ENVIRONMENTAL IMPROVEMENT AND ENERGY EFFICIENCY IN BUILDINGS: OPPORTUNITIES TO REDUCE CO_2 EMISSIONS

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Energy production, distribution and use have a variety of environmental impacts, and it is frequently acknowledged that improved energy efficiency could reduce the burden of energy activities on the environment. In particular for the climate change issue, more efficient use of fossil fuels seems to be a promising response strategy. Greater energy efficiency in buildings is an important target area, as this sector accounts for about one-third of final energy consumption in OECD countries. The environmental benefits directly derived from energy conservation depend on the type of energy source, the nature of the energy process, and the extent of the efficiency gain. Based on an IEA analysis of the residential and commercial sectors, this paper examines the realistic scope for energy efficiency improvements and the role that they may play in environmental protection, particularly in the limitation of CO_2 emissions.

A first step in this analysis is an assessment of the contribution to CO_2 emissions of the various end-use sectors, including buildings. This review reveals marked variations among countries related to differences in their fuel mix, particularly for electricity generation. Technology options for increasing efficiency, such as improvements in the building shell or more efficient household appliances, are reviewed and the scope for cost-effective energy savings that can realistically be achieved is evaluated, as are the associated emissions reductions. The evaluation also includes a description of the market place and an assessment of institutional barriers that hamper the widespread introduction of cost-effective energy-efficient technologies. A broad range of policy options, such as information and regulation, pricing and fiscal policies, as well as other economic incentive programmes, are available to help accelerate the market development of these technologies.

INTRODUCTION

Environmental considerations are increasingly playing a part in energy decisions and concerns about climate change are further influencing the orientation of policies towards environmental goals. Recent studies, such as the Brundtland report, the IEA's Energy and Environment Policy Overview and work carried out in the framework of the Intergovernmental Panel on Climate Change (IPCC), recognise the close links between energy, the economy and the environment. Energy use has a variety of significant environmental impacts and it is common knowledge that reduced energy demand could also reduce the related burden on the environment. In particular, the more efficient use

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[1] *The views expressed in this paper are those of the authors and do not necessarily reflect those of the International Energy Agency or its Member countries.*

The International Energy Agency is an autonomous body within the Paris-based Organization for Economic Cooperation and Development (OECD). There are 21 member countries.

of those fuels that emit greenhouse gases is a promising response strategy to combat climate change, in the absence of economically viable CO_2 abatement technologies.

Energy efficiency policy measures have in the past contributed to improved energy security in the Member countries of the IEA, where oil dependence has been significantly reduced since the first oil shock. Oil requirements between 1973 and 1988 decreased by 7.8%, or 137 Mtoe, although the economic activity increased substantially. During this period, the Gross Domestic Product (GDP) increased by 50% in real terms. At the same time, Total Primary Energy Requirements (TPER) increased by only 13.5%. Various studies have documented that a broad range of energy efficient technologies is currently available (e.g., Schipper et al. 1987). Although the potential for cost-effective energy savings seems to be high, there exists market barriers that hinder the penetration of improved end-use technologies. Furthermore, softer energy prices since 1986 have reduced the economic incentive to carry out efficiency improvements and blurred awareness about the economic costs and longer term security implications of energy use. The change in perspective due to growing environmental concern is providing renewed interest in potential energy savings and their effect on emission levels, as well as a fresh impetus for the design of effective energy conservation programmes.

The analysis presented here concentrates on the residential and commercial/public sector, which accounted in 1988 for about 30% of energy use in the IEA. It examines how the end-use of energy contributes to emissions of CO_2 and how energy efficient technologies and other measures, such as energy management, could be further developed in order to help reduce growth in energy demand and related emissions.

POLLUTANT EMISSIONS AND ENERGY DEMAND TRENDS

The energy sector is a major contributor to the production of a broad range of atmospheric pollutants including SO_2, particulate matter, NO_x, VOCs, CO_2, CH_4, N_2O and CO. The first five of these pollutants contribute to serious local or regional air quality problems such as acid rain and ozone pollution. The last six contribute directly or indirectly to the greenhouse effect. Recent studies (IPCC, WG I 1990) show that CO_2 holds by far the largest share in both the greenhouse effect due to anthropogenic activities (71%) and the increase in the greenhouse effect due to these activities (about 50%). Though other human activities, such as deforestation and agriculture, are contributing to increases in the atmospheric concentration of CO_2, the energy sector is clearly of most concern as it is responsible for about 61% of anthropogenic CO_2 emissions (IPCC, WG III 1990). This fact is the basis of the current energy focus of much of the attention given to the risk of global warming.

