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Methodology for the Policy Analysis Modeling System (PAMS)

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Methodology Description for the Policy Analysis Modeling System (PAMS)

Abstract

The Policy Analysis Modeling System is a spreadsheet tool developed to provide an estimate of costs and benefits of appliance efficiency standard and labeling programs. PAMS is a self-contained spreadsheet model that provides both a consumer-oriented analysis and a national cost-benefit analysis in the style of the analysis performed for U.S. appliance efficiency standards. The tool allows policy analysts from many countries to produce a first-cut analysis of appliance efficiency program costs and benefits, examine the sensitivities of the analysis with respect to different policy parameters and assumptions, and continually refine the analysis as more data becomes available. The methodology is a bottom-up approach, using technical specifications for particular products in estimating the increased cost to the consumer resulting from implementation of particular energy-saving designs. It is designed to operate for the widest possible variety of countries, and with as little need as possible for detailed input data. For more accurate results, it can be easily customized to use the most reliable country-specific data inputs. In addition to consumer financial impacts, the tool provides national primary energy savings and estimates of carbon emissions mitigation resulting from the program.

1. Introduction

Energy efficiency standards provide a policy option that governments can use to save energy and money for their local or national economies. Usually when consumers purchase appliances and equipment for a particular purpose, they do not have complete information regarding the total life-cycle cost of operating the appliance in terms of energy and environmental costs. Well-designed energy efficiency standards can help assure that the appliances that consumers do buy do not produce cause excessive negative environmental impacts or high operating costs. Information regarding the consumer and national economic impacts of energy efficiency standards assists policy makers in designing such standards to maximize national energy, environmental, and economic benefits.

The Collaborative Labeling and Appliance Standards Program (CLASP) was founded in order "to facilitate the design, implementation, and enforcement of energy efficiency standards and labels for appliances, equipment, and lighting products in developing and transitional countries throughout the world." (www.clasponline.org). One of the most expensive components of setting appliance standards is evaluating the costs and benefits of specific appliance standards or labeling programs for a variety of potential standards, conditions, and scenarios. In this document we describe the methodology of an efficiency standards model that attempts to provide energy efficiency standards cost/benefit impact information for a range of appliances for a large number of both developed and developing countries.

2. Model Overview

The objective for PAMS in calculating policy cost/benefits is to provide a quantitative assessment of the costs and benefits for several different appliances in a single spreadsheet. Further, the tool is constructed in such a way that a wide variety of country scenarios can be accommodated through user selection of macro-level forecast data. The overall cost benefit accounting model can be described in terms of several component models that provide important inputs for the final aggregate cost/benefit calculation.

The PAMS model is designed to model the impacts of Minimum Efficiency Performance Standards (MEPS). With this type of policy comes into effect, the efficiency of every product on the market is assumed to exceed the minimum value set by the policy. PAMS assumes that before standards are put in place, all products on the market operate at a well-defined *baseline* efficiency. The impacts of labeling programs are not modeled[1]. The efficiency policy analysis model calculates the costs and benefits of efficiency standards from two distinct but related perspectives:

1. The *Consumer Perspective* examines costs and benefits from the perspective of the individual household or enterprise. The calculation from the consumer perspective is called the ***Life-Cycle Cost*** (LCC) calculation.
2. The *National Perspective* projects the total national costs and benefits including both financial benefits, energy savings and environmental benefits. The national perspective calculations are called the ***National Energy Savings*** (NES) and the ***Net Present Value*** (NPV) calculations.

2.1. Life-Cycle Cost (LCC) Calculation

The Life-Cycle Cost of any appliance or other energy-consuming equipment accounts for all expenditures associated with purchase and use. From the consumer perspective, the two main components of Life-Cycle Cost are the equipment (first cost) and the operating cost[2]. Equipment cost is the retail price paid by the consumer purchasing the appliance. Operating cost is the cost of energy, in the form of utility bills, for using the equipment. Life-Cycle Cost is given by:

$$LCC = EC + \sum_{n=1}^{L} \frac{OC}{(1+DR)^n}$$

, where EC is equipment cost (retail price), n is the year since purchase and OC is the annual operating cost. Operating cost is summed over each year of the lifetime of the appliance L.

[1] Extension of PAMS to model labeling programs is under consideration.

[2] For some appliances, installation and maintenance are also significant costs, but these are not generally important for the types of appliances modeled by PAMS.

Operating cost is calculated by multiplying the Unit Energy Cost (UEC, in kWh) by the price of energy (*P*, in dollars per kWh) as follows:

$$OC = UEC \times P$$

Unit energy consumption and energy price are assumed constant from year to year[3]. The fact that future costs are less important to consumers than near-term costs is taken into account by dividing future operating costs by a *discount factor* $(1+DR)^n$, where *DR* is the discount rate. Consumer discount rates are parameterized by the model according to to the Human Development Index.

The PAMS spreadsheet tool calculates LCC for the case in which a specific efficiency improvement is made to an appliance (the policy case), and to the case where no improvements are made (the baseline). LCC for both cases are shown on the 'Summary' page. The LCC calculation therefore demonstrates how increases in efficiency may increase the purchase price of an appliance or piece of equipment for a consumer, and how the energy savings can result in reduced energy expenses. The impact on LCC provides a guideline for whether the policy would result in net financial benefits or costs to the consumer.

