Chapter 3

Energy Services: Residential and Commercial

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Energy Services: Residential and Commercial

INTRODUCTION AND SUMMARY

Energy use in the residential/commercial sector of developing countries typically accounts today for about one-third of commercial (primarily fossil fuel-based) energy use and two-thirds or more of traditional biomass fuel use (see table 3-1). In traditional rural areas, the primary residential energy services demanded are cooking, water heating, lighting, water hauling, grain grinding, and in colder areas, space heating. Economic and social development foster dramatic changes in each of these energy services. This can be seen today by tracing how these energy services change from traditional rural areas to modern urban areas (see tables 3-2, 3-3).

Traditional rural areas around the world use biomass fuels—wood, crop residues, animal dung—in open "three-stone' fires or simple fireplaces to cook their food. As incomes grow and access to improved fuels becomes more reliable, people shift to purchased fuels such as charcoal or coal,[2] kerosene, LPG (or natural gas) and/or electricity for their cooking and water heating needs. Lighting technologies similarly shift with income and fuel access from open fires to kerosene lamps to electric lights. Water hauling and grain grinding-back breaking labor that typically requires several hours of household labor each day in traditional rural and many poor urban areas-is largely eliminated in modern urban areas: water is piped to the proximity or directly to the household and grain is ground in commercial mechanical mills before being sold in the market.

Completely new residential/commercial energy services are provided in the modern economy as well. Refrigeration allows long term storage of food. Electric fans or air conditioners improve personal comfort even in the hottest and most humid of climates. Electronic equipment such as televisions or radios at home and computers at modern offices provide entertainment and information services.

Together, six energy services account for most direct[3] residential and commercial energy use in traditional rural as well as modern urban areas: cooking, water heating, lighting, refrigeration, space conditioning, and electronic equipment (see table 3-2). Each of these is examined in detail below. A variety of other appliances also contribute modestly to energy use in industrial countries and are likely to become more important in developing countries in the future. These include dishwashers, clothes washers and dryers, electric irons, and others. For example, dish and clothes washers/dryers may account for as much as 10 percent of household electricity use in the United States.[4]

Of particular interest in this chapter are those services provided by electricity. This focus is based on the rapid growth in demand for these services and their high cost. Lighting, refrigeration, air conditioning, and information *services are* primarily powered by electricity; cooking and water heating often use electricity.

The residential/commercial sector in developing countries has a rapidly growing demand for energy services, particularly electric services. This demand is driven by a number of factors, including: rapid

[1]Note the two distinct meanings of "commercial" used here. Commercial, as in the residential/commercial sector, refers to commercial buildings-retail stores, offices, hotels, restaurants, etc. Depending on the data source, it also usually includes government offices, schools, hospitals, and other public buildings. Commercial, as in commercial fuels, refers to those fuels that are purchased for cash in the marketplace. These fuels include primarily coal, oil, gas, and electricity. Although biomass fuels are also sold for cash in public markets in many areas, they are nevertheless often still counted as a traditional fuel rather than a commercial fuel. This distinction for biomass fuels varies with the data source. Elsewhere in this report, commercial is also used to refer to those technologies which can be purchased in the market or near-commercial-will soon be available.

[2]The intermediate shift to charcoal occurs primarily in areas with a tradition of charcoal use. The shift to coal is primarily in China, parts of India, and a few other countries where there are large supplies of coal and limited alternatives. See: U.S. Congress, Office of Technology Assessment, *Energy In Developing Countries, OTA-E-486* (Washington DC: U.S. Government Printing Office, January 1991), and Willem Floor, World Bank, personal communication, 1991.

[3]Only "direct" energy use in the residential/commercial sector is considered here—that used to power stoves, lights, refrigerators, air conditioners, etc. Indirect energy use—that used to produce the steel and cement for constructing commercial buildings or to haul goods sold to the residential sector—are considered separately in the industrial and transport sectors.

[4]Leo Ranier, Steve Greenberg, and Alan Meier, "The Miscellaneous Electrical Energy Use in Homes,' *American Council for an Energy Efficient Economy, 1990 Summer Study on Energy Efficiency in Buildings* (Washington, DC: 1990).

Table 3-l—Total Delivered Energy by Sector, in Selected Regions of the World, 1985 (exajoules)[a]

	Residential/commercial		Industry		Transport		Total		
Region	Commercial fuels	Traditional fuels[b]	Commercial fuels	Traditional fuels[b]	Commercial fuels	Traditional fuels[b]	Commercial fuels	Traditional fuels[b]	Total energy
Africa	1.0	4.0	2.0	0.2	1.5	NA	4.4	4.1	8.5
Latin America	2.3	2.6	4.1	0.8	3.8	NA	10.1	3.4	13.5
India and China	7.3	4.7	13.0	0.2	2.0	NA	22.2	4.8	27,1
Other Asia	1.9	3.2	4.0	0.4	1.9	NA	7.8	3.6	11.3
Developing countries	12.5	14.5	23.1	1.6	9.2	NA	44.5	15.9	60.4
United States	16.8	NA	16.4	NA	18.6	NA	51.8	NA	51.8

NA = Not available or not applicable.

NOTES: This is delivered energy and does not include conversion losses from fuel to electricity, in refineries, etc. The residential and commercial sector also includes others (e.g., public services, etc.) that do not fit in industry or transport. Traditional fuels such as wood are included under commercial fuels for the United States.

[a]Exajoule (10^{18} Joules) equals 0.9478 Quads. To convert to Quads, multiply the above values by 0.9478.

[b]These estimates of traditional fuels are lower than those generally observed in field studies. See references below.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991) p. 49.

population growth, economic growth, and urbanization; the transition from traditional biomass to modern commercial fuels (made possible by growing access to these energy carriers); and the dramatic reductions in the real costs of consumer goods—refrigerators, air conditioners, televisions, etc.—made possible by modern materials and manufacturing techniques, Further, as women in developing countries increasingly enter the formal workforce, the demand for and the means to purchase labor-and time-saving household appliances such as dishwashers, clothes washers, or refrigerators (to store food and thus reduce the frequency of grocery shopping) can be expected to grow rapidly. Factors limiting appliance penetration include capital and operating costs, availability, and the lack of electric service, particularly in rural areas. In Brazil, for example, 90 percent of urban households but only 34 percent of rural households have electric services

The increase in consumer appliances is creating an explosive demand for energy both directly to power these goods and indirectly to manufacture and distribute them. A recent review of 21 of the largest developing countries in Asia, Latin America, and Africa found electricity use to be growing faster in the residential than in other sectors in all but four countries. Growth rates in residential electricity use averaged about 12 percent in Asian countries examined, 10 percent in African countries, and 5 percent in Latin American countries.[6] This rapid growth is further straining many electric power systems that are already having difficulty meeting demand and poses serious financial, institutional, and environmental problems for developing countries.

The costs and difficulties of meeting residential electricity needs are particularly high. Much of the residential load comes during early evening and contributes to system peak demand; costs of providing peak electricity demand are high as generating equipment to meet this peak is left largely idle during other hours and premium fuels are often used. Residential demand is also spread over many widely dispersed small users. The cost of serving this demand is high due to the extensive distribution system required and because transmission and distribution losses are proportionately larger due to both the long transmission distances and the low voltages the power is supplied at. Finally, electricity sold to residential consumers in many countries is subsidized for social and political reasons; this is compounded by poor billing and collection practices and by theft.

A European or U.S. level of electricity services, using today's most commonly adopted residential and commercial technologies, requires an annua1 systemwide—including the upstream costs of generating electricity supplies-capital investment of

[5]Gilberto De Martino Jannuzzi, "Residential Energy Demand in Brazil by Income Classes," *Energy Policy, vol. 17, No.* 3, p. 256, 1989.

[6]Stephen Meyers et al., "Energy Efficiency and Household Electric Appliances in Developing and Newly Industrialized Countries," report No. LBL-29678 (Berkeley, CA: Lawrence Berkeley Laboratory, December 1990).

Table 3-2—Per Capita Primary Energy Use by Service in Traditional and Modern Economies

	Traditional India, 1980		Modern U.S. 1988	
	Fuel GJ/cap	Electricity[a] GJ/cap	Fuel GJ/cap	Electricity[a] GJ/cap
Cooking	7.8	—	1.4	2.7
Water heating	1.9	—	6.0	6.1
Lighting	0.3	0.1	—	10.7
Refrigeration	—	—	—	5.7
Space conditioning	—	—	30.9	38.4
Information services	—	—	—	2.4[b,c]
Subtotal	10.0	0.1	38.3	66.0
Other energy services	—	—	3.3	4.7

— = Not available or very small.

[a]Electricity converted to primary fuel equivalent using a conversion factor of 0.33 for generation, transmission, and distribution combined.

[b]Leo Ranier, Steve Greenberg, and Alan Meier, "The Miscellaneous Electrical Energy Use in Homes," in ACEEE 1990 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington, DC 1990.

[c]Les Norford, Ari Rabl, Jeffrey Harris and Jacques Roturier, "Electronic Office Equipment: The Impact of Market Trends and Technology on End-Use Demand for Electricity," in Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams, *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989). Estimated information services electricity demand has been subtracted from the Holtberg et al "other" category.

SOURCES: 1. Data for India is adapted from: "Rural Energy Consumption Patterns: A Field Study," ASTRA, Indian Institute of Science, Bangalore, 1981; and N.H. Ravindranath, et al., "An Indian Village Agricultural Ecosystem—Case Study of Ungra Village, Part I: Main Observations," *Biomass*, vol. 1, 1981, pp. 61-76. 2. Primary source of residential and commercial data for the United States is: Paul D. Holtberg, Thomas J. Woods, Marie L. Lihn, and Nancy C. McCabe, "Baseline Projection Data Book: 1989 GRI Baseline Projection of U.S. Energy Supply and Demand to 2010," Gas Research Institute, Washington, DC.

Table 3-3—Per Capita Energy Use by Service in Selected Countries (gigajoules)

	Brazil	China	India	Kenya	Taiwan	Us.
Residential	6.2	11.7	5.5	16.9	8.9	64.9
Cooking	5.3	8.5	5.0	16.4	4.7	3.5
Lighting	0.3	0.4	0.5	0.5	0.7	NA
Appliances	0.6	NA	0.05	NA	3.1	13.0
Space conditioning	0.05	2.8	NA	NA	1.0	38.2
Commercial	1.5	0.7	0.26	0.4	4.2	45.2
Space conditioning	0.4	NA	0.13	0.24	1.9	NA
Lighting	0.5	NA	0.05	0.16	0.8	7.2
Appliances	0.06	NA	0.07	NA	1.5	NA

NA= Not available or not applicable.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy* in Developing *Countries,* OTA-E-486 (Springfield, VA: National Technical Information Service, January 1991). Table 3-3 and app. 3-A.

over $200 per person (see figure 3-1).[7] For the five billion people that will be living in developing countries in the year 2000, an annual capital investment of over $1 trillion would be required. This level of investment is 10 times that currently projected for all electric services in developing countries, including industry and agriculture. To meet even a part of these huge capital needs for energy services as well as to save funds for all the other pressing needs of development, energy systems must be carefully optimized.

It is now recognized in the industrial countries that high efficiency technologies for lighting, refrigeration, space conditioning, and other needs are usually cost effective on a life cycle basis: the higher initial capital cost of these technologies to consumers is counterbalanced by their lower operating costs. Equally important for capital constrained developing countries, high efficiency technologies dramatically reduce the need for expensive utility generating plants. When the total systemwide costs--including both the generation equipment and the end use appliance—are summed, energy efficient equipment usually allows a substantial reduction in the total societal capital costs compared to the less efficient equipment now commonly in use (see figure 3-l).

[7]Note that this does not include all the *costs,* particularly in the end use *sector.* See app. A of this report for details.

If the most efficient commercial or near-commercial residential and commercial electricity service technologies were purchased, societies could realize systemwide capital savings of over 10 percent, operating savings of about 40 percent, and electricity savings of 60 percent (see figure 3-1 and app. A at the back of this report) compared to the conventional technology now in use in the industrial and developing countries.[8] A brief listing of a few of these improved technologies is given in table 3-4 and appendix A. These capital and operating savings could then be invested in other pressing development needs. The reduced energy use would also lessen a host of local, regional, and global environmental impacts. Further cost effective efficiency improvements are possible beyond the few technologies surveyed below. Developing countries have the opportunity to leapfrog past today's industrial countries in their selection of residential/commercial energy service technologies.

Figure 3-1 does not, however, include the environmental or other costs of energy use. Although these costs are difficult to quantify, they cannot be ignored. Rather than choosing the least-cost energy service on a purely financial basis as in figure 3-1, even more efficient energy service technologies could be justified on the assumption that their use will mitigate some of these as yet unmeasured external costs. Large scale production will usually dramatically reduce the premium for these higher efficiency technologies as well.

Yet consumers generally do not adequately invest in these technologies due to a variety of market barriers (see table 3-5). These include a resistance to the higher cost of efficient appliances. In the United States, some studies find that this resistance implies an effective discount rate 10 times actual market discount rates.[9] This extreme sensitivity to the first cost of a consumer good is likely to be an even more important constraint in the developing countries. The critical role of this first cost sensitivity can be seen in figure 3-lB for the dramatic shift in capital costs with more efficient end-use equipment from utilities to consumers.

Implementing high efficiency technologies in the residential/commercial sector will require institutional changes and reallocation of funds, but probably will not demand significantly higher levels of technical manpower to put into place. Since much of the technology is interchangeable-a compact fluorescent lightbulb for an incandescent, an efficient refrigerator for an inefficient one—a large amount of technical expertise is not required. There are exceptions, however, including daylighting design in commercial buildings, which requires training of architects and building engineers, or training of construction workers to properly incorporate building-shell improvements. Some additional work may also be needed to incorporate design features for handling the widely fluctuating voltages found in developing countries into electronic ballasts for fluorescent lights and into adjustable speed electronic drives in refrigerators, building ventilation systems, or other equipment, or for other adaptations to developing-country conditions. A variety of these possible policy responses are summarized in table 3-6.

Public interventions to redress inadequacies of the marketplace, however, also carry substantial risks. A few of these difficulties are listed in table 3-7.

There is no shortage of technical opportunities. The technologies examined here are all currently commercially available or nearly so. Many more technologies are at various stages of research, development, and demonstration, but this chapter does not attempt to enumerate them. Rather, it examines the potential of existing or near commercial energy efficient technologies.

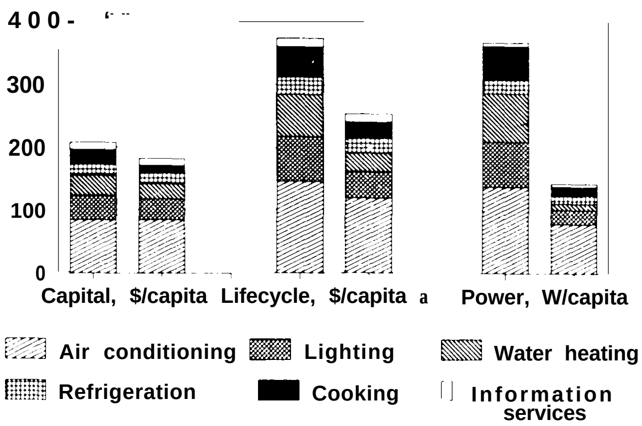
COOKING

The most important energy service in many developing countries today is cooking food. In rural areas of developing countries, traditional fuels—wood, crop residues, and dung-are the primary fuels used for cooking; in many urban areas, charcoal is also used. More than half of the world's people depend on these crude polluting biomass fuels for their cooking and other energy needs.

[8] These figures differ somewhat from those shown in ch. 1 due to the exclusion of industrial motors here. This assumes the mix of energy services, technologies, and utilization rates as detailed in app. A.

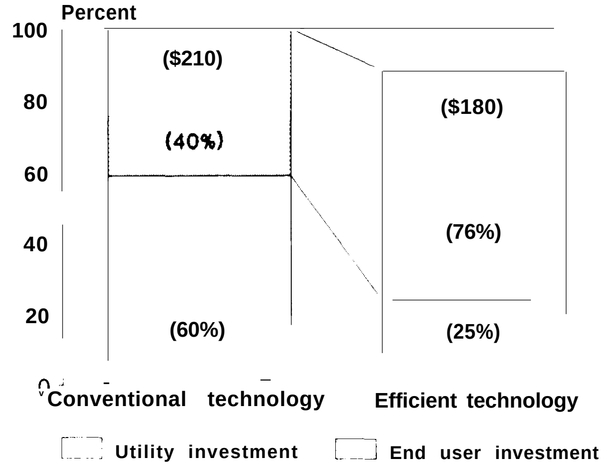
[9] Henry Ruderman, Mark D. Levine, and James E. McMahon, ''The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment," *The Energy Journal*, vol. 8, No. 1, January 1987, pp. 101-124; U.S. Department of Energy, technical support document, 'Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces,' DOE/CE-0277, November 1989; Malcolm Gladwell, "Consumers' Choices About Money Consistently Defy Common Sense," *The Washington Post*, Feb. 12, 1990, p. A3.

Figure 3-1 A—Total System-Wide Capital and Lifecycle Operating Costs and Energy Consumption for Conventional and High Efficiency Residential/ Commercial Energy Service Technologies



Over a wide range of conditions high efficiency technologies have a lower system wide capital cost than the conventional technologies because the increased capital cost to consumers is more than offset by the decreased capital investment required in upstream electricity y generating plants. Lifecycle operating costs are lower because the increased capital costs to the consumer are more than offset by the lower electricity costs to operate the equipment.

Figure 3-1 B—Allocation of Capital Costs for Conventional and High Efficiency Residential/ Commercial Energy Service Technologies



Although the high efficiency technologies have lower system wide capital costs, they dramatically shift the capital costs from the utility to the consumer. The high capital cost of efficient equipment to consumers is the reason why it is not more heavily invested in-even though it provides net savings to society overall and, indirectly, to the consumer. Means of reducing this initial capital cost barrier to the consumer are critical and can be found in table 3-6.

SOURCE: U.S. Congress, Office of Technology Assessment, 1992, See app. A for details of this calculation, including the assumptions and sensitivity analysis.

Table 3-4—Selected Energy Efficient Technologies

Energy service	Technologies/remarks
Residential/commercial cooking ... , . .	Improved biomass stoves, kerosene stoves, LPG and gas stoves, microwave ovens. Improved wood-and charcoal-burning stoves have demonstrated 30-percent savings in the field. Further development work is needed to make them inherently low emitters of pollutants while maintaining high efficiencies. As biomass will continue to be the primary fuel for the rural and urban poor for many years to come, this is a particularly important technology to develop.
Water heating	Increased insulation, flow restrictors, traps to prevent thermosyphoning. Solar water heaters can be very cost effective and perform well in many areas.
Lighting	Compact fluorescent bulbs, voltage stabilizing electronic ballasts, high performance reflectors, task lighting, high efficiency fluorescent lights, high pressure sodium lights, daylighting, advanced lighting controls, and spectrally selective window coatings.
Refrigeration	More and/or improved (aerogel, vacuum, etc.) insulants, improved motor/compressor systems for small scales, voltage stabilizing adjustable speed drives, load management techniques, adaptive defrost, two compressor systems.
Space conditioning	White roofs, planting trees, awnings, roof sprays, spectrally selective window coatings, increasing insulation and reducing infiltration (while using air-to-air heat exchangers if indoor air quality becomes a problem), air economizers, adjustable speed electronic drives, updating design rules for ventilation systems, improved motors/compressors/coils in air conditioners.
information services	CMOS integrated circuits, power management techniques, flat panel displays.

NOTE: Technologies can be viewed as on a spectrum of: C) Commercially available; A) commercially available in industrial countries but needing Adaptation to the conditions of developing countries; N) Near commercial development, and R) requiring further Research and development. Since most technologies have variations at many points on this spectrum-for example, compact fluorescent are available, may need further adaptation in developing countries in some cases, have improved phosphors or other advances near commercial development, and may have more fundamental advances under research the status of these technologies-C, A, N,R--will not be discussed; instead, particular opportunities will be presented.

SOURCE: Off Ice of Technology Assessment, 1992

Table 3-5—Barriers to Investment in Energy Efficient Technologies

Technical

Availability y

High efficiency technologies and their needed support infrastructure of skilled manpower and spare parts may not be locally available. Foreign exchange may not be available to purchase critical spare parts. For the residential and commercial sectors, in particular, high efficiency technologies need to be marketed in a complete package to allow "one stop" shopping.

Culture

Culture is rarely an impediment to the use of energy efficient technologies, although it is frequently cited as a problem in disseminating technologies in rural areas. In most cases, the technology itself is found to have significant technical shortcomings or is unable to meet the multiple uses desired.

Design rules

Conventional design rules often lead to excessive oversizing of equipment--raising capital cost and wasting energy.

Diagnostics

Technologies for measuring the efficiency of equipment, as in energy audits, are often awkward and inaccurate. Some of them may require shutting down a commercial business or making intrusive measurements, such as cutting holes in pipes or ducts to make flow and pressure drop measurements.

Infrastructure

The available infrastructure within a developing country may not be able to adequately support a particular high efficiency technology. This might include an electric power system with frequent brownouts or blackouts that the high efficiency technology is unable to handle well; dirty fuels that clog injectors; or poor water quality for high performance boilers. The developing country may also lack a reliable spare parts supply system and trained manpower to ensure adequate maintenance. finally, the existing infrastructure might impede the implementation of a more efficient technology system. An extensive road system and/or little land use planning, for example, might slow or stop the development of an efficient mass transport system.

Reliability

Innovative high efficiency equipment may not have a well proven history of reliability, particularly under developing country conditions, as for other equipment.

Research, development, demonstration

Developing countries may lack the financial means and the technical manpower to do needed RD&D in energy efficient technologies, or to make the needed adaptations in existing energy efficient technologies in use in the industrial countries to meet the conditions—such as large fluctuations in power supply voltage and frequency-in developing countries. Technology development and adaptation is particularly needed in rural enterprises and other activities.

Scale

Energy efficient technologies developed in the industrial countries are often too large in scale to be applicable in developing countries, given their smaller markets and lower quality transport infrastructure.

