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FINAL REPORT: ANALYSIS OF MICHIGAN'S DEMAND-SIDE ELECTRICITY RESOURCES IN THE RESIDENTIAL SECTOR

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Final Report: Analysis of Michigan's Demand-Side Electricity Resources in the Residential Sector

Volume III. End-Use Studies

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ANALYSIS OF MICHIGAN'S DEMAND-SIDE ELECTRICITY RESOURCES IN THE RESIDENTIAL SECTOR*

Volume III

End-Use Studies

by

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1. REFRIGERATORS

A. MEOS BASELINE DATA

END-USE:	Food Refrigeration
FUEL:	Electricity
TECHNOLOGY:	Refrigerators and refrigerator/freezers

GENERAL

The following section covers refrigerators and refrigerator/freezers. A separate section deals with appliances that are used for freezing only, i.e. freezers. An electric refrigerator is defined as a cabinet for storing food at temperatures above 32°F. It may include a compartment for the freezing and storage of food at lower temperatures but is lacking a separate compartment for freezing and long-term storage of food below 8°F.

A refrigerator/freezer consists of two or more compartments with at least one of the compartments designed for the refrigerated storage of foods at temperatures above 32°F, and with at least one compartment for the freezing and storage of frozen foods at 8°F or below. The freezer compartment may be adjustable to 0°F or below. Residential refrigerators are defined as having a size of less than 36 cu.ft.

Contribution to total electricity use. Refrigerators and refrigerator/freezers (RRFs) constitute the single largest end-use in Michigan's residential sector (see Table 1-1). They accounted for 1.86 billion kWh or 23 percent of Consumers Power's 1985 residential sales (2.57 billion kWh or 26 percent in the case of Detroit Edison). The total consumption in both service territories of 4.43 billion kWh amounts to the annual output of one very large (890 MW) baseload power plant running at a capacity factor of 57 percent, with 7% transmission and distribution losses.

Table 1-1. Refrigerator and Refrigerator/Freezer Energy Use and Loads

Utility	Equip. Type	Saturation 1985 (%)	Stock 1985 (x1000)	UEC (kWh)	UPD (summer) (W)	Total Use (GWh)	Peak Demand (MW)	Marginal UEC 1984 (kWh)
CP	Standard	29.8	362	803	108	291	39	868
	Frost-Free	69.9	851	1609	216	1370	184	1186
	Second Units	17.1	208	939	125	196	26	
	ALL					1857	249	
DE	Standard	26.8	438	835	112	366	49	868
	Frost-Free	72.8	1190	1530	205	1821	244	1186
	Second Units	20.2	330	1167	157	386	52	
	ALL					2573	345	

Contribution to peak demand. RRFs show a moderate, but not negligible seasonal and diurnal variation in energy consumption. CP's submetering data show that energy consumption, and therefore total demand, is about 20 percent above the annual average in the month of the summer peak, and 10 percent lower during the month of the winter peak. During the day, peak loads occur in the evening period of heaviest usage, and are an estimated 30 to 40 percent higher than the daily average. Because of this seasonality and diurnal variation, refrigerator/freezers contribute more significantly to the residential summer peak than to the winter peak.

Main product types. From a performance and utility point of view, refrigerators and refrigerator/freezers can be grouped into the following eight subtypes:

- manual defrost refrigerator
- partial automatic defrost refrigerator
- automatic defrost with top-mounted freezer
- same with through-the-door features
- automatic defrost with side-by-side freezer
- same with through-the-door features
- automatic defrost with bottom-mounted freezer
- compact refrigerators.

US sales by type. The Association of Home Appliance Manufacturers last published national sales data by type for 1984 (AHAM 1985). AHAM uses four rather than eight product classes (compacts combined with manuals, bottom-mounted with side-by-side, and through-the-door units combined with standard units). Table 1-2 gives sales shares for 1972 and 1984. These data show that top-mounted-freezer models are by far the most dominant category. These accounted for over 70 percent of total sales in 1984.

Table 1-2: Sales Shares of Refrigerator Subtypes[1]

Refrigerator Subtype:	1972 (%)	1978 (%)	1981 (%)	1983 (%)	1984 (%)
Manual Defrost	15	9	8	6	5
Partial Auto-Defrost	20	13	11	10	7
All Standard	35	22	19	16	13
Top-Mounted Auto-Defrost	49	61	66	69	72
Side-by-Side/Bottom-Mounted Auto-Defrost	16	18	15	15	16
All Frost-Free	65	78	81	84	88

(1) Source: AHAM 1985.

Saturation of refrigerator/freezer ownership. Virtually all households own at least one refrigerator (99.6 percent for CP, 100 percent for DE). A significant number of customers own a second refrigerator/freezer (16.9 percent for CP, 20.2 percent for DE).

Demographic distribution by subtype. The utility surveys distinguish only between manual (including partial automatic defrost) and frost-free refrigerators. Manual units are more common than frost-free models among residents of multifamily homes, i.e. renters and poorer households. Within the CP service area manual defrost refrigerators are found in 21.2 percent of the single family and 53 percent of the multifamily residences. Automatic defrost refrigerators occur in 78.5 percent of the single family residences and 47.1 percent of the multifamily. Seventy eight percent of the DE area single family residences have frost-free refrigerators while 22 percent have manual defrost models. Whereas 66 percent of the multifamily residences have manual refrigerators, only 34 percent have the automatic defrost model.

BASIC ENERGY CHARACTERISTICS

Ratio of energy costs to capital costs. Energy costs for a standard top-mounted freezer of 1986 vintage, at 7.75 cents/kWh, range from $61 to $124 per year. This is 9 to 18 percent of the purchase price (Sears 1986 Fall-winter Catalog Midwest).

Key factors affecting electricity use. The major determinants of refrigerator efficiency are:

- Compressor efficiency
- Thermal integrity of the cabinet (insulation and gaskets)
- Form of coupling between freezer and refrigerator compartments
- Form of defrost mechanism (automatic or manual)
- Controls (anti-sweat switch, temperature control)
- Features (through the door icemakers, etc.)
- Utilization intensity
- Temperature settings
- Maintenance (cleaning of condenser coil, defrosting)

A detailed discussion of these aspects is found under the "Measures" section. Here, we sketch the relationship of energy consumption to the designs of the various product classes.

All other things being equal, automatic defrost models consume more energy than "standard" manual defrost units because they circulate dry, cold air, melt frost when performing a defrost cycle, and have to remove defrost heat from the cabinet. While top-mounted freezers are the most common frost-free type, and are the most energy-efficient design, side and bottom-mounted freezers are preferred by some consumers because they find access to the fresh food compartment more convenient.

Side-mounted freezers use more energy because of larger door seal areas, and because the hot motor compartment of the compressor is adjacent to the bottom of the freezer section. This tends to increase heat gain into the cabinet. Bottom-mounted designs have the same heat gain problem from the motor, and also require increased fan power to transport cold air upwards from the evaporator to the top of the fresh-food compartment. This form of cold air transport often results in the need for auxiliary heat to prevent freezing in the colder stratum of the refrigerator compartment.

Through-the-door features for chilled liquids and ice bring with them an area of reduced door insulation, and electric heaters may be required to prevent condensation on the dispenser hardware. Consequently, these models, which constitute about five to ten percent of top- and side-mounted shipments, consume more electricity than standard models.

Compact refrigerators (less than 9 cu.ft.) are typically less efficient (in terms of kWh per unit of refrigerated volume) because smaller cabinets have increased surface to volume ratios, and because smaller compressors, motors and fans are usually less efficient as well.

Formula for calculating energy consumption. Refrigerator energy consumption is usually tested in a standard DOE test cycle. Detailed discussions of model-based engineering-economic methods for calculating energy consumptions can be found in several reports (DOE 1982, ADL 1980, ADL 1977). Two formulas are in use for extrapolating such test results to different volumes. The California Energy Commission's standards are based on

$$EC = a + bV,$$

where EC = energy consumption (in kWh/year)
V = volume in cubic feet

a and b are numerical constants.

The Department of Energy's *energy factor (EF)* is defined as

EF = corrected volume (cubic feet)/daily power consumption (kWh/day).

The corrected volume is given by

corrected volume = (freezer vol. x C) + refrigerated volume

where C is a constant to adjust for different freezer/fresh food compartment volume ratios. The value for C is 1.63 for refrigerator-freezers and 1.73 for freezers.

EXISTING MICHIGAN STOCK

Composition of Existing Stock

Saturations by type. The surveys of the two utilities provide information on refrigerator/freezer types only for first units, and distinguish only two categories: frost free and manual defrost. Consumers Power indicated that the second units are mainly manual defrost. Table 1-1 shows the total number and percentages by type.

Saturation trends. In Detroit Edison's largely urban territory, manual and frost-free models had approximately equal market shares in 1967, and second units were found in 21 percent of all households. By 1985 the frost-free model saturation was an estimated 72.8 percent. According to the MEOS WG5 forecast, the frost-free models will reach a saturation of 80 percent in 2005. Second model saturations will remain constant at 20 percent.

In Consumers Power's territory, manual models dominated the 1967 stock (75 percent saturation). Second units had only an 11 percent saturation. By 1985, the proportions had become similar to those of DE (70 percent saturation for frost-free units, and 17 percent for second units). The MEOS WG5 forecast sees a 75/25 share of manual and frost-free units in 2005, and an 18.9 percent saturation of second units.

Unit size. Historic size trends for US sales are shown in Table 1-3. Approximate sizes for Michigan can be inferred from these data.

Table 1-3: Size Trends in U.S. Refrigerator Subtypes[1]

	Size (cubic feet/unit)[2]				
Refrigerator Subtype:	1972	1978	1981	1983	1984
Manual	11.75	11.93	11.94	12.35	12.65
Partial Auto-Defrost	14.80	15.11	15.22	15.39	15.04
All Standard	13.46	13.75	13.76	14.18	14.06
Index	*1.0*	*1.02*	*1.02*	*1.05*	*1.04*
Auto-Defrost Top-Mounted	19.35	20.13	20.08	20.39	20.30
Side-by-Side/Bottom-Mounted	24.89	25.83	26.32	26.25	26.54
All Frost-Free	20.69	21.40	21.29	21.45	21.44
Index	*1.0*	*1.03*	*1.03*	*1.04*	*1.04*

(1) Source: AHAM 1985.

(2) AHAM Adjusted Volume/Unit (cu. ft.)

Unit life. AHAM indicates a range of 11 to 18 years for the average refrigerator life. We use a value of 19 years in this study. This estimate is based on LBL's residential data base, which reflects a compilation of national sales statistics since 1940. This figure also agrees with the estimates of major manufacturers.

The life of a refrigerator has an important socio-economic component. First, poor households have been found to keep their units for much longer than 19 years, e.g. up to 25 years, while better-off households will buy a new unit earlier. These households also keep a significant fraction of their old refrigerators as second units. We assume that second units have a life of 6 additional years and first units a life of 18 years on average. The weighted average lifetime using CP and DE saturations is then about 19 years.

Unit Energy Consumption of Existing Stocks

UECs by appliance type. There are two sources for estimating unit energy consumptions: manufacturer's test data, and submetering data from the utilities. Since submetering samples are very small, it is necessary to compare metered results with manufacturer's test data.

Only Consumers Power has recently conducted submetering load studies (in 1983/84 and 1979/80). These studies were limited to frost-free refrigerator-freezers. They involved small samples (31 and 35 customers) and are therefore unreliable for generalization to the customer base at large. Both tests resulted in identical consumption figures of 1640 kWh/year. The average size of the units was 17 cubic feet in both studies. Average vintages were 7 years and 5 years, respectively. Temperature settings deviated widely from the recommended settings of 38°F for the fresh food compartment, and 0°F for the freezer compartment (27-52°F and -10 to 16°F, respectively). Gains in efficiency from newer equipment were apparently compensated for by a greater number of larger and more energy-intensive side-by-side units in the 1983/84 sample. The share of electricity used for refrigeration in total household consumption was 20 percent, close to the average for the customer base at large.

By comparison, AHAM shipment-weighted averages for unit energy consumption are available for 1972 and from 1978 to the present. 1978 most closely approximates the average vintage of the existing stock at the time of the submetering experiment. The 1978 weighted average for automatic defrost units of all kinds was 1622 kWh/year (see Table 1-4). There is close agreement between the two numbers, but no analytic importance can be assigned to this fact, because it could be coincidence.

Table 1-4: Trends in Efficiencies in U.S. Refrigerators[1]

	1972		1978		1981		1983		1984		Best Current
Refrigerator Subtype:	UEC	EF[2]	UEC	EF	UEC	EF	UEC	EF	UEC	EF	UEC
Manual	641	6.69	606	7.18	590	7.39	565	7.98	566	8.19	400
Partial Auto-Defrost	1262	4.28	1029	5.36	980	5.67	966	5.82	982	5.69	748
All Standard	990	5.34	849	6.14	807	6.43	808	6.67	812	6.66	
Index	*100*		*86*		*82*		*82*		*82*		
Auto-Defrost Top-Mounted	1986	3.56	1548	4.75	1198	6.12	1150	6.47	1099	6.75	748
Side-by-Side/Bottom-Mounted	2547	3.57	1879	5.02	1626	5.93	1570	6.10	1584	6.12	1265
All Frost-Free	2121	3.56	1622	4.81	1297	6.08	1226	6.40	1188	6.63	
Index	*100*		*76*		*61*		*58*		*56*		

(1) Source: AHAM 1985.

(2) Energy Factor=corrected volume/daily power consumption (ft^3/kWh-day).

Another method for estimating the average unit energy consumption of existing stock is to weight the historic sales by their respective average efficiencies. The results for frost-free models are within one to two percent of the utility-provided estimates (CP: 1615 kWh frost-free, 1076 kWh standard for 1984 stock; DE: 1504 kWh/yr frost-free, 737 kWh standard for 1985 stock)

Load Profiles

Average annual load. For Detroit Edison the average annual load (UEC spread over 8766 hours) of frost-free units is 172 W, and that for standard units is 84 W. Second units draw 110 W on average. For Consumers Power, the corresponding values are 184 W, 123 W, and 123 W.

Unit power input ratings. The power requirements of top-mounted frost-free refrigerator/freezers of standard size and stock-weighted average consumption are approximately 300 W. More efficient models require 180-200 W, e.g. Whirlpool's high efficiency 17 cu.ft. model consuming half the Michigan stock average kilowatt hours uses 175 -190 W for the compressor (70 - 90°F ambient, 115 V). For auxiliaries, the unit uses 4 W for the anti-sweat feature, 8.6 W for the mullion heater, 10 W for the interior fan, and 13.5 W for the condenser fan. The defrost cycle draws 655 W (120 V test).

Seasonal variations. Refrigerator/freezers show a significant seasonal variation in their energy use. Two submetering studies by Consumers Power found that the peak monthly consumption in the hot summer months of July and August was about 30 percent higher than during the winter and shoulder season months. Detroit Edison estimates that the peak-to-average load ratio (the ratio of diversified unit demand at system peak compared to the average annual demand that results from dividing the UEC by 8766 hours) is 1.3 to 1.4.

Diurnal variations. No measured hourly load data were available from Michigan utilities. Recent submetering studies by Pacific Gas and Electric Co., Sierra Pacific Power Co., and Niagara Mohawk Power Co. indicate that a significant diurnal variation of refrigerator loads occurs, e.g. PG&E's study found a small breakfast peak and a larger evening peak, reflecting the period of most intensive use (Brodsky et al. 1986). This evening peak would be expected to be highly coincident with the evening components of winter and summer peak. The utility studies generally found little variation in the hourly profile during winter and summer, so that the seasonal effect can be represented by a seasonal factor that applies to all 24 hours.

To illustrate the aggregate impact of this load profile on the system, consider the following order-of-magnitude estimate. From an annual average point of view, the load of CP's 1984 RRF stock was 200 MW. Using the seasonal peak-to-average load factors of 1.20 and .9, and a daily peak-to-average load factor of 1.3, one obtains a 312 MW contribution to summer peak, and a 234 MW contribution to winter peak.

As refrigerator efficiencies increase and the heat gains from door openings become more dominant in total power consumption, an even more pronounced peaking in the refrigerator load profile can be expected.

Diversified loads. Because of the lack of Michigan-specific hourly data, we estimated a fraction-in-use profile (here an hourly-to-average load profile based on the average annual load) for winter, transition season, and summer days, using CP's monthly measurements and the profile found in the PG&E submetering experiment. The results are shown in Appendix B.

CURRENTLY SOLD EQUIPMENT

General Characteristics

Marginal saturations of subtypes. The composition of recent US shipments by product type can be seen in Table 1-2. The trends toward automatic defrost units at the expense of manual and partial automatic units was strong between 1972 and 1978 but has slowed over the last few years. Side-by-side and bottom-mounted units have kept a virtually constant share of sales. MEOS estimates of relative saturations are found in the tables of the Appendix.

Marginal size. The shipment-weighted average volume of refrigerators has increased only slightly since 1972, from 18.2 cu.ft. to 20.5 cu.ft., and has recently remained stable. The same statement holds true for the various subtypes (Table 1-3).

Current costs. A cursory survey of five retail stores in Michigan showed that standard automatic defrost top-mounted freezer models are available for ca. $600 to $700 in Michigan (1986). For manual defrost models of average (12 cu.ft.) size, the estimated cost range is $300 to $400. These numbers should be taken as rough order-of-magnitude estimates only. The design of incentive programs should be preceded by more systematic surveys of the average cost and efficiency of equipment currently sold in Michigan.

Marginal Unit Energy Consumption

Marginal UECs. The marginal unit energy consumption of new refrigerators by type can be inferred from the most recent AHAM statistics for shipment-weighted average energy efficiencies. As shown in Table 1-4, stock-average UECs have dropped steadily since 1972; the drop is largest for the most popular top-mounted frost-free models, whose UEC has dropped by almost half. This means that the turnover of equipment alone will bring a substantial reduction in electricity demand for refrigeration. Table 1-4 also shows that the most significant efficiency gains occurred in the late 1970s. Since 1981, the shipment-weighted average has changed very little, decreasing by about 1.5 percent per year.

B. DEMAND-SIDE MEASURE DATA BASE

END-USE:	Food Refrigeration
FUEL:	Electricity
TARGET TECHNOLOGY:	Refrigerators and refrigerator/freezers
DS MEASURE:	Highly efficient new refrigerator or refrigerator/freezer
IMPACT OF MEASURE:	Primarily baseload electricity conservation

GENERAL DESCRIPTION

Technology Features

Technical options to increase the energy efficiency of refrigerators can be grouped into five categories: Reduction of conductive heat gains, reduction of infiltration heat gains, reduction of internal heat gains, improvements in the compressor and evaporator/condenser systems, and better controls. Even though these technologies have been proven in the laboratory or as prototypes, there remains considerable work in constructing a refrigerator with these features that can be reliably mass-produced. Some options are already appearing in refrigerators; however, no model has incorporated them *en masse*.

Better compartment insulation.

1. Polyurethane foam insulation can be substituted for fiberglass insulation in freezer and refrigerator compartment doors. Polyurethane has a thermal conductivity lower than that of fiberglass.
2. Insulation in the refrigerator compartment can be increased from current levels of less than 2 inches to at least 2 and up to 2.5 inches, and to up to 3 inches in the freezer compartment.
3. An advanced technology is evacuated panel insulation, which would drastically reduce conductive heat gains and provide large energy savings. The panels would provide insulation levels of R-150 per inch of evacuated space. This means that not only would the thermal integrity of the cabinet be vastly improved but storage space would increase as well. The technology is currently being considered by all U.S. manufacturers and is also being developed by A.D. Little, Inc. and the Solar Energy Research Institute.

Better gaskets.

4. Adding a second gasket on the inside of the door can cut heat gains. These double gaskets are added to both the refrigerator and the freezer doors.
5. Instead of using double gaskets, improved single gaskets can also be used. They offer a significant portion of the energy savings potential of the two-gasket concept. Other features may also be effective, since it is not clear at this time how much of the heat loss attributed to gaskets is in fact caused by other thermal short-circuits in the door area, e.g. a measure that has been used in recent prototype work to reduce the convective heat transfer to the gasket area is a protruding moulding on the inside of the door that fits into an equivalent recess in the cabinet.
6. The cooling load contribution of through-the-door features in automatic defrost models can be decreased with improved insulation.

Increased compressor and fan efficiencies.

7. Compressor efficiency can be increased with off-the-shelf units to 4.6 EER. In 1980, refrigerator/freezers typically used compressors with energy efficiency ratios (EER) around 3.2. Typical units now have EERs of close to 4.

8. Compressor efficiency can be further raised to 5.0. A compressor unit with an EER of 5.0 has been developed and field tested under Department of Energy sponsorship and is expected on the market in the very near future.
9. Variable speed drives for refrigerator compressors can also increase refrigerator efficiency, in two ways. First, the average efficiency of the electric motor driving the compressor increases, because the motor runs closer to full load. Second, the compressor, which must be sized to meet the need for rapid cool-down, can be reduced in size when using a VSD compressor, since the extra capacity needed for cool-down can be provided by changing the motor speed and output as required.
10. In automatic defrost units, a dual or hybrid evaporator can substantially reduce the energy needed for defrosting, as well as avoid the overcooling of the refrigerator compartment's air, which is a problem with current designs. A separate cold coil is fitted in the refrigerated compartment. This coil defrosts naturally during the off-cycle when the temperature in the refrigerator compartment rises above 32°F. With the freezer and fresh food section separated, the humidity load can be reduced by 90 percent, and the need for defrost energy is reduced proportionately.
11. A more radical redesign is to use two separate compressor/evaporator systems for the refrigerator and freezer compartment. This design also provides excellent temperature control. One small U.S. firm and several European manufacturers use this design.
12. Increased evaporator surface areas can provide for more efficient operation of the refrigeration system.
13. Adding more condenser surface is another option to achieve the same goal.
14. Relocating the compressor and the condenser to the top of the unit would make both run cooler and therefore, more efficiently. Heat would be more efficiently convected away from the unit.
15. Another possible energy saving approach is to use a heat pipe and heat exchanger located outside the heated building envelope. This would eliminate almost all energy use in cold weather.
16. Compressor motor compartments are often cooled with electric-motor driven fans. Both fans and motors can be replaced by more efficient units.

Reduced internal gains.

17. Fans and fan motors that are used to transport cold air from the freezer compartment to the refrigerator compartment consume 10-16 W and can be replaced with dry-film capacitor motors using 5-8 W and fans of better design. This saves energy not only in the fan motor, but also reduces the internal heat gain of the unit.
18. Mounting the fan motor externally can avoid the dissipation of motor heat into the cooled space.
19. In some units with dual compressors, natural convection can be used to replace fans entirely. This saves both fan motor power and avoids the heat gain from internal motors and fans.

Better controls.

20. An anti-sweat heater switch can be fitted to allow customers in low humidity environments to switch off the external heating function that prevents condensation on the cabinet in humid environments. The wattage used by this function can also be reduced.

21. Adaptive defrost controls (demand defrost) for frost-free models are "smart" controls that use microchip technology. They can save significant energy depending on the model, usage, and ambient conditions. These controls can be of several types. For example, in one version the unit "learns" how often a defrost cycle is needed from the time required to defrost the unit previously. Others sense the frost build-up on the evaporator coil. Several prototypes have been developed and demonstrated.

Technology Status and Availability

Perhaps with the exception of evacuated insulating panels, all of the above 21 options can be called currently demonstrated with available technology. Some of the listed options, such as improved compressors with EERs of up to 4.6, are available off-the-shelf. Other technical options, such as microchip controls, have been successfully applied in other consumer products and can be transferred with little adaptation. Also, a number of the above-mentioned options can be found in the various high-efficiency models, but these improved features are dispersed over different models and manufacturers. Often implementation is only partial (e.g., insulation thickness). More detailed discussion of refrigerator technologies can be found in Goldstein and Miller (1986), Goldstein et al. (1986), and Levine et al. (1985 and 1986).

To translate the many possible combinations in which these technologies could be applied into features of a marketable product often requires a considerable amount of testing and product development. In particular, manufacturers seek to ensure that efficiency improvements do not compromise the reliability of the product, which is of top priority to consumers. Appliance manufacturers have limited budgets for pursuing this R&D work, and implementation of significant gains in efficiency can only be expected over a period of several years. We briefly review best current models, typical practice, and recent prototype work.

The best currently available top-mounted refrigerator-freezer, a Whirlpool 17.2 cu.ft. model, uses a compressor of 4.5 EER; a more efficient defrost fan motor (with the fan in its conventional location); 2.5 inch polyurethane foam insulation in the walls, and 1.5 inches in the doors; and some minor improvements in the cooling system. It achieves an annual energy use of only 750 kWh compared to the sales-weighted average of 1100 kWh for top-mounted frost-free models in 1984. This superior performance was achieved without retooling, and specifically does not include demand defrost, larger heat exchangers, or any other more far-reaching modifications.

Average practice incorporates fewer options, despite significant efficiency gains over the last ten years. For example, the same company reports for its overall production that for new cabinets being tooled, insulation levels are 1.9 inches in the refrigerator compartment walls, and 2.0 inches in the freezer compartment walls. Over 75 percent of the models have foam insulation in the freezer door, but only a few have foam in refrigerator doors. Nearly all units have EERs of 3.9, but only a few reach 4.3 or 4.5. Virtually all units have anti-sweat switches, and the wattage for the feature has been reduced by about 50 percent in the last few years. Evaporator fan power has been reduced 20 percent since 1980.

Recently, a high performance prototype 18 cu.ft. top-mounted automatic defrost unit was built by a Danish university/industry team under joint sponsorship by the California Public Utility Commission (CPUC) and two large California utilities. The unit, which consumes 530 kWh in DOE tests, exceeds the 1992 California standard by 26 percent, makes use of 2.5 inches and 3.35 inches insulation in the fresh food and freezer compartments, dual compressors, electronic defrost controls, and larger heat exchanger surfaces.

The condenser is mounted on the inside of the outer cabinet and provides the anti-sweat function without additional energy. The same mounting allows for the use of condenser heat to prevent the freezer door gasket from freezing shut.

An even more efficient 17 cu.ft. custom-built partial-automatic defrost unit is available from a small U.S. manufacturer. It uses roughly less than half the calculated energy requirements of the CPUC prototype. The unit, which is geared toward photovoltaics-powered applications, features three to four inches of polyurethane foam insulation and dual compressors.

Special problems and current limitations. Refrigerators using dual evaporators have been produced in the past by one manufacturer in the U.S., but were discontinued due to apparent problems of temperature regulation. Manufacturers say that the hybrid evaporators can create problems with temperature regulation in some applications. The problem could be remedied by the addition of a small fan to improve the convective heat transfer from the evaporator. A further alternative to deal with these applications at additional efficiency gain would be to use dual compressors.

Another improvement that has raised concern among some manufacturers are double door gaskets. Alignment problems, freezing between the door gaskets, and less than the expected 50 percent heat gain reduction are some of the reported problems. Currently, additional development and field testing is required to overcome these problems. However, the 50 percent reduction in heat gains attributed to gasket conductance can likely be achieved or exceeded by alternative measures, such as better single gaskets, redesigned door moldings, and attention to heat bridges that might be reducing gasket effectiveness.

High levels of insulation thickness have to be accommodated with either a larger cabinet or by reducing storage volume. This is mainly a problem with the very large units, where outside dimensions cannot be extended further. The loss of storage space in standard-sized frost-free units of constant outside dimensions ranges from 2 to 10 percent for insulation thicknesses of less than 2.5/3.0 inches, depending on the baseline. For large-sized refrigerator/freezers, evacuated powder panels offer the most promising solution. With these panels, storage space is actually increased over that of standard models.

Further development is needed to ensure that evacuated panels will hold their vacuum for the entire service life of the refrigerator.

One manufacturer has raised the issue that highly efficient (EER 5.0) compressor units appear to be noisier than ones that are currently in use. If forthcoming commercial products do not overcome this problem through better design, special noise insulation may be required.

In field tests, the DOE-sponsored EER 5.0 prototypes also achieved a slightly lower than calculated efficiency. These prototypes used electric motors of standard efficiency. Here, the use of electric motors of improved efficiency can likely restore or augment the nominal performance.

A potential disadvantage of externally mounted defrost/cold air fan motors is that they would require seals that may need servicing. If better motors and fans or dual compressors and demand defrost controls are used, the load contribution of the fan unit will be substantially reduced. The significance of this measure would be correspondingly reduced. In dual compressor units where convective defrosting is applicable, the fans can be eliminated entirely.

Highly efficient refrigerators require additional heat capacity in the heat exchanger unit to keep condenser and evaporator temperatures at their optimum. (Pedersen et al. 1986). Another possible approach is to use electronic motor controls (variable speed drives), which also bring other important benefits (described previously).

Improvements in refrigerator utility. The use of a hybrid evaporator or dual compressor set-up improves not only the energy efficiency of the unit, but also substantially improves the freshness of stored food in the refrigerator compartment. Because the periodic injection of an overly cold air stream from the freezer compartment into the refrigerator compartment is avoided, the drying out of food is slowed significantly. Freezer burn is also eliminated.

An advantage of dual compressor units, besides their superior temperature control capabilities and more effective preservation of freshness, is that they allow the use of the energy- and money-saving partial-automatic defrost mechanism without most of the attendant inconveniences currently posed by units of that design. Frost build-up in the isolated freezer compartment is very slow, as is the case in the hybrid system, and a very efficient unit may require as little as one defrost operation every six months. When defrosting is done, food no longer has to be removed from the refrigerator entirely, but can be simply transferred from the freezer to the fresh food compartment. The freezer compressor can be switched off separately. Quick-melting items such as ice cream can be prevented from spoiling while the ice bond in the compartment breaks (within an hour or so) and the frost ice is removed. Similarly, the fresh food compartment can be switched off during vacations without affecting the frozen food. This brings energy savings beyond those based on standard test cycles.

Highly insulated refrigerators also provide better protection against food spoilage in the case of power outages.

Evacuated panels would bring two utility benefits. One is increased storage volume, compared to both high-efficiency designs using foam insulation and models with current standard insulation levels. The other is avoidance of atmospheric impacts from additional chlorofluorocarbon (CFC) releases associated with increased use of polyurethane foam.

Secondary energy impacts. The energy consumption of refrigerator/freezers constitutes a heat gain in the home which reduces heating needs slightly in the winter and adds a small cooling load in the summer. With increased efficiency, both of these contributions diminish proportionately. Detailed calculations of this effect, based on hour-by-hour simulation of heating and cooling loads in four types of houses located in 3 climates of the Pacific Northwest, can be found in Sherman et al. (1985). The analysis shows that the fraction of refrigerator kWh savings that need to be replaced by heating system kWh can be as much as 50 percent, depending on the length of the heating season. The heating season can be substantially shorter, and a higher fraction of the refrigerator savings thereby realized, due to either a more benign climate or improved building insulation. It also shows that in the same region, the cooling season is shortened by about five percent due to the reduced refrigerator heating load.

In the present analysis, the interaction with *electric* space heating loads is taken into account in the calculation of building shell savings rather than appliance savings. The CIRA building simulation model we use contains algorithms to adjust for appliance efficiency.

Since most refrigerators in Michigan are located in gas-heated homes and these are not part of this study, our analysis does not explicitly analyze possible increases in space heating gas costs. Such secondary cost impacts can, however, be safely neglected for two reasons.

First, the average price for residential gas in Michigan is only a fraction of the space heating electric rates. More efficient refrigerators are in effect a form of fuel switching from heating with refrigerator electricity to furnace gas. Secondly, our building simulations show that the average Michigan gas-heated home is far from cost-effectively insulated, even considering the low price of gas relative to electricity rates. Thus, had gas-heated homes been included in the scope of the MEOS study, they would have shown space heating savings potentials far in excess of the small reductions in internal gains from refrigerators.

As a further simplification, we neglect the air conditioning savings that result from more efficient appliances. Note that these savings replace air conditioner electricity of comparable or higher cost.

Measure lifetimes. The lifetimes of improved refrigerators are expected to be about the same as those of standard models. Currently, the reliability of the more advanced technology options, such as evacuated panels, still needs to be established. It is reasonable to assume that for reasons of marketing these components will be incorporated into commercial products only after development has progressed sufficiently to offer at least the reliability of current products.

Appliance Standards

Efficiency levels and effective dates. A summary of current and proposed refrigerator standards is provided in Table 1-5, along with market shares and current shipment-weighted average UECs. At the time of this report, only the state of California has appliance efficiency standards in effect. A number of other states are currently in the process of following the California example. The California standards are primary rather than fleet-average standards. For top-mounted frost-free models, which constitute the bulk of the existing stock and of marginal sales, the current California standards for a 17 cu.ft. unit translate into a maximum UEC of 1422 kWh, far above the 1984 sales-weighted average. California's 1987 standards limit the unit's UEC to 976 kWh and the state's 1992 standards set a maximum of 675 kWh for the same size.

Table 1-5. Appliance Efficiency Standards for Refrigerators						
		Maximum Permissible UEC (kWh)				
Product Class	UEC kWh (1)	Size (cu.ft.) Ship-wtd Avg. 1984	Market Share % 1984 (1)	1987 Calif. Standard	1990 Consensus Standard	1992 Calif. Standard
Manual Defrost	566	12.7	5.1	560	523	441
Partial Auto-Defrost	982	15.0	7.4	857	756	605
Standard	812	14.1	12.5	735	661	538
Index	*100*			*91*	*81*	*66*
Top-Mounted, Frost-Free	1099					
w/o Ice Thru Door		20.3	70.0	976	948	675
w/ Ice Thru Door		20.3	1.5	1084	1071	750
Side-Mounted, Frost-Free	1584					
w/o Ice Thru Door		26.5	11.0	1338	1222	989
w/ Ice Thru Door		26.5	4.0	1484	1366	1095
Bottom-Mounted, Frost-Free	1584	26.5	1.0	1338	1222	989
ALL FROST-FREE	1188	21.4	87.5	1051	1007	739
Index	*100*			*89*	*84*	*62*
ALL CLASSES	1141	20.5	100.0	1011	964	713
Index	*100*			*89*	*84*	*62*

(1) AHAM 1985

In October 1986, both houses of the U.S. Congress passed national "consensus" standards supported by both industry, state, and environmental intervenors. These standards, which were vetoed by the President on November 1, 1986, set the maximum energy use for the same unit at 948 kWh for 1990, with a weighted average of 960 kWh for all product classes. Under the language of these standards, California's 1992 standards will become effective in 1993 in that state, unless the federal government promulgates national standards for 1993 by 1989. These national standards could consist of a continuation of the 1990 standards, establish the California 1992 standards nationally, or move to more stringent standards than both. Unless the federal government establishes a final rule on refrigerator and freezer standards by January 1 1992, states can replace the 1990 federal standard with new standards of their own. If the federal government does promulgate 1993 standards, states can escape their preemptive effect by applying for an exemption.*

*Under the criteria established by the consensus law, California is likely to qualify for such an exemption. In effect the consensus law gives manufacturers an extra year to meet California standards in California. In return, the manufacturers have agreed to drop two legal challenges of the California standards.

The average maximum UEC under the 1992 California standard for all product classes would be 713 kWh (Table 1-5). Since the California 1992 standards are far from exhausting the longer-term technical potential of highly cost-effective improvements (see below for an analysis of costs), more stringent standards could be an important least-cost option for Michigan in the late 1990s.

Impact of standards on future average appliance efficiencies. It should be noted that the California 1992 standards do not go more than 10 percent beyond the best models now on the market, and in some product classes, they actually lag behind currently available efficiencies. As discussed above for top-mounted frost-free refrigerators, current best models rely on a very modest subset of the total range of technical options. It is evident that achieving the 1992 standards does not require many or most of the available technical improvements. Recently developed prototypes, sponsored by two California utilities and the California Public Utility Commission, already outperform the 1992 standard by 33 percent (see above). It is therefore likely that significantly greater efficiencies will be achieved in the future. These will be the result of the manufacturer's own efforts at improving their products, utility incentives programs that create a market pull for highly efficient products, and/or revisions of the "consensus" standards or new state-imposed standards.

It is sometimes overlooked that the 1990 and 1993 standards will themselves push the sales-weighted average efficiencies below the maxima set in those standards. This is because manufacturers tend to offer products tailored to different market segments, including low-cost models for the multifamily and contractor market, luxury models for affluent consumers, and high efficiency models for energy-conscious consumers. These specialized market segments imply a wide range of efficiencies measured against the standard.

How far sales-weighted efficiencies can be expected to deviate from the standard level is difficult to predict, and is a function of time. In the first few years of its implementation, the sales-weighted average may be five percent below the standard or less. California utilities assume a five percent efficiency "overshoot" in their demand forecasts.

The longer-term impact of standards is even more difficult to estimate, though evidence exists that it is substantial. Fig. 1-1 shows the impact of standards on the range of marketed efficiencies as a function of time. Here, an informative point in time is 1983, which was about five years after the refrigerator standards promulgated in 1976 began to take effect, but before updated refrigerator standards were formulated in 1984. According to the California Energy Commission (CEC), the California shipment-weighted averages in 1983 were 15 percent lower than the standard required (CEC 1984). This reduction may have reflected, in part, the manufacturers' response to the national deliberations over the federal appliance standards law between 1980 and 1982.

Since the remaining potential for efficiency improvements beyond the 1993 standards is still large, since the issue of state standards or more stringent national standards is unresolved, and since the untapped measures allow the construction of highly cost-effective package improvements (see below), it is reasonable to expect an efficiency overshoot beyond the 1990 standard. A recent survey of refrigerator/freezer sales in California finds that manufacturers have reduced the shipment-weighted averages in that state by another 15 percent between 1983 and 1986, in order to meet the state's 1987 interim standards.

COST AND PERFORMANCE IMPACTS

Per-Unit Energy Savings

Prototype analysis. Studies of potential refrigerator efficiencies, including the DOE and California appliance standards analyses, are based on various product class prototypes. The present analysis is based on prototype calculations for three product classes: manual defrost, and standard (no through-the-door features) top-mounted and side-mounted automatic defrost units. These three classes accounted for 5, 70, and 11 percent of total 1984 U.S. shipments, respectively. Results are aggregated into the two product classes of the MEOS forecast, i.e. standard and frost-free units.

Efficiency levels. The guidelines for the MEOS study limit demand-side options to technologies that are expected to be commercially available in 1987. In the present context we interpret this constraint to allow the consideration of most of the design options and measures listed above for refrigerators. The rationale for this broad interpretation is that (1) many of these efficiency options rely on presently demonstrated technologies and are scheduled to be commercially implemented by the manufacturers, as their own forecasts and the schedule of "consensus" appliance standards attest, and (2) two large California utilities are expected to arrange the commercial production and marketing of their high efficiency prototype by the late 1980s. Michigan utilities could make use of this technology as well.

We distinguish between four different efficiency levels, in order of increasing efficiency: 1990 consensus standard, best current models, 1992 California standards, and a "best-available technology" package. The corresponding UECs for the most important product class (top-mounted automatic defrost) are shown in Fig. 1-2, along with the expected performance of some more advanced models we do not consider.

We believe that a realistic portrayal of refrigerator demand-side options over the next 20 years should include an efficiency level beyond that of the standards. First, as discussed below, a very large cost-effective technology potential remains currently untapped. Best available data suggest that the point of diminishing returns for improving refrigerators and refrigerator/freezers lies approximately 50 percent below the efficiency level of the 1992 standards. Second, rebates, prototype developments, or other incentives programs by utilities will likely stimulate the production of even more efficient models over time. Third, two California utilities and the California PUC have undertaken a prototype development program aimed at the early introduction of highly efficient models that significantly exceed the requirements of the 1992 California standard. These prototype developments have already established the technical viability of such efficiencies and will likely lead to commercial production of units with similar efficiency. Finally, it is likely that state proceedings to implement state standards will resume unless more of the technical options are introduced in commercial products by the late 1990s.