For each product type modeled in PAMS, there are several levels of efficiency, or design options, which may be evaluated as possible policy targets. Individual efficiency measures are combined to form these design options in such a way that with each subsequent improvement in efficiency, the first cost increases. There is no a priori best choice for efficiency, since LCC depend on factors such as baseline UEC and energy price, which differ from country to country.

2.2. Efficiency and Price

The main factor that affects the life-cycle cost of each design option is the degree to which first cost increases with improved efficiency. The relationship between the efficiency of a product and its cost is based on the cost to manufacturers to implement a particular energy-saving design. The model assumes that these incremental costs will be passed on through the distribution chain to the consumer, who will pay a higher retail price for the product. An implicit assumption is that manufacturer and retail markup factors are not dependent on product design. Retail price therefore scales, in percentage terms, as the manufacturer's incremental costs. This assumption allows for the estimation of retail prices by using an estimate of price of current baseline models in combination with fractional price increases. Since detailed efficiency cost curves are not available for an arbitrary country, data from another country may be used as a proxy, as long as it is verified that general product design and class configuration is similar between the proxy country, and the country being studied.

[3] In fact, energy prices are not constant over time. Energy price trends are difficult to predict, however, and vary greatly between countries. Therefore, PAMS does not attempt to forecast energy prices.

In order to assess the potential savings from a particular appliance, we rely on detailed engineering data, which relate the efficiency improvement afforded by particular design options to the additional manufacturing cost in the form of materials and labor. Although this type of data is not available for a wide range of countries, CLASP has collected data from a number of different countries, and these data are generally appropriate as a proxy for products in the particular country being modeled. These proxy data, while not exact, provide a solid basis for projecting prices and efficiency savings to the household and national level.

Table 1 gives an example of the engineering data utilized by the PAMS model. This example is for a two star (snowflake) single-door refrigerator-freezer with 169 liters of fresh food volume and 19 liters of freezer volume. This product class was analyzed during the development of efficiency standards in the European Union[4], but is a common product class and capacity in many countries.

Table 1. Engineering Parameters for Two-Star Refrigerator - European Union

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Cons.
		%	$		$	kWh/yr
0	Baseline	0%	0	1.00	420	335
1	Baseline + increased door insul. (+15 mm)	12%	5	1.01	425	299
2	1 + decreased door leakage	14%	6	1.01	426	293
3	2 + optimized compressor	30%	15	1.04	435	258
4	3 + increased cabinet insul. (+15 mm)	64%	35	1.08	455	204
5	4 + increased door insul. (+15 mm)	75%	40	1.09	460	191
6	5 + increased cabinet insul. (+15 mm)	102%	59	1.14	479	166
7	6 + doubled evap. Heat cap.	107%	69	1.16	489	162
8	7 + doubled cond. Heat cap.	111%	77	1.18	497	159
9	8 + doubled cond. Surface	116%	112	1.27	532	155

The engineering data considers nine combinations of efficiency improvement options in order of increasing efficiency. Design options combinations are cumulative, that is each subsequent option includes all of the measures of the previous combination, and adds an additional one. According to this data, the efficiency can be improved up to 116%, equivalent to a 54% reduction in consumption. The corresponding price increase is 27%. Complete details for all engineering data used in PAMS are given in the Appendix. PAMS uses the engineering data to derive efficiency improvement and price factors. The model then applies these factors to local baseline equipment prices (*EC*) and unit energy consumption (*UEC*), which may be different for the country studied. The implicit

[4] GEA, Group for Efficient Appliances, *Study on energy efficiency standards for domestic refrigeration appliances*. Group for Efficient Appliances, for DG-XVII, March 1993

assumption is that, while the capacity, price and use patterns for a given product class may vary from country to country, the relative effectiveness and cost of improvement options will be similar.

2.3. Other Life-Cycle Cost Parameters

Additional parameters which impact the LCC calculation, and which can be modified through the spreadsheet interface are:

1. *Discount Rate (DR)* - The average interest rate for money that the consumer would use for paying the potential extra cost of a higher efficiency appliance. By default, discount rates are modeled according to current local interest rates.
2. *Unit Energy Consumption (UEC)* **-** Typical annual energy usage for each class of equipment, according to local use patterns and climate conditions.
3. *Equipment Lifetime (L)* **-** The average amount of time that a class of equipment is used before it is discarded or replaced.
4. *Energy Price* (*P***)** - The increment to the customer's utility bill from the last unit of energy consumed. This may be estimated as the *average* price paid by customers for one unit of electricity. Ideally, however, the *marginal* price should be used, which takes into account the local tariff structure as it applies to typical owners of the product being modeled.

3. National Energy Savings and Net Present Value Calculation

The Life-Cycle Cost calculation detailed above provides an estimate of the financial impacts of a minimum efficiency standard at the unit level, that is, for each household or business that uses the product. This evaluation is a critical factor in the decision for which products to target for MEPS, and the most appropriate minimum efficiency levels. A second critical set of critical calculations involve *national* impacts. The two main national impacts calculations are called National Energy Savings and Net Present Value. National Energy Savings (NES) is the total primary (input) fossil fuel energy saved in the *policy case* versus the *base case*. Net Present Value is the discounted net benefit of financial savings to the entire market of consumers.

