clothing type and size of the laundry load. A horizontal axis clothes washer utilizes a cylinder that rotates horizontally to wash, rinse, and spin the clothes. These types of washing machines can be top-loading or front-loading, and use significantly less water (hot and cold) than the standard vertical axis machines. A vertical axis machine generally fills the tub until all of the clothes are immersed in water. In contrast, the horizontal axis machine only requires about one third of the tub to be full, since the rotation of the drum around its axis forces the clothes into the water and thus can drastically reduce the total energy use for washing. These machines are also easier on clothes and use less detergent.

ENERGY STAR® Dishwashers. ENERGY STAR® -labeled dishwashers save by using both improved technology for the primary wash cycle, and by using less hot water to clean. They include more effective washing action, energy efficient motors, and other advanced technology such as sensors that determine the length of the wash cycle and the temperature of the water necessary to clean the dishes.

B.4.4 Cooking

Convection Ovens. These can be more energy efficient than standard ovens because the heated air is continuously circulated around the food being cooked. They provide more even heat distribution, and for many foods, temperatures and cooking time can be decreased.

High Efficiency Grill: Instead of standard burners, these units are equipped with porous ceramic plates, which glow-red hot. Efficiency is increased because the ceramic burner emits infrared heat in addition to the heat from combustion, increasing cooking speed with evenly distributed heat.

B.4.5 Clothes Drying

Energy Efficient Clothes Dryers. A standard clothes dryer uses various temperatures and drying durations to dry clothes depending on the clothing type and size of the laundry load. In general, the dryer cylinder is spun to rotate the wet clothes as hot air is injected into the drying cylinder. Wet moist air is then exhausted from the dryer. The cycle duration is manually set. An energy efficient clothes dryer uses a moisture-sensing device to terminate the drying cycle rather than using a timer. In addition, an energy efficient motor is used for spinning the dryer tub.

B.4.6 Whole House Measures

Residential New Construction: Both the ENERGY STAR® New Home and Best Practice New Home measures were directly based on BEopt modeling results completed for the Southwest Energy Efficiency Project's (SWEEP) 2007 study "*High Performance Homes in the Southwest: Savings Potential, Cost Effectiveness and Policy Options*."

B.5 Commercial Gas Measures

This subsection provides brief descriptions of the commercial gas measures included in this study.

B.5.1 Space Heating

High-Efficiency Furnace/Boilers. High-efficiency condensing gas furnaces and boilers have AFUEs of greater than 90% compared to base efficiencies in the 80% range. For furnaces, efficiencies above 90% can be achieved with a number of technologies, pulse combustion being just one of many design approaches. High-efficiency gas furnaces can be installed in new construction or can be retrofitted to existing commercial structures which have other heating systems. In most cases, a condensate drain must be added and a new or modified venting system must be installed.

Condensing boilers are available which operate with thermal efficiencies as high as 95% or more. These condensing units achieve their high efficiency by operating with stack gas temperatures around 100°F. At this low stack temperature the water vapor in the products of combustion is condensed. When the water vapor is condensed, its latent heat from the phase change is recovered, resulting in very high efficiencies.

Boiler Tune-Up. A high efficiency boiler tune-up performed by a properly trained technician can improve average combustion efficiency by 2-10%. To ensure that the boiler tune-up is a success, the tune-up technician should use an electronic flue-gas analyzer that is capable of continuously monitoring stack temperature, oxygen (O_2 in percent), and carbon monoxide (CO in ppm). In addition, the technician should determine the boiler's actual gas input rate (cubic feet per minute). Some boilers cannot be tuned up because there is no way to control the excess air or gas flow. Before examining this measure, the technician or auditor must determine if the boiler is tunable.

Boiler Pipe Insulation. Insulating accessible steam or hot water supply pipes in the boiler room is a cost-effective way to save energy. Savings will vary depending on the temperature of the hot water or steam and the ambient temperature.