The performance level we assume for the "best-available technology" package has been demonstrated in the previously-mentioned prototype models that were constructed by the Danish Technical University for the California Public Utility Commission (Pedersen et al. 1986, see above). Here it should be noted that the performance of this prototype can be achieved in more than one way. Other packages than the one used in constructing the CPUC prototypes have been formulated on the basis of simulation studies using the A.D. Little or similar engineering models (ACEEE 1986). According to these simulations, the "best-available technology" performance level can be achieved entirely with conventional technology. It does not require more far-reaching design changes now considered by various manufacturers, such as evacuated panels, variable speed controls, etc., though some of the more advanced or unconventional measures will likely be incorporated in the package as their practical advantages are firmly established.

Determination of energy savings. Unit energy consumptions for best available models were taken from tests as reported by the manufacturers to the Federal Trade Commission under the appliance energy labeling program. For not-yet-commercial efficiency levels, we reproduce calculations based on the prototypes, engineering models, and algorithms developed by A.D. Little Inc. (ADL 1977:156-168 and 1980:15-22) for the 1982 federal appliance standards analysis, and supplementary calculations based on the same models from subsequent analyses. These engineering calculations are the basis for the efficiency gains shown in Table 1-6 and Fig. 1-2 for top-mounted frost-free models. We are confident that the prototypes are feasible, but there remains considerable work in converting them into commercially acceptable, mass-produced appliances.

Table 1-6. Cost and Potential of Efficiency Improvements in Top-Mounted Auto-Defrost Refrigerators/Freezers[1,2]

Measure	UEC	Additional First Cost		CCE	
	(kWh/yr)	Marginal (1985 $)	Cumulative (1985 $)	Marginal (1985 $/kWh)	Cumulative (1985 $/kWh)
1. Baseline	1166	0	0	0	0
2. EER 3.65 Compressor	983	7.35	7.35	0.0028	0.0028
3. Double Gasket on Freezer Compartment	920	20.34	27.69	0.0225	0.0079
4. 2"/2.4" Insulation	752	19.57	47.26	0.0081	0.0080
5. 2.5"/3" Insulation	672	9.33	56.59	0.0081	0.0080
6. More Efficient Fan	609	10.98	67.57	0.0122	0.0085
7. EER 4.5 Compressor	510	27.11	94.68	0.0191	0.0101
8. Double Gasket on Fresh Food Compartment	463	49.76	144.44	0.0739	0.0143
Additional measures not included in analysis					
9. External Fan Motor	451	1.64	146.08	0.0095	0.0143
10. EER 5.0 Compressor and Dual Evaporator	386	70.51	216.59	0.0757	0.0194
11. Evacuated Powder Panels	268	75.15	291.74	0.0445	0.0227
12. Bottom-Mounted Condensor	222	40.65	332.39	0.0617	0.0246

(1) ACEEE, 1986.
(2) Assuming refrigerator life span of 19 years, and a real discount rate of 3%.

Costs of Improved Refrigerators

There are two sources for estimating the incremental costs of efficiency improvements. For current highly efficient models on the market, the incremental cost can principally be calculated from retail prices as found in Michigan. For efficiency levels beyond current market models, estimates have been developed on the basis of detailed engineering-economic analyses.

Costs of best models on the market. To date, no regional survey of average refrigerator costs as a function of efficiency has been undertaken in Michigan, or for that matter, elsewhere. Manufacturers and dealers consider this information proprietary. Even a cursory survey of appliance prices encounters difficulties. First, many stores do not quote prices over the phone.

Second, attributing a definite cost increment to differences in the efficiency of commercially available refrigerators is difficult because many features besides energy consumption influence and dominate consumer choice.

Thus, the cost differential between the most efficient models and average efficiency models varies significantly, depending on which models are compared. For example, among manual defrost models that are close to the shipment-weighted average size and efficiency, prices per unit as quoted by three Michigan retailers range from $300 to $440.* Depending on which unit is taken as a reference, the incremental cost for improved efficiency ranges from negative to about $60.

There are other problems in ascertaining the market price of high efficiency models. For frost-free refrigerators, the most efficient model on the market, a 17 cu.ft. Whirlpool model test-rated at 748 kWh/year, was not sold by any of the half a dozen Michigan retailers we contacted. We were able to make at least some Michigan-based comparisons at the high-efficiency end of the technology-cost curve by comparing the most efficient Whirlpool 18 cu.ft. unit for which we could get quotes with a standard version of the same size. For example, the efficient model (ET18XKXR) consumes 890 kWh and was available at $630.* The standard efficiency 18 cu.ft. Whirlpool top-mounted freezer uses 1045 kWh per year and was available for $597. This corresponds to a 1.5 cents/kWh cost of conserved energy (assuming 19 years and a 3 percent real discount rate). Here, the efficiency premium that a customer would have to pay depends to a great extent on the time spent on shopping around, since discounting and promotional sales are widespread. Moreover, efficient models tend to have a high mark-up so long as they occupy a small market niche, but plummet in price when utility incentives programs or standards direct larger customer demands in their direction.

Technology costs for future efficiency levels. Detailed estimates of the cost of conserved energy for a number of refrigerator efficiency measures were developed in the Department of Energy sponsored analysis (ADL 1977, ADL 1980, DOE 1982,1983), and in subsequent studies by the California Energy Commission, the Northwest Power Planning Council (1986), the Association of Home Appliance Manufacturers (AHAM 1984), and the American Council for an Energy Efficient Economy (ACEEE 1985). An update of the A.D. Little and DOE analyses is currently being conducted by the Department of Energy, but results are not yet available. In the absence of results from this update, we refer to the previous analyses to indicate the rough magnitudes of the expected economics of various major design options. A range of estimates exists for the incremental cost increases to meet the 1992 standards. For example, for the DOE top-mounted automatic defrost prototype of 17 cu.ft., the range of incremental costs to meet the 1992 California standards are $49 (ACEEE 1986), $53 (NPPC 1986), $84 (ADL 1977), $112 (CEC 1984), and $266 (AHAM 1984). All estimates within that range easily make the 1992 California standards cost-effective for Michigan consumers. Some of the above-mentioned cost studies examine efficiency levels beyond the 1992 standard. These analyses indicate that the point of diminishing returns is not reached until performance levels rise significantly above the "best-available technology" package considered in this study.

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*A Montgomery Ward 10.2 cu.ft. model consumes 606 kWh/yr and was available at $440 to $360 (sale price), the 11 cu.ft. Whirlpool consumes 581 kWh and was offered at 300, the 13 cu.ft. Whirlpool consumes 645 kWh and cost $350. One of the most efficient models on the market, the Kenmore 10.6 cu.ft. unit, consumes 438 kWh and was offered for $360.

* Subsequent conversations with Whirlpool revealed that the refrigerator has been re-rated and now uses 10% more electricity.

Costs of Conserved Energy

The range of costs of conserved energy that can be expected for improved refrigerators over the MEOS forecast is summarized in Tables 1-7, 1-8, and 1-9 for prototypical manual, top-mounted automatic defrost, and side-by-side models. These costs are based on incremental first costs that represent the mid-range of documented currently available estimates. The figures are likely to be on the high side in view of the considerable economies of scale that can be achieved over the time period of the MEOS forecast.

Marginal costs (going from one package to the next) range from 0.9¢/kWh to 3.9¢/kWh for the most common frost-free models. Cumulative CCEs (based on package implementation of all measures up to the specified technology level) range from 0.9¢/kWh to 2.2¢/kWh (1985 dollars). For manual units, the costs of improvements beyond the 1992 standard level are about twice as high.

Table 1-7. Costs of Conserved Energy for Manual Defrost Refrigerators

Technology	UEC (kWh)	UPD (W)	Additional First Cost		CCE		$CCPP_{20}$	
			Marginal ($)	Cumulative (1985 $)	Marginal ($/kWh)	Cumulative (1985 $/kWh)	Marginal ($/kW)	Cumulative (1985 $/kW)
Baseline	566	76	0	0	0.000	0.000	0	0
1990 Standard	523	70	10	10	0.016	0.016	1803	1803
1992 Standard	441	59	60	70	0.051	0.039	5672	4341
Best Avail. Tech.	270	36	140	210	0.057	0.050	6346	5499

Table 1-8. Costs of Conserved Energy for Top-Mounted Auto-Defrost Refrigerators/Freezers

Technology	UEC (kWh)	UPD (W)	Additional First Cost		CCE		$CCPP_{20}$	
			Marginal ($)	Cumulative (1985 $)	Marginal ($/kWh)	Cumulative (1985 $/kWh)	Marginal ($/kW)	Cumulative (1985 $/kW)
Baseline	1099	147	0	0	0.000	0.000	0	0
1990 Standard	948	127	20	20	0.009	0.009	1027	1027
1992 Standard	675	90	60	80	0.015	0.013	1704	1462
Best Avail. Tech.	460	62	120	200	0.039	0.022	4326	2426

Table 1-9. Costs of Conserved Energy for Side-by-Side Refrigerators/Freezers

Technology	UEC (kWh)	UPD (W)	Additional First Cost		CCE		$CCPP_{20}$	
			Marginal ($)	Cumulative (1985 $)	Marginal ($/kWh)	Cumulative (1985 $/kWh)	Marginal ($/kW)	Cumulative (1985 $/kW)
Baseline	1584	212	0	0	0.000	0.000	0	0
1990 Standard	1222	164	50	50	0.010	0.010	1071	1071
1992 Standard	989	133	60	110	0.018	0.013	1996	1433
Best Avail. Tech.	572	77	165	275	0.028	0.019	3067	2106

These figures show that the average cost of improving refrigerators is low, especially for frost-free units, which constitute close to 90 percent of current purchases.

Sensitivity analysis. With a 7 percent rather than 3 percent real discount rate, the cost of conserved energy increases by 38 percent for the various packages. For frost-free units, this brings the maximum CCE (best-available technology package) to 5.4¢/kWh.

B. DEMAND-SIDE MEASURE DATA BASE

END-USE:	Food Refrigeration
FUEL:	Electricity
TARGET TECHNOLOGY:	Refrigerators and refrigerator/freezers
DS MEASURE:	Highly efficient new refrigerator or refrigerator/freezer
IMPACT OF MEASURE:	Primarily baseload electricity conservation

IMPLEMENTATION PROGRAMS

Scope of Current Programs

In a 1986 survey of 76 utilities representing 52 percent of U.S. electricity sales, we found only three utilities that had first-hand experience from operating large refrigerator incentives programs (i.e. programs paying more than 10,000 rebates per year). These three are Florida Power and Light (FLP&L), Southern California Edison (SCE) and Pacific Gas and Electric (PG&E). Since the inception of the full-scale programs in 1982, the California utilities issued 300,000 rebates. The Florida program rebated 330,000 sales. Eight other utilities were involved in or had conducted pilot or small-scale programs. The following discussion draws mainly on the experience of the two California companies.

In 1985, SCE paid out 28,000 rebates. The program lasted two months. PG&E paid out 46,000 rebates in 3 months of operation. In addition, both companies operated a year-round bounty program for second refrigerators. Three thousand seven hundred units were donated to charities under SCE's program in 1985, while PG&E retired some 40,000 second units that year. The costs and effectiveness of these programs as quoted below are based on evaluation and market research studies of the two companies, a summary report by the California Energy Commission (1986), and personal communications with program staff from these institutions and other utilities.

How the Programs Work

Method of implementation. The refrigerator programs are part of a larger appliance efficiency program. For new purchases, the programs work with the appliance dealers, who are provided with informational (point-of-purchase) materials such as banners, leaflets, yellow stickers, tag hangers, brochures on eligible models, etc., and who announce the rebates in their stores and advertisements. Customers who apply for the rebates fill out a form that the salesperson hands to them and mail it to the utility, which then sends a check. The utilities also use advertisement campaigns including, in the case of SCE, a well-known TV entertainer, to attract attention to their rebates. In addition, they work in close cooperation with dealers and manufacturers. PG&E announces its 2-month program 9-12 months in advance to the manufacturers, and visits most of a network of about 1000 distributors three to four months before the program starts in the summer, and then again at least once during the program. As a result, a number of manufacturers stock up on efficient models well in advance and piggy-back on the utility program with their own promotional campaigns, offering manufacturers' discounts in addition to utility discounts.

The bounty programs are conducted year-round through participating charities. In PG&E's program, charities solicit donations of old but still operational second units during their routine pick-up runs through the neighborhoods and in their newspaper advertisements.

About 80 percent of the units are destroyed. The remainder are still-serviceable units of smaller size and energy consumption. These are slightly reconditioned and sold to low-income households. Sales people in the stores use the availability of the free pick-ups and bounties on old units as additional in-store pitches to close deals on new purchases.

Range of rebate levels. Market research by several utilities has found that a threshold rebate level for defrost units is $50. In SCE's and PG&E's programs, rebates are structured in two tiers. For units that are 25 percent better than the California 1978 standards, the rebate level is $50. For 35 percent or more additional efficiency, the rebate is $75. (A $100 rebate has also been offered for this level in the past.) For second refrigerators, the rebate to the customer upon donation is $25 plus a free pick-up and a tax-free receipt. The charity receives $5 for the pick-up and $20 if the unit is destroyed rather than resold.

Impact of incentive on customer first cost. The companies do not have precise data on the average cost increment between the models customers would have bought in absence of the rebates, and the more efficient models rewarded by their incentives. It is estimated, however, that the rebates cover at least 50 to more than 100 percent of this incremental cost. With the availability of manufacturers' and discount store rebates, it is now cheaper, in the case of some models and some suppliers, to buy the efficient model rather than the standard one.

Program Experience

Fraction of annual sales affected. This fraction is not precisely known since manufacturers and dealers treat regional sales data as confidential. Sales can be estimated on the basis of average appliance lifetimes and the growth in customers. It is estimated by PG&E that 10-15 percent of annual sales are being awarded rebates when the program is run for two to three months only (due to limited funds approved for the program). During the two to three months of the program duration itself, dealers report that two-thirds to three-quarters of all their sales are rebate sales. This high participation rate reflects the effectiveness of PG&E's outreach program.

Dealer surveys suggest that roughly twice as many sales could be eligible if the program was conducted twice a year. If rebates were offered on a continuous basis, the number of rebate sales per month would necessarily decline because neither manufacturers nor distributors would be able to maintain the same promotional effort, and also because the psychology of ongoing rebates is different. The maximum fraction of rebated units sold that is considered desirable is 30 percent, since at significantly larger penetrations, the manufacturers are in effect being subsidized.

Average savings per rebate. Utilities in California report energy savings to the Public Utility Commission on the basis of the nominal difference between their minimum incentive efficiency and the 1978 standard. This overestimates the savings by a significant amount since the sales-weighted average efficiency is significantly higher than the standard. A detailed evaluation study by SCE that used surveys to estimate the pre-rebate average efficiency in its area found that the average savings per rebate (both levels combined) was 94 kWh rather than the 300 kWh of savings found with respect to the 1978 standard.

Impact of level of rebate on savings. In SCE's evaluation the savings per $50 rebate were only 38 kWh, while the $75 level brought 184 kWh of savings, a 4.8 fold increase. Though the $75 rebate accounted for only 35 percent of all rebates given out, these higher rebates achieved 83 percent of the program's total energy savings. In PG&E's program the ratio of $75 and $50 rebates is about 50:50. These findings suggest that within a well-run program, the level of rebate can be used as an effective "handle" for motivating high efficiency selections.

Free-riders. No clear conclusions can be drawn from available studies on whether the so-called free-rider issue is significant in terms of its impact on the utility's (or ratepayers') cost for buying conserved energy. Free-riders are those consumers that would have purchased efficient models without a rebate; therefore, the utility is not obtaining "extra" conserved energy by paying a rebate to these individuals. Both utilities attempted to determine the fraction of so-called free-riders by means of follow-up surveys. The SCE study's post-program participant survey found that, overall, 33.6 percent of rebate recipients were actually motivated to buy a more efficient model than they would have without the program. The figures for the $50 participants and the $75 participants were 27.3 percent and 43.2 percent respectively. In the case of PG&E, the fraction was estimated to be 38 percent on average.

These data suggest that several rebates must be spent to get one additional savings increment. That is, if a rebate covers 100 percent of the additional first cost for higher efficiency, and free-riders make up 50 percent of purchasers, the cost of conserved energy to the utility or ratepayer is twice as high as the cost of conserved energy we calculate for the technology alone. Administration costs can make the actual cost of conserved energy more than twice as high as the calculated figure. However, these survey results are likely to be significantly distorted by the well-known self-response bias: in follow-up surveys, people tend to portray their actions as reflecting their independent decision-making rather than an outside influence.

This self-response bias is evident in the following numbers: in 1984, the year preceding the 1985 SCE program, only 10 percent of all California sales fell into the efficiency bracket that SCE's $75 rebate required (Messenger 1986). The participants in SCE's program should be reasonably comparable to the average California consumer as represented in the overall 1984 sales data: the program was large scale, was not targeted to a particular customer segment, shifted most purchases occurring during its two-month duration, had a diversified participant profile (see below), and was run in the state's largest metropolitan region. The 1984 sales-by-efficiency figures then suggest that the fraction of free riders should have been no more than about 10-15 percent (allowing for a trend-based shift in sales shares between 1984 and 1985).

If we take the survey response at face value, the preference of customers would have changed much more significantly in one year. The fraction of people buying high-efficiency units ($75 rebate level) and claiming to do so on their own represents 25 percent of the program participants.* Thus, if we assume that participants are not too different from the average California consumer, preference for these models would have increased "naturally" from 10 percent in 1984 to 25 percent in 1985. Such a sizable one-year shift in consumer behavior "out of the blue" is not likely. We therefore conclude that, at least for the higher rebate level, the reported free-rider shares are greatly exaggerated.

Within this fundamental bias, the SCE survey results do show sensitivity to the efficiency requirement stipulated for the rebate level. This finding and the above discussion point to the need to tie incentives to sufficiently stringent efficiency requirements in order to curb free-riders. With such an appropriate design, it would seem possible to limit free-riders to a small fraction of participants. Generally speaking, free riders would be limited to that fraction of customers that purchased high efficiency equipment already before the program came into existence.

*Thirty-eight percent chose the high-efficiency rebate, and of them, 67 percent claimed that they would have purchased the unit they bought without the rebate.

For example, in California the fraction of 1983 sales of top-mounted refrigerators with energy factors greater than 8.0 was 3.4 percent. An EF of 8.0 represented 80 percent of the best efficiency level on the market. If rebates were tied to this top twenty percent span of efficiency levels and improved program designs were used, as much as a third of sales might be shifted.

In this case, the portion of free riders would have been no more than 10 percent (.034/.33).

Reduction in the economic significance of this issue is also likely as utilities increasingly direct their program toward the dealer, distributor, and manufacturer links in the distribution chain. These efforts are likely to lower the size of the rebates needed to shift customer purchasing patterns, and thus reduce the cost of free riders as well.

Free contributors. A related area of uncertainty pointing in the opposite direction is the secondary program effects which could induce customers to buy more efficient units without rebates (e.g., after the rebate period has ended). Such effects have not been studied by the utilities. Improved customer awareness, more knowledgeable sales personnel, changes in the mix of stocked units, and shifts in marketing strategies of manufacturers are just some of the possible lingering effects.

These secondary effects, together with appropriate design of rebate efficiency levels and innovative program strategies aimed at upstream links in the distribution chain, could likely offset most free-rider impacts that would still exist in a well-designed incentive program.

Change in timing of appliance purchases. Available evaluation studies indicate that the rebates have no significant impact on the timing of new appliance purchases. The SCE study found that 15 percent of participants were affected in the timing of their purchases, with 1 percent delaying purchases in order to be able to participate, and 14 percent advancing them. On average, market entry was found to be about six months earlier than would have occurred otherwise.

Change in average unit volume. While SCE's $50 participants chose models with an average volume of 19.5 cu.ft., $75 participants bought slightly smaller models at 17.2 cu.ft. Also, the share of inherently more energy-intensive side-by-side and bottom-mounted freezer models was only 9 percent in SCE's participant purchases, compared to 22 percent in all California shipments in 1983. These differences reflect, among other things, the fact that currently the models with high insulation levels are available mostly in the medium sizes. Apparently, customers were quite willing to switch to somewhat smaller units to reap the efficiency and rebate benefits.

Socio-economic characteristics of participants. In SCE's program, 62 percent of participants were homeowners, 33 percent were tenants, and 5 percent were landlords or condominium associations. Minorities were seriously underrepresented at 4.4 percent. In PG&E's zero interest loan (ZIP) and rebate programs, low-income groups are similarly underrepresented. For example in the ZIP program, low-income households represented less than one percent of participants. These data suggest the need for programs that address low-income and minority groups.

Program Cost-Effectiveness

Program administration costs. The cost of administering refrigerator efficiency programs can vary considerably depending on economies of scale and the design of trade ally cooperation. SCE monitors program costs for its residential energy management financing program as a whole, which amounted to $29 million in 1984 and $15 million in 1985 (including costs of rebates).

The share of administration costs (including promotion, research, and evaluation) varied between 18 and 35 percent depending on the program level and the composition of program activities. For a relatively simple and large subprogram such as the refrigerator program, the administration and promotion costs including market research and evaluation studies can be expected to be near the bottom end of this range, or $13-15 per rebate.

PG&E's program staff estimate that their program costs about $7 per rebate. Of this sum, only $1.75, i.e. the cost for check processing, varies directly with the number of rebates. Florida Power and Light budgeted $15 per rebate in its 1985 program but costs were only $7.14 per rebate during that year.

The scope for cost-reducing designs is illustrated by PG&E. Unlike SCE, PG&E charges a fee to manufacturers and dealers that participate in its program. This fee reduces the utility's cost by one-third. If one includes in the total program administration cost the expenditures and promotional efforts by manufacturers and dealers, PG&E's program costs constitute about 20 percent of that total.

All-ratepayer costs. The cost to ratepayers of the above-mentioned refrigerator programs strongly depends on the assumptions about free-riders. Below, we calculate as a point of orientation the program-based cost of conserved energy assuming that there is no free-ridership, for both the average, the high, and the low rebate level. As discussed, this assumption seems reasonable for the higher SCE and PG&E rebate efficiency levels, but does not apply to the average or lower rebate efficiency level.

Based on SCE's estimated savings, a program administration cost of $10 per rebate, and an average rebate of $60, ratepayers as a whole spent $70 for a first-year saving of 94 kWh, or $0.74/kWh (1st-yr). This corresponds to a cost of conserved energy to the ratepayers of 5.2¢/kWh (19 year average life, 3 percent real discount rate). For the $50 rebate, the corresponding figures are $1.60/kWh (1st-yr) and 11.0¢/kWh. For the $75 rebates, the costs are much lower: $0.50/kWh (1st-yr) and 3.1¢/kWh. If we compare these costs with average rates or long-term marginal costs, The lower rebate is not necessarily cost-effective. Significant free-ridership must be taken into account at the relatively low efficiency requirement of that rebate. For the higher rebate, where the free-rider effect is likely to be small, cost-effectiveness would be comfortably achieved. This is even the case if one were to believe the survey results on the fraction of participants motivated by the rebates, in which case a kWh saved costs 7.2 cents.

These figures illustrate that the cost-effectiveness of refrigerator rebate programs is sensitive to, and primarily a function of, the right choice of rebate efficiency requirements. If these requirements are set too low, the minimum rebate payment needed to overcome psychological thresholds is excessive compared to the obtained savings. At the same time, this erosion of cost-effectiveness is reinforced by a strong free-rider impact at lenient efficiency requirements. On the other hand, rebates can be a reliably cost-effective means of buying demand-side resources when targeted toward models that are significantly more efficient than current units.

Cost-effectiveness of bounty program. The cost-effectiveness of bounty programs is particularly pronounced. The ratepayer cost in PG&E's program, which removed 200,000 units so far, is $50 per donation (weighted average of incentives plus $5 per donation for administration and promotion) and eliminates an estimated 1000 to 2000 kWh per year and unit. Even if retirement is advanced by only one year, the cost of conserved energy is no more than 2.5-5.0¢/kWh. Michigan utility staff estimate that the average life of second units is 9 years. Assuming that an on-going bounty program cuts this life expectation in half, the cost of conserved energy is only 0.5-1.0¢/kWh.

Low-income programs. Several California utilities are currently proposing to create special refrigerator efficiency programs oriented toward low-income people. PG&E's proposal consists of simply offering a no-cost exchange of old units with a selection of highly efficient new units. The cost-effectiveness of this approach can be estimated as follows: cost of efficient standard-sized automatic defrost unit when bought in bulk is assumed as $600; delivery, pick-up and administration cost $100; effective energy savings of 1000 kWh/year assumed only for 10 years to account for upgrading and/or less than full remaining life of existing unit; cost of conserved energy is therefore 8.2¢/kWh.

Cost-Effectiveness of Standards Programs

Rebates or other incentives can be looked at as a means to give appliance-purchasing customers a market signal of the true economic cost of their efficiency choices. Incentives are an important and potentially cost-effective instrument to move greater portions of sales into the upper range of available efficiencies. At the same time, incentives are inherently limited in moving the bulk of sales to higher efficiency levels. Were incentives used for that purpose, they would end up subsidizing manufacturers and putting an unnecessary cost burden on ratepayers. This would defeat their intended purpose.

Rebates can work best if they are complimented by efficiency standards that periodically raise the floor of the market. Standards have important equity benefits and offer the advantage of giving greater certainty to demand-side resource estimates. This reduces forecasting uncertainties for utilities. Utilities also tend to benefit from standards because they reduce the burden on utility incentives programs to achieve conservation targets that Public Service Commissions may wish to see implemented. Though the costs of demand-side programs are commonly expensed, and are merely a transfer payment, such programs may still involve substantial entrepreneurial risks depending on the targets that are established for them in the regulatory process. For these reasons, a number of utilities have actually supported the establishment of appliance efficiency standards.

One very important advantage of standards over rebates is their immensely greater cost-effectiveness per unit of energy saved. We again quote California numbers since that state is the only one that has promulgated such rules so far. According to an evaluation by the California Energy Commission (Messenger 1983), the average California homeowner pays 4 cents per month to pay for the entire CEC staff. By comparison, the average household saves $5 per month from the state's appliance and building efficiency standards. For a standards program like the 1978 Appliance Efficiency Standards, the CEC calculates a net present value of $1.5 million for establishment of the standards program (30 person-years of staff plus hearings, contracts, administration, etc.) and annual enforcement costs (of $100,000 per year in the first three years, and $50,000/year thereafter).*

Standards reap diminishing benefits over time as market efficiency trends would presumably reach the standards level eventually. The benefit period of standards can be estimated to be 5-15 years, depending on how stringent they are. If Michigan were to promulgate a refrigerator standard similar to the California 1992 standard, benefits would be achieved at least until 2005 compared to the current MEOS/AHAM forecast. Such a standard would save on the order of 1300 GWh between 1992 and 2005. Based on this 13-year program effectiveness, the cost of conserved energy to the state would be 0.14¢/kWh, or one-twentieth the cost of a well-designed rebate program.

* This program covered refrigerators, freezers, furnaces, central air conditioners, and water heaters. Separate estimates for the refrigerator program are not available.

TECHNICAL AND ACHIEVABLE POTENTIAL

General

Annual and cumulative replacements, 1986-2005. Annual and cumulative replacements follow the MEOS forecast By 2005, practically all existing units will have been replaced at least once. We assume that neither standards nor rebates change the level of turnover that would be expected under market conditions. The various scenario assumptions on marginal UECs for the years 1985-2005 are shown in Tables 1-10 and 1-11.

Table 1-10. Summary of Scenario Assumptions for Standard Refrigerators[1]

Year	Frozen Efficiency		Technical Potential		Standards Scenario		Program Scenario			
							Penetr. Fraction	Reward Level	All Sales	
	UEC (kWh)	UPD (kW)	UEC (kWh)	UPD (kW)	UEC (kWh)	UPD (kW)		UEC (kWh)	UEC (kWh)	UPD (kW)
1985	741	99	716	96	716	96	0.00	716	716	39
1986	741	99	691	93	691	93	0.00	691	691	39
1987	741	99	666	89	666	89	0.00	666	666	38
1988	741	99	546	73	640	86	0.01	565	639	38
1989	741	99	518	69	615	82	0.02	537	613	37
1990	741	99	490	66	590	79	0.05	510	586	37
1991	741	99	462	62	576	77	0.10	485	567	36
1992	741	99	434	58	562	75	0.20	460	542	35
1993	741	99	406	54	547	73	0.30	434	513	34
1994	741	99	378	51	533	71	0.30	409	496	33
1995	741	99	350	47	519	70	0.30	384	478	33
1996	741	99	350	47	519	70	0.30	384	478	32
1997	741	99	350	47	519	70	0.30	384	478	32
1998	741	99	350	47	519	70	0.30	384	478	32
1999	741	99	350	47	519	70	0.30	384	478	32
2000	741	99	350	47	519	70	0.30	384	478	31
2001	741	99	350	47	519	70	0.30	384	478	30
2002	741	99	350	47	519	70	0.30	384	478	29
2003	741	99	350	47	519	70	0.30	384	478	28
2004	741	99	350	47	519	70	0.30	384	478	27
2005	741	99	350	47	519	70	0.30	384	478	26

(1) In the MEOS WG5 forecast, and in this table, half of the partial auto-defrost units are included in the "Frost-Free" category, to more accurately represent the actual consumption of this type of refrigerator. In the text, we cite adjusted figures; "Standard" units include partial defrost, and "Frost-Free" includes all frost-free only.

Table 1-11. Summary of Scenario Assumptions for Frost-Free Refrigerators[1]

Year	Frozen Efficiency		Technical Potential		Standards Scenario		Program Scenario			
							Penetr. Fraction	Reward Level	All Sales	
	UEC (kWh)	UPD (kW)	UEC (kWh)	UPD (kW)	UEC (kWh)	UPD (kW)		UEC (kWh)	UEC (kWh)	UPD (kW)
1985	1179	158	1140	153	1140	153	0.00	1140	1140	184
1986	1179	158	1101	148	1101	148	0.00	1101	1101	182
1987	1179	158	1062	142	1062	142	0.00	1062	1062	179
1988	1179	158	839	112	1023	137	0.01	876	1022	176
1989	1179	158	788	106	984	132	0.02	827	981	172
1990	1179	158	736	99	945	127	0.05	778	937	168
1991	1179	158	685	92	925	124	0.10	733	906	163
1992	1179	158	633	85	905	121	0.20	687	861	158
1993	1179	158	582	78	885	119	0.30	643	812	154
1994	1179	158	531	71	865	116	0.30	598	785	148
1995	1179	158	480	64	846	113	0.30	553	758	143
1996	1179	158	480	64	846	113	0.30	553	758	138
1997	1179	158	480	64	846	113	0.30	553	758	133
1998	1179	158	480	64	846	113	0.30	553	758	129
1999	1179	158	480	64	846	113	0.30	553	758	126
2000	1179	158	480	64	846	113	0.30	553	758	125
2001	1179	158	480	64	846	113	0.30	553	758	125
2002	1179	158	480	64	846	113	0.30	553	758	125
2003	1179	158	480	64	846	113	0.30	553	758	125
2004	1179	158	480	64	846	113	0.30	553	758	123
2005	1179	158	480	64	846	113	0.30	553	758	121

(1) In the MEOS WG5 forecast, and in this table, half of the partial auto-defrost units are included in the "Frost-Free" category, to more accurately represent the actual consumption of this type of refrigerator. In the text, we cite adjusted figures; "Standard" units include partial defrost, and "Frost-Free" includes all frost-free only.

Second unit refrigerators. For second units, we assume a lifetime of six years and an average age of 18 years at the time the unit becomes a second refrigerator. The UEC of refrigerators moving into second-unit status in a given year is assumed to be equal to the sales-weighted average UEC found in U.S. sales 18 years earlier. This approach treats all second refrigerators as units that were not specifically bought to increase the number of cabinets in the home on a permanent basis, but ended up in second unit status because it was more convenient to keep the old first-unit around than to dispose of it. This assumption seems reasonable in view of recent PG&E evaluation studies. The surveys found that of the 26 to 37 percent of customers that still had their old refrigerator when they bought a new one in 1982-84, only 12-21 percent kept the old unit for regular use.

Behavioral factors. We assume no changes in the intensity of refrigerator utilization that would affect unit energy consumption.

Eligible fraction. All purchases of new equipment are eligible for implementing the efficiency measure. For second unit, we assume that an effective program would reduce the number of second units (saturation) by half.

Constant Efficiency and Utilization Forecast

With UECs frozen at the average 1985 level, total refrigerator consumption in 2005 would be 4412 GWh for the CP and DE territories combined. Even at frozen efficiencies, the consumption of refrigerator electricity declines, as shown in Appendix A, Table R-A.** The MEOS forecast brings total refrigerator consumption in 2005 down to 3687 GWh.

Technical Potential/Best Technology Scenario

Here we construct a hypothetical, upper-limit case that implements best available technology in all purchases. We assume that between now and 1990, the marginal average UEC of best commercially available models declines roughly in parallel with the shipment-weighted average. We calculate the current weighted average of the best commercially available models (1985/86) in the two MEOS product classes. i.e. 606 kWh for standard models (manual refrigerator and partial automatic defrost refrigerator/freezer) and 853 kWh for auto defrost (top-mounted, side-mounted, and bottom-mounted units). We then calculate the percentage gap between these best UECs and the shipment-weighted averages for the two categories. In 1990, best models maintain the same efficiency advantage over the proposed 1990 consensus standard's maximum UEC. Between 1990 and 1995, best efficiencies drop to the best-available technology level (370 and 480 kWh). We truncate the improvements at this level for the rest of the study period. Note that this approach makes cumulative savings compared to the MEOS forecast smaller than they might be, both in this and in the program-based scenario below.

Second refrigerators. Here we calculate a hypothetical case in which 80 percent of all existing second refrigerators are junked at the end of each year starting in 1988.

Results. The total potential savings in 2005 is 1758 GWh compared to the MEOS forecast's 3687 GWh. Consumption would be 40 percent lower than in 1985.

Program-Based Scenario

In this calculation, shipment-weighted average refrigerator UECs for new sales are driven by a combination of standards and incentives programs. We calculate their combined effect by taking the standards as a reference scenario that is supplemented by incentives. We explicitly assume a 1990 consensus standard only. We are equivocal as to the method for achieving further reductions in UECs. To indicate an upper limit for the costs of the demand-side resource, savings are calculated on the basis of an incentives program. They could be achieved more cost-effectively and exceeded by means of a more stringent federal or state standard.

**As explained previously, shipment-weighted UECs have dropped since 1972. As older units are retired, they will be replaced with higher-efficiency units, lowering total electricity consumption for refrigerators.

Under the Standards Scenario, UECs fall linearly until 1990, when they reach a level 5% below the 1990 "consensus" standard. UECs decrease further to 15% below the 1990 standard level by 1995 (Tables 1-10 and 1-11, standards scenario). This decrease mainly represents the estimated effect of differential marketing strategies to meet the needs of the various customer segments.

Program reward level. The program is assumed to have a two-tier structure. The first tier would shift a certain percentage of purchases from the average efficiencies of the standards scenario to a subset of models that represent the high end of the efficiency spectrum. The average efficiency of this subset is assumed to incorporate 80 percent of the efficiency differential between the best technology of the technical potential scenario and the standards scenario, e.g. in 1996 the standards-only scenario for frost-free models indicates a shipment-weighted average UEC of 856 kWh, compared to 480 kWh for best technology. The average UEC for units bought in response to incentives is then 856 - (856 - 480) x .8 = 555 kWh.

The second tier is oriented toward stimulating a strong market pull for product development beyond available models by giving substantial rewards to manufacturers, retailers, and consumers of such units and creating guaranteed start-up markets for them. The financing of prototype development and field testing, as done recently by the California Public Utility Commission, or the joint marketing with manufacturers of such high efficiency models as are already developed, could be one aspect of this market pull strategy.

Our calculations assume all incentives are paid directly to consumers. The second program activity does not enter into the scenario calculations. It mainly ensures that the best technology indicated in the technical potential scenario will indeed be available to Michigan consumers. With the second tier, a number of models will be available in the specified efficiency range, which will facilitate consumer choice (features, styles, sizes, etc.).

Bounty program and low-income program. Low-income groups benefit from a free exchange program. The saturation of second refrigerators is cut in half over five years by a bounty program and is then maintained at that level.

Penetration fraction. This fraction (Tables 1-10 and 1-11) specifies the fraction of the year's purchases affected by the incentives program. It is estimated on the basis of past experience with rebate programs. and reflects the program's first year pilot stage, second and third year demonstration phase, and subsequent maturation. We assume that pilot programs are begun in 1988 and reach their take-off phase in 1991. The maximum fraction of sales that is shifted is assumed to be 30 percent. For the second unit bounty program, the effective penetration fraction is 0.5 x 0.8, to account for the twenty percent of second units that are resold by the charities rather than junked.

Results. As shown in Appendix A, Table R-A, the annual savings for the program-based scenario compared to the MEOS forecast are 650 GWh, or 18 percent in 2005.

IMPACTS ON UTILITY SYSTEM LOAD SHAPES

Tables 1-7, 1-8, and 1-9 show the estimated reductions in unit input power for manual defrost, top-mounted frost-free, and side-mounted frost-free units at various efficiency levels. Using these figures and the baseline data on load profiles (Appendix B) we calculate the diversified per unit contributions to system peak as a function of technological efficiency level. The resulting peak contributions and savings are shown in Appendix A, Tables R-B and R-C. Estimated savings for hours and days other than system peak can be calculated from the fraction-in-use data for refrigerators.

CUMULATIVE INVESTMENT AND PROGRAM COSTS

We calculate the annual and cumulative (1988-2005) costs that need to be incurred to obtain the scenario efficiencies. Here we use two perspectives:

1. the technology costs (no programs); this perspective is used for the technical potential/best available technology scenario;
2. the total program (incentives plus administration) costs including corrections for free riders and low-income programs (all ratepayer perspective);

Program costs. We estimate that in a well-designed program, the penetrations of the scenario can be achieved with an average rebate level equivalent to buying conserved energy at its full marginal cost. We base our cost scenario on the marginal extra first cost for the dominant product class, i.e. frost-free refrigerator/freezers (see Table 1-12). This cost increases over the years as higher efficiencies are being targeted. Administration costs, on the other hand, decrease somewhat from $15 to $7 per rebate as program delivery and trade ally cooperation are optimized. After 2000, rebates are discontinued, but information activities continue to maintain customer preference for more-efficient models.