In some sense, national impacts are a scaling up of unit level impacts to cover the whole market. National impacts also introduce an important time component to the evaluation of program impacts. MEPS generally affect only *new* products, not products already installed before the implementation year. In the first year of standards implementation, therefore, savings are small, since the standard only has an effect on the products purchased in that year. As time goes on, more and more of the product stock is impacted by standards. The national impacts calculations describe the evolution of the stock, and therefore give a time profile of costs and benefits.

3.1. Stock Forecast

In order to determine the national-level impacts of MEPS, a forecast must be made of the total number of products operating in the country in each year, and the rate at which old, inefficient products are replaced with new, efficient ones. Therefore, product sales (shipments) and stock forecasting are a major component of the model.

3.1.1. Ownership Model

Appliance stock and national end use consumption are driven by population growth and trends in appliance ownership rates. In developed countries, the market for most major appliances is saturated, that is, nearly every household owns the appliance, and ownership rates are further increased only by ownership of multiple units of each appliance. In developing countries, however, ownership rates of even basic appliances are dynamic, and depend critically on household income level, degree of urbanization and electrification. In countries experiencing rapid growth in those parameters (e.g. China and India), appliance ownership growth is also dramatic. The PAMS model therefore bases projections of end use consumption and subsequent savings from efficiency programs on a model relating ownership response to household income, electrification and urbanization. It utilizes population forecasts in combination with an income model and econometric parameterization to arrive at the national ownership rate for each year in the forecast.

The general form of the econometric parameterization of product saturation (rate of ownership) is given by

$$Sat = \left(K \times I(y)\right)^{\lambda_a} \times \left[1 - e^{-\left(bE(y)^{\lambda_b} + cU(y)^{\lambda_c}\right)}\right]^a$$

Where:

Sat	is the saturation of the appliance
I	is the monthly household income, given by Gross Domestic Product divided by the number of households in the country.
U	is the national percentage of urbanization
E	is the national percentage of electrification
y	is the year of the projected saturation

Since Air Conditioner ownership is affected by national climate, the urbanization variable is replaced with a climate variable in the saturation equation for that product. The climate variable used is an estimate of the number of cooling days per year.

The dependency on each parameter is assumed to be mediated through a power law, with an arbitrary scaling factor and exponent. By definition, the electrification and urbanization range between 0 and one, while income is unbounded. The logistic factor in the large brackets ranges from 0 to 1. The income dependence is outside of the brackets. Therefore, saturation can exceed 100% for wealthy countries (which is in fact the case)

A least squares fit to the data for each appliance yields the parameters given in Table 2.

Table 2. Saturation Model Parameters for Climate-Independent Appliances

Appliance	K	a	λa	b	λb	c	λc
Refrigerator	0.1028	1.2382	0.2081	0.3168	3.9955	0.1576	0.6789
Washing Machine	0.0004	2.8308	0.3519	1.2897	3.7727	0.7280	0.3591
Air Conditioners	0.0025	5.3961	1.5296	0.4023	0.9296	0.1974	2.1188

Saturation of appliances grows over time with increases in household income, urbanization and income. In order to account for differences in cost of living between countries, income is corrected according to Purchase Power Parity (PPP). Per household income is forecast according to projections of GNI, population and household size as estimated by the United Nations (UN Habitat[5]). Urbanization forecasts are also taken from the UN. Historical electrification rates are taken from the International Energy Agency's World Energy Outlook till 2002. Projections are made using a correlation between electrification growth and economic growth. The relationship between them is determined from development surveys, and follows the following equation:

$$Growth_{ELEC}(y) = \left(-4.32 \times E(y-1) + 4.46\right) \times Growth_{ECON}$$

,where $Growth_{ELEC}(y)$ is the growth in electrification rate in the present year, E is the electrification rate in the previous year, and $Growth_{ECON}$ is the annual economic growth rate. This takes in account the fact that the relationship between electrification and economic growths is itself a function of the level of development. The economic growth rate is assumed to be constant throughout the forecast.

Because economic growth is such a critical parameter to ownership, affecting both income levels and electrification rates, the model allows the user to choose between several growth scenarios. These are: current growth rates, low, medium and high growth projections. Growth rates are estimated on a regional level and forecast rates are those used in the Intergovernmental Panel on Climate Change's Special Report on Emission Scenarios[6].

Imposition of a standard generally raises prices, which in principle impacts ownership rates. These effects are usually small, but in a developing country, where price impacts are large, imposition of a standard does have the potential to slow the purchase of the appliance. The ownership rates in the standard case are modeled with the same equation but with an equivalent income that takes in account the increase in the price of the appliance. After the standard is set, the saturation will flatten until the market catches up.

3.1.2. Shipments Model and Stock Accounting

Determination of economically-driven appliance ownership rates allows for the calculation of the total stock of appliances and product sales. Details of shipments (sales)

[5] Available at http://www.unhabitat.org/habrdd/CONTENTS.html
[6] Available at http://www.grida.no/climate/ipcc/emission/

are important, since only those appliances sold after the date of program implementation will provide energy savings. The shipments model therefore determines the fraction of appliances that will be affected by efficiency programs at any point in the forecast.

Shipments are driven by the increase in households owning appliances, or by the replacement of retired appliances. In developing countries, the combined effect of rapid economic growth, urbanization, electrification and number of household (population is growing whereas the households become smaller), the “first purchase” component is the dominant driver of sales. In developed countries, where the household ownership rate may be saturated, replacements play a larger role.