Scorekeeping methods

Methods of "measuring" energy savings may not be sufficiently accurate yet for the purpose of paying utilities or energy service companies for the savings that they have achieved. This must be contrasted with the ease of measuring the power generated or used. It is a particularly important issue for utilities that usually earn revenues solely on the basis of energy sold and so have little incentive to assist efficiency efforts.

Technical/managerial manpower

There is generally a shortage of skilled technical and managerial manpower in developing countries for installing, operating, and maintaining energy efficient equipment. This may not be a significant problem where turnkey equipment is used.

Financial/economic

Behavior

Users may waste energy, for example, by leaving lights on. In some cases, however, this seeming waste maybe done in order to meet other user needs, such as personal security.

cost

The high initial cost of energy efficient equipment to the end user and the high effective discount rate used by the end user discourage investment.

Currency exchange rate

Fluctuations in the currency exchange rate raises the financial risk to firms who import high efficiency equipment with foreign exchange denominated loans.

Dispersed energy savings

Energy efficiency improvements are scattered throughout the residential and commercial sectors and are difficult to identify and exploit. In contrast conventional energy supplies maybe more expensive, but are readily and reliably identified and employed. This tends to give planners a supply side bias irrespective of the potential of efficiency improvements.

Table 3-5--Barriers to Investment in Energy Efficient Technologies-Continued

Financial accounting/budgeting methods
Commercial accounts for paying energy bills may be separated from accounts for capital investment in more efficient equipment. Budgets for more efficient equipment maybe rationed, forcing energy eff iciency improvements to compete with each other for scarce budgeted funds even though the return on investment may be much higher than the overall cost of capital to the firm.

International energy prices
Uncertainty of international energy prices, such as oil, raises risks that price drops will reverse the profitability of investments in efficiency.

Multiple needs
The multiple roles and needs served by an existing technology may not be adequately met by a new energy efficient technology. Draft animals, for example, can provide meat, milk, leather, and dung in addition to traction power. They also reproduce. Mechanical drive only provides traction.

Risk
Particularly in poor rural and urban areas, people are highly risk averse; they have to be if they are to survive through the vagaries of drought and other disasters. That villagers are risk averse should not, however, be construed to mean that they are technology averse. A variety of technologies have been adopted very rapidly in poor rural and urban areas.

Seasonality
Rural life is dominated by the seasons, with sharp labor shortages during the agricultural season and serious underemployment during the rest of the year that rural enterprises can only partly support. Capital investment in efficient agricultural or rural commercial technologies is relatively more expensive as it must pay for itself during just the fraction of the year it is used.

Secondary interest
Energy efficiency is often of secondary interest to potential users. In industry, for example, efficiency must compete with other equipment parameters--quality and quantity of product; timeliness, reliability, and flexibility; etc.—as well as other factors of production when investment choices are made and when the scarce time of skilled manpower is allocated. These are aspects of overall corporate strategy to improve profitability and competitiveness.

Secondhand markets
Low efficiency equipment may be widely circulated in secondhand markets in developing equipments, either among industries within developing countries, or perhaps as “gifts” or “hand-me-downs” from industrial countries. Further, users who anticipate selling equipment into the second hand market after only a few years may neither realize energy savings over a long enough period to cover the cost premium of the more efficient equipment nor, if secondhand markets provide no premium for high efficiency equipment, advantage in its sale.

Subsidized energy prices
Energy prices in developing countries are often controlled at well below the long run marginal cost, reducing end-user incentive to invest in more efficient equipment. Energy prices may be subsidized for reasons of social equity, support for strategic economic sectors, or others, and with frequent adverse results. On the other hand, however, the low cost of power results in substantial financial costs to the utilities, providing them a potential incentive to invest in more efficient equipment on behalf of the user.

Threshold level of energy/cost savings
Users may not find a moderate level of energy or cost savings, particularly if spread over many different pieces of equipment, sufficiently attractive to justify the investment of technical or managerial manpower needed to realize the savings.

Institutional

Bias
There is often a bias towards a small number of large projects, usually for energy supply, than for small projects, usually energy efficiency, due to administrative simplicity and to minimize transaction costs.

Disconnect between purchaser/user
In a rental/lease arrangement, the owner will avoid paying the higher capital cost of more efficient equipment while the renter/lessor is stuck with the resulting higher energy bills. Similarly, women in some countries may not have a strong role in household purchase decisions and may not themselves earn a cash income for their labor, but must use inefficient appliances purchased for them.

Disconnect between user/utility
Even though the total system capital cost is generally lower for energy efficient equipment, it is the user who pays for the more efficient equipment but only recoups the investment over the equipment lifetime while the utility sees an immediate capital savings.

Information
Potential users of energy efficient equipment may lack information on the opportunities and savings.

Intellectual property rights
Energy efficient technologies may be patented and the royalties for use may add to the initial costs for the equipment.

Political instability
Political instability raises risks to those who would invest in more efficient equipment that would only pay off in the mid-to long-term.

Turnkey system
Turnkey and other package systems are often directly adopted by commercial or industrial operations in developing countries. In many cases, however, the equipment within these systems is based on minimizing capital cost rather than minimizing life cycle operating rests.

SOURCE: Office of Technology Assessment, 1992.

Table 3-6-Policy Options

Alternative financial arrangements
Currently, the capital costs of generation equipment are paid by the utility and the capital costs of enduse equipment are paid by the enduser. As shown above and in ch. 2, the high effective discount rate of the enduser as well as this separation between utility and user (or for leased equipment, the separation between owner and user) leads to much lower levels of Investment in end-use equipment efficiency than is justified on the basis of either total system capital costs or life cycle operating costs. Alternative financial arrangements to redress this "disconnect" might range from the enduser choosing equipment according to the total life cycle cost and paying this cost in monthly installments on the utility bill; to the enduser paying a front-end depositor posting a bond to the utility to cover the life cycle operating costs of the equipment, against which the utility would charge the capital cost of the equipment and the monthly electricity y bills. Either of these approaches would force the enduser to directly face the total systemwide life cycle costs of the equipment when purchasing it. See also Integrated Resource Planning, below,

Data collection
The range of opportunities for energy efficient equipment, enduser preferences, and operating conditions are not well known in many countries. Data collection, including detailed field studies, would help guide policy decisions.

Demonstrations
Many potential users of energy efficient equipment or processes remain unaware of the potential savings or unconvinced of the reliability and practicability of these changes under local conditions. Demonstration programs can show the effectiveness of the equipment, pinpoint potential problems, and thereby convince potential users of the benefits of these changes.

Design tools
Computer design tools can be developed, validated, demonstrated, and widely disseminated to potential users.

Direct installation
In some cases, particularly where the cost of energy is subsidized by State operated utilities or where peak loads are reduced, the direct installation of energy efficient equipment or processes at low-or no-cost by the utility can reduce costs for both the utility and the user.

Energy audits
Energy audits by a skilled team, either enterprise employees or from the outside--perhaps associated with an energy service company--can provide highly useful specific information on where energy can be saved. In new plants or in retrofits, submetering of equipment in order to maintain an ongoing record of energy use can also be a very useful means of monitoring performance.

Energy service companies
Energy service companies (ESCos)--third parties that focus primarily on energy efficiency improvements within a factory and are paid according to how much energy they save--can play a valuable role in implementing energy efficiency gains. They can bring great expertise and experience to bear on the problem, and as their goal is saving energy rather than maintaining production, they are able to devote greater effort and focus to conservation activities. On the other hand, industry employees are sometimes reluctant to work with ESCos, believing that they could implement efficiency activities equally well if they had the time; and worrying that any changes to process or related equipment by the ESCo could disrupt the production line. Generic forms of contracts for ESCo services to industry need to be developed in order to adequately protect both parties, and pilot programs with ESCo's can demonstrate the potential savings by ESCos and their ability to avoid disruption to processes. Compensation for the work done by ESCos should be based on "measured" energy savings, not on the basis of listing the measures taken, irrespective of their effectiveness. Utility programs that provide for competitive bidding on energy savings risk paying the enduser and ESCo twice, once for the energy saved and once for the lower utility bill. This problem can be minimized by appropriately sharing the costs and benefits.

Extension efforts
Extension efforts may be useful at several levels. The efficiency and productivity y of traditional rural industries might be significantly increased in a cost-effective manner with the introduction of a limited set of modern technologies and management tools. To do this, however, is extremely difficult due to the small and scattered nature of traditional rural industries and the large extension effort needed to reach it. Large industry in developing countries has many of the same needs—technical, managerial, and financial assistance-but can be reached more readily.

Grants
See Direct installation, above.

Information programs
Lack of awareness about the potential of energy efficient equipment can be countered through a variety of information programs, including distribution of relevant literature directly to the industries concerned, presentation of competitions and awards for energy efficiency improvements; and others

Integrated resource planning (IRP)
Currently, utilities base their investment budgets on a comparison of the costs of different sources of generating capacity-coal, oil, gas, hydro, etc.—and the supply option that has the lowest cost for its particular application is chosen. Integrated resource planning expands this "least cost" planning system to include end use efficiency as an alternative to supply expansion in providing energy services. If energy efficiency is shown to be the lowest cost way of providing energy services, then under IRP utilities would invest in energy efficiency rather than new generating capacity.

Labeling programs
The efficiency of equipment can be clearly listed by labels. This provides purchasers a means of comparing alternatives. Measuring the efficiency of equipment, however, needs to be done in conjunction with standardized test procedures, perhaps established and monitored by regional test centers, rather than relying on disparate and perhaps misleading manufacturer claims.

Loans/rebates
Loans or rebates from the utility to the purchaser of energy efficient equipment can lower the first cost barrier seen by the user, and if incorporated in the utility rate base, can also prove profitable for them. On the other hand, users that would have purchased efficient equipment anyway then effectively get the loan/rebate for free--the "free rider" problem. This reduces the effectiveness of the utility program by raising the cost per additional user involved. This problem can be minimized by restricting the loans/rebates to high efficiency equipment for which there is little market penetration, or by other means.

Table 3-6—Policy Options-Continued

Marketing programs
A variety of marketing tools might be used to increase awareness of energy efficient technologies and increase their attractiveness. These might include radio, TV, and newspaper ads, billboards, public demonstrations, product endorsements, and many others.

Pricing policies
Energy prices should reflect costs, an obviously highly politicized issue in many countries. Where prices are heavily subsidized, the introduction of energy efficient equipment might be done in conjunction with price rationalization in order to minimize the price shock to users. Prices alone, however, are often insufficient to ensure full utilization of cost effective energy efficient technologies. There are too many other market failures as discussed above. As evidence of this, even the United States has adopted efficiency standards for a variety of appliances.

Private power
Opportunities to cogenerate or otherwise produce private power have frequently not been taken advantage of because State-owned or controlled utilities have refused to purchase privately generated power at reasonable costs-many State electricity y boards simply refuse to take privately generated power; many States impose a sales tax on self-generated electricity; many states decrease the maximum power available to enterprises with onsite generation capabilities, and then are reluctant to provide back-up power when cogeneration systems are down. In other cases, well-intentioned self generation taxes intended to prevent use of inefficient generators by industry penalizes efficient cogeneration. Finally, power is subsidized in many areas, making it difficult for private power to compete. Changes in laws mandating utility purchase of private power—such as that established by the U.S. Public Utility Regulatory Policies Act (PURPA) laws-at reasonable rates would allow many of these opportunities to be seized. This should include establishing generic contracts that provide adequate protection to all concerned parties but that can be readily developed and implemented.

Protocols for equipment interfaces
The use of power line carriers or other techniques of utility load management will require the development of common equipment interfaces and signaling techniques.

Rate incentives
See loans/rebates.

R&D: equipment, processes, design rules
Examples of R&D needs are listed in the text. R&D programs might be established at regional centers of excellence in developing countries, possibly in conjunction with sister research institutes in the industrial countries.

Regional test/R&D centers
Regional centers of excellence are needed to help gather a crucial mass of highly skilled technical manpower at a single site. The technologies to be developed should focus on those amenable to mass production while maintaining quality control under field conditions. Researchers and field extension agents should, in many cases, make greater use of market mechanisms to guide technology development efforts and to ensure accountability.

Scorekeeping: savings/validation
Technologies and software for "measuring" energy savings need to be further developed and their effectiveness validated under field conditions. This would be a particularly valuable activity at regional centers of excellence.

Secondhand markets-standards
Efficiency labels or standards might be set for secondhand equipment. This might be particularly valuable for such things as secondhand factories sold to developing countries.

Standards for equipment/process efficiency
Many industrial countries have chosen to largely accept the financial "disconnect" between the utility and the user. Instead of providing low-cost, easily available capital to the enduser and at the same time incorporating the full life cycle cost of the end-use equipment in t he initial purchase, many industrial countries are attempting to overcome the economic and energy inefficiency of this disconnect by specifying minimum efficiency standards for appliances, buildings (residential and commercial), and, in some cases, industrial equipment.

Tax credits, accelerated depreciation
A variety of tax incentives-tax credits, accelerated depreciation, etc.—to stimulate investment in energy efficient or other desirable energy technologies might be employed.

Training programs
Training programs are needed in order to ensure adequate technical/managerial manpower. In addition, means of adequately compensating highly skilled and capable manpower are needed. Currently, skilled manpower—trained at government expense-k frequently attracted away from developing country governmental organizations by the higher salaries of the private sector. Similarly, a more clear career path is needed for skilled technical and managerial manpower in efficiency just as utility operations now provide a career path for those interested in energy supply.

Utility demand/supply planning
Methodologies for integrated supply and demand least-cost planning have been developed by the industrial countries. These should now be adapted to the needs of developing countries and utility planners and regulators trained in their use.

Utility regulation
Utility regulations that inhibit the generation of private power (see above) or limit the role of the utility in implementing energy efficiency improvements on t he supply or demand side need to be reevaluated. Means of rewarding utilities for energy saved as well as energy generated need to be explored (see also scorekeeping). This might include incorporation of energy efficient equipment into the utility ratebase.

SOURCE: Office of Technology Assessment, 1992.

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Table 3-7—Some Problems of State Intervention

- Individuals may know more about their own preferences and circumstances than the government.
- Government planning may increase risk by pointing everyone in the same direction--governments may make bigger mistakes than markets.
- Government planning may be more rigid and inflexible than private decisionmaking since complex decisionmaking machinery may be involved in government.
- Government may be incapable of administering detailed plans.
- Government controls may prevent private sector individual initiative if there are many bureaucratic obstacles.
- Organizations and individuals require incentives to work, innovate, control costs, and allocate efficiently, and the discipline and rewards of the market cannot easily be replicated within public enterprises and organizations.
- Different levels and parts of government maybe poorly coordinated in the absence of the equilibrating signals provided by the market, particularly where groups or regions with different interests are involved.
- Markets place constraints on what can be achieved by government, for example, resale of commodities on black markets and activities in the informal sector can disrupt rationing or other nonlinear pricing or taxation schemes. This is the general problem of "incentive compatibility."
- Controls create resource-using activities to influence those controls through lobbying and corruption--often called rent-seeking or directly unproductive activities in the literature.
- Planning may be manipulated by privileged and powerful groups that act in their own interests and further, planning creates groups with a vested interest in planning, for example, bureaucrats or industrialists who obtain protected positions.
- Governments may be dominated by narrow interest groups interested in their own welfare and sometimes actively hostile to large sections of the population. Planning may intensify their power.

SOURCE: N. Stern, "The Economies of Development: A Survey," *Economic Journal, vol. 99, No. 397,* September, 1989.

Higher incomes and reliable fuel supplies enable people to switch to modern stoves and cleaner fuels such as kerosene,[10] LPG, and electricity (and, potentially, modern biomass[11])----a transition that is widely observed around the world largely irrespective of cultural traditions (see figure 3-2).[12] These technologies are preferred for their convenience, comfort, cleanliness, ease of operation, speed, efficiency, and other attributes.[13]

The efficiency, cost, and performance of stoves alone generally increase as consumers shift progressively from wood stoves to charcoal, kerosene, LPG or gas, and electric stoves (see figure 3-3).[14] Background data and supporting documentation for the stoves shown in the figure, as well as for other stoves, are summarized in appendix A and discussed elsewhere.[15]

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[10] For example, kerosene 1S the predominant household cooking fuel in parts of Asia-35 percent, 42 percent, and 30 percent of urban households in India, Pakistan, and Sri Lanka, respectively. See: Willem Floor and Robert van der Plas, "Kerosene Stoves: Their Performance, Use, and Constraints," draft report prepared for the World Bank and U.N. Development program, Energy Sector Management Assistance Program (Washington, DC: Mar. 7, 1991).

[11] Modern technologies can use biomass directly or convert it into liquid or gaseous fuels or into electricity with low emissions. See ch. 6 and Samuel F. Baldwin, U.S. Congress, Office of Technology Assessment "Cooking Technologies," staff working paper, Aug. 15, 1991.

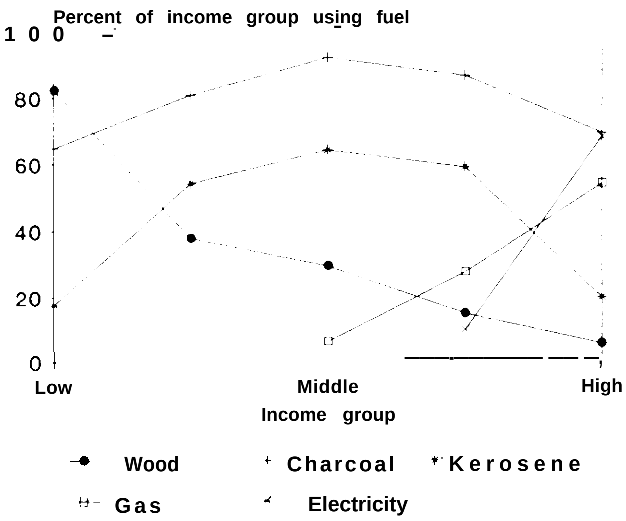
[12] Cultural factors frequently have been cited as a barrier to the adoption of improved wood, Charcoal, or Other stoves/fuels. Cultural factors may play a role in stove/fuel choice; a wide variety of stoves and fuels have nevertheless been adopted across the full range of class, cultural, and income groups in developing counties, and a strong preference is displayed for superior stoves/fuels such as kerosene, LPG, or electricity. More typically, the reason why various improved biomass stoves have not been adopted by the targeted developing country group is that the proposed technology did not work well or did not meet the multiple needs of the user (see box 3-A).

[13] These issues, particularly the problems of smoke pollution and other environmental impacts from traditional biomass stoves/fuels, the effort required to forage for biomass, and the role of women are discussed in a previous OTA report—U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, op. cit., footnote 2.

[14] Even among high efficiency stoves, such as those using LPG *or gas,* there can be further improvements in efficiency. In practice, the high efficiency of gas stoves can be largely negated when pilot lights are used. Gas stoves that are lit by electric ignition systems (or simply matches) typically use just half the energy that stoves with pilot tights consume. Higher efficiency natural gas stoves under development combine advanced ceramic materials and new designs to augment both infrared and convective hinting in a burner with very low emissions. There are similarly many potential efficiency improvements in ovens (such as convection ovens), pots used to cook with (such as pressure cookers), and other cooking devices. See Howard S. Geller, American Council for an Energy Efficient Economy, "Residential Equipment Efficiency: A State of the Art Review," contractor report prepared for the Office of Technology Assessment May, 1988; Jorgen S. Norgard, "Low Electricity Appliances-Options for the Future,' *Electricity: Efficient End Use and New Generation Technologies, and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989); K.C. Shukla, J.R. Hurley, and M. Grimanis, *Development of an Efficient, Low NOX Domestic Gas Range Cooktop, Phase II,* Report No. TE431 1-36-85, Thermo Electron Corp., Waltham, MA, for the Gas Research Institute, Chicago, IL, GRI-85/0080, 1985.

[15] Samuel F. Baldwin, U.S. Congress, Office of Technology Assessment, ''Cooking Technologies," staff working paper, Aug. 15, 1991.

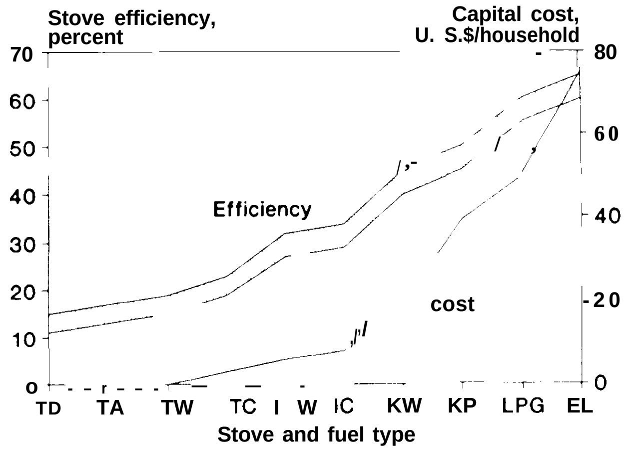
Figure 3-2—Choice of Cooking Fuel by Income for Five Medium-Sized Towns in Kenya



Many households use more than one fuel depending on the particular food cooked and the supply and cost of fuel. Note the shift in fuel choice from wood to charcoal and kerosene, and then from charcoal and kerosene to gas and electricity. This transition is very complex and not yet well understood. Factors that affect a household's shift to modern stoves and fuels include: household income and fuel producing assets (land, trees, animals, etc.); reliability of access to modern fuels; relative cost of traditional and modern fuels and stoves; level of education of the head of household; cooking habits; division of labor and control of finances within the household; and the relative performance of the stove/fuel.

SOURCE: John Soussan, "Fuel Transitions Within Households," Discussion paper No. 35, Walter Elkan et. al. (eds.), *Transitions Between Traditional and Commercial Energy in the Third World* (Guildford, Surrey, United Kingdom: Surrey Energy Economics Center, University of Surrey, January 1987).

Figure 3-3-Representative Efficiencies and Capital Costs for Various Stoves



Stoves listed are: (TD), (TA), (TW), (TC)--traditional stoves using dried animal dung, agricultural residues, wood, and charcoal, respectively; (IW), (IC)--improved wood and charcoal stoves; (KW), (KP)--kerosene wick and kerosene pressure stoves; (LPG)—LPG or natural gas stoves; and (EL)--electric resistance stove. Efficiencies and capital costs are for the stove alone and do not include upstream capital costs for producing and delivering fuel. The range of performance both in the laboratory and in the field is much larger than that suggested by this figure and is affected by such factors as the size of the stove and pot, the climate (wind), the quality of the fuel used, the care with which the stove is operated, the type of cooking done, and many other factors. The type of material that the pot is made of is also a significant factor: aluminum pots are almost twice as efficient as traditional clay pots due to their better conduction of heat.