Table 1-12. Rebate Levels and Administration Costs

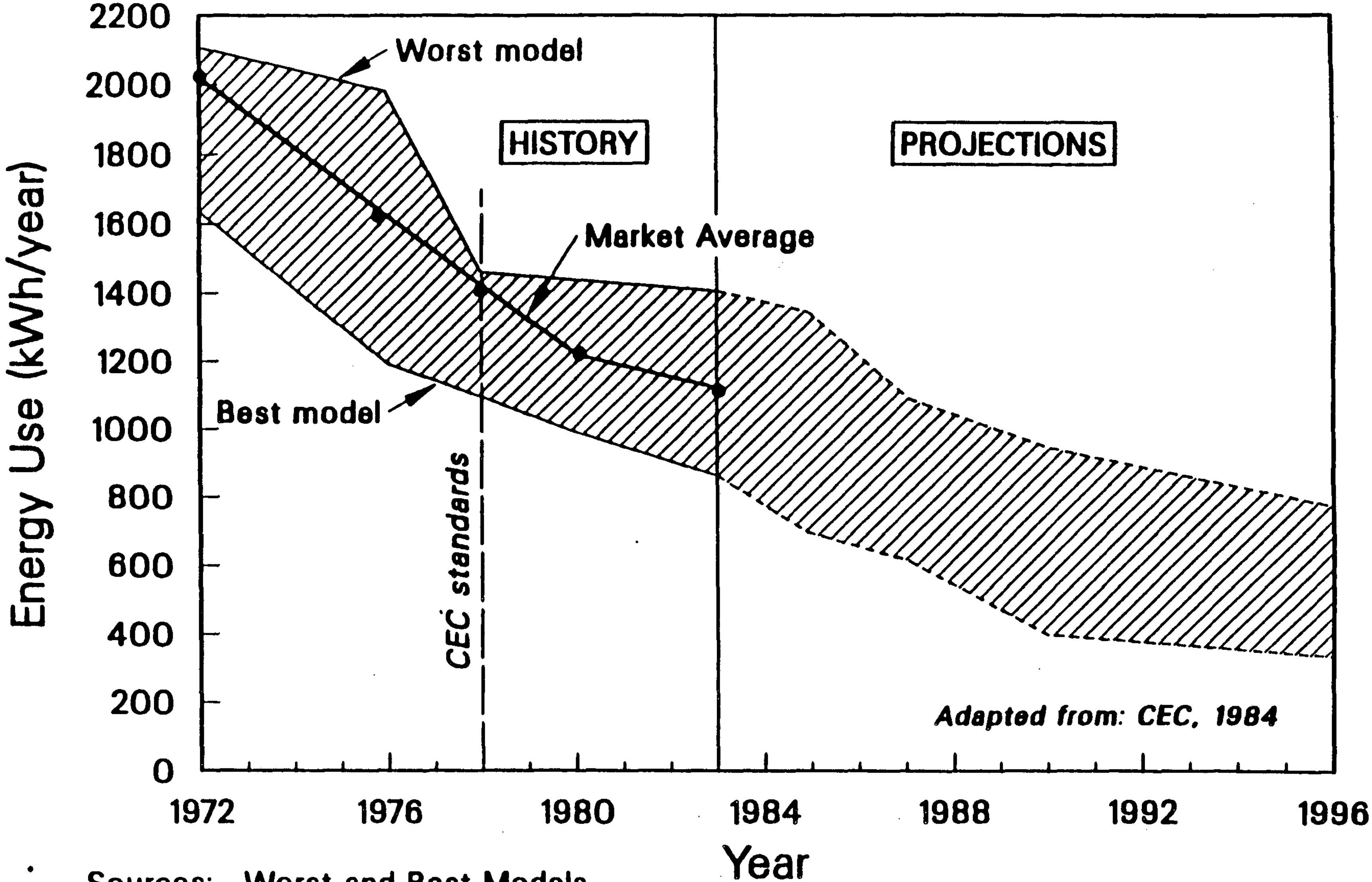
Year	Frost-Free $/unit		Standard $/unit		Second Units $/unit	
	Rebate	Admin.	Rebate	Admin.	Rebate	Admin.
1991	70	15	40	15	45	15
1992	85	13	60	13	45	13
1993	100	11	80	11	45	11
1994	115	7	100	9	45	9
1995	130	7	120	7	45	7
1996	130	7	120	7	45	7
1997	130	7	120	7	45	7
1998	130	7	120	7	45	7
1999	130	7	120	7	45	7
2000	130	7	120	7	45	7
2001	0	7	0	7	45	7
2002	0	7	0	7	45	7
2003	0	7	0	7	45	7
2004	0	7	0	7	45	7
2005	0	7	0	7	45	7

Results. The results of the cost calculations are shown in Appendix A, Table R-D. Cumulative ratepayer costs by 2005 are $135 million.

Figure 1-1

Trends in Refrigerator Energy Usage

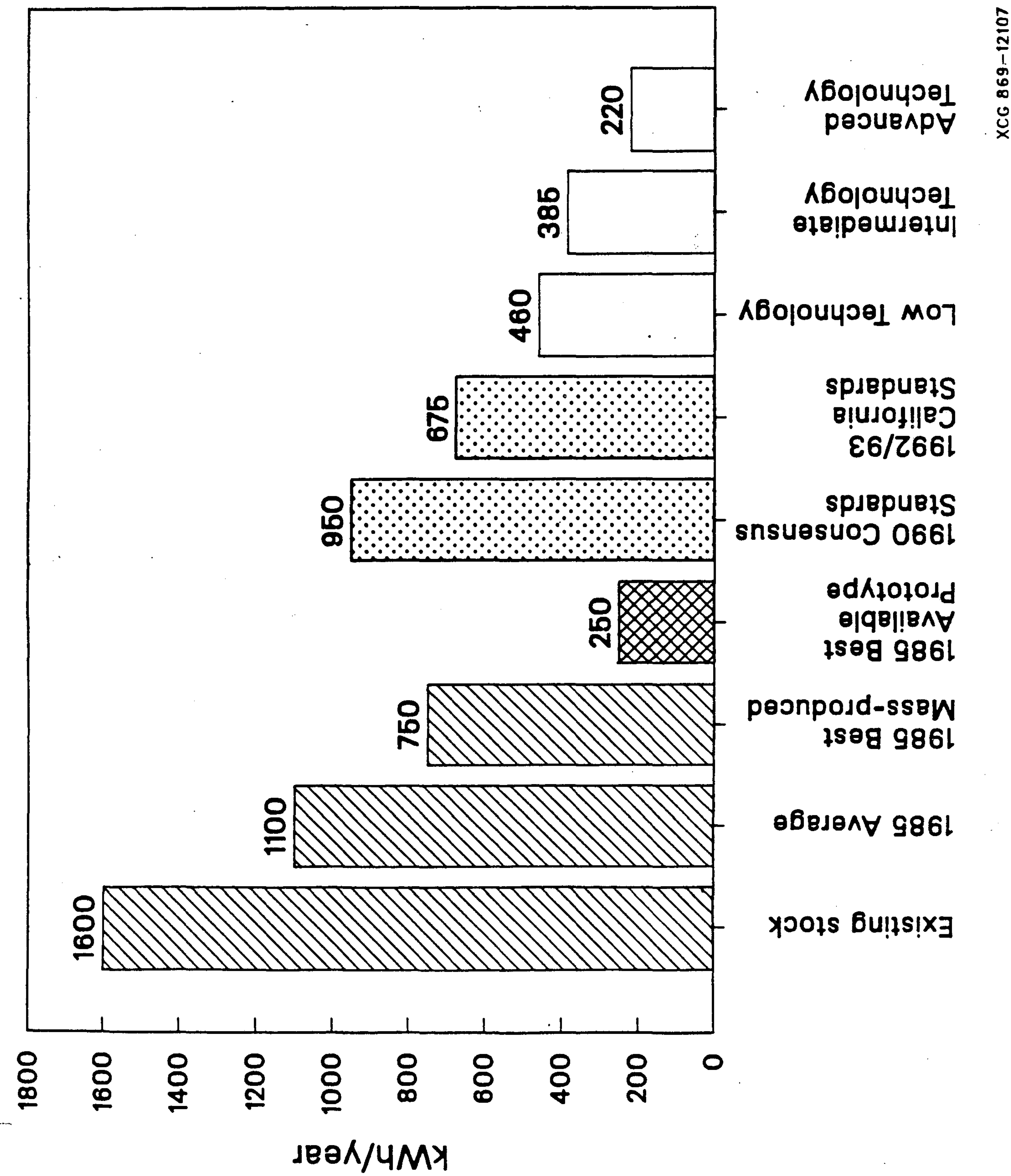
Top Mount Refrigerator



Sources: Worst and Best Models
Historical from AHAM Directories
Projections from Staff Estimates
Market Average
Historical from AHAM Energy Consumption & Efficiency Data, 6/1/84

XCG 8611-12286

Figure 1-2 Refrigerator Efficiencies: Present and Future
(Top-mounted Refrigerator-freezer)



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2. FREEZERS

A. MEOS BASELINE DATA

END-USE: Food Refrigeration
FUEL: Electricity
TECHNOLOGY: Freezers

GENERAL

Contribution to total electricity use. The utilities report that in 1985, freezers contributed an estimated 746 GWh or 9.1 percent to Consumers Power's total residential sales. For Detroit Edison, the corresponding figures are 612 GWh or 6.1 percent. We recalculated these figures using the companies' present and historic saturations and present and historic sales-weighted efficiencies as reported by AHAM (AHAM 1985). These revised energy uses and and loads for freezers are shown in Table 2-1.

Contribution to peak demand. Freezers contribute 112 MW to Consumers Power's 1985 system peak and 99 MW to Detroit Edison's system peak.

Main product types. Freezers come in two configurations (chest and upright) and two defrost options (manual and automatic). All chest freezers are of the manual type.

U.S. sales by type. Manual chest and upright freezers constitute the bulk of total sales, with a combined share of 94.1 percent of 1984 sales. Frost-free units accounted for only 5.9 percent.

Table 2-1. Freezer Energy Use and Loads

Utility	Equip. Type	Saturation 1985 (%)	Stock 1985 (x1000)	UEC (kWh)	UPD summer (W)	Total Use (GWh)	Peak Demand (MW)	Marginal UEC (kWh)
CP	Standard	40.6	494	1143	154	565	76	770[1]
	Frost-Free	13.4	163	1624	220	266	36	1285[1]
	ALL					831	112	
DE	Standard	28.4	464	1093	146	508	68	770[1]
	Frost-Free	8.5	139	1642	222	229	31	1285[1]
	ALL					737	99	

(1) U.S. 1984 shipment-weighted averages.

BASIC ENERGY CHARACTERISTICS

The basic energy characteristics of freezers are very similar to those of refrigerators. We refer to the discussion in that section.

EXISTING MICHIGAN STOCK

Composition of Existing Stock

Saturation of freezer ownership. Saturations in Michigan are 40.6 percent manual and 13.2 percent automatic defrost in CP's territory, and 28.4 and 8.5 percent in DE's territory.

Saturations by type. Both utilities indicate that about one third of their freezer stocks are of the auto-defrost type. Data on the distribution of manual types between chest and upright models do not seem to be available.

Saturation trends. The saturation of freezers has basically reached steady-state levels in both service territories. The MEOS forecast projects further increases of only a few percentage points.

Unit size. The utilities had no data on the average size of their freezer stocks. Historical national sales data from the Association of Home Manufacturers indicate that the size of units has declined substantially over the last decade. The average adjusted volume for the three major categories was 25.4 cu.ft.

Unit life. We assume a unit life of 20 years for this appliance.

Unit Energy Consumption of Existing Stocks

UECs by appliance type. In Table 2-1 we show the stock-weighted average UECs as calculated from historic saturations and AHAM efficiency data. These figures are different from the values supplied by the companies. Surveys that would establish the actual subtypes and sizes, and therefore the efficiencies, of existing stocks do not seem to be available.

Load Profiles

Seasonal variations. We use Consumer Power's submetering data to establish the relative loads of freezers in the summer, winter, and spring/fall season (not shown). Based on an index of 1.00 for spring/fall, the winter index is 0.936 and the summer index is 1.176.

Diurnal variations. Unlike refrigerators and refrigerator/freezers, dedicated freezer appliances are not operated on a regular diurnal schedule. We therefore represent the unit peak demand as equal to the average annual load, corrected by the appropriate seasonal index.

Diversified load. The unit peak demands for summer and winter are shown in Table 2-1. These values are derived from the unit energy consumptions reported in the same table.

CURRENTLY SOLD EQUIPMENT

Marginal saturations of subtypes. The share of the three freezer types in 1984 sales, as reported by AHAM, is shown in Table 2-2. Note that the reported share of automatic defrost freezers in Michigan's stock has been historically significantly above the national average.

Marginal size. Current equipment is 13 percent smaller than the average unit sold in 1972. This size reduction has mainly occurred among chest freezers.

Marginal unit energy consumption. Assuming 1984 market shares for chest and upright manual units, currently sold manual units are 30-33 percent more efficient than existing Michigan stocks. For automatic defrost units, the corresponding figure is 22 percent (see Table 2-1).

Table 2-2. Appliance Efficiency Standards for Freezers

Product Class	UEC 1984 (kWh)[2]	Size (cu.ft.) Ship-wtd. Avg. 1984[2]	Market Share % 1984[2]	Maximum Permissible UEC (kWh)[1] 1987 Calif. Standard	1990 Consensus Standard	1992 Calif. Standard
Chest Manual	708	23.9	51.5	737	576	542
Upright Manual	843	26.6	42.6	1049	712	709
All Manual	769	25.1	94.1	878	638	618
Upright Auto-Defrost	1285	30.0	5.9	1766	1103	1116
ALL FREEZERS	757	25.4	100.0	930	665	647

(1) Assuming 1984 sizes and market shares.

(2) AHAM 1985.

B. DEMAND-SIDE MEASURE DATA BASE

END-USE:	Food refrigeration
FUEL:	Electricity
TECHNOLOGY:	Freezers
DEMAND-SIDE MEASURE:	Freezer efficiency improvement

GENERAL DESCRIPTION

Technology Features

The technical options to improve freezer efficiency are more or less identical to those for refrigerator/freezers. We refer to the extensive discussion in the corresponding section of the data base.

Appliance Standards

Like refrigerators, freezers have first been regulated in the state of California. The national appliance "consensus" standards that are to go into effect in 1990 also cover this appliance. The 1990 minimum efficiency levels for freezers are very close to the 1992 California standards. Both are listed in Table 2-2. The projected UECs under these standards are based on 1984 average sizes and market shares.

COST AND PERFORMANCE IMPACTS

Per-Unit Energy Savings

Efficiency levels. We again use prototype simulations from previous studies to estimate expected savings and costs from technology improvements. We distinguish a 1990 standard, best-available technology, and technically-achievable level. The 1990 standard can be met with presently available models in some size ranges and categories, and almost so in others. A 3.65 EER compressor and 2 in. polyurethane insulation in walls and door are sufficient to achieve or exceed the standard. The best-available level can be achieved with improved door gaskets and 3.5 in insulation. The technically-achievable level reflects evacuated panels and EER 5.0 compressors.

Tables 2-3 and 2-4 show the reductions in energy use as obtained from the DOE analysis and supplementary heat loss calculations (ACEEE 1986). The best-available technology versions are 47-57 percent more efficient than the baseline models, which are close to current sales-weighted averages.

Costs of Improved Freezers

Costs for the above-mentioned improvements are shown in Tables 2-3 and 2-4 for automatic defrost and chest manual units. They were obtained in a manner analogous to those for improved refrigerators, using the ACEEE figures as the reference point. Because upright manual models have larger sizes and higher UECs on average, the economics of improvements for them are expected to fall between those for chest manuals and automatic defrost units. They are not separately shown.

Costs of Conserved Energy

As shown in Tables 2-3 and 2-4, the marginal costs of conserved energy for the 1990 standards are less than 1 cent/kWh, while the best-available technology improvements range from 2.4 to 3.7 cents/kWh (three percent discount rate). At a 7 percent discount rate, the figures are 40 percent higher.

Table 2-3. Efficiency Potentials in Manual Defrost Freezers

Technology	UEC (kWh)	UPD (W)	Additional First Cost		CCE		$CCPP_{20}$	
			Marginal ($)	Cumulative (1985 $)	Marginal ($/kWh)	Cumulative (1985 $/kWh)	Marginal ($/kW)	Cumulative (1985 $/kW)
Baseline	760	102	0	0	0.000	0.000	0	0
1990 Standard	600	80	20	20	0.008	0.008	933	933
Best Avail. Tech	330	44	150	170	0.037	0.027	4146	2950
Tech. Achievable	170	23	170	340	0.071	0.039	7929	4301

Table 2-4. Efficiency Potentials in Auto-Defrost Freezers

Technology	UEC (kWh)	UPD (W)	Additional First Cost		CCE		$CCPP_{20}$	
			Marginal ($)	Cumulative (1985 $)	Marginal ($/kWh)	Cumulative (1985 $/kWh)	Marginal ($/kW)	Cumulative (1985 $/kW)
Baseline	1285	172	0	0	0.000	0.000	0	0
1990 Standard	1100	147	20	20	0.007	0.007	807	807
Best Avail. Tech.	680	91	150	170	0.024	0.019	2665	2097
Tech. Achievable	280	38	190	360	0.032	0.024	3545	2673

IMPLEMENTATION PROGRAMS

Like refrigerators, freezer efficiency has been promoted both by appliance standards and through incentive programs. Several utilities have given rebates for improved freezer efficiency as part of their refrigerator rebate programs. The operational aspects and costs of these programs have been discussed in the refrigerator section.

TECHNICAL AND ACHIEVABLE POTENTIAL

The calculation of technical and achievable potentials follows that for refrigerators. We again assume a slight overshoot of the 1990 standard.

Technical Potential/Best Technology Scenario

To be conservative, the technical potential scenario reflects the best-available technology efficiencies of Tables 2-3 and 2-4.

Results.

Appendix A, Table F-A shows the GWh energy savings from 1984 to 2005. (Appendix A, Tables FCP-A and FDE-A show the corresponding results for Consumers Power and Detroit Edison.) Annual energy savings of 31 percent, or 406 GWh, are projected by 2005.

Program-Based Scenario

Here, we follow the program design described for refrigerators, with the same method for determining the reward level efficiency for rebates.

Results. This scenario results in annual energy savings of 14%, or 182 GWh, by 2005.

IMPACTS ON UTILITY SYSTEM LOAD SHAPES

Results. Winter and summer peak power savings are show in Appendix A, Tables F-B and F-C. Based on the program scenario, winter peak power savings of 20 MW, and slightly larger summer peak power savings (24 MW), can be expected annually by 2005.

ANNUAL AND CUMULATIVE INVESTMENT AND PROGRAM COSTS

Technology costs are taken from Tables 2-3 and 2-4. Program rebates are based on approximately 100 percent of the marginal cost of improvements. The administration cost is the same per unit as for the refrigerator program.

Results. Annual and cumulative costs are shown in Appendix A, Table F-D. A cumulative expenditure of $44 million by 2005 would be required for the program scenario.

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3. LIGHTING

A. MEOS BASELINE DATA

END-USE: Lighting
FUEL: Electricity
TECHNOLOGY: Incandescent and Fluorescent Lighting

GENERAL

Contribution to total electricity use. Electric lighting constitutes a significant share of both utilities' residential sales. The Detroit Edison share was 12 percent in 1985. The Consumers Power share was 11 percent (Table 3-1).

Contribution to peak demand. The contribution to summer peak (at 3 PM) is an estimated 67 MW for CP and 91 MW for DE. During winter peak, the corresponding figures are 273 MW and 375 MW (Table 3-1).

Table 3-1. Lighting Energy Use and Loads

Utility	Equip. Type	Saturation 1985 (%)	Stock 1985 (x1000)	UEC (kWh)	UPD winter (W)	Total Use (GWh)	Winter Peak (MW)
CP	General	100.0	1217	685	212	834	258
	Outdoor	18.6	226	295	66	67	15
	ALL					901	273
DE	General	100.0	1635	675	211	1104	345
	Outdoor[1]	14.0	229	571	131	131	30
	ALL					1235	375

(1) UEC adjusted to account for lamppost lighting

Main product types. The main lamp technology in the residential sector are incandescent lightbulbs.

U.S. sales by type. A General Electric study conducted during the 1970s found that 93 percent of the residential lighting market is comprised of incandescent bulbs, with the remainder being fluorescent lights (GE 1976).

Saturation of electric lighting. The two utilities distinguish between indoor lighting and outdoor lighting, with Detroit Edison also separating out a third category of lamp posts. Indoor lighting is assigned a 100 percent saturation, while the outdoor lighting saturation is 18.5 percent for CP (1984) compared to 14.0 percent for DE (1985). The saturation for DE's lamp post lights is 0.9 percent.

BASIC ENERGY CHARACTERISTICS

Ratio of energy costs to capital costs. The duty factor of lightbulbs varies widely, depending on their location. For a high-use incandescent bulb (1000 hours/year) of average wattage (75 W), annual electricity costs are about $6 compared to a capital cost of $1.20. This high energy to capital cost ratio indicates the possibility of highly cost-effective efficiency improvements.

Key factors affecting electricity use. The electricity consumption required for achieving a desired level of illumination depends on the following three factors:

- the efficacy of the bulb
- the efficiency of the lamp including reflectors and shades
- the reflectance of surfaces in the illuminated environment.

In the context of residential lighting, we will concentrate only on lightbulb efficacy, since it is the only factor that can be changed without affecting other behavioral components of perceived lighting utility.

Formula for calculating energy consumption. The output of a light source is measured in lumens. Efficacy is the ratio of lumen output per watt input. For a given level of lighting (lumen output), the required electricity $w(2)$ for a change in efficacy e is calculated by multiplying the baseline electricity consumption $w(1)$ with the inverse ratio of the two lightbulb efficacies $e(2)$ and $e(1)$:

$$w(2) = w(1) \times e(1)/e(2).$$

EXISTING MICHIGAN STOCK

Composition of Existing Stock

No Michigan-specific breakdown of residential lighting by type (incandescent versus fluorescent) is available. We base our estimates on national sales data, which indicate that incandescents make up 93 percent of the market.

Lightbulb wattages. Detroit Edison estimates that the average lightbulb wattage in its territory is 75 W. We use this estimate for our analysis of both the CP and the DE service territories.

Saturation of sockets. Detroit Edison provided data from a 1959 survey which showed that on average, 20 sockets were being used per household. Differences in the frequency distributions for various building types are modest. Significantly different UECs are reported by the two utilities for outdoor lighting, suggesting divergent socket concentrations in that application.

Saturation trends. Saturations as used in the MEOS forecast refer to application of an undetermined number of lightbulbs in a particular mode (indoor, outdoor, lamp post) rather than the number of sockets per household. The only application in which a modest change in saturations has been observed in the past is outdoor lighting. In the Detroit Edison service territory, that application moved from 11 percent saturation 14 percent in 1985. Approximately the same figure is forecast by MEOS for the next 20 years.

Unit life. Standard incandescent bulbs have a service life of 750 hours. Long life incandescents with a 2500 hour life are also available. The life of fluorescent bulbs is an order of magnitude higher than that of standard incandescents. Note that in standard incandescent bulbs, the efficacy decreases by up to 20 percent over time, due to the darkening of the bulb by burned-off tungsten filament particles.

Energy Efficiency and Consumption of Existing Stocks

Efficacy. The efficacy of standard incandescents is in the range of 15 lumens/watt.

Unit energy consumption. The unit energy consumptions are shown in Table 3-1. Consumers Power reports an average indoor lighting UEC of 685 kWh/year, and of 295 kWh/year for outdoor applications. Overall, the average household uses 742 kWh/year for lighting. For Detroit Edison, the corresponding indoor and outdoor numbers are 675 and 521 kWh/year. Detroit Edison also reports a separate UEC for outdoor pole lamps of 964 kWh/year. For all applications combined, the UEC is 756 kWh.

Operating hours. Based on 20 sockets per household and an average wattage of 75 W, the average lightbulb is operated 500 hours. However, the range of operating hours for particular installations ranges from more than 3000 hours for outdoor lighting, to 1000-1200 hours for bulbs in the kitchen, living room, hallways, and other frequently used areas, to maybe 50 hours for closet lights. The cost-effectiveness of improved lightbulbs must therefore be ascertained for a range of operating conditions.

Load Profiles

Average annual load. Consumer's Power average annual loads are 95 MW for general lighting and 8 MW for outdoor lighting. The corresponding average annual loads for Detroit Edison are 126 MW and 15 MW.

Non-coincident maximum demand. Based on an average of 20 sockets and 75 W bulb size, the installed demand from lighting is 1.5 kW per household.

Seasonal variations. There is a clear seasonal variation in lighting, due to the shorter daylight periods during winter.

Diurnal variations. The hourly-to-average load ratios, based on an estimated load profile, are shown in Appendix B. We use one load profile for all lighting areas combined. Coincident loads are up to three times as high as average loads. Note that system peak contribution in the winter (7 PM) is much higher than in the summer, while the summer contribution (3 PM) is not zero.

Unit peak demand. The diversified demand contributions at system peak are shown in Table 3-1 for the various applications.

CURRENTLY SOLD EQUIPMENT

Because of the short lifetime of conventional lightbulbs, the stock of existing bulbs and currently sold equipment do not differ significantly from each other in terms of average size or efficacy. A number of improved incandescent and new fluorescent lightbulbs have appeared on the market but do not as yet command a significant market share.

B. DEMAND-SIDE MEASURE DATA BASE

END-USE:	Lighting
FUEL:	Electricity
TECHNOLOGY:	Lightbulbs
DEMAND-SIDE MEASURE:	Replace with more efficient lightbulbs

OVERVIEW

Currently, four types of improved lightbulbs are commercially available or about to be available for residential applications. These are:

- Slightly *improved incandescents* ("wattmiser" or "supersaver" bulbs); these offer 5-10 percent savings over standard incandescents at an extra cost of about 10 cents per unit. Lifetimes are the same (750 hours).
- *Coated incandescents* (heat-mirror bulbs); this lightbulb is still in the prototype stage. Its efficacy is about twice as high as that of conventional incandescents, thus offering a 50 percent savings. The lifetime is estimated to be approximately 2500 hours, while costs are expected to be of the order of $5.00.
- *Compact fluorescents*; the efficacies of these bulbs are 3 to 5 times as high as those of incandescents, and last for up to 10,000 operating hours or more. Bulbs for residential applications cost $10-15.
- *Metal halide lamps*; these lamps offer even greater efficacies than compact fluorescents, and lifetimes of up to 24 000 hours, but are currently only available in sizes of 150W incandescent equivalent (32 W) or larger. They are a practical alternative to incandescents in high output outdoor security light applications, where some customers use large floodlight arrangements (especially in multifamily buildings).

In the following analysis, we concentrate on compact fluorescents and heat-mirror bulbs as the most commercially advanced and/or practically applicable current residential lightbulb technologies.

GENERAL DESCRIPTION

Fluorescent lightbulbs convert electricity into light by generating an electric discharge process in the gas within the bulb, which causes a phosphor coating on the inside of the bulb to emit light. A ballast is required to regulate the flow of electric current. This ballast is of the electromagnetic variety (core-coil) in most current models, but microchip versions of smaller size are becoming available. The bulbs are sold in one of two forms: either the ballast and bulb are one unit (SL-type), or the ballast is separate from the bulb and contained in a socket conversion base (PL-type).

Efficacy. Currently available compact fluorescent lightbulbs have efficacies of 40-69 lumens per Watt, compared to 11-18 lumens per Watt for incandescents. The efficacy of heat-mirror bulbs is 30 lumens per Watt. For the smallest available metal halides (32 W or equivalent to 150 W incandescents), the figure is 78 lumens per Watt.

Technology status and availability. Compact fluorescent lamps are currently available from all major manufacturers in the U.S., including General Electric, Sylvania, Panasonic, Philips/Norelco, Hitachi, Osram, and Mitsubishi. Available wattages for residential applications range from 5-39 W, allowing the replacement of ca 20 W to 200 W conventional bulbs. Models are available in the usual warm white, cool white, and bright white categories. Until now, manufacturers in the U.S. have not aggressively marketed these bulbs for residential uses, but have mostly promoted them for commercial applications where operating hours for incandescents tend to be highest.

The heat-mirror bulb has been developed by Durotest Corp. and was introduced into the market in early 1987.

Special problems and current limitations. The tubes used in compact fluorescents bring with them some constraints on the shape and size of the lightbulb. Manufacturers have attempted to minimized space requirements by a variety of designs, including using a long and narrow double-finger or parallel-tube shape, or an approximation of the bulb shape in form of a cylinder in which the fluorescent tube is coiled or bent into a double-folded S-shape and contained in an impact-resistant shell. This shell helps diffuse light output and can also serve as a decorative cover. Shapes and reflectors to replace PAR-, ER-, and R-type bulbs in recessed ceiling or high-hat fixtures and G-40 globular-type lamps for decorative applications are also available.

While several manufacturers including Mitsubishi, Panasonic, and Osram, are now offering units comparable in size to conventional lightbulbs, currently available bulb-type models (e.g. the Philips/Norelco SL models) are somewhat larger (ca. 6.5-7.25 inches and 3-4 in in diameter) than ordinary incandescents and will not fit all fixtures or lamps in which incandescents are used. On the other hand, recess lighting fixtures easily accept these fluorescents while reducing the risk of fire from waste heat trapped in the ceiling. In many restricted applications, the two-finger type offers a retrofit alternative. For table lamps, short (4.75 in length, 1.75 in diameter) screw-in parallel tube screw-ins are now available to replace 25 W incandescents in table lamps and other low-wattage applications, and 7 W bulbs replacing 40 W incandescents measure 6 in or less.

The move to microchip ballasts is helping miniaturization. Additional miniaturization will be possible with progress in using 2-photon phosphor coating in the tubes. This innovation, which is currently under development, would increase efficacies by 30-50 percent and allow a corresponding reduction of tube length for the same light output.

Meanwhile, a number of fixture manufacturers have adapted to the advent of compact fluorescents by designing fixtures, desk lamps, and other decorative lighting specifically for use with high efficiency bulbs. Fluorescent-adapted lanterns, pole lamps, porch lights, entry way, hall, bath, and vanity lights including, where needed, special moisture-resistant features or cold weather ballasts are available from a number of manufacturers. Development has been particular intense in California, where the state's residential building standards require the use of fluorescent bulbs in permanent fixtures of newly constructed buildings.

Like conventional fluorescents, compact fluorescents can have start-up delays of up to a second which customers may find bothersome. However, new models are available with a built-in rapid-start mechanism that overcomes these problems. Another feature of compact fluorescents is that they take approximately 60 seconds to reach full brightness.

Consumers sometimes associate compact fluorescents with cold light and flicker, characteristics they may have encountered with earlier circlite fluorescents or office lighting at their workplace. However, the color rendition of compact fluorescents is now equivalent or better than that of incandescents.

Currently, most compact fluorescents are not suitable for outdoor operation in cold winter climates because they do not start and/or have reduced output at low temperatures. For example, the rated operating range of the Philips SL bulb extends to 0 deg F. However, at least one manufacturer (Valcon, Inc.) introduced an adapter base for the Phillips and Osram parallel tube bulbs that will start them at -20 deg F. Still, a significant reduction in light output at low temperatures remains. For these outdoor applications, heat-mirror incandescents are a viable alternative. Another option are metal halide lamps, particularly for outdoor security lights of larger lumen requirements. Unlike compact fluorescents, these require a separate ballast.

Current compact fluorescents do not work satisfactorily in standard dimming circuitry. In the future, this disadvantage can be overcome, however, by integrating the dimming feature into the electronic ballast at the base of the bulb. Mitsubishi is already offering a dimmable bulb in the Japanese market.

Improvements in lightbulb utility. One major benefit to customers is the extended life of fluorescent and heat-mirror light bulbs which makes frequent changes and the associated inconvenience and risk of accident unnecessary. Other benefits are the dimming features that can be integrated into the electronic ballasts at the base of the bulbs.

Secondary energy impacts. Like other efficiency improvements in household appliances, improved lightbulbs remove some internal gains during the heating season and cooling season. The impact of these savings is minor, though, and is accounted for in the calculation of space heating savings.

Lifetimes. Currently available compact fluorescent models have rated lifetimes of 5000 to 12,000 hours, depending on the type. GE recently announced a 39 W two-finger model (F40BX) that would achieve a lifetime of 20 000 hours, and already offers a 39 W rapid-start model (F39 BX) that lasts 12 000 hours. These lifetimes are based on the standard ANSI test for fluorescents, in which bulbs are on for three hours at a time. Lifetimes are somewhat shorter if the duration of operation is less than three hours at a time. Lumen maintenance at 40 percent of rated life is on the order of 90 percent. For heat-mirror bulbs the rated life is 2500 hours. The lifetimes of the screw-in adapters containing the ballast for parallel-tube type bulbs is in excess of 20,000 hrs.

COST AND PERFORMANCE DATA

Determination of Energy Savings

We base our calculations on the replacement of a standard 75 W incandescent lightbulb by a high-efficacy fluorescent lightbulb that uses only 25 percent of the energy to produce the same lumen output. This performance can be achieved, using the Philips/Norelco SL-18 bulb, which has an efficacy of 61 lumens/watt. It should be noted that even greater savings are available from the Osram Dulux D model with 69 lumens/watt. Further improvements in the technology are being made. In the future, savings of 80% could very well become the norm. For the heat-mirror bulb, we assume a 50 percent savings compared to standard incandescents, based on test ratings of prototypes by Durotest and LBL.

Costs of Improved Lightbulbs

The costs of compact fluorescents are still relatively high because they are not currently marketed in the residential sector and have not achieved volume production. Suggested retail prices range from $17-$18 for the Philips/Norelco SL-18 to $12 for the Mitsubishi Marathon B models. Many outlets now offer 18 W bulbs for less than $ 10, and for as little as $ 8 in consumer warehouses. The costs of imports are somewhat dependent on currency exchange rates.

Some retrofit applications may require the installation of a new fixture to accommodate the longer compact fluorescents. This would involve an additional equipment and installation cost beyond the cost of exchanging the bulb. We have neglected these costs primarily because they would most likely not apply to most applications. Estimating such costs is also difficult because it is not known what fixtures might have to be replaced, and because changeovers of fixtures also occur as part of remodeling activities or due to breakage. To nevertheless make an allowance for such costs, we assume higher bulb costs than would be likely in a major utility program.

We assume a retail cost of $15 and a bulk purchase/wholesale cost of $10 for a 60-69 lumens/watt model with a 10 000 hr life.

For the heat-mirror bulb, the expected retail price is $5-6.

Costs of Conserved Energy

We calculate the cost of conserved energy for a retail and bulk purchase case, respectively, on the basis of the following assumptions:

Compact fluorescents:
10,000 hour life, no labor cost for installation, replacement of a string of 13.3 standard lightbulbs of 750 hours service life and $1.00 retail cost, $.50 wholesale/bulk purchase cost.

Heat mirror bulbs:
2500 hour life, no labor cost for installation, replacement of a string of 3.33 standard incandescents of 750 hour service life and $1.00/$0.50 purchase costs.

Tables 3-2 and 3-3 and Fig. 3-1 show the results as a function of operating hours, for a range from 100 to 8760 hours. Each case in the table is examined for both a 3 percent and 7 percent real discount rate. As shown in Fig. 3-1, the $6 price makes the heat-mirror bulb cost-competitive with compact fluorescents. We assume a cost of $4.00 for bulk purchases. As can be seen from the figure, fluorescents and heat-mirror bulbs are cost-effective against present average electricity rates at virtually all operating hours. Above 200 hours, they are cheaper than the shortrun marginal costs from Michigan's baseload power plants at both the 3 percent and 7 percent discount rates. Above 500 to 1000 hours, the CCE is about 1¢/kWh or less.

Table 3-2: Cost of Conserved Energy, Compact Fluorescents								
	Bulk Purchase (I = $0.5, F = $10)				Retail Purchase (I = $1, F = $15)			
Operating Hours	NPV of Incandescents Over Life of Fluorescents		C.C.E. (¢/kWh)		NPV of Incandescents Over Life of Fluorescents		C.C.E.(¢/kWh)	
	3%	7%	3%	7%	3%	7%	3%	7%
100	2.38	1.25	4.23	10.75	4.77	2.51	5.68	15.36
200	3.68	2.16	2.16	4.99	7.36	4.31	2.61	6.79
500	5.15	3.84	1.14	2.04	10.29	7.68	1.11	2.42
1000	5.84	4.97	0.86	1.26	11.67	9.94	0.68	1.26
2000	6.23	5.73	0.72	0.91	12.46	11.46	0.49	0.76
5000	6.49	6.27	0.64	0.72	12.98	12.53	0.37	0.48
8760	6.56	6.43	0.62	0.67	13.13	12.87	0.34	0.40

I = incandescent, F = Fluorescent

Table 3-3: Cost of Conserved Energy, Heat-Mirror Incandescents								
	Bulk Purchase (I = $0.50, HM = $5)				Retail Purchase (I = $1, HM = $6)			
Operating Hours	NPV of Incandescents Over Life of H.M. Bulb		C.C.E. (¢/kWh)		NPV of Incandescents Over Life of H.M. Bulb		C.C.E.(¢/kWh)	
	3%	7%	3%	7%	3%	7%	3%	7%
100	1.31	1.02	3.11	7.43	2.63	2.05	2.84	4.42
200	1.47	1.27	1.83	3.60	2.94	2.55	1.59	2.43
500	1.58	1.49	1.22	1.77	3.17	2.94	1.02	1.89
1000	1.62	1.57	1.06	1.30	3.25	3.15	0.86	1.66
2000	1.64	1.62	0.98	1.10	3.29	3.24	0.79	1.55
5000	1.66	1.65	0.93	0.99	3.32	3.29	0.75	1.48
8760	1.66	1.66	0.92	0.96	3.32	3.31	0.73	1.46

I = standard incandescent, HM = heat mirror incandescent

Table 3-4 summarizes the costs of conserved energy for indoor and outdoor lighting applications. We assume that porch lights account for about 40% of general lighting. These lights can be converted to heat-mirror bulbs. Of the remaining 400 kWh, 80% are consumed in sockets with operating hours of more than 200 hours per year. These sockets can be economically converted to fluorescent bulbs. Indoor bulbs with less frequent usage are not replaced. The savings are thus (275 x 0.5 plus 400 x 0.8 x 0.75) kWh, or 56 percent of the total.

Cost of conserved peak power. Table 3-4 shows the cost of diversified savings ($CCPP_{20}$) for indoor and outdoor lighting during the summer afternoon and the winter evening peak, based on the respective fractions-in-use.

Table 3-4. Cost of Conserved Energy and Peak Power: General Lighting									
Application	Baseline			Savings			Bulk Purchase		
	UEC (kWh)	UPD winter (kW)	UPD summer (kW)	Electricity (kWh)	Peak Power winter (kW)	Peak Power summer (kW)	CCE (¢/kWh)	$CCPP_{20}$ winter ($/kW)	summer ($/kW)
Porch Lights	275	0.10	0.00	138	0.05	0.00	0.95	1049	0
Indoor (> 200 hours/year)	320	0.12	0.04	240	0.09	0.03	1.2	516	1639
Indoor (others)	80	0.03	0.01	--	--	--	--	--	--
TOTAL	675	0.25	0.05	378					

IMPLEMENTATION PROGRAMS

Program design. Lighting efficiency programs represent one of the largest and most cost-effective demand-side resources in the residential sector. This end-use also has several features that facilitate the operation of effective programs, including the short lifetime of incandescent bulbs, and their high ratio of energy to capital costs. This affords unlimited freedom in the timing of efficiency replacements without significantly affecting their economics.

The extra first cost for efficient lightbulbs is several times larger than the first cost of standard equipment (about ten to 20 times in the case of fluorescents and 5 to 10 times as high in the case of heat-mirror bulbs). This has important implications for the design and impact of utility incentives. Following the principle of offering a rebate equivalent to roughly the full extra first cost, as in other incentives programs, essentially translates into buying the lightbulb for the customer. In other end-uses, a free-exchange program would mean high costs to ratepayers. For example, buying the customer an efficient refrigerator results in costs of conserved energy of about 7¢/kWh (see the measures section on refrigerators). In lighting, the same practice is equivalent to buying electricity at below one cent per kWh, plus the cost of administration.

These features greatly facilitate the design of an aggressive retrofit program for high-efficiency lightbulbs: utilities and ratepayers can cost-effectively give the lightbulbs away. Participation rates could be very high.

There are other advantages with a give-away program. By giving the bulbs away, utilities and ratepayers do not have to pay the high mark-up of lighting equipment retailers, as they would in a conventional coupon-based rebate approach. As very large whole-sale buyers, utilities would enjoy considerable negotiating power to obtain very low bulk prices. These could easily be lower than the $10 per unit assumed here, and thus make up for the 5-10 percent administration costs we assume for the program.

Lighting efficiency improvements based on change-over to fluorescents are persistent. Once they are installed, no replacement will be necessary for 10 to 20 years in indoor sockets, except due to breakage. Each fluorescent rebate or give-away eliminates not one but 13 temptations to buy inefficient lightbulbs.

In the case of heat-mirror bulbs installed in high-usage outdoor sockets, on the other hand, replacements would still be needed more than once a year, and a successful lighting program would have to maintain customer loyalty to this new product for some time before a new purchasing pattern would be firmly established. Here, free trade-ins or coupons for rebates on replacement bulbs would be a suitable mechanism.