Duct Insulation. Insulation material inhibits the transfer of heat through the air-supply duct. Several types of ducts and duct insulation are available, including flexible duct, pre-insulated flexible duct, duct board, duct wrap, tacked or glued rigid insulation, and water proof hard shell materials for exterior ducts.

Duct Repair and Sealing. An ideal duct system would be free of leaks, especially when the ducts are outside the conditioned space. Leakage in unsealed ducts varies considerably with the fabricating machinery used, the methods for assembly, installation workmanship, and age of the ductwork. To seal ducts, a wide variety of sealing methods and products exist. Care should be taken to tape or otherwise seal all joints to minimize leakage in all duct systems and the sealing material should have a projected life of 20-30 years. Current duct sealing methods include use of computer-controlled aerosol and pre- and post-sealing duct pressurization testing.

Programmable Thermostat. Setback programmable thermostats are appropriate controls for HVAC equipment that serve spaces with regular occupied and unoccupied periods, resulting in long periods when heating and cooling setpoints can be adjusted.

EMS installation. The term Energy Management System (EMS) refers to a complete building control system which usually can include controls for both lighting and HVAC systems. The HVAC control system may include on/off scheduling and warm-up routines. The complete lighting and HVAC control systems are generally integrated using a personal computer with control system software.

EMS optimization. Energy management systems are frequently underutilized and have hundreds of minor inefficiencies throughout the system. Optimization of the existing system frequently results in substantial savings to the measures controlled by the EMS (e.g. lighting, HVAC) by minimizing waste.

Heat Recovery from AC. Air conditioning and refrigeration systems remove enormous amounts of heat. Usually, this heat is discarded. The waste heat from these systems can be recovered and utilized in applications such as space heating or preheating domestic water. The temperature of the recovered heat is relatively low, which limits the uses of the recovered heat.

Installation of Air Side Heat Recovery Systems. Air-to-air heat exchangers can be used to transfer heat between the intake ventilation air stream and the HVAC exhaust air stream. During periods when the outside air is colder than the inside air, the heat exchanger transfers heat from the exhaust air to the incoming air reducing heating energy use. When the outside air is warmer than the inside air, the heat exchanger transfers heat from the incoming air to the exhaust air, lowering the temperature of the incoming air, and reducing cooling energy use. Installing an air-to-air heat exchanger will cause a slight increase in fan energy due to increased air flow resistance through the heat exchanger. The increase in fan energy is more than compensated for by energy savings in buildings with high outdoor air ventilation requirements. Air-to-air heat exchangers are most cost-effective in buildings having high outdoor air ventilation rates such as hospitals, hotels (kitchens), and restaurants.

Stack Heat Exchanger. Economizers and/or air preheaters are the most common heat exchangers used to capture waste heat from the flue gas. Economizers transfer heat to boiler feedwater, and air preheaters to combustion air. These heat exchangers are usually installed directly in the boiler stack, or are ordered integral to new boilers as part of the design.

Condensing Unit Heater. Unducted, ceiling- or wall-mounted unit heaters consist of a burner, propeller fan and louvers to direct conditioned air. Unit heaters are ideal for structures with high ceilings and open floor plans, and are typically installed in warehouses, factories, repair shops, and loading docks. As of 2009, the market for unit heaters is approximately half gravity vented heaters with pilot lights, and half power-vented heaters with electronic ignitions. Both typically achieve thermal efficiencies around 80%, but the former have seasonal efficiencies around 62-64% because conditioned air continuously escapes up the heater's flue in the off-cycle. In contrast, condensing unit heaters achieve thermal efficiencies of >90% as the latent heat of the flue gas is captured, condensing any water vapor into liquid.

Radiant (Infrared) Unit Heater. Infrared heaters have a blower which forces air into the burner assembly and directs the flame into a long heating tube, which radiates heat directly onto the area below. The high surface temperature (ranging from 400-900˚F) of the heating tube necessitates mounting the heater at a height of at least sixteen feet, and should not be applied in areas where combustible gases, dust, or vapors are present in high concentrations. Radiant heaters are an alternative to standard unit heaters which transfer heat via forced convection, and offer both substantial fuel savings and increased occupant comfort in buildings where conditioned air would rapidly disperse because of constant air exchanges or high ceilings.