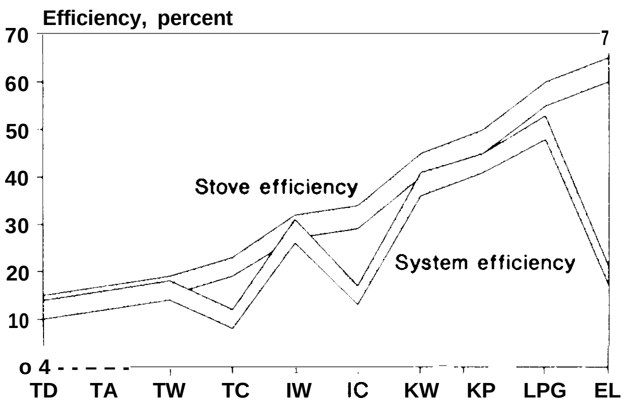
SOURCE: Samuel F. Baldwin, "Cooking Technologies," Office of Technology Assessment, staff working paper; and U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991).

Efficiencies and costs tell a much different story, however, when examined from a system, rather than the individual purchaser's, perspective. When the energy losses of converting wood to charcoal, fuel to electricity, refining petroleum products, and transporting these fuels to consumers, etc. are included, the system efficiency of delivering cooking energy by charcoal and electric stoves, in particular, drops precipitously (see figure 3-4).[16] These are important attributes to consider when evaluating the environmental impacts and financial feasibility of different cooking systems.

As for the efficiency estimates, there are substantial variations between the capital costs for individual stoves and for the entire cooking system. This is particularly notable in the case of electricity where

[16] Actual capital and operating costs will vary widely from these nominal values according to local fuel and stove costs, taxes, and Other factors. Actual stove and system efficiencies and *other* performance factors will vary widely according to household size, diet, income, fuel availability, cooking habits, activity level, season, and many other factors. Some of these factors also tend to change at the same time stove type is changed. Migrants to urban areas may simultaneously change their stove and fuel type, family size, diet, etc. Financial savings gained by moving up to more efficient stoves may also induce greater energy consumption as diet is changed, cooking habits relax, or more food is consumed. For example, estimates are that 15-25 percent of the savings with improved charcoal stoves will be offset through subsequent, income induced consumption. The systemwide fuel savings achieved by going from traditional wood stoves to kerosene or LPG stoves also tend to be less than that expected from simply comparing the efficiency of different stoves as measured in the laboratory. See Donald W. Jones, "Some Simple Economics of Improved Cookstove Programs in Developing Countries," *Resources and Energy*, vol. 10, 1988, pp. 247-264; Kevin B. Fitzgerald, Douglas Barnes, and Gordon McGranahan, World Bank, Industry and Energy Department, *Interfuel Substitution and Changes in the Way Households Use Energy: The Case of Cooking and Lighting Behavior in Urban Java* (Washington, DC: World Bank June 13, 1990).

Figure 3-4-Stove and System Efficiencies



Stove efficiencies are nominal values for the stove alone; system efficiencies include the energy losses in producing, converting, and delivering fuel to the consumer. Note particularly the low system efficiencies for charcoal (TC and IC) and electric (EL) stoves due to the large energy losses in converting wood to charcoal and fuel to electricity.

SOURCE: Samuel F. Baldwin, "Cooking Technologies," Office of Technology Assessment, staff working paper.

the upstream costs of generation, transmission and distribution, and other facilities are much larger than the capital cost that the consumer sees for the stove itself (see figure 3-5).[17]

There can be, however, a substantial reduction (depending on relative fuel and stove prices) in both operating costs and energy use in going from traditional stoves using commercially purchased fuelwood to improved biomass, gas, or kerosene stoves (see figure 3-6). There may be opportunities to substitute high performance biomass stoves for traditional ones or to substitute liquid or gas stoves for biomass stoves.[18] Local variations in stove and fuel costs[19] and availability, and in consumer perceptions of stove performance, convenience, and other attributes will then determine consumer choice. Regardless, there are substantial differences in systemwide capital and operating costs for different stoves, many of which are not directly seen by the consumer.

Public policy can help shift consumers toward the more economically and environmentally promising cooking technologies as judged from the national perspective. In particular, improved biomass stoves may be the most cost effective option for the near- to mid-term but require significant additional work to improve their performance (see box 3-A, 3-B, figure 3-7), In rural areas, biomass is likely to be the fuel of necessity for cooking for many years to come.

Alternatively, particularly in urban areas, liquid or gas fueled stoves may offer the consumer greater convenience and performance at a reasonable cost. Foreign exchange requirements, however, will usually require that stove and system efficiencies be maximized and that as much as possible of the stove and other system equipment be manufactured in-Country.

Finally, although past efforts in solar cooking have generally been disappointing,[20] recent work suggests that solar box ovens may yet offer an opportunity to meet a portion of cooking needs in areas with high levels of sunshine and cuisine that is adaptable to that style of cooking (i.e, boiling or baking, not frying).[21] The potential of solar cookers nevertheless remains highly controversial due to past failures. They remain expensive, bulky, and fragile; may require changes in cooking practice in many areas; and materials to repair them with are often difficult to obtain. Much more extensive field trials will be needed if the actual potential of newer designs is to be determined.

[17] The impact of electric cooking on the grid can be substantial. For example, more than one-third of electricity consumption in Costa Rica and Guatemala is for cooking, where about half of all electrified households have electric stoves. Annual electricity consumption for cooking in Guatemala is roughly 2,500 kilowatt hour (kWh)/year per household compared to 700 kWh/y in the United States. In parts of Asia, electric rice cookers are becoming a substantial electric load. These demands can cause significant local problems for the power grid where loads are low and there is little diversified demand. With larger, more diversified grids, however, such demands pose fewer difficulties. Further, in some cases such as the use of microwave ovens for some baking, electric cooking may lower total energy use compared to, for example, baking in a conventional gas oven. Costa Rican and Guatemala data from: Andrea N. Ketoff and Omar R. Masera, "Household Electricity Demand in Latin America," *ACEEE 1990 Summer Study on Energy Efficiency in Buildings* (Washington, DC: 1990).

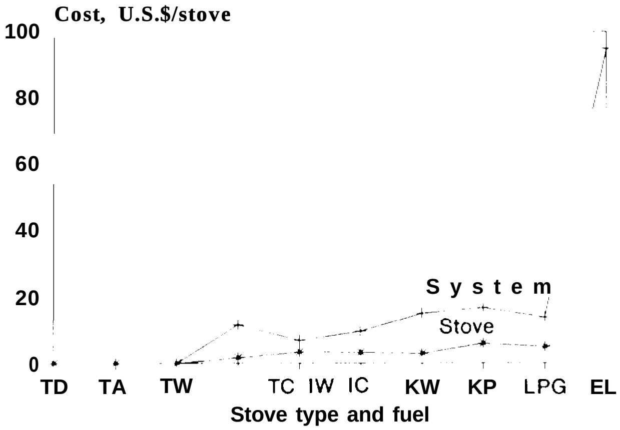
[18] Some argue that the biomass not used in cooking could instead be diverted to high efficiency electricity generation or process heat applications. Backing biomass out of the household sector in this reamer poses significant difficulties in the collection and transport of the biomass to a central facility. This will be discussed in chs. 5 and 6.

[19] The values shown are for residential stoves. Commercial stoves exhibit similar trends, with a general shift upwards in efficiency and down in cost per quantity of food cooked due to scale effects. Further, this analysis does not separately consider foreign exchange costs.

[20] Richard Pinon, "About Solar Cookers," *Passive Solar Journal,* vol. 2, No. 2, 1983, pp. 133-146.

[21] Daniel M. Kammen and William F. Lankford, "Cooking in the Sunshine," *Nature,* vol. 348, Nov. 29, 1990, pp. 385-386.

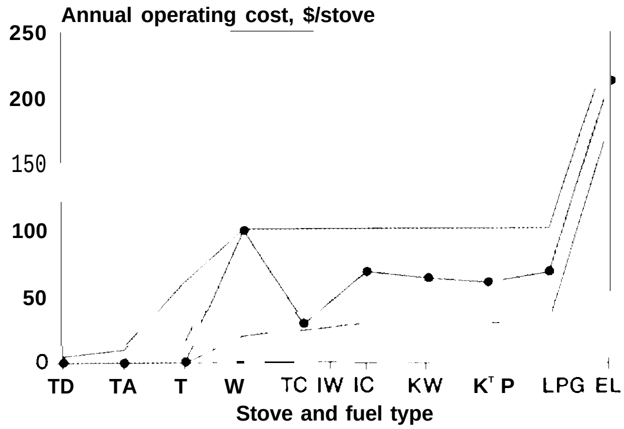
Figure 3-5-Stove and System Capital Costs



When system costs are included, electric stoves can be seen to be particularly expensive. There is a wide range of costs around these nominal values. Note the logarithmic scale.

SOURCE: Samuel F. Baldwin, "Cooking Technologies," Office of Technology Assessment, staff working paper.

Figure 3-6-Annual Cost of Cooking for Different Stoves



Data points show the cost as estimated from the nominal values. The gray band suggests the wide variation in costs using any particular stove depending on local stove and fuel costs, diet, and a host of other factors.

SOURCE: Samuel F. Baldwin, "Cooking Technologies," Office of Technology Assessment, staff working paper.

In the long term (assuming income growth and the ability to finance imports), the transition to high quality liquid and gas fuels for cooking is inexorable.[22] With this transition, substantial amounts of labor now expended to gather biomass fuels in rural areas may be freed; the time and attention needed to cook when using crude biomass fuels may be substantially reduced; and household, local, and regional air pollution from smoky biomass (or coal) fires may be largely eliminated. On the other hand, high quality fuels will increase financial costs to the individual consumer and, if fuels or stove equipment are imported, could have significant impacts on national trade balances and foreign exchange holdings.

The transition to modern stoves and fuels thus offers users many benefits—reduced time, labor, and possibly fuel use for cooking, and reduced local air pollution[23]—but this transition is also often sharply constrained due to their frequently higher capital and operating costs and uncertain fuel supplies. Means of lowering capital and operating costs and ensuring the reliability of supply are needed if the poor are to gain access to these clean, high efficiency technologies. Further, this transition could impose a substantial financial burden on poor nations.

A large scale transition to LPG, for example, would require a significant investment in both capital equipment and ongoing fuel costs. Optimistically assuming that the capital cost of LPG systems would average $50 per household, including bottling, storage, and transport, the investment would be roughly 3.5 percent of current Gross National Product and 20 percent of the annual value-added in manufacturing for the three billion people in the lowest income countries.[24] The LPG used[25] would be equivalent to one-fourth total commercial energy consumption today by these countries and would be

[22] It maybe possible, however, to use biomass in a domestic gasifying stove or in a central gasification plant from which it is then piped to the household to generate producer gas for cooking. Examples of this are discussed in Samuel F. Baldwin, U.S. Congress, Office of Technology Assessment, "Cooking Technologies," staff working paper, Aug. 15, 1991.

[23] It might, however, increase global carbon dioxide emissions.

[24] World Bank, *World Development Report 1989 (New* York, NY: Oxford University Press,1989), tables 1 and 6.

[25] Assuming a per-capita power rate for cooking with LPG systems of 100 watts. This is comparable to that seen in the United States and about twice that seen in European countries. It is likely that people in developing countries would continue to eat less processed foods, less restaurant food, and probably more grains and so would continue to use somewhat more fuel than that seen in households in the industrialized countries. Energy use rates for household cooking in different countries are given in K. Krishna Prasad, "Cooking Energy," paper presented at Workshop on End Use Focussed Global Energy Strategy, Princeton University, Princeton, New Jersey Apr. 21-29, 1982.

a significant fraction of their export earnings.[26] Significant economic growth and a gradual phase-in of these technologies are needed if these costs are to be absorbed.

WATER HEATING

The demand for hot water—for bathing, washing clothes and dishes, and other uses—is a significant energy end use in industrial countries and will become more important in developing countries as their economies grow. Hot water demand for a single family in the United States in 1985 was roughly 200 liters/day--40 percent for showers, 25 percent for clothes washers, 20 percent for dishwashers, and 15 percent for other uses-or about 50 liters per person each day.[27] On average, heating water is the second largest use of energy, after space conditioning (heating and cooling), in the U.S. residential and commercial sectors (see table 3-2).

The use of hot water is also important in developing countries, even with their generally warmer climates. For example, electric water heating accounts for 20 to 25 percent of residential electricity demand in Brazil, Colombia, Ecuador, and Guatemala.[28] In Brazil, instant (rather than storage) electric water heaters are widely used for showers. In use, they draw as much as 7 kilowatts and account for perhaps half of the residential peak electricity demand in Sao Paulo.[29] In a study of six villages in India, water heating used about one-fifth as much fuel as cooking.[30] A study of households that used fuelwood in the large urban area of Bangalore, India, found fuelwood consumption almost equally divided between cooking and water heating.[31]

In many rural and poor urban areas, use of hot water remains modest today but will generally increase in the future. There are many technical approaches to water heating that greatly reduce fuel consumption and, from the societal perspective, can reduce capital costs and life cycle operating costs. The most simple, and perhaps the most readily applicable in developing countries, is the use of solar water heaters. These can range from simple devices that simply hold the water in a container exposed to the sun, to complex devices that actively monitor water temperatures and move it into large storage tanks until it is needed. The fuel demands of these systems are generally quite low.[32]

A variety of solar water heating technologies are now well developed. The 7,400 square meter building in which the Office of Technology Assessment is housed has a solar system on its roof that provides all of the hot water and up to 70 percent of the space heat needed. Solar water heating systems for developing countries can, in principal, be lower in cost and more efficient than those in the industrial countries. Complicated and expensive protection mechanisms used in cold climates to keep the water from freezing and breaking the system are largely unnecessary in the warm developing countries. Solar water heater efficiencies are generally higher in the developing countries because of the warm outside temperatures.

Solar water heaters have been put into widespread use in some countries. There are more than two million solar water heaters in Japan and 600,000 in Israel. More than 50 firms manufacture or market solar water heaters in Turkey; a total area of 19,000 square meters of collectors was installed in 1982. China has an installed collector area of 150,000 square meters; Kenya has about 19,000 residential

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[26] World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989), table 5, and converting kilogram oil equivalent to energy at 42 megajoules (MJ)/kg.

[27] American Council for an Energy Efficient Economy, "Residential Conservation Power Plant Study: Phase I—Technical Potential," Pacific Gas and Electric Co.

[28] Andrea N. Ketoff and Omar R. Masera, "Household Electricity Demand in Latin America,' *ACEEE 1990 Summer Study on Energy Efficiency in Buildings* (Washington DC: 1990).

[29] Stephen Meyers et al., *Energy Efficiency and Household Electric Appliances in Developing and Newly Industrialized Countries*, report No. LBL-29678 (Berkeley, CA: Lawrence Berkeley Laboratory, December 1990); Alfredo Behrens and Stefano Consonni, "Hot Showers for Energy Rich Countries, ''*Energy*, vol. 15, No. 9, pp. 821-829, 1990.

[30] ASTRA, ''Rural Energy Consumption Patterns: A Field Study," Centre for the Application of Science and Technology to Rural Areas, Indian Institute of Science, Bangalore, India, 1981.

[31] Amulya Kumar N. Reddy and B. Sudhakar Reddy, "Energy in a Stratified Society," *Economic and Political Weekly*, vol. XVIII, No. 41, October 1983, p. 1762.

[32] Fuel may be required even in a warm climate to supplement solar heating when there is heavy cloud cover.

Box 3-A—Improved Stoves in Developing Countries

Traditional stoves, with their high levels of smoke and heat, awkward use, and heavy demand for fuel (and its attendant laborious collection), have long been a central focus of efforts to improve the lives of women in developing countries. Gandhian organizations developed stoves with chimneys to reduce indoor smoke pollution beginning in the 1930s. S.P. Raju worked on stove design at the Hyderabad Engineering Research Laboratory and published a pamphlet, "Smokeless Kitchens for the Millions" in 1953 in which he promised women five freedoms-from smoke, from soot, from heat, from waste, and from fire risk. Following their own energy crisis in 1973, the Western World began to perceive corresponding energy problems in developing countries, particularly that of fuelwood use in traditional stoves and a possible connection between fuelwood use in cooking and deforestation.[1]

Following the path pioneered in India and elsewhere, a variety of improved stove programs were begun by western donors and host countries in the mid- to late- 1970s. Program design and technology choice were strongly influenced by the ''appropriate technology' movement: local materials were used, designs were kept simple (and supposedly low-cost), and low-skill labor intensive construction was emphasized both for its own sake and to allow easy maintenance.

The first generation of woodstoves that resulted from these considerations were typically thick blocks of a sand and clay mixture; chambers and holes were carved in the block for the fire, for the pots to sit on, and for the smoke to exit to the chimney. A fire was built under the first pot; the second and subsequent pots were heated by the hot gases flowing toward the chimney. These were known as "massive multi-pot" stoves (see figure 3-7A).

In many cases, little or no testing was done of these first generation designs before dissemination programs began. Numerous competing projects were launched—some countries in West Africa had a dozen or more largely independent stove programs supported by different international nongovernmental organizations, bilateral and multilateral aid agencies, and domestic organizations. These countries never individually had a critical mass of technical manpower to do proper design work, perform detailed field evaluations or followup, or conduct careful economic or social analysis. Operating independently and with little interprogram communication, the same mistakes were repeated.

When field evaluations of these massive stoves began, serious problems began to surface. Field surveys found that most users quickly returned to using their traditional stoves; laboratory and field studies alike showed that these massive stoves often used more fuel and emitted as much smoke into the kitchen as traditional stoves; the stoves cost users a significant amount of time and effort (and sometimes money) to build; and the stoves were hard to maintain-they cracked and crumbled easily in the heat of the fire.

Contrary to then accepted wisdom, it appeared that traditional stoves were actually well optimized for the local materials, pots, and other conditions from many, many years of trial and error. To do better required sustained technical input in design, quality control in production, careful field testing and followup, and extensive input at every stage from women users. These factors were missing from nearly all the programs. Improved heat resistant materials such as metals or ceramics also proved important.

In response to the numerous independent stove programs, their lack of success, and the need for firm technological underpinnings, efforts were launched in the early 1980s to coordinate these programs and develop the technological foundations necessary. In West Africa, for example, IBM-Europe and the Club du Sahel asked Volunteers in Technical Assistance, a private U.S. volunteer organization, to work with CILSS (The Interstate Committee To Fight Drought in the Sahel-an eight country African organization) in a program funded by USAID and IBM-Europe, and later by the Netherlands to coordinate disparate technical development and dissemination efforts. The technical effort showed that, at least under West African conditions, massive stoves typically used substantially more wood than traditional stoves. Using the principles of engineering combustion and heat transfer, a ''second generation' of simple lightweight stoves made of metal or ceramic was developed that achieved fuel savings in the field of about one-third compared with traditional stoves (see figure 3-7 B). To realize these savings required that critical stove dimensions be maintained to within a fraction of an inch. In turn, this required that the

[1] It is now generally acknowledged that use of wood for fuel is not usually a strong contributor to deforestation. There are a few exceptions, particularly arid regions where biomass growth is low, or around urban or industrial areas with unusually high levels of fuel demand. See: Office of Technology Assessment, *Energy In Developing Countries*, (Washington, DC: U.S. Government Printing Office, January 1991).

Box 3-A—Improved Stoves in Developing Countries--Continued

stoves be "mass-produced" to match standard pot sizes. This was best done at central sites where tight quality control could be ensured. In comparison to massive stoves that were hand-crafted on site, centralized production also had the advantages of more rapid production, lower stove and program costs, and ready commercialization. For the user, the lightweight stoves had the advantage of somewhat more rapid cooking, protection from burns that are likely when cooking over an open fire, and portability: the stove could be moved across a courtyard to take advantage of afternoon shade or across town when the household moved.

These stoves have proven popular in the field. A World Bank program to disseminate lightweight metal stoves in Niamey, Niger, set an ambitious target of 20,000 stoves in 2 years; 40,000 stoves were sold. Similar large-scale efforts are now underway in Mali, Burkina Faso, and elsewhere.

Other countries have similarly enjoyed considerable success recently with improved stove programs. Some 130,000 improved jiko stoves (which use charcoal rather than wood, as above) with average savings of 15 to 40 percent are now sold annually in Kenya. In China, an estimated 80 million improved stoves had been disseminated by the end of 1987. In Karnataka State, India, over 100,000 massive stoves have been disseminated, and with careful technical input and field followup, have also realized savings. Ironically, the widespread failure of the first generation 'massive' stoves discredited stove programs generally and caused many aid organizations to cut back financial supports just as significant improvements in stove performance were finally being realized with these second generation lightweight and (in the case of Karnataka State) massive stoves.

Centralized mass production and commercial sale of lightweight stoves has, however, generally shifted the programmatic focus of remaining stove efforts from traditional rural areas largely outside the cash economy to poor urban areas. Effective means of addressing rural areas have not yet been developed. Considerable work also remains to further refine biomass stove designs so as to improve efficiencies and reduce noxious emissions.