Lighting programs would have to overcome another hurdle. The residential lightbulb market is in great part characterized by impulse buying, for example in supermarkets as part of miscellaneous shopping. A successful lighting program must therefore get supermarkets, hardware stores, and other retailers to stock efficient lightbulbs as regular items, and get them to accept and promote utility coupon purchases that would complement direct outreach programs.

An aggressive relamping program would conceivably have several components to be effective. These would include:

1. An outreach program based on canvassing and on-the-spot free installation of efficient lightbulbs, along with handing out rebate coupons for purchasing high efficiency replacement bulbs.
2. An advertisement and informational campaign, along with rebate coupon distribution in the form of bill stuffers.
3. An offer to trade in any burned-out lightbulb for a new high efficiency unit at participating dealerships or regional utility offices.
4. Well-designed trade-ally cooperation to shift impulse buying from incandescents to fluorescents.

A number of utilities have successfully used one or several of these approaches. The trade-in approach has a history in Michigan. Detroit Edison used such a program as a load building method: customers were given free lightbulbs of higher wattage in exchange for bringing in their burnt-out bulbs.* Southern California Edison has given away more than 100,000 compact fluorescents in its low-income oriented conservation program. In Santa Monica, a canvassing-based residential audit and retrofit program included the immediate installation of several compact fluorescents as porchlights, hallway and kitchen lights during the first customer contact. Other utilities have used rebate coupons in the form of bill stuffers covering partial or full extra first costs.

Rebates for bulk purchasers of bulbs are a tested means of spreading fluorescent bulbs. One principal addressee of this program variant would be multifamily building owners or operators who provide common-area lighting for their tenants in parking lots, hallways, etc. Both Southern California Edison and Pacific Gas and Electric operate *common-area lighting efficiency programs* as part of their conservation efforts. PG&E reports that its 1986 program has been very successful. Allocated funds for rebates were exhausted within the first few months of the program year.

To date, we are aware of only one give-away program. This program was conducted in early 1987 in Traer, Iowa, a community with close to a thousand households. The municipal utility enlisted Philips Lighting Company to help with the program. A customer survey was first carried out to determine the usage hours, bulb wattages and types, and fixtures now existing in the homes. Based on this survey, which achieved a 74 percent response rate, two one-day lightbulb exchanges were held. The participation rate in the actual exchange was 57 percent. On average, residential customers obtained about 20 fluorescent bulbs of the PL and SL type. Customers were given assistance in choosing the right kind of bulb model for their fixtures and could come back to exchange bulbs that did not fit.

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*The program, which ran for more than ten years, was stopped in 1978 because a retailer sued the company. At the time, the active intervention of utilities in appliance and lighting marketing was still a novelty. The company still maintains retail stores.

Actual installations could have been lower than the number of bulbs exchanged. There is also the possibility for buy-back of some of the savings in the form of more careless attitudes toward switching off the lights. The utility is currently evaluating customer bills to measure actual savings.

TECHNICAL AND ACHIEVABLE POTENTIAL

It is assumed that 320 kWh of general lighting consumption occurs in 8 indoor sockets with more than 200 operating hours (see Table 3-4), and that this consumption can be modified by means of compact fluorescents. (Note that this level of installation is much lower than the number of fluorescents obtained by the average household in the Traer experiment). The average operation of these sockets is about 720-730 hours (two hours per day), and the average life of fluorescent bulbs in these sockets is 14 years.

In outdoor lighting applications and porchlights, we assume 12 hours of operation per day, or 4380 hours per year. In this application, the average life of heat-mirror incandescents is 7 months. Based on these operating hours, the estimated UEC of 275 kWh for porchlights is roughly equivalent to one (60 W) incandescent bulb.

Based on the same operating hours, the UECs reported by the utility companies for outdoor lighting are equivalent to about two (60 W) incandescent bulbs per household in the Detroit Edison territory, compared to one bulb for CP.

MEOS/AHAM Forecast

Lighting efficiencies increase by 7.5 percent between 1985 and 2005, due to a ten percent penetration of fluorescent lightbulbs.

Technical Potential/Best Available Technology Scenario

In the technical potential scenario, all incandescent lightbulbs in indoor applications are replaced by fluorescents, and all outdoor applications by metal halide bulbs with equivalent efficiencies and wattages, reducing lighting consumption by 80 percent. The conversion is achieved in 1988-1990. Participation among households is 100 percent. Results are summarized in Appendix A. By 2005, the yearly technical potential for savings is 1801 GWh, or 74 percent of the MEOS forecast.

Program-Based Scenario

In this scenario, efficient lightbulbs are aggressively promoted using several techniques: give-aways through door-to-door canvassing, trade-ins, and coupons offering efficient bulbs at the cost of incandescents. The average household receives 8 compact fluorescents and two to three heat-mirror bulbs. Outdoor lighting and porch sockets are fitted with heat-mirror bulbs saving 50 percent electricity, while indoor sockets are fitted with compact fluorescents saving 75 percent of incandescent electricity consumption. *In general lighting*, only the estimated 8 indoor sockets with more than 200 hours of operation are retrofitted, using compact fluorescents of average efficacy. This reduces indoor lighting consumption by 60 percent (20 percent unaffected, 80 percent reduced by three quarters). Porchlight sockets are converted to heat-mirror bulbs, reducing consumption there by 50 percent. Weighted average savings are 56 percent.

Outdoor lighting including lamp post and security lighting is changed over in the same manner as porch lights.

Program phases and timing: Field tests and pilot programs are conducted in 1988-89. The program is operated aggressively in 1991-94, with large penetrations achieved through both rebates and exchanges for new purchases and targeted retrofits through give-aways. Thereafter, a maintenance mode is achieved that focuses on maintaining the prevalence of efficient bulbs among existing and new households through promotion and customer information.

Note that the speed of penetration is slower than that achieved in the Traer experiment by a factor of at least 1000. This is of the same order of magnitude as the ratio of total populations between that community and the state of Michigan.

Lighting experts familiar with industry trends predict that by the turn of the century, incandescents will have been replaced as standard technology by fluorescents. After 2000, the program is therefore discontinued.

Eligible fraction: Virtually 100 percent of all households are eligible for full high efficiency relamping.

Maximum penetration fraction: Though many lighting programs have been successful in reaching large numbers of households quickly, no ambitious program aimed at changing over most or all households in a service territory. We assume that with the large incentives outlined below and the targeted and coordinated implementation of the above-described approaches, the maximum fraction of households reached by the program is 90 percent. Within each participating household, all outdoor sockets and about half of all indoor sockets are changed over.

Annual program penetration rates: In the program scenario, penetration rates rise from 1.8 percent per year in 1988 to 18 percent per year in 1991. Between 1991 and 1994, a steady state penetration rate of 18 percent is maintained. By 1995, the maximum penetration of 90 percent of all households has been reached. Subsequent program activities maintain the 90 percent penetration for a slowly growing number of households.

Calculation of annual energy savings:
For 1995 and after, the savings are calculated as follows:
(# of households in year Y) x (max. penetration fraction = 0.9) x (UEC of porch lights x 0.5 plus UEC of indoor lights x 0.8 x 0.75)

Results. The GWh savings for both scenarios are shown in Appendix A, Table L-A. (Tables LDE-A and LCP-A show the corresponding figures for Detroit Edison and Consumers Power, respectively.) Program scenario savings for 2005 are 1123 GWh, or 46 percent of MEOS predicted energy consumption.

IMPACTS ON UTILITY SYSTEM

As shown in Appendix A, Tables L-B and L-C, the savings during summer peak are much smaller than during winter peak. Specifically, total program-based peak savings over MEOS are 340 MW (winter) and 82 MW (summer) for 2005.

CUMULATIVE INVESTMENT AND PROGRAM COSTS

Incentive level:
The rebate costs to maintain efficient lighting in the average participant household are estimated as follows: Rebates and other forms of incentives cover the full cost of efficient lightbulbs. Rebate costs average $12.50 per compact fluorescent (50 percent purchased at retail prices, 50 percent in bulk by the utility) and $5 per heat-mirror bulb (50 percent at $6 retail and 50 percent at $4 bulk).

Each participating household initially receives 8 compact fluorescents and one heat-mirror bulb for general lighting, and one (CP) or two (DE) heat-mirror bulbs for outdoor lighting. In the course of the program, participants also receive enough coupons for replacement heat mirror lightbulbs to maintain the new efficiency for at least 10 years. The incentive cost is $105 for the initial set of general lighting (indoor plus porchlight) bulbs, and $5 (CP) to $10 (DE) for the initial set of outdoor lighting bulbs.

Each participating household is also given 100 percent rebates, for replacement purchases, for example in the form of coupons, to allow free maintenance of the shorter-lived porchlight and outdoor savings over 10 years. Each year, an average of 12 months/7 months life = 1.7 bulbs are needed per initially installed heat-mirror bulb. Annual maintenance costs are 1.7 x $4 = $7 for porchlights, and $7 (CP) and $14 (DE) for outdoor lighting sockets. Due to their long life, compact fluorescents are expected to be replaced only after high-efficacy bulbs have become standard equipment throughout the lighting market. Thus, no program costs are counted for their replacement. After 1994, incentive payments cover only heat-mirror replacements for past participants and the costs of maintaining the 90 percent penetration level among a slowly growing number of households. The program is ended in the year 2000.

Administration costs. Some components of the program can be conducted at very small administrative cost. Detroit Edison's staff reports that the administrative costs of its lightbulb exchange program were negligible. However, coupons, trade ally cooperation, and canvassing and outreach would involve significant initial and some ongoing administration costs. We estimate the total administration cost of the program to be $10 per participating customer.

Free riders.
In the MEOS forecast, about 5 percent of indoor lighting would be from efficient lightbulbs in 1995. In the program-based scenario, 90 percent of households will have switched 80 percent of their incandescent consumption to efficient lightbulbs by that year, equivalent to 72 percent of all lighting use. The free-rider fraction is thus 7 percent.

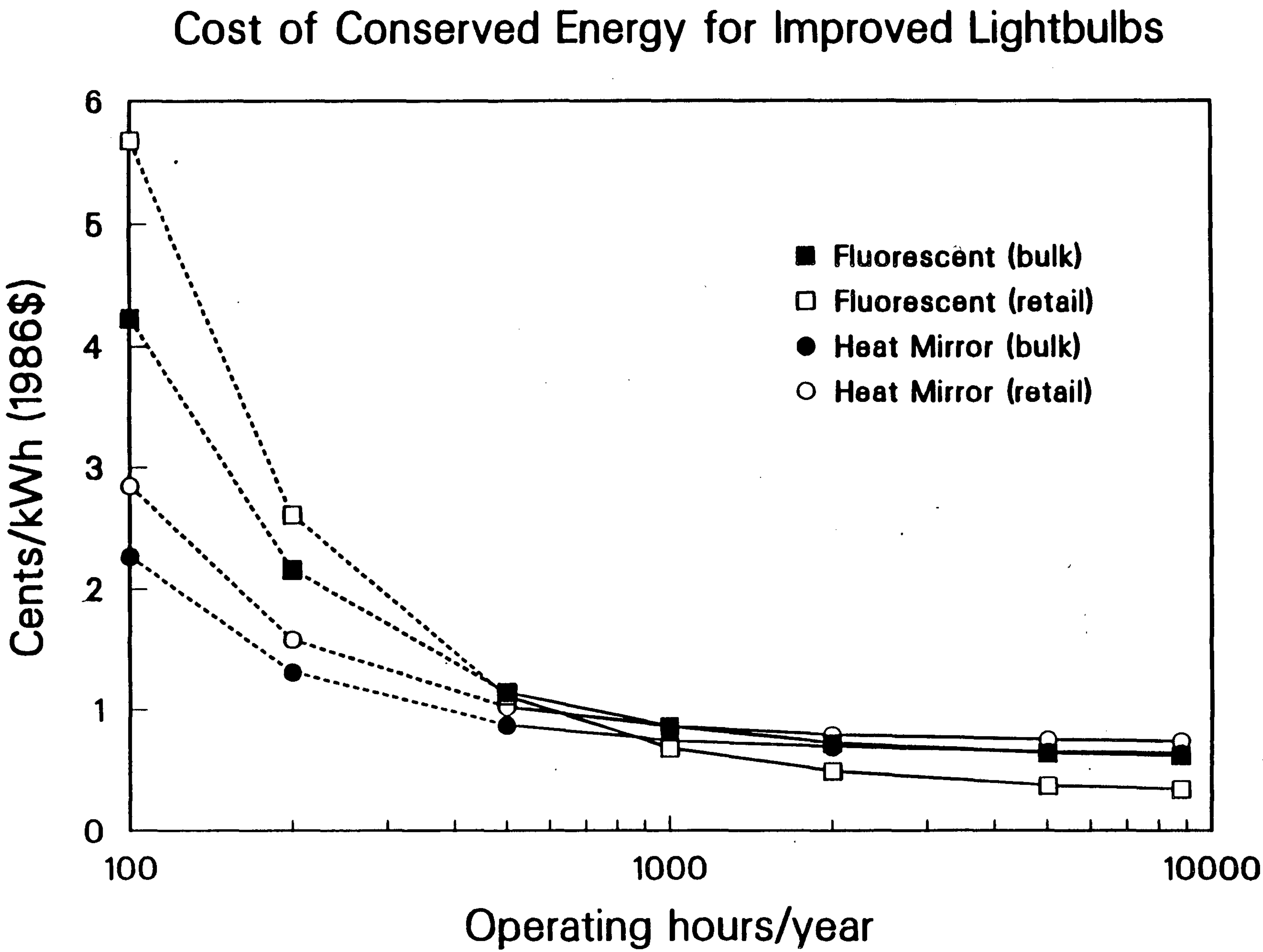
Calculation of annual program costs:
For the core general lighting program in 1988-94, the calculation is:
(# of participating households) x (rebate and admin. costs per household = $115) x (free rider correction = 100/93) + $7 x (number of households that participated up to the previous year).

Results. As shown in Appendix A, Table L-D, the cumulative program costs to ratepayers are approximately $572 million (for both utility territories). The net present value is $ 443 million (3 percent discount rate) or 323 million (7 percent discount rate).

REFERENCE:

GE 1986: "Market Potential for the Litek Lamp," General Electric Lighting Business Group, Nela Park, OH.

Figure 3-1



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4. WATER HEATING

A. MEOS BASELINE DATA

END-USE: Water Heating
FUEL: Electricity
TECHNOLOGY: Water heaters and associated equipment

GENERAL

Contribution to total electricity use. Water heating is the second largest contributor to Consumers Power's residential sales, after refrigerators. It accounted for 1418 GWh or 17 percent of 1985 sales. For Detroit Edison, the corresponding figures are much smaller, 709 GWh and 7 percent, respectively.

Contribution to peak demand. The contribution of Consumers Power's electric water heaters to its 1984 summer system peak was 197 MW or 4 percent, compared to 241 MW or 6 percent of the winter peak. For Detroit Edison, the estimated contribution to summer peak is 69 MW or 1 percent; for winter peak, its share is 98 MW or 2 percent (see Table 4-1).

Table 4-1. Water Heater Energy Use and Loads.

Utility	Equip. Type	Saturation 1985 (%)	Stock 1985 (x1000)	Energy Factor (EF)	UEC (kWh)	UPD (summer) (W)	Total Use (GWh)	Peak Demand (MW)	Marginal EF
CP	Storage Tank	33.9	413	0.81[1]	3431	477	1418	197	0.836[2]
DE	Storage Tank	10.1	165	0.81[1]	4282	417	709	69	0.836[2]

(1) U.S. shipment-weighted average energy factor at time the average Michigan water heater was purchased.

(2) U.S. 1984 shipment-weighted average energy factor.

Main product types. Storage tank water heaters are the main product type. The residential product class is defined as units with up to 120 gallons of water storage. Other types of electric water heaters are heat pump water heaters, instantaneous water heaters, and desuperheaters using condenser heat from residential cooling equipment. They are discussed as efficiency options in the measures section.

U.S. sales by type. Currently, 3.48 million electric storage water heaters are sold annually in the U.S. (1985). Sales for all other types amount to less than one percent of this figure.

Saturation of electric water heater ownership. There is a marked difference in the saturation of this appliance between the Consumers Power and Detroit Edison territories. The saturation for CP is 31.1 percent among its electrical customers, while it is only 8.9 percent for DE.

Demographic distribution. In both territories, electric water heaters are mainly found in single-family homes and mobile homes. For example, among CP's electric water heater households, single-family dwellings account for 73.6 percent. Only 5.7 percent of electric water heaters are found in multifamily homes, although 11.8 percent of all residences are multifamily units.

BASIC ENERGY CHARACTERISTICS

Ratio of energy costs to capital costs. The typical cost for an electric water heater is $200, compared to an annual operating cost of $320 (4000 kWh at 8 cents/kWh). This very high ratio of energy cost to capital cost indicates that conservation measures (and fuel switching) can be highly cost-effective.

Key factors affecting electricity use. In rough order of importance, the main factors determining water heating energy use are:

- the volume of hot water consumption
- the efficiency of electricity to heat conversion
- the standby losses of the storage system
- the hot water temperature
- the cold water supply temperature
- the ambient temperature in the water heater location.

The standby losses are a function of the size of the storage tank (surface to volume ratio) and are larger for smaller units as compared to larger tanks with equal levels of thermal insulation.

The volume of hot water consumption is a function of

- household size
- ownership of dishwashers
- ownership of clothes washers
- personal consumption patterns.

Formula for calculating energy consumption. Hot water consumption W can be calculated on the basis of personal water use P, the water use of clothes washers C, the water use of dishwashers D, the saturations S_c and S_d for these two appliances, and the household size HS:

$$W = (P \times HS) + (S_c \times C) + (S_d \times D)$$

Estimating energy used for water heating involves calculating the useful heat required to raise this quantity of water from the average inlet temperature to the desired outlet temperature, based on the conversion efficiency or *heat recovery efficiency* for electricity. This efficiency depends on the type of water heater (heat pump, resistance, desuperheater).

Standby losses are determined on the basis of a standard heat loss calculation for the storage tank and associated lines and fittings, based on the surface areas and insulation levels in the storage and distribution system.

Overall water heater efficiency is commonly expressed in terms of a single *energy factor* indicating the percentage of input electricity that ends up being supplied in the form of useful water heat. Note that the same level of technology will have higher energy factors for heaters with larger tanks.

EXISTING MICHIGAN STOCK

Composition of Existing Stock

The two major utilities' 580,000 electric water heaters are virtually all standard storage tank units.

Saturation trends. In the DE territory, saturations have steadily declined by a total of 30 percent since 1967. Consumers Power experienced a 10 percent saturation increase between 1967 and 1975, but has since seen a similar decline to less than the 1967 saturation level. The MEOS forecast for 2005 projects another 15 to 17 percent drop in both territories.

Unit size. Survey data on unit size were available only from CP in three broad size categories (less than 30 gallons, 30-50 gallons, more than 50 gallons). According to these data, 70.7 percent of all units fall into the midrange. The smallest storage tank sizes (less than 30 gallons, accounting for 17.6 percent of all units) are largely concentrated in single-family homes (63 percent of this size class), with a disproportionately large saturation in mobile homes (21.5 percent of the size class compared to 7.8 percent of dwellings). The largest size class (more than 50 gallons, or 11 percent of all units) are found almost entirely in single-family homes.

Unit life. We assume an average water heater life of 13 years. The actual life of the heater depends partly on the unit's first cost (quality). The quality of the water used in the region can also have an effect. For example, the buildup of scale in electric water heaters can cause the electric heating element to fail periodically. Hard water supplies can exacerbate the scaling problem and shorten water heater lifetime. A three-year study conducted by the Gas Research Institute found that treated (soft) water, lower water temperatures, and smaller heating surface areas reduced the amount of scale formation (Talbert et al. 1986).

Energy Efficiency and Consumption of Existing Stocks

Hot water consumption. Based on LBL's data base of measured consumption from several hundred water heaters across the nation, the average hot water use is about 16 gallons per occupant per day (Usibelli 1984), or 5326 kWh per customer per year. An EPRI survey of 12 utilities across the U.S. found an average estimated hot water energy use of 66 gallons/day per customer (EPRI 1985), corresponding to 6,006 kWh per customer.

Michigan's energy and hot water consumption is lower. Based on UECs reported by CP and DE, and a 0.80 energy factor (see below), we calculated average hot water use to be 34.4 and 42.1 gallons/day per customer, respectively (see Table 4-2). We estimated the contributions from the various hot water end-uses from appliance saturations and previous studies (ACEEE 1985, Meier et al. 1983). They are based on an identical apportionment of water energy use for both utilities because differences in dishwasher and clothes washer saturations between the two companies are smaller than the range of water consumptions in these appliances.

Table 4-2. Hot Water Energy Consumption: Losses and Useful Energy			
	Contribution (%)	DE (kWh)	CP (kWh)
Unit Energy Consumption	100	4222	3453
Less: Losses, Tank	17	718	587
Losses, Pipes	3	127	104
Useful Energy	80	3377	2762
Gallons/Day for 90°F Temperature Increase		42.1	34.4

Energy factor. Based on a lifetime of 13 years, the average energy factor of existing stocks would be 0.81 according to AHAM data. Stand-by losses from pipes and connections decrease heater system efficiency by 3-4 percentage points to 0.77. The actual system energy factor in Michigan is likely to be somewhat higher, since some fraction of water heaters has since been retrofitted with insulating blankets. CP reports a 31.4 percent saturation of water heater wraps in 1984 from its customer survey. This figure stands in contrast to the evaluations of Michigan's RCS program by Kushler and Saul (1985). According to their study, only about 10 percent of Michigan's households have water heater wraps. To keep energy savings estimates on the conservative side, we assume a system energy factor of 0.80. With this EF, conversion losses and useful energy outputs are as shown in Table 4-3.

Table 4-3. Hot Water Consumption and Electricity Use								
Application	Hot Water (gal/day)		Contribution (%)		Useful Energy (kWh)		UEC for EF=0.80 (kWh)	
	CP	DE	CP	DE	CP	DE	CP	DE
All Uses	34.4	42.1	100	100	2762	3377	3453	4222
Showers	13.7	16.9	40	40	1105	1351	1381	1689
Clothes Washers	8.6	10.5	25	25	691	844	863	1056
Dishwashers	5.2	6.3	15	15	414	507	518	633
Sink/Miscellaneous	6.9	8.4	20	20	552	675	691	844

Unit energy consumption. The two companies report values that are about ten percent different. For Consumers Power, the average UEC of electric water heaters is 3453 kWh/year. For Detroit Edison, the value is 4222 kWh/year.

Load Profiles

Seasonal variations. There is a moderate seasonal variation in water heating use, both in terms of the daily load profile and in terms of the average monthly energy use.

Diurnal variations. Coincident loads as measured in Michigan are up to five times as high during the evening hours of peak water heating demand as during the graveyard/early morning period. The timing of the water heating morning and evening peaks depends somewhat on the day of the week (weekday versus weekend) and on the season, with peak demands stretching further into the night during summer. The basic pattern of variation appears to be quite similar in different utility regions of the country (EPRI 1986).

Unit peak demand. Diversified demand at system peak (summer, 3 PM) for Consumers Power is 0.50 kW per customer, based on submetering data. During winter peak, the value is 0.61 kW (11 AM or 7 PM). For Detroit Edison, figures are very similar except when the company uses its radio control to interrupt load. In previous years, up to 200 such interruptions were performed annually. This control would typically be exercised in the evening hours and would bring the average water heating load per customer down to 0.15-0.20 kW. Currently, this load management capacity is not being used.

We calculate a unit peak demand of 0.42 kW (summer peak) and 0.52 kW (winter peak) from load research data.

Fraction-in-use. Both utilities have conducted submetering experiments on their water heating loads. The average maximum non-coincident demand from CP's submetering data is 3.89 kW, compared to 3.48 kW for DE. Appendix B includes the fraction-in-use figures for the two companies. Again, the Detroit Edison data display the effect of load control in the evening hours. In addition, Consumers Power has submetered water heating loads for heat pump water heaters. Fraction-in-use figures for heat pump water heaters also appear in Appendix B.

CURRENTLY SOLD EQUIPMENT

Marginal sales composition by type. Currently, more than 99 percent of the electric water heaters sold in the U.S. are of the conventional storage type.

Marginal efficiencies. According to statistics from the Gas Appliance Manufacturers' Association, the average energy factor of 1984 U.S. shipments was 0.836.

Current costs. The cost of an electric water heater depends on its size and energy factor. A typical 52-gallon unit with an energy factor of 0.76 can be bought for $199 dollars in Michigan (uninstalled). A 52-gallon unit with an energy factor of 0.89 sells for $329. The same high-efficiency model with a 10-year (instead of a 5-year) warranty sells for about $429.

B. DEMAND-SIDE MEASURE DATA BASE

END-USE:	Water Heating
FUEL:	Electricity
TECHNOLOGY:	Water heaters and associated equipment
DEMAND-SIDE MEASURE:	Hot water demand reduction

OVERVIEW

Electricity conservation options for water heating fall into three broad categories:

1. more efficient use of hot water (hot water demand reduction) in dishwashers, clothes washers, and shower plumbing;

2. more efficient water heating and storage equipment;

3. switching to other fuels (gas or solar energy).

While water demand reductions and water heater efficiency improvements are complementary measures, fuel switching options compete directly with electrical efficiency improvements. We present our water heater analysis in two parts. The first covers water demand reductions including thermostat setback. In the second section, we evaluate conventional, other electric, and solar water heater system alternatives, using present and reduced hot water demands as a sensitivity test.

The economics of fuel switching, which mainly affects water heating, but also involves dryers and ranges, are addressed in a separate data base section, Fuel Switching (section 8).

MORE EFFICIENT USE OF HOT WATER

Thermostat Setback

Thermostat setback is basically a no-cost measure and is therefore the cheapest water heating conservation option so long as it does not interfere with the hot water functions in the various household operations and appliances. Temperature requirements are about 97-100°F for hand washing, 105°F for showering, and at most 130-140°F for conventional U.S. dishwashing machines that do not have internal booster water heaters as clothes washers do (see below).

Current settings. According to data from Detroit Edison, which load controls the majority of its electric water heaters, the average setting in the company's territory is now 145°F (Settings were reduced by the company about ten years ago). This average setting of 145°F implies that there is a substantial remaining potential for temperature reduction. Only 44 percent of households own a dishwasher now, and the company projects this end-use to saturate at 46 percent in 2005 (see MEOS forecast). Thus, the majority of Detroit Edison's customers could lower their settings to 120°F without loss of comfort. The same probably applies to Consumers Power Co., which does not currently control water heaters and had no data on average settings. Even for customers that do own dishwashing machines, a setback to 130°F can be quite acceptable. An Oregon utility is having success in getting customers across the board to choose this setback as they participate in the company's water heater wrap program (see implementation below).

Setback Savings. Savings result both from the reduced heating requirement and from reduced standby losses. Tests by the National Bureau of Standards suggest that each 10°F reduction in water temperature reduces overall water heating energy consumption by about 5 percent in a standard efficiency system (ACEEE 1985). A setback from 140 to 120°F thus gives an estimated saving of 10 percent. Measurements by two utilities, Seattle City and Light and Pennsylvania Power and Light, resulted in a 362 kWh/yr saving with only a 10 percent variance from a 20°F setback, based on a baseline tank of 52 gallons, 27.5 sq.ft. total surface area, and R-6 insulation (EPRI 1986). This value is compatible with the 10 percent estimate one would calculate on the basis of the NBS findings.

Low-Temperature Dishwashers

According to the Association of Home Appliance Manufacturers, the average electricity use of new dishwashers has declined 36 percent between 1972 and 1984. Most of these gains have been achieved by improved mechanical efficiencies and by reducing the need for hot water. Further improvements could be feasible with improved sump geometry, reduced fill levels, and better fill controls.

The water efficiency of dishwashers is not only important in terms of quantity of hot water demand, but also in terms of hot water temperature. Currently, the dishwasher is the appliance that sets the minimum temperature requirement in the water heater system. The minimum 140°F setting now recommended and commonly found on water heaters is designed to allow effective dishwasher operation with current standard detergents, though tests have shown that such detergents can provide good to excellent cleaning results at temperatures of 100°F (Stinson 1987). A reduction in the hot water temperature required for dishwashers makes it possible to lower the temperature of the entire household supply.

Such temperature setbacks can be made feasible by two methods. One is the use of a booster resistance heater element in the dishwasher. This 2 kW unit would raise temperatures to the higher dishwashing levels while adding little diversified peak load. The electricity used to heat the dishwasher water is much less than the sum of water heater standby losses and additional input to heat all water to 140°F. A few models on the market currently have this feature.

The second option is an innovative low temperature dishwasher which is scheduled for market introduction in mid-1987 by Eco-Tech of San Jose, California. The company's machine partially replaces the thermal action of high water temperatures with the mechanical action of high pressure water jets. The spray-arms are driven by hydraulic pressure from the water supply, affording significant electricity savings in the non-hot water related operations of the machine. The same feature seems to enable the manufacturer to offer his unit at zero to negative extra first cost.

Cost of conserved energy. Dishwashers can be substantially improved in terms of their internal electricity requirements. Savings of 235 kWh/y can be achieved for 1 cent/kWh assuming a 13 year life and a 3 percent discount rate (Geller et al., 1986). The reduction of external electricity requirements for hot water preparation would have approximately a zero cost in the Eco-Tech design, and a cost of up to 8 cents/kWh with a booster heater and a setback to 110°F (duPont 1986).

High-Efficiency Showerheads

Conventional showerheads that were used virtually everywhere before 1980 use 4-6 gallons/minute and more. Participants in conservation programs who were given these flow restrictor disks often removed them soon after they were fitted. Well-designed second-generation showerheads are now available that provide fully equivalent comfort, tingliness, and wetting action at flow rates of only 1.4-2.4 gal/min. A number of these units are also adjustable, and feature fingertip valves for flow interruption during shampooing, etc., which can reduce consumption further. They are increasingly found in newly constructed hotels and motels in Michigan and elsewhere and seem to be acceptable in an industry where guest comfort is critical. A "high technology" air-blower driven shower achieves the same high quality shower action at 0.5 gal/min.

Savings. Energy savings are in direct proportion to hot water savings. Measured data from about 200 geographically dispersed U.S. homes are available from a study by the U.S. Department of Housing and Urban Development (Brown & Caldwell 1984). The study found that savings from low-flow showerheads were 7.7 gal/person per day on average. This figure seems high. The California Energy Commission estimates a saving of 3.5 gal/person per day, or 10.5 gal/day for a 3-person household. We estimate that on average, Michigan households can save 70 percent of shower hot water use with an efficient 1.5 gal/min unit, such as the "Turbojector" air venturi showerhead of Energy Technology Laboratories.

Unit costs. The cost of high quality showerheads is less than $10 at the retail level. The average home may require more than one showerhead. We assume a $20 cost per household.

Unit life. Metal fixtures, and brass ones in particular, can last 20 years or more but plastic products are less durable. We conservatively assume a 10 year lifetime for new high-efficiency showerheads.

Cost of conserved energy. Table 4-4 shows the savings and CCEs for application in the DE and CP territories. The cost of high quality fixtures is measured in mills/kWh for even the most unfavorable assumptions. High efficiency showerheads represent one of the most highly attractive energy conservation investments available to Michigan consumers and ratepayers.

Water-Efficient Clothes Washers

Among currently available washing machines in the U.S., there is considerable variation in water use between front-loading and top-loading models. A front-loading washing machine consuming typically 450 kWh/y saves an estimated 480 kWh electricity or 6 gal/day of hot water compared to the average top-loading model (the ratings of top-loading machines lie between 620-1580 kWh/y, see ACEEE 1985). Greater water efficiency in clothes washers of both configurations can be achieved by means of a number of methods:

1. Eliminate the warm rinse or use a filtered recirculating rinse system;
2. Improve the fill control to optimize warm water use;
4. Change the geometric configuration to eliminate water-filled space between the clothes tub and outer tub;
5. Provide a suds-saver feature that allows reuse of suds and warm water for consecutive washes;
6. Add thermostatically controlled mixing valves to optimize hot water use when mixed with cold water of seasonally different inlet temperatures;
7. Redesign the wash cycle by separating chemical action, which benefits most from hot water but does not require large volumes of it, from mechanical agitation which is more efficient with more water but does not benefit particularly from warm water;
8. Use enzymatic presoak or electrolytic dissociation in cold water.

The latter method has been tested and shown to reduce energy consumption per wash cycle by close to 50 percent (from 2.5-2.8 kWh per cycle to 1.3-1.5 kWh per cycle, see Bertolino 1982). The European Economic Community's Appliance Efficiency Project is currently developing clothes washers using several of these techniques that save up to 86 percent of hot water consumption in European-type machines (Heeboll & Norgard 1985). These options and developments, along with continuing improvements in cool water detergents, point to significant future gains in the water efficiency of clothes washers.

Unit costs and CCE. The extra first cost for a front-loading machine is about $150. This cost differential seems to reflect the typically high mark-ups on product versions that have small, low-volume market shares. Based on this premium, the cost of conserved electricity through water demand reduction is 2.9 cents/kWh (3 percent discount rate, 13 year life).

NPPC (1986) estimates that best available clothes washer technology using only some of the more straightforward options listed above (automatic fill control with wider range, improved temperature controls, suds-saver) can save several hundred kWh of hot water use for an investment cost of $22, or a cost of conserved energy of less than one cent/kWh.

Water-Efficient Faucets

The miscellaneous uses of hot water consist of uses in which only the volumetric flow rate of the faucet matters, such as filling a bathtub, and uses where the water flow from faucets is mainly used to create a wetting action, as in rinsing and washing dishes or hands. In the latter applications, hot water efficiency can be substantially improved by using faucet aerators that create a dispersed, low-impact flow. The share of wetting-type end-uses in total miscellaneous water use is not well-known. We conservatively estimate it as 30 percent.

Energy savings. Unrestrained faucet flow is typically three to five gallons per minute in U.S. plumbing. Screw-in aerators for kitchen and bathroom sinks reduce this flow to about one third (1-1.5 gal/min). Fingertip faucet aerators allow even greater savings through the momentary interruption of sink flows without having to reset the hot and cold water valves for the correct temperature.

Cost of conserved energy. Screw-in aerators are available at hardware stores for about one dollar. Assuming five units per household and a 10-year life, the cost of conserved energy is 4-5 mills/kWh with Michigan usage patterns.

Combined Energy Impact of Demand Reduction Measures

In Table 4-4 below we show the combined effect of these demand reduction measures on useful energy requirements. We apply the zero-cost thermostat setback option first and then calculate the independent savings in the four major hot water uses. Thermostat setback, low flow showerheads, front loading washing machines, and faucet aerators combined can save 48 percent of the baseline water heater input energy. Additionally, Table 4-4 includes subsequent savings resulting from water heater efficiency improvements, discussed in more detail in the next section.

Table 4-4. Savings and Costs of Conserved Energy from Water Heating Measures

Measure	Savings %	Savings kWh	Input Electricity kWh	Input Electricity Index	Measure Cost-Effectiveness: Additional First Cost 1985 $	Life yrs.	CCE Marginal ¢/kWh	CCE Average ¢/kWh
Baseline UEC (145°F, EF=0.8)			4000	100				
1. Temperature Setback (145°F→120°F)	-12.5	-500	3500	88	0		0	0
2. Demand Reductions								
Useful Energy @ EF=0.80			2800					
Useful Energy Savings:								
a)High-Eff. Showerheads (4.8→2.0 gal/min)	-23.2	-650	2150					
b)Front-load Washer	-12.5	-350	1800					
c)Faucet Aerator	-5.0	-140	1660					
Input Energy Savings @EF=0.80:								
a)High-Eff. Showerheads		-812	2688	67	20	10	0.3	0.3
b)Front-load Washer		-438	2251	56	150	13	3.2	2.8
c)Faucet Aerator		-175	2076	52	5	10	0.3	0.3
3. Efficiency Improvements/ Alternative Water Heaters								
a)Tank Wrap & Traps	-6.2	-129	1946	49	50	13	3.6	1.2
b)New Water Heater EF=0.96	-10.4	-216	1859	46	130	13	5.7	1.8
c)Heat Pump Heater EF=1.6		-919	940	24	1000	13	10.2	4.6

Note that the thermostat setback effectively increases the energy factor of the water heater by reducing the heat losses from the tank. In first approximation, this heat loss reduction is proportional to the ratio of the setback and the tank-to-ambient temperature differential. With a 70°F differential and a 25°F setback, the setback reduces tank losses by 36 percent and thus increases the baseline energy factor of 0.80 by 0.36 x 0.17 to 0.86. (Distribution losses would not show significant reductions unless pipes were insulated, too.) This effective EF increase, together with the reduced need for water heating and the increased need for volumetric flows of somewhat cooler hot water in showering, etc., is accounted for in the 12.5 percent savings estimate for that measure. However, the higher effective EF taken into account when evaluating the impact of subsequent water heater conservation measures such as tank wraps, etc.

TECHNICAL AND ACHIEVABLE POTENTIAL

Behavior function. The behavior function for domestic hot water use is tied to the index of household size. Following the MEOS forecast, we incorporate about a 10 percent reduction in household size between 1984 and 2005, leading to a corresponding reduction in all hot water demands except the sink and miscellaneous category, which remains constant. The resulting 10 percent per capita increase in miscellaneous uses accounts for possible growth in such applications as hot tubs.

Water-Efficient Dishwashers and Thermostat Setback

We assume savings from reductions in the hot water volume consumption of dishwashers and savings from reductions in hot water temperature. For the former savings, we follow the MEOS forecast, which assumes a 23 percent improvement between 1984 and 2005.

The low-temperature dishwasher option is important because it determines the degree to which customers owning the device can reduce their water heater thermostat setting. In the *technical potential scenario,* all customers start switching to a 120°F setting in 1988. In the *program scenario* utilities conduct a campaign to reduce thermostat settings among its customers. The utilities promote the setbacks by means of advertisements and informational literature that emphasize the safety advantages of lower water temperatures to avoid scalding hazards. This approach was successfully used by Seattle City and Light, which has been conducting an aggressive water heater conservation program including a setback to 130°F. As in that utility's approach, we assume that thermostat setbacks would be part of the rebate and retrofit water heater blanket program of the Michigan utilities (see the section on water heater efficiencies). Thermostat setback among non-dishwasher owners is promoted at the 120°F level and is achieved with a 50 percent participation rate by 1990. This program is accompanied by a strong information campaign on available new low-temperature or booster heater dishwashers. Starting in 1990, a rebate is given for these units at a level set according to the results of a pilot program. By 1995, fifty percent of all customers set back their thermostats to 120°F, and 100 percent do so in 2005.

Low-Flow Showerheads

Current implementation programs. Virtually all states have adopted the industry's ANSI norm for showerheads which limits flow rates to 2.75 gal/min (plus 0.25 gal/min production tolerance). This product norm was established in 1981. It is, however, not legally binding and not enforced outside California, which established this norm as a legal standard in 1978. Most manufacturers seem to "comply" with the ANSI norm by supplying a flow restrictor disk in a separate little bag. Only about 10 percent of currently sold showerheads have the flow reducing feature permanently installed. Customers thus have the choice of using the flow restrictor or not. As a result, the California Energy Commission is currently revising its standard to require a fixed, non-removable flow restrictor design. In essence, this revision will shift the market toward those manufacturers that had been using fixed restrictions all along and had taken care to reproduce high-flow comfort with more sophisticated low-flow designs. In 1986 hearings by the California Energy Commission, manufacturers estimated that about half of all customers end up not using the flow restrictor when separately provided. No actual surveys seem to be available.

In addition to standards for new showerheads, utility programs have also promoted hot water savings by handing out flow restrictor retrofit disks or by selling or advertising higher quality low flow showerheads. Flow restrictor disks were handed out in Michigan's RCS program which reached about 650,000 households by early 1986.