Shipments due to increased ownership are given by

$$FP(y) = \frac{Pop(y) \times Sat(y)}{HHSize(y)} - \frac{Pop(y-1) \times Sat(y-1)}{HHSize(y-1)}$$

,where *FP* stands for first purchase, *Pop(y)/HHSize(y)* is the number of households in each year, *Sat(y)* is the function presented above. Population data is from Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2003) and Household Size is from United Nations Habitat.

In addition to first purchases, the model describes the replacement of an appliance in terms of an annual retirement probability that varies as a function of the appliance age, given by

$$P_R(age) = \frac{1}{1 + e^{(age - age_0)/D_{age}}}$$

where P_R *(age)* is the probability of retirement at a given appliance age, age_0 is the average lifetime of the product, and where D_{age} is the mean deviation of replacement ages, assumed to be two years. Replacements in each year are given by the relationship

$$REP(y) = \sum_{age=1}^{L} Stock(y-1, age) \times P_R(age)$$

, where *Stock(y,age)* is the number of products of vintage *age* remaining in each year. Finally, the total shipments for the current year are

$$Shipment(y) = S(y) = FP(y) + REP(y)$$

The final step in stock accounting is to update the number of remaining older products in the stock, according to:

$$Stock(y, age) = Stock(y-1, age-1) \times (1 - P_R(age-1))$$

3.2. National Energy Savings Calculation

National Energy Savings is defined as the difference in energy consumption between the *base case* and the *policy case*. In the base case, all products are assumed to be operating at the baseline efficiency. In the policy case, those products purchased after the implementation date (a user-adjustable parameter), are assumed to operate at the efficiency determined by a specific design option combination chosen by the user.

PAMS calculates National Energy Savings (NES) in each year by comparing the national energy consumption of the product under study in the base case to the policy case, according to

$$NES = NEC_{Base} - NEC_{Policy}$$

In turn, the total energy consumption (*NEC*) of the national stock of products in year *y* is given by:

$$NEC(y) = \sum_{age} Stock(y, age) \times UEC(y - age)$$

, where the *UEC* of each cohort is determined according to the year of purchase *(y-age)*. UEC differs between the base and policy case for years after the implementation date, due to the improvement in efficiency, according to the following relationship:

$$UEC = UEC_{Base} \times Eff_{Base}/Eff_{Policy}$$

In addition, the model takes into account how the efficiency of appliances in the market may evolve due to factors other than specific efficiency policies. In general, there is some incremental innovation over time, due to market-based improvement of manufacturing practices. The rate of improvement will vary between markets, and is not known in general. This parameter is therefore left as a user input.

Modeling of efficiency improvement in the base case is appropriate in the following cases: (1) There are historical data on efficiency trends, or (2) There is an expectation of political and economic pressure for continuing efficiency improvement. The efficiency in each year is then given by

$$Eff\ (y) = Eff_0 \times (1 + R_{eff})^{(y - y_0)}$$

, where Eff_0 is the appliance base efficiency in the reference year y_0, and R_{eff} is the annual improvement rate. Efficiency improvement applies to both the base and policy case, except that after policy implementation, no *additional* improvement occurs until the year in which the 'natural' improvement would dictate, that is, the year in which the base case 'catches up' to the policy case. After this date, efficiency improvement proceeds at the same rate in the base and policy case.

Calculation of National Energy Consumption in the base and policy case allows for determination of National Energy Savings. The equations given above show energy savings calculate on a *site* basis. National utility and environmental impacts, however are driven by *primary* energy consumption, that is, total inputs of fossil fuel energy. Primary energy savings (PES) is calculated from site savings by taking into account the electricity generation fuel mix, and losses through transmission and distribution (T&D). The formula for PES is:

$$PES = \frac{NES}{1 - TD} \times HR$$

, where *TD* is the fraction of energy lost in transmission and distribution, and *HR* is the heat rate. PAMS applies *TD* on a regional basis, relying on consumption and production data from IEA. The heat rate is calculated according to the relative amount of fossil fuel and nuclear generation, relative to hydroelectric and other renewable sources, as provided by IEA.

Finally, carbon dioxide emissions savings (*CES*) are calculated from energy savings, by applying carbon factors to site energy savings according to:

$$CES = \frac{NES}{1 - TD} \times CF$$

, where the carbon factor CF is derived from fossil fuel generation fraction, assuming emissions of 1000 g/kWh for thermal generation.

3.3. Net Present Value Calculation

The Net Present Value (NPV) of a policy is a measure of the net financial benefit from its implementation to the nation as a whole. As in the case of National Energy Savings, the calculation is somewhat parallel to the unit LCC calculation. National financial impacts in year y are the sum of equipment (first) costs and consumer operating costs. National equipment cost (NEC) is equal to the retail price times the total number of shipments.

$$NEC = EC \times S(y)$$

Likewise, national operating cost (NOC) is simply the total (site) energy consumption times the energy price.

$$NOC = NEC(y) \times P$$

As in the case of efficiency, the model takes into account the tendency for equipment costs to decrease over time, in real terms. Historical price trends show that the real (inflation adjusted) cost of many appliances has decreased dramatically over the decades, transforming appliances that were once luxuries into standard household items. The decreasing real price of appliances can be expressed as a deflation rate, which is left as a user input.

The real price of the appliance in the base case is given by:

$$EC_{Base}(y) = EC_{Base}(y_0) \times \left(1 - R_{def}\right)^{y-y_0}$$

,where $P_{Base}(y)$ is the appliance base price in year y, $P_{Base}(y_0)$ is the appliance base price in the reference year y_0, and R_{def} is the real price deflation rate.