SOURCES: S.P. Raju, "Smokeless Kitchens for the Millions," Christian Literature Society, Madras, India, 1953, reprinted 1961. Samuel F. Baldwin, *Biomass Stoves: Engineering Design, Development, and Dissemination* **(Rosslyn, VA and Princeton, NJ: Volunteers in Technical Assistance and Center for Energy and Environmental Studies, Princeton University, 1986); Kirk R. Smith, "Dialectics of Improved Stoves,"** *Economic and Political Weekly, Mar.* **11, 1989; Jas Gill, "Improved Stoves in Developing Countries,"** *Energy Policy*, **April 1987, pp. 135-144, and Addendum, Energy Policy, June 1987, pp. 283-285; Margaret Crouch, "Expansion of Benefits: Fuel Efficient Cookstoves in the Sahel, The VITA Experience,'** *Volunteers in Technical Assistance,* **Rosslyn, VA, July 1989; H. Mike Jones, "Energy Efficient Stoves In East Africa: An Assessment of the Kenya Ceramic Jiko (Stove) Program,'' Oak Ridge National Laboratory, report No. 89-01, Jan. 31, 1989. "China: County-Level Rural Energy Assessments: A Joint Study of ESMAP and Chinese Experts," Activity Completion report No, 101/89; World Bank/UNDP, May 1989.**

solar hot water heaters; Papua New Guinea has about 8,000.[33]

The initial capital cost to the individual consumer is substantially higher for a solar water heater than for an electric heater.[34] When the upstream capital costs for the electric utility are included, however, the total capital cost to society is almost 30 percent greater for the electric water heater than for the solar water heater. When the total operating costs (capital plus fuel) to the user are considered, the solar heated water costs less than one-half that heated by electric heaters (see app. A). These comparisons are sumrnarized in figure 3-8 for electric resistance water heaters, electric heat pump water heaters,[35] and solar water heaters of comparable performance. Gas or liquid fueled water heaters can also be compared with solar water heaters but are not considered here.

The efficiency of hot water systems can also be improved by: increasing the amount of insulation on the storage tanks and distribution pipes, and by using traps to prevent convective loops from carrying heat away through distribution lines. Low flow shower-

[33] Christopher Hurst, ''Establishing New Markets for Mature Energy Equipment in Developing Countries: Experience with Windmills, Hydro Powered Mills and Solar Water Heaters,' *World Development.* vol.18, No.4, *1990,* pp. 605-615.

[34] The comparison here will be restricted to electric water heaters. Water heaters using natural gas or other fuels are also widely available and extensively used in many countries. The financial advantages of solar water heating may be largely offset or negated compared to gas or other types of water heaters.

[35] Note that in large commercial applications, heat pump water heaters can be coupled with air conditioning loads and can then be more economic under a variety of circumstances.

Figure 3-7A—A Massive Multipot Stove

A broken massive multipot stove is in the foreground. Only one of the two potholes is in use. A second pot to the side of the massive stove is supported by two stones and the stove wall. To the rear are women grinding grain with traditional mortars and pestles.

Site: near Niamey, Niger. Photo credit: Sam Baldwin.

Figure 3-7B—A Lightweight Metal Stove

Construction of an improved lightweight stove by a metalsmith.

Site: Ouagadougou, Burkina Faso. Photo credit: Sam Baldwin.

heads and cold water washing of clothes can reduce the quantity of hot water needed.

LIGHTING

Lighting accounts for only a small fraction of total national energy use in both developing and industrial countries, typically ranging from about 2 to 5 percent of the total (see table 3-8). Lighting's share of electricity use is higher, ranging from about 8 to 17 percent of total electricity use in industrial countries,[36] with similar shares in developing countries. In India, for example, lighting accounts for about 17 percent of total national electricity consumption and about 30 to 35 percent of the peak power demand.[37]

Lighting merits particular attention as it plays a very important social role in domestic life and in commerce and industry--enabling activities at night or where natural lighting is inadequate. As rural incomes increase, or as people move to urban areas and gain greater access to modern fuels and electricity, lighting services and the energy used to provide them increase dramatically.

As shown elsewhere,[38] lighting technologies follow a fairly clear technological progression in performance, efficiency, and cost—going from the simple open fire, to kerosene wick or pressure lamps, to the use of electric-powered incandescent or fluorescent lamps. Consumers' choices of lighting technologies largely follow the same progression as household incomes increase and as electricity becomes available.

The shift to electric lighting is observed everywhere electricity has been made available. In contrast to kerosene lamps or other nonelectric lighting technologies, electric lighting is clean (within the home), relatively safe, easy to operate, relatively efficient, and provides a high quality light.

[36] Terry McGowan, "Energy Efficient Lighting," *Electricity: Efficient End Use and New Generation Technologies, and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989).

[37] Ashok Gadgil and Gilberto De Martino Jannuzzi, *Conservation Potential of Compact Fluorescent Lamps in India and Brazil*, report No. LBL-27210 (Berkeley, CA: Lawrence Berkeley Laboratory, July 1989).

[38] U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, op. Cit., footnote 2.

Box 3-B—Research Needs for Improved Biomass Stoves in Developing Countries

The use of biomass resources for fuel contributes to several problems: they generate air pollution--particularly in village households-and possibly greenhouse gases; [1] they demand large amounts of time and labor; and in some areas they can contribute to deforestation.[2] Nevertheless, biomass will continue to be the primary cooking fuel for rural and poor urban areas in developing countries for many years to come. Higher quality liquid or gas fuels are simply too expensive and too irregular in supply to supplant biomass anytime soon.

Although biomass will continue to be a primary fuel in the mid-term, it may be possible to improve the performance of biomass stoves significantly. Some successes have already been realized (Box 3-A) but much more could be done. Significant technical challenges remain to be overcome, however, if clean burning, fuel efficient biomass stoves are to be developed.

The performance of a biomass stove is the product of several difficult technical tradeoffs. Fuel efficiency is improved by narrowing the gap between the pot wall and the stove to increase convective heat transfer; by limiting the flow of air into the stove to increase the average temperature of the combustion gases; by lowering the pot closer to the fire to increase the fraction of radiant heat from the fire that is intercepted by the pot; and by other means. But too narrow a gap can choke the fire and greatly increase cooking times; too little airflow into and through the stove can increase emissions of carbon monoxide and hazardous smoke; and lowering the pot closer to the fire can prevent complete combustion and greatly increase smoke emissions-this can easily be seen by putting an object into the flame of a candle. Further, unlike commercial fuels such as kerosene or LPG, biomass fuels vary markedly in density and form--from grass to logs, in composition, moisture content, and a host of other factors important in determining combustion characteristics. Combustion of biomass is also extremely complex, involving many thousands of interacting chemical species. Achieving both high fuel efficiency and low smoke emissions in a cook stove thus remains a substantial technical challenge.

The technical complexity of this task has several important implications.

First, the technical complexity requires a high level of technical expertise that is often difficult to assemble given the often small size of existing improved stove projects in developing countries. An alternative approach might be to form regional centers of excellence in developing countries where a relatively large number of researchers can be brought together to form the critical mass of skilled manpower that is needed. Such a center would draw the best manpower and concentrate the research effort, but base selection and continued participation on peer-reviewed performance. When the technology was developed, these researchers could then return to their respective regions to direct further development and dissemination efforts.

Such regional centers of excellence could themselves have several important benefits. They would provide an opportunity to further develop institutional capacity in the developing countries through goal oriented research focussed on technologies of particular interest in developing countries.

Regional centers of excellence might also offer a means of enhancing the training of scientists and engineers. Too often, students returning to smaller developing countries with a Masters or Doctoral degree in science or engineering are expected to immediately play an important role in national research organizations. In contrast, in the industrial countries, scientists and engineers often spend many years--even after receipt of their doctorate-working under the tutelage of a more experienced researcher, both as a postdoctoral fellow and as a member of a research team. Such experience is important. Much of what is required to select a viable approach to solving a research problem, to direct the research, and to manage the research budget and related administrative matters is not taught in school; it is instead learned through the modem equivalent of an apprenticeship. A regional center of excellence would provide budding scientists and engineers more opportunity to learn such skills from mentors, rather than being expected to learn it all by trial and error on their own.

Regional centers of excellence in developing countries have been successfully developed for agricultural research, development, and field trials. An example is the International Rice Research Institute. The experience of these institutions may hold useful lessons for the development of energy technologies.

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[1] If the biomass is used on a sustainable basis, then greenhouse gas emissions are essentially eliminated. In contrast, fossil fuels always generate greenhouse gases.

[2] See Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991).

Second, appropriate technologists have often suggested that technologies must be adapted to a very large extent to the locality in which they are used and that failure to make such adaptations is a principal cause of failure. In this context, it is important to recognize that a number of different factors might be adapted, including the underlying technology, product design, manufacturing process, or means of product dissemination.

The basic technology of a stove or of most other devices will remain largely the same globally. Indeed, the technical complexity of biomass combustion and the similarities of wood in Latin America, Africa, or Asia suggests that much of the basic research might be best undertaken at the global level, as long as it was closely coupled to nearby field trials.

Variations in the practical use of stoves between regions may require some adaptation of the product design-such as the means of holding pots down when vigorously stirring, modified shapes to hold different types of pots, etc. Nevertheless, gas and kerosene stoves have been used equally well in the United States, Africa, and Asia with little or no adaptation of their design.

The choice of fabrication method is more commonly an aspect that might be adapted to local conditions. Although the maintenance of precise dimensions in stoves will generally require mass production and quality control techniques, these can be implemented in ways as varied as village metalsmith artisanal production using standardized templates to automated metal stamping facilities. Similarly, the choice of materials can also be varied somewhat depending on local conditions, from low quality scrap metal recovered from barrels or wrecked cars to new high quality steel alloys or ceramics.

Finally, product dissemination methods must be adapted to local conditions if they are to be successful.

Third, past failures in improved stove programs indicate the need to link laboratory research activities with practical field experience. It is important to avoid the creation of laboratory curiosities with no practical field application. Means of rewarding researchers that successfully see their work through to full scale commercialization need to be explored.

Fourth, the complexity of biomass combustion and heat transfer requires close attention to design and quality control. This is particularly significant because of the importance of the informal artisanal sector in disseminating such technologies as biomass stoves. Greater effort needs to be made to work with this important sector in terms of upgrading their production technologies, improving their access to adequate finance, developing better means of technology transfer, providing training, and other *issues,*

Finally, the experience with improved biomass stoves has shown the market mechanism to be a particularly valuable tool in urban areas for weeding out poor technology designs or weighing alternatives through competition. The market mechanism is not as effective, however, in rural areas largely outside the cash economy, Methods of adequately meeting the needs in these areas are needed.

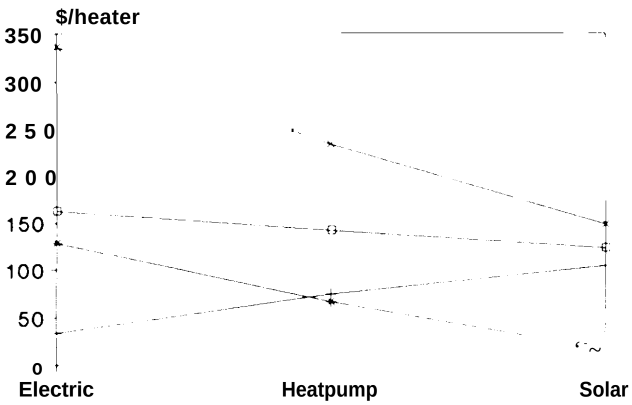
SOURCES: Samuel F. Baldwin, *Biomass Stoves: Engineering Design, Development, and Dissemination,* **(Rosslyn, VA and Princeton, NJ: Volunteers In Technical Assistance and Center for Energy and Environmental Studies, Princeton University, 1986). San Baldwin et at. "Improved Woodburning Cookstoves: Signs of Success,"** *AMBIO*, **vol. 14, No. 4-5, pp. 280-287, 1985. Dilip R. Ahuja, "Research Needs for Improving Biofuel Burning Cookstove Technologies, "** *Natural Resources Forum,* **May 1990, pp.125-134; Kirk R. Smith,** *Biomass Fuels, Air Pollution, and Health: A Global Review (New* **York, N?': Plenum Publishing Co. 1987); K. Krishna Prasad, E. Sangen, and P. Visser, ''Woodburning Cookstoves," in James P. Hartnett and Thomas F. Irvine, Jr.** *Advances in Heat Transfer, (New* **York, NY: Academic Press, 1985).**

As incomes increase with economic development, households begin to buy other appliances—radios, TVs, fans, refrigerators, and air conditioners. Electricity use for lighting usually continues to increase, but is then only a small fraction of total residential electricity use (see figure 3-9). Electricity use for lighting in the commercial and service sectors also grows rapidly as the economy expands.

The demand for lighting has continued to increase in the industrialized countries over the past 30 years as incomes have increased. Today, lighting ranges from roughly 20 to 100 million lumen-hours per capita per year (Mlm-hr/cap-yr) in the industrial countries, with most in the range of 25 to 40 Mlm-hr/cap-yr.[39] In comparison, annual household light production in South Bombay, India, varies with

[39] **Terry McGowan, "Energy Efficient Lighting, '** *Electricity Efficient End Use and New Generation Technologies, and Their Planning Implications* **(Lund, Sweden: Lund University Press, 1988).**

Figure 3-8-Capital Costs, Operating Costs, and Electricity Consumption for Electric Resistance, Electric Heat Pump, and Solar Water Heaters

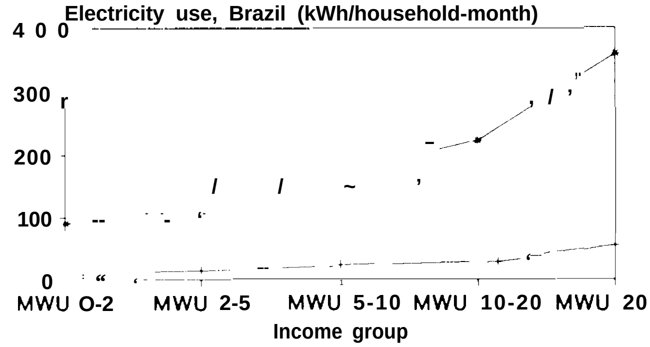


Capital costs to the individual consumer are substantially higher for solar water heaters than for electric resistance heaters. When upstream utility investment is included, however, the capital costs for solar water heaters are modestly lower than the systemwide capital costs for electric resistance and heat pump water heaters. Lifecycle operating costs to the consumer are dramatically lower for solar heaters than for electric heaters.

SOURCES: See app. A. Cost data for electric resistance water heater and solar water heater, installed costs, are from Sunpower Solar Hot Water Systems, Barbados, West Indies, 1990, provided by Robert van der Plas, World Bank, Washington, DC. Heat pump water heater data is from Howard S. Geller, "Residential Equipment Efficiency: A State-of-the-Art Review," American Council for an Energy-Efficient Economy, contractor report for the Office of Technology Assessment, May, 1988. See also, Electric Power Research Institute, "Heat Pump Water Heaters: An Efficient Alternative for Commercial Use," Palo Alto, CA.

household income from about 1 to 3 Mlm-hr/cap-yr;[40] light production in the commercial sector might double these numbers. This is equivalent to a light output level 10 to 30 percent that of the lowest industrialized countries.

Figure 3-9—Household Electricity Use for Lighting v. Household Income, Brazil



This graph shows that electricity y use for lighting continues to grow with income even in a relatively prosperous developing country such as Brazil. Lighting electricity is, however, only a small fraction of total household electricity use in this case. MWU are minimum wage units.

SOURCE: Ashok Gadgil and Gilberto De Martino Jannuzzi, *Conservation Potential of Compact Fluorescent Lamps in India* **and** *Brazil* **(Lawrence Berkeley Laboratory, Berkeley, CA and Universidade Estadual de Campinas, Brazil: June 23, 1989).**

The choice of electric lighting technology has a strong impact on upstream utility investment, and this impact is accentuated by lighting's large contribution to the peak utility load, Incandescent lights are the least efficient electric lighting technology and have the highest capital and operating costs (see figure 3-lOA). Currently, roughly 60 percent of total lighting electricity used in India is consumed by incandescent lightbulbs, and a higher fraction of residential lighting is used in incandescent bulbs.[41] In Brazil, some 95 percent of residential lighting is with incandescents,[42] about the same as in the United States.[43]

Much more efficient, cost effective lighting technologies are available.[44] For example, compact fluorescent lights with the same light output as an

[40]Calculated from Gadgil, op. cit., footnote 37.

[41]Ashok Gadgil and Gilberto De Martino Jannuzzi, op. Cit., footnOte 37.

[42]Gilberto De Martino Jannuzzi, et al., "Energy Efficient Lighting in Brazil and India: Potential and Issues of Technology Diffusion," Apr. 28,1991, draft.

[43]Howard S. Geller, American Council for an Energy Efficient Economy, "Residential Equipment Efficiency: A State-Of-The Art Review," contractor report prepared for the Office of Technology Assessment, May, 1988. Note, however, that most lighting electricity in the United States is used in the commercial sector.

[44]Much more than just the energy efficiency and light output of the lighting hardware should be considered in practical applications. Lighting hardware is also characterized by its chromaticity (the color of the light), correlated color temperature (the temperature of a perfect emitter that has the same chromaticity as the lighting hardware), and color rendering index (how realistic the colors of objects illuminated by the light appear to be). Sources: Robert van der Plas and A.B. de Graaff, "A Comparison of Lamps for Domestic Lighting in Developing Countries," (Washington, DC: World Bank, industry and Energy Department, June 1988); General Electric, "Lighting Application Bulletin: Specifying Light and Color."

Table 3-8—Lighting as a Share of National Energy and Electricity Use

	Energy use for lighting, GJ/cap				Percent of national total	
	Residential	Commercial	Industrial	Total	Energy	Electricity
Brazil	0.3	0.5	0.1	0.9	2.1	14.6
China	0.4	NA	NA	NA	NA	NA
India	0.5	0.05	0.05	0.6	5.1	14.2
Kenya	0.5	0.16	NA	0.66	2.6	27.2
Taiwan	0.7	0.8	NA	1.5	2.2	6.9
Us.	NA	7.2	NA	NA	NA	NA

NA = Not available or not applicable.

SOURCE: U.S. Congress, Off Ice of Technology Assessment, *Energy in Developing Countries,* OTA-E-486 (Springfield, VA: National Technical Information Service, Washington, DC: U.S. Government Printing Office, January 1991). Table 3-3 and app. 3-A.

incandescent have an initial capital cost for the lamp alone that is 20 times that of the incandescent but use just one-fourth as much electricity and last 10 times as long.[45] When the longer lifetime of these lamps and the required capital investment in utility equipment to power these different lights are taken into account, the total capital cost of compact fluorescent lighting is half that of incandescent lighting. Further, the total operating cost—including the cost of the lamp and the electricity to power it--of the compact fluorescent is one-third the cost of the incandescent. These results are summarized in figure 3-10 and are tabulated in appendix A.[46]

The high first cost of a compact fluorescent is a significant deterrent. (Of course, in places where a light is rarely used—such as a closet—it makes good economic sense to use a low cost, lower efficiency light, see figure 3-10.) The highly subsidized price of electricity in many developing countries reduces the consumers perceived benefit of higher efficiency lights. Making such an investment also poses a significant risk for the poor if such an expensive lamp is accidentally broken or stolen.

Utilities in developing countries may directly benefit by reducing the amount of subsidized power that they sell. It will often be less costly for the utility to subsidize the sale of efficient lightbulbs than to continue to subsidize the cost of electricity, particularly when utilities must finance expensive new generation capacity .47

If compact fluorescent are to be used in developing countries, special conditions should be taken into account. For example, conventional core-coil ballasts may have difficulties where power line voltage or frequency fluctuations are excessively large; large overvoltages, for example, could cause the lamp to burn out prematurely. Electronic ballasts can be used, however, particularly if modified with special voltage regulators .48 At the same time, the electronic ballast raises the lamp efficiency (from 50) to about 60 lumens/watt. In contrast, to make standard incandescent more robust to the voltage fluctuations found in developing countries, the filament is made heavier at the cost of lowering the efficiency from 12 to typically 10 lumens per watt.[49] As many of the applications in developing countries will be new installations, properly sized and designed fixtures to hold compact fluorescent can be installed from the beginning, avoiding the difficulty and expense of retrofitting fixtures that industrial countries are now encountering.

There are similar opportunities in commercial buildings, even though they often now use fluorescent lighting. A standard fluorescent tube, not

45 Prices are highly uncertain due to a variety of factors. Prices (o original equipment manufacturers for the PL-13—the equivalent of a 60 W incandescent—are estimated at $7: $3.50 for the 10,000 hour glass element and $3.50 for the 20,000 hour base. Ashok Gadgil and Gilberto De Martino Januzzi, op. cit., footnote 37.

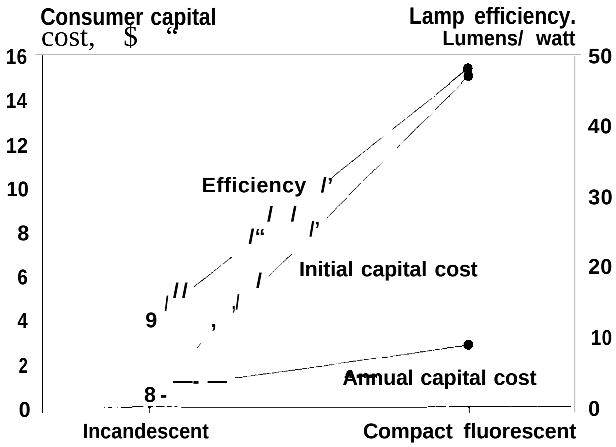
46 See also: Howard S. Geller, "Electricity Conservation in Brazil: Status Report and Analysis, ' contractor report prepared for the Office of Technology Assessment, November 1990; Howard S. Geller, *Efficient Electricity Use: A Development Strategy for Brazil,* (Washington, DC: American Council for an Energy Efficient Economy, 1991).

47 A detailed discussion of these various perspectives can be found in: Ashok Gadgil and Gilberto De Martino Januzzi, op. cit., footnote 37.

48 These voltage regulators might be as simple as a zener diode or a neon lamp and could add about $1 to the factory cost of the lamp. This could allow the lamp to operate while voltages fluctuated around 220 V, from 80 V to 650 V. In contrast, core-coil ballasts can only withstand a 2 percent fluctuation in frequency and about +/-10 percent fluctuation in voltage, Total factory cost of the lamp with a modified electronic ballast might then be about $12. Ashok Gadgil, Lawrence Berkeley Laboratory, personal communication, Jan. 23, 1991.