Eligible fraction. We estimate that no more than about half of the RCS participants in Michigan, or no more than 10 percent of Michigan's households, now use showerheads meeting the upper limit ANSI norm of 3.0 gal/day. The savings-weighted eligible fraction is thus 1.00 - 0.1 x 2.0/5.0 = 0.96.

Technical potential scenario.
In this scenario, all households use 1.5 gal/min high efficiency showerheads starting in 1988. On average, consumption drops by 0.96 x 70 = 67 percent.

Standards/incentives scenario.
In this scenario, Michigan adopts the revised California version of the ANSI norm in 1990. In addition, utilities promote retrofits of the devices as part of their RCS and water heater programs, for example by supplying households with free high efficiency showerheads that significantly exceed the ANSI standard. The program is designed to provide customers information on how much money the product can save them and a free opportunity to test the most water-saving products. We assume an average reduction from 5.0 gal/min to 2.0 gal/min in new sales and retrofits, or a 60 percent saving. Because of the combination of standards, rebates for units that exceed the standard, and retrofit programs at zero customer cost, 90 percent penetration is reached in 2005. The average hot water reduction per customer is 40 percent by 1995 and 52 percent in 2005.

Water-Efficient Clothes Washers

Technical potential scenario. In the technical potential scenario, new purchases of clothes washers consist entirely of front loading machines saving 50 percent of baseline hot water consumption for that end-use. By 1995, sixty percent of the remaining clothes washers hot water demand is eliminated through the advent of current prototypical machines and cycles on the market.

Program scenario. In this scenario, a rebate program is started in 1988 to promote front-loading washing machines (or other machines that can give an equivalent saving). The goal of the program is to make these machines the most popular and widely used category, as is now the case in Europe. The rebate is initially close to the price difference between top-loading and front-loading machines, with a program administration cost of $10 per rebate. As in refrigerator rebate programs, manufacturers and dealers are brought to participate by offering matching discounts, which will make the units cheaper than top-loaders. Eventually, the greater market penetration of water-efficient units will allow the utilities to lower their rebate levels. The strategy of the rebate program thus is to create a significant market for manufacturers and to move the machines out of their current low volume, high mark-up bracket. By 2005, front loaders saving 50 percent of present hot water consumption for clothes washing constitute seventy five percent of the appliance stock.

Faucet Aerators

A number of utility programs have handed out faucet aerators as part of their RCS audit programs. The units are widely used because they add convenience, but no data are available on their current saturation. We assume that one third of all households currently uses them. In the technical potential scenario, all remaining households are retrofitted in 1988, resulting in a (0.67x0.3x0.67) percent hot water saving, or 13.3 percent. In the program scenario, utilities hand out the units as part of their high-efficiency showerhead promotion. The total savings, at a maximum saturation of 75 percent of eligible households, is ten percent in 1995 and remains constant thereafter.

IMPACTS ON UTILITY SYSTEM LOAD SHAPES

We calculate these impacts after combining the above water demand reductions with improvements in the energy factor of water heating systems (see following section).

ANNUAL AND CUMULATIVE INVESTMENT AND PROGRAM COSTS

We calculate these impacts after combining the above water demand reductions with improvements in the energy factor of water heating systems (see following section).

END-USE:	Water Heating
FUEL:	Electricity
TECHNOLOGY:	Water heaters and associated equipment
DEMAND-SIDE MEASURE:	Improved electric water heaters

ENERGY-EFFICIENT CONVENTIONAL WATER HEATING SYSTEMS

Conventional resistance water heaters can be improved through retrofits and/or purchase of high efficiency units. In both approaches, the goal is to reduce standby tank and distribution losses.

Reducing Standby Losses

Water heater wraps. Water heaters of average energy factor (EF 0.81) are typically equipped with no more than R-3 to R-6 insulation in their tanks. The substantial standby losses through the tank walls can be reduced with simple do-it-yourself water heater wraps, using fiberglass insulation blankets of R-5 to R-11 or more. The savings from measured data are summarized in Usibelli et al. (1984) and EPRI (1986). Usibelli estimates an average saving of 9.7 percent. EPRI calculates a normalized saving from measured data in terms of kWh/y per °F temperature difference per square foot of retrofitted tank area per R-value of blanket added. The value from utility measurements is 0.025 to 0.029 for an R-11 wrap. For a 52 gallon, R-6 insulation rating tank of 27.5 sf surface area, a 140°F temperature setting, and a 70°F ambient air and floor temperature, this translates into 514 kWh/yr.

The savings from water heater wraps are highly interactive with thermostat setback. If a thermostat setback has been done first, losses through the tank surface will have been reduced substantially already, and vice versa. For example, a R-11 wrap covering 90 percent of a R-6 tank will reduce heat loss by 69 percent. Conversely, a 25°F setback reduces heat losses by 36 percent if the baseline ambient-to-tank temperature differential is 70°F. These interactions must be taken into account in determining net savings and cost-effectiveness.

Costs of conserved energy. Water heater wraps are one of the most cost-effective measures for achieving residential energy savings. Water heater blankets cost $15-45 when bulk-purchased and installed by utilities, and as little as $10 for the do-it-yourselfer. Assuming a $25 cost, a 13-year life (matching the water heater life) and a 9.7 percent saving (the average found from measured data (Usibelli 1984), or 340-410 kWh/y in Michigan), the cost of conserved energy is $0.0069-0.0057/kWh.

Reducing Distribution Losses

Distribution losses in water pipes account for about 3-4 percent of total water heating input energy in standard systems. In these systems, heat stored in the tank is lost also through a convective loop of warm water rising into adjacent pipes and dissipating through them. A further loss is incurred in the form of the column of unused hot water that remains in the distribution lines after each draw. These losses can be reduced by several technologies.

Thermal traps. Thermal traps are small fittings for the tank-to-distribution line connections that stop the convective heat loss into the pipes. The measured savings for the device show a ten-fold range in currently available studies, from a mere 35 kWh as measured by Ontario Hydro (Perlman 1986) to 482 kWh/y as found by Seattle City and Light. (see Usibelli et al. 1984). The latter figure is likely much too high. Costs range from $8-12 in the store, or $30 installed when retrofitted.

At the low end of the savings estimates, retrofitting thermal traps would cost about 8 cents/kWh, at the high end, 0.6 cents/kWh. Most new water heaters still come without the device. If a new water heater without traps is installed and traps are installed at that time, the same range of CCEs is only 0.24 to 3.2 cents/kWh.

Pipe insulation. Pipe insulation seems to save about as much energy as the lower range of savings for thermal traps, and at comparable cost. We do not consider this measure separately.

Hot water return. Recently a product was introduced into the market that allows the return into the storage tank of hot water that would usually remain unused in the pipes after each draw. Consisting of an expansion tank and a check valve, it can be retrofitted to existing tanks at an installed retail cost of about $225 and saves about 10 percent of hot water consumption at a CCE of $0.016/kWh (Meier 1986).

Improved New Electric Water Heaters

Best currently available electric water heaters come with R-12 to R-25 insulation and heat traps as standard features. They have energy factors above 0.90, as high as 0.96. Table 4-5 shows examples of how the manufacturers have achieved additional efficiency in their recent water heaters.

Table 4-5. R-Value and Energy Factors for Currently Available Water Heaters

	Inches of polyurethane	R-value of walls	GAMA-rated energy factor	Comments
Example 1	0.75	3	0.82	heat traps optional, cost $10 extra
Example 2	1.4	12	0.90	heat traps optional, 3" insulation under tank
Example 3	3	25	0.96	heat traps standard, 3" insulation under tank

Cost of conserved energy. The premium for buying a new water heater with additional tank insulation typically ranges from $60 to $120. The premium for heat traps on a new water heater is $10 to $20. We calculate the cost of conserved energy for a new, state-of-the-art water heater with R-25 walls, heat traps, and an energy-factor of 0.96, compared to a "standard" water heater with R-3 walls, no heat traps and an energy factor of 0.81. We assume an added cost of $130 for the higher-efficiency water heater. Investing in the highest efficiency water heater available (EF=0.96) instead of a standard unit (EF=0.81) results in a cost of conserved energy of 2¢/kWh (3% discount rate) or 2¢/kWh (7% discount rate).

Retrofit potential for high-efficiency water heaters. High efficiency units have, of course, a lower savings potential from retrofits, since they incorporate some of the features mentioned above (e.g., additional insulation and heat traps). It can nevertheless be cost-effective to add a blanket and other retrofit measures to a water heater with an energy factor of 0.90. In fact, at least one utility incentives program for water heater efficiency by Seattle City and Light gives customers the option of buying a very high efficiency new unit or purchasing a better than average unit and retrofitting it with an R-10 wrap.

We calculate the cost of conserved energy for adding an R-12 blanket and heat traps to an electric water heater with R-12 walls, no heat traps, and an energy factor of 0.90. We assume a cost of $20 for the R-12 blanket and $30 for installing heat traps on the inlet and outlet lines. We also assumed that these retrofits would increase the energy factor of the water heater from 0.90 to 0.96. Retrofit of a high-efficiency water heater with an R-12 blanket and heat traps has a cost of conserved energy of 1.8¢/kWh (3% discount rate) or 2.4¢/kWh (7% discount rate).

HEAT PUMP WATER HEATERS

Coefficient of performance and energy factor. The coefficient of performance is defined as the ratio of heat delivered to the heat pump to the amount of electricity required to run the heat pump. Since heat pumps deliver more heat to the water than the electrical energy they consume, they have a COP greater than one. Industry lists an "energy factor" for heat pumps, which is a measure of COP and does not represent average operating conditions and include standby losses. The energy factor that we use is based on average conditions, includes standby losses, and gives the amount of useful heat obtained per unit of input during those operating conditions, so is slightly lower than the COP. The energy factor of an average integrated HPWH in the 40 to 55 gallon range is 1.6, and the most efficient currently available HPWH made by DEC International of Madison, Wisconsin, has an energy factor of 2.4. Models with an EF of 2.6 are within range of current technology and are expected in the market in 1987 (ACEEE 1986).

Technology status and availability. HPWHs were first introduced in 1980 and are currently available from 14 manufacturers. There are two basic types of HPWH: integral and remote. The integral unit is designed to replace an existing water heater; The compressor and evaporator are mounted on top of a conventional storage tank. Back-up heating can be supplied by a coil in the water storage tank. The remote HPWH is intended for retrofit; the compressor and evaporator are contained in a casing that is connected to the inlet and outlet of an existing electric resistance water heater.

The technological advances that have increased HPWH efficiency are an improved plate condenser, thicker insulation, and thermal traps. Further improvements that can increase HPWH efficiency are a modified compressor, variable speed motor drives, and improved heat exchangers. The Electric Power Research Study (EPRI) conducted a major evaluation of the performance of HPWHs installed in residential conservation programs at five utilities. This report relies largely on data from that study. Unfortunately, the EPRI results do not reflect recent advances in heat pump performance and reliability.

Heat pump water heaters are generally available from plumbing supply houses; however, there are a few key limitations to their adoption by the general public. They are not well advertised or generally accepted as an alternative to conventional electric resistance water heaters. Few dealers have a wide selection of available models. For example, a BPA survey found that 60 % of the HPWH dealers in their territory sold only one type of HPWH system.

Special problems and current limitations. The high first cost of HPWHs (see costs below) often overshadows their lower life-cycle cost. Most consumers are not aware of HPWHs, and when their water heater fails they need a replacement immediately. Few are willing to spend the premium to buy a water heater that is twice as efficient. In addition, selling, installing and maintaining a HPWH requires more skill than a conventional water heater, since it requires knowledge of both the plumbing and air-conditioning trades.

The temperature of the air entering a HPWH is one of the most critical factors affecting performance. The performance of HPWHs located in an unheated space can drop dramatically in the winter.

Secondary energy impacts. The energy consumption of a HPWH constitutes a heat gain in the home that reduces heating needs slightly in the winter and adds a small cooling load in the summer. Based on Consumer Power customer survey results, we estimate that 75 % of Michigan water heaters are located in a space-conditioned area. The effect on heat load varies according to the level and intensity of hot water use.

A study by Ontario Hydro in Canada (Perlman 1985) estimated that, in a typical residence, the HPWH would increase the space heating load by 1500 kWh -- 7% (assuming 60 gallons/day of hot water usage) or 3250 kWh -- 15% (assuming 120 gallons/day). [These calculations are based on a typical heating load of 22,000 kWH and a heating season of 250 days.] This effect will be enhanced with more efficient HPWHs. The Ontario Hydro report also suggests that venting a dryer indoors can offset most of the increased heat load. In installations where a dryer and a HPWH are both located near each other (e.g., in the basement), the humidity of the dryer exhaust air can be offset by the HPWH. (Note that the above numbers do not take into account the air-conditioning savings that will result from HPWHs in air-conditioned houses in the summer.)

In the present analysis, the interaction with electric heating loads is taken into account in the calculation of building shell savings rather than appliance savings. The CIRA building simulation model we use contains algorithms to adjust for appliance efficiency.

Lifetimes. Tank corrosion, rather than heat pump performance, appears to be the limiting factor in HPWH lifetime. HPWHs should last as long as electric resistance water -- an average of 10 to 13 years (Meier et al. 1983, ACEEE 1986). The lifetime will be shorter due to scaling and corrosion problems in areas with "hard" water (ASHRAE 1986).

Cost and Performance Data

Determination of energy savings. Studies have consistently shown that HPWHs use on the order of 50% less electricity to provide water as a comparably sized electric water heater. The Consumer Power survey found that the average annual water heating energy use in its service territory was 3598 kWh. Assuming an effective COP of 0.81 for an electric water heater and 1.6 for the HPWH, a 90°F temperature rise, and a family of 3, the HPWH would reduce annual water heating energy use by 49%.

Costs of heat pump water heaters. The first cost of a HPWH varies dramatically depending on whether it is a remote or integral unit and whether it is self-installed. In all cases, the first cost of the HPWH represents a barrier, since it is much higher than the first cost of a conventional electric water heater. The Consumer Power survey assumed a first cost of $400 for a remote self-installed unit, $800 for an integrated self-installed unit, and $1,400 for an integrated, contractor-installed unit.

More recently, an EPRI survey of HPWH programs at four large utilities found a range of $550-$1900 for an installed remote HPWH, and $1100 to $1400 for installed integral HPWH (the $1900 is so high because of the high installation cost -- $500-700 at PP&L). Bonneville Power Administration issued a survey of HPWH dealers in its territory in April, 1986. The dealers all participated in a heat pump water heater incentive program. The minimum allowable COP of HPWHs installed under the program was 2.2. Of the lowest-priced HPWH systems, 63% sold for between $750 and $1300 installed. Of the best-selling HPWHs (often the same as the lowest-priced) 1/3 sold for $800-900 and the remaining 2/3 for $1500-3000 installed.

In addition to the first costs, maintenance costs of HPWHs need to be considered. Because the HPWH is more complex, maintenance costs of the HPWH will be higher than for a conventional electric water heater.

Costs of conserved energy. In all of our calculations, we assume a discount rate of 3% and 7%, an annual water heating load of 4,000 kWh/yr, and a baseline system consisting of an average 52-gallon electric water heater with an energy factor of 0.81 and an installed first cost of $264. We calculate the cost of conserved energy (CCE) for three different replacement options: an add-on HPWH with an energy factor of 1.6 and an installed cost of $800; an "average" integrated HPWH with an energy factor of 1.6 and an installed cost of $1250; and the most efficient HPWH with an energy factor of 2.4 and an installed cost of $1500. The CCEs range from 2.5 to 4.6¢/kWh (see also Table 4-4).

SOLAR WATER HEATERS

Coefficient of performance and energy factor. The most detailed field evaluations of solar water heaters to date have been conducted by the Florida Solar Energy Center (FSEC). They measured 20 solar water heaters in Florida over a period of two years and found an average COP of 2.4. FSEC also monitored 24 solar installations in North Carolina for the North Carolina Alternative Energy Corporation. The North Carolina climate is more representative of solar conditions in Michigan. They measured COPs ranging from 0.85 to 2.73, with an average COP of 1.52 (FSEC 1986A).

Technology status and availability. There are a wide variety of solar systems available in all sizes. Both active and passive solar systems can be used. The range of available models and performance ratings are listed in FSEC's Thermal Performance Ratings for flat-plate solar collectors. The thermal performance of conventional systems is listed in Btu/day and Btu/sq.ft. for intermediate temperature conditions (120-160°F). (FSEC 1986B)

The recent slump in world oil prices and the discontinuation of federal tax credits has constricted the range of available SWH models because a number of undercapitalized, smaller manufacturers were forced out of production. However, the innovations and production experience for a wide variety of system designs are still available, and efforts are currently being made to introduce new high-efficiency, low-cost systems.

Lifetimes. Conventional electric resistance water heaters have an average lifetime of 10 to 13 years. We assumed, conservatively, that solar water heaters will have an average lifetime of 15 years.

Determination of Energy Savings

2. *Costs of solar water heaters.* The average cost of a conventional, refrigerant charged, solar domestic hot water system in Michigan in 1985 was $5155 installed, or $85 per square foot of installed panel. This is considerably higher than the average cost of a solar installation in other parts of the country. The contractor who accounted for almost all of Michigan's few installations is apparently being investigated for fraud. A TVA study found an average cost of $60 per square foot of installed panel for 10 commercial and institutional installations (in $1983) (Adams 1985).

Costs of Conserved Energy. To illustrate the economics of conventional systems, we made the following assumptions: Baseline is an average 52-gallon electric resistance water heater with an energy factor of 0.81, an installed first cost of $264, and an annual electricity consumption of 4,000 kWh; we add a solar water heater with an energy factor of 1.62. We calculated the CCE for three cases: a 15-year solar water heater lifetime at Michigan costs ($5155/unit installed); a 20-year solar water heater lifetime at Michigan costs; and a 20-year solar water heater lifetime at TVA costs ($3648/unit installed). Table 4-6 shows the costs of conserved energy for all three cases. Even under the most favorable conditions the CCE is 11.4¢/kWh for conventional systems, much higher than the cost of conventional supply options. Clearly, without tax credits, such solar water heating is not a cost-effective alternative. Our calculations do not include maintenance costs, which would make the economics even less favorable. A conventional electric water heater requires virtually no maintenance during its lifetime. A single maintenance visit to repair a solar hot water system can significantly affect the payback time.

Table 4-6. Costs of Conserved Energy for Solar Water Heaters

	case 1 15-year life $5155 first cost	case 2 20-year life $5155 first cost	case 3 20-year life $3648 first cost
3% discount rate	CCE=20.5¢/kWh	CCE=16.4¢/kWh	CCE=11.4¢/kWh4
7% discount rate	CCE=26.9¢/kWh	CCE=23.1¢/kWh	CCE=16.0¢/kWh

Best low-cost technology using selective absorbers, heat pipes, and thermo-syphon designs using methanol-water mixtures under vacuum seem to be able to achieve high performance at an installed cost of less than $2000. At that price, such systems would be cost-competitive with heat pump water heaters.

Interactions of Water Heater Economics with Demand Reduction Measures

We have so far analyzed water heater efficiency economics in isolation from each other and from demand reduction measures. To illustrate the interactions of these groups of measures, we refer back to Table 4-4, showing the savings and costs of conserved energy when improved new water heaters or retrofits are implemented only after the temperature setback and hot water demand reduction are in place, and compare them to the costs of the measure when implemented singularly. The figures show that the HPWH cost of conserved energy roughly doubles, moving it beyond current average electricity prices in Michigan. The cost-effectiveness of conventional water heater improvements remain cost-competitive with short-run marginal costs from Michigan's existing supply capacities.

IMPLEMENTATION PROGRAMS

Conventional Water Heater Programs

Most utilities conducting RCS programs have promoted water heater wraps as part of their retrofit packages. Some of the most aggressive programs were run in the BPA region, where participating utilities received a fixed payment for each installation. Some utilities reported more than 90 percent saturation of wraps in their territory. An ambitious and highly successful program is that of Seattle City Power and Light, which is based on the goal to convert all residential water heaters in the territory into high EF units over 12 years. The utility simultaneously promotes water heater wraps, traps, setback to 130°F, and purchases of more efficient water heaters. Rebates are $100 for high efficiency (EF 0.95) models. So far, the company has met its annual retrofit and conversion target and has found a 97 percent compliance with thermostat setback and other program requirements among its customers.

Heat Pump Water Heater Programs

Heat pump water heaters have been promoted by a number of utilities using often substantial rebates. So far, little progress has been made in achieving substantial participation rates. Early programs were in part handicapped by mixed performance in terms of equipment reliability, which seems to have been overcome since then. A more important barrier to significant participation may be the fact that the majority (a BPA report estimates about 60 percent) of water heater purchases occur in an emergency situation, i.e. when the old unit has sprung a leak. In this situation, customers tend to shy away from new technology that they don't know and that costs six hundred to a thousand dollars more, even if the dealer happens to stock the units and participates in the rebate program.

Incentives should be more successful, at least in non-emergency replacement purchases in the future, once recent lessons in effective program delivery find more widespread application.

TECHNICAL AND ACHIEVABLE POTENTIAL

Based on the above analysis, the promotion of demand reduction measures and improvements in conventional water heaters stand out as the more economic and higher priority option than HPWH alternatives. If they are implemented first, the HPWH loses its attractiveness. In fact, cumulative savings from these measures can be as large or larger than from the relatively more expensive and difficult to implement HPWH unit. Conventional solar water heater systems do not seem to be cost-competitive with present electricity prices. However, recent innovations in solar water heaters could be a cost-competitive option, and more so if hot water demand has been reduced significantly so that back-up systems can be avoided. Of course, fuel switching represents another electricity conserving option (see the section on fuel switching).

We translate these considerations into the following scenario assumptions: in the *technical potential scenario*, we assume heat pump water heaters with efficiencies of 2.4 are installed as resistance heaters wear out.

In the *program-based scenario*, only conventional water heater improvements are implemented (measures shown in Table 4-4, excluding heat pump water heaters). The 1990 consensus standard of EF 0.91 is reached not only for new units by then, but also for existing units by continuing and aggressively expanding Michigan's water heater retrofit programs. In ensuing years, the EF level in the stock rises to 0.96.

Results

Scenario results are shown in the summary tables in Appendix A. By 2005, the MEOS forecast for electric water heating is five percent below the frozen efficiency forecast. In the technical potential scenario, drastic reductions in hot water demand combine with high energy factors to eliminate 83 percent of the MEOS forecast. The program scenario saves 44 percent compared to the MEOS forecast, with savings over MEOS amounting to 1069 GWh in 2005.

IMPACTS ON UTILITY SYSTEM

Program scenario savings over MEOS are 197 MW peak load in the summer, and 217 MW in the winter. The technical potential figures are 290 and 318 MW, respectively.

CUMULATIVE INVESTMENT AND PROGRAM COSTS

The cumulative investment required to achieve the technical potential is $666 million. Program costs that would be borne by ratepayers to achieve the program scenario efficiencies are much lower, about $94 million, of which $84 million would be rebate costs.

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5. AIR CONDITIONERS

A. MEOS BASELINE DATA

END-USE: Space Cooling
FUEL: Electricity
TECHNOLOGY: Room and central air conditioners

GENERAL

Contribution to total electricity use. The electricity consumption for air conditioning is of minor importance in Consumers Power's electrical sales, but substantially more significant for Detroit Edison. Residential air conditioners account for 300 million kWh or 3.7 percent of Consumers Power's 1985 residential sales, and for 780 million kWh or 7.7 percent in the case of Detroit Edison (see Table 5-1). The combined consumption in both service territories of 1080 million kWh is equivalent to the annual output of a 220 MW baseload plant (assuming a 57 percent capacity factor).

Table 5-1. Air Conditioning Energy Use and Loads

Utility	Equip. Type	Saturation 1985 (%)	Stock 1985 (x1000)	SEER[1]	UEC (kWh)	UPD[2] summer (W)	Total Use (GWh)	Peak Demand (MW)	Marginal SEER[3]
CP	Central	9.6	117	7.47	1434	1673	168	196	8.82
	Room	25.7	313	6.87	421	326	132	102	7.48
	ALL						300	298	
DE	Central	23.7	387	7.47	1415	2075	549	805	8.82
	Room	30.6	500	6.87	461	377	231	189	7.48
	ALL						780	994	

(1) Based on 1979 equipment vintage.

(2) DE central UPD from 1983 submetering data.
DE room UPD based on outdoor temp of 87-92°F and CP's fraction in use factor for that temperature range.

(3) 1985 for central units.
1984 for room units.

Contribution to peak demand. In contrast to their small contribution to electricity use, air conditioners contribute significantly to summer system peak demand, particularly in the Detroit Edison system, where they contributed 13.5% to the 1984 annual system peak of 7350 MW (see Table 5-1). Central air conditioners account for 805 MW of this peak (11.0%).* Room air conditioners make up 102 MW, and central systems 196 MW, of system peak in Consumers Power's territory. Together, these 298 MW are 6% of the system (summer) peak.

* Based on the coincident demand per customer at system peak as measured in 1983.

Main technology types. Air conditioners can be classified by source of cooling (air-cooled, evaporatively cooled, or water-cooled). We limit our discussion to air-source air conditioners, which are dominant among mechanical cooling technologies. Air conditioners come in two versions: room (window or through-the-wall) units and central units. and are further categorized by function (cooling only vs. year-round heating/cooling units). Central air conditioners are further categorized into single-package and split systems.

In year-round systems, the heating function is either achieved by reversing the air conditioner into a heat pump mode, using a separate resistance heater element, or both.

Room air conditioners range in size from 4000 Btu/hr to 35,000 Btu/hr. Central air conditioners range from 16,000 to 135,000 Btu/hr, with almost all sales concentrated in the 16,000 to 65,000 Btu/hr bracket.

DOE product classes. The Department of Energy has established product classes to reflect design-specific limitations encountered in improving the efficiencies of the various available products. Generally, large units cannot benefit as much as smaller units from increased heat exchanger size to raise their efficiency, due to cabinet and building size limitations. Also, single package systems have a slight efficiency handicap due to the close proximity of cool and warm air flows in the units. DOE classifies central air conditioning units as follows:

1. Split systems - cooling only - 39,000 Btu/hr or less
2. Single package units - cooling only - 39,000 Btu/hr or less
3. Split systems -cooling only - above 39,000 Btu/hr
4. Single package units -cooling only - above 39,000 Btu/hr.

DOE established three further categories for air-source heat pumps (central air conditioners with reverse cycle):

1. Air source, split system
2. Air source, single package system
3. Air source, split system, heating only.

For room units, DOE divides equipment into designs with side louvers (WSL) on the outdoor portion of the cabinet, and designs without side louvers (WOSL). Side louvers facilitate efficiency by reducing air flow pressure drops, but cannot be mounted flush with the wall. Very small units are less efficient, due to their compact design and restricted air flow . The WSL types are grouped into four size ranges:

1. WSL 8000 Btu/hr or less
2. WSL greater than 8000 Btu/hr through 14,000 Btu/hr
3. WSL greater than 14,000 Btu/hr through 20,000 Btu/hr
4. WSL greater than 20,000 Btu/hr.

The WOSL types fall into two product classes:

5. WOSL 8000 Btu/hr or less

   WOSL more than 8000 Btu/hr.

The year-round units (reverse cycle for heating) are somewhat less efficient due to the presence of a reversing valve. They are subsumed in the WOSL classes.

The consensus standards passed by Congress (bu vetoed by the President) would establish 12 product classes by dividing the size ranges more finely and assigning two separate classes to reverse cycle units.

Total U.S. sales by type. In 1985, 3.148 million central units were sold in the U.S. During 1984, 4.038 million room units were produced, of which 2.4 million were sold in the U.S.

Of the *central air conditioners*, 71 percent were for cooling use and 29 percent for year-round use (23 percent heat pumps and 6 percent year-round air conditioners). In terms of equipment type, 77 percent were air conditioner systems and 23 percent were heat pumps. In terms of configuration, 85 percent of total sales were split systems (66 percent split-system air conditioning condensing units, and 19 percent split heat pumps), and 11 percent single package air conditioners (about half for year-round application and half for air conditioning only).

Among *room units*, air-conditioners designed for cooling use only accounted for more than 90 percent of total sales in 1984. Units with side louvers made up 89 percent of shipments. By far the most important size category were units smaller than 8000 Btu/hr, with 45 percent of all shipments. Units with capacities larger than 20,000 Btu accounted for about 10 percent of sales.

Saturation of air conditioner ownership. Air conditioner ownership among residential customers varies by climate region. In Michigan, about 42 percent of all households have air conditioning units (1984). In Detroit Edison's service territory, more than half the customers (56 percent) own or use electric air conditioners and heat pumps. The figure for Consumers Power is significantly lower (29.3 percent).

Demographic distribution. Ownership of air conditioning is strongly shaped by income class and dwelling type. Central air conditioners are disproportionately concentrated in multifamily homes and large single family homes of high income groups. Ownership of room units is less skewed toward higher income groups and follows the composition of the building stock more closely, but again saturations are higher than average in multifamily homes.

BASIC ENERGY CHARACTERISTICS

Ratio of energy costs to capital costs. Based on average unit energy consumptions and residential electricity prices, energy costs in Michigan range from about $60-$190 per year for central air conditioners, which is about 3-10 percent of the first cost for standard new units. * For room units, the range is $15-$50 per year, or again 3-10 percent of the purchase price. Because operating costs are such a low percentage of purchase price, not many large efficiency investments will be cost-effective for air conditioning.

Key factors affecting electricity use. The major determinants of air conditioning electricity use are:

- Weather patterns and climate
- Seasonal energy efficiency ratio (SEER)
- Thermal integrity of the building (conductive heat gains)
- Solar gains through windows

* Assuming a maximum kWh cost of 9.49 cents/kWh (based on Detroit Edison's higher block rate), and a minimum of 6.8 cents/kWh (based on the average residential price in CP's territory).

- Infiltration heat gains
- Temperature settings, zonal cooling, and other aspects of utilization.

For a given building, climate, and utilization pattern, the energy consumption of air conditioners is a function of the SEER only. This parameter, in turn, depends on five major design factors:

- the efficiency of the fans and of the electric motors that drive fans and compressors;
- the compressor efficiency;
- the refrigerant cycle efficiency, which is determined by the heat exchange surfaces;
- the air circuit efficiency, as measured by the pressure drop in the air flow across the heat transfer surface;
- the thermostatic control efficiency, which determines the responsiveness of the unit to temperature and humidity changes.

In addition, maintenance of the unit (replacement of air filters) is important to avoid a decline in EER over time due to increased fan loads and icing and gumming up of the evaporator coils.

Note that the product class has only a limited influence on central unit energy performance. In 1985, the shipment-weighted average SEERs of split, single package, and heat pump central systems differed by only 0.26 SEER units or 3 percent. The differences are more pronounced among room units. Here, the most common size (8000 Btu/hr and less, 45 percent of shipments) had an average shipment-weighted SEER of 6.76, compared to 8.40 for the next most common product class (WSL units of more than 8000 Btu/hr to 14,000 Btu/hr, 19 percent of shipments).

Calculation of energy consumption. Air conditioners are characterized by a Seasonal Energy Efficiency Ratio (SEER). The SEER is calculated from the measured equipment performance in a standardized test cycle. This cycle covers a variety of operating conditions that approximate real conditions during the cooling season. To calculate energy consumptions, the Btu/hr rating is multiplied by the hours of operation and divided by the SEER.

EXISTING MICHIGAN STOCK.

Composition of Existing Stock

Saturations by type. In Consumers Power's service territory in 1985, the total fraction of (electrical) customers with air conditioning was 29 percent. Nineteen point two percent of customers had (one or more) room units and 10.1 percent had central units (9.2 percent air conditioners and 0.9 percent heat pumps). About one percent of central system owners also had room units. The fraction of customers with only one room unit was 14.4 percent, while 3.2 percent owned two units, and 1.6 percent owned three or more. The saturation of room units weighted by multiple ownership was 25.4 percent.

The saturations among Detroit Edison were larger, in particular for central units: 23 percent of all customers had these, and another 2 percent used central air conditioning furnished by the landlord. Thirty percent had room units (22 percent with one unit, 6 percent with two, and 2 percent with 3 or more). The overall saturation of room units (accounting for multiple ownership) was 40 percent. An additional one percent of all customers had heat pumps.

Saturations by dwelling type. Compared to the distribution of building types, central air conditioners in Consumers Power's service territory are disproportionately concentrated in multifamily homes and large single family homes. About 66 percent of Consumer Power's electric customers with central air conditioning live in single family homes, compared to 78 percent for all-electric customers.* Central air conditioner saturations are 8.3 percent in single family homes compared to 28 percent in apartment buildings (three or more units) and 9.2 percent for all homes. The highest saturations are found in condominiums (82 percent) and town houses (53 percent); however, they constitute only small fractions of the building stock (less than 1 percent each).

Ownership of room units is less skewed toward higher income groups and follows the composition of the building stock more closely. Seventy-five percent of the units are found in single family homes and 14.4 percent in apartments, compared to a 76 percent and 6.7 percent share of these residences in the total electrical customer building stock. Average saturation of room units for single family homes is 18.8 percent, and for apartments 41.4 percent, compared to 19.2 percent for all buildings.

In Detroit Edison's service territory, the saturation of room air conditioners is 27 percent in single family dwellings and 42 percent in multifamily dwellings (1984 survey). Central air conditioning is similarly concentrated in multifamily homes (32 percent compared to 22 percent in single family homes). A sizable portion of the multifamily central units (44 percent) are operated by landlords, but the share of landlord-owned central units is only eight percent of all single family and multifamily central units.

Saturation by income class. The patterns of saturation by dwelling type are closely correlated with the distribution of air conditioners across income groups. In both service territories, the saturation of room units is reasonably flat across all income classes, with a moderate decrease at the high and low ends of the spectrum. By contrast, the ownership of central units is heavily skewed toward higher income brackets. Central unit saturations are three times as high in the $30,000/year plus bracket than in the less than $10,000/year bracket.

Historic saturation trends. The saturation of room air conditioners in Michigan has increased moderately over the last ten years: in Consumer Power's territory, saturations increased from 21 percent to 25 percent over the same period. For central units, more saturation growth has been experienced.

Energy Efficiency Ratios (SEER) of existing stock. We estimate existing stock SEER values on the basis of historic shipment-weighted averages for national sales. (These historic values are given in terms of EER, a slightly different efficiency measurement). We estimate 1979 to be the average vintage of air conditioning units. From ARI and AHAM statistics, the shipment-weighted average SEER of the stock in 1979 was 7.47 for central air conditioners and 6.87 for room air conditioners (EER interpolated from 1978 and 1980 data).

Historic SEER/EER trends. Between 1976 and 1985, the shipment-weighted average EER/SEER values increased from 7.03 to 8.82 for central units (excluding heat pumps), an increase of 25 percent. During this period, front pump values increased from 6.87 to 8.56. The average EER of room units increased from 5.98 in 1972 to 7.48 in 1984, representing an increase of 25 percent as well.

*LBL's analysis considers CP's all-electric and combination customers only. The overall saturation of air conditioning among CP's electric customers is significantly lower than among all CP customers: 9.2 percent compared to 16.1 percent for central units, and 19.2 percent compared to 21.3 percent for room units. A significant number of the gas customers buy electricity for their air conditioners from Detroit Edison or other utilities. CP's 1985 Major Appliance Usage and Attitude Survey covered both all-electric, all-gas, and combination customers. We have extracted figures for the electricity subgroup from the survey data.

Capacity size. No utility survey data on average sizes are available. Based on shipment-weighted averages of national sales in the 1970s, the average central unit in Michigan would have a capacity of 35,000 Btu/hr (2.9 tons), while room units would have a capacity of about 10,000 Btu/hr. Because sizing depends in part on climate, national shipment-weighted averages may be not totally representative of the Michigan stock.

Historic trends in capacity size. Industry data on national sales show that the shipment-weighted average size of room air conditioners has remained virtually unchanged over the last 15 years (10,413 Btu/hr in 1984 compared to 10,227 Btu/hr in 1972). For central air conditioners, the average size sold in 1978 was 35,000 Btu/hr and has declined somewhat since then (32,900 Btu/hr in 1984).

Unit life. Estimates of the average life of air conditioners vary according to source. A recent survey by ARI of its members indicated that the average life expectancy of air-source heat pumps is 14.28 years (Indoor Comfort News, February 1985). A survey of 492 HVAC contractors commissioned by the American Gas Association found that the average age at replacement of unitary air conditioners is 12-15 years (AGA 1986). The authors of the survey recommend a point value of 14 years. The same survey also found that compressor units tend to last only 70-75 percent of the unit's total useful life.

Because typical operating hours are comparatively low in Michigan (from 250 to 400 hours per year), the average unit life can be expected to be somewhat longer in this state. AHAM statistics on Michigan sales also indicate a longer service life. In 1984, 57,000 room units were sold in that state. Based on a CP/DE weighted average saturation of 34 percent for room air conditioners, and a total of 3.23 million households in Michigan, this means that 5.2 percent of the stock was replaced that year. This corresponds to an average life of 19 years; however, this value may partially reflect market fluctuations. We assume the average lifetime of both room and central units to be 15 years.

Unit Energy Consumption of Existing Stocks

Unit energy consumptions for air conditioners are a function of the weather and vary by year. The following figures are based on normal year performance. Both Detroit Edison and Consumers Power have conducted repeated submetering experiments on air conditioners, with the main emphasis on room and central units in single family homes. Consumers Power's most recent submetering data cover the 1984 and 1985 season. (1984 was virtually identical with a normal (30-year mean) season year.) Detroit Edison's last submetering experiments were done in 1983, which had a significantly warmer than normal summer.

UECs by type. From submetering data, the normal year air conditioning UEC for CP's electric customers can be estimated to be 849 kWh for central units, and 147 kWh for room units. The equivalent values for Detroit Edison are 1582 kWh and 420 kWh.*

Unit peak demand. The diversified per-unit contribution to system peak as found in the two utilities' submetering experiments was 0.33 kW (room) and 1.72 kW (central) for Consumers Power (1984, 1-3 pm hour ended), and 2.12 kW (central) for Detroit Edison. These data refer to single family homes only.

* These figures are best estimates and are subject to some uncertainty due to the demographic bias and limited size of the submetering samples. In the case of Detroit Edison, no recent submetering results are available for room air conditioners. The room UEC for Detroit Edison is per unit and not per customer with (one or more) room air conditioners. Based on per customer accounting, DE estimates a UEC of 555 kWh per year. This estimate is based on the average capacity ratio of central and room units and somewhat lower load factors.

The two companies reach system peak in the afternoon, a couple of hours before the period of maximum air conditioner usage. (Note that the system peak day and hour does not necessarily coincide with the day and hours of summer extreme temperature.) *Utilization patterns.* Though submetering samples are usually too small to be statistically relevant, some order-of-magnitude figures on operating characteristics and user patterns can be gleaned from these data. Consumers Power's Major Appliance Usage and Attitude Survey gives additional insight into the behavioral patterns reflected in the above unit energy consumptions. That survey found that more than half of the owners of room units only turn on their units a few times during the season. This explains the very low submetering UEC found for room units. By contrast, central systems are more likely to be operated continuously when people are at home (62 percent). Only 27 percent turned off their unit when gone, while 21 percent reset their thermostats to a higher temperature when leaving the house.

Operating hours can be estimated on the basis of average UECs and historic capacity and SEER figures. On that basis, equivalent full load operating hours would be expected to range from 180 to 350 hours per year for central units, and from 100 to 300 hours for room units. Detroit Edison reports a range of 330 to 400 hours for central units in its 1978 submetering study.

Thermostat settings found among Detroit Edison's 1983 central A/C submetering participants were 77.1°F during the day and 74.6°F at night, with an average of 75.9°F. By comparison, the 1978 sample had reported an average setting of 73.6°F. The at-home index found in the 1983 sample ranged from a low of .5 during weekday afternoons to a high of .9 during weekday evenings. On weekends, the index remained between .8 and .9 for all periods of the day.