The net savings in each year arises from the difference in first and operating costs in the standards versus the base case, ΔNEC and ΔNOC. Net Present Value of the policy option is then defined as the sum over a particular forecast period of the net national savings in each year, multiplied by the appropriate national policy discount rate

$$NPV = \sum_{y} (\Delta NOC(y) + \Delta NEC(y)) * (1 + DR_N)^{-(y-y_0)}$$

,where the subscript N indicates that in general the national policy discount rate will not be identical to the discount rate used in calculating *LCC*. For the calculation of *NPV*, y_0 is the current year, which may be different from the policy implementation year.

The following list summarizes important inputs to the national impacts calculation:

1. **National Policy Discount Rate** is the discount rate that is applied to a financial analysis of efficiency policy. It may be based on the average cost of private capital, or it may be based on the social discount rate applied to government projects. A lower, social discount rate may be particularly relevant if the volatility of national energy supplies or costs hold the potential for creating economic or social crises.
2. **Equipment Price Deflation Rate** reflects the long-term changes in equipment prices that may be expected.
3. **Efficiency Improvement Rate** can impact future savings from a standard because with a baseline trend of increasing efficiency, a fixed standard becomes less important farther in the future, while with a baseline trend of decreasing efficiency, efficiency standards become more important farther in the future.

APPENDIX – Engineering Data

To determine the incremental cost of energy efficiency improvement, an engineering study is necessary. The following tables provide the engineering data for cost, efficiency and/or the electricity consumption of each design option. The available appliances are Refrigerators, Washing Machines and Air Conditioners.

PAMS, uses ratios so that the user can adapt the baseline price or efficiency to a specific market. By doing that, we assume that between the marker country and the interpolated one, the same design option will have a price proportional to the cost of the appliance and, that its effect on the efficiency will be proportional to the average consumption. For example, if a design option reduces consumption from 250 kWh/year to 200 kWh/year, improvement is 25%.

Table A- 1. Efficiency and Price Parameter Summary for all Products.

Appliance Name	*Eff Units*	*Base Price*	*Base UEC*	*Life yrs*	***Efficiency vs. Design Index***										***Relative Price vs. Design Index***									
					0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
Refrigerator, India	kWh/yr	$189	438	15	1.00	1.05	1.30	1.85	1.90	2.03					1.00	1.01	1.04	1.11	1.13	1.19				
Refrigerator, China	kWh/yr	$250	431	15	1.00	1.13	1.40	1.51	1.74	1.83	2.05				1.00	1.02	1.08	1.10	1.18	1.20	1.27			
Refrigerator, Brazil, 1 Star	kWh/yr	$212	493	15	1.00	1.21	1.25	1.39	1.41	1.51					1.00	1.09	1.11	1.21	1.24	1.31				
Refrigerator, Europe, 2 Star	kWh/yr	$420	335	12	1.00	1.12	1.14	1.30	1.64	1.75	2.02	2.07	2.11	2.16	1.00	1.01	1.01	1.04	1.08	1.09	1.14	1.16	1.18	1.27
Refrigerator, Europe, 3 Star	kWh/yr	$502	367	12	1.00	1.02	1.10	1.26	1.43	1.47	1.62	1.67	1.70	1.78	1.00	1.00	1.01	1.03	1.07	1.08	1.11	1.13	1.14	1.21
Refrigerator, Europe, 4 Star	kWh/yr	$688	591	16	1.00	1.14	1.19	1.23	1.24	1.38	1.48	1.71	1.84	1.88	1.00	1.01	1.02	1.03	1.03	1.06	1.08	1.13	1.16	1.18
Washing Machine, EU	kWh/yr	$388	255	15	1.00	1.05	1.08	1.21	1.28	1.34	1.40				1.00	1.01	1.02	1.07	1.09	1.12	1.21			
Room Air Conditioner, China	EER	$542	426	12	2.27	2.37	2.53	2.62	2.89	2.92	3.06	3.08	3.09		1.00	1.00	1.01	1.02	1.04	1.04	1.08	1.08	1.09	
Room Air Conditioner, US	EER	$179	379	12.5	2.41	2.55	2.73	2.85	2.93	3.04	3.10	3.44			1.00	1.00	1.02	1.04	1.06	1.21	1.54	2.23		
Room Air Conditioner, US2	EER	$199	471	12.5	2.48	2.58	2.75	2.83	2.90	3.03	3.08	3.42			1.00	1.01	1.02	1.04	1.06	1.21	1.52	2.14		
Room Air Conditioner, US3	EER	$257	694	12.5	2.73	2.85	2.89	2.96	3.21	3.27	3.63				1.00	1.02	1.03	1.05	1.18	1.44	1.95			
Room Air Conditioner, US4	EER	$328	1063	12.5	2.64	2.84	2.92	2.97	3.15	3.25	3.28	3.37	3.74		1.00	1.04	1.05	1.06	1.36	1.46	1.50	1.74	2.19	
Room Air Conditioner, US5	EER	$405	1573	12.5	2.41	2.46	2.49	2.60	2.76	2.88	2.94	3.26			1.00	1.01	1.03	1.12	1.27	1.32	1.53	1.98		

Refrigerator Data

India

Appliance Characteristics:

- The refrigerator studied is a 165-liter, manual-defrost, single-door domestic refrigerator-freezer. Its market share in 1990 was estimated to be 90% (Government of India 1993).
- Baseline price is 189.7 USD (7500 Rs).
- Lifetime is 15 years

Table A- 2. Engineering Parameters for Indian Baseline Refrigerators and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Cons.
		%	$		$	kWh/yr
0	Baseline design	0%	0	1.00	189	438
1	0+ Gasket heat leak reduction by 25%	5%	3	1.01	192	416
2	1+ Use higher EER(4.13) compressor	30%	8	1.04	197	336
3	2+ Increase insulation thickness in door and wall by 50%	85%	20	1.11	210	237
4	3+ Increase evaporator area by 33%	90%	25	1.13	215	230
5	4+ Increase condenser area by 50%	103%	35	1.19	225	215

Source:
P. Bhatia, *Development of Energy-Efficiency Standards for Indian Refrigerators*, ASHRAE Annual Meeting Program, Seattle, WA, June 19-23 1999, 4288

China

Appliance Characteristics:

- The model is a Top-Mount Refrigerator/Freezer of 182 liters

Table A- 3. Engineering Parameters for Chinese Baseline Refrigerators and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Cons.
		%	$		$	kWh/yr
0	Baseline	0%	0	1.00	250	431
1	0 + Reduce Gasket Heat Leak	13%	5	1.02	255	382
2	1 + 5.2 EER Compressor	40%	20	1.08	270	307
3	2 + 1.27cm Insulation to Doors	51%	26	1.10	276	286
4	3 + 1.27cm Insulation to Walls	74%	44	1.18	294	248
5	4 + 1.27cm Insulation to Doors	83%	50	1.20	300	236
6	5 + 1.27cm Insulation to Walls	105%	68	1.27	318	210

*Based on Exchange rate of 8.2 Yuan/USD

Reference:
LBNL China Refrigerator Analysis Using ERA model, 2002

Brazil

Appliance Characteristics:

- The refrigerator studied is a one-door model, 320 L capacity, 1 star[1].
- Appliance Lifetime: 15 years

Table A- 4. Engineering Parameters for Brazilian Baseline Refrigerators and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor *	Retail Price**	Elec. Cons.
		%	$		$	kWh/yr
0	Baseline		0	1.00	212	360
1	Baseline + more efficient compressor	21%	18	1.09	230	298
2	1 + increase of door insulating thermal thickness 1.27 cm	25%	24	1.11	236	289
3	2 + increase of wall insulating thermal thickness 1.27 cm	39%	44	1.21	256	260
4	3 + increase of the door insulating thermal thickness 2.54 cm	41%	50	1.24	262	255
5	4 + increase of the wall insulating thermal thickness 2.54 cm	51%	66	1.31	278	238

*Based on estimated retail price of 699 R$

**Based on Exchange rate of 3.66 R$/USD

Source: G. Queiroz, *Technical improvement of residential refrigerator in Brazil: energy efficiency analysis*, 3rd International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL'03), 1-3 October 2003, Turin - Italy , Energy Discussion Paper No.2.56-02/03 http://www.clasponline.org/files/Brazil_LCC_Refrigerator_July03.pdf

[1]Refrigeratos are classified according to technical standard ISO7371 according to the temperature inside the refrigerator cabinet and in the low-temperature compartment:

No star: from 0°C to 4°C

1 star: up to -6°C

2 stars: up to -12°C

3 stars: up to -18°C

4 stars: -18°C and less

3.4. European Union

Appliance Characteristics:

- Refrigerator with 2 stars
- Adjusted Volume: 204 L
- Refrigerator Volume: 169 L
- Frozen food compartment: 19 L
- Lifetime: 12 years

Table A- 5. Engineering Parameters for European 2-Star Baseline Refrigerators and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Cons.
		%	$		$	kWh/yr
0	Baseline	0%	0	1.00	420	335
1	Baseline + increased door insul. (+15 mm)	12%	5	1.01	425	299
2	1 + decreased door leakage	14%	6	1.01	426	293
3	2 + optimized compressor	30%	15	1.04	435	258
4	3 + increased cabinet insul. (+15 mm)	64%	35	1.08	455	204
5	4 + increased door insul. (+15 mm)	75%	40	1.09	460	191
6	5 + increased cabinet insul. (+15 mm)	102%	59	1.14	479	166
7	6 + doubled evap. Heat cap.	107%	69	1.16	489	162
8	7 + doubled cond. Heat cap.	111%	77	1.18	497	159
9	8 + doubled cond. Surface	116%	112	1.27	532	155

Appliance Characteristics:

- Refrigerator with 3 stars
- Adjusted Volume: 192 L
- Refrigerator Volume: 155 L
- Frozen food compartment: 17 L
- Lifetime: 12 years

Table A- 6. Engineering Parameters for European 3-Star Baseline Refrigerators and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Cons.
		%	$		$	kWh/yr
0	Baseline	0%	0	1.00	502	367
1	Baseline + increased door insul. (+15 mm)	2%	1	1.00	503	359
2	1 + decreased door leakage	10%	6	1.01	508	332
3	2 + optimized compressor	26%	15	1.03	517	292
4	3 + increased cabinet insul. (+15 mm)	43%	33	1.07	535	256
5	4 + increased door insul. (+15 mm)	47%	38	1.08	540	249
6	5 + increased cabinet insul. (+15 mm)	62%	55	1.11	557	227
7	6 + doubled evap. Heat cap.	67%	64	1.13	566	220
8	7 + doubled cond. Heat cap.	70%	71	1.14	573	216
9	8 + doubled cond. Surface	78%	107	1.21	609	206