49 Ashok Gadgil, ibid.

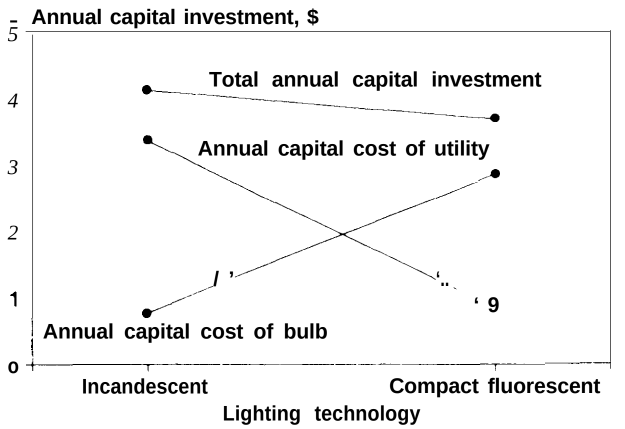
Figure 3-10A--First (Capital) Cost, Annualized Capital Cost, and Efficiency of a 60 Watt Incandescent Bulb and Its Equivalent Compact Fluorescent Bulb



This figure indicates the barrier to buying the compact fluorescent bulb faced by the first-cost sensitive consumer. It also shows that the longer lifetime of the compact fluorescent bulb, shown on the basis of annualized capital cost, largely offsets its higher initial capital cost.

SOURCE: See app. A for details.

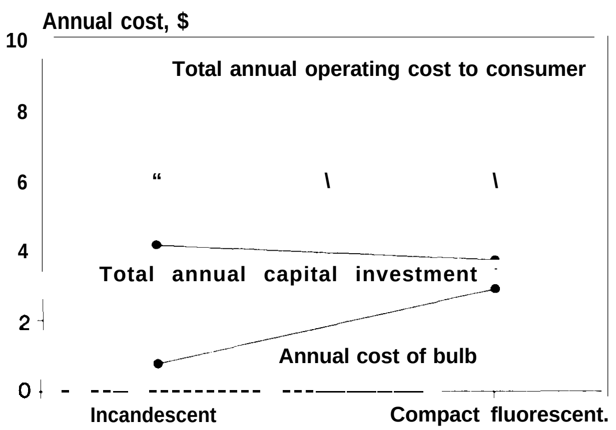
Figure 3-10 B—Annualized Capital Cost for Incandescent and Compact Fluorescent Lamps, Upstream Utility Generation, Transmission, and Distribution Equipment to Power the Lamps, and the Two Combined to Give the Total Annual Capital Investment



The total annualized capital investment declines substantially for the high efficiency compact fluorescent light bulbs.

SOURCE: See app. A for parameters in the case of 4 hours of operation per day. Note that the capital costs do not include switches, interior house wiring, etc.

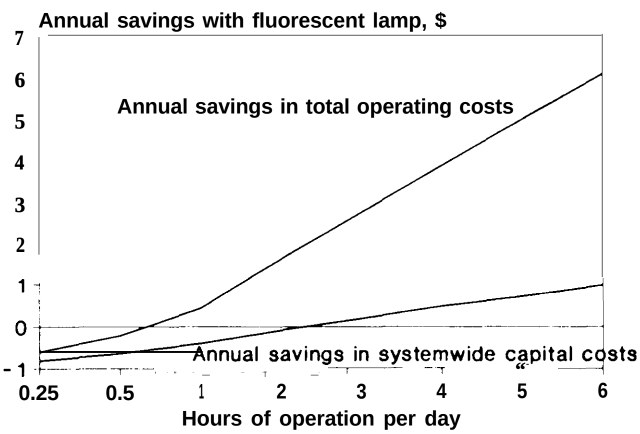
Figure 3-10C—Annual Capital and Operating Costs for Different Lamps



The total cost to the consumer decreases substantially for the high efficiency compact fluorescent.

SOURCE: See app. A.

Figure 3-10D—Cost Effectiveness of Compact Fluorescent Bulbs Versus Incandescent for Different Daily Operating Times



As the daily use of a compact fluorescent bulb increases, it is increasingly cost effective both in terms of systemwide capital costs and total annual operating costs (capital plus fuel). Only for daily operating times of less than about 40 minutes per day does the higher initial capital cost of the compact fluorescent outweigh savings in electricity costs over the lamps lifetime.

SOURCE: See app. A for parameters.

including the ballast, produces 3,150 lumens with a 40-watt (W) input for an efficiency of roughly 79 lumens per watt.[50] Through a variety of improvements in design and materials, tubes with efficiencies of more than ***95*** lumens per watt are now available.

To operate these lamps, ballasts must be used that lower their overall efficiency .51 Conventional core-coil ballasts are typically made of aluminum wire and low quality laminated iron cores and consume typically 8 to 18 W per lamp.[52] This lowers the **lamp** efficiency from about ***79 lm/W*** to about 55-65 lm/W--an efficiency loss of as much as one-third,

High efficiency core-coil ballasts use high quality materials-iron and copper—to cut ballast losses in half, to 3 to 4 W per lamp. Electronic ballasts can cut losses in half a second time, to 2 W, and at the same time increase the efficiency of the fluorescent tube itself, improve the quality of the light generated, reduce sensitivity to voltage and frequency fluctuations, and—for advanced designs—allow the lamp to be dimmed when, for example, daylighting is available (see boxes 3-C, and 3-D). The overall efficiency of a high efficiency tube and an electronic ballast is over 90 lm/W--about 40 percent higher than the standard lamp and ballast. If poorly designed, however, electronic ballasts can generate power line harmonics that may interfere with other electronic equipment or increase transmission and distribution losses somewhat.[53] This technology is now well established in the U.S. market, with annual sales approaching the two million mark in 1988.[54]

Reducing the temperature of the lamp 20 °C by raising efficiency and providing air cooling can also raise the operating efficiencies of lamps by as much as 10 percent.[55]

Efficiency improvements in the lighting systems of commercial buildings are particularly important in the newly industrializing countries due to the rapid growth of this sector. Commercial buildings in the ASEAN countries-Indonesia, Malaysia, Philippines, Singapore, and Thailand-now consume about one-third of the total electricity generated in the region, and of the electricity used, roughly one-third goes to lighting.[56] Lighting's share of commercial building electricity use is even higher in many other countries.

Further efficiency improvements in the lamp itself are possible .57 In addition, better reflectors and diffusers can improve direction of the light generated and can allow the number of lamps per fixture to be reduced. Fixtures in many developing countries are particularly low quality due to the lack of highly reflective coatings. In Brazil, the combination of high efficiency lamps, ballasts, and fixtures was found to raise the useful light output of a fluorescent lamp system by a factor of three (see table ***3-9).***[58]

Better controls, such as occupancy sensors or photocell controlled dimmers used with advanced

50Based on a standard 4-foot long cool white fluorescent tube, with an output of 3,150 lumens and an input power of 40 W for the lamp and 15-20 W for the ballast. see: Terry McGowan, op. cit., footnote 36; and Gautam S. Dutt, "End Use Oriented Energy Strategies for Member Developing Countries (With Special Reference to India), " draft report to the Asian Development Bank, Manila, Philippines, January 1991.

51 *Core-coil* ballasts are current limiting inductors used *to* prevent high currents from developing in the lamp and burning it out. Without the ballast, the plasma discharge of the fluorescent lamp---with its negative coefficient of resistance--would support an increasing current and basically turn the lamp into a miniature arc welder.

52The higher figure is feud for low quality ballasts operating a single tube. See: Howard S. Geller, op. cit., footnote and Gautam S. Dutt, "End Use Oriented Energy Strategies for Member Developing Countries (With Special Reference to India), draft report to the Asian Development Bank, Manila, Phillipines, January 1991.

53Rudolph R. Verderber, Oliver C. Morse, Francis M. Rubinstein, "Performance of Electronic Ballast and Controls With 34-and40-Watt F40 Fluorescent Lamps," *Transactions on Industrial Applications, vol. 25, No. 6, 1989,* pp. 1049-1059; Amory B. Lovins and Robert Sardinsky, *The State of the Art: Lighting* (Snowmass, CO: Rocky Mountain Institute, 1988).

54Verderber, ibid.

55M. Sminovitch et al., The Energy *Conservation Potential Associated With Thermally Efficient Fluorescent Fixtures*, report No. *LBJ-27315* (Berkeley, CA: Lawrence Berkeley Laboratory, June 1989).

56M.D. Levine, J.F. Busch, and J.J. Deringer, "Overview of Building Energy Conservation Activities in ASEAN,'' paper presented at the ASEAN Special Sessions of the ASHRAE Far East Conference on Air Conditioning in Hot Climates, Kuala Lumpur, Malaysia, Oct. 26-28, 1989, Lawrence Berkeley Laboratory, report No. LBL-28639, Berkeley, California.

57The combination of isotopic enrichment, two photon phosphors, and gighertz operation, among others, may be able to push efficiencies to as high as 230 lumens/watt. See: Samuel Berman, "Energy and Lighting," *Energy Sources: Conservation and Renewables, (New* York, NY: American Physical Society, 1985).

58H. Geller, op. cit., footnote 46.

electronic ballasts, can help ensure that the light generated is neither excessive nor in unoccupied spaces. Finally, the controlled use of daylight, particularly with falters to keep out unwanted heat, can dramatically cut lighting needs in buildings. Combined, the use of a photocell or otherwise controlled dimmer that adjusts for daylighting or other lighting can reduce electricity use in many buildings by perhaps 35 percent or more without degrading lighting quality or quantity .59 Retrofits of the lamps and light fixtures at the U.S. Environmental Protection Agency building in Washington, DC recently allowed it to cut its lighting electricity use by 57 percent.[60]

Hardware is, however, only a part of the total consideration in developing an efficient, attractive lighting system. Lighting design must also include such factors as producing attractive displays for retailers and maintaining high productivity among office workers—avoiding glare, flicker and hum, and strobing on computer display screens (for the time when computers are as prevalent in developing-country offices as they are today in industrial countries) while providing sufficient light for employees to work efficiently. For a typical office in which wages are ***90*** percent and lighting electricity is 3 percent of operating costs, it makes little sense to reduce lighting by one-third-a l-percent savings—if it lowers worker productivity by 10 percent—a 9-percent cost. On the other hand, overlighting is also found widely and offers a substantial opportunity for savings. In Brazil, for example, overlighting of one-third or more has been found in a number of office buildings surveyed.[61]

Therefore, along with improved lighting hardware, careful attention is also needed to lighting design. Considerable savings, for example, may be possible by carefully and appropriately lighting the task—i.e., the desk—and reducing background lighting levels. Good lighting is design intensive; the importance of design should not be minimized. Design tools need to be further developed and widely disseminated so that developing countries can also take advantage of these opportunities.

As in other cases, even the most careful technical assessment of potential can be blunted when users fail to clean lamps, leave them running for longer hours than needed, or—in response to lower monthly electricity bills-add more lights. In some applications, consumers may also prefer to use incandescent lights for their warmer color or because the very short periods of use—such as in a closet--do not warrant the larger expense of a high efficiency light. Market costs for all lighting hardware that reflect the total capital and operating costs—including upstream capital investment in generation, transmission, and distribution facilities-will help to ensure that all choices of lighting equipment are more economically rational.

Improvements in lighting efficiency have a synergistic impact on other important uses of electricity such as air conditioning. In large buildings or residences cooled by air conditioning, every kW of lighting power saved cuts the needed air conditioning by as much as one-third kW.[62] Together, saving this 1.3 kW of electrical power reduces, for example, coal consumption at a rate of 4.5 kW or 0.63 kilograms (kg) per hour.[63] Reducing the lighting load will also reduce the size of air conditioner and related equipment needed, saving capital costs. Of course, in the winter the heat generated by lights can help warm the building and reduce space heating requirements. This is likely to be less important in most developing countries.

59Terry McGowan, op. cit. footnote 36; See&o: Y.J. Huang, B. Thom, B. Ramadan, ''A Daylighting Design Tool For Singapore Based on DOE-2.1C Simulations, '' *in Proceedings of the ASEAN Special Sessions of the ASHRAE Far East Conference on Air Conditioning in Hot Climates,* Kuala Lumpur, Malaysia, Oct. 26-28, 1989, Lawrence Berkeley Laboratory, Report. LBL-28639. Of particular importance in implementing effective daylighting systems is the development of high performance algorithms for controlling the daylighting system and of computer design tools for designing the office workspace. See: R.R. Verderber, F.M. Rubinstein, and G. Ward, ''Photoelectric control of Daylight-Following Lighting Systems, ' report No. CU-6243 (Palo Alto, CA: Electric Power Research Institute, 1989).

60Matthew L, Wald, ''E.P.A. Urging Electricity Efficiency, ' *The New York Times,* Jan. 16, 1991.

61Howard S. Geller, op. cit., footnote 46.

62One kW of heat input into a building from lights adds a load of 3,412 BTU/hour to the cooling load. For an air conditioning unit with an energy efficiency ratio—Btu per hour of cooling capacity divided by watts of electrical input-of 10.0, this demands an additional 3412/10= 341 W or one-third kW of power for cooling. Because the power required to move air through ducts increases as the cube of the flow velocity, there maybe further energy savings by reducing the flow rates necessary to cool the building when using efficient lighting.

63Assuming technical losses in transmission and distribution of 15 percent, a 1.34 kW load requires 1.58 kW of power to be generated. At an average generation efficiency of 35 percent, this requires burning 4.5 kW of coal, or 16 MJ/hour. At an average calorific value of 25.58 M.J/kg, this saves 0.63 kg of coal per hour.

Box 3-C—Development of Electronic Ballasts in the United States and Brazil

The Department of Energy established a Lighting Research Program at the Lawrence Berkeley Laboratory (LBL) in 1976. This program was to accelerate the introduction of new energy efficient lighting technologies in the marketplace. One of the frost technologies targeted was high-frequency electronic ballasts. Data showed that lamps operated at frequencies above 10 kHz were 15 to 30 percent more efficient; advances in transistor and switching power supply technologies and reductions in their costs during the 1960s and 1970s made such high frequency operation both possible and potentially cost-effective.

LBL looked for companies that would share development costs and who, if the project was successful, could manufacture the electronic ballasts for the marketplace. None of the major manufacturers of conventional core coil ballasts indicated any interest, but fourteen small entrepreneurial firms responded. LBL selected two firms in 1977. IOTA engineering proposed a low-cost nondimmable design; Stevens Electronics proposed a sophisticated, higher efficiency design that could adjustably reduce lamp light output by 90 percent. The first prototypes showed the 15-percent efficiency gain due to higher frequency lamp operation, and saved 10 percent more by reducing losses in the ballast compared to conventional core coil ballasts—a total efficiency gain of 25 percent. These savings were then confirmed in field tests in PG&Es main office building in San Francisco. These field trials also provided data on reliability that was then incorporated into the prototype design.

Despite the success of the trials, major U.S. ballast manufacturers showed little interest. Meanwhile, a number of small U.S. firms and, beginning in 1980, several foreign firms-Toshiba (Japan) and O.Y. Helver (Finland)--picked up on the LBL work and began manufacturing solid-state ballasts during 1980-84. In 1984 to 1986, major U.S. manufacturers such as General Electric, GTE, Advanced Transformer, and Universal Manufacturing entered the market. By 1986, one million solid state ballasts were sold annually in the United States and sales were increasing 60 percent per year.

The year 1985 witnessed the beginnings of the Brazilian effort to develop and produce solid-state ballasts. Researchers at the University of Sao Paulo tested potential designs and, with funding from the Sao Paulo State electrical utility, produced about 50 prototype units in 1986-87 that demonstrated performance comparable to electronic ballasts produced in industrial countries. The technology was transferred to a private company (Begli) in 1988 with subsequent scaleup of production and tests to 100 demonstration units, then 350 units, and finally mass production in 1990.

Several features of this case are important. The United States took the lead in initially developing and proving the technology. In part based on this work, Brazilian researchers could then move more quickly and with some confidence that their efforts would result in a workable design. Key elements in Brazil were a capable staff of research and development scientists and engineers that could effectively adapt a foreign technology to locally produced components and conditions; critical (and farsighted) early and long-term support from the Brazilian Government and electric utility; gradual and careful scaleup of production with detailed demonstrations and field testing; and effective technology transfer—at an early stage—to a private company for production and commercialization.

SOURCE: Howard Geller, Jeffrey P. Harris, Mark D. Levine, and Arthur H. Rosenfeld, "The Role of Federal Research and Development In Advancing Energy Efficiency: A $50 Billion Contribution to the U.S. Economy," *Annual Review of Energy* **Vol. 12, 1987, pp. 357-395; and Howard S. Geller, ''Electricity Conservation in Brazil: Status Report and Analysis," contractor report for the Office of Technology Assessment, November 1990, and to be published as "Efficient Electricity Use: A Development Strategy for Brazil, ' American Council for An Energy Efficient Economy, Washington, DC, 1991.**

Finally, energy, systemwide capital cost, and operating cost savings are also possible in street lighting and other lighting applications. High pressure sodium lamps, for example, have much higher efficiencies than other types of street lighting and, because of their longer lifetime, have lower maintenance costs as well.

Cost effective lighting technologies are available, but under the present institutional structure dividing responsibility for the supply and the use of electricity between the utility and the consumer, substantial inefficiencies arise in the consumer choice of end-use technology and in the allocation of capital between energy supply and end-use efficiency.

REFRIGERATION

Refrigerator ownership is at present quite low in most developing countries, but it is increasing rapidly. This rapid penetration is also occurring at much lower income levels than was the case in the

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Box 3-D—Lighting Efficiency Programs in Europe

Electric utilities in Sweden, Denmark, the Netherlands, and West Germany operated 40 residential lighting efficiency programs in late 1988/early 1989. These programs provided compact fluorescent lamps (CFLs) to consumers through a variety of means, including give-aways, rebates, wholesale discounts, tax breaks by governments, and by adding small monthly payments for the CFL to the consumer's electric bill.

These programs provided more than two million CFLs to the 4.9 million eligible households, accounting for 80 to 95 percent of all CFLs placed in use in the residential sector during that time. The average cost of these programs-including both the CFL and administrative costs-was equivalent to about $0.02 per kWh of electricity saved, much less than the cost of generating electricity. The most cost-effective programs were those that simply gave the CFL away for free and thus minimized administrative costs. By increasing the demand for CFLs, these programs also lowered the retail price for CFLs by 20 to 50 percent even after the programs ended.

Among program participants, two-thirds were satisfied with the brightness and color of the lamps, but more than half were dissatisfied with the lamp's appearance. Many had trouble fitting the CFLs to their existing lighting fixtures. Nonparticipants lacked interest or knowledge of the program, considered CFL prices excessive, or found the CFL too large or heavy for their needs. Many of these technical shortcomings are being addressed by manufacturers with the development of smaller CFLs, electronic ballasts, and other improvements.

SOURCES: Evan Mills, Agneta Persson, Joseph Strahl, "me Inception and proliferation of European Residential Lighting Efficiency Programs," in ACEEE 1990 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington, DC 1990; Evan Mills, "Evaluation of European Lighting Programmed: Utilities Finance Energy Efficiency," *Energy Policy*, April 1991, pp. 266-278.

Table 3-9-Cost and Performance of Commercial Lighting Improvements, Brazil

	Standard[a]	Efficient[b]
Performance	192 W	60 W
Power input		
Rated light output	10800 lm	*5000* lm
Useful light output	2260 lm	2100 lm
Capital costs	$ 9.70	$ 5.80
Lamps		
Ballasts	$33.30	$ 16.65
Reflectors		$33.95
Subtotal	$ 43.00	$56.40
Annualized capital costs . .	$ 12.66	$ 16.60
Annual energy use	507 kWh	203 kWh
Direct electricity use		
Air conditioning energy[c] . .	142 kWh	57 kWh
Total electricity use ... , . .	649 kWh	260 kWh
Utility Costs[d]		
Capital investment, ...	$296.00	$118.00
Annualized capital cost . . .	$23.85	$ 9.51
Annual electricity costs . . .	$35.70	$ 14.30
System wide costs		
Total annual capital cost. .	$36.50	$27.60
Total annual operating . . .	$48.36	$30.90

NA = Not applicable.
a Based on four 40 W tubes with conventional core-coil ballast in a standard fixture with completely exposed lamps.
b Based on two 32 W high efficiency tubes with a mirrored glass reflector. Useful output is so high because of: 1)the narrow 32 W tubestrap less light in the fixture; 2) the mirrored reflector increases useful light output.
c This is the amount of air conditioning power needed to remove the heat generated by the lights.
d utllity capital costs are set at estimated marginal prices as calculated in app. A. Electricity prices are set at prevailing Brazilian rates for large commercial users of $0.055/kWh.

SOURCE: Adapted from Howard S. Geller, "'Electricity Conservation in Brazil: Status Report and Analysis," contractor report to the Office of Technology Assessment, November 1990, tables 15 and 16; published as "Efficient Electricity Use: A Development Strategy for Brazil," American Council for an Energy Efficient Economy, Washington, DC 1991.

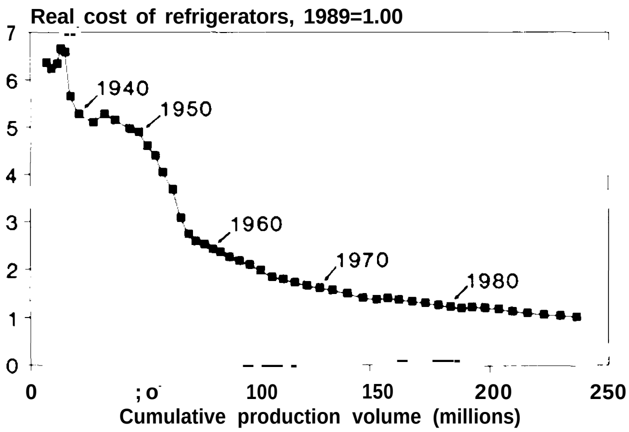
United States or other industrial countries due to the declining real cost of refrigerators as materials and manufacturing techniques have improved (see figure 3-1 1).

Refrigerators are typically not the first appliance acquired by a household when it gets electric service; lights are first, followed by refrigerators or other equipment depending on household income, region, and other factors (see figure 3-12). In India, fans are typically among the frost appliances acquired, followed by televisions and refrigerators. In Brazil, even relatively poorer, newly electrified households often have televisions and refrigerators, as these appliances are comparatively inexpensive and are available secondhand.[64]

The refrigerators used in developing countries are typically half the size of American refrigerators or less. They are also much less efficient than the best refrigerators now commercially available. (The average refrigerator used in the United States is similarly much less efficient than the best available).

[64] Gadgil and Jannuzzi, op. cit., footnote 37.