The important role of carbon dioxide is of particular interest to those involved in the development of improved energy efficiency: in the current absence of any economically justifiable CO_2 abatement technology, energy efficiency appears to be one of the most promising response strategies to limit greenhouse gas emissions. The possibilities offered by carbon offsetting through reforestation and "carbon-neutral" biomass plantations are also considered to be promising, though the need to rationalise our use of energy clearly appears to be the central priority. In addition, carbon dioxide is a fuel dependent emission, i.e, the emission of carbon dioxide decreases proportionally with the use of a given fuel. SO_2 and particulate matter are also essentially fuel dependent pollutants, the difference being that abatement technologies such as flue gas desulphurisation or electrostatic filters are available and have indeed been developed in many applications. Although increased efficiency can contribute to a reduction in the quantity of emissions of other pollutants such as NO_x, VOC and CO, the relationship between energy use and emission levels is not linear as these pollutants are essentially technology-dependent. As for other pollutants such as CH_4 and CFCs, their generation is not directly related to energy combustion.

CO_2 emissions therefore appear to be a special case for energy efficiency efforts: for other fuel-dependent pollutants, abatement technologies are available and for technology-dependent pollutants, reduced energy use does not necessarily result in reduced emissions. As a result, improved end use energy efficiency is not the "first-order" response that it is for CO_2 emissions. This paper therefore focuses mainly on the benefits of improved energy efficiency in terms of reductions in CO_2 emissions. It should nevertheless be emphasised that, where efficiency improvements displace fossil fuels, reduced energy use will reduce the need for expensive abatement technologies for fuel-dependent pollutants and emissions of other pollutants may also be reduced. In addition, the cumulative effect of energy efficiency improvements will ultimately reduce the pressure exerted on the environment by other energy activities, including for instance land use and water quality problems often associated with energy production, transformation and transport.

Trends in energy demand. Energy demand developments during the last fifteen years show a substantial reduction in consumption after the oil prices hikes of 1973 and particularly after 1979. Since 1986, the price signals have weakened and this is reflected in a gradual increase in energy demand. These developments appear clearly in the evolution of energy intensity between 1970 and 1988 -- energy intensity being defined as TPER, measured in million tons of oil equivalent (Mtoe), per unit of economic output, which is usually measured in the OECD in constant US dollars. The period between 1980 and 1984 saw the greatest achievements in energy efficiency, and intensity declined by 2.6% per annum (p.a.). But these improvements in energy productivity were largely driven by relatively high energy prices, compared to other commodity prices. The price-induced momentum dropped off during a second four-year period, between 1984 and 1988, when intensity declined by only 1.4% p.a.

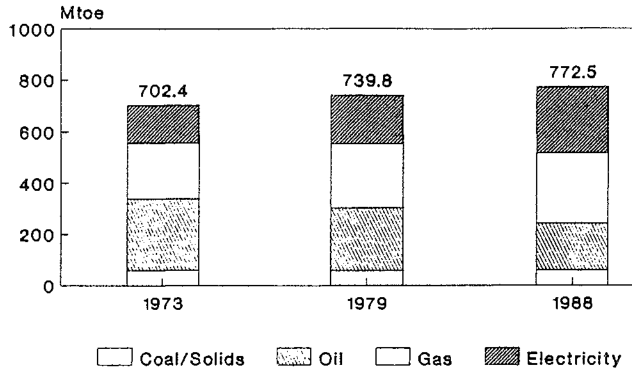
But energy demand developments have not been uniform among different end-use sectors, as shown in Table 1. While overall annual energy demand increased by less than 1% between 1973 and 1988, and by 2.4% between 1985 and 1988, sectoral trends varied substantially. The strongest increase in demand between 1985 and 1988 was experienced in the transport sector (4%), which is almost entirely oil dependent. The commercial and public service sector, as well as industry, exhibited strong growth in energy demand that was influenced largely by the economic expansion the IEA region has experienced in recent years. Between 1985 and 1988, the aggregate GDP of the IEA grew by 3.6% p.a. Compared to these trends, the growth of energy demand in the residential sector was rather modest: less than 1% p.a. between 1985 and 1988.