Load Profiles

Seasonal variations. In general, air conditioner usage, and therefore loads, closely follow the weather pattern during the summer months. An exception is the first hot weather period during the year, when more users leave their systems turned off and use natural ventilation for cooling. This results in an "abnormally" low fraction-in-use when compared to occurrences of the same weather conditions later in the season.

Diurnal variations. A typical 24-hour load profile for hot days is shown in Fig. 1. The figure shows that air conditioner use is highest in the evening hours. Consumers Power obtained additional information on user patterns in its 1985 Major Appliance Usage and Attitude Survey, which had sample size of 3,973 customer responses. According to this special survey, the use of air conditioners in CP's service territory is concentrated in the hours from 5 pm to midnight (52 percent of usage for central units, and 45 percent for room units). The second most important period is midnight to 8 am (43 percent and 33 percent, respectively), with the rest of the usage concentrated in the noon to 5 pm period.

Fraction-in-use profiles. Appendix B shows the fraction-in-use profiles derived from CP and DE submetering data, for central and room air conditioning. The average maximum non-coincident demand observed in the sample is 3.89 kW for CP and 4.07 kW for DE. Fraction-in-use values are highest in the late afternoon and evening hours. The fraction-in-use matrices are somewhat different with DE showing higher values than CP during the early evening hours. It should be noted that these matrices are based on the small samples that characterize submetering experiments and are therefore associated with considerable uncertainty. Also, DE was only able to provide data for central units, and these data were derived from the 1983 submetering experiment. We use CP's room unit fractions for both utilities.

The 1983 summer was 40 percent warmer than 1984, though the temperature conditions during the peak day was about the same in both years (average temperature 82°F, maximum 94-95°F). Also, DE eliminated lifeline rates in 1984, which may have changed the fractions-in-use since then.

Differences by day of week. Greater coincidence of peak usage is observed during weekdays than during weekends. Much lower coincidence is observed among room units than among central system owners.

CURRENTLY SOLD EQUIPMENT

Marginal capacity sizes. The 1984 average capacity was 10,413 Btu/hr for room units, down 4 percent from the 1978/79 shipment-weighted average. For central units, the 1984 shipment-weighted average of 32,900 Btu/hr represents a decrease of 9.4 percent over the same period.

These down-sizing trends may reflect improved thermal integrities of homes. The thermal integrity of homes has improved significantly over the last eight years, particularly in new construction where most of Michigan's and other regions' gains in air conditioning saturation have occurred. Part of the down-sizing trend is also attributed to more smaller-sized houses (such as condominiums).

Marginal UECs. Based on the assumption of constant utilization patterns, the marginal UECs can be calculated using the difference in the EER/SEER figures and in the capacity sizes for existing stocks and marginal sales. As of 1984, marginal SEERs of 7.48 for room units and 8.66 for central units were available. Taking into account both the marginal SEERs and reductions in the average capacity of new units, the 1984 marginal UECs are 10.9 percent and 20.8 percent lower than 1979 stock averages (374 kWh and 1253 kWh for Detroit Edison and 133 kWh and 672 kWh for Consumers Power).

Assuming that utilization patterns do not change, unit peak demands will be lower by the same percentages as unit energy consumptions.

Current costs. Average-sized room air conditioners of standard efficiency (SEER 7.5-8) are available for $450 to $500, based on price quotations from Michigan dealers. The price of a split system of typical capacity (Lennox Power Saver with 36,000 Btu/hr) and standard efficiency (9.0 SEER) was quoted as $1700 to $1800 installed. According to AGA's HVAC installer survey (AGA 1986), replacement of the compressor in a central unit costs 40-45 percent of the total unit's first cost and can be expected after 12 years of service.

More efficient room units cost $30 extra per unit of SEER improvement in the range from 7.5 to 9.0 SEER. More efficient central air conditioners and heat pumps cost $280 extra per unit of SEER improvement in the range from 9.0 to 13.2 SEER.

B. DEMAND-SIDE MEASURE DATA BASE

END-USE:	Space Cooling
FUEL:	Electricity
TECHNOLOGY:	Air Conditioners
DEMAND-SIDE MEASURE:	Overview of Available Options

OVERVIEW

Energy conservation options for space cooling fall into the following broad categories:

1. *More efficient mechanical cooling devices.* These include high-efficiency air conditioners, direct evaporative coolers, and hybrid systems (combined indirect evaporative coolers and air conditioners or direct evaporative coolers).
2. *Reduced building shell heat conductance.* This can be achieved by means of better insulation in building walls and ceilings, and by means of attic fans and soffit vents.
3. *Reduced building infiltration heat gains.* The main techniques here are vapor barriers, sealing cracks and holes, and weatherstripping.
4. *Reduced solar radiation gains.* the most important approaches are window shading, reflective window coatings, and reflective outside building surfaces to increase albedo.
5. *Thermal storage.* Systems that can be applied in the residential sector include partial storage and full storage systems based on clathrates or eutectic salts, as well as portable ice spot coolers.
6. *Ventilation cooling.* When cool outside air is available, this ambient cooling source can be used to replace chiller operation by switching to a ventilation cycle (economizer cycle).
7. *Zonal control cooling.* This technology involves automatic controls and microprocessors, as well as variable speed operation of the air conditioning system to allow cooling of individual rooms and dwelling zones.
8. *Moderating urban heat islands.* A variety of techniques can be applied to achieve this goal, including using the evapotranspiration of trees.
9. *Air conditioner cycling.* Direct load control of air conditioners by means of interruptible service technologies can reduce peak power demand. This option is discussed in a separate section.

This brief overview shows that a large number of technologies can be pursued to reduce air conditioning energy use and peak demand. The field of residential cooling is undergoing rapid technological evolution in several areas. A discussion of recent development efforts and expected economics for a variety of emerging options can be found in ACEEE (1986).

APPLICABLE OPTIONS IN MICHIGAN

The applicability of the above approaches in Michigan is constrained by the fact that the state's cooling season is short and that air conditioning equipment is not intensively utilized. We discuss several options to illustrate these constraints.

Higher Air Conditioner Efficiencies

Cost-effectiveness of improved central air conditioners. The cost of improving central air conditioners by one unit of SEER has been estimated by the California Energy Commission (1985) based on manufacturer surveys. Additional inferences of current efficiency costs can be made from current prices of standard and higher efficiency equipment. For the predominant split system central air conditioners the CEC investigation found the minimum estimate by Carrier corporation (with a 25 percent market share) to be $116/unit SEER for going from SEER 8 to SEER 10. The Commission's average estimate, based on these and other manufacturer's survey data supplied by the American Refrigeration Institute (ARI), was $236 (1985). Prices quoted by Michigan dealers for equipment in the range from SEER 9-13 translate into an extra cost of $280 per unit of SEER. ACEEE (1986) reports $310 per unit of SEER for equipment in the range from SEER 8-15.5, which includes best currently available models.

We can calculate the maximum cost per unit SEER that would make more efficient air conditioners cost-effective against a peak power gas turbine at an investment cost of $500/kW (20 year life). Assuming a baseline coincident demand of 2 kW (a value that marks about the middle of the range of observed coincident demands at system peak in Detroit Edison's and Consumers Power's submetering studies), a unit of SEER increase must not cost more than $40-70, depending on the span of the total SEER improvement.* Even if one takes into account that volume production will reduce the cost of high efficiency air conditioners to half the CEC estimate, and extends this analysis to SEERs greater than 10, cost-effectiveness remains elusive.

The same holds true for the cost of conserved energy. Assuming the Detroit Edison normal year UEC of 1582 kWh and $236/unit SEER improvement, the cost of conserved energy is 15 cents/kWh. For Consumers Power, where the average UEC is only 849 kWh, the cost of conserved energy is 28 cents/kWh.

Cost-effectiveness of room air conditioners. For room air conditioners in Michigan, the cost-effectiveness limit, based on peak power savings, is $12-15 per unit of SEER improvement.** This limit is again exceeded several-fold by current SEER premiums.

Based on Detroit Edison's estimate of room air conditioner UECs, a room air conditioner with SEER 9 saves about 70 kWh over a standard (SEER 7.5) unit in the Detroit Edison service territory. At an extra cost of $43 and a 14 year service life (3 percent real discount rate), the cost of conserved energy is 5.4 cents/kWh. In Consumers Power territory, the observed UEC among customers participating in a recent submetering experiment is 65 percent lower than the estimated average UEC for Detroit Edison's customers. At this lower UEC, the cost of conserved energy would roughly triple.

Heat pump air conditioners are evaluated in a separate section (see Section 7 - Heat Pumps).

*Assuming a diversified unit peak demand of 2.0 kW at the 1985 shipment-weighted SEER of 8.82, and a change to SEER 12.82, or a 31.2 percent savings, the maximum allowable cost is $257 or $64.25 per unit SEER improvement (three percent discount rate, 15 year life for air conditioner). At the CEC cost estimate of $236 per unit SEER improvement, the cost of conserved peak power, normalized to 20 years, is $1830.

**Assuming a coincident demand at system peak of 0.33 kW (Consumers Power 1984 submetering experiment), and a 34 percent savings (SEER 7.5 to 11.3), the net present value of efficiency investments at $500/kW must not be higher than $56. With a three percent discount rate and a 14 year life, the cost per unit of SEER improvement is limited to $12. At $30/unit SEER, the cost of conserved energy is $1300/kW peak.

Reducing Building Heat Gains

Based on CIRA modeling of prototypical Michigan existing and new construction single-family electrically heated homes, building shell measures that are highly cost-effective in electrically heated homes can reduce cooling loads by up to 30-40 percent. These model calculations for cooling are, however, less reliable for predicting savings than the results for heating load reductions. A study of Tennessee Valley Authority air conditioning customers based on actual billing data found that ceiling and other insulation retrofits had much less of an impact on cooling energy consumption than expected from engineering calculations (ICF 1980). Not only was the average response lower than expected, but also the variability among customers was much greater. This discrepancy was attributed to a greater behavioral flexibility among customers when they respond to hot weather compared to their response to cold weather. A similarly sluggish and variable response to shell improvements has been observed in other studies.

These results suggest that savings from building shell retrofits in Michigan should be evaluated very conservatively. At the same time, much greater thermal integrities are worth achieving in Michigan homes, solely on the grounds of cost-effective heating savings. Most air conditioners in Michigan are located in gas-heated homes. Though we did not specifically analyze heat load reduction potentials in gas heated homes the range of costs of conserved energy found in the electrically heated homes is less than the current cost of residential gas (about 2.8 cents/kWh after accounting for furnace losses). This suggests that similar space heating savings could be achieved cost-effectively in gas-heated homes, particularly since the latter have lower baseline thermal integrities than EHH. Thus, reductions in cooling loads, once better understood and quantified, can be incorporated into the demand-side resource as a side benefit of future heating-oriented programs that retrofit existing gas-heated and electrically heated homes and tighten building standards for new homes.

Window films. Heat-reflecting window films reflect up to 80 percent of incident light. Some self-adhesive films cost less than $2.00 per square foot of window area, and have an estimated life of five years. Mylar films that can be pulled down and retracted like a shade cost $6.00/sf (EA&R 1985). Order-of-magnitude estimates for this technology indicate costs of conserved energy of 5-10 cents/kWh and cost of peak power savings of $500-1000/kW. Here again, heat gain calculations can easily overstate actual savings because of the great variability in customer response. Since the measure does not seem to be easily cost-effective with current electricity and peak power costs, we do not provide savings estimates for this measure.

Evaporative coolers. Direct evaporative coolers are inapplicable in Michigan because of the state's humid climate. Using indirect evaporative coolers as pre-coolers for central units is not cost-effective in Michigan because of the large capital cost required. For example, a 3 ton/hr central unit would require an indirect evaporative cooler of approximately 1000 cfm. Based on manufacturer prices, the installed cost would be $1400 (single stage) or $2700 (two stage). with savings of 30 and 42 percent. At DE's average central air conditioning UEC of less than 1600 kWh/year, this translates into a cost of conserved energy of 25-32 cents/kWh for each of the two configurations.

Ventilation and zonal control cooling. Ventilation cooling probably has limited application in Michigan because humidity levels and night-time temperatures remain relatively high during the summer. Zonal cooling is definitely applicable in Michigan, and emerging central air conditioning technology using variable speed compressors and fans, microprocessors, and separate coils for individual rooms or zones, is making such control possible. Both the ventilation and zonal control options should be studied further for Michigan. In the meantime, they are difficult to quantify in terms of expected savings, and we do not pursue them further in this study.

Urban heat islands. Urban heat islands are common in metropolitan areas of the US. The daily average increase of temperatures in the summer is 3-5°C. The larger the metropolitan area, the more pronounced the temperature rise. This has profound effects on air conditioner demand and energy use. Assuming, for example, that the Detroit metropolitan area exhibits a 4 degree C (7.2 degree F) heat island, one can determine from the fraction-in-use matrix the approximate difference in air conditioning load experienced by Detroit Edison during peak summer periods. At 3 pm to 5 pm hour ended, the average expected fraction-in-use at an outdoor temperature of 91-95°F is 57 percent higher than at the next lower temperature bin of 86-90°F. This translates into a coincident demand increase of at least 0.7 kW per customer at system peak. For the metropolitan region of Detroit, with about 1.5 million households and an estimated 350,000 central air conditioning units, this heat island effect then accounts for an additional peak demand of 250 MW.

A number of options for reducing heat island effects have been proposed, including whitewashing buildings, using concrete roads instead of asphalt, and massive tree planting to cool streets and buildings by means of evapotranspiration. The impact of trees alone can be very substantial (Akbari et al. 1986). We do not pursue this or other options further in this study but draw attention to them for future consideration.

TECHNICAL AND ACHIEVABLE POTENTIAL

Both in our technical and standards scenarios, we incorporate a gradual reduction of space cooling loads and energy use, reaching 18 percent in 2005. This percentage decline in space cooling demand is about one half of the estimated cost-effective reduction in space heating obtained from improvements in the thermal integrity of gas-heated homes.

Technical Potential Scenario

In this scenario, the best currently available equipment (SEER 16 for central units and SEER 11.5 for room units) is rolled in starting in 1988.

Results. The energy savings resulting from this scenario are shown in Appendix A, Table C-A. (Results disaggregated by utility are shown in Tables CDE-A and CCP-A.) By 2005, annual savings of 400 GWh, or 40% of the MEOS forecast are realized.

Program-Based Scenario

This scenario is based on the "consensus" national appliance efficiency standards recently passed by the US Congress. According to these standards, the minimum SEER for room air conditioners would be 8.6 (weighted average over all product classes) starting in 1990. For central air conditioners of the split system configuration, the standard prescribes a minimum SEER of 10.0 starting in 1992. For single package systems, it is 9.7 beginning in 1993. Since 85 percent of current sales are split systems, we simply assume that all central systems must conform to the 10.0 SEER requirement.

We further assume that the central air conditioner standard will be exceeded by the industry by 5 percent within one year of the effective date of the standard, based on current market segmentation patterns (builder market with lower SEERs and first cost, basic replacement market, and discretionary replacement market). For room air conditioners, we assume no similar overshoot because these units are purchased more on impulse than on the basis of careful SEER comparison shopping. We truncate the SEER improvements in the standards scenario at these efficiency levels.

Due to the large cost premiums currently charged for higher efficiency equipment and due to the high cost and/or uncertainty of most other space cooling demand-side options, we do not develop a separate incentives-based scenario. We also do not count any program costs that would be associated with insulation improvements in gas-heated homes. Such an investigation should be an element of a future, broadened least-cost study that includes gas-based end-uses.

Results. The energy impacts of the scenario are shown in Appendix A, Table C-A. Savings of 114 GWh per year are realized by 2005 (11 percent of MEOS forecast).

IMPACTS ON THE UTILITY SYSTEM

The summer peak savings for the technical potential scenario and the program-based scenario are shown in Appendix A, Table C-C. Program-based peak savings are 147 MW or 13% compared to the MEOS forecast in 2005.

CUMULATIVE INVESTMENT COSTS

We only show the technology costs associated with the purchase of technical potential level air conditioner efficiency. These costs are displayed in Appendix A, Table C-D. Individual results for Detroit Edison and Consumers Power are shown in Tables CDE-D and CCP-D. Between 1984 and 2005, cumulative costs for the technical potential scenario are $1663 million.

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6. SPACE HEATING

A. MEOS BASELINE DATA

END-USE:	Space heating in electrically heated homes (EHH) and other electricity use for space heating.
FUEL:	Electricity
TECHNOLOGY:	Existing building shells and heating systems.

OVERVIEW

Electricity use for space heating in Michigan occurs in a variety of applications, heating systems, and building types. These are:

1. *Existing electrically heated homes.* These are defined as homes in which electricity is the main heating fuel and an electrical heating system is permanently installed. Less than three percent of Michigan homes are electrically heated. The state's principal home heating fuel is gas.
2. *New construction electrically heated homes.* These homes tend to be better insulated and are more likely to have heat pumps instead of conventional resistance heating systems. Less than ten percent of new-home construction in Michigan is electrically heated.
3. *Conventional main heating systems.* These are central electric furnaces with a forced air system, or baseboard electric heaters. More than 90 percent of electrical heating systems in Michigan are of this type.
4. *Heat pumps.* Currently, less than ten percent of electrically heated homes (EHH) use this technology in the CP territory.
5. *Portable and built-in auxiliary electric heaters.* The saturation of these two heating sources is less than 10 percent in Michigan homes.
6. *Electric fans in gas furnace heating systems.* Electricity consumption for these fans is larger than electric space heating consumption in EHH because the overwhelming majority of homes are gas heated.

In the following analysis we discuss baseline data for all six space heating uses combined. In our assessment of demand-side options, we treat new and existing EHH as separate end-uses. Heat pumps are analyzed separately from building shell measures, as a demand-side option for improving heating system efficiency. Only rough estimates are developed of how auxiliary heating and gas furnace fan electricity use may change as gas-heated homes become more efficient. Improvements in gas-heated homes cannot be justified on the basis of electricity savings in these two applications alone, but can be an important and highly cost-effective demand-side option when examined in terms of least-cost natural gas heating. Further investigation into this option lies outside the scope of the MEOS study, which is limited to electricity.

GENERAL

Contribution to total electricity use. The contribution of electric space heating to Michigan's total residential electricity consumption is significantly smaller than the U.S. average. In 1985, an estimated 3 percent of Consumers Power's residential electricity sales were used for space heating. The figure for Detroit Edison was 2.4 percent (see Table 6-1). By comparison, about 11 percent of U.S. residential electricity sales are used for home heating.

Furnace fans in gas-heated homes account for a significant fraction of electricity used for space heating. They consume an estimated 4 percent of residential electricity sales in the case of CP, and 4.4 percent in the case of DE. These proportions suggest that the energy savings potential in furnace fans should receive further attention.

Table 6-1. Electric Space Heating Energy Use and Loads

Utility	Equipment Type	Saturation 1985 (%)	Stock 1985 (x1000)	UEC (kWh)	UPD winter (W)	Total Use (GWh)	Winter Peak (MW)
CP	Existing Elec. Heated	4.0	49	4490	2265	222	112
	New Elec. Heated	0.2	2	3529	1764	8	4
	Portable Heaters	6.6[1]	80	203[1]	100	16	8
	Furnace Fans	72.7	884	359	253	318	224
	ALL					564	348
DE	Existing Elec. Heated	1.4	23	7974	3491	185	81
	New Elec. Heated	0.1	1	5326	2663	8	4
	Portable Heaters	6.6	108	203	97	22	11
	Auxiliary Baseboard	1.6	26	1014	498	26	13
	Furnace Fans	76.0	1242	359	253	446	314
	ALL					687	423

(1) These figures include electricity use for auxiliary baseboard heating and portable heaters in fuel-heated homes. Consumers Power had no estimates for the magnitude of portable heater applications but felt they were being used in its territory. We used DE figures as a default. Auxiliary baseboard systems were not considered by the company.

Consumers Power had no estimates for the magnitude of portable heater applications but felt they were being used in its territory. We have used Detroit Edison figures for portable heater saturations and UECs as a default.

Contribution to peak demand. Because of its seasonal nature, the contribution of space heating to the winter system and residential peak demand is significantly larger than to total and residential sales. In the Consumers Power territory, electrically heated homes contributed an estimated 124 MW to winter peak.

BASIC ENERGY CHARACTERISTICS

Contribution of energy costs to life-cycle costs. The cost of providing energy to heat buildings is typically an order of magnitude smaller than the cost of renting or purchasing and maintaining a home. Therefore, in improving the energy performance of buildings, the emphasis is usually on retrofits.

Key factors affecting electricity use for space heating. The major determinants of space heating energy use are:

-weather conditions
-the heat transmittance of the gross building shell
-the rate of outdoor air infiltration
-the energy efficiency of the heating system
-control systems of the heating system
-solar gains
-internal gains from occupants and lighting and appliances
-occupant behavior.

Further details can be found in the sections on energy efficiency improvements and conservation measures.

Calculation of energy consumption. The performance of various insulating materials is measured in terms of the heat loss resistance (R-value) per unit thickness of material. The total R-value of a building element is the sum of the R-values of all its components including the insulating material itself, of structural materials such as wall studs and floor joists, and of finishing materials such as sheet rock. R-values for a large variety of frequently used construction practices can be found in LBL (1985).

Calculating the total heat loss and net space heating requirements in a building involves a large number of variables including building and window orientation, solar and wind shading, wind speeds, indoor and outdoor temperatures, available solar radiation, and internal heat gains from occupants. Heat loss can be estimated by approximate methods using the U-value of each heat loss path (windows, doors, walls, ceilings, floors, etc.) and multiplying it with the surface area of that path (UA method). More accurate results, and in particular, the calculation of net space heating energy use require detailed building simulation models such as DOE-2 or CIRA.

EXISTING MICHIGAN STOCK

Composition and Insulation Levels

Saturation of electric space heating. The availability of relatively inexpensive natural gas has limited the penetration of electric heating in the state. In 1984, only 51,070 homes out of CP's stock of 1.217 million, or 4.2 percent, were electrically heated, and an even smaller number were so heated in the DE territory (24,645 homes out of 1.643 million, or 1.5 percent) (see Table 6-1).

Building types. The distributions by building type are shown in Table 6-2. Though multifamily homes account for a larger share of the electrically heated housing stock than of the gas-heated stock, single-family detached homes are still the dominant building category. Single family homes in the CP service territory made up 53 percent of the electrically heated stock compared to 76 percent in the total stock. In the DE territory, the corresponding numbers are 68 percent and 75 percent.

Table 6-2. Distribution of Electrically Heated Homes by Building Type			
Utility	Building Type	% of EHH	% of All Homes[1]
CP	Single Family	53.1	76.0
	Multi-Family	32.8	11.8
	Other	14.0	12.2
DE	Single Family	67.9	75.0
	Multi-Family	29.9	21.6
	Other	2.2	3.4

(1) Fraction of all electric customers within each service territory.

Building configuration. Available survey data further indicate that 62 percent of single-family homes are one-story buildings (CP), 50 percent have basements (CP), and that the most typical architectural style is the so-called "ranch house".

Building size. Based on the two companies' residential surveys, the average floor space for EHH homes is, respectively, 1387 sq.ft. (CP) and 1434 sq.ft (DE). Among Detroit Edison's homes, a significantly higher percentage are considerably larger than Consumers Power homes (17% of DE homes are above 2000 sq.ft., while only 8% of CP homes are over 1800 sq.ft.). Compared to the distribution of floor area in the total housing stock, the electrically heated size distribution is skewed toward smaller units in the CP territory, and toward larger units in the DE territory. The average square footage for all homes is about 1400 square feet in both territories.

Building vintage. On average, electrically heated homes are significantly younger than the overall housing stock. The average age of EHH (as of 1984) is 16 years for CP and 15 for DE.

Building life. The average life of buildings in Michigan has apparently not been monitored. We were unable to obtain statistics on state-wide demolitions and replacements. We assume an average life of 50 years.

Heating systems. Most heating systems in existing homes are of the resistance type (baseboard or central electric furnace). The CP survey found that 72.3 percent of electrically heated homes had a forced air system. For DE, the number is 76.0 percent. Heat pumps had a saturation of only 7.9 percent and 1 percent, respectively. Electrically heated homes also show a significant saturation of secondary heating systems based on wood (e.g. 24.5 percent for EHH compared to 23.3 percent for all CP homes).

Michigan weather. The range of normal year (30-year average) heating degree-days in the service territory of Consumers Power spans from 6281 to 8412 HDD (65°F base) among its eight weather stations (Flint, Pontiac, Grand Rapids, Lansing, Jackson, Kalamazoo, Midland, and Cadillac). Eighty-eight percent of CP sales fall into a more narrow climatic range of 6281 to 7068 HDD. Detroit Edison's territory is represented by the Detroit Metro weather station and has 6510 HDD 30-year normal. The MEOS WG 5 forecast assumes an average figure of 6802 HDD for both territories. During 1983-1985, total annual HDD were within one percent of this normal value.

Insulation levels in existing building shells. Precise information sources on the average composition and U-values of electrically heated Michigan dwellings are not available. Utility surveys provide information on a limited number of energy-related building features, such as the saturations of attic and wall insulation, storm windows, storm doors, and heated basements. The 1984 data show that CP's electrically heated homes have an average attic insulation of six inches, and that 59 percent have some wall insulation and heat loss surfaces.* The average multi-family UEC is then 3030 kWh/year for CP (4550 kWh/year for DE), and the average single-family UECs are 6060 kWh and 9090 kWh.

Load Profiles

Seasonal variations. Most space heating energy consumption is concentrated in the winter months, with only ten to 20 percent of consumption occurring in the transitional periods of the heating season.

Diurnal variation. The heating rate has a significant diurnal variation. In addition to variations in outside temperature and wind chill factors, daytime solar gains and nighttime sky temperatures modulate heating loads. Among behavioral factors, nighttime thermostat setback and daytime occupancy are key. Households may also practice zonal heating in different areas of the house over the course of the day.

Variation by day of the week. The only submetering data on space heating available from the Michigan utilities were for heat pumps from Consumers Power. These data suggest that differences in heating system use between weekday and weekend are mainly in the morning hours (higher fractions-in-use on weekends) and in the evening hours (higher fractions in use on weekdays). These trends are based on very small samples and should be treated as rough figures only.

Fractions-in-use. Consumers Power was able to supply fractions-in-use for air-to-air heat pump systems from its 1984/85 submetering study. These are shown in Appendix B. The data indicate an expected range from 0.65 to 0.75 for average minimum temperature conditions (minus 4°F) and from 0.60 to 0.65 for the somewhat less severe conditions (15°F at 7 pm) of the 1984/85 winter peak. These values for heat pump fans are in good agreement with common space heating coincidence assumptions used in load forecasting. In absence of better data from submetered Michigan resistance-heated homes, we use the heat pump fan fractions-in-use as an approximation for both territories.

Unit peak demand. Measurements of maximum average non-coincident demands from submetering experiments were only available for a 12-customer sample from CP, which yielded a value of 8.0 kW (7-8pm). CP feels, however, that this figure is too high to be representative. Using a comparison of load research on space heating customers and water heating customers, the company estimates that diversified demand from space heating is 2.3 kW at system peak. If one apportions this number between single-family and multifamily buildings in a fashion analogous to the UECs for those building categories, the diversified unit peak demands are 3.0 kW and 1.5 kW, respectively. A similar comparison of the average coincident demands at system peak between Detroit Edison's space heating customers (space heating rate D2, 4.6 kW) and average domestic customers (rate D1, 1.0 kW) yields 4.7 kW for single-family units and 2.3 kW for multi-family units.**

*To put these data into context, we compared them with UECs one would estimate from measured Residential Energy Consumption Survey data (RECS 1984) obtained in the East North Central region. This comparison yielded an estimated UEC for space heat only of 11,770 kWh for single-family homes (9,900 to 14,700 kWh depending on the use of air conditioning). Although the RECS homes are fully electrically heated, the utility UECs include a substantial number of homes which use electric heaters in combination with wood heat. The difference between utility and RECS values for space heat consumption can at least partially be explained by this use of supplemental heating fuels. We arrived at this estimate by first calculating the annual electricity use per unit of heated floor area in single-family dwellings using data for the East North Central region and a heating degree range of 5500 to 7000 HDD (65° F base). (The RECS data do not yield statistically significant data on the difference in energy use between single-family and multi-family buildings that are electrically heated, because of the small sample sizes involved). We then determined the portion of this total consumption used for space heating based on regional RECS data on consumption by end-use. This yields a space heating intensity of single-family buildings in the Michigan region. of 7.8 kWh/sf-yr. Using the single-family heating intensity of 7.8 kWh/sf and a 40 percent lower intensity for multifamily buildings, we converted the electrically heated floor space of single-family and multifamily buildings in Consumers Power's territory into UECs. (Detroit Edison did not have data on floor space by building type.) The ratio of single-family to multi-family UECs is then about 2:1.

**We also calculated the heating load of a prototypical single-family home at an outdoor temperature of 15°F (the temperature at

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These conditional demand based figures somewhat underestimate the peak load contribution from space heating customers because electric space heating loads from auxiliary and portable equipment and furnace fans in oil- and gas-heated homes are counted as miscellaneous loads there, rather than as electric space heating loads. Correcting for this factor would raise the average UPD for EHH by 0.2-0.3 kilowatt.

NEWLY CONSTRUCTED ELECTRICALLY HEATED HOMES

Composition and General Characteristics of New Electrically Heated Buildings

New construction activity. Between 1977 and 1984, an average of 27,100 new residential units were constructed in Michigan (F.W. Dodge 1985).

Building size. The Dodge report indicates an average size of 1958 sq.ft. per project. A survey of 909 newly constructed Michigan single-family homes conducted by the National Association for Home Builders for 1984 showed an average floor space of 1708 square feet per single-family detached home (NAHB 1986) compared to 1155 sq.ft. for multifamily new construction.

These data alone do not, however, allow inferences about housing size trends because home sizes fluctuate widely from year to year, depending on the business cycle. Survey data from the utilities suggest that no significant changes in the average size of homes have occurred over the last 30 years. It is probably reasonable to assume that the average dwelling size will remain approximately constant. This assumption also underlies the MEOS WG 5 forecast.

Marginal saturations of electrically heated homes. Utilities did not provide records of the number of new electrically heated homes that are connected to their grids each year. The previously mentioned 1984 NAHB survey found 64 electrically heated homes in in its single-family sample (7.0 percent). Utility staff estimated the current penetration of electrically heated homes across all building types as 5 percent.

Marginal saturations of heating systems. Among electrically heated single-family homes, 45 percent of the NAHB sample had heat pump systems, while the remainder used resistance heaters. Only 0.2 percent of the buildings had solar heating systems. Again, these numbers are somewhat uncertain because of the survey design.

Insulation levels in new construction. Insulation levels in new construction can be inferred from the electric space heating rate requirements, and from the results of the previously mentioned 1984 NAHB survey.** The 1984 NAHB survey found that the penetration of infiltration reduction measures in new

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7pm during the CP winter peak day in 1985). This calculation was normalized to the estimated single family electric heating UEC of the CP territory (6060 kWh). The calculated heat load at 15°F (temperature at 7pm in the evening of the system peak day in 1984/85) was 4.3 kW. Based on the heat pump fan fraction-in-use of 0.65 at system peak, the diversified peak demand at that hour would be 2.8 kW. For DE, where UECs are higher, the corresponding figure would be 4.2 kW. This range of 2.8-4.2 kW is in good agreement with the single family dwelling loads of 3.0-4.7 kW estimated from conditional demand analyses.

**Required minimum R-values: R-35 in ceilings, R-11 in side-walls, R-19 in floors above unheated areas, R-11 in basement walls if used as living area, and 2 in. rigid foam around perimeter of slab in slab construction, extending 2 ft vertically or under slab horizontally; no specification for windows or air infiltration.

construction was low. Only 20 percent of the sample's single-family homes used separate vapor barriers, and only about one third had special air infiltration barriers of any kind (e.g., vapor barriers plus roofing paper and other materials).

Construction practices in gas-heated homes compared to electrically heated homes. Utility customer survey data from 1983 and 1984 suggest that the utility EHH requirements are currently being largely met in newly constructed *average* (i.e. gas-heated) homes, and in some building elements even exceeded. For example, the entire single-family sample had ceiling insulation of at least R-38, and 98 percent had R-16 wall insulation. For the most important windows, 82 percent used double glazing and 15 percent had triple glazing.* These average building practices suggest that currently built EHH do indeed meet or slightly exceed the insulation requirements set by the utilities and the PSC.

UECs in new stock. For new electrically heated single-family homes, we estimated the baseline UEC as follows: Using CIRA, we simulated a single-family home with insulation characteristics as required by the utilities for space heating customers. We also simulated a single-family home with characteristics typical of the existing stock. The input data and results are shown in the following Measures section. The ratio of the two was used to calculate a UEC for new buildings from the UECs for existing buildings. On this basis, new single-family homes are estimated to consume 39 percent less energy than existing stock.

FURNACE FANS

Unit energy consumption. The utilities provided diverging estimates of 297 kWh (DE) and 400 kWh (CP). The figures, which are not based on submetering experiments, imply significantly different fractions-in-use, fan efficiencies, or building efficiencies, but most likely reflect data uncertainty about this end-use.

We obtained measured UECs of furnace fans from tests of 10 different furnaces conducted by the American Gas Association laboratories (AGA 1986). The average UEC was 409-567 kWh for 100-50 percent fuel input compared to rated input.

Unit peak demand. The same source gave an average installed fan wattage of 433W for the ten furnace models. Assuming a fraction-in-use of 0.65 at the peak hour of the winter system peak day (7 pm), the diversified contribution is 281 W. Based on 1.023 million installations in the service territory of CP (1.369 million for DE), furnace fans contribute 224 MW and 314 MW, respectively, to the system peaks of CP and DE.

*On the other hand, about half of the 187 dwellings with crawl spaces or floor joists had no insulation in these surface elements; few houses used storm doors, and half of the 559 dwellings with full basements had no insulation in basement walls.

B. DEMAND-SIDE MEASURE DATA BASE

END USE:	Space heating
FUEL:	Electricity
TECHNOLOGY:	Existing and new construction building shells
DEMAND-SIDE MEASURE:	Insulation improvements and infiltration reduction

GENERAL DESCRIPTION

Efficiency Technologies for Building Shells

Retrofitted insulation and air infiltration measures reduce heat losses in winter months, and heat gains during the summer, by reducing conductive, radiative, and infiltrative heat exchange through the building shell. These losses and gains occur through six major heat loss paths: doors; windows; attics and ceilings; house and basement walls; floors and subfloors; and cracks, holes, and openings that allow the exchange of indoor air. Below we briefly summarize the most important thermal integrity technologies for each of these heat transfer paths.

Doors. Doors can be retrofitted with storm doors (interior or exterior), weatherstripped, or replaced with new insulated doors.

Windows. Window measures include fitting storm windows (interior or exterior), high-performance windows using multiple glazing layers, low-emissivity films, nighttime insulation (drapes, insulating shades, or other systems), and window heat-gain retardants such as retractable awnings, shutters, etc.

Attics and ceilings. Infiltration losses through ceilings can be reduced by sealing cracks and holes in the ceilings, and by increasing ceiling insulation (blown or batts). Access to attic areas may require the installation of an attic hatch; if a hatch is already present, weatherstripping will further reduce infiltrative losses. Summer heat gains can also be reduced by installing attic fans, vents (in roof, gables, or soffits) to allow convective displacement of hot attic air, and radiant barriers on top of attic floor insulation to reduce the radiative heat transfer of hot attic air (often as high as 150°F) through the insulation and into the living space (see also air conditioning).

The method of installation of ceiling insulation depends on the type of roof. Roofs can be flat, pitched with an attic, or of the cathedral type. Attics can be floored or unfloored. In either case, both loose fill and fiberglass batt insulation is applicable. Flat roofs may have crawl spaces, or may be inaccessible to installers, requiring blown insulation methods with access to joist spaces from the fascia.

Walls. Wall insulation can be applied on the outside or on the inside. Rigid styrofoam or polyurethane boards, loose fill, or batts can be used. Walls also have cracks and penetrations that need to be sealed with caulking materials to achieve the full benefit of added insulation materials. In wood frame housing, wall cavities between framing studs can be filled with loose fibrous insulation, using holes to blow the insulation into these cavities. These holes are then patched and repainted as necessary. For masonry walls, exterior sheathings can be fitted that combine a vapor barrier, insulating board, and a new outer-wall finish in one unit.

Floors and basements. Depending on the type of house, the floor may be a crawl space or a basement ceiling. The basement, in turn, may be heated or unheated and ceilings may be finished or unfinished. For buildings with heated basements, the floor is usually a slab resting on the soil. Part of the basement walls will also be in contact with the soil, while other portions are in direct contact with the outdoor environment and may have windows and doors. For these wall surfaces, generic wall insulation retrofit measures apply. Retrofitted insulation around the building perimeter is also feasible, extending into the ground past the basement floor level.

Infiltration reduction. The cracks, penetrations, and holes in conventional building shells combine to form a significant leakage area that is measured in square feet. Careful sealing, weatherstripping, and caulking can significantly reduce this area; the application of vapor barriers will also decrease infiltration. The supply of fresh air can then be restored by means of mechanical ventilation, using air-to-air heat exchangers to minimize heat losses or gains.

Technology Status and Availability

The above insulating materials, technologies, and measures are generally established commercial technologies. Most technologies are simple to install and can be applied by the do-it-yourselfer.

Secondary energy impacts. During winter peak, electric heating is often the driving element of the residential class peak. Increased insulation levels can shift the occurrence of this peak to a different hourly period or day within the extreme weather period, by increasing the thermal flywheel effect of the building thermal mass. Reductions in heat losses and air infiltration reduce heat gains during the summer period, leading to energy savings in space cooling. These air-conditioning savings are discussed under that end-use. Improved insulation also reduces the needed size of the heating (and air conditioning) system, and can thus save costs when these systems are installed or replaced.

Special Problems and Benefits

Attic bypass. Actual savings from residential building retrofit programs are usually less than predicted energy savings. Among insulation retrofits, ceiling insulation in particular shows lower than expected performance which can be traced to ineffective infiltration-reduction measures, in many cases. Penetrations in ceilings can create an *attic bypass* that reduces energy savings from attic insulation substantially below calculated levels. Attic bypasses have been estimated to account for more than ten percent of all heat losses in U.S. houses.

To remove these and other bypass losses, it is necessary to identify the exact locations of leaks in the building shell using an accurate diagnostic tool such as a blower door. Once a blower door test has been performed, infiltration reduction and insulation measures can be applied jointly in a manner that achieves the target thermal integrity.

Indoor air quality. Weatherstripping, caulking, and other infiltration-reducing retrofits lower the rate of air exchange. This has raised concerns over corresponding increases in the concentration of indoor air pollutants. The major indoor air pollutants are combustion products from gas ranges, cigarette smoke, and radioactive gasses emitted from subdwelling soils, most notably radon. A full discussion of the indoor air quality issue is found in the environmental section of this report.

The concern over indoor air pollution is not limited only to tighter homes. In fact, some indoor air pollutants, such as radon, are likely to be more prevalent in leaky homes, where they can freely enter from the soil.

These environmental health concerns, as well as the desire for greater control of comfort in the home, point toward the increased use of mechanical ventilation systems and tight vapor barriers in residential buildings. These ventilation systems allow building occupants to set the air change rate at the level they desire. The Bonneville Power Administration, for example, has found mechanical ventilation to be the most effective and affordable method of reducing indoor radon pollution of the five control strategies it tested. Such systems can easily be complemented by air-to-air heat exchangers, with the result that the desired levels of fresh air can be maintained, and air pollution levels kept low or even decreased, while the energy efficiency of the building shell is enhanced. Mechanical ventilation systems and air-to-air heat exchangers can be installed both in existing and new buildings. Infiltration rates of existing buildings cannot be curbed as effectively as in new buildings; therefore, it is more difficult to achieve the full potential energy savings of the heat exchanger.