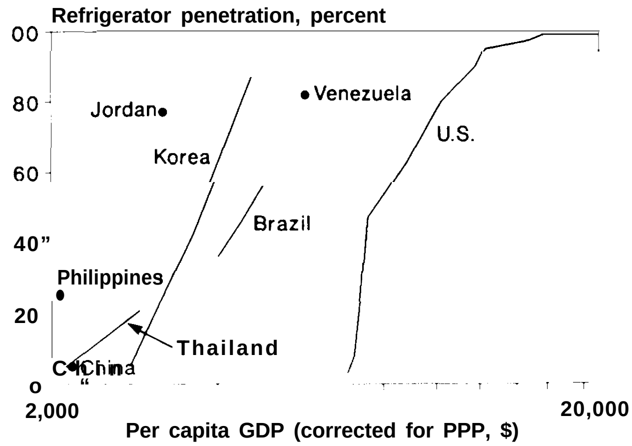
Figure 3-11 A—Reduction in the Real Cost of Refrigerators Over Time in the United States



Over the past 40 years, the real price of refrigerators has dropped by almost a factor of 5 (measured by the consumer price index for refrigerators divided by either the overall change in consumer price index or by the GNP deflator). For developing countries, such price reductions are allowing households to invest in refrigerators at a much earlier point in time than was the case for the United States and other industrialized countries at a similar level of development.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries.*

Figure 3-11 B—Nationwide Refrigerator Penetration Versus Per Capita GDP Corrected for Purchasing Power Parity



This figure shows that a much higher percentage of the developing-country households shown own refrigerators than did households in the United States at a similar level of economic development as measured by PPP corrected per-capita incomes. Note that the per-capita GDPs have been smoothed--otherwise the curves shown would reverse themselves during serious recessions-so that the curves are monotonic along the GDP axis.

SOURCE: GDP data is from: Angus Maddison, "The World Economy in the 20th Century," (Paris, France: Organization for Economic Co-Operation and Development, 1989); and Robert Summers and Alan Heston, "A New Set of International Comparisons of Real Product and Price Levels Estimates for 130 Countries, 1950-1985," *The Review of* **Income and Wealth, vol. 34, pp. 1-25, 1988. See especially the diskettes accompanying the article. Refrigerator penetration data for the United States is from: Donald W. Jones, "Energy Use and Fuel Substitution in Economic Development: What Happened in Developed Countries and What Might be Expected in Developing Countries?" Oak Ridge National Laboratory, ORNL-6433, August 1988; Refrigerator penetration data for the various developing countries shown is from: S. Meyers et al., "Energy Efficiency and Household Electric Appliances in Developing and Newly Industrialized Countries," Lawrence Berkeley Laboratory, LBL-29678, December 1990.**

In Indonesia, for example, most refrigerators are assembled locally from imported components and, in general, do not take advantage of proven energy efficiency features such as rotary compressors and increased insulation.[65] In many countries, popular models still use fiberglass insulation rather than better polyurethane foam.

The efficiency of refrigerators has improved in many countries in recent years. In the United States, energy consumption by the average new refrigerator dropped from about 1,700 kWh per year in 1972 to about 975 kWh by 1990, an efficiency improvement of about 3 percent per year.[66] Factors contributing to this efficiency improvement included:

- The technological push of low cost efficiency improvements such as shifting from fiberglass to polyurethane foam insulation, and the use of more efficient motors, compressors, and heat exchangers;
- the market pull generated by a more well informed public-mandatory efficiency labeling was instituted in 1980--faced with a 40 percent real increase in residential electricity prices between 1973 and 1984; and
- the regulatory shove of minimum efficiency standards first adopted in California in 1977 and nationally in 1987.[67]

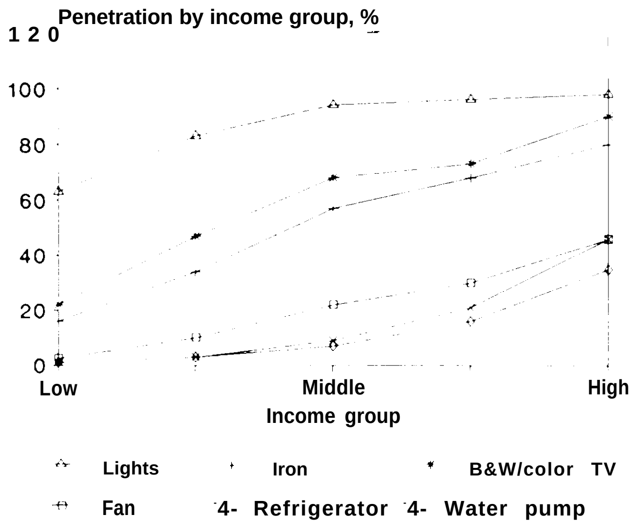
The energy consumption of the average new refrigerator in Brazil similarly dropped by almost 13 percent between 1986 and 1990, a rate of improve-

[65] Lee Schipper, "Efficient Household Electricity Use in Indonesia," Lawrence Berkeley Laboratory, Draft, January 1989.

[66] Association of Home Appliance Manufacturers, "Major Home Appliance Industry Fact Book, 1990191," Chicago, IL, 1991.

[67] Howard S. Geller, *Energy Efficient Appliances* (Washington, DC: American Council for an Energy Efficient Economy, June 1983); Howard S. Geller, American Council for an Energy Efficient Economy, "Residential Equipment Efficiency," contractor report prepared for the Office of Technology Assessment, May 1988.

Figure 3-1 2—Electric Appliance Ownership in Urban Java, 1988



This figure shows the rapid penetration and relative importance within household purchasing patterns of lights, TVs, irons, fans, refrigerators, and water pumps. Income groups (share of households) in ascending order are: less than 75,000 Rp/month (24 percent), 75-120 (22 percent), 121-185 (21 percent), 186-295 (14 percent), and greater than 295 (9 percent).

SOURCE: Lee Schipper and Stephen Meyers, "Improving Appliance Efficiency in Indonesia," *Energy Policy*, forthcoming.

ment of about 2.5 percent per year (see table 3-10).68 Brazilian manufacturers, however, are unable to make use of the very efficient motor-compressors in domestic refrigerators that Brazil manufactures and exports, as these units cannot readily tolerate the voltage fluctuations found in Brazil (but substantial improvements in refrigerator performance are never-

Table 3-lo-Progress in Improving the Efficiency of Refrigerators in Brazil

	Electricity consumption (kWh/year)		
Year	Best	Worst	Average
1986	440	570	490
1987	440	490	460
1988	440	490	460
1989	335	490	435
1990	335	490	435

For single-door 250 to 300 liter refrigerators

SOURCE: Howard S. Geller, "Electricity Conservation in Brazil: Status Report and Analysis," contractor report prepared for the Off ice of Technology Assessment, August 1990; published as "Efficient Electricity Use: A Development Strategy for Brazil," American Council for an Energy Efficient Economy, Washington, DC, 1991.

theless possible).[69] In South Korea, energy consumption by the average new refrigerator dropped by a remarkable 65 percent between 1980 and 1987, a rate of improvement of about 12 percent per year (see table 3-1 1).[70] The initial costs of achieving these efficiency gains have generally been small, and have been more than offset by savings in electricity bills.

In the United States, the failure of market forces alone to push the energy efficiency of refrigerators and other products sufficiently rapidly has led to enactment of laws mandating efficiency standards for 13 types of consumer products.[71] Different levels of technology for implementing these standards in an 18 cubic foot (510 liter)[72] top-mount automatic defrost refrigerator/freezer-the most popular design in the U.S. market with 73 percent of annual

68Howard S. Geller, op. cit. footnote 46.

69Howard Geller, Ibid.

70Stephen Meyers et al., op. cit., footnote 29. Note that these appliances are not strictly comparable in terms Of their actual power consumption. The Brazilian and South Korean refrigerators are just half the size of the average American refrigerator, and the features offered on these refrigerators differ significantly, with varying impacts on their energy consumption.

71These laws include: the Energy Policy and Conservation Act (Public Law 94-163) as amended by the National Energy conservation PO@ Act (P.L. 95-619), the National Appliance Energy Conservation Act of 1987 (P.L. 100-12), and the Appliance Energy Conservation Amendments of 1988 (P.L. 100-357). Note that although Law 95-619 required standards, the U.S. Department of Energy never issued them. Action has only begun with Laws 100-12 and 100-357. The 13 products covered are: 1) refrigerators and freezers, 2) room air conditioners, 3) central air conditioners and heat pumps, 4) water heaters, 5) furnaces, 6) dishwashers, 7) clothes washers, 8) clothes dryers, 9) direct space heating equipment, 10) kitchen ranges and ovens, 11) pool heaters, 12) television sets, and 13) fluorescent lamp ballasts. Other products can be included at the discretion of the Secretary of Energy. See: U.S. Department of Energy, *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators, Furnaces, and Television Sets*, report No. DOE/CE-0239 (Washington R : U.S. Department of Energy, November 1988); and U.S. Department of Energy, *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces*, report No. DOE/CE-0277 (Washington DC: U.S. Department of Energy, November 1989).

72Efficiency ratings for refrigerator/freezers are normally cited in the United States in terms of the refrigerators adjusted volume, given by the volume of interior refrigerated space plus the 1.63 times the interior volume of the freezer compartment. The refrigerator/freezer cited here has unadjusted volume of 20.8 cubic feet (590 liters).

73U S Department of Energy, *Technical Support* Document.. *Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces*, op. cit. footnote #71.

Table 3-1 l—Progress in Improving the Efficiency of Appliances Produced in Korea

Year	Refrigerator 200 liter (kWh/year)	Room AC 7,100 Btu/hr (Btu/hr-W)	Color TV 14 inch (W)
1980	672	7.6	82
1981	456	7.8	69
1982	336	8.4	55
1983	312	9.0	57
1984	288	11.0	54
1985	264	11.3	56
1986	240	11.3	62
1987	240	11.3	60

SOURCE: Stephen Meyers et al., "Energy Efficiency and Household Electric Appliances in Developing and Newly Industrialized Countries," Lawrence Berkeley Laboratory, report No. LBL-29678, December 1990.

Table 3-1 2—Description of Refrigerator/Freezer Technology Levels

Level	Description
A	Baseline-1 8 ft^3(20.8 ft^3 adjusted volume) refrigerator/freezer, side wall insulated with 2.2 inches foam in freezer, 1.9 inches foam in refrigerator; door insulated with 1.5 inches foam in freezer and 1.5 inches fiberglass in refrigerator; back insulated with 2.2 inches foam; Features include improved thermal seal gasket, antisweat switch, 4.5 EER[a] compressor, bottom-mounted condenser, auto-clef rest timer, 10 W evaporator, and 13.5 W condenser fans.
B	Baseline-Level A plus enhanced evaporator
c	Level B plus Door Foam Insulation
D	Level C plus 5.05 EER Compressor
E	Level D plus 2 inches door insulation
F	Level E plus more efficient evaporator and condenser fans
G	Level F plus 2.6 inches/2.3 inches side insulation and 2.6 inches back insulation
H	Level F plus 3.0 inches/2.7 inches side insulation and 3.0 inches back insulation
I	Level F plus evacuated panel (K=O.055)
J	Level I plus two compressor system
K	Level J plus adaptive defrost

a EER is the Energy Efficiency Ratio measured in terms of BTU/hr cooling output divided by watts of electrical power input.

SOURCE: *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces* (Washington, DC: U.S. Department of Energy, November 1989) publication DOE/CE-0277.

sales[73]—that does not use ozone damaging (CFCs)[74] (CFC-11, CFC-12) are listed in table 3-12 and shown in figure 3-13.75 Although this refrigerator is larger and has more features than those typically found in developing countries today, it will nevertheless be used here to demonstrate the potential of energy efficiency improvements because: the size and variety of features in refrigerators used in developing countries is increasing and will likely continue to increase in the future; and the relative impact of different technical options to improve refrigerator performance is similar.

The cost of this model refrigerator increases slowly as its efficiency is improved. Between the baseline-Technology A—and Technology H, for example, the energy consumption of the refrigerator decreases by one-third while its U.S. retail cost increases by just 12 percent. For consumers, this modest increase in cost nevertheless appears to be a very large barrier in practice. Studies of appliance purchases in the United States have shown that consumers behave as if there was a discount rate on refrigerators (and other consumer goods) of more than 60 percent.[76] That is, consumers do not buy more efficient refrigerators unless the energy saved pays for its higher first cost in less than about one and a half years, providing a net savings to the consumer for the rest of its typical 20-year life.[77] Indeed, consumers may often not even consider energy savings and may rarely actually compute the potential payback of more efficient models. In developing countries, higher first costs may prove to be an even larger barrier in practice, due to the lack of cash or access to credit.

Every time a consumer purchases a refrigerator, however, he or she commits the nation as a whole to a large investment in upstream power generation, transmission, and distribution equipment.[78] Pur-

74 L.E. Manzer, "The CFC-Ozone Issue: Progress on the Development of Alternatives to CFCs," *Science*, vol. 249, July 6, 1990, pp. 31-35.

75 This analysis is based on Department of Energy standard refrigeration testing procedures and simulations. There are indications that these testing procedures overestimate the usc of electricity in actual practice by 20 to 25 percent. This suggests that allocations of electricity use in residences may give too much weight to refrigerators and seriously underestimate certain other uses. See, for example: Michael Shepard, et al., *The State of the Art: Appliances*, (Snowmass, CO: Rocky Mountain Institute, August 1990).

76 Henry Ruderman, Mark D. Levine, James E. McMahon, "The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment," *Energy Journal, vol.* 8, No. 1, January 1987, pp. 101-124; Harry Chernoff, "Individual Purchase Criteria for Energy Related Durables: The Misuse of Life Cycle Cost,' *Energy Journal, vol. 4, No. 4,* October 1983, pp. 8 1-86; Malcolm Gladwell, "Consumers' Choices About Money Consistently Defy Common Sense,' *The Washington Post*, Feb. 12, 1990, p. A3.

77 Average lifetimes for refrigerators in the United States are 19 years. See: U.S. Department of Energy, *Technical Support Document." Energy conservation Standards for Consumer Products." Refrigerators and Furnaces,* op. cit., footnote *#71.*

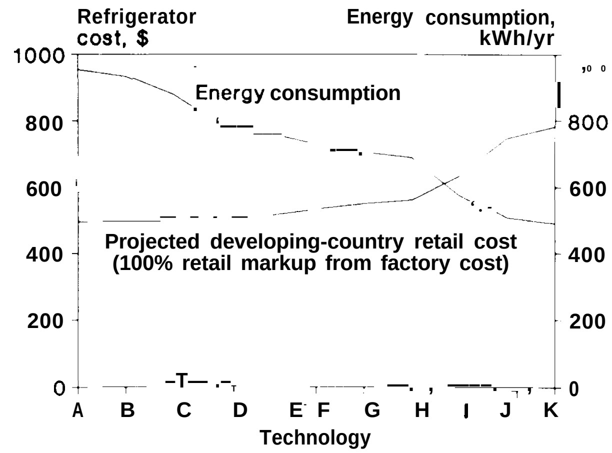
78 Note that this applies primarily t. Where new investments must be made or existing equipment is being retired and must be replaced.

chasing an inefficient refrigerator at a slightly lower cost to the consumer commits the nation to a larger investment in utility equipment. The total capital investment required per refrigerator is shown in figure 3-13. Although the cost to the consumer for the refrigerator increases, the total capital cost including the cost of electricity generating equipment decreases through technology "I' and remains slightly lower for the most efficient technology considered than for the baseline technology-which is still better than the technology found in most developing countries.

Similarly, the total operating cost to consumers (including the discounted first cost of the refrigerator and the cost of electricity) decreases steadily as the efficiency of the refrigerator is increased (see figure 3-1 3). Thus, purchasing the most efficient refrigerators examined here saves the consumer money over the lifetime of the appliance and saves the Nation both initial capital investment and fuel costs to power the refrigerator. This can free capital for investment in other critical development needs.

Yet further improvements are possible. The improvements listed in table 3-12 were chosen based in large part on whether or not U.S. appliance manufacturers could implement them in a 3 year period-by 1992/93. Over a longer time span, additional cost effective improvements may be possible.[79] In fact, more efficient commercial designs have already been developed. One U.S. company[80] now makes and commercially sells in small lots a refrigerator/freezer (18.5 ft^3 adjusted volume) that uses just 280 kWh/yr[81]--just over half the energy used by the most efficient design listed in table 3-12 and figure 3-13 (costs are high, however). Further improvements are also possible using better insulation—including various types of vacuum insulation,[82] electronic adjustable speed drives,[83] and other changes.

Figure 3-13A—Retail Costs and Energy Consumption for Technology Improvements in Refrigerators



Projected developing country retail costs are assumed to be marked up by 100-percent from the factory cost for each technology. This 100 percent markup is somewhat lower than the retail markups assumed by Lawrence Berkeley for the United States, but was chosen to be more representative of retail overheads in developing countries. Retail costs do not include any additional markup for taxes or tariffs.

SOURCE: See table 3-12 and app. A.

Much of the potential improvement in refrigerator performance can be achieved without resorting to high efficiency motor/compressor systems.[84] This is of interest in developing countries where large voltage fluctuations may limit the use of high efficiency motors.

[79] See, for example: David B. Goldstein, Peter M. Miller, and Robert K. Watson, "Developing Cost Curves for Consumed Energy in New Refrigerators and Freezers: Demonstration of *Methodology* and Detailed Engineering Results," Natural Resources Defense Council, San Francisco, CA, and American Council for an Energy Efficient Economy, Washington DC, Jan. 15, 1987.

[80] Sun Frost Co., Arcata, CA, cited in Michael Shephard et al., *The State of the Art: Appliances* (Snowmass, CO: Rocky Mountain Institute, August 1990).

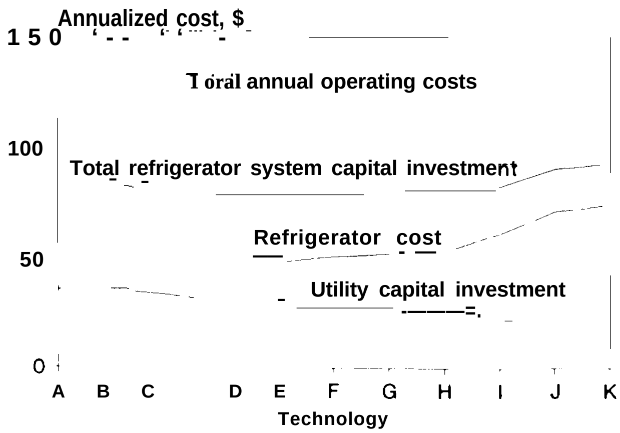
[81] Note that this is the company test procedure—not the standard Department of Energy test procedure—for 70 °F ambient temperatures; at a high 90 °F ambient temperature, the energy consumption is 365 kWh/yr. The refrigerator is also not strictly comparable to the other ones listed because it is manual rather than automatic defrost.

[82] Extensive research is now being done on soft vacuum panels con-g powder, aerogels, and hard vacuum panels, among others. *See*, for example, Michael Shepard et al. *The State of the Art: Appliances* (Snowmass, CO: Rocky Mountain Institute, August 1990).

[83] S. Zubair, V. Bahel, and M. Arshad, "Capacity Control of Air Conditioning Systems by Power Inverters," *Energy*, vol. 14, No. 3, 1989, pp. 141-151.

[84] *See*: U.S. Department of Energy, technical support document, "Energy Conservation Standards for Consumer Products: Refrigerators, Furnaces, and Television Sets," report No. DOE/CE-0239 (Washington DC: U.S. Department of Energy, November 1988); and U.S. Department of Energy, technical support document, "Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces," Report No DOE/CE-0277 (Washington, DC: U.S. Department of Energy, November 1989); and David B. Goldstein, Peter M. Miller, and Robert K. Watson, "Developing Cost Curves for Conserved Energy in New Refrigerators and Freezers: Demonstration of Methodology and Detailed Engineering Results,' Natural Resources Defense Council, San Francisco, CA and American Council for an Energy Efficient Economy, Washington DC.

Figure 3-13B—Refrigerator Retail Cost, Utility Capital Investment To Power the Refrigerator, Total System Capital Investment, and Total Annual Operating Costs for Different Refrigerator Technologies



This diagram shows that the total capital cost-including both the retail cost of the refrigerator in the developing country and the capital cost of utility investment in generation, transmission, and distribution equipment--decreases slightly with more efficient refrigerators until technology "E" is reached, whereupon it increases slightly. Technology "A" represents a more efficient refrigerator than most of those now sold in the U.S. market. Total annual operating costs, including the annualized capital cost of the refrigerator and the cost of electricity to power it, decrease with more efficient technologies until Technology "I" is reached. The total annual operating cost even with the most efficient and expensive refrigerator, technology "K", however, is substantially lower than that for the baseline technology '(A".

SOURCE: See app. A.

In this situation, electronic adjustable speed drives (ASDs) (see ch. 4) offer several additional opportunities, particularly as advances increase their reliability and reduce their cost. First, the ASD could be used to buffer fluctuations in line frequency and voltage and allow higher efficiency motors/compressors to be used. Second, if standard protocols can be agreed on, these ASDs could, at little additional cost, be programmed to be controlled by high frequency signals sent by the utility over the power lines or by other means. The utility, for example, might use this technique to cycle off a certain fraction of the refrigerators for short periods

Table 3-13-Commercial Refrigeration Efficiency Improvements

Technology	Energv savings
Glass doors	40-50%
Strip curtains	10-20% and more
Parallel unequal compressors	13-27%
Variable speed compressor control	NA
Evaporative pre-coolers	8-1 1% depending on climate
floating head pressure control	2-15%

SOURCE: A. Usibelli et. al., "Commercial-Sector Conservation Technologies," Lawrence Berkeley Laboratory Report No. LBL-18543.

in order to prevent blackouts or brownouts when large utility generating plants failed or peak demand was excessive. Such techniques are already in use in the United States with air conditioners and have proven cost effective even with retrofits. If such systems could be built into new refrigerators at little or no cost, this might be a useful means of improving power reliability in developing countries.[85]

Large cost-effective reductions in energy consumption are also possible with commercial refrigerators, particularly in the retail food industry. The *use* of glass doored rather than open refrigerator cases; improved glass doors and door seals (and the subsequent elimination of antisweat heaters); improved compressors; improved display lighting; and other improvements can significantly reduce electricity consumption (see table 3-13). Improvements primarily in the compressors of grocery store refrigeration systems alone have demonstrated overall electricity savings of about 23 percent and reduced peak demands by 30 percent.[86]

SPACE CONDITIONING

Space conditioning includes heating, cooling, and ventilating residential and commercial buildings in order to create more comfortable conditions. Space heating is important only in a few colder or mountainous areas in developing countries. An example is Northern China: nearly one-fifth of China's total annual coal and 5 percent of China's annual biomass consumption is used for space heating.[87] Residences rarely have any insulation and

[85]Samuel F. Baldwin, ' 'Energy Efficient Electric Motor Drive SystemS, " *Electricity: Efficient End Use and New Generation Technologies, and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989).