Hot Water Temperature Reset. This uses outdoor temperature as a proxy for heating demand, and decreases the boiler supply water temperature setpoint as the weather warms. Conventional non-condensing boilers are typically set at about 180˚F to meet the heating demand on the coldest days of the year, and maintaining this temperature results in high standby losses. Savings are achieved as the temperature setpoint is decreased and idle losses cut, weather permitting. The setpoint on non-condensing gas boilers can decrease to 140˚F (below which, significant condensation occurs), and condensing boilers can be lowered to arbitrarily low temperatures.

Demand Controlled Ventilation (DCV). Demand-controlled ventilation uses carbon dioxide levels as a proxy for occupancy in order to regulate the amount of conditioned air admitted. It consists of two technologies: CO2 sensors and an air-handling system that uses data from the sensors. DCV is considered a mature technology and can be applied to a range of different building activities, with the savings most pronounced wherever there are highly variable and unpredictable occupancy patterns.

Refrigeration Heat Recovery – Space Conditioning. Several case studies produced by Ecotope in the Pacific Northwest have documented aggressive space heating savings in grocery stores by incorporating heat recovery from the refrigeration system to the main air handler. Savings of 70-80% can be achieved with an estimated budget of $40,000, but require significant design-build, commissioning, and integrated understanding between HVAC and refrigeration contractors and maintenance personnel.

Retrocommissioning. Retro-commissioning (RCx) is a systematic process to identify low-cost operational and maintenance improvements in existing buildings. RCx typically focuses on the performance of existing systems (HVAC, lighting, etc.), rathe than relying on equipment replacement. RCx typically includes a building audit, a review of past utility bills, and interviews with facility personnel. Building systems are monitored and tested, and the results are analyzed. Changes in response to the findings can lead to gas savings in the range of 2 to 10%.

B.5.2 Building Shell

Ceiling/Wall Insulation. Installing fiberglass or cellulose insulation material in floor, wall or roof cavities will reduce heat transfer across these surfaces. The type of building construction limits insulation possibilities. Choice of ceiling insulation material will vary depending on the roof construction type. Nominal R-values are used as the performance factor for insulation levels. The overall R-values include the thermal resistances of construction layers (gypsum, air gaps, framing, sheathing, concrete, roofing, etc.).

High Performance Dual Pane Windows. Windows affect building energy use through thermal heat transfer (U-value), solar heat gains (shading coefficient), daylighting (visible light transmittance), and air leakage. The performance of a window is determined by the type of glass, the number of panes, the solar transmittance, the thickness of, and the gas type used in the gap between panes (for multi-pane windows). Current Montana code has a minimum U-factor of 0.40 for commercial windows. High performance dual pane windows have a U-factor of 0.35 or less This measures involves an equipment efficiency upgrade during normal window replacement.

B.5.3 Water Heating

High Efficiency Water Heater. Efficient gas water heaters consist of a high efficiency natural gas storage-type hot water heater and tank. Many small commercial buildings and even some large commercial buildings use residential-sized water heaters to meet their needs for hand washing in restrooms or janitorial purposes (i.e. small office, small retail, supermarket, warehouse).

Instantaneous or Demand Hot Water Heater. Demand water heaters are available in propane (LP), natural gas, or electric models. Unlike "conventional" tank water heaters, tankless or instantaneous water heaters heat water only as it is used, or on demand. A tankless unit has a heating device that is activated by the flow of water when a hot water valve is opened. Once activated, the heater delivers a constant supply of hot water. The output of the heater, however, limits the rate of the heated water flow. They come in a variety of sizes for different applications, such as a whole-building water heater, a hot water source for a remote bathroom, or as a boiler to provide hot water for a heating system.