Appliance Characteristics:

- Refrigerator with 4 stars
- Adjusted Volume: 355 L
- Refrigerator Volume: 171 L
- Frozen food compartment: 86 L
- Lifetime: 16 years

Table A- 7. Engineering Parameters for European 4-Star Baseline Refrigerators and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Cons.
		%	$		$	kWh/yr
0	Baseline	0%	0	1.00	688	591
1	Baseline + improved compressor	14%	10	1.01	698	520
2	1 + increased door insul. to 35/65 mm	19%	14	1.02	702	497
3	2 + increased door insul. to 50/80 mm	23%	19	1.03	707	482
4	3 + decreased door leakage	24%	21	1.03	709	476
5	4 + increased cabinet insul. to 45/65 mm	38%	39	1.06	727	429
6	5 + increased cabinet insul. to 60/80 mm	48%	56	1.08	744	399
7	8 + doubled cond. Surface	71%	93	1.13	781	345
8	7 + doubled cond. Heat cap.	84%	112	1.16	800	322
9	8 + doubled evap. Surface	88%	127	1.18	815	314
10	9 + doubled Evap. Heat cap.	98%	163	1.24	851	299

Reference:

GEA, Group for Efficient Appliances, *Study on energy efficiency standards for domestic refrigeration appliances*. Group for Efficient Appliances, for DG-XVII, March 1993.

4. Washing Machine Data

European Union

Appliance Characteristics:

- Load weight: 3kg
- Lifetime: 15 years

Table A- 8. Engineering Parameters for Baseline European Washing Machines and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Consump.	
		%	EUR		EUR	kWh/cy.	kWh/yr
0	Baseline	0%	0	1.00	540	1.15	255
1	Baseline + Time Temp Trade off	5%	3	1.01	543	1.1	244
2	1 + Tub Drum Clearance	8%	11	1.02	551	1.06	235
3	2 + sensors & CPU electronic	21%	39	1.07	579	0.95	211
4	3 + Thermal Efficiency	28%	50	1.09	590	0.9	200
5	4 + Mech. Action	34%	63	1.12	603	0.86	191
6	5 + Chopper Motor	40%	113	1.21	653	0.82	182

Reference:
Revision of energy labelling & targets washing machines (clothes), Final report, SAVE-Project 4.1031/Z/98-091, March 2001, 67 S.
http://www.ceced.org/sites/ceced.org/community/files/211/php3TjZad/SAVEWASH.pdf

5. Air Conditioner Data

China

Appliance Characteristics:

- Baseline Unit representing Split System Heat Pump-type, 2500 W < Capacity < 4500 W Product Class
- Average Lifetime: 12.5 years

Table A- 9. Engineering Parameters for Chinese Baseline Air Conditioners and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Cons.	Capacity	EER
		%	$		$	kWh/yr	Watts	W/W
0	Baseline	0%	0.0	1.00	536.8	426	3102	2.27
1	0 + Evaporator Slit Fins	4%	1.1	1.00	538.4	409	3316	2.37
2	1 + Cond Groove Tube	11%	4.3	1.01	543.2	383	3388	2.53
3	2 + Evap Groove Tube	15%	6.5	1.02	546.5	370	3560	2.62
4	3 + 3.0 EER Compressor	20%	13.8	1.04	557.4	355	3556	2.89
5	4 + Condenser Slit Fins	28%	15.6	1.04	560.0	332	3572	2.92
6	5 + 3.16 EER Compressor	34%	27.7	1.08	578.0	317	3574	3.06
7	6 + Cond Fan Motor +10%	36%	30.1	1.08	581.6	314	3574	3.08
8	7 + Evap Fan Motor +10%	36%	32.5	1.09	585.1	313	3577	3.09

Reference:

D. Fridley, G. Rosenquist, J. Lin, L. Aixian, X. Dingguo, and C. Jianhong, *Technical and Economical Analysis of Energy Efficiency of Chinese room air conditioner*, February 2001, LBNL for US EPA, LBNL-45550
http://china.lbl.gov/pubs/tech_econ_ac020701.pdf

5.1. United States

Appliance Characteristics:

- Room Air Conditioners without Reverse Cycle and With Louvered Sides, less than 6000 Btu/hour

Table A- 10. Engineering Parameters for U.S. Baseline Air Conditioners <6,000 btu/hr and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Cons.	Capacity	EER
		%	$		$	kWh/yr	Watts	W/W
0	Baseline	0%	0.0	1.00	179.4	379	1715	2.41
1	0 + Evap/Cond Enhanced Fins	6%	0.8	1.00	180.2	358	1776	2.55
2	1 + PSC Fan Motor	13%	3.8	1.02	183.2	334	1780	2.73
3	2 + Evap/Cond Grooved Tubes	18%	6.6	1.04	186.0	321	1907	2.85
4	3 + Add Subcooler	21%	10.4	1.06	189.8	312	1924	2.93
5	4 + Increase Evap/Cond Coil Area	26%	37.5	1.21	216.9	300	1972	3.04
6	5 + BPM Fan Motor	28%	97.5	1.54	276.9	295	1972	3.10
7	6 + Variable Speed Compressor	43%	221.4	2.23	400.7	265	1972	3.44

