Direct Environmental Impacts of Demand-Side Management

Steve Bernow, Frank Ackerman, Bruce Biewald, Mark Fulmer, Karen Shapiro and Kristin Wulfsberg, Tellus Institute

The environmental benefits demand side management (DSM) provides by deferring construction of new power supply resources and by backing off the operation (and hence pollution from) marginal generating units have been thoroughly studied. Little attention, however, has been given to the direct environmental impacts of DSM technologies, which can in some instances, such as asbestos or urea-formaldehyde foam insulation, be significant. In this paper, we quantify and discuss the direct environmental impacts of several broad DSM categories, including: building shell tightening, fuel switching, efficient air conditioners and refrigerators, and efficient motors. We also discuss how DSM programs can be implemented to minimize any direct environmental impacts or take advantage of any potential environmental benefits.

We found that the direct impacts from these programs varied widely, from combustion pollutants in fuel switching programs to CFC emissions from increased appliance foam insulation to increased metals requirements for efficient motors. Because the impacts took on such a wide variety of forms, we described them, when possible, as "pollutant emissions (or benefits) per kWh of electricity saved." In some cases, this allowed for direct comparisons of the environmental impacts of conservation technologies and the impacts of pollutants from marginal generating facilities. We also found that a vast majority of the severe direct impacts of DSM technologies can be mitigated or eliminated through careful program design and implementation.

Introduction

The objective of this paper is to identify and discuss the potential adverse environmental impacts of selected DSM programs, to assess the relative harm versus benefits of these programs, and to suggest ways in which careful program design can minimize any undesirable environmental effects.

An increasing number of utilities are choosing demand-side management (DSM) programs to meet at least part of their customers' growing energy needs. The motivations for DSM programs are varied, including reduction of peak demand, energy savings, postponement of the need for expansion in generation, transmission, and/or distribution, and financial incentives offered by state regulatory bodies. However, it is widely believed that DSM is also good for the environment. By reducing the need for electricity generation, DSM programs reduce the air and water emissions, fuel handling, and waste disposal requirements associated with power plants.

But DSM programs, especially if poorly designed or carelessly implemented, can lead to environmental problems of their own. Breakage or improper handling of old fluorescent lighting equipment can cause exposure to mercury and PCBs. Weatherization and building shell tightening can, under some conditions, worsen indoor air quality problems. Some (but not all) of the wide range of new refrigeration technologies may have undesirable health and atmospheric effects.

The objective of this paper is to identify and discuss the potential adverse environmental impacts of selected major DSM programs and to assess the relative harm versus benefits of these programs.

Selection of Case Studies

To examine the links between DSM and the environment, this study focuses on four major program areas. These selections include programs in all major customer sectors --residential, commercial, and industrial. They also display a broad range of environmental impacts, from manufacturing emissions and materials usage to on-site end-user effects and disposal impacts. And they encompass many of the most widely used DSM measures.

Two of the areas involve relatively clear, easily quantified environmental effects:

- fuel substitution programs
- energy-efficient motor technologies.

In contrast, the other two areas involve more variable, uncertain or less thoroughly researched environmental effects:

- building shell insulation
- refrigeration alternatives.

For each of these areas, the case study begins with a brief description of typical DSM measures, then examines available technologies in detail, assesses their environmental effects, and finally suggests program design options to ameliorate environmental problems.

The two principal conclusions of the study, described in more detail below, are 1) well-designed programs in each area provide clear environmental benefits, and 2) program design and implementation techniques are of great importance in avoiding potential environmental problems.

Methodology

When the environmental and energy impacts of the DSM measure being examined are quantifiable, we present the results as "pounds of pollutant per kWh saved." For example, an engine driven gas chiller operating at a COP of 1.4 requires 0.0086 MMBTU of gas per hour per ton of cooling, resulting in an emission of 0.99 pounds of CO_2 per hour per ton of cooling. If such a chiller replaces an electric chiller with a COP of 4.1 (EER = 14), it saves approximately 0.85 kW per ton of cooling. Dividing the 0.99 pounds of CO_2 by the 0.85 kW saved results in the value found in section 4.1 of 1.16 pounds of CO_2 per kWh saved.

The advantage of this method of presentation is that no particular electric generation technology or mix is assumed. The pollution created per kWh of savings can be compared to whatever generating technology or mix of technologies is appropriate for a particular utility system. In some cases, we provide a emissions from a "typical" marginal mix (e.g., New York Power Pool) or plant (usually a scrubbed baseload coal plant or a natural gas fired combustion turbine). However, comparisons made between the pollutant per kWh saved and by our sample generating technologies should be seen as illustrative rather than definitive.

Results

Fuel Switching

Many DSM programs involve fuel switching or substitution to obtain higher overall energy efficiency and lower costs. Moreover, switching between electricity and other fuels for selected end-uses will change the amounts and sites of pollutant emissions. We examined selected options for residential and commercial fuel switching options, and sought to calculate the generated versus avoided air emissions.

We compared electric and gas equipment for several end uses: residential space heating, water heating and clothes drying: and several technologies for commercial air conditioning. Efficiency and emissions assumptions are shown in Table 1. It is important to note that we in general tried to compare the more efficient technologies in each category, capturing the likely types which would be part of a DSM program, rather than the average of the typical existing stock. In each case we estimated the criteria air pollutants produced by the gas appliance, and compared them to the pollution created by generating enough electricity for the electric appliance at "typical" baseload and peaking power plants.

Absolute Emissions Levels. Figures 1 through 3 compare the absolute levels of selected pollutants per kWh of electricity saved from the direct fuel use technologies and for two sample marginal power plants--a baseload, scrubbed coal plant and a natural gas combustion turbine. Each of the graphs compares emissions of certain pollutants from the various fuel switching options, and from the two power plants. Gas appliance emissions are per kWh of electricity saved, while power plant emissions are per kWh generated, including transmission and distribution losses.