Performance of air-to-air heat exchangers. Field tests of air-to-air heat exchangers in cold climates have shown several defects of currently available systems, leading to such problems as freezing in cold temperatures, excessive noise, and reduced heat exchanger efficiencies and energy savings (Abrahamsson and Mansson 1986). Recent research (Fisk et al. 1984a, 1984b) has produced a more detailed understanding of the freezing problem, and suggests strategies with which it can be eliminated. Mitsubishi's paper filter element seems to perform well under cold weather conditions (Energy Design Update 1986). With increased emphasis on indoor air quality and correspondingly growing residential markets, the problems of current commercial products will likely be overcome.

Impacts on comfort. Retrofit measures substantially improve indoor comfort. Reductions in heat loss decrease the temperature difference between shell surfaces and indoor air, resulting in less convective air flow (drafts), less floor-to-ceiling stratification of air temperature, and a more comfortable radiative balance. Therefore, not only is space heat consumption reduced, but the comfort of the indoor environment is substantially improved.

Extension of building life. Improved shell efficiency also can bring secondary benefits in the form of greater building value and extended building life.

COST AND PERFORMANCE IMPACTS

Simulation Method for Calculating Energy Savings

Detailed information on the composition of Michigan's housing stock, in terms of building styles, unit energy consumptions, and other relevant data, is much sparser than available information on appliance stocks. In addition, electrically heated homes constitute a small (2-4 percent) fraction of residential electricity sales. The calculation of energy and peak power savings from conservation measures in buildings is relatively complex, however, requiring building simulation models that can take into account a number of interactive effects. To keep a sensible proportion between available baseline data, sales contribution, and computer simulation efforts, we limited our analysis to a CIRA building simulation of the most important building category, single-family homes. Single-family homes constitute more than fifty percent of the EHH stock and account for two-thirds of residential floor space. We then extrapolate the findings for single-family homes to the rest of the building stock, using appropriate correction factors to keep our energy savings estimates conservative.

CIRA simulation model. We used the CIRA building simulation model (CIRA 1982) to calculate energy savings as a function of wall construction, window types, insulation levels, and infiltration rates in newly constructed and existing electrically heated homes. An exhaustive description of the computational procedures underlying the CIRA runs can be found in the CIRA program documentation.

The model has been extensively verified and is accurate to within less than ten percent for space heating loads. Note that the above runs included simulation of heating system operation (thermostat setting and setbacks) and non-space heating end-uses as well. Also, the results for space heating savings incorporate secondary impacts from changes in solar gains that result from the retrofitted shell measures, and to some extent, changes in internal gains due to efficiency improvements in non-space-heating end-uses.

Description of Baseline Prototypes

We limited our simulation work to the most frequently found type of dwelling, a one-story detached ranch-style single-family home (see Fig. 6-1). The home was modeled with a Michigan-average heated floor area of 1540 ft^2. As reference points for evaluating demand-side measures, we used two starting levels of thermal integrity. The first was a home with significant levels of infiltration and only moderate insulation, representative of the average EHH. The second was a home with somewhat improved insulation characteristics, as found in current Michigan building practice and recently built electrically heated homes. Building shell composition was chosen to match survey data from the utilities and builder surveys whenever these were available. The most important prototype characteristics are summarized in Tables 6-3A and 6-3B.

Table 6-3A. CIRA Inputs: Constant for all Prototypes.

Heating Equipment	Type:	Electric baseboard
	Rated input capacity:	50 kBtu/hr
	Steady state efficiency:	100%
	Heating thermostat setting:	68°F
	Heating night setting:	55°F
Occupancy	Daytime:	1.6 persons
	Nighttime:	3.2 people
Water Heater	Type:	Electric
	Setting:	140°F
	Standby Losses:	to living space
	Daily Hot Water Use:	52.5 gal./day
Infiltration	Type:	Natural cooling ventilation
	Terrain:	Low buildings and trees
	Shielding:	Moderate local shielding
		Some obstructions within 2 house heights

Table 6-3B. CIRA Inputs: Variable between Prototypes.		
Input variable	Average House	New House
Walls		
Framing:	2" x 4" 16" o.c.	2" x 6" 24" o.c.
Insulation:	R-11 blown cellulose	R-16 fiberglass batts
Ceiling Insulation:	R-27 cellulose	R-38 fiberglass batts
Subfloor:	No insulation	R-11 fiberglass batts
Basement walls		
Above Grade:	R-11	R-11
Below Grade:	No insulation	R-11
Windows		
Glazing:	Single	Double
Storms:	Exterior only	None
Sash Fit:	Average	Tight
Doors		
Front:	Wood, solid core, exterior storm	Wood, solid core, exterior storm
Garage to Inside:	Wood hollow core	Wood solid core
Patio:	Glass single-paned, exterior storm	Glass double-paned
Sash Fit:	Average	Tight
Infiltration		
Summer:	.29 ach	.23 ach
Winter:	.53 ach	.44 ach

The prototype has an attached garage and an un heated basement. The total window area of 154 ft^2 (10% of the heated floor area) is evenly divided between the four wall orientations. In addition, the south wall is assumed to contain a 6' X 8' sliding glass door. A representative floor plan with elevations is shown in Fig. 6-1. This figure is meant to give a general idea of the house we modeled. The actual computer input does not contain all of the details shown.

CIRA inputs for average electrically heated homes. The average home is modeled as having a 2" X 4" wood frame with R-11 blown cellulose insulation in the walls. The above-grade portions of the basement walls are also insulated with R-11. The below-grade portions of the basement are not insulated, nor is the subfloor between the basement and the main floor of the house. All windows are single-glazed with exterior storm windows and have average sash fits. The unfinished attic is insulated with 7" of cellulose fill (R-27).

CIRA inputs for recently built electrically heated homes. The recently built electrically heated home representing current Michigan building practices is better insulated and more tightly constructed than the average home. It is wood-framed with 2" X 6"s and has an average of R-16 insulation in the walls. The basement walls, both above and below grade, and the subfloor are insulated with R-11. Windows are doubled-glazed with tight sash fits. The ceiling is insulated with R-38 fiberglass batts. The infiltration rates vary between the new and existing homes because of the tighter construction of the new houses. For the heating season of October through April, the new house has an air exchange rate of .51 air changes per hour (ach) while the average house has a rate of .60 ach. During the cooling season, these rates drop to 0.36 ach for the new house and 0.39 ach for the average house.

Calculation of Baseline Performance: Results

Energy use for space heating. All CIRA simulations are based on full indoor comfort levels and electric heating only. Wood heating and zonal heating are not included in the model runs. With these assumptions, the baseline new construction prototype uses 6124 kWh of electricity annually for space heating. The baseline prototype for the average existing single-family home uses 12,000 kWh for heating. This simulation result agrees reasonably well with the space heat consumption of 11,170 kWh that can be calculated for such a home from the measured consumption data of the RECS data base for the East North Central region (see the Baseline section).* However, as is to be expected, the simulation results are higher than the UECs that the utilities report from their load analyses. The discrepancy, which is a common phenomenon in building simulations, can be explained by a number of factors. Auxiliary heating is obviously important. About one quarter of CP's EHH have wood stoves, and the proportion of wood stoves among single-family homes is likely to be even higher. Zonal heating may also play an important role. Occupant patterns may not follow the modelling assumptions, since observed data are not available. Finally, there are some uncertainties in characterizing "typical" building shell components for the Michigan stock; therefore, the simulation inputs may not be exactly representative of existing homes.

We base our calculations of space heating savings and costs of conserved energy on the heating patterns modeled. If present patterns of partial space comfort and auxiliary heating were to persist after the building has been made more efficient, actual savings would be smaller and the cost of conserved energy higher. The relatively lower CCE can be seen to reflect the consumer welfare benefit from increased comfort. The higher simulation UECs are also informative insofar as they yield savings and cost-effectiveness data at present levels of utilization for buildings that are larger than average, fully electrically heated and intensively utilized, or more poorly insulated.

Portfolio of Conservation Measures

For existing buildings, we used a library of 42 shell retrofits (see Table 6-4). They included weatherstripping, sealing any cracks and holes, installing additional insulation, adding storm windows and doors, installing double- or triple-glazed windows and adding window shading devices. Sixteen other retrofit measures were included that did not apply directly to the building shell. These measures included lowering the space heating and water heater thermostats, installing a low flow showerhead, wrapping the water heater with an R-6 blanket, buying a more efficient refrigerator, and adding a new heat pump water heater. For new buildings, we analyzed eight improvements in new construction practice. These are summarized in Table 6-5. They include triple glazing, subfloor and wall insulation up to R-38, attic insulation to R-49, and effective infiltration reduction combined with an air-to-air heat exchanger.

Measure lifetimes. The lifetimes for the above technologies vary by type of measure, and also depend on the remaining life of the building they are installed in. Some components, such as wall and ceiling insulation, can last as long as the building, provided that they are properly installed and protected from moisture. Tables 6-4 and 6-5 below lists estimated lifetimes and replacement fractions as used in our CIRA building simulations. The replacement fractions are the fraction of the initial capital investment (e.g. for windows) that will have to be reinvested again once the installation has deteriorated and is replaced. This fraction accounts for the fact that the second time around, some retrofits will be easier to do (e.g. modifications to window sashes, sills, etc.).

*For buildings in the RECS data set in this climate region, 50% of the all electricity is used for space heating, 3% for cooling, 20% for hot water and 27% for miscellaneous usage. Consumers Power estimates that space heating accounts for 41 percent of all electricity use in its EHH.

Table 6-4. CIRA Inputs: Retrofit Measures

Building Component	Retrofit Measures	Unit Cost ($) Fixed	Marg.	(units)	Repl.Frac. (%)	Lifetime (years)
Doors	Install interior storm	0	9.50	sqft	100	20
	Install new insulating door	20	7.00	sqft	100	30
	Weatherstrip	10	.90	sqft	25	5
Roof-Ceiling	Install small attic fan	280		each	100	20
	Install large attic fan	380		each	100	20
	Seal largest cracks and holes	30	.10	sqft	100	15
	Seal cracks & holes thoroughly	60	.20	sqft	100	15
	Weatherstrip attic hatch	12		each	100	15
	Add 13" fiberglass insulation R-38	20	.85	sqft	25	20
	Add 6" fiberglass insulation R-19	20	.45	sqft	25	20
	Add 4" fiberglass insulation R-11	20	.30	sqft	25	20
	Add 16" cellulose insulation R-49	0	1.07	sqft	25	20
	Add 11" cellulose insulation R-38	30	.85	sqft	25	20
	Add 8" cellulose insulation R-30	30	.55	sqft	25	20
	Add 5" cellulose insulation R-19	30	.40	sqft	25	20
Subfloor	Seal largest cracks & holes in floor	20	.10	sqft	100	15
	Seal cracks & holes thoroughly	40	.20	sqft	100	15
	Weatherstrip basement door	12		each	100	15
	Put 6" R-11 fiberglass batts under floor	40	.55	sqft	25	20
	Put 4" R-19 fiberglass batts under floor	40	.42	sqft	25	15
	Seal largest cracks & holes in walls	50	.30	perim.	50	10
	Seal cracks & holes in walls thoroughly	50	.60	perim.	50	10
	Frame & ins. with 4" R-11 fiberglass	100	8.75	perim.	100	50
	Frame & ins. with 6" R-19 fiberglass	150	12.95	perim.	100	50
Walls	Seal largest cracks & holes	20	.15	sqft	50	10
	Seal all cracks & holes thoroughly	30	.30	sqft	50	10
	Add 2" insulating sheathing R-10	100	1.40	sqft	100	50
Windows*	Install exterior shutter	125	1.30	sqft	50	15
	Install summer exterior shade	100	1.10	sqft	50	15
	Install winter exterior glass storm	100	10.00	sqft	100	30
	Install winter exterior plastic storm	40	1.20	sqft	100	3
	Double glaze	60	1.80	sqft	100	30
	Triple glaze	60	3.00	sqft	100	30
	Install low emissivity film	25	1.50	sqft	100	9
	Weatherstrip	20	.33	sqft	100	9
	Install winter interior glass storm	53	3.00	sqft	5	20
	Install winter interior plastic storm	40	1.10	sqft	100	3
	Install nighttime R-4 insulation	50	4.80	sqft	25	10
	Install nighttime R-6 insulation	50	7.00	sqft	25	10
	Install nighttime R-8 insulation	50	8.50	sqft	25	10
	Install interior reflective shade	50	.60	sqft	50	10
	Hang inside drapes-close in summer	90	.90	sqft	25	10

*For windows, the fixed cost is per window. We assume four average windows of ca. 9 sq.ft. for each building face. Thus, the fixed cost is applied four times, and to this cost the variable, sq.ft.-based costs are added.

Table 6-5. CIRA Inputs: Improved New Construction Practices					
		Marginal Cost		Replacement	
Component	Improved New Construction Practice	$/unit	(units)	Fraction (%)	Lifetime (years)
Windows	Triple glaze with thermal break frame	1.53	sqft	100	30
Subfloor	Increase insulation from R-11 to R-19	.12	sqft	25	20
	from R-11 to R-30	.30	sqft	25	20
	from R-11 to R-38	.40	sqft	25	20
Walls	Increase insulation from R-19 to R-27	.29	sqft	100	50
	from R-19 to R-38	.68	sqft	100	50
Attic	Increase insulation from R-38 to R-49	.18	sqft	25	20
House	Install vapor barrier and heat exchanger	.09, .69	package*	50	20

* Cost is calculated as $.09/sqft times the surface area of walls, ceiling, and subfloor (4166 sqft.) plus $.69/sqft times the square footage of the house (1540 sqft.).

Costs of Conservation Measures

Technology costs for most building measures show significant local and regional variations. This is due, in part, to the local, decentralized nature of the building contractor's business, whose labor rates reflect local labor markets. We rely on Michigan data when available.

Retrofit costs. Regional cost data for retrofit technologies are available from several sources (Michigan 1986). In this study, we draw primarily on the Michigan Public Service Commission's latest update of its Residential Conservation Service factor file (May 19, 1986). We compared this cost source with the results from a uniquely detailed field study of 320 monitored homes in the Hood River community of the Bonneville Power Administration's service territory. There is reason to believe that the Hood River data are somewhat higher than they would need to be because of the special incentives builders were provided to participate in the demonstration program. Cost data for Michigan were slightly lower for most measures.

It should be noted that for insulation retrofit jobs, the total cost consists of a fixed cost and a variable cost, reflecting, respectively, the fixed charge for bringing equipment and people to the building, and the variable charge for adding variable amounts of insulation.

New construction incremental costs. When conservation measures are incorporated during construction their unit costs are substantially lower than for retrofit application. Again, we used actual field-monitored data, this time from BPA's Residential Standards Demonstration Program (Vine 1986).

The data are derived from monitored builder costs in 395 Model Conservation Standards homes. These data represent the first comprehensive field study of the cost of new building efficiency. We used the BPA costs "as is", though they could probably be adjusted for construction labor rates and material costs in Michigan. Table 6-5 shows the costs of improved construction practices.

Savings and Costs of Conserved Energy

Starting from the baseline prototypes, we calculate the costs and cost-effectiveness of three types of building improvement:

1. the cost of retrofitting average existing EHH;
2. the cost of retrofitting homes that were recently built in compliance with the utilities' minimum insulation requirements; and
3. the cost of improving current construction practice.

The simulation of the two retrofit cases use the cost and lifetime library of Table 6-4, while the improved new construction case uses the library of construction practices as shown in Table 6-5.

Table 6-6 summarizes the results of the CIRA simulation for three categories of electrically heated single-family homes.

Table 6-6. Summary of CIRA EHH Simulations.

Prototype Single-Family House	Baseline		Improved Dwellings			
	UEC (kWh)	UPD Winter 7 PM (kW)	Savings (kWh)	Savings (%)	Cost (1985 $)	CCE (1985 ¢/kWh)
Average Existing	12000	6.187	6000	50	2740	3.27
Recently Built	6100	3.781	1400	23	854	4.63
Improved Construction	6100	3.781	2900	47	3340	5.94

The range of CCEs is 1.2-6.7¢/kWh for existing homes, and 1.9-13.2¢/kWh for new construction. We show in Tables 6-7 to 6-9 the detailed costs of conserved energy for each additional measure in an optimized sequence of retrofits. This allows one to determine the approximate savings that would still be cost-effective against the cost of gas heating at the room register. The Michigan price of gas for residential customers is about 2¢/kWh, and the cost of useful heat at the room register is about 4¢/kWh in a gas-heated home. Since the thermal integrity of both existing and newly built electrically heated homes matches or exceeds that of corresponding average gas-heated homes, the savings found against this 4¢/kWh cost can, on average, also be cost-effectively achieved in gas-heated homes. On that basis, the average existing gas-heated home could be cost- effectively retrofitted against present gas prices to save up to about one third of space heating energy needs if marginal costing is used, and up to 48 percent if the retrofit is treated as a package. Depending on the forecast of gas prices in the future, the entire set of retrofit measures could also become cost-effective at the margin.

The most expensive measure is the heat-exchanger/infiltration-reduction package for improved new construction. The heat exchanger has a CCE of 13.2¢/kWh if the entire ventilation system cost is charged to the energy benefits. Since the major objective for installing such units in new buildings is likely to be indoor air quality, this accounting overstates the actual CCE. The measures other than the heat exchanger have an average CCE of only 4.5 ¢/kWh.

In new construction, all retrofit measures and about three quarters of the new construction measures are cost-effective at the margin against Consumers Power's residential electricity price of 6.8¢/kWh, which has the lower rate among the two major Michigan utilities.

Energy savings per building. The average existing Michigan EHH is far from energy efficient. Its space heating budget can be cut by about 50 percent with an investment of about $2700. The recently built EHH which conform to the utilities' rate requirements are likewise suboptimal. Here, an investment of $850 affords about 23 percent savings. A much larger cost-effective improvement can be achieved in new construction. Here, doing things right the first time allows savings of 47 percent for an increase in building costs of about $3300.

Costs of conserved energy by measure. We use an economic horizon of 30 years and a real discount rate of 3%. Note that in this analysis, CCE is calculated for the stream of investment needed to maintain the savings over 30 years instead of being based on the life of the measure as in the rest of this report. Replacements and maintenance investments are appropriately discounted. Note that the measures listed here are prototypical, and that other combinations of measures could give similar total savings at comparable cost.

For the *average EHH*, the CIRA simulation recommends large improvements in several building shell elements, including adding a total of 8'' of insulation to the existing attic insulation of 8'' (R-27), putting 5.5'' fiberglass batts under the basement subfloor. Weatherstripping and caulking is also cost-effective, and so is installing nighttime insulation. First costs and CCEs by measure are shown in Table 6-7.

Table 6-7. Retrofit Potential: MEOS Average Single-Family House

Baseline Conditions: Initial Space Heat Use=12013 kWh

Retrofit Description	Name & Location	% Change in Heating	Initial Cost	CCE ¢/kWh
Seal wall cracks & holes thor'ly	Subfloor	-5.6	$148.40	1.21
Weatherstrip attic hatch	Roof-ceiling	-0.5	$12.00	1.67
Put 5.5'' fiberglass batts und. floor	Subfloor	-24.5	$887.00	2.52
Install new insulating door	Garage/inside door	-1.8	$160.00	3.78
Install 5'' of cellulose	Roof-ceiling	-6.8	$646.00	4.35
Seal largest cracks and holes	N. garage wall	-.6	$41.00	4.79
Install nighttime R-4 insulation	Patio door	-4.3	$430.40	5.63
Seal largest cracks and holes	S. Wall	-.8	$73.03	6.39
Install 3'' more cellulose insulation	Roof-ceiling	-1.6	$231.00	6.62
Seal largest cracks and holes	E. Wall	-.5	$47.83	6.70
Seal largest cracks and holes	W. Wall	-.5	$47.83	6.70
TOTAL		-48.0	$2736.49	3.27

In *recently built EHH*, some weatherstripping is still cost-effective, and attic insulation is worth increasing by 5" of cellulose. The CIRA simulation also recommended installing nighttime insulation in all windows and the patio door of the new house. The initial costs and range of CCEs for full and partial utilization is shown in Table 6-8.

Table 6-8. Retrofit Potential: MEOS Recently Built Single-Family House

Baseline Conditions:	Initial Space Heat Use=6124 kWh			
Retrofit Description	Name & Location	% Change in Heating	Initial Cost	CCE ¢/kWh
Weatherstrip attic hatch	Roof-ceiling	-1.2	$12.00	1.37
Seal wall cracks & holes thor'ly	Basement walls	-9.8	$148.40	2.08
Seal largest cracks and holes	N. garage wall	-.9	$41.00	6.26
Install nighttime R-4 insulation	Patio door	-7.1	$430.40	6.69
Seal largest cracks and holes	S. Wall	-1.3	$73.03	7.72
Seal largest cracks and holes	N. no garage wall	-.9	$53.22	8.12
Seal largest cracks and holes	E. Wall	-.8	$47.83	8.21
Seal largest cracks and holes	W. Wall	-.8	$47.83	8.21
TOTAL		-22.8	$853.71	4.63

New construction practice should incorporate the most extensive efficiency improvements including R-49 ceilings, R-38 walls, and triple-glazed windows to achieve comfort at minimal life cycle cost. Table 6-9 shows the first costs and range of CCEs for full and partial utilization of the new building. Note that the total investment cost for these improvements is dominated by the air-to-air heat exchanger. This cost allocation of the entire mechanical ventilation investment to energy benefits alone is conservative. The major portion of this extra cost could arguably be assigned to environmental health and indoor air quality benefits.

Note that both the selection of cost-effective measures and the costs of conserved energy are only illustrative of the likely average costs and savings in a large retrofit program and cannot be used to evaluate individual homes unless they closely match the simulated building. An audit-based evaluation would likely produce substantial variations in the cost-effectiveness or applicability of particular measures. However, the prototype simulations reasonably capture the savings that various combinations of measures in various kinds of homes would produce on average, and indicate the average range of CCEs in the measure portfolio.

Table 6-9. Conservation Potential of Improved New Construction Practices: MEOS New House				
Baseline Conditions:	Initial Space Heat Use=6124 kWh			
Retrofit Description	Name & Location	% Change in Heating	Initial Cost	CCE ¢/kWh
Triple glaze with thermal break frame	N. Window	-2.6	$58.90	1.89
Increase subfloor insulation from R-11 to R-19	Subfloor	-6.6	$184.80	2.33
Triple glaze with thermal break frame	E. Window	-2.4	$58.90	2.04
Triple glaze with thermal break frame	W. Window	-2.4	$58.90	2.04
Triple glaze with thermal break frame	Patio door	-2.7	$73.44	2.27
Triple glaze with thermal break frame	S. Window	-2.0	$58.90	2.45
Increase wall insulation from R-19 to R-27	N. Wall	-1.2	$64.24	4.46
Increase wall insulation from R-19 to R-27	E. Wall	-1.0	$53.79	4.48
Increase wall insulation from R-19 to R-27	W. Wall	-1.0	$53.79	4.48
Increase wall insulation from R-19 to R-27	S. Wall	-1.9	$102.51	4.49
Increase subfloor insulation from R-19 to R-30	Subfloor	-4.4	$277.20	5.25
Increase wall insulation from R-19 to R-27	Gar. Wall	-0.6	$40.60	5.64
Increase subfloor insulation from R-30 to R-38	Subfloor	-1.9	$154.00	5.75
Increase attic insulation from R-38 to R-49	Attic	-3.4	$277.20	6.79
Increase wall insulation from R-27 to R-38	N. Wall	-0.8	$86.39	9.00
Increase wall insulation from R-27 to R-38	W. Wall	-0.7	$72.35	8.61
Increase wall insulation from R-27 to R-38	E. Wall	-0.7	$72.35	8.61
Increase wall insulation from R-27 to R-38	S. Wall	-1.3	$137.87	8.84
Increase wall insulation from R-27 to R-38	Gar. Wall	-0.4	$54.60	11.37
Add vapor barrier and heat exchanger	House	-8.8	$1398.72	13.24
TOTAL		-46.8	$3339.45	5.94

IMPLEMENTATION PROGRAMS

Residential weatherization and conservation programs have been conducted by state governments, communities, and utilities in most regions of the U.S. since the early 1980s. They range from the provision of audits under the Federal Residential Conservation Service (RCS) program to loan subsidies and grant and rebate programs. A number of these programs have been subjected to thorough evaluations regarding their effectiveness in bringing about predictable and persistent energy savings. We draw in our discussion on a recent review of both U.S. and foreign evaluation results (Stern et al. 1986). We also take into account the Michigan RCS experience (Kushler and Witte 1985), and experience with unique programs in the Bonneville Power Administration region and in Santa Monica, California, to illustrate the range of options for future implementation in Michigan.

Participation Rates

The key aspects of weatherization retrofit programs in terms of demand-side resource mobilization are the *participation rate* (the percentage of eligible customers participating per year) and the *intensity of participation* as reflected in the scope of efficiency improvements and investments undertaken by the participant. In most U.S. programs, financial incentives are subject to a prior energy audit of the customer's home. This audit, which is provided free of charge, is usually seen as a tool to avoid waste and steer customer investments toward the most cost-effective measures, or toward the measures most beneficial to the utility's demand-side management objectives. In this common U.S. approach, participation in grant and rebate programs is conditional on participation in the audit process. Though audits induce some energy conservation on their own, this service is more cost-effective if it leads to significant investments under a related incentives program. In traditional weatherization programs, the rate of participation in incentives programs has been found to be significantly lower than audit participation rates. Some programs have, however, succeeded in inducing most audited customers to make efficiency investments.

We summarize some of the available experience on potential participation rates and responses to incentives in the following "lessons learned":

- Participation cannot be predicted solely on the basis of the size of the financial incentive. Larger incentives alone do not seem to induce households to become interested in a conservation program. For identical (and large) financial incentives, participation rates can vary by a factor of ten.

- Participation rates are strongly dependent on the method of contacting customers, on the reputation and motives of sponsors, and on the program's marketing and promotion. People are attracted most to programs run by local community groups or other organizations they trust (e.g., a local utility with a good service record and reputation). Canvassing, word-of-mouth and other ways of spreading information are effective in raising participation.

- Once customer contact with the program has been effectively established, the size of the incentive does have an impact on participation.

- The form of the incentive has different effects on different customer groups. Available experience suggests that low-income homeowners prefer grants or rebates, while households with higher incomes prefer loans. Offering a choice in the form of incentives (loans versus grants versus rebates) should be most effective in overcoming participation barriers related to such preferences.

- Low-income households can be reached with conservation programs if strong grant or rebate incentives are provided and if an aggressive outreach and marketing approach is pursued, preferably by existing community groups that are trusted by low-income people.

- Rates of participation usually increase over the first two to three years of a program, reflecting a learning curve.

Below we explore what participation rates could be achieved by an *aggressive* audit and/or incentives-based residential conservation program.

Range of participation rates in large-scale incentives programs. From national and international experience, annual participation rates range from less than 1 percent for the most ineptly designed programs to more than 10 percent for well-designed and well-managed efforts (Stern et al. 1986).

Participation rates in Michigan. As of January 1986, 650,000 homes had received an RCS audit. This represents a cumulative participation of 18.6 percent of Michigan's 3.5 million year-round housing units, or an annual participation rate of 3.7 percent. Michigan has also operated low-income weatherization programs under various auspices since 1974. Total participation under these programs has been just over 100,000 households (Kushler and Witte 1986).

Maximum participation rates. For audit programs, the maximum participation rate reported in the U.S. is 33-35 percent for the Santa Monica program (see below). Some utilities in the Bonneville Power Administrations Interim Residential Weatherization Program also achieved above-average rates, ranging from 9 to 23 percent per year. A typical value for the traditional RCS program is 5 percent per year. For audit-based incentive programs, the highest participation rate has been achieved in the Hood River County (Oregon) project, a $21 million demonstration program of the Bonneville Power Administration. In this county of 15,000 people, 95 percent of all electrically heated dwellings were retrofitted between 1983 and 1985, including most low-income households.

The average cost at which conservation resources were purchased from Hood River customers was only 69¢/kWh (Hirst et al. 1986). The retrofit investments averaged $3760 per household, while measured savings were 6140 kWh/year. The estimated cost of conserved energy of the program was 3¢/kWh (3 percent discount rate). Project personnel see the careful preparation of the community outreach program as key to this success. Without this element, they feel that the full grant incentive would not have yielded nearly as great a response. The involvement of respected long-time community residents was obtained, and basic community values such as attitudes toward intervention by government institutions and utilities were researched.

This very high participation rate at the demonstration level in a small community cannot be automatically transferred to large-scale programs that may cover entire metropolitan areas or states. Reproducing this success at a larger scale requires replicating the community outreach element in appropriate forms at the urban and suburban neighborhood level, as well as using other effective outreach mechanisms based on large-scale trade ally cooperation. One such mechanism is to rely on installer contractors to canvass neighborhoods and solicit customers on their own. Installers are motivated to find themselves retrofit business with predictable risks and costs, while utilities can limit their involvement to inspection and verification of building measurements. Several utilities, including Southern California Edison, discovered this approach inadvertently after setting rebates at levels close to the full cost of the retrofit measures, thereby making it worthwhile for the contractors to aggressively seek out new customers.

Another approach, which has been widely used in Europe and was recently successfully introduced by PG&E for small commercial customers, is to drop the audit requirement for receiving incentives. PG&E apparently achieved a 9 percent annual participation rate. Though audits can be instrumental in steering customers toward investments that the utility defines as most cost-effective (Hirst et al. 1986) it is not clear whether more energy is being saved with them than would be without them. The omission of the audit requirement allows participants to choose the conservation investments they are most interested in, is singularly unbureaucratic, and avoids the resistance of people to letting representatives of a utility or government agency inspect their private homes.

On the other hand, experience in the FRG with this laisser faire approach has been less positive. Here, building owners often retrofitted double-glazed, tightly weatherstripped windows into existing uninsulated masonry walls, while at the same time turning down thermostats. In many cases, water vapor that used to escape through leaky windows or condense on the panes was now increasingly condensed in the walls, leading to condensation damage.

An intermediate approach is to develop standard cost-effectiveness estimates for the major categories of the building stock and limit the audit to an assignment of each customer's dwelling to the appropriate building category. This approach was successfully used in the Santa Monica program (see below).

Impact of form of incentive. Available data suggest that rebates or grants are the most effective form of incentive, generating participation rates two to seven times higher than zero-interest or partial subsidy loans.

Participation among low-income households. Both audit and incentives programs have historically achieved very low participation rates among low-income households, renters, and senior citizens. A number of programs have demonstrated that with appropriate outreach efforts, low-income households can be brought to participate at the same or higher rate than other customers. Zero-interest loans are usually very ineffective, and partial grants are also a weak incentive if substantial additional investments have to be borne by low-income participants. Full grants and an aggressive outreach program with sponsorship from credible community groups are the best way to ensure a strong response among the economically and socially disadvantaged.

An example that illustrates this point very well is the Energy Fitness Program of the city of Santa Monica, California (Egel 1986). All households were eligible under this audit program, whether renters, owners, living in multi-family or single-family homes, or using gas, electricity, or other heating fuels. Participation was solicited with door-to-door canvassing after two previous written notifications. During the audit, the auditors provided and installed, free of charge, up to three of five measures including a water heater wrap, energy-efficient shower heads, faucet aerators, water heater pipe insulation, and doorsweep weatherstripping.

This innovative delivery technique resulted in a 33-35 percent annual participation rate, as compared to the typical 5 percent found in traditional RCS programs. Moreover, the participation of low-income and minority group reached 60-70 percent of their population share while renters matched their share and senior citizens exceeded their representation by 50 percent. It should also be noted that in many of the more successful programs, the annual participation rate has been constrained by limited utility budgets for the program. As a result, program funds were exhausted earlier than expected, while a significant demand for audits and rebates remained unsatisfied.

Actual versus Predicted Savings

A thorough comparison of audit-predicted and actual energy savings based on billing records has been conducted for the BPA weatherization program (Hirst et al. 1983). This study examined several hundred participant households in geographic areas with 5000 to 7700 HDD that invested an average of $2100 in audit-recommended retrofits (up to $6700). They saved on average 6200 kWh/year or 27 percent of their electricity use. The average cost of conserved energy was 2.5¢/kWh (3 percent discount rate). The median ratio of actual-to-predicted saving was 0.66. The ratio showed a large variation, which could be correlated mainly to the severity of the winter and to the intensity of participation (amount of investment). The more severe the winter, and the greater the retrofit investment, the higher the ratio of actual-to-predicted savings.

Persistence of savings. Only a limited number of investigations into the persistence of savings is available. Participants in weatherization programs in Michigan and elsewhere have been found to further reduce their energy consumption one to three years after program participation, presumably because they installed additional measures (Hirst et al. 1986b). On the other hand, a certain amount of *buy-back* (as much as 20%) has been observed for some customers who increased their comfort or intensity of heating service after participation. For example, people who used to burn a lot of wood before investing in shell efficiency may rely more on utility-supplied energy after their house has been insulated.

Gross versus net savings. Gross savings refer to the savings per household when compared to the pre-retrofit consumption of the dwelling. Net savings refer to the savings relative to a non-participant control group that may have changed their space heating energy usage on their own. Note, however, that this distinction can be blurred by the spill-over effect of weatherization programs on non-participants who follow the example of participants independently. In the BPA program, net savings were lower than gross savings and also declined over time because electricity prices had risen sharply and motivated non-participant households to insulate their homes (Hirst et al. 1986b). In Michigan's low-income program, net savings exceeded gross savings (Kushler and Witte 1985). In the current study, gross and net savings are calculated by subtracting the technical potential and standards/incentives scenario (see below) from the MEOS forecast.

Program Costs

Range of incentive levels. Historically, a wide range of incentives have been offered, ranging from less than ten to 100 percent of retrofit costs. Some utilities offer rebates or grants for close to the full cost of the retrofit. The cost limit set by the program is as important as the percent reimbursement in determining participation rates. The Hood River project provided 100 percent of costs for retrofits than were significantly more extensive than those in BPA's other programs (for example, R-49 ceiling insulation). The incentive was in the form of a grant covering costs up to $1.15/kWh (first-year) saved. This cost-effectiveness limit was about four times as high as the $0.28-0.32/kWh (first year) limit used in BPA's region-wide weatherization program.

Administrative costs of audits and incentives programs. The costs of audits typically range from $50 to $200 per household, depending on the organization that carries it out. Utility staff tend to be most costly, followed by private subcontractors, and then by community groups. The latter can reduce audit costs by as much as a factor of three, while greatly increasing the participation rate and delivering the highest quality service.

Audit programs that achieve high participation rates and effective low-income outreach do not necessarily cost more per audit than more traditional, much less successful approaches. For example, the Santa Monica program achieved one of the lowest reported audit costs per household ($54) while delivering one of the highest participation rates. With administration, training, promotion, and free conservation devices, the cost of the Santa Monica program was $87 per participant.

In incentives programs, the costs of audits can be a substantial portion of the total program cost. This is particularly true when the audits do not induce high rates of investment among audit participants. In many incentives programs, it takes ten audits or more to induce one customer to make a retrofit investment. This lack of participation can easily double the cost of the incentive. The omission of the audit requirement may therefore have the double benefit of substantially reducing program cost and increasing participation rates through unbureaucratic delivery.

The cost of administration (including inspections, rent, clerical staff, transportation, etc.) in Michigan has been reported as $580 per household for the low-income program of the Bureau of Community Services (Kushler and Witte 1986). In the most aggressive audit-based incentive program to date, the Hood River Demonstration project, administration costs were $435 per household or 10 percent of total costs (including the audit but excluding the extensive one-time evaluation research associated with the project, see Hirst et al. 1986c). This percentage figure matches experience of well-run programs elsewhere. Because of the high incentives paid ($3700 compared to a typical range of $1500 to $2500 in other programs), the absolute Hood River costs are, of course, larger.

Building Energy Standards

Currently, no state energy standards are in effect or planned to be introduced in Michigan. The State of Michigan Construction Code Commission uses the ASHRAE 90-80A standards as a minimum requirement for current new construction. For existing buildings, retrofit ordinances have been established in many parts of the country at a local level, and state-wide implementation of such ordinances has been proposed in at least one state. No state-wide initiatives of this sort are in effect in Michigan. For newly constructed electrically heated homes, utilities have had minimum insulation requirements since 1978 (see Baseline section).

Building energy standards are the most cost-effective method for bringing about significant improvements in building energy efficiency. The state of California spent a staff effort of thirteen years and roughly $500,000 in contracts to establish its residential standards. The state sees the need for an additional effort to complement the standard's point system, which provides flexibility for the builder, with a home energy rating system for homeowners. This homeowner-oriented part of standards is seen as important to establish a market for energy-efficient housing, and thus diffuse builder opposition over the cost of complying with the standards. The California Energy Commission estimates that each dollar spent by the state on developing these standards generates about $3,000 in benefits.

TECHNICAL AND ACHIEVABLE POTENTIAL

General

Turnover of housing stock. We use an average life of 50 years for Michigan's residential dwellings, or a linear 2 percent annual replacement rate. Between 1985 and 2005, some 40 percent of the building stock will have been replaced by new construction.

Behavior function. We take into account several opposing trends: a reduction of space heating needs related to the demographic change toward smaller household size; the possibility of further program-induced conservation actions after the original retrofit; and the possibility of a partial buy-back of conservation benefits in the form of higher comfort levels following participation. These trends are assumed to cancel each other.

We also derate the savings from retrofits and new building standards as calculated by CIRA in proportion to the ratio between utility UECs and simulated UECs. This avoids overestimating savings from existing buildings. In tight new electrically heated buildings, which may be more intensively utilized than leaky existing ones, this procedure is likely to underestimate actual savings.

Eligible fraction. For new construction, eligibility for the package of improvements in Table 6-9 is 100 percent. All but 20 percent of existing EHH are considered eligible for retrofits. These 20 percent are a proxy for dwellings where special structural or other features make retrofits uneconomic or inapplicable. They include many multi-family homes and dwellings that have been extensively retrofitted in previous years.

It should be noted that retrofit measures applied under Michigan's past RCS and low-income programs were of a very limited nature. Gas-heated households that were audited in 1981 invested an average of $575 within two years after the audit, about $200 more than non-audited households. 34 percent of audited households installed some ceiling insulation compared to 28 percent of non-audited households. Only about 9-10 percent invested in other measures such as clock thermostats, wall insulation, and basement wall insulation. The state's Low-Income Home Weatherization Service conducted by the Bureau of Community Services of the Michigan Department of Labor was limited to caulking and weatherstripping, ceiling insulation up to R-33, storm windows, and floor perimeter insulation. The average expenditure per home was $913, and space heat fuel savings were 14.7 percent. Electrically heated homes are likely to have been underrepresented among participating households in this program.

Treatment of multifamily homes. We treat the potential for shell improvements in multifamily homes as proportional to that in single-family homes. Savings in absolute terms are lower by the 2:1 ratio of single-family and multi-family UECs. The eligible fraction of 0.8 mainly reflects the greater economic and other obstacles to multi-family building retrofits.

Technical Potential Scenario

In the technical potential case, all existing and eligible electrically heated homes are retrofitted within three years. The consumption of these EHH drops to half of the average electricity for space heat observed in the base year (Table 6-6).* We do not distinguish between pre-1978 and post-1978 homes (the year when utility insulation requirements were introduced). For new construction, we assume that a new building standard will go into effect in 1988 and will reduce the new construction UEC by 40 percent below the baseline of Table 6-6.

Results.

By 2005, the technical potential scenario results in annual energy savings of 43 percent (619 GWh) over the MEOS forecast. Disaggregated results for the Consumers Power and Detroit Edison territories are displayed in Appendix A, Tables H-CPA and H-DEA.