Appliance Characteristics:

- Room Air Conditioners without Reverse Cycle and With Louvered Sides, 6000 to 7999 Btu/hour

Table A- 11. Engineering Parameters for U.S. Baseline Air Conditioners 6,000 to 7,999 btu/hr and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Cons.	Capacity	EER
		%	$		$	kWh/yr	Watts	W/W
0	Baseline	0%	0.0	1.00	199.3	471.1	2192	2.48
1	0 + Evap/Cond Enhanced Fins	4%	1.1	1.01	200.4	452.8	2258	2.58
2	1 + PSC Fan Motor	11%	4.1	1.02	203.4	424.9	2263	2.75
3	2 + Add Subcooler	14%	7.8	1.04	207.2	412.3	2287	2.83
4	3 + Evap/Cond Grooved Tubes	17%	12.1	1.06	211.4	402.0	2361	2.90
5	4 + Increase Evap/Cond Coil Area	22%	41.2	1.21	240.5	385.7	2407	3.03
6	5 + BPM Fan Motor	24%	103.0	1.52	302.3	379.3	2408	3.08
7	6 + Variable Speed Compressor	38%	227.6	2.14	426.9	341.4	2408	3.42

Appliance Characteristics:

- Room Air Conditioner without Reverse Cycle and With Louvered Sides, 8000 to 13999 Btu/hour

Table A- 12. Engineering Parameters for U.S. Baseline Air Conditioners 8,000 to 13,999 btu/hr and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Cons.	Capacity	EER
		%	$		$	kWh/yr	Watts	W/W
0	Baseline	0%	0.0	1.00	256.5	694.1	3561	2.73
1	0 +Incr Compressor EER to 10.8	4%	6.1	1.02	262.6	666.4	3645	2.85
2	1 + Add Subcooler	6%	8.4	1.03	264.9	657.2	3666	2.89
3	2 + Evap/Cond Grooved Tubes	8%	13.2	1.05	269.7	640.0	3823	2.96
4	3 + Increase Evap/Cond Coil Area	18%	47.1	1.18	303.6	590.0	3949	3.21
5	4 + BPM Fan Motor	20%	111.7	1.44	368.2	580.3	3950	3.27
6	5 + Variable Speed Compressor	33%	242.5	1.95	499.0	522.3	3950	3.63

Appliance Characteristics:

- Room Air Conditioner without Reverse Cycle and With Louvered Sides, 14000 to 19999 Btu/hour

Table A- 13. Engineering Parameters for U.S. Baseline Air Conditioners 14,000 to 19,999 btu/hr and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Cons.	Capacity	EER
		%	$		$	kWh/yr	Watts	W/W
0	Baseline	0%	0.0	1.00	327.7	1062.8	5264	2.64
1	0 + Incr Compressor EER to 10.8	8%	11.5	1.04	339.2	986.8	5405	2.84
2	1 + Condenser Grooved Tubes	11%	15.8	1.05	343.4	958.9	5476	2.92
3	2 + Add Subcooler	13%	20.4	1.06	348.0	943.0	5496	2.97
4	3 + Increase Evap/Cond Coil Area	19%	117.3	1.36	444.9	890.6	5655	3.15
5	4 + Incr Compressor EER to 11.3	23%	149.8	1.46	477.5	863.1	5720	3.25
6	5 + Incr Compressor EER to 11.4	24%	164.8	1.50	492.4	856.1	5722	3.28
7	6 + BPM Fan Motor	28%	243.1	1.74	570.8	832.3	5728	3.37
8	7 + Variable Speed Compressor	42%	390.8	2.19	718.5	749.1	5728	3.74

Appliance Characteristics: 1

- Room Air Conditioner without Reverse Cycle and With Louvered Sides, greater than 20000 Btu/hour

Table A- 14. Engineering Parameters for U.S. Baseline Air Conditioners >20,000 btu/hr and Efficiency Improvement Options.

Design Number	Design Option	Efficiency Improvement	Price Increase	Price Factor	Purchase Price	Elec. Cons.	Capacity	EER
		%	$		$	kWh/yr	Watts	W/W
0	Baseline	0%	0.0	1.00	405.1	1572.7	7117	2.41
1	0 + Incr Compressor EER to 10.9	2%	5.9	1.01	411.0	1542.5	7088	2.46
2	1 + Add Subcooler	3%	10.5	1.03	415.6	1520.4	7111	2.49
3	2 + Incr Compressor EER to 11.5	8%	49.7	1.12	454.7	1457.4	6959	2.60
4	3 + Increase Evap/Cond Coil Area	15%	107.8	1.27	512.9	1372.6	7174	2.76
5	4 + Incr Compressor EER to 11.7	20%	127.8	1.32	532.9	1314.7	7093	2.88
6	5 + BPM Fan Motor	22%	215.3	1.53	620.4	1289.6	7098	2.94
7	6 + Variable Speed Compressor	36%	397.9	1.98	803.0	1160.6	7098	3.26

Source:
U.S. Department of Energy,*Technical Support Document for Energy Conservation Standards for Room Air Conditioners, Volume 2 - Detailed Analysis of Efficiency Levels*, September 1997
http://www.eere.energy.gov/buildings/appliance_standards/residential/pdfs/tsdracv2.pdf