All residential gas appliance options show a substantial savings in NO_X emissions over either electric power plant. Not surprising, all of the gas alternatives show substantial SO_X savings relative to that plant. Because of its high ancillary electric requirements and the assumed marginal mix serving these requirements[1], the gas-fired absorption chiller has an intermediate level of SO_X emissions.

For gas furnaces and water heaters replacing electric resistance heating, gas clothes drying replacing electric, the emissions for direct use appliances are significantly less than for either of the power plants.

Table 1. Assumed Efficiencies and Emission Factors in Fuel Switching Analysis

	Efficiency	Emissions, pounds per MMBTU (gas) or pounds per MWh NOx	SOx	CO	VOC	CO2
Residential Gas Furnace	92%	0.066	0.0006	0.017	0.007	116
Residential Electric Heat Pump	HSPF 7					
Residential Gas Water Heater	59%	0.066	0.0006	0.016	0.007	116
Residential Electric Water Heater	95%					
Electric Heat Pump Water Heater	COP 2					
Gas Clothes Dryer	4100 Btu gas	0.068	0.0006	0.125	0.005	116
Electric Clothes Dryer	per kWh					
Engine Driven Gas Chiller	COP 1.4	0.216	0.0006	0.665	0.082	116
Absorption Gas Chiller	COP 1.0	0.152	0.0006	0.019	0.006	116
Electric Chiller	COP 4.1					
Scrubbed Coal-Steam heat rate =	9486	5.69	5.69	0.23	0.04	1925
Gas Combustion Turbine heat rate =	12311	4.84	0.0074	1.348	0.148	1465

Sources:
Efficiencies: GAMA 1991, Chernick 1990, Southwest Gas 1991, Caneta Research 1991, Tellus 1990.
Emissions Factors: Tellus 1990, Hanser et al 1990, Caneta Research 1991.