Pipe Insulation. The first five feet of pipe closest to the domestic water heater should be insulated. Small pipes are insulated with cylindrical half-sections of insulation with factory applied jackets that form a hinge-and-lap or with flexible closed cell material. Current Title 24 Energy Standards require insulation only on the portion of DHW piping through which water is recirculated. Some energy savings are possible by insulating non-recirculating branch piping, depending on the frequency of hot water use through this piping. If usage is infrequent, savings will be low.

Tank Insulation. Commercial water heater insulation is available either by the blanket or by square foot of fiberglass insulation with protective facing. Insulation blankets range from 50 to 82 gallon tank sizes, with thicknesses of 2 to 4 inches, and R-values ranging from 5 to 14. Many retailers and wholesalers surveyed suggested using two or more blankets for larger tanks, and double-wrapping tanks for increased R-value. They also note that squeezing the blanket to fit into tight applications lowers the R-value.

DHW Circulation Pump Time Clock Retrofit. Installing a time clock on the circulation pump for the domestic hot water system can reduce demand during periods when the building is unoccupied. Since, systems must be protected from damaging freeze in many climates, time clocks may include an override setting if the temperature drops below a predetermined set point.

Pre-Rinse Spray Valve. Pre-rinse spray valves are used in commercial food service to rinse dishes before dishwashing. As with low-flow faucets and showerheads, reducing the flow rate in spray valves can significantly reduce hot water consumption and thus energy use. There is a federal standard that sets the maximum flow rate for pre-rinse spray valves to 1.6 gallons per minute (significantly better than the average unit of a decade ago), but there are valves available with flow rates at or below 1.3 gallons per minute. This measure assumes that a 1.3 gallon per minute valve replaces a 1.6 gallon per minute valve.

Thermally Activated Heat Pump/Chiller. A thermally-activated heat pump/chiller based on an ammonia-absorption cycle can simultaneously produce hot water at 130 to 170 degrees Fahrenheit and chilled water at 33 to 45 degrees. The heating efficiency of the device is 160 percent, and cooling efficiency is about 60 percent. The overall efficiency exceeds 200 percent . The device requires an initial heat input which may be provided by waste heat, natural gas, propane, or solar energy. Costs and savings are based on a product called the ThermoSorber®, produced by Energy Concepts. Robur produces a similar product, marketed primarily to commercial customers.

B.5.4 Cooking

Convection Oven. Convection ovens use a small fan to circulate hot air within the oven cavity. Circulating air can heat food more efficiently than the still air found in conventional ovens. The hot air in the oven can be heated by gas or electricity. In general, a convection oven will save 30% of the energy used by an oven. These savings result from burners cycling off for a longer period.

Efficient Infrared Griddle. A griddle is a thick slab of flat steel heated from below by electric or gas burners. Gas griddles are rated at 60-80 kBtu/hour. In an infrared griddle, standard burners are replaced with a porous ceramic plate having about 200 holes per inch. Combustion is designed to take place very near the ceramic burner surface, causing it to glow red at a temperature of about 1,650° F. Efficiency is increased because the red-hot ceramic burner increases heat transfer to the griddle plate.

Energy Star Fryer. Fryers cook foods by submerging them in hot animal or vegetable oils, and utilize a range of different burner types. The oil is heated by gas burners with the flame traveling through several tubes that are submerged in the oil. Infrared fryers use internal fins or other heat-absorbing obstructions attached to the inside of the tubes. The fins or obstructions pick up more heat from the flame, resulting in less exhausted heat (lower temperature exhaust). Catalytic fryers have woven wire or steel wool-like material inside the fire tubes. These materials capture even more heat from the flame that can then be radiated to the tube walls and to the oil. Energy Star gas fryers have advanced burner designs and heat exchangers allowing shorter cook times and higher production rates, as well as decreased standby losses, and produce savings over 40%.