[86]D.H. Walker and G.I. Deming, *Supermarket Refrigeration Modeling and Field Demonstration*, report No. CU-6268, (Palo Alto, CA: Electric Power Research Institute, 1989).

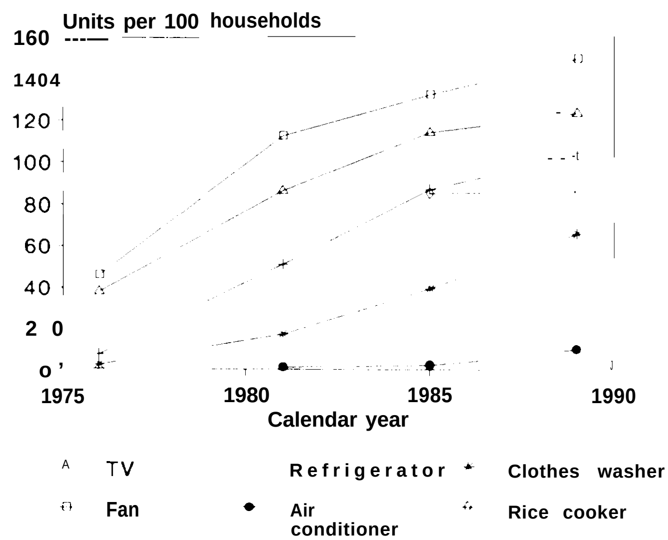
[87]Vaclav Smil, "China's Energy, " contractor report prepared for the Office of Technology Assessment, 1990.

often have large gaps around doors and windows.[88] Indoor temperatures in these homes are controlled not by a thermostat or by comfort requirements, but by fuel supply—and fuel, though cheap, is scarce. In Kezuo county, Northeast China, for example, average indoor temperatures are near the freezing point during the winter, compared to average outdoor temperatures of –3 °C to –5 ºC with lows of –25 °C. Additions to coal supply, more efficient stoves, or better wall insulation would thus result mainly in comfort improvements and not in energy savings.

Many developing countries have temperate climates year around that require little space heating or cooling. In Latin America, examples include Mexico City, Sao Paulo, Caracas, and Buenos Aires.[89] Nevertheless, large amounts of electricity may still be used for ventilation in the commercial buildings that use mechanical ventilation systems. Even with Sao Paulo's temperate climate, for example, roughly 20 percent of the total electricity use in all commercial buildings is for air conditioning; when buildings with central air conditioning are considered alone, air conditioning accounts for half of energy use.[90] Proper design of the air handling system—fans, ducts, controls, etc.—and careful choice of components can substantially lower both capital investment and/or energy consumption in these systems .91 These issues are examined in chapter 4 within the broader context of electric motor drive systems.

In hotter climates, air conditioning systems are desirable but are now found only in the highest income households in developing countries.[92] In contrast, most people in the United States who need it have air conditionering and, on a national average (including cool regions and buildings without air conditioning), use about 1,400 kWh per person per year to cool residential and commercial buildings.[93]

Figure 3-14—Appliance Ownership in South Korea



This figure shows the rapid increase in ownership of various appliances in Korea.

SOURCE: S. Meyers et al., "Energy Efficiency and Household Electric Appliances in Developing and Newly Industrialized Count ries," Lawrence Berkeley Laboratory, LBL-29678, December 1990.

The use of air conditioning or other cooling techniques is likely to grow rapidly in importance in most developing countries,[94] and may eventually dominate electrical energy use in the residential/commercial sector in the hottest and most humid countries. Already, active space ventilation by electric fans has become popular in many areas where there is reliable electric service and costs are affordable. In Korea, household fans have increased rapidly in number to the current level of 1.5 per household (see figure 3-14). Electric fan ownership in Beijing, China jumped from 47 percent of

88 Robert M. Wirtshafter, "Energy Conservation Standards for Buildings in China," *Energy,* vol. 13, No. 3, 1988, pp. 265-274; Robert M. Wirtshafter and Chang Song-ying, "Energy Conservation in Chinese Housing," *Energy Policy,* April 1987, pp. 158-168.

89 Andrea N. Kctoff and Omar R. Masera, "Household Electricity Demand in Latin America," *American Council for an Energy Efficient Economy, 1990 Summer Study on Energy Efficiency in Buildings* (Washington, DC: American Council for an Energy Efficient Economy, 1990),

90 Howard S. Geller, op. cit., footnote 46.

91 J. Barrie Graham, "Air Handling," *Technology Menu for Efficient End Use of Energy: Volume I, Movement of Material,* Environmental and Energy Systems Studies, Lund University, Lund Sweden, 1989.

92 Jayant Sathaye and Stephen Meyers, "Energy Use in Cities of the Developing Countries," *Annual Review of Energy* (Palo Alto, CA: Annual Reviews, Inc., 1985)

93 Adapted from Paul D. Holtberg, et al., *Baseline Projection Data Book: 1991 Edition of the GRI Baseline Projection of U.S. Energy Supply and Demand to 2010,* Gas Research Institute, Washington, DC 1991.

94 All 50 of the hottest cities in the world are in the developing world—the hottest is Djibouti, with an average annual high temperature of 113 F. None of the 50 coldest cities in the world are in the developing world (V. Showers, *World Facts and Figures* [New York, NY: John Wiley and Sons, 1979]).

households in 1981 to 77 percent in 1984.95 Households are effectively restrained from using electric air conditioning, however; electricity tariffs increase sharply for usage sufficient to support an air conditioner.[96] On the other hand, one-in-five households in Rio de Janeiro, Brazil, now has an air conditioner and typically uses 600-800 kWh/yr. In coastal Mexico, those with air conditioners typically use about 1,800 kWh/yr due to the long cooling season and the low efficiency of their systems.[97] In Thailand, air conditioning is projected to become the dominant demand over the next decade (see table 3-14).

In hot/humid climates with low quality construction of homes, electricity use for air conditioning can be much greater than these estimates if the desire for cooling is to be fully satisfied. A study of uninsulated concrete block homes in southern Florida found an average of nearly 8,200 kWh used per year for cooling, or 4.14 kWh per square foot of living space in the house.[98] Uninsulated concrete block construction is common in much of the developing world,

There are a variety of ways that ventilation/cooling needs can be met. First, external heat gain by the building can be minimized. Shade trees;[99] awnings that allow windows to receive indirect light but minimize the entry of direct sunlight that would heat the room;[100] exterior or interior shades; reflective or tinted coatings[101] on windows;[102] insulated windows;[103] light colored roofs; roof sprays; and wall and roof insulation[104] can each cut building heat gain. Natural ventilation and use of the ground for cooling can also be effective.

Table 3-14—Estimates of Electricity y Consumption, Bangkok

Appliance	Power (w)	Usage (hours)	Annual consumption (kWh)
Color TV	79	2,014	159
Refrigerator	109	5,760	628
Rice cooker	1,149	230	264
Clothes washer	1,567	91	143
Air conditioner:			
Window	1,815	1,442	2,617
Central	2,257	1,564	3,530
Ceiling fan	77	2,061	159
Water heater	4,418	54	239

SOURCE: Load Forecast Working Group, 1989, Thailand, as cited in: Stephen Meyers et al., "Energy Efficiency and Household Electric Appliances in Developing and Newly Industrialized Countries," Lawrence Berkeley Laboratory, report No. LBL-29678, December 1990.

Many of these techniques are used in traditional building styles and have proven highly effective.[105] Increasing urbanization and the use of commercial building materials have made some of these traditional practices less practical and less popular, however. Cramped urban areas often have fewer shade trees and less opportunity for natural ventilation, while suffering higher temperatures due to the urban ' 'heat island' effect. Sheet metal has often

95J. Sathaye, A. Ghirardi, and L. Schipper, "Energy Demand in Developing Countries: A Sectoral Analysis of Recent Trends," *Annual Review of Energy* (Palo Alto, CA: Annual Reviews,Inc., 1987), pp. 253-281.

'J. Sathaye et al., "An End Use Approach to Development of Long Term Energy Demand Scenarios for Developing Countries, " report No. LBL-25611 (Berkeley, CA: Lawrence Berkeley Laboratory, February 1989). Prices increase several times for usage above 80-100 kWh/month.

97Andrea N. Ketoff and Omar R. Masera, "Household Electricity Demand in Latin America, " *ACEEE 1990 Summer Study on Energy Efficiency in Buildings* (Washington, DC: 1990).

98Danny S. Parker, ' 'Monitored Residential Space Cooling Electricity Consumption in a Hot Humid Climate: Magnitude, Variation and Reduction From Retrofits," *ACEEE 1990 Summer Study on Energy Efficiency in Buildings* (Washington, DC: 1990).

99U.S. Department of Interior, National Park Service, *Plants/People/and Environmental Quality,* (Washington DC: U.S. Government Printing Office, 1972).

100Aladar Olgyay and Victor Olgyay, *Solar Control and Shading Devices,* (Princeton, NJ: Princeton University Press, 1957).

101Other coatings of particular interest are spectrally selective coatings that allow visible light to enter but keep infrared light out; photochromic coatings (like sunglasses) that become darker as light intensity increases; thermochromic coatings that become darker as temperatures increase; and electrochromic coatings whose transrnissivity can be adjusted using an applied voltage.

102Claes Goran Granqvist, *"Energy Efficient Windows: Options with present and Forthcoming Technology, " *Electricity: Efficient End Use andNew Generation Technologies, and Their Planning Implications* (Lund, Sweden: Lund University Press, 1989).

103 Ashok Gadgil et al., "Advanced Lighting and Window Technologies for Reducing Electricity Consumption and Peak Demand: Overseas Manufacturing and Marketing Opportunities, ' report LBL-30389 (Berkeley, CA: Lawrence Berkeley Laboratory, Mar. 29, 1991).

104Insulation must b. sized s. that it optimizes the tradeoff between g aining heat from outside versus losing internal heat to the outside.

105Lim Jee Yuan, "Traditional Housing: A Solution to Hopelessness in the Third World: The Malaysian Example," The *Ecologist, vol.* 18, No. 1, *1988,* pp. 16-23; Mehdi N. Bahadori, "Passive Cooling Systems in Iranian Architecture, ' *Scientific American,* vol. *238, 1978,* p. 144-154; R.K. Hill, "Utilization of Solar Energy for an Improved Environment Within Housing for the Humid Tropics, Division of Building Research, CSIRO, Victoria Australia 1974.

replaced thatch in urban as well as many rural areas-it is more durable, but also leads to higher interior temperatures. Good design in residential as well as in commercial construction can capture the cooling benefits of the above techniques while providing the durability and performance of modern construction materials. Simulation studies of good commercial building design in Brazil found that air conditioning electricity use could be reduced 60 to 75 percent by the use of these and other design features compared to conventional buildings.[106]

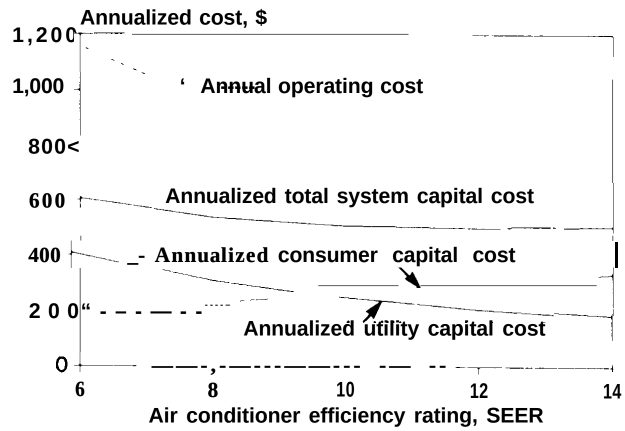
Even retrofits can be highly cost effective in some cases. Putting reflective plastic film on windows to cut heat gain, for example, can pay for itself in some climates in less than 2 years.[107]

Second, internal heat gains could likewise be kept low. This is accomplished in part by using the most energy efficient appliances-lights, refrigerators, ventilation fans, electronic equipment. Each unit of energy saved by using more efficient appliances can also reduce cooling energy requirements-where air conditioning is used—by 0.2 to 0.4 units of energy.

Third, high efficiency mechanical cooling equipment can be used. Variable-pitch fans and variable speed motor drives can increase the efficiency of ventilation equipment by one-third.[108] Direct and indirect evaporative coolers and absorption chillers can also be effective in some climates. Air-to-air heat exchangers can reduce heat loss/gain of ventilation air brought in from outside.[109] Gas fried absorption chillers and engine driven chillers can be useful on large buildings.

Conventional electric powered air conditioning equipment is also increasing in efficiency and becoming more widely available. Between the late 1970s and mid- 1980s, air-and water-cooled centrifugal chillers in the United States improved their energy efficiency ratings from averages of 7.5 to a best of 10 and from 13 to a best of 17-19, respectively.[110] Electronic adjustable speed drive systems have proven very effective in air conditioning units, reducing energy use by 25 percent over conventional fixed speed systems. Adjustable speed AC systems now account for over half the Japanese air conditioning market with sales of more than one million units annually.[111] In addition to large energy savings, advantages of these adjustable speed systems include: better capacity control; better temperature and humidity control; longer lifetime; reduced maintenance; and others. As discussed above for refrigerators, the use of an electronic adjustable speed drive in an air conditioner may also allow the use of higher efficiency motors where voltage and

Figure 3-15A—Annualized Consumer, Utility, Total, and Consumer Operating Costs for Different Levels of Air Conditioner Efficiency Rating (SEER)



This figure shows that the annualized cost of more efficient air conditioners increases for consumers but the corresponding annualized cost of utility generation, transmission, and distribution equipment to power these air conditioners falls a little faster for the assumed intensity of use. The total annual operating costs for the consumer decrease substantially with the more efficient air conditioner.

SOURCE: See app. A for the 8,000 kWh annual cooling power case.

[106] Howard S. Geller, op. cit., footnote 46.

[107] A west window can gain up t. 200 Btu/hr per square foot in the late afternoon. A reflective plastic film for windows can reduce this heat gain by 80 percent at a cost of $2.00 per square foot. This saves 23 W of air conditioning power for a system with an SEER of 7.0 (0.8x200/7=23 W). If there are 3 hours of sun on this window for 6 months of cooling season per year, then it saves 3x182x0 .023kWx$0.09/kWh=$ 1.13/year. Window gain and costs for plastic films from: American Council for an Energy Efficient Economy, "Residential Conservation Power Plant Study: Phase I—Technical Potential." op. cit. footnote #27.

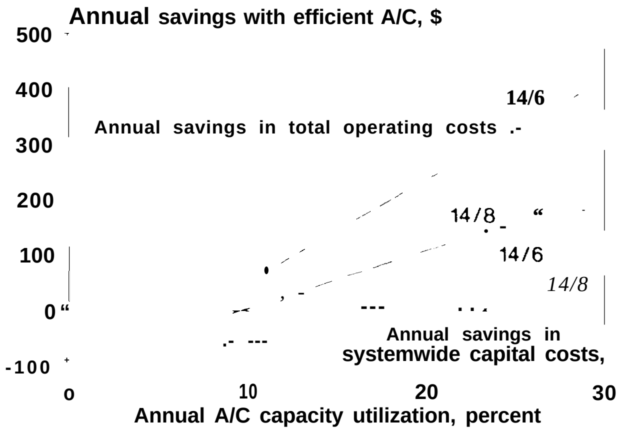
[108] Samuel F. Baldwin, "Energy Efficient Electric Motor Drive Systems," *Electricity : Efficient End Use andNew Generation Technologies, and Their P/arming Implications* (Lund, Sweden: Lund University Press, 1989).

[109] Edward Vine, "Air-To-Air Heat Exchangers and the Indoor Environment," *Energy vol. 12, No. 12, 1987,* pp. 1209-1215.

[110] Howard S. Geller, "Commercial Building Equipment Efficiency: A State-Of-The-Art Review," contractor report prepared for the Office of Technology Assessment, May 1988.

[111] S. Zubair, V. Bahel, M. Arshad, "Capacity Control of Air Conditioning Systems by Power Inverters," *Energy,* vol. 14, No. 3, 1989, pp. 141-151.

Figure 3-15B—Cost Effectiveness of an Efficient Air Conditioner for Different Levels of Annual Usage



This figure shows that the cost effectiveness-both systemside capital costs and total (capital plus power) operating costs--of an efficient air conditioner increases as annual usage increases. Shown is the comparison of a high efficiency SEER 14 air conditioner with one that has a low SEER of 6 and one that has an average SEER of 8. For the high efficiency air conditioner to cease being cost effective on a lifecycle basis, it must be used at less than 10 percent of its annual capacity (this does not directly translate into annual days of cooling due to air conditioner cycling). Air conditioner costs do not include taxes or tariffs.

SOURCE: See app. A for parameters.

frequency fluctuations in the power line would otherwise cause the high performance system to stall and burn out. Other possible improvements include larger heat exchangers, improved control systems, occupancy sensors, and others.[112]

The range of efficiencies of air conditioners now available in the United States is quite large, For room air conditioners, the average energy efficiency rating (EER) is ***8 with*** a best of 12; for central air conditioners, the average sold in 1988 had an SEER (seasonal EER) of 9 with the best on the market at 16.9—nearly twice as efficient as the average.[113]

High efficiency systems are, or could be, available in most developing countries. The most efficient room air conditioner sold in the United States in 1989 was assembled in Brazil using an imported rotary compressor. If such rotary compressors were similarly used in air conditioners sold in Brazil, they could reduce electricity consumption by 20 to 40 percent.

As shown in figure 3-15, the capital cost to consumers for more efficient air conditioners rises significantly. From a societal perspective, however, this increased cost to consumers is usually (depending on the amount of cooling time, etc.) offset by the decrease in the cost of utility generation, transmission, and distribution equipment needed to power it. For systems in hot and/or humid areas that operate more of the year, the total system capital cost significantly decreases for more efficient systems.[114] The total annual operating cost to the consumer also decreases for the more efficient system.

Similarly, in the commercial sector, numerous technologies have been developed to reduce the energy consumption of space cooling; some of these are listed in table 3-15.[115] Although they do not save much energy directly,[116] thermal storage systems can store ‘ ‘cold’ ‘ in building concrete walls, in water, in ice, or in other media during the night for use during the heat of the day. This reduces the peak load on electric utilities, reducing the need for expensive peaking capacity.

Although improvements in the air conditioner itself usually reduce capital costs and life cycle operating costs, building insulation, shading devices, insulating windows, and numerous other improvements described above can often be even more cost effective. For example, high efficiency windows[117] can reduce annual heat gain by a building in, for example, Thailand by an average of some 180 kWh per square meter of window at an

[112] Stephen Meyers et al., "Energy Efficiency and Household Electric Appliances in Developing and Newly Industrialized Countries,' draft report No. LBL-29678 (Berkeley, CA: Lawrence Berkeley Laboratory, October 1990).

[113] American Council for an Energy Efficient Economy, *The Most Energy Efficient Appliances: 1989 to 1990 Edition* (Washington, DC: American Council for an Energy Efficient Economy, 1990).

[114] Note that this cited decrease in capital cost with operating time is based on the highly conservative assumption that the capital cost of electricity generating equipment is considered only when it is being used to power the air conditioner, while the capital cost of the air conditioner is fixed irrespective of operating time. See app. A at the back of this report for details.

[115] A. Usibelli et al., "Commercial Sector Conservation Technologies, " report No. DE-AC03-76SFOO098 (Berkeley, CA: Lawrence Berkeley Laboratory, February 1985); American Gas Association, "1988 Commercial Gas Cooling Fact Sheet and Market Assessment Summary," issue brief 1988-15 (Arlington, VA: Nov. 4, 1988).

[116] In fact, they could increase total energy consumption.

[117] Argon filled, spectrally selective double pane window.

Table 3-15-Commercial Space Cooling Equipment Technologies

Technology	Percent reduction in cooling energy demand	
High efficiency mechanical cooling		
Small, air cooled	20-50	
Water cooled	10-25	
Absorption chiller	10-50	
Part load COP improvement	15-30	
Gas fired absorption chillers	100	of electricity
Adjust evaporator/condenser temperatures	3-1o	
Outside air economizers	15-80	depending on climate
Direct and indirect evaporative cooling	5-50	depending on climate
Cooling tower	0-1o	
Off peak ice/chilled water storage	0	but reduces peak load
Mass storage and night venting	NA	
Dessicant cooling systems	NA	
Roof insulation	NA	
Light-colored roofs	NA	
Roof-spray cooling	NA	
Heat removing light fixtures	NA	
Air-to-air heat exchangers	NA	
Technology	**Percent reduction in ventilation energy demand**	
Variable air volume systems	18-80	
Fan shutoff during unoccupied hours	60	
Motion/sensor control of ventilation	17-40	
Energy efficient motors	3-11	
Variable speed electronic motor drives	10-40	

NA =Not available.