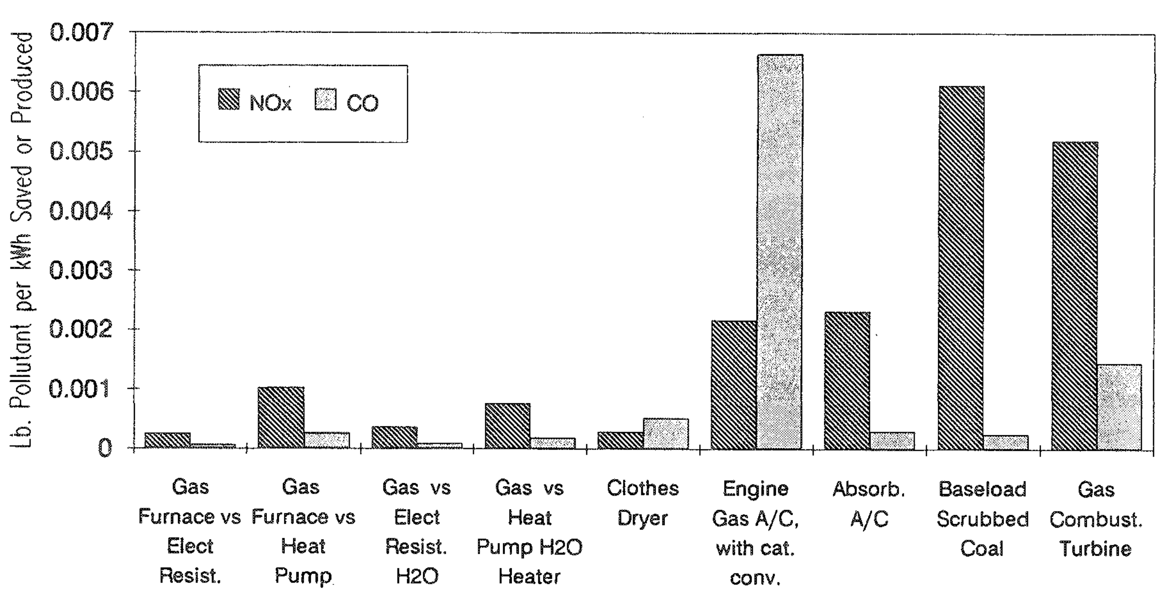

Figure 1. CO and NOx Emissions for Fuel Switching Measures

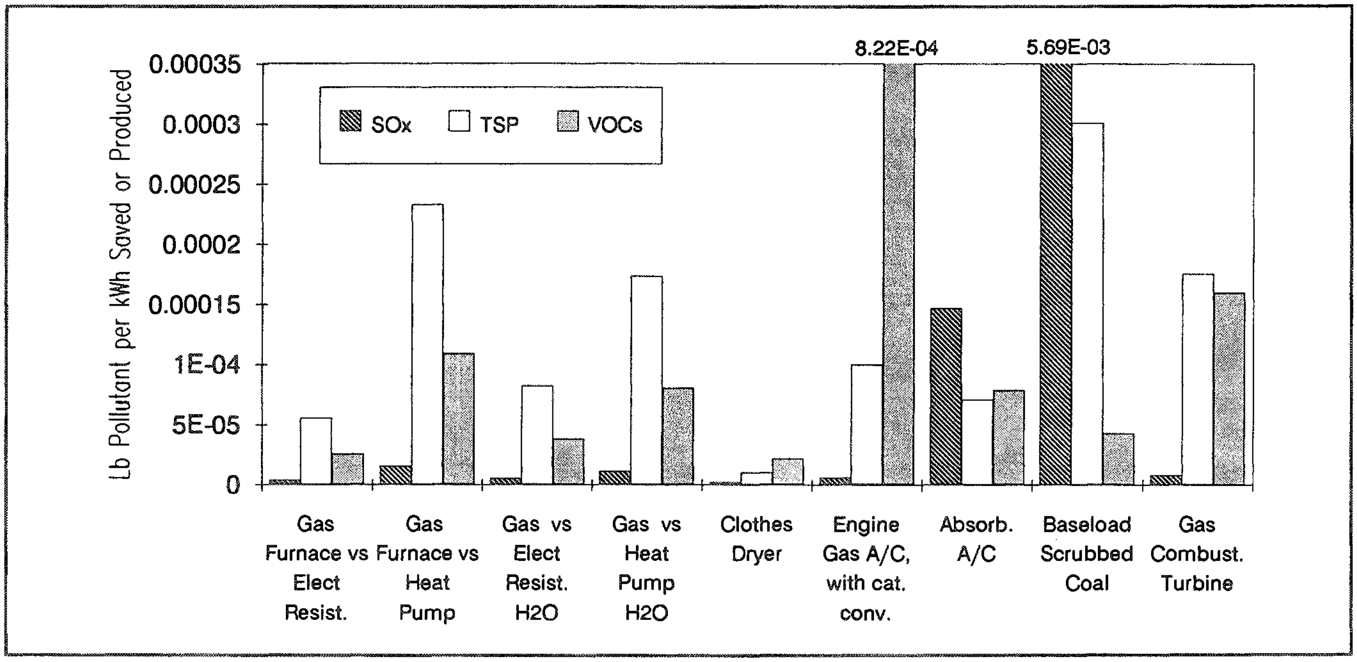

Figure 2. SOx, Particulate and VOC Emissions for Fuel Switching Measures

For the remaining pollutants, the comparison is more complicated. There is on balance no clear emissions gain or loss from switching to direct natural gas space from an electric heat pump. CO_2, particulate, volatile organics and CO emissions from using natural gas space heating instead of electric heat pumps are roughly comparable to power plant emissions per kWh--the emissions for each pollutant fall between the two power plant emissions. For water heating, direct natural gas use as a replacement for an electric heat pump almost always results in emissions

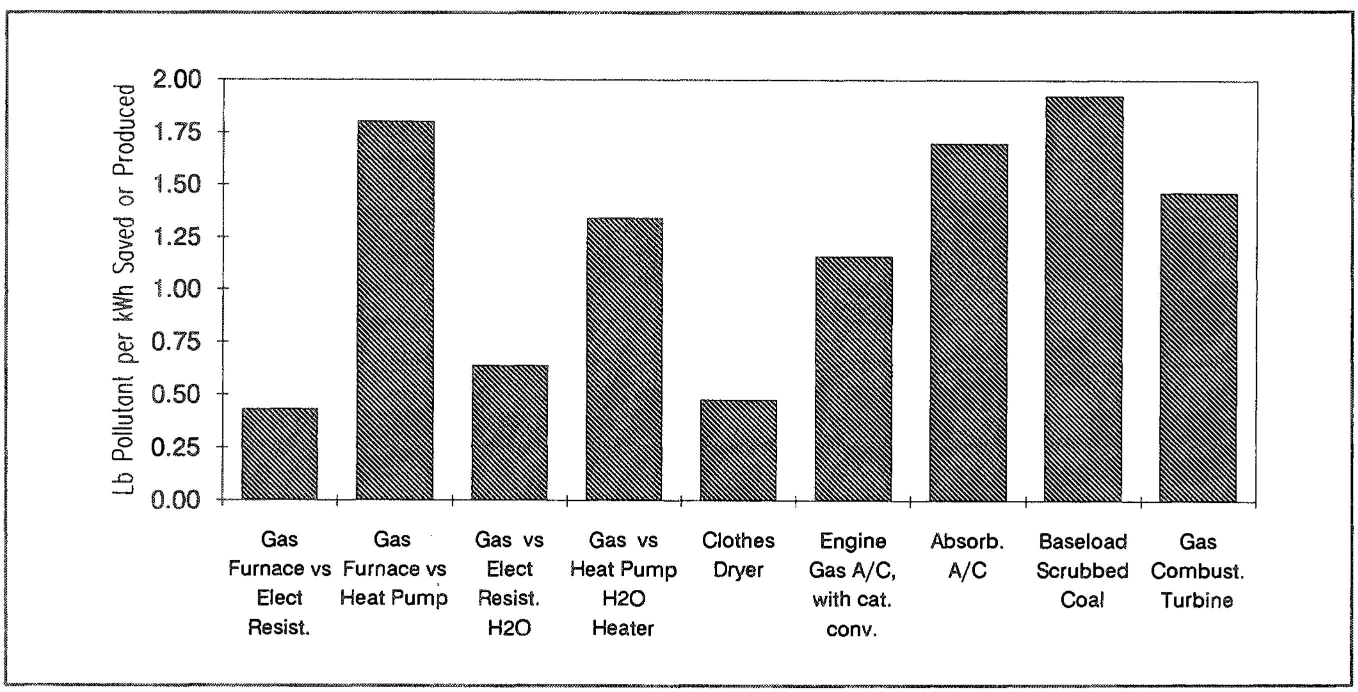

Figure 3. CO2 Emissions from Fuel Switching Measures

savings compared with a baseload plant, which would be used to supply this end use; the exception is volatile organics, where gas use for water heating produces higher emissions.

In the commercial sector, the environmental benefits of switching to gas are more limited. The emissions from natural gas chillers are in some categories comparable to or higher than the emissions from electric chillers. Engine driven chillers have particularly high emissions of some pollutants. Even when fitted with a catalytic converter, carbon monoxide and volatile organic emissions are still about five times greater for an engine driven chiller than for either of the sample power plants.

Absorption gas air conditioning also requires significant amounts of electricity to operate the absorbent pumps. Even, when these higher emissions are included, the absorption chillers still emit fewer pollutants than either of the proxy power plants. Absorption chillers also have the advantage of using no ozone depleting chlorofluorocarbons (CFCs) or hydrogen-chlorofluorocarbons (HCFCs).