Energy Star Steamer. Commercial steam cookers are versatile appliances which can be used to quickly prepare any foods that do not require a crust. Steamers come in a variety of configurations but generally resemble an oven, with between one and four gasketed and windowless compartments. The stacked compartments typically accommodate a standard 12 by 20-inch hotel pan. Pressure steamers have an external boiler that produces potable steam under pressure, and atmospheric steamers have a steam generator located directly below the compartments. Both require a water line and drain hookup. In contrast, the connectionless steamer is a closed loop system with a reservoir that is periodically drained and refilled. Significant improvements in water- and energy- efficiency are achieved because no steam is allowed to escape down the condensate drain. Energy Star gas connectionless steamers can save 70-80% in energy and 90% on water consumption.

High-Efficiency Range. Ranges are the most widely used piece of commercial cooking equipment, similar to a residential stove but far more durable and with versatile burner configurations. The power burner range is an improved atmospheric burner. The term "power" means that a blower drives gas and air flow to the burner. Gas and air are mixed in a plenum and the mixture is regulated to achieve more efficient combustion. During combustion, the flame moves sideways from the burner and impinges on a bowl made of low-carbon stainless steel located underneath the burner. This bowl glows bright orange and increases the amount of radiant heat transmitted to the cooking utensil. The power burner can be adjusted from a maximum of 20,000 Btu/hour down to 6 Btu/hour. The thermal efficiency of the power burner is 63% compared to 42% for standard atmospheric burners found on conventional cooktop ranges.

B.6 Industrial Gas Measures

B.6.1 Industrial Measure Descriptions

B.6.1.1 Cross-Cutting Efficiency Measures

Boilers

Improved process control: Flue gas monitors are used to maintain optimum flame temperature and monitor levels of carbon monoxide (CO), oxygen, and smoke in the flue gas. By combining an oxygen monitor with an intake airflow monitor, it is also possible to detect small leaks. Monitoring allows for improved control of the fuel/air mixture so that energy efficiency is maximized and pollutant emissions are minimized.

Maintain boilers: Burners and condensate return systems can wear or get out of adjustment over time, which can cost a steam system up to 30% of its original efficiency over 2-3 years. Regular maintenance can ensure steam systems are operating at maximum efficiency.

Flue gas heat recovery/economizer: Heat from flue gases can be recovered using an economizer and used to preheat the feed water flowing into the boiler. By using waste heat to preheat feed water, the fuel consumption of the boiler can be reduced. This measure is fairly common in large boiler systems.

Blowdown steam heat recovery: When water is blown from high-pressure boilers as part of regular blowdown procedures, the pressure reduction often produces substantial amounts of low-grade steam. This low-grade steam can be used for space heating and feed water preheating.

Upgrade burner efficiency: A boiler will run only as well as the burner performs. A poorly designed boiler with an efficient burner may perform better than a well designed boiler with a poor burner. An efficient burner provides the proper air-to-fuel mixture throughout the full range of firing rates, without constant adjustment. An efficient natural gas burner requires only 2% to 3% excess oxygen, or 10% to 15% excess air in the flue gas, to burn fuel without forming excessive carbon monoxide.

Water treatment: Water impurities can form scale on heat transfer tubes and surfaces and lead to corrosion of system components, which can steadily degrade the energy efficiency of a steam system. Water treatment can reduce scale and corrosion, and therefore help to maintain a steam system's optimal energy performance over time.

Load control: A boiler economic load allocation system optimizes the loading of multiple boilers by providing steam to a common header so as to obtain the lowest cost per unit of steam. Modern, multiple burner load control, coupled with air trim control can result in steam system fuel savings of 3 to 5 percent.

Improved insulation: Advancements in insulating materials have produced a new generation of insulation with low heat capacity and better insulating capabilities. Energy savings of 6-26% can be achieved by upgrading boiler insulation and installing improved heater circuit controls (improved controls are often necessary to maintain proper output temperatures for older firebrick systems).

Steam trap maintenance: A simple program of checking steam traps to ensure they are operating properly can save significant amounts of energy. Without regular maintenance, steam traps can malfunction, wasting up to 10% of the energy consumed by a steam system.

Automatic steam trap monitoring: Attaching automated monitors to steam traps allows for the quick diagnosis and correction of steam trap malfunction. This measure can lead to energy savings above and beyond the energy savings achieved through regular steam trap maintenance.