In addition, the pattern of energy demand within the residential/commercial sector experienced significant shifts. Figure 1 depicts the changes in requirements for oil, solid fuels, gas, and electricity from 1973 to 1988. District heating is not shown in Figure 1 as it provided less than 1% of the energy requirements of the residential and commercial sectors in 1988. While demand for fuels that are primarily used to provide the service "heat" slightly declined between 1973 and 1988, while electricity demand increased significantly and electricity increased its share in the fuel mix from 21% to 33%.

Table 1. Trends in Sectoral Energy Demand in the IEA

	Energy Demand Mtoe			Annual Changes (%)		
	1973	1985	1988	73-85	85-88	73-88
Industry	965.90	842.79	894.75	-1.13	2.01	-0.51
Residential	492.45	489.13	502.67	-0.06	0.91	0.14
Comm/Publ.	209.92	250.78	273.63	1.49	2.95	1.78
Transport	635.35	735.33	823.30	1.22	3.84	1.74
Others	175.10	162.48	174.33	-0.62	2.37	-0.03
TFC	**2478.72**	**2480.51**	**2668.68**	**0.01**	**2.47**	**0.49**
Trans. Losses	834.11	1029.00	1094.16	1.76	2.07	1.83
TPER	**3312.82**	**3509.51**	**3762.84**	**0.48**	**2.35**	**0.85**

Source: Energy Balances of OECD Countries, Paris, 1990.



Source:
Energy Balances of OECD Countries,
Paris, IEA, 1990.

Figure 1. IEA Residential/Commercial Energy Use by Fuel

The trends described above reflect many, often related, developments, such as changes in energy prices, consumer behaviour and levels of disposable income, that affect the way individuals make investment decisions. They are significant in determining the scope for further energy efficiency improvements, as they have a strong influence on the likely achievable savings potential. For instance in the case of electricity use, increases in income foster the market penetration of new household appliances that improve the level of comfort and convenience, such as dishwashers. Furthermore, changes in lifestyle result in stronger demand for certain leisure or business services that require more electricity: e.g., for office automation and lighting in financial or real estate services.

Table 2. Carbon Emissions of the IEA, 1988[1]

	Mt Carbon	Percent
Industry	987.6	36.5
Transport	732.4	27.1
Road	596.6	22.1
Air	94.0	3.5
Other	983.7	36.4
Residential	566.5	21.0
Commercial/Public	349.0	12.9
Total Final Consumption	2703.7	100.0

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[1] Calculations are based on delivered energy

Source: Energy Balances for OECD Countries, Paris, 1990.
M. J. Grubb, 1989.

Table 3. Emission Factors on a Delivered Energy Basis for the IEA
(Mt carbon/Mtoe)

Coal	1.13
Other solid fuels	0.89
Oil	0.88
Gas	0.73
Electricity	1.95

Carbon dioxide emissions from energy end-use sectors. Table 2 shows estimates of CO_2 emissions from different end-use sectors in the IEA in 1988. The calculations are based on energy consumption data derived from IEA Energy Balances and on standard primary energy emission factors (Grubb 1989) which express CO_2 emissions in tonnes of carbon released by the combustion of fossil fuels. However, the emission factors shown in Table 3 also take into account a range of upstream energy uses in order to provide estimates of emissions at end-use level. They rely on the calculation of delivered energy emission factors (EFde) that incorporate emissions which occur at other stages of the fuel cycles, particularly during transformation and electricity generation. These emissions are allocated to the different end-use sectors on a pro-rata basis. Compared to the methodology that applies emission factors only to primary energy requirements, the approach chosen here provides a more accurate picture of CO_2 emissions brought about by the various sectors of economic activity and is better suited to the investigation of response measures such as improved energy efficiency.