Local Versus Global Impact of Emissions. While almost all of the natural gas end use fuel switching technologies examined here have lower emissions than their electric counterparts, they also differ in the location of the emission source. In some cases this is of great importance: emissions in California's South Coast Air Quality Management District around Los Angeles, for example, will have different impacts than emissions in rural Arizona or Nevada. A fuel switching measure which lowers net emissions on a global basis, but increases on-site emissions in an environmentally sensitive area, might still be rejected on environmental grounds.

Motor Efficiency

Many studies have identified changes by which the energy efficiency of electric motors and motor driven systems may be improved, offering major opportunities for electricity savings. Virtually every aspect of conventional motor design offers room for improvement. High-efficiency motors offer on-site environmental benefits during operation, due to reduced waste heat, quieter operation, and lower replacement needs for insulation and lubricants. Innovations in motor driven systems, such as appropriate sizing, adjustable speed drives, and other electronic control systems offer additional opportunities for substantial economic and environmental savings due to reduced requirements.

Advances in motor design imply changes in motor manufacturing requirements. Generally, energy savings are possible through the user of a higher quantity and/or quality of material input. The additional manufacturing, requirements associated with equipment for motor system improvements were not examined.

Impacts from Motor Production. Since increased material use may improve motor efficiency, it is important to consider the upstream environmental impacts from the production of materials used in energy efficient motors. However, it is impossible to generalize about the incremental material requirements for standard versus energy efficient motors. Unsophisticated improvements can be made simply by using more material, but because of the importance of motor geometry and quality of material, efficiency gains can also be made while using less material (Kellum, 1991). Indeed, optimizing motor dimensions in single-phase motors may raise efficiencies by 4.5% over the current standards at no additional costs (Baldwin, 1989).

Nonetheless, it is still of interest to compare the environmental impacts of motor material manufacturing requirements to the avoided electric generation. For this analysis, efficient motor energy savings are taken from Nadel et al. 1991, materials requirements from communications with a major motor manufacturer[2], and material production emissions from Frische 1991.

Since motor design can improve efficiency without increased material requirements, this calculation represents the "pessimistic" or minimal environmental improvement from efficient motors. The additional material serves to reduce the load losses (stator and rotor I^2R losses) and the rotor core losses. The energy savings are only those associated with those loss reductions. Table 2 compares the air emissions from the production of the additional material to the air emissions from baseload coal-fired electricity generation. A net emission rate for the efficiency improvements is calculated over a motor lifetime of fifteen years. The negative net emission rates show that even with increases in material air emissions to make efficiency improvements, the energy savings emissions are greater.

Environmental Impacts of Motor Rewinding. Winding and bearing failure may necessitate motor replacement. However, when the damage is limited, it is possible to rebuild the motor using the same rotor and stator iron and case. The process of stripping out the copper windings and replacing them is called rewinding.

Again, it is interesting to compare the emissions associated with the production of the copper for rewinding and the resulting additional annual energy consumption

Table 2. Incremental Emission Potential due to Pessimistic Efficiency Improvements

a. Emissions from the Production of Material for Efficiency Improvements

Loss Category	Material Difference	Percent Increase	Production Emissions CO2 lb	SO2 lb	NOx lb	Partic. lb
Stator I^2*R	More CU	35.00%	131.30	0.06	0.07	0.01
Rotor I^2*R	More AL	30.00%	68.03	0.13	0.13	0.24
Rotor Core Loss	More Steel	30.00%	272.65	0.15	0.09	0.21
	Total Emissions		**471.98**	**0.34**	**0.30**	**0.46**

b. Emissions from Annual Energy Savings (Coal-fired Generation)

Loss Category	Annual Savings kWh	Annual Emissions Savings CO2 lb	SO2 lb	NOx lb	Partic. lb
Stator I^2*R	953	1,835	5.42	5.42	0.27
Rotor I^2*R	332	639	1.89	1.89	0.09
Rotor Core Loss	485	934	2.76	2.76	0.14
Total Emissions		**3,408**	**10.07**	**10.07**	**0.50**

c. Net Emission Rates of Efficiency Improvements

Loss Category	Lifetime Savings kWh	Net Emission Rate Over Lifetime CO2 lbs/MWh	SO2 lbs/MWh	NOx lbs/MWh	Partic. lbs/MWh
Stator I^2*R	14,294	-1,916	-5.69	-5.69	-0.28
Rotor I^2*R	4,975	-1,912	-5.67	-5.67	-0.24
Rotor Core Loss	7,278	-1,888	-5.67	-5.68	-0.26

$$\text{Net Emission Rate} = \frac{\text{Production Emissions - (Annual Emission Savings * Motor Lifetime)}}{\text{Lifetime Energy Savings}}$$

Motor Lifetime = 15 yrs

21-50 HP Motor

(assuming the core loss increases) versus the emissions from the production of a new energy efficient motor and the resulting decrease in annual energy consumption.

Table 3 shows the emissions associated with the copper production and the additional energy consumption. Compared to Table 2, the avoided air emissions from the decrease in energy consumption for the efficient motor more than offset the emissions from the motor production. Clearly, the air emission impacts are more favorable for motor replacement than for motor rewinding.

Motor rewinding does however, re-use the original motor materials. Motors which are replaced are scrapped to junkyards or used equipment dealers.

Careful attention must be paid to the practice of motor rewinding, given both the economics of material recycling and energy losses, and the environmental benefits of reduced energy use from energy efficient motors. Nadel et al. 1991 urge motor operators to closely examine rewind shop practices, and suggest that utilities provide motor performance testing to evaluate the effects of rewinding.