Leak repair: As with steam traps, steam distribution pipes often have leaks that go unnoticed without a regular program of pipe inspection and maintenance. In addition to detecting and repairing leaks, thereby reducing wasted energy, this measure can also prevent small problems from developing into major leaks, which are often more difficult and expensive to repair.

Condensate return: Returning the hot condensate that occurs within a steam system to the boiler can save energy and reduce the need to treat boiler feed water. The substantial savings in energy costs and purchased chemical costs associated with this measure often make the building of a return piping system financially attractive.

HVAC

Improve ceiling insulation: Installing fiberglass or cellulose insulation material in floor, wall or roof cavities will reduce heat transfer across these surfaces. The type of building construction limits insulation possibilities. Choice of insulation material will vary depending on the roof construction type. The assumed scenario for this measure: increasing insulation from R-5 to R 24.

Install high-efficiency (95%) condensing furnace/boiler: High-efficiency condensing gas furnaces and boilers have AFUEs of greater than 90% compared to base efficiencies in the 80% range. For furnaces, efficiencies above 90% can be achieved with a number of technologies, pulse combustion being just one of many design approaches. Condensing boilers are available which operate with thermal efficiencies as high as 95% or more. These condensing units achieve their high efficiency by operating with stack gas temperatures around 100°F.

Stack heat exchanger: Air-to-air heat exchangers can be used to transfer heat between the intake ventilation air stream and the HVAC exhaust air stream. During periods when the outside air is colder than the inside air, the heat exchanger transfers heat from the exhaust air to the incoming air reducing heating energy use. When the outside air is warmer than the inside air, the heat exchanger transfers heat from the incoming air to the exhaust air, lowering the temperature of the incoming air, and reducing cooling energy use.

Duct insulation: Insulation material inhibits the transfer of heat through the air-supply duct. Several types of ducts and duct insulation are available, including flexible duct, pre-insulated flexible duct, duct board, duct wrap, tacked or glued rigid insulation, and water proof hard shell materials for exterior ducts.

EMS install: The term Energy Management System (EMS) refers to a complete building control system which usually can include controls for both lighting and HVAC systems. The HVAC control system may include on/off scheduling and warm-up routines. The complete lighting and HVAC control systems are generally integrated using a personal computer with control system software.

EMS optimization: Energy management systems are frequently underutilized and have hundreds of minor inefficiencies throughout the system. Optimization of the existing system frequently results in substantial savings to the measures controlled by the EMS (e.g., lighting, HVAC) by minimizing waste.

B.6.1.2 Sector-Specific Natural Gas Efficiency Measures

NAICS 311: Food Manufactring
NAICS 312: Beverage and Tobacco Product Manufacturing

Controls: This is a general measure to implement computer-based process controls, where applicable, to monitor and optimize various processes from an energy consumption perspective. In general, by monitoring key process parameters, processes can be fine tuned to minimize energy consumption while still meeting quality and productivity requirements. Control systems can also reduce the time required to perform complex tasks and can often improve product quality and consistency while optimizing process operations. This measure could include the installation of controls based on neural networks, knowledge based systems, or improved sensor technology.

Process heat recovery: This is a general measure to recover waste heat from processes wherever possible for use in other processes and/or facility applications, such as process feed preheating, space heating, water heating, and process air preheating.

Process integration: Process integration refers to the exploitation of potential synergies that are inherent in any system that consists of multiple components working together. In plants that have multiple heating and cooling demands, the use of process integration techniques may significantly improve plant energy efficiency. Developed in the early 1970s, it is now an established methodology for continuous processes. The methodology involves the linking of hot and cold streams in a process in a thermodynamic optimal way. Process integration is the art of ensuring that the components are well suited and matched in terms of size, function, and capability.

Efficient drying: Replacing existing dryers with the most efficient dryer technology can lead to energy savings. The most efficient dryers are those that recapture otherwise lost waste heat. Direct dryers are typically more efficient than indirect dryers. Typical efficiencies for direct dryers range from 95-98%, while indirect dryers typically have efficiencies in the range of 70-85%.