Electricity poses specific CO_2 accounting problems, as none of the emissions involved occur at the end-use level, but result from the combustion of a range of fossil fuels in power stations. The emission factor calculated here is an *average* that can be related to 1 Mtoe of final electricity demand. It reflects the fuel mix used to generate electricity in the IEA (or, in the case of national data, in the country concerned) but does not take account of the differential use of different generation sources for base load versus peak load generation. Its application to end-use electricity consumption figures is therefore an approximation which should be treated with caution when changes in electricity demand are being considered. The short term effect of demand reduction is to reduce the load on the "marginal power station", which is usually oil-fired in the daytime in winter and coal-fired or hydro at most other times. The longer term effect of electricity demand reduction on fuel use is more complex as it depends on the effect on the load profile. But where the load profile is not significantly altered, the savings are likely to fall approximately proportionally on each type of station, in which case the average emission factor calculated here is in fact appropriate. It should also be noted that reductions in electricity demand can be used to provide greater flexibility to reduce the operation of high emitting power stations. CO_2 reductions could then be higher than the average emission factor used here suggests.

The industrial sector is by far the largest contributor to CO_2 emissions, with 36.5% of IEA-wide emissions related to industrial operations. Emissions resulting from transport energy use cause approximately 27% of total CO_2 releases. The residential sector contributes about 21% and the commercial/public service sector almost 13%. Similar calculations carried out at for IEA countries are summarised in Table 4 below. They reveal that the carbon intensity of electricity generation, measured by the average emission factor for electricity generation, plays a key role in the share of the buildings sector in total CO_2 emissions. In countries that rely heavily on fossil fuels, and particularly coal, for electricity production, the buildings sector typically represents over 40% of total emissions. This is the case for the UK (43%) and Denmark (48%). Where electricity is essentially produced by non-fossil fuels, the share of the buildings sector falls to 28% (in Sweden or Canada), or even as low as 15% (Norway).

Residential and service sector CO_2 emissions by end-use categories. Although it is extremely difficult to allocate carbon emissions to the different end-use categories, such as heating, warm water, refrigeration or lighting, this is necessary in order to attempt an evaluation of different options to reduce emissions. The results of a tentative analysis of end-use CO_2 releases are shown in Figure 2. The calculations are based on country-specific estimates of energy end-uses for countries where such data is available. The energy requirements of the buildings sector of these countries cover about 80% of the total service sector energy demand of the IEA and over 75% of the demand of the residential sector. These energy uses were extrapolated to the remaining countries in order to obtain IEA-wide estimates of end-use demand which were then multiplied by fuel-specific EFde to give estimates of CO_2 emissions.

Taking the commercial and residential sector together, about 54% of carbon releases are related to space conditioning, 13% to water heating, 6% to residential refrigeration, and 12% to lighting. The remaining 15% are caused by other uses, such as cooking and various domestic appliances. Although these estimates are only indicative, they do provide a more detailed picture of the origin of carbon emissions in the building sector which needs to be taken into account in any response strategy. Measures that can be applied to reduce energy requirements - and to reduce emissions - depend crucially on the characteristics of these different end-use categories. 54% of emissions are related to the energy services "heating", "cooling" and "ventilation", whereas the remainder includes a varied range of dispersed categories, from office automation and lighting to residential uses, such as dish washers and refrigerators. Energy requirements of the former category can be mainly influenced by

Table 4. Share of End-Use Sectors in CO_2 Emissions

	% Share of CO_2 Emissions			Electricity Emission Factor (Mt carbon/Mtoe)
	Industry	Transport	Other	
IEA	36.5	27.0	37.0	1.96
Australia	41.1	26.9	32.0	3.32
Austria	32.1	27.8	40.1	0.70
Belgium	43.1	22.6	34.3	1.15
Canada	40.1	28.9	31.0	0.77
Denmark	23.0	22.0	55.0	2.92
Germany	38.4	21.5	40.1	2.11
Greece	35.6	25.6	38.9	3.49
Ireland	33.5	20.0	46.4	2.87
Italy	39.6	26.6	33.6	1.82
Japan	51.9	20.9	27.2	1.49
Luxembourg	58.9	24.5	16.4	0.47
Netherlands	43.0	20.2	36.8	2.04
New Zealand	45.9	35.1	19.0	0.55
Norway	36.7	34.8	16.5	0.02
Portugal	49.7	27.9	22.3	1.32
Spain	43.2	34.0	22.8	1.43
Sweden	40.3	30.3	29.4	0.17
Switzerland	15.3	36.6	48.1	0.12
Turkey	35.7	20.1	44.2	1.72
UK	32.4	23.8	43.8	2.64
United States	31.8	29.2	39.0	2.34