Standards/Incentives Scenario

In this scenario, existing buildings are improved in a well-designed retrofit program with strong outreach and marketing efforts and a good inspection program. The participation rate is ten percent per year, leading to the retrofit of 80 percent of all eligible homes by 1998 (within eight years after a two-year pilot phase). This program will pay approximately the full cost of the retrofits up to the retrofit levels of Table 6-6. Twenty percent of eligible customers are assumed unreachable by the program despite strong incentives. These customers include people who plan to move, don't like to interact with utility programs on principle, or belong to groups that are particularly hard to reach, such as renters, multi-family residents, and low-income people.

We further assume that retrofits will achieve actual savings of 80 percent of the CIRA-predicted percent savings for the average existing home shown in Table 6-6, which is equivalent to a 40 percent savings over baseline consumption. This actual-to-predicted savings ratio of 80 percent is somewhat higher than the 66 percent ratio found in BPA's weatherization program. The same BPA program found that the ratio of actual-to-predicted savings increases with the size of the retrofit investment. Since the average retrofit investment in Michigan's EHH would be about $3200 compared to $2100 in the BPA program, we use a higher figure. For new construction, the scenario introduces a tighter building standard or utility electric space heating rate requirement in 1990. Savings are 40 percent and compliance is 95 percent.

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* The definition of this scenario potential is not strictly a technical potential because it is limited to the percentage savings as shown in Table 6-6. These savings are based on a portfolio of measures that has been prescreened for highest cost-effectiveness.

Results. Yearly savings from the program scenario are 481 GWh, or 34 percent of the MEOS predicted consumption.

IMPACT ON UTILITY SYSTEM

Tighter houses bring with them a substantial reduction in winter peak load. This reduction is not fully proportional to the reductions in UEC since savings are relatively larger in the shoulder period than in mid-winter. Within the context of the present analysis, we neglected this correction and show megawatt savings in direct proportion to reductions in UECs.

CUMULATIVE INVESTMENT AND PROGRAM COSTS

We use the investment costs as calculated in Tables 6-6 through 6-9. For new construction, we assume program costs of $2 million to establish state-wide standards that go beyond the current utility or ASHRAE-90 norms, plus a $100,000 per year enforcement cost. The latter cost also covers continuing efforts to create a housing efficiency market in Michigan and to monitor the performance of new homes in field experiments. These costs could easily be shared between savings in gas-heated homes and in electrically heated homes.

For existing homes, the cost of achieving 80 percent of predicted savings, as assumed in the scenario, is 90 percent of the cost shown in Table 6-6, or $2900 in round numbers. Program administration is assumed to be 10 percent of the total or $300 per home. The cost including program administration is $3,200.

For new homes, we calculate the cost of establishing and enforcing a tighter building standard.

Results. From 1984 to 2005, cumulative costs to ratepayers for the program scenario are $146 million, with $47 million being borne by Detroit Edison customers, and $99 million by those in the Consumers Power territory.

LBL 1985: *Affordable Housing Through Energy Conservation: A Guide to Designing and Constructing Energy Efficient Homes*, Technical Support Document for Building Energy Performance Standards, Lawrence Berkeley Laboratory, July.

Michigan 1986: "RCS Factor File," Michigan Public Service Commission, May 15 - Nov. 15.

NAHB 1986: "Selected Characteristics of New Single Family Detached Units: Michigan - 1984," NAHB Research Foundation, Inc., August 15, 1986.

RECS 1984: "Residential Energy Consumption and Expenditures by End-Use for 1978, 1980, and 1981," Residential Energy Consumption Survey, Energy Information Administration, Washington, DC, DOE/EIA-0458.

Stern, P.C., E. Aronson, J.M. Darley, D.H. Hill, E. Hirst, W. Kempton, T.J. Wilbanks 1986: "The Effectiveness of Incentives for Residential Energy Conservation," *Evaluation Review*, Vol. 10, #2, pp.147-76, April.

Vine, E. 1986: "The Residential Standards Demonstration Program: Cost Analysis," Lawrence Berkeley Laboratory, Berkeley, CA, report # LBL-21318, May.

FLOOR PLAN AND ELEVATION OF 1-STORY RANCH HOUSE

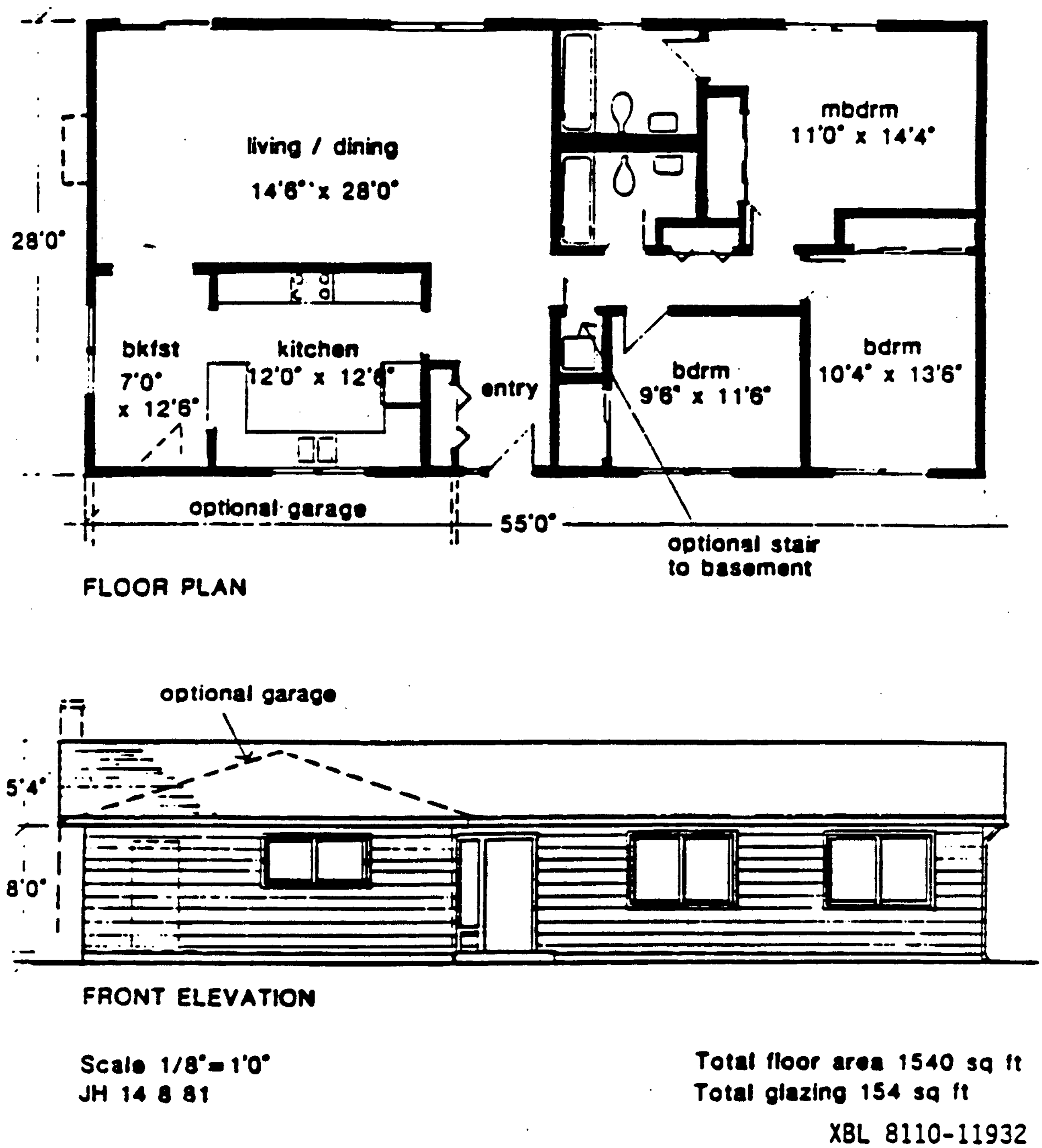

Figure 6-1

7. HEAT PUMPS: DEMAND-SIDE MEASURE DATA BASE

END-USE:	Space Heating
FUEL:	Electricity
TECHNOLOGY:	Improve space-heating equipment efficiency
DEMAND-SIDE MEASURE:	Replace resistance heating with heat pumps
IMPACT OF MEASURE:	Energy savings during shoulder months of heating season; peak demand savings in shoulder months of heating season only; increase in energy consumption and peak demand in summer months in buildings where air conditioning is not already installed.

GENERAL DESCRIPTION

Technology Features

A heat pump provides heating and cooling by pumping heat from a cooler to a warmer location. In the heating mode, a heat pump operates exactly like an air conditioner in reverse. A heat pump can absorb heat from the air, water, or the ground. Electric heat pumps have a higher efficiency than electric resistance heating, since they utilize the heat in the ambient environment surrounding the space to be heated. The efficiency of the heat pump increases with a decreasing temperature difference between the heated or cooled space and the outdoor environment.

Heat pump types. Most residential heat pumps installed in the U.S. are air-to-air units, very similar to residential air conditioners (see section on air conditioning), with the added feature of a reversing valve that allows the unit to run in the heating mode (absorbing heat from the outdoor air and pumping it in the space, rather than absorbing heat from the space and pumping it outside). These heat pumps can be classified into four types (EPRI/NRECA 1985):

1. Room and packaged terminal heat pumps, requiring no air ducts. Capacity range: 5,000 to 20,000 Btuh heating, 6,000 to 24,000 Btuh cooling.
2. Central, single-package heat pumps. Capacity range: 18,000 to 120,000 Btuh heating and cooling.
3. Central, split-system heat pumps (generally the most common type of heat pump installed in the U.S.). Capacity range: 12,000 to 60,000 Btuh heating and cooling.
4. Multi-zone heat pumps (multiple indoor air-handling units). One or more zones may be turned off while others are heated or cooled.

Under colder winter conditions (typically less than 20°F) air-source heat pumps start to switch over to an auxiliary heating system, usually electric resistance. Under these conditions, performance deteriorates until ultimately only the electric resistance unit is in operation, offering no savings compared to a resistance system. Savings are strongly dependent on local climate conditions. (So-called "add-on" heat pumps can be installed in gas-heated homes, using gas as the auxiliary system. Such systems are not considered in our analysis.)

Several other types of heat pumps are on the market today, and although not as frequently installed, offer advantages in terms of efficiency and availability during longer periods of the heating season. These are only mentioned here; our performance and cost analysis considers only air-to-air electric heat pumps.

Water and ground source heat pumps absorb heat from the ground or water, reducing diurnal and seasonal temperature differences, improving performance during colder periods.

Gas-fired heat pumps, either engine-driven or absorption cycle, have fuel costs and generally operating costs lower than electric heat pumps.

Advanced electric heat pumps, utilizing techniques such as variable-speed control or non-azeotropic refrigerant mixtures, improve performance over the range of heat pump operating conditions.

Heat pump performance. Heat pumps with cooling capacities of 65,000 Btuh or less must be tested and rated in accordance with ARI-established rating procedures. Seasonal performance is rated in terms of Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER). Both HSPF and SEER vary according to building heating and cooling loads, respectively, and outdoor air temperature distribution.

Technology Status and Availability

After the first two oil price shocks, sales of heat pumps in the United States increased dramatically. Installation has been most popular in the Southeast, where a mild winter climate results in a relatively high heat pump performance during the winter, and a summer cooling load allows one piece of equipment to fulfill both heating and cooling needs.

Heat pumps in Michigan. In Michigan, electric heat pumps are becoming more popular in all-electric homes, although state-wide saturations remain small. Consumer Power's residential survey reports that 1.1% of their electric customers (13,000 customers) now use heat pumps for heating. Detroit Edison reports that 1.6% of their 1.6 million customers have heat pumps (16,000 customers, all in single family houses).

Performance of available equipment. A recently-completed study at Texas A&M University evaluated potential efficiency improvements in residential air-to-air heat pumps. The study established "baseline" heat pump performance levels, based on units "typical of the lower efficiency and lower priced units sold in 1985," HSPF 6.50 (SEER 7.05) for a 3-ton split system and HSPF 5.99 (SEER 6.91) for a 5-ton package unit. The study also reported that the best available heat pumps sold in 1985 had HSPFs ranging from 8.75 for a 3-ton split system to 6.8 for a 5-ton package unit (ESL 1986). The most energy-efficient heat pumps available on the market in 1986 have an HSPF of 8.85 (ACEEE 1986).

For heat pumps, the HSPF is used primarily for comparing seasonal performance across units, and cannot easily be used to calculate a UEC, since actual heat pump performance will vary considerably according to local climate conditions. Both DE and CP performed submetering studies on heat pumps in the late seventies, showing heat pump HSPFs of about 5.5 (DE 1979) and 5.1 (CP 1978) for homes in their service territories. Using these results, we estimate HSPFs for heat pumps operating in Michigan to be about 10% less than the HSPFs resulting from the ARI standard testing procedure.*

*On the basis of historic shipment-weighted averages for national sales (given at rating points of 47 and 17°F), heat pump performance has improved by about 5% between 1982 and 1985. From ARI statistics, the 1982 shipment-weighted average COP (single package and split-system heat pumps) was 2.64 at 47°F, and 1.85 at 17°F. In 1985, these COPs increased to 2.76 at 47°F, and 1.90 at 17°F (ARI 1986). We assume the same increase for the period 1978-1982, for a 10% improvement in HSPF since the submetering studies were performed. Therefore, the 5.3 measured HSPF in Michigan would correspond to a 5.8 HSPF in 1985, 10% less than the baseline HSPF of 6.5 in the Texas study.

Special problems and limitations.

1. System sizing. Heat pump sizing is a trade off between first cost and operating costs. A larger capacity unit will cost more, but will provide better performance at lower temperatures, with more of the annual heating load met by the heat pump and less by the auxiliary system. Further, in colder climates like Michigan, the heating load will require installation of a heat pump that is oversized for air conditioning in the summer by as much as 35% (EPRI/NRECA 1985). This means that the customer pays for a larger air conditioner than he would normally buy, in addition to the incremental cost of the heat pump over a cooling-only unit.

2. Peak demand considerations. On the coldest days of the heating season, the heat pump heating system will operate almost exclusively on auxiliary power. Energy consumption and power demand will be identical to an electric resistance system, so one would expect little or no reduction in peak power with heat pumps.

3. Air conditioning benefits. In new construction, heat pumps are economically attractive opportunities as they provide both heating and cooling, potentially reducing first costs, as one piece of equipment takes the place of two. For customers that already have air conditioning, installing a heat pump can be an excellent opportunity when the existing air conditioner needs to be replaced. In some cases, however, the heat pump may provide cooling that otherwise would not have been installed at all. Of course, this increases the customer's comfort and summer bill as well as the summer load on the utility.

Secondary energy impacts. At the present time, heat pump SEERs are lagging slightly behind Seeers of cooling-only units. In cases where a heat pump is installed to provide both heating and cooling, cooling season energy consumption will increase slightly.

Measure lifetimes. Estimates of heat pump service life vary according to source. A recent survey by ARI of its members indicated that the average life expectancy of air-source heat pumps is 14.28 years (Indoor Comfort News, February 1985). A recent EPRI study found that for a sample of heat pumps installed in Atlanta, the median replacement age was 20 years (ASHRAE 1985). We have used a 15 year lifetime for our cost of conserved energy calculations.

Appliance Standards

The "consensus" national appliance efficiency standards recently passed by the U.S. Congress include heat pumps, specifying an SEER of 10.0 for split systems, and an SEER of 9.7 for package units (starting in 1992). Standards for HSPFs were not specified, and are in fact difficult to estimate based on SEER. As shown in the Texas A&M study, there is considerable variation in HSPF for a given SEER across heat pump types and manufacturers. In our analysis, therefore, we have chosen performance levels based on available HSPF data only, and not on proposed standard levels.

COST AND PERFORMANCE IMPACTS

Determination of energy savings. We circumscribe the economics of heat pumps in Michigan by calculating the cost of conserved energy (CCE) for four applications. These are:

1. Existing electrically-heated home of average thermal integrity.
2. Existing electrically-heated home of improved thermal integrity.

3. New home with thermal integrity typical of current construction practice.
4. New high-efficiency home, or "best" new construction practice. For existing electrically-heated homes, we evaluate replacement of resistance heating only (heating-only heat pump), and replacement of both resistance heating and central air conditioning with a heat pump. For new homes, we evaluated the heat pump as an alternative to resistance heating or a gas-fired furnace, and as an alternative to electric resistance or gas heating combined with central air conditioning. As further parametric tests, we distinguish between fully utilized shells and heating systems (based on our simulation runs) and the partial levels of utilization observed in DE's and CP's average electrically-heated homes (see baseline data section on space heating).

Finally, we evaluate the impact of different levels of heat pump HSPF and associated costs on the economics of heat pumps in Michigan. Input data for our analysis are summarized in Tables 7-1, 7-2 and 7-3. We describe major assumptions below.

Baseline UECs. For our savings calculations, we have used baseline UECs for electric resistance heating systems in Michigan as given in the baseline data section for space heating, and have assumed a HSPF of 1.0 for these systems. These UECs are summarized in Table 7-1.

Table 7-1. Baseline UECs (kWh/yr): Electrically Heated, Single Family Homes

	Average Existing	Improved Existing	Average New Construction	Best New Construction
Full Utilization	12,600	6,000	7,600	4,560
Partial Utilization, Detroit Edison	9,000	4,300	5,400	3,300
Partial Utilization, Consumers' Power	6,000	3,000	3,700	2,200

Efficiency levels. We have considered 4 performance levels, summarized in Table 7-2:

1. Baseline performance, based on lower efficiency and lower priced units sold in 1985 (widely available today with current technology);
2. Best level of performance available on today's market;
3. Engineering estimate of performance with "conventional improvements" available in the near future, as determined in the Texas A&M study. These improvements include: increased heat exchanger surface area, improved heat transfer coefficient, decreased compressor size, increased combined fan and motor efficiency, demand defrost control systems, and high efficiency compressors.
4. Engineering estimate of "technically achievable" performance (costs speculative, the "best case"), with improvements including variable speed and scroll compressors, variable speed fan motors, and electronic expansion valves. The Texas A&M study estimated a technically achievable HSPF for an air-to-air electric heat pump of 11.5, and manufacturers are reporting introduction of heat pumps with HSPFs of 11.0 in 1987 (ESL 1986).

Table 7-2 also includes our estimate of equivalent HSPF for the Michigan area, based on a 10% reduction, as well as the corresponding SEER (ARI standard rating procedure).

Table 7-2. Heat Pump Heating Seasonal Performance Factors (HSPF) and Seasonal Energy Efficiency Ratios (SEER)

Heat Pump Technology	HSPF ARI Test Procedure	HSPF Adjusted for Michigan	SEER ARI Test Procedure
Baseline	6.50	5.85	7.05
1986 Best Available	8.85	7.97	11.20
With Conventional Improvements	9.64	8.68	14.98
Technically Achievable	11.50	10.35	17.80

Equipment sizing and installation costs. Heat pump size and cost assumptions used in our analysis are summarized in Table 7-3. For "average existing" construction, we have estimated that a 5-ton (cooling) unit will be required, due to a higher heating load, resulting in a system that is oversized for cooling. For both the improved existing shell and current construction practice, we estimate a 3-ton unit is required. The considerably improved building shell in our "best new construction" case allows for further downsizing of the system, to 2 1/2 tons. In all cases, the heat pump will require auxiliary heating (electric resistance) during the coldest winter periods. All heat pump installed costs used in our analysis are based on data compiled by EPRI for its *Heat Pump Manual*, giving average installed costs in 1985, based on *Means Mechanical Cost Data 1985* (EPRI/NRECA 1985). Costs will vary by region, supplier and installer. We use split-system heat pump costs of $4,000 for a 5-ton unit, $2,500 for a 3-ton cooling-only unit, and $2,200 for a 2 1/2 ton unit (installed), each of baseline efficiency.

Increased costs for heat pumps of higher efficiency are similar to costs for higher-efficiency air conditioners, as the improvements in equipment and controls are of similar technology. We use an incremental cost of $236 per unit SEER increase above the baseline case, as given in Table 7-2 (see the section on air conditioner equipment efficiency improvements). This translates into a considerably higher incremental cost per unit of HSPF improvement.

Cost credits for replaced equipment. If the heat pump replaces a failed air conditioner, only the incremental cost of the heat pump over the air conditioner is used. We assume an installed cost of $1,800 for a 3-ton unit, and $1,500 for a 2-ton unit (both of standard efficiency). In new construction, the cost of the heat pump is credited with the cost of an electric furnace, or about $500.*

*The EPRI *Heat Pump Manual* lists an average installed cost of $610 for a 47,000 Btuh electric furnace, and $720 for a 76,000 Btuh electric furnace, showing only a slight cost difference for units of different capacity. For the newly-constructed building shells considered in our analysis, the required heating system capacity is on the order of 30,000 Btuh. We assume a cost of $500 for these cases.

Table 7-3. Equipment Sizing and Installation Costs

	Average Existing	Retrofit Existing	Average New Construction	Best New Construction
Heat Pump Capacity				
Cooling Btuh	60,000	36,000	36,000	30,000
Heating Btuh at 0°F	27,000	13,000	13,000	10,500
Heat Pump Installed Cost, Baseline HSPF	$4,000	$2,500	$2,500	$2,200
Air Conditioner, no heat pump				
Cooling Btuh	36,000	36,000	36,000	24,000
Installed Cost	$1,800	$1,800	$1,800	$1,500
Electric Furnace Installed Cost (New Constr.)	-	-	$500	$500

Formula for energy savings. Given a baseline UEC for electric resistance heating, the UEC for the heat pump is determined by the improvement in HSPF, or

$$UEC_{heat\ pump} = UEC_{electric\ resistance} \times (HSPF_{electric\ resistance}/HSPF_{heat\ pump}).^{**}$$

Costs of conserved energy. Our analysis shows costs of conserved energy ranging from 0.5¢/kWh to 24.1¢/kWh for replacing electric resistance heating with heat pumps. CCEs are summarized in detail in Table 7-4. The lowest CCEs occur in new construction, where a credit is taken for both an electric furnace and a central air conditioner. For these cases, we have also compared first-year costs for a heat pump to a gas furnace and central air conditioner, summarized in Table 7-5.

**The HSPF for a given heat pump is different for homes of differing thermal integrity. For a tighter building shell, the heating season "shoulder" period is smaller, reducing the HSPF and the energy savings. Our analysis does not account for a reduced HSPF is buildings with tighter construction, although we have accounted for reduced installation costs in these buildings due to a smaller heat pump requirement.

Table 7-4. Costs of Conserved Energy, Heat Pumps (cents/kWh)

	HSPF Level	Average Existing Full	Average Existing DE	Average Existing CP	Improved Existing Full	Improved Existing DE	Improved Existing CP	Avg. New Constr. Full	Avg. New Constr. DE	Avg. New Constr. CP	Best New Constr. Full	Best New Constr. DE	Best New Constr. CP
A/C Credit	1	3.5	4.9	7.4	2.2	3.1	4.7	0.5	0.7	1.1	0.9	1.2	1.8
	2	3.7	5.2	7.8	3.9	5.5	8.2	2.2	3.1	4.7	2.8	3.9	5.9
	3	4.5	6.2	9.4	5.6	7.9	11.8	3.7	5.2	7.8	5.3	7.4	11.1
	4	4.7	6.6	9.9	6.4	9.0	13.5	4.4	6.2	9.3	6.6	9.2	13.8
No A/C Credit	1	6.4	8.9	13.4	8.0	11.2	16.8	5.2	7.3	11.0	7.4	10.4	15.5
	2	5.8	8.1	12.2	8.1	11.3	17.0	5.7	7.9	11.9	8.5	11.9	17.9
	3	6.4	9.0	13.5	9.6	13.4	20.1	6.9	9.7	14.6	10.7	14.9	22.4
	4	6.5	9.1	13.6	10.0	14.0	21.0	7.4	10.3	15.5	11.5	16.0	24.1

15 year lifetime, 3% discount rate assumed. HSPF level: 1-baseline, 2-best available (1986), 3-with conventional improvements, 4-technically achievable.

Table 7-5. New Construction: Heat pump vs. gas furnace and central A/C

	Avg. New Constr. Full	Avg. New Constr. DE	Avg. New Constr. CP	Best New Constr. Full	Best New Constr. DE	Best New Constr. CP
Installed Cost ($)						
Heat Pump	2500	2500	2500	2200	2200	2200
Gas Furnace	500	500	500	500	500	500
Air Conditioner	1800	1800	1800	1500	1500	1500
Annualized Inst. Cost ($)						
Heat Pump	209	209	209	184	184	184
Gas Furnace and A/C	193	193	193	168	168	168
Annual Heating Cost ($)						
Heat Pump (res. elec. rate)	297	212	141	178	127	85
Heat Pump (heat pump rate)	165	118	78	99	71	47
Gas Furnace	200	143	95	120	86	57
Total First Year Cost ($)						
Heat Pump (res. elec. rate)	506	421	351	362	311	269
Heat Pump (heat pump rate)	374	327	288	283	255	231
Gas Furnace	393	336	288	288	253	225

Heating season efficiency: Gas Furnace - 0.75 AFUE, Heat Pump - 5.85 HSPF (baseline). 15 year lifetime, 3% discount rate assumed.

The range in CCEs shown in Table 7-4 is due to several different factors, discussed below. In general, we can conclude that heat pumps are only cost-effective compared to other conservation options in the case of new construction where summer air conditioning is desired. This case is not necessarily cost-competitive with a gas furnace alternative.

Only in the case of an average, existing building shell is the CCE for high efficiency heat pumps comparable to the CCE for a heat pump with baseline efficiency. In these cases, however, the CCE for improving the shell is considerably less than the CCE for the heat pump retrofit. The heat pump option would only be considered in homes where the shell has already been improved or in new construction. In these cases, a standard efficiency heat pump will be the choice.

Effect of improved building shell. Our analysis shows a lower CCE for heat pumps in existing homes with improved thermal integrity. Although the baseline UECs for these buildings are lower, reducing the savings, these homes benefit from installing a smaller heat pump, and do not pay a penalty for installing a unit that is oversized for cooling. In the case of new construction, however, the best construction practice shell pays a penalty for a slightly oversized air conditioner, and the first cost savings are not enough to overcome reduced savings due to the thermal integrity of the building (compared to current construction practice). From this result, we conclude that the CCE for heat pumps is very sensitive to proper system sizing (for both heating and cooling).

Credit for air conditioning equipment costs. The CCE is dramatically reduced when a credit is given for air conditioning equipment. In existing buildings, a credit for air conditioning equipment is only relevant in exceptional cases, specifically, in electrically-heated homes with a central A/C unit that needs to be replaced. The CCE with the A/C credit is considerably more important in new construction, where the cost of an air conditioner really is avoided when a heat pump is installed. At the same time, however, there will be cases where a heat pump is installed for heating purposes, and the air conditioning is a side benefit (from a comfort perspective) that would not otherwise be installed. In these cases, both the customer and the utility pay for additional energy consumption and peak load during the summer.

Heat pumps in new construction. Given the variations discussed above, the heat pump is an attractive option to electric resistance heating and air conditioning in new construction. The additional cost of a heat pump (of standard efficiency) over a separate electric furnace and air conditioner is quite small compared to the heating season energy savings.

Other options for heating equipment, however, may be more attractive than the heat pump option. Particularly in new construction, gas-fired heating is becoming more popular in Michigan and the U.S. in general. In homes where gas service is available, increasing heating system efficiencies and lower fuel prices make operating costs for heating with gas much lower than costs with electric resistance, and comparable to costs for heating with a heat pump.

In new homes without air conditioning, the lower cost of gas furnaces make them much cheaper to install and operate than heat pumps. In homes with air conditioning, the tradeoffs are not as clear, and depend primarily on the relationship between residential electricity and fuel prices. Taking a typical seasonal efficiency of 75% for a gas furnace, and a baseline HSPF of 5.8 for Michigan, the electricity-to-gas price ratio would have to be less than 2.3 for heat pump costs to be less than gas costs.* In Michigan, the current residential electricity-to-gas price ratio is 3.4. Using the heat pump electricity rate, this ratio drops to 1.9.

* (5.8 Btu/Wh x 1 Wh/3.413 Btu)/0.75 = 2.3

In Table 7-5, we show first year equipment costs (annualized) for a heat pump of baseline efficiency and for a gas furnace/central air conditioner combination, along with annual fuel costs for heating (at today's rates in Michigan). These results show that only given a preferential heat pump rate is the heat pump competitive with a gas furnace/central air conditioner in new construction.

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8. FUEL SWITCHING: DEMAND-SIDE MEASURE DATA BASE

END-USE:	Water heating, clothes drying, cooking
FUEL:	Electricity/Gas
TECHNOLOGY:	Fuel switching

OVERVIEW

Fuel switching is another kind of electricity conservation. In the residential sector, most electric water heaters, stoves, and dryers can be replaced with their natural gas equivalents. With fuel switching, the entire electrical load for an appliance can be removed from the grid rather than the limited gains possible through improved efficiency. Fuel switching thus has the technical potential for major electricity savings in the residential sector. The difference between residential gas and electricity rates is much larger than the difference between end-use efficiencies of gas and electric appliances. At the same time, consumers often exhibit strong personal preferences for either gas or electric gas electric appliances. This is especially true for stoves and dryers.

Unlike in the industrial sector, where a reverse fuel switching from gas to electricity can be observed in sensitive process heat applications, the potential physical advantages of the more refined electrical energy form do not find sufficient utilization in water heating, cooking, or clothes drying. For these reasons, the potential for fuel switching can not only be large, but also very cost-effective. The costs depend, of course, on the presence of a natural gas connection and the cost of installing the gas appliance.

Consumers and contractors often initially select electric appliances because they are cheaper and easier to install. Gas and electric appliances also provide essentially the same service but differ with respect to certain features, such as open flames, ease of heat variability, and capacity. These features will sometimes influence consumer preference. Utilities play a role, too. In Southern California, where gas and electric utilities compete, nearly twice as many homes have gas dryers as in Northern California, where a single utility provides both gas and electricity.

There are also cases where fuel switching from gas to electricity may be cost-effective. For example, superinsulated new homes may require so little space heating that it becomes cheaper to install electric resistance heating. (However, they must truly be "super"insulated.) Specialized, point source applications of heat may be supplied cheaper with electricity than gas. An electric hot water booster on a dishwasher may prove to be cheaper (and safer) than maintaining the entire domestic hot water system at 140°F. Fuel switching -- in both directions -- deserves further research.

ECONOMICS OF FUEL SWITCHING

Conversions of appliances from electricity to gas typically require modification of the house even if the house already has gas service. The most common technical problems involve installation and extension of gas pipes and flues to the room with the appliance.[1] Water heaters and clothes dryers are generally located near a gas line (leading to the furnace) or can be inexpensively connected to the gas stub. Electric space heating can be converted to gas but may require extensive modifications to provide ductwork and a flue. We did not include space heating in this analysis.

Gas appliances draw combustion air from space around them and vent it through the flue. Infiltrating air replaces the lost combustion air. If the appliance is located in the envelope, then the infiltrating air must

[1] The latest, high-efficiency water heaters and furnaces can now vent horizontally through a wall. This offers additional flexibility for conversion.

be heated or cooled. This adds to the cost of operating a gas appliance, especially a water heater. We did not include this cost in our calculations.

Gas water heaters and dryers cost about $50 more than comparable electric appliances. However, gas stoves cost about $130 more than similar electric stoves. In our calculations, we used the same Michigan-based installation cost of $186 for all gas appliances.[2] Most Michigan communities also require a plumbing permit. In one specific case (in Jackson, Michigan), the water heater conversion cost about $400, consisting of $210 for the gas heater, $110 for labor, $70 for flue and gas line connections, and $6 for the permit. In Vermont, a vented propane power burner (needing no chimney) can be purchased and installed for $600.[3] In both cases, the cost of a new electric water heater must be subtracted to obtain the incremental cost. This assumes that the electric appliance is replaced at the time it expires; if it is replaced prematurely then the value of lost service must also be included. Our cost assumptions for fuel switching are given in Table 8-1. (Note that we assigned no cost to the small differences in features of gas and electric appliances.)

Table 8-1. Appliance Assumptions for Fuel Switching

	Water Heater	Clothes Dryer	Range
Incremental purchase cost	$50	$40	$130
Installation cost	$186	$186	$186
Total conversion cost	$236	$226	$316

The economics of fuel switching is normally analyzed in terms of life-cycle cost-benefit calculations, as shown in Table 8-2.

[2] These estimates are based on Montgomery Ward and Sears catalogue appliance prices and telephone inquiries about installation costs in Michigan, however, they need additional case-studies to document real conversion costs. It is conceivable that some gas lines to the houses are sized too small to accommodate the three gas appliances but we expect this to be rare.

[3] "Energy Efficiency Supply Options for Washington Electric Cooperative", prepared by Energy Solutions Inc. Barre, Vermont. September, 1986 (page 17).

Table 8-2. Cost-Benefit Analysis of Fuel Switching				
	Units	Water Heater	Clothes Dryer	Range
UEC of original electric appliance	kWh/year	3753	968	704
Annual elec. bill (@ 8¢/kWh)	$/year	300	77	56
Present worth of electric bills (@ 3% discount rate)	$	3193	1065	774
Gas UEC	MBtu/year	30	4	5
Annual gas bill (@ $5.71/MBtu)	$/year	171	23	29
Present worth of gas bills (@ 3% discount rate)	$	1821	314	393
Incremental operating costs (electric - gas)	$	-1371	-751	-382
Conversion cost	$	236	226	316
Total "investment"	$	-1135	-525	-66
Benefit-cost ratio	-	5.8	2.4	1.2
Simple payback time	years	1.8	4.2	12

The annual fuel bill is less than the electricity bill for all three appliances. As a result, all conversions have a positive net benefit (i.e., benefit-cost ratio greater than one). The magnitude of the benefit is most clearly seen in the simple payback time, which varies between 1.8 and 12 years. Water heating is the most attractive conversion because of the large energy savings and the low conversion cost. The economics would not significantly change if different discount rates or fuel escalation rates were used. At the other extreme, gas ranges are relatively expensive and the energy savings are small. Even though the conversion results in a net benefit, the payback time is quite long and more sensitive to the choice of discount and fuel escalation rates.

We assumed that the electric appliance was replaced in its last serviceable year. Replacing it earlier -- hence losing valuable years of service life -- would not significantly affect the overall net benefit because the fuel costs are the dominant element in the total investment. Including the entire cost of the gas water heater, for example, would extend the payback period only one more year (to about three years).

Cost of Conserved Energy of Fuel Switching

In the framework of cost of conserved electricity calculations, the gas costs for the gas appliance become maintenance costs of the conversion installation. The electricity-conserving investment is simply the cost of conversion. The total conversion cost includes the incremental cost of the gas unit installation, extension of gas lines and flues, plus any permits. We assume a 13 year life for the appliance and a 30 year life for the conversion installation. The resulting CCEs for a 3 percent discount rate are shown in Table 8-3.

Table 8-3. Costs of Conserved Electricity for Fuel Switching				
	Units	Water Heater	Clothes Dryer	Range
Total conversion cost	$	236	226	316
Lifetime of appliance	years	13	18	18
Lifetime of installation	Years	30	30	30
Electricity savings	kWh/yr	3753	968	704
CCE of conversion	¢/kWh_{elec}	0.4	1.3	2.7
Maintenance costs (gas)	¢/kWh_{elec}	4.6	2.4	4.1
Total CCE	¢/kWh_{elec}	5.0	3.7	6.8

IMPLEMENTATION PROGRAMS

We are not familiar with any aggressive programs to encourage fuel switching, although Massachusetts will shortly offer interest-free loans to middle-income homeowners to switch from electric to gas water heaters using PVEA money. Also, California utilities have been promoting the installation of gas pipe connections in new buildings to allow an easy fuel switch in the future should the need arise.

Major fuel switching programs will need careful planning to be successful. For example, water heaters are typically replaced at time of failure when the consumer is only concerned with replacing a leaking unit as soon as possible. Therefore a conversion program must identify and install replacements prior to failures. It is not clear what kinds of rebates or incentives will be most effective. Some consumers prefer electric ranges to gas ranges because of their unique features and will not respond to incentives. Conversion costs for clothes dryers and ranges might be reduced if the gas extensions were performed at the same time.

Michigan consumers are presently converting to gas at a slow rate -- about 0.5% per year for water heating -- but the state might consider accelerating the fuel switching and extend it to dryers and ranges. An attractive program would be to offer the consumer an incentive equal to the cost of conversion. With a 10 percent administration cost, the program CCE to the state or ratepayers would be of the order of 0.5 to 3.4 cents/kWh, based on the conversion CCEs of Table 8-3.

The cost of conserved electricity for the conversion investment alone is especially low for water heating (0.4¢/kWh). The CCE for converting a clothes dryer (1.3¢/kWh) is also quite low. A gas range conversion is somewhat more expensive and might not be cost-effective under slightly different conditions. For example, the increased use of microwave ovens, toaster ovens, and other specialized heating appliances is leading to reduced use of conventional ranges. The success of incentive programs for ranges and dryers will probably hinge on the benefits perceived by individual customers.

Our calculations in Table 8-3 show that the incentives to switch fuels could be substantially larger than just the capital and installation costs without affecting the cost-effectiveness of the measure (from the ratepayer perspective or the consumer perspective). Even if the *whole* cost of the gas water heater were paid for by the utility, the cost of conserved electricity to the all-ratepayer would still be less than the 3.0-4.0 cents/kWh short-run marginal cost of electricity generation from existing plants. The replacement of still-working appliances -- such as might occur when simultaneously replacing all three appliances in a house -- could be undertaken without a significant cost penalty.

TECHNICAL AND ACHIEVABLE POTENTIAL

The potential for fuel switching in Michigan's homes is surprisingly large. For a variety of historical reasons, many homes heat with gas but use electricity for water heating, clothes drying and cooking. Only 3% of Michigan electric customers have no gas connection, but 17% use an electric water heater, 36% an electric clothes dryer, and 55% an electric range. We therefore investigated the feasibility and costs of typical conversions from electric to gas appliances.[4]

To estimate the technical potential for electricity savings from fuel switching, we first determined the number of Michigan homes that had gas service but used electric water heaters, clothes dryers, or ranges. We then assumed that all appliances were converted to gas. The electricity savings are simply the UEC for that appliance multiplied by the number of homes eligible for conversion. These calculations are summarized in Table 8-4. Note that this potential would take many years to achieve since the appliance conversion will generally wait until the existing appliances are near the end of their working lives.

[4] The estimates are admittedly crude, so we expressed all values with two significant digits, therefore some rounding errors appear in the totals.

Table 8-4. Fuel Switching Potential by Appliance				
	Units	Consumers Power	Detroit Edison	Both Utilities
Water Heaters				
Customers with no gas service	millions	0.043	0.037	0.08
Customers with electric water heaters	millions	0.32	0.17	0.48
Net customers that could switch	millions	0.28	0.13	0.41
UEC for electric water heaters	kWh/year	3600	4010	3753
Total switchable electricity	GWh/year	1000	510	1510
Average diversified demand at system peak				
summer	kW	0.5	0.5	
winter	kW	0.61	0.61	
Total switchable demand at peak				
summer	MW	140	170	310
winter	MW	64	78	142
Clothes Dryers				
Customers with no gas service	millions	0.043	0.037	0.08
Customers with electric clothes dryers	millions	0.540	0.49	1.0
Net customers that could switch	millions	0.49	0.46	0.95
UEC for electric clothes dryers	kWh/year	960	980	970
Total switchable electricity	GWh/year	470	450	920
Average diversified demand at system peak				
summer	kW	0.11	0.11	
winter	kW	0.08	0.08	
Total switchable demand at peak				
summer	MW	54	50	104
winter	MW	39	36	75
Ranges				
Customers with no gas service	millions	0.043	0.037	0.08
Customers with electric ranges	millions	0.71	0.86	1.6
Net customers that could switch	millions	0.66	0.82	1.5
UEC for electric ranges	kWh/year	583	801	704
Total switchable electricity	GWh/year	390	660	1050
Average diversified demand at