Thermally Activated Heat Pump/Chiller. A thermally-activated heat pump/chiller based on an ammonia-absorption cycle can simultaneously produce hot water at 130 to 170 degrees Fahrenheit and chilled water at 33 to 45 degrees. The heating efficiency of the device is 160 percent, and cooling efficiency is about 60 percent. The overall efficiency exceeds 200 percent . The device requires an initial heat input which may be provided by waste heat, natural gas, propane, or solar energy. Costs and savings are based on a product called the ThermoSorber®, produced by Energy Concepts. Robur produces a similar product, marketed primarily to commercial customers.

These devices are appropriate for buildings with large balanced hot water and chilling needs, such as dairies, breweries, poultry processors, meat processors, fruit and vegetable dryers, hospitals, hotels, laundries, swimming pools and ice rinks.

NAICS 322: Paper and Allied Products

Controls: See discussion for NAICS 311/312.

Closed hood: Paper machines with enclosed hoods require about one-half the amount of air per tonne of water evaporated that paper machines with a canopy hoods require. Enclosing the paper machine reduces thermal energy demands since a smaller volume of air is heated.

Process integration: See discussion for NAICS 311/312.

Extended nip press: After paper is formed, it is pressed to remove as much water as possible. Normally, pressing occurs between two felt liners pressed between two rotating cylinders. Extended nip presses use a large concave shoe instead of one of the rotating cylinders. The additional pressing area allows for greater water extraction, (about 5-7% more water removal) to a level of 35-50% dryness. Since this technology reduces the load on the dryer, it allows plants to increase capacity up to 25% in cases where the plant was dryer limited.

Thermally Activated Heat Pump/Chiller. See discussion for NAICS 311/312.

NAICS 323: Printing and Publishing

Process heat recovery: See discussion for NAICS 311/312.

Efficient Drying: See discussion for NAICS 311/312.

NAICS 325: Chemicals and Allied Products

Controls: See discussion for NAICS 311/312.

Process integration: See discussion for NAICS 311/312.

Improved separation processes: Separation processes are important energy users, for which energy efficiency improvement is often possible. The most common separation processes in the chemical industry are distillation, crystallization, adsorption, extraction, and membranes. Improved separation processes that can lead to energy savings include combined reaction and distillation (e.g. reactive distillation), ion exchange and bio-separation, and hybrid processes.

Thermal oxidizers: In many facilities VOC emissions are controlled by thermal oxidizers. The VOC-containing waste gas stream is mixed with natural gas and combusted, incinerating the VOCs. Regenerative thermal oxidizers can be used to recover some of the heat generated during the incineration. The heat can be used for preheating combustion air or steam generation.

NAICS 324: Petroleum and Coal Products

Controls: See discussion for NAICS 311/312.

Flare gas controls and recovery: Flare gas recovery (or zero flaring) is a strategy evolving from the need to improve environmental performance. Reduction of flaring can be achieved by improved recovery systems, including installing recovery compressors and collection and storage tanks. Reduction of flaring will not only result in reduced air pollutant emissions, but also in increased energy efficiency replacing fuels, as well as less negative publicity around flaring.

Fouling control: Fouling is a deposit buildup in heat transfer units and piping that impedes heat transfer, driving the combustion of additional fuel. Currently, various methods to reduce fouling focus on process control, temperature control, regular maintenance and cleaning of the heat exchangers (either mechanically or chemically) and retrofit of reactor tubes.

Process integration: See discussion for NAICS 311/312.

Efficient furnaces: This measure considers improvements to furnace efficiency. The efficiency of furnaces can be improved by improving heat transfer characteristics, enhancing flame luminosity, installing recuperators or air-preheaters, and improved process controls. New burner designs can facilitate improved mixing of fuel and air and more efficient heat transfer. Many different concepts are developed to achieve these goals, including lean pre-mix burners, swirl burners, pulsating burners, and rotary burners.