SOURCE: A. Usibelli et al., "Commercial-Sector Conservation Technologies," Lawrence Berkeley Laboratory, LBL-18543, February 1985.

incremental cost of $7 per square meter, compared to conventional uncoated single pane glass. For typical air conditioner efficiencies, this avoids the use of 60 kWh of electricity per year for cooling.[118] Corresponding annualized capital costs are an incremental $0.56 for the high efficiency window, which is offset by a four times greater capital savings of $2.20 in reduced investment in utility generation, transmission, and distribution equipment, not including the smaller air conditioner this makes possible. Similarly, building insulation can be extremely cost effective.[119]

ELECTRONIC EQUIPMENT

Electronic equipment has become a significant consumer of power in the commercial sector of industrial countries in recent years as personal TUs computers, photocopiers, facsimile machines, and others have gained importance. Studies in the United States have found miscellaneous loads on receptacles within offices—primarily due to the use of various types of electronic equipment-to range from 9 to 24 W per square meter of office floor space (W/m^2) with an average of 17 W/m^2. The corresponding power demand for lighting was 19 W/m^2. A second case study in the United States found lighting loads in an office building to average 16 W/m^2 from 8am to l0 pm during weekdays and drop to near zero at night and on weekends, while office equipment averaged 12 W/m^2 during the day, but only dropped to 6 W/m^2 at night and on weekends as much of it was left on—usually unnecessarily. A study in Australia similarly found a range going as high as 66 W/m^2 with an average of 15 W/m^2.[120] Electronic equipment such as televisions and stereos are also important end uses for electricity in the home. Although the corresponding demands for power by electronic equipment are currently far lower than this in developing countries, these loads

[118] Ashok Gadgil et al., "Advanced Lighting and Window Technologies for Reducing Electricity Consumption and Peak Demand: Overseas Manufacturing and Marketing Opportunities,' report No. LBL-30389 (Berkeley, CA: Lawrence Berkeley Laboratory, Mar. 29, 1991).

[119] See, for example: Kuwait Institute for Scientific Research, *Economics of Thermal Insulation in Hot Climates* (Kuwait, August 1982).

[120] L. Norford et al., "Electricity Use In Information Technologies," *Annual Review of Energy, vol. 15,* 1990, pp. 423-453.

Table 3-16-Energy Use by Display Technologies

Display	Approximate power demand watts/cm²
Monochrome CRTs	0.06
Color CRTs	0.13
LCD, nonbacklit	0.004
LCD, backlit	0.03
Electroluminescent	0.02
Plasma	0.02

SOURCE: L. Norford et. al., "Electricity Use In Information Technologies," *Annual Review of Energy, vol.* 15, pp. 423-453, 1990; Michael Shepard, "The State of the Art: Appliances, " Rocky Mountain Institute, Snowmass, CO, 1990,

can be expected to markedly increase in the future. Appropriate planning in developing countries for efficient electronic equipment now could save substantial capital investment in the electric supply sector in the future.

Electronic equipment is usually chosen on the basis of performance and cost rather than on its electric power requirements. In recent years, however, the proliferation of high performance, low power equipment such as laptop computers makes it possible to also consider energy consumption when choosing electronic equipment. The power requirements of this equipment is substantially reduced through a variety of means—the use of CMOS [121] integrated circuits, liquid crystal displays (see table 3-16), and various power management techniques. Measured electric power consumption for some of the most popular types of electronic equipment are given elsewhere.[122]

A variety of energy efficiency improvements in electronic equipment may quickly pay for themselves--both from the society perspective of systemwide capital investment and from the consumer perspective of life cycle cost. Improvements in the energy efficiency of TVs in South Korea is shown in table 3-1 1; cost and efficiency data for modest efficiency improvements in color TVs in the United States are shown in tables 3-17 and 3-18. Table 3-18, for example, shows that a 2-percent increase in factory unit costs of more efficient color TVs can yield energy savings of up to 17 percent, Corresponding calculations of systemwide capital and life cycle costs are shown in appendix A.

Much larger improvements may be possible. For example, laptop computers use less than one-tenth the power of desktop machines. Although the current premium of as much as $500 or more for a laptop compared to a desktop could only be justified on the basis of systemwide capital costs or life cycle costs if the machine were left on virtually 24 hours per day[123] (as some offices do), many of these energy saving design features could be incorporated into a desktop machine at much lower costs. Timers or occupancy sensors could also reduce this energy consumption significantly.

BARRIERS TO CONSUMER PURCHASE OF' ENERGY EFFICIENT APPLIANCES

Energy efficient appliances are often highly cost effective: their higher initial cost is more than offset by lower electricity bills over their lifetime. Further, the higher initial cost of efficient appliances to consumers ignores the upstream cost savings in capital equipment to generate the power needed to operate them. From a system and societal perspective, energy efficient appliances often cost less in capital and less to operate. Yet consumers frequently fail to take advantage of these opportunities. A variety of reasons for this have been summarized in table 3-5; a few of these issues are presented below: 124

- Consumers may not have access to information about the costs and benefits of energy efficiency,
- Consumers often do not have market access to high efficiency appliances.
- In many cases, consumers may effectively require savings of greater than a certain threshold value before they will make the effort to

[121] CMOS means Complementary Metal Oxide Semiconductor

[122] L. Norford et al., ' 'Electricity Use In Information Technologies, ' *Annual Review of Energy, vol. 15, 1990* pp. 423-453.

[123] For example, comparing a laptop consuming 16 W to a desktop AT computer using 166 W, the difference in Power consumption of 150 W has an annual upstream capital cost of about $50 and an annual electricity consumption of $120. Over a 5 year period at a 7-percent real discount rate, these costs have a present value of about $700, or $200 more than the premium on the typical namebrand laptop today.

[124] Sources: U.S. Department of Energy *Technical Support Document, Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces,* report No, DOE/CE-0277 (Washington, DC: U.S. Government Printing Office, November 1989). Henry Ruderman, Mark D. Levine, and James E, McMahon, "The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment, ' *The Energy Journal,* vol. 8, No. 1, January 1987, pp. 101- 124; Malcolm Gladwell, ' '*The Washington Post,* Feb. 12, 1990, p. A3.

Table 3-17—Power Demand by Color TVs

Size (inches)	Power (watts) White	Black	Standby	Annual energy consumption
13"-14"	69	42	0.0	122 Mechanical off/on
13"-14"	69	48	4.9	161 kWh electronic off/on
19"-20"	100	60	4.4	205
26"-27"	134	87	6.2	284

SOURCE: U.S. Department of Energy, "Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators, Furnaces, and Television Sets," National Technical Information Service, Springfield, VA, November 1988, see p. 3-60, table 3-28.

Table 3-18-Cost and Efficiency Data for 19-20 inch Color TV Sets

Level	Design option	Factory unit cost	Energy consumption
0	Baseline (100/60W)	$158.00	205 kWhr/yr
1	Reduce standby power to 2W.	$160.15	184
2	Reduce screen power by 5 (93/55W)	$161.45	176
3	Increase display efficiency (91/53W)	$161.75	171

Baseline: Electronic tuning with standby power of 4.4 W; white picture/black picture of 100 W/60 W.

SOURCE: U.S. Department of Energy, "Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators, Furnaces, and Television Sets," National Technical Information Service, Springfield, VA, November 1988, see p. 3-60, table 3-29.

locate and purchase a more efficient appliance. Individually these savings may be small, but to society overall they may sum to a very large benefit. Higher efficiency appliances may also have an excessively large premium-they might be loaded with unnecessary extras or be used to subsidize the cost of less efficient models.

- Consumers--even when they are aware of the advantages of higher efficiency appliances—tend to be extremely sensitive to the first cost of an appliance. In developing countries, this sensitivity to frost cost may be even greater: consumers may simply not have access to the additional capital needed for a more efficient appliance.
- Consumers may have their electricity costs heavily subsidized. On average, the cost of electricity to consumers in developing countries is just 60 percent of the cost of producing it.[125]
- Consumers are often not the ones who purchase the appliances that they use. The 'building contractor or landlord often purchase the appliances used in the building and base their choice on lowest first cost rather than life cycle operating costs. Their tenants, not they, must pay the cost of operating this inefficient equipment.
- Consumers do not directly see the high upstream cost of capital equipment to power their inefficient appliances. While consumers face high interest rates, utilities can borrow at commercial (or better) interest rates over typically a 30-year period.
- Many consumers purchase secondhand goods where energy efficiency information is unavailable, and efficiency is not usually considered. Correspondingly, consumers who plan to sell their used appliances, knowing that they cannot get a premium for a more efficient appliance, may initially choose a less efficient design.

Together, these market failures or inefficiencies pose a powerful barrier to the rapid adoption of more efficient residential and commercial energy technologies.

POLICY RESPONSES

Numerous policy responses have been used in both industrial and developing countries to deal with the market failures listed above and in table 3-5. A variety of these policy responses are summarized in

125A. Mashayekhi, World Bank, Industry and Energy Department, ' 'Review of Electricity Tariffs in Developing Countries During the 1980s,' Industry and Energy Department working paper, *Energy Working Paper No. 32,* November 1990.

Box 3-E—The Brazilian PROCEL Program

The Brazilian Government established PROCEL--a nationwide electricity conservation program-within Eletrobras—the national utility holding company—in 1985. PROCEL funds or otherwise supports activities at utilities, universities, private manufacturers, and elsewhere within Brazil. These activities include:

- Research and Development—more energy-efficient technologies-refrigerators, lights, motors, controls, etc.;
- Education and information programs-testing the efficiency of equipment and labeling it in the marketplace, conducting energy audits of industries and commercial buildings, and promoting energy efficiency through publications and public events;
- Financial Assistance and Direct Installation programs-providing low-interest loans or directly installing more efficient equipment, such as street lights; and
- Setting standards for equipment efficiency—such as refrigerators (a 5-percent annual increase in average efficiency is now required for new models produced between 1994 to 1998 on top of the best performance currently achieved), and lights (standard incandescent are to be phased out in favor of more efficient incandescents and compact fluorescent, among other improvements).

Total cumulative funding of PROCEL reached $20 million by 1990 with perhaps an equal amount from State and local utilities and other organizations. The more than 150 projects funded had resulted indirect savings of 1,000 gigawatt/hour/yr (GWh) by 1989, allowing utilities to defer at least $600 million in new generating capacity. This is a return some 15 times greater than total investment.

As a result of these successes, the PROCEL program was planned to expand to nearly $35 million in funding during 1990. Even this large sum is less than 1 percent of current annual utility investment. Long term goals are to save 10 percent of national electricity use by 2000 and 14 percent by 2010, equal to 88 Terawatt/hour (TWh)-the equivalent of nearly half of total Brazilian electricity consumption in 1988.

SOURCES: Howard S. Geller and JoseR.Moreira,"Brazil's National Electricity Conservation Program (Procel): Progress and Lessons,' paper presented at the Conference, "DSM and the Global Environment" Apr. 22-23, 1991, Arlington, VA.; and Howard S. Geller, "Efficient Electricity Use: A Development Strategy for Brazil,'American Council for An Energy Efficient Economy, Washington, DC, 1991.

table 3-6, and a few of them are discussed in more detail below. One should carefully note, however, some of the potential problems of State intervention in the marketplace (see table 3-7). Examples of policies that have been implemented in Brazil are discussed in box 3-E.

The United States and other industrial countries could take the lead in developing efficient technologies, offering large scale markets within which manufacturing costs can be brought down, and in generally proving both the concept and the potential for savings (see box 3-F).

If these technologies are Frost developed and proven in industrial countries, widespread distribution of information to potential developing country users is then more readily possible and networks for distributing the technologies can be more easily established. In many cases, however, some local adaptation of the technology may be necessary—such as making the technology more robust in the presence of large voltage fluctuations. National or regional centers of excellence might play an important role in adapting these technologies to local conditions or in developing new technologies (see box 3-B). Such centers have played a central role in improving agricultural productivities in many developing countries and are particularly noted for their role in the ' 'green revolution.

Regional or national centers of excellence might also perform such tasks as establishing standard methodologies for measuring and comparing equipment efficiency; developing ''scorekeeping' techniques for determining energy savings in the field; collecting data; conducting field energy audits or extension; and other activities, in addition to technology adaptation or more basic research, development, and demonstration.

These activities may be made easier by following the lead of the industrial countries, but they can also be done independently of the industrial countries. Brazil, Korea, Taiwan, China, and a number of other countries have shown the potential for independent energy efficiency activities.

Box 3-F—The Appliance Industry: Obstacles and Opportunities in Manufacturing Efficient Appliances

The appliances sold in developing countries vary from finished goods imported ***from*** overseas, to "kits" assembled from mostly imported components, to largely locally manufactured components and finished products. The terms under which these appliances are made vary as widely, from wholly owned foreign subsidiaries, to products made under license to foreign firms, to small local entrepreneurs with few foreign components or technological inputs. Limits on the efficiency of locally assembled or manufactured appliances may range from inability to get license agreements at sufficiently attractive terms to high import duties.

One of the most effective means of improving appliance efficiency is to work with manufacturers directly. In many developing countries, manufacturers produce appliances based on technology many years behind the state-of-the-art found in the industrial countries: they are often able to get this obsolete technology at relatively low cost from leading-edge manufacturers who, in turn, could not earn much additional return on the technology except by selling or licensing it to developing countries where markets maybe less discriminating. In some cases, import tariffs may prevent the use of high efficiency components or equipment at the (unrecognized) cost of even greater imports of utility generating equipment.

By assisting licensing of high-efficiency technologies, by joint ventures, or by other means including adjustment of import duties on high efficiency components, developing countries might gain better access to these technologies and substantially reduce total systemwide capital requirements when utility investment is considered. Joint ventures between international and Thai manufacturers have enabled them to improve the energy efficiency of their refrigerators, but import tariffs largely prevented the use of high efficiency rotary compressors until 1990. The drive to manufacture for export markets has also played an important role in the Thai effort to improve the quality and efficiency of the refrigerators and other appliances that they manufacture.

Governments and research institutes can also work directly with domestic manufacturers. Funding from the State utility enabled researchers at the University of Sao Paulo to develop high efficiency solid state ballasts for fluorescent lights and transfer the technology to a private company for manufacturing (box 3-C). The Brazilian Procel program has worked with private manufacturers to establish voluntary energy efficiency protocols for refrigerators, lamps, ballasts, and motors.

SOURCES: S. Meyers et al., "Energy Efficiency and Household Electric Appliances in Developing and Newly Industrialized Countries," Lawrence Berkeley Laboratory, LBL-29678, December 1990; Howard S. Geller and Jose R. Moreira, ' 'Brazil's National Electricity Conservation Program (Procel): Progress and Lessons, " paper presented at the Conference, "DSM and the Global Environment,' Apr. 22-23, 1991, Arlington, VA.

Many, if not most, energy efficient technology development activities are best done by the private sector. These can be done either independently—spurred by national initiatives--or as joint ventures or in other forms of partnerships between manufacturers in the developing and industrialized countries. Means of encouraging these partnerships need to be explored.

In many developing countries, electricity prices paid by residential and commercial users are far below supply costs, with the difference made up by government subsidies. Raising prices would encourage the adoption of energy efficient appliances, as well as improving the government budgetary situation. Raising electricity prices, however, is a difficult political issue, High efficiency equipment may offer a way out of this dilemma. If more efficient equipment could be introduced at the same time as higher prices, the cost of energy services to consumers need not increase nearly as much, if at all.

Higher prices alone are often insufficient to ensure full utilization of cost effective energy efficient technologies because of the market failures described in table 3-5. Even the United States, where electricity prices are much closer to long run supply costs, has reinforced the price effect with mandatory efficiency standards for a variety of appliances.

Finally, and perhaps most importantly, means of better reflecting total societal costs in consumer investment decisionmaking could be explored. Currently, the capital costs of generation equipment are paid by the utility and the capital costs of end-use equipment are paid by the end user. As shown above, the high implicit discount rate of the end user as well as this separation between utility and user (or for leased equipment, the separation between owner and

Box 3-G—Integrated Resource Planning[1]

Conceptually, Integrated Resource Planning[2] (IRP) is straightforward. Planners rank by cost all the different energy supply and energy end use technologies that might be used to provide an energy service, and implement them beginning with the lowest cost opportunities. Thus, various electricity supply technologies such as conventional coal plants, steam-injected gas turbines, and combined-cycle plants are compared with each other and with end-use technologies such as compact fluorescent lights, adjustable speed electronic drives for motors, and increased insulation in buildings to reduce air conditioning loads. Of all the different possibilities, the lowest cost options are chosen for investment.

The manner in which energy institutions are organized, however, has not encouraged the implementation of integrated resource planning. Under the traditional regulatory framework found in most countries, utilities are in the business of selling energy supplies, not energy services. Each kiloWatthour (kWh) sold by an electric utility increases gross earnings, no matter how much it costs to generate; conversely, each kWh saved by using an energy efficient technology decreases earnings, no matter how little it cost to implement.[3] Similarly, displacing utility generated power with purchases of power from nonutility sources such as industrial cogeneration usually reduces utility earnings. These considerations often hold even where electricity costs are heavily subsidized-the State simply replenishes utility funds while utility managers and workers are rewarded in terms of job security, increased salaries or staffs, etc. for the amount of electricity generated, irrespective of its cost and usefulness.

In contrast, Integrated Resource Planning changes the regulatory framework in order to encourage utilities and others to implement the least-cost demand and supply options, Among other changes, regulators allow utilities to earn income based on the net benefits from investments in energy efficiency improvements. This focuses the financial, managerial, and technical skills of the utility on some of the market failures on the demand side (table 3-E) and helps realize some of the most important policy responses (table 3-6), especially the capital cost-related ones.

Factors that should be considered in IRP programs include: providing appropriate financial rewards for utilities to support efficiency improvements as well as supply-decoupling utility profits from the number of kWh sold—in order to minimize the overall cost of supplying energy services; ensuring that the startup costs of the IRP program and the administrative complexity and overheads are kept to a minimum; developing adequate methods for ‘‘measuring’ savings (also known as scorekeeping); avoiding the ‘‘free rider’ problem and others.

Numerous utilities in the United States have begun to implement Integrated Resource Planning Programs. In developing countries, the efforts in IRP have generally been much more limited to date. One exception, however, is the PROCEL program in Brazil (see box 3-E). Shown in figure 3-16 is a supply curve of the equivalent cost of energy of different end-use technologies in Brazil. Based on such a supply curve, the utility planner can tailor programs to maximize the utility return-on-investment in energy efficiency improvements.

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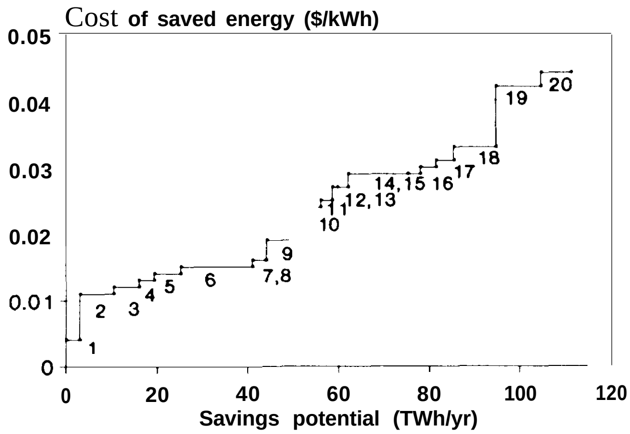
[1] Sources and further reading: David Moskovitz, “Profits and Progress Through Least-Cost Ptanning,” National Association of Regulatory Utility Commissioners, Washington DC, November, 1989; Jonathan Koomey, Arthur H. Rosenfeld, and Ashok Gadgil, “Conservation Screening Curves to Compare Efficiency Investments to Power Plants,” *Energy Policy,* October 1990, pp. 774-782; Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams, *Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications,* (Lund, Sweden: Lund University Press, 1989); Howard S. Geller, “Efficient Electricity Use: A Development Strategy for Brazil, ’ contractor report for the Office of Technology Assessment, (Washington DC: American Council for an Energy Efficient Economy, 1991); *Proceedings: 5th National Demand-Side Management Conference,* Electric Power Research Institute, Palo Alto, CA. report CU-7394; 1991; P. Herman, et. al., “End-Use Technical Assessment Guide, volume 4: Fundamentals and Methods, ” Electric Power Research Institute EPRI CU-7222, vol. 4, April 1991, Palo Alto, CA; Linda Berry and Brie Hirst, “The U.S. DOE Least-Cost Utility Planning Program, ’*Energy, vol. 15, No. 12,* pp. 1107-1117, 1990; Glenn Zorpette, “Utilities Get Serious About Efficiency,“ *IEEE Spectrum, May* 1991, pp. 42-43.

[2] Other names associated with Integrated Resource Pl arming include Least Cost Planning and Demand Side Management. Least Cost Planning has sometimes been taken to mean only comparisons of energy supply options, with no comparisons with end use options. Demand side management commonly examines end-use options, with no comparisons with energy supply options.

[3] Adapted from David Moskovitz, Op. Cit., footnote 1.

Figure 3-16-Electricity Efficiency Supply Curve, Brazil, 2010



This curve shows the equivalent cost of saving energy for various improvements in the energy efficiency of end-use technologies. (1 ,14,15)-improvements to residential and commercial (residential/ commercial) refrigerators and freezers; (2)-more efficient industrial furnaces and boilers; (3,1 3) more efficient res/com air conditioning; (4,17) more efficient residential electric water heating; (5,1 9) more efficient industrial motors and adjustable speed drives; (6)--miscellaneous industrial improvements; (7) more efficient industrial electrochemical processes; (8,9,10,1 1,12, 16,1 8,20)-various improvements to residential, commercial, industrial, and public lighting.

SOURCE: Howard S. Geller, *Efficient Electricity Use: A Development Strategy for Brazil*, contractor report for the Office of Technology Assessment (Washington, DC: American Council for An Energy Efficient Economy, 1991).

user) leads to much lower levels of investment in end-use equipment efficiency than is justified on the basis of either total system capital costs or life cycle operating costs.

A powerful tool to redress this "disconnect" is Integrated Resource Planning (see box 3-G). If utilities planned on a systemwide energy services basis, they could use resources that would otherwise have been devoted to expanding capacity to financing efficient appliances. Examples of such innovative financing approaches might range from the end user choosing equipment according to the total life cycle cost and paying this cost in monthly installments on the utility bill; to the end user paying a front-end deposit or posting a bond to the utility to cover the life cycle operating costs of the equipment, against which the utility would charge the capital cost of the equipment and the monthly electricity bills. Either of these approaches would force the end user to directly face the total life cycle costs of the equipment when purchasing it.

CONCLUSION

This review of energy efficient and/or alternative technologies for the residential and commercial sectors shows that substantial reductions in society wide capital costs, life cycle operating costs, and energy consumption are possible. Achieving these savings will require, however, significant longterm efforts and institutional changes to overcome a variety of market and institutional failures (see table 3-5). Many approaches to these failures are possible (see table 3-6). The United States can help in this effort (see ch. 8) by accelerating programs of research, development, and demonstration of energy efficient technologies, by providing technical assistance and training in both technology and institutional change, and by setting an example.