Table 3. Rewound and Energy Efficient Motor Emissions Comparison

a. Energy Usage Emissions

Rewound Motor				Lifetime	Emissions of Energy Increase		
Motor HP	Average Efficiency	with Core Loss	Efficiency Energy Inc KWh	CO2 ,000 lbs	SO2 lbs	NOx lbs	Partic. lbs
10	86.30%	83.97%	7,913	15,237	45,036	45,036	2,252
30	89.90%	88.20%	15,842	30,506	90,167	90,167	4,508
60	92.00%	90.65%	33,923	65,325	193,078	193,078	9,654
125	92.00%	90.56%	75,615	145,609	430,372	430,372	21,519

b. Copper Production Emissions

Motor HP	Pounds Copper	CO2 ,000 lbs	SO2 lbs	NOx lbs	Partic. lbs
10	20	352	160	200	40
30	47	827	376	470	94
60	58	1,021	464	580	116
125	106	1,866	848	1,060	212

c. Net Emissions

Motor HP	CO2 ,000 lbs	SO2 lbs	NOx lbs	Partic. lbs
10	15,589	45,196	45,236	2,292
30	31,334	90,543	90,637	4,602
60	66,345	193,542	193,658	9,770
125	147,475	431,220	431,432	21,731

Net Emissions = Increase from Copper Production + Increased Energy Emissions

Building Shell Insulation

Shell tightening and weatherization, one of the most popular and cost-effective DSM program areas, is frequently associated--correctly or incorrectly--with indoor air quality problems. All else being equal, tighter building shells would be expected to worsen some but not all indoor air quality problems. However, building shell quality is not a primary determinant of indoor pollution levels; rather, the problem lies primarily with the source of the pollutants. On average, studies find no systematic relationship between ventilation rates and pollutant concentrations (EMR 1987, Turk et al. 1987).

Shell Tightening in Residential Buildings. Identified a few years ago as a major indoor pollution hazard, radon is a gaseous, radioactive decay product of radium, an element naturally occurring in rock and soil. Radon enters homes from the soil through cracks, leaks, and drains in the basement, foundation slab, or crawlspace below the house. The entry is driven by very small pressure differences between the interior of the house and the soil. The most important factors in determining indoor radon levels are the presence and concentration of radium in the soil, and the permeability of the soil--the ease of diffusion from radium-bearing rock to the building[3]. The next most important factor is the quality of interface between the building and the soil. The best interface is a well-ventilated crawlspace, followed by a tightly sealed slab foundation or basement.

Weatherization is relevant to radon problems, but one cannot even predict the direction of the net effect of shell tightening on radon concentrations. On the one hand, a tight house minimizes the stack effect, reducing the driving pressure difference between the soil and the house (DuPont and Morrill 1989). On the other, a decrease in air exchange will increase the concentration of whatever pollutants are in the air.

A toxic and potentially carcinogenic organic compound, formaldehyde is used as a binding agent and resin in building materials such as pressed wood products such as particle board, fiberboard and plywood. Other emission sources include urea formaldehyde foam insulation (UFFI), combustion devices such as gas stoves and heaters, tobacco smoke, paper products such as grocery bags, paper towels and facial tissue, floor coverings such as carpet backing and linoleum, and textile products such as water repellents, stiffeners, and permanent press clothing.

Because formaldehyde is generally emitted within the building, weatherization will generally increase concentrations. However, there are a number of additional complexities affecting indoor formaldehyde levels. For instance, pressed wood emission rates increase exponentially with temperature and linearly with humidity (Matthews et al. 1986). Moreover, formaldehyde emission rates are inversely related to existing levels in the air--the higher the airborne concentration, the lower the emission rate. Thus, while tightening a shell will usually increase formaldehyde concentrations, the increase will not be proportional to the reduction in air exchange rate.

Combustion inside a home can also be a source of indoor air pollution. "Environmental" tobacco smoke[4] is the most important combustion related indoor pollution source. One study showed that 5,000 cancer deaths per year can be attributed to lung cancer caused by environmental tobacco smoke (Replace and Lowery 1985).

Unvented kerosene heaters are another common source of indoor combustion pollutants. Poorly tuned kerosene heaters are major sources of indoor carbon monoxide (CO) and nitrogen oxides (NO_X). The CO concentration in a closed room with a kerosene heater can reach 35 ppm or higher, an order of magnitude higher than typical outdoor concentrations (DuPont and Morrill 1989). NO_X levels can easily exceed the 0.5 ppm EPA guideline.

Other potential combustion sources of indoor air pollutants include fireplaces, wood burning stoves, and automobiles in attached garages (particularly if the garage is below the home).

Like formaldehyde, most combustion products originate inside the house. Therefore, weatherization will usually increase indoor concentrations of combustion products. However, if combustion products are an air quality problem in a building, other measures are called for: even in a home with high infiltration rates, there will be a significant health hazard from the operation of unvented kerosene heaters or from environmental tobacco smoke.

Energy Conservation and Shell Tightening in Commercial Buildings. With the exception of radon and combustion products from portable heaters, the same indoor air pollutants occur in commercial buildings as in residential ones. However, because forced ventilation often plays a large role in both commercial building air quality and energy use, the ties between energy conservation and indoor air quality are closer. Numerous studies show that building design and heating, ventilation and air conditioning (HVAC) design and operation are related to air quality, but find the relationships to be quite complex. One cannot conclude that tighter, energy-efficient buildings necessarily have poorer air quality. On average, the opposite appears to be true: older, naturally ventilated buildings with high infiltration and openable windows generally have higher concentrations of indoor air pollutants than ones with mechanical ventilation (Harrison, et al. 1990).

Decreased ventilation and tighter building shells for energy conservation do, however, result in buildings where there is greater potential for error in managing air quality (Hansen 1990). Pollutants from maintenance problems, organic compounds in furniture, and tobacco smoke, which where previously removed by frequent air exchanges, remain in the building longer when ventilation rates are lower. Similarly, as HVAC systems become more complex, operators and designers must become more sophisticated. Errors in HVAC maintenance or operation can contribute to energy inefficiency, indoor air quality problems and discomfort for the building occupants (Hansen, 1990, Lavender 1990). As in the case of residential buildings, the more effective way to confront indoor air pollution in commercial buildings is to address the pollutant source (e.g. through routine HVAC maintenance) rather than try to dilute it down to harmless levels (Hansen 1990).