NAICS 327: Nonmetallic Mineral Products

Controls and management: See discussion for NAICS 311/312.

Efficient burners: The efficiency of natural gas-fired process heaters is governed by burner performance. An efficient burner provides the proper air-to-fuel mixture throughout the full range of firing rates, without constant adjustment. An efficient natural gas burner requires only 2% to 3% excess oxygen, or 10% to 15% excess air in the flue gas, to burn fuel without forming excessive carbon monoxide.

Oxyfuel: Oxy-fuel furnaces provide an oxygen-rich combustion environment that improves energy efficiency while reducing NOx emissions. The energy savings of converting to an oxy-fuel furnace depend on the energy use of the current furnace, use of electric boosting, and air leakage. Energy savings are typically between 20 and 45% (45% for replacing energy inefficient furnaces).

Batch cullet preheating: In a cullet preheater, the waste heat of the fuel-fired furnace is used to preheat the incoming cullet batch. Cullet preheaters are marketed by a number of companies, and are either direct or indirect preheaters. In the direct preheater, the cullet is in direct contact with the flue gas. The indirect preheater is a cross-flow plate heat exchanger. Energy savings of cullet preheaters are estimated to be between 12 and 20%.

NAICS 331: Primary Metal Industries

Controls and management: See discussion for NAICS 311/312.

Preventative maintenance: Preventative maintenance involves training personnel to be attentive to energy consumption and efficiency. Successful programs have been launched in many industries. Examples in steel making include timely closing of furnace doors to reduce heat leakage and reduction of material wastes in the shaping steps. At an integrated steel plant in the Netherlands, 2% of total energy use was saved via such preventative maintenance measures as those cited above.

Efficient burners: See discussion for NAICS 327.

Heat recovery: See discussion for NAICS 311/312.

NAICS 332: Fabricated Metal Products

Combustion controls: Combustion controls aim to improve combustion efficiency by ensuring the proper air-to-fuel ratio is used, which generally requires establishing the proper amount of excess air.

Efficient burners: See discussion for NAICS 327.

Optimize furnace operations: The improvement opportunity addresses the losses that are associated with the combustion of fuel and the transfer of the energy from this fuel to the material within a furnace. Key improvement areas include air-to-fuel ratio control, reducing excess air, preheating of combustion air or oxidant, furnace waste heat recovery, and oxygen enrichment.

Insulation/reduce heat losses: This measure includes all opportunities for better heat containment within a furnace. Opportunities include improved insulation of furnace walls, the reduction or elimination of air infiltration, the repair and maintenance of furnace seals, and improved insulation of related piping and ductwork.

Other Industries

The following SIC codes represent only a small fraction of the industrial natural gas consumed in Colorado.

- NAICS 313: Textile mills
- NAICS 314: Textile product mills
- NAICS 315: Apparel
- NAICS 316: Leather and leather products
- NAICS 321: Wood products
- NAICS 326: Rubber and misc. plastics products
- NAICS 333: Industrial machinery and equipment
- NAICS 334: Computers and electronic products
- NAICS 335: Electronic equipment, appliances, and components
- NAICS 336: Transportation equipment
- NAICS 337: Household and institutional furniture and kitchen cabinets
- NAICS 339: Miscellaneous manufacturing

For these NAICS codes, two generic efficiency measures were considered: (1) process controls and management, and (2) heat recovery.

Process controls and management: This is a general measure to implement computer-based process controls, where applicable, to monitor and optimize various processes from an energy consumption perspective. In general, by monitoring key process parameters, processes can be fine tuned to minimize energy consumption while still meeting quality and productivity requirements. Control systems can also reduce the time required to perform complex tasks and can often improve product quality and consistency and optimize process operations. This measure could include the installation of controls based on neural networks, knowledge based systems, or improved sensor technology.

Heat recovery: This is a general measure to recover waste heat from processes wherever possible for use in other processes and/or facility applications, such as process feed preheating, space heating, water heating, and process air preheating.