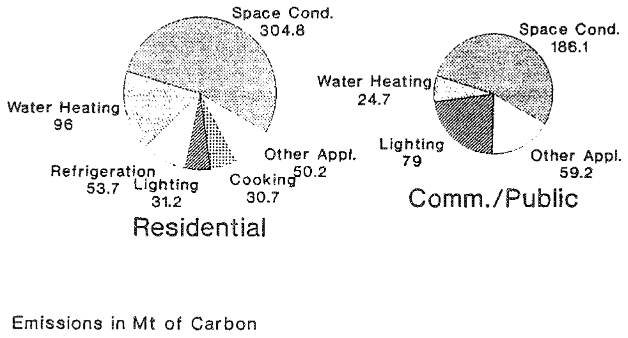


Figure 2. CO_2 Emissions - IEA Estimates

improvements in the building shell or other measures to reduce the heat load, such as the passive use of solar energy, as well as by efficiency improvements for space heating technologies, including boilers or building management systems. In addition, there are also significant differences in the time horizon in which the full scope of efficiency improvements may be translated into demand reductions, as the difference in the turnover of the capital stock between the two categories is one to five, with appliances replaced every 10 to 15 years. Initiatives that are aimed to increase energy efficiency, such as retrofit programmes or the replacement of boilers, have to take these differences into account.

TECHNOLOGY OPTIONS

The buildings sector has experienced significant improvements in efficiency due to better insulation or appliance efficiency, largely in response to high energy price levels in the late 1970s and early 1980s. To evaluate technology options that are available for further efficiency improvements, those that increase the performance of the building shell and thus reduce the energy requirements for space conditioning, and those that relate to improved appliance efficiency are considered in turn.

Space Conditioning. Energy requirements for space heating are primarily influenced by the thermal efficiency of the building shell and by the conversion efficiency of burners and furnaces as well as distribution losses. Other factors that influence energy requirements include climatic variations, the amount of space to be heated or cooled, and the required comfort level.

The performance of the building shell is influenced by thermal insulation, air infiltration, window characteristics, and the orientation of the building (passive use of solar energy). Table 5 gives an overview of the scope for efficiency improvements for service sector space heating in the UK, both in technically achievable and economically feasible terms. The largest potential is for measures that reduce heat losses through walls and roofs, for which improvements of 20 to 40% are regarded as being cost-effective. Heat losses can also be significantly reduced by replacing single-glazing windows with multiple glazing. A comparison of heat losses based on a survey of different types of windows can be found in Giovannini et al. 1989.

Improved technologies are also available to increase the efficiency of space heating and cooling. Figure 3 illustrates the scope of efficiency improvements based on efficiency data on current stock, new stock and best available technology. The potential is particularly high for heating, ventilation and air conditioning systems (HVAC). For example, in Sweden, new systems are more than twice as efficient as the existing stock.

Appliances. About 36% of carbon releases are caused by lighting, refrigeration, and electricity appliances other than those used for space conditioning in the building sector of the IEA. As noted above, this IEA average figure is much higher in countries that use a large share of coal for their electricity generation. As a response to rising concerns about the energy, environmental and economic costs of growing electricity consumption, the IEA has recently carried out a study to evaluate the economic potential for efficiency improvements in electric appliances and uses (IEA 1989) and analyzed several specific end-uses which together account for about 70% of total electricity use: lighting, residential space and water heating, refrigeration, commercial/public building space conditioning and industrial motors. Table 6 summarises the results of this study.