Refrigeration Alternatives

Refrigeration, heat pumps and air conditioning--end uses which involve refrigerant fluids--are targeted in many demand side management measures. Most of the existing end use equipment in this category relies on a type of refrigerant fluids known as chlorofluorocarbons (CFCs). Insulating foam used in the same equipment typically contains CFCs as well.

Unfortunately, despite their efficiency as refrigerants and insulators, CFCs have been found to cause depletion of the atmospheric ozone layer, and to contribute to the greenhouse effect, or global warming. The half-pound of CFC-12 in a typical domestic refrigerator, if released into the atmosphere, would persist for 139 years, during which time it would destroy 37,000 pounds of ozone; it could contribute as much to global warming as 1,900 pounds of carbon dioxide equivalent[5]. Spurred by the recognition of these dangers, international agreements and U.S. legislation both call for the elimination of CFC use in the near future.

CFC recovery from old refrigerators and other equipment is an important step toward reduction of atmospheric releases. However, it does not answer the question of the appropriate alternative refrigerants. Table 4 presents the global warming, ozone depleting and other impacts of the commonly used refrigerants and some of the proposed alternatives. Some of the most readily available alternatives have lower environmental impacts per pound of release, but are less efficient as refrigerants. For example, a related chemical, HCFC-22, has only about one-twentieth of the ozone depleting potential, and one-seventh of the greenhouse warming impact, of CFC-12 (UNEP 1989a). Yet refrigeration with HCFC-22 is 5% - 8% less energy efficient than with CFC-12 (UNEP 1989a, EPRI 1990). Fossil fuel-based generation of the additional electricity required for a HCFC-22 refrigerator also has a greenhouse warming impact, potentially negating the gain from switching to the environmentally "better" refrigerant[6]. If, in replacing old CFC-12 refrigerators with new HCFC-22 ones, as much as 15% of the CFC-12 from the retiring refrigerator is lost to the atmosphere, then there is no net gain in terms of global warming impact[7].

Research in the field suggests that a number of alternatives such as HFC-134a, or certain mixtures of several related fluorocarbons, may eventually offer much-reduced environmental impacts and no loss of energy efficiency relative to CFC-12 (UNEP 1989a). However, these approaches are still under development; currently available refrigerators based on HFC-134a still impose efficiency losses.

Similar issues arise in regard to the choice of refrigerant fluids for commercial air conditioning chillers. CFC-11 and CFC-12 are the leading refrigerants at present; a number of less environmentally damaging alternatives have been proposed, and may eventually become as energy-efficient as the standard designs. However, substantial emission reductions can be achieved without replacement of existing chillers. Such housekeeping measures as leak reduction, recovery of refrigerant during servicing, use of alternative gasses to flush chiller systems, and recovery of refrigerant on disposal could reduce CFC emissions from chillers by 65% (UNEP 1989a).

CFCs are also used in the insulating foam in refrigerators, and can be reduced or replaced by a number of insulation alternatives. Water-based substitutes can be used for up to 30% of the CFC in foam without energy penalty (RMI 1990). HCFCs, members of a related chemical family with somewhat better environmental impacts, can also be used to make insulating foams. For the longer term, a number of vacuum or low-pressure insulation techniques can replace CFCs and HCFCs in foam altogether, and ultimately produce much better insulation (RMI 1990, UNEP 1989b). This will reduce requirements for refrigerant fluids and for electricity generation.

One of the simplest and most effective near-term ways to reduce CFC emissions is through recovery and recycling. For instance, residential refrigerators and freezers rarely loose their refrigerant charge, even after 20 years or more (UNEP, 1989a). Thus, all of the initial refrigerant remains available at the end of the appliance's lifetime, to be either recovered or released into the atmosphere. Recovering the CFC-12 and either destroying the refrigerant or recycling it in applications that have no suitable alternative is relatively simple.

Recapturing and recycling the CFC-11 content of insulating foam is much more difficult than recapturing the CFCs in the refrigerant. CFC-11 can theoretically be recycled by mechanically grinding the foam, thermal desorbing and recondensing the CFC-11. It can also be disposed of by incineration at temperatures above 590°C (1095°F) (UNEP, 1989a). Cost estimates of CFC-11 recycling or disposal range from an additional $15 up to $94 per unit. (UNEP, 1989, low estimate German, high estimate Japanese). More recently, a German firm has licensed a technology which recovers the CFCs by shredding the material in a vacuum.

Table 4. CFCs in Residential Refrigeration and Commercial Air Conditioning (Refrigerants only)

Sector/ Application	Present CFC	Ozone Depleting Potential	Global Warming Potential	Toxicity TLV (1) (approx)	Alternative	Ozone Depleting Potential	Global Warming Potential	Toxicity TLV (1) (approx)	Other Hazards and Impacts
Residential Refrigeration	CFC-012	0.93	3700	1000	CFC-500 (73.8% CFC-12, 26.2% HCF-152a)	0.74	2700		
					HFC-134a	0	400	1000	5%-15% energy penalty
					HCFC-22	0.05	510	1000	energy penalty
					DiMethyl Ether (DME)				Toxic, flammable
					HcFc-152a	0	46	5 to 10	flammable; little toxicity data
Commercial Unitary a/c	HCFC-22	0.05	510	1000	HCFC-123	0.02	28		Different seals efficiency reduced 1-2%
	CFC-12	0.93	3700	1000					
Commercial Chiller	CFC-11	1	1300	1000	HCFC-123 (78%) CFC-11 (22%)	0.24	308		
					HCFC-134a	0	400	1000	not compatible with dessiants requires larger impeller-existing CFC-12 oils not compatible with Polyalkyine glycol based oil or ester based oil
	CFC-12	0.93	3700	1000					
	HCFC-22	0.05	510	1000					
	CFC-500 (73.8% CFC-12, 26.2% HCF-152a)	0.74	2700						

(1) TLV, Threshold Limit Value, specifies the airborne concentration of pollutants that workers may be continually exposed to, averaged over a 40 hour without causing adverse health effects.

Sources:

Technical Progress in Protecting the Ozone Layer, Refrigeration, Air Conditioning and Heat Pumps Technical Options Report. United Nations Environmental Programme, 1989.

Epstein and Manwell, An Assessment of the Environmental Tradeoffs Between CFC Use and Lower Efficiency Cooling with Alternative Refrigerants," Demand-Side Management and the Global Environment, Synergic Resources Corp, April, 1991.

"CFCs and Electric Chillers: Selecting Large Water Chillers as CFCs are Phased Out", EPRI Document CU.2039.11.90, EPRI, Palo Alto, CA., 1990.

James M. Calm, "Equipment for Alternative Refrigerants," ASHRAE Journal, Feb, 1992, p.40.

Temporal Aspects of DSM Environmental Impacts

DSM measures can affect both the overall level of energy usage as well as the daily and seasonal timing of that usage. The magnitude and temporal variations of DSM savings depend upon both the particular end-use affected and the option employed to modify its electricity consumption patterns. Some DSM options, such as pure load management (e.g., air conditioner controls) are primarily designed to save peaking capacity requirements without substantial effect on annual energy consumption. Other options, such as residential refrigerator programs, lower baseload demand throughout the year. Still others, such as weatherization or lighting options, have seasonal and/or diurnal patterns of impact.

The avoided costs, both economic and environmental, also vary by season and time of day. As the type of generation being displaced by DSM changes, so does the net environmental impact of a DSM program. To cite just one of many examples, during the spring and autumn seasons when demand tends to be lower, electricity generation tends to rely more upon baseload resources than in the winter or summer, when most utilities experience their peak demand. As the mix of supply resources change, there will be changes in the average emissions from the system, and more importantly, in the emissions of the generating facilities on the margin. The impact of the seasonal and time-of-day variations of DSM programs and marginal supply resources must be considered when determining the overall environmental impacts of DSM measures.

The time of day and seasonal characteristics of pollutant releases may also affect their ultimate environmental consequences. This is due to the physical, demographic and ecological conditions that affect the exposure and sensitivity of the populations at risk. For example, seasonal and diurnal wind conditions affect the dispersion and concentration of air pollutants; the presence and amount of sunlight affects the production of photochemical smog; the growth cycles of vegetation and spawning cycles of organisms have temporal characteristics that amplify or cancel the temporal patterns of pollutant release and dispersion.

A very different issue of timing also arises in comparisons of DSM versus power supply impacts. A long-lived DSM measure may displace many years of power generation; many of the most important avoided impacts are spread evenly over those years. However, the DSM impacts differ in timing, depending on the specific measure under consideration, and the point in the DSM product lifecycle at which the impacts occur. Thus DSM impacts may occur years before or after the avoided impacts of generation.

To address this problem in depth it would be necessary to choose, and justify the selection of, a discount rate for environmental impacts. This, however, would further complicate an already complex problem and is beyond the scope of this paper. The illustrative calculations presented work are based on simply adding environmental effects regardless of their timing, i.e. without discounting. Furthermore, many of the comparisons are so one-sided that the outcome would not be affected by any plausible discount rate.

Conclusions

This study reaches two principal conclusions. First, well-chosen DSM technologies in each of the areas considered can provide clear environmental benefits. Although a variety of environmental problems can be raised in connection with DSM, these problems can generally be minimized or eliminated through careful program design and technology choice. In every case in which quantitative comparison is possible, the direct environmental impacts of well designed DSM programs are much smaller (often by one or more orders of magnitude) than the avoided impacts of electricity generation.

For programs such as shell tightening and weatherization, in many instances simply being aware of the potential impacts of DSM programs can help to mitigate environmental problems. Informing residential customers about the conditions under which household appliances or products can create indoor air hazards is a valuable service that could be performed while marketing DSM programs.

In other cases, mitigation of environmental impacts of DSM through program design may be more complex. For example, recapturing and recycling CFCs from residential refrigerators can be a complicated undertaking. Replacement of CFCs with less energy-efficient refrigerants, or even a moderate level of losses of CFCs to the atmosphere during recycling, can reduce or eliminate the anticipated environmental gains of the program. Careful attention must be paid to research in the field, as well as to the details of program design and implementation.

In others areas such as efficient motors, the direct environmental impacts are negligible.

In fuel switching, environmental benefits can potentially be achieved or costs incurred. The emission characteristics of each individual technology, along with the marginal emissions of the host utility and the sensitivity of the environmental into which the emissions are being must be considered in the environmental analysis of any fuel substitution program.

The issues identified in this study will not be the only environmental issues facing DSM planners. Continuing research will be required to minimize the adverse environmental impacts of DSM. This is not accidental, but is intrinsic to the nature of the service being provided. When a utility sells electricity, it provides a single, well-known commodity. But when it provides DSM measures, it reshapes the living and working spaces of its customers, touching a wide array of technologies, materials, and potential hazards. The resulting range of impacts on the environment is a vital area for further research.

Endnotes

1. We assumed that the electricity serving the absorption chiller is provided by the summer marginal mix of the New York Power Pool (Tellus, 1990).

2. Materials from personal communications with Jim Hirzel, General Electric Motors, 1991.

3. Soil permeability can vary by over 8 orders of magnitude, from very impermeable clay-silt type soils to highly permeable loose gravel soils.

4. "Environmental," "side-stream" or "secondhand" tobacco smoke referred to here is the smoke emitted by the smoldering cigarette or exhaled by the smoker, which can then be inhaled by non-smokers.