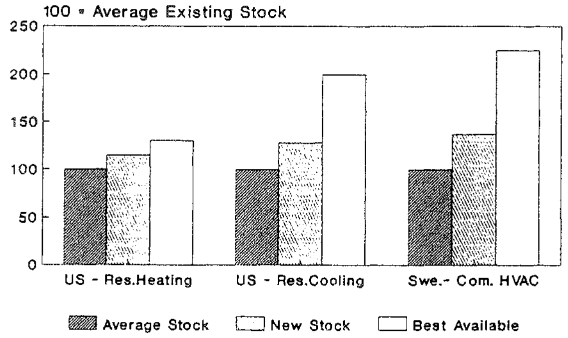
Although there exists a potential for economic justifiable efficiency improvements in all end-uses, the largest economic saving potential was found in lighting. Electricity consumption in most lighting systems could be more than halved by the use of high efficiency light bulbs, electronic ballasts, improved reflectors, and better controls. The efficiency of home refrigerators could also be significantly improved. An efficiency improvement was assumed to be economic if savings can pay back the first cost in less than about five years, based on current prices. Based on the shares of the five different end-use categories that are identified in Table 6 and the quantification of the potential savings not likely to be achieved if current trends were not changed (Column D in Table 6) the scope for efficiency improvements in end-use electricity can be calculated.

These estimates suggest that savings in the range of 10 to 20% per unit of service could result from efficiency improvements that are not likely to be realised by present efforts, though they are economically viable. The full achievement of this potential would require the replacement of major existing capital stock and could only happen over about two decades. If a 10 to 20% saving from

Table 5. Potential Improvements in Energy Efficiency for Space Heating in the Service Sector in the UK

		Technical	Cost-effective
Building fabric measures:	insulation of roofs and walls, double glazing	40-50	20-40
Ventilation control:	draught proofing, door seals, etc.	10-15	5-10
Control systems:	time and temperature energy-use optimizers, energy management systems	20-25	10-20
Reduction in distribution losses and heat recovery, etc.		10-20	5-10
Overall for electric heating systems		55-65	30-55

Source: Energy Efficiency Office, 1988.



Source: IEA, 1987.

Figure 3. Efficiency Potential Selected Technologies

improved efficiency were achieved, it would amount to a reduction of 0.5 to 1.1% per year in the growth rate of total electricity use that would have otherwise occurred (IEA analyses of possible trends in electricity consumption to 2005 indicate that electricity demand, leaving this potential untapped, may grow by 2.7% p.a.). But this would require that the numerous barriers to efficiency investments, described in the following section, be overcome.

In the commercial sector the most important uses for electricity are lighting, space conditioning and office automation. The contribution to electricity demand of the last category is likely to increase in the future as our economies move to more service sector oriented activities which require more electronic devices. Office automation already has in some commercial premises electricity requirements comparable to those of lighting (Harris et al. 1989). Growing electricity demand for these devices may outweigh the impact on energy demand of energy efficiency improvements. There are nevertheless technologies that significantly reduce energy demand, e.g., microchips used for battery driven lap-tops.

Table 6. Economic Opportunities for Efficiency Improvements of Selected Electricity End-Uses[1]

	(A) Share of total Electricity Final Consumption[2]	(B) Total Savings Possible[3]	(C) Existing Market/Inst. Barriers[4]	(D) Potential Savings not Likely to Be Achieved[5]	(E) Time-Frame for Savings (years)[6]
Residential Space Heating	4.5%	Medium/high	Some/Many	Mixed	More than 20
Residential Water Heating	5.4%	Mixed	Some/Many	Mixed	10-20
Residential Refrigeration	6.8%	High	Many	Medium	10-20
Lighting	16.7%	Very high	Many	High	10-20
Commercial Space Heating	9.9%	Mixed	Some/Many	Mixed	20 or more

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[1] *How to read this table:* For example, for lighting, "very high" (more than 50% per unit) savings would result if the best available technology were used to replace the average lighting stock in use today over the next "10-20 years". Some of these savings would take place under existing market and policy conditions. But due to the "many" market and institutional barriers, there would remain a "high" (30-50%) economic potential for savings that would not be achieved.

[2] Average share for the six countries examined (United States, Japan, Germany, United Kingdom, Italy, Sweden).

[3] Based on a comparison of the average efficiency of existing capital stocks to the efficiency of the best available new technology. This estimate includes the savings likely to be achieved in response to current market forces and government policies as well as those potential savings (indicated in Column D) not likely to be achieved by current efforts: Low (0-10% reductions per unit, on average): Medium (-10-30%/unit); high (-30-50%/unit); very high (more than -50%/unit); and mixed (spanning at least three categories).

[4] Extent of existing market and institutional barriers to efficiency investments.

[5] Potential savings (reduction per unit) *not* likely to be achieved in response to current market forces and government policies (part of total indicated in Column B).

[6] Required to achieve most of the economic potential for savings.

NB: 27% of electricity is used by industrial motors in the six countries selected

Source: IEA, 1989.

BARRIERS TO THE EFFICIENT USE OF ENERGY

One of the first measures likely to accelerate the market penetration of the energy-efficient technologies described above is to remove market distortions and institutional barriers which still hinder the economically efficient use of energy in the residential/commercial sector.

Market barriers in the residential sector are largely due to lack of information about energy use *and* related costs, *as well as* technologies available to reduce energy use. Furthermore, individual consumers often do not have access to information on means of financing investments in general and energy-efficiency technologies in particular. They make decisions to meet his day-to-day requirements, of which energy-related decisions represent only a minor part, and are usually only moderately interested in their energy bills. Energy efficiency is not among the most important criteria for purchase decisions. This means that individual discount rates significantly exceed those usually applied in business (25 to 35%). For certain residential appliances, the purchasers use an implicit discount which is above 60% (Meier 1983).

There are many examples for such market imperfections. The building owner or developer is interested in reducing investment and the tenant who will have to pay the energy bills is often not in a position to influence these decisions. Furthermore, in multi-family houses where individual heat requirements are not separately metered, the single customer is not aware of the cost related to the "heat" service provided and might regulate the indoor air temperature by opening the windows instead of lowering the temperature of the heating source. Billing and metering procedures often do not provide accurate information on energy use and costs, even if the dwelling is individually metered. Such imperfections can break the feedback mechanism that is required for the market to function correctly and that can be summarised as follows:

Energy use -> energy costs -> consumer actions (behaviourial changes, investment decisions) -> cost reductions -> money saved

REVIEW OF POLICY AND PROGRAMME OPTIONS

The range of policy and programme options is similar for all IEA Member countries and generally concern three major categories of instruments: information, regulations and economic instruments. These three categories, on which policy makers have acquired considerable experience in the area of energy conservation over the last fifteen years, are briefly reviewed below.

Once a policy has been agreed, *information programmes* can urge compliance with and continued support for the chosen policy as well as provide information about available benefits that might not otherwise be widely known to the general public or to specific target groups such as industrial managers or architects. Informing energy users about the energy consumption of equipment is a well-established policy in Member countries. In addition to energy efficiency labelling, a number of Member countries have introduced the "eco-label" which guides consumers to products that are "environmentally friendly", at a time when green consumerism is becoming a major force in the marketplace. Training programmes by governments have also been used at times to improve the skills of economic actors closely involved in energy efficiency developments. Testing and training can entail substantial costs and one alternative to government involvement is to shift such tasks to industry.

Information programmes tend to work best on actions that make good economic sense for an industry or for the consumer, but that may not be widely known. On the one hand, to the extent that a government wants to implement a certain policy or influence certain actions, information programmes are probably an essential part of any such effort. On the other hand, to the extent the government wants to influence more directly or more persuasively the individual's choices, direct market interventions, in addition to some form of information programme, are probably necessary.

Regulatory instruments applied to energy demand policy include the broad array of standards and control mechanisms, such as restriction on fuel use, building codes, efficiency and emission requirements for burners, etc. While standards and regulations can be fairly effective and easy to promulgate, their initial design often assumes and requires considerable technical knowledge. For this reason, standard setting is likely to be an iterative process, whereby standards are promulgated and revised to reflect current experience and technology as well as national situations. As a result, this process often produces quite different results in various countries (Boyle 1989).

Unless regularly revised or upgraded, standards can fail to encourage the adoption of new technologies to fulfil or improve upon existing minimum requirements. Though the use of energy efficiency standards is well established as a policy instrument, the introduction and upgrading of such standards pose technical and economic problems. The mandatory use of available, cost effective technologies is usually the centre of a debate involving issues such as market choice (leaving it to users to decide the trade-offs between convenience features, purchase price and operating costs) and the commercialisation of new technologies (particularly in terms of reliable, low-cost mass production). These familiar issues are being revived by the need to reconsider new energy standards and technologies in terms of their potential for reducing polluting emissions.

Building standards usually apply only to new buildings and therefore are slow in producing an effect on energy demand. Typical rates of building for housing are 1 to 3% of the stock per year. Rapid improvements to the energy efficiency of the building stock would require that existing buildings were also improved, in which case regulations could take the form of the procedure applied in Denmark where energy inspections are required when houses are sold.

Economic instruments include taxes, pricing, charges, subsidies and other financial inducements. These instruments have been widely applied in years of high energy prices. Most schemes have been gradually reduced in recent years when energy prices declined and, simultaneously, the political will to limit public spending reduced the availability of funds. There are a number of other reasons that concurred in making governments increasingly reluctant to grant financial incentives. A major pitfall of financial incentive programmes is the fact that individuals who would have invested in energy-demand reducing measures anyway, also benefit from the programmes. This so-called free-rider effect has been considered as resulting in a non-optimal allocation of public resources. Developments in the area of environmental protection are fuelling interest in two types of economic instruments, market based instruments and taxes, which, when implemented in the energy sector, are likely to affect energy efficiency improvements and policy instruments designed to encourage their development.

Market-based economic instruments include a variety of policy instruments that use the power of the market place to achieve environmental goals such as emissions reductions. Emission trading schemes are of particular interest to energy-efficiency efforts because they have been specifically developed to increase the cost effectiveness of emission control and allow industry a large flexibility in choosing technical solutions. Emission reductions achieved through improved energy efficiency actions can be fully credited in emission control efforts, which is not always the case if the approach rests on traditional emissions standards. If the market-based trading system is designed in an appropriate fashion, it can in fact provide much incentive to energy efficiency actions. So far, experience with emission trading schemes has been limited to the United States and Germany and applied to the control of traditional pollutants such as SO2 in the industrial and power generation sectors. Within the IPCC and other forums, the use of similar schemes to limit CO_2 to introduce more flexibility and equity in any international limitation agreement is being examined (IPCC, WG III 1990).

Carbon taxes, proportional to the carbon content of fossil fuels, are also the subject of much attention. As is the case with any tax increasing energy prices, the effect on demand is a function of the price elasticity. Though few would question that higher oil prices have in the past prompted improved energy efficiency, the ultimate relative impacts of non-price policy measures, structural change and prices on energy demand are difficult to separate. A review of international literature carried out recently by E.Mills (1989) showed a bewildering degree of variation in elasticity estimates for a given country, fuel and sector. Given the investment criteria applied by energy users in the residential and commercial sector and the market barriers these investments need to overcome, any price increase would probably have to be more marked than in other sectors to produce a significant effect not only on fuel choice, but also on absolute levels of demand.

There is nevertheless a range of measures that can be taken or encouraged to enhance the development of cost effective energy efficiency improvements even at present low energy prices. The achievements of demand-side management programmes run by utilities and local authorities in North America are promising, providing this experience can be in fact transferred to other parts of the IEA where utilities function under different regulatory regimes and supply constraints.

CONCLUSIONS

The efficient use of energy - both in terms of economic soundness and rational use of energy - can contribute to a reduction of the anticipated growth rates of greenhouse gas emissions. There exists a variety of cost effective measures to reduce energy consumption without sacrificing individual comfort requirements. The buildings sector requires special attention from a policy makers point of view. The various energy uses in the residential/commercial sector, e.g., space conditioning and residential appliances as well as office equipment, are important contributors to the anthropogenic CO_2 emissions. There are, however, substantial market imperfections that reduce or slow down the penetration of the technology options available. On the other hand, the array of different policy options can help reduce such barriers to energy efficiency. A careful selection of appropriate policies, flexibility and strong commitment will be required to address the remaining saving potential and translate it into emission reductions.

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