5. Recent research has suggested that the ozone depleting characteristics of CFCs can counterbalance their greenhouse impacts.

6. This tradeoff depends upon the generation mix serving the appliance and the amount of refrigerant released during use and upon retirement.

7. Assume that 0.79 million refrigerators and freezers--10% of the number sold in the U.S. in 1988--were replaced with HCFC-22 units, which used 5% more electricity than equivalent CFC-12 models. Then electricity use would increase 30 GWh/yr due to the introduction of these new units (assuming 700 kWh/yr base electricity use). The emissions associated with this energy penalty over the lifetime of the refrigerators and freezers have a global warming potential equivalent to the release of the CFC-12 in 1.6 million refrigerators, assuming the New York Power Pool marginal baseload mix emissions (Tellus Institute, 1990). If as little as 15% of the CFC-12 in retiring refrigerators is not recaptured, then the efficiency loss of switching to HCFC-22 negates all of its greenhouse gas savings of switching to the more greenhouse friendly refrigerant.

   Note that this addresses only greenhouse gas release, and not ozone depletion issues. Policy makers will have to weigh such tradeoffs when setting efficiency standards and CFC regulations.

References

Baldwin, Samuel F., 1989. "Energy Efficient Electric Motor Drive Systems," in *Electricity: Efficient End-Use and New Generation Technologies, and Their Planning Implications*, Johansson, Thomas B., Birgit Bodlund, and Robert H. Williams, eds. Lund University Press, Sweden.

Caneta Research, 1991. "Gas Cooling Study, prepared for Consumers Gas and Canada Dept. of Energy, Mines and Resources. Toronto Ontario.

Chernick, Paul, Eric Espenhorst and Ian Goodman, 1990. "Analysis of Residential Fuel Switching as an Electric Conservation Option," presented at the 7th National Association of Regulatory Utility Commissioners Biennial Regulatory Information Conference.

DuPont, Peter and John Morrill, 1989. *Residential Indoor Air Quality and Energy Efficiency, American Council for an Energy-Efficient Economy,* Washington, DC.

Electric Power Research Institute 1990, Brochure, "CFCs and Electric Chillers: Selecting Large Water Chillers as CFCs are Phased Out," EPRI, Palo Alto, CA.

EMR (Energy, Mines and Resources, Canada), 1986. "Ventilation and Air Quality in R-2000 Homes: Measurement and Analysis." Technical report for the R-2000 Home Program. Ottawa, Ontario.

Epstein Gary J and Steven P. Manwell, 1991. "An Assessment of the Environmental Trade-offs Between CFC Use and Lower Efficiency Cooling With Alternative Refrigerants," *DSM and the Global Environment*, p 265-276. Synergic Resources, Bala Cynwyd, PA.

Frische, Ewe, 1991. *Total Emission Model for Integrated Systems (TEMIS),* OKO-Institut, Darmstadt, FRG.

GAMA (Gas Appliance Manufacturers Association) 1991, *April 1991 Consumers' Directory of Certified Efficiency Rating of Residential Heating and Water Heating Equipment*, GAMA, Arlington VA.

Hansen, Shirley, 1990. "Quality Indoor Air Through Preventive Strategies," *Indoor Air '90, Proceedings of the 5th International Conference on Indoor Air Quality and Climate*, Vol 3, pp 407-412. Toronto, Ontario.

Hanser, Philip and Edward Weaver, 1991. "Direct Environmental Impacts of End-Use Technologies," proceedings, *DSM and the Global Environment*, pp 243, Synergic Resources, Inc. Bala Cynwyd PA.

Harrison, J., C.A.C. Pickering, E.B. Faragher and P.K.C. Austwick, 1990. "An Investigation of the Relationship Between Microbial and Particulate Indoor Air Pollution and the Sick Building Syndrome," *Indoor Air '90, Proceedings of the 5th International Conference on Indoor Air Quality and Climate*, Vol 1, pp 149-154. Toronto, Ontario

Kellum, Ziba, 1991. North Carolina Alternative Energy Corporation. Personal communication, October 22.

Lavender, R. Gerald, "On-Site Procedures of Assessment and Solution of Indoor Air Quality Problems Related To HVAC Systems Performance," *Indoor Air '90, Proceedings of the 5th International Conference on Indoor Air Quality and Climate*, Vol 4, pp 65-70. Toronto, Ontario.

Nadel, S. et al., 1991. *Energy Efficient Motor Systems: A Handbook on Technology, Programs, and Policy Opportunities*, American Economy for an Energy-Efficient Economy, Washington D.C., and Berkeley, CA.

Repace, J.L. and H.S. Lowery, "A Quantitative Estimate of Non-Smokers Lung Cancer Risk from Passive Smoking," *Environmental International*, 11(1):3-22. Quoted in Dupont and Morrill, 1989.

RMI, 1990. *Competitek* Residential Refrigerators and Freezers, pp. 47-60. Rocky Mountain Institute, Snowmass CO.

Southwest Gas Corp, 1991. "1990 Southern Nevada Resource Plan, Revised Demand Management Plan Technical Appendix," Las Vegas, NV.

Tellus Institute, 1990, "Long Island Power Authority Comments on the LILCO 1991-2 Electric Conservation and Load Management Plan. Volume II: Appendices," p. 20. Boston, MA.

Turk, B.H., et at, 1987. "A Comparison of Indoor Air Quality in Conventional and Model Conservation Standard New Homes in the Pacific Northwest: Final Report." LBL report no. LBL-23429, Berkeley, CA.

UNEP 1989a, "Technical Progress in Protecting the Ozone Layer" Refrigeration, Air Conditioning and Heat Pumps. Technical Options Report," United Nations Environment Programme., p.31. New York, NY.

UNEP 1989b, "Technical Progress in Protecting the Ozone Layer" Flexible and Rigid Foams. Technical Options Report," United Nations Environment Programme, p.19. New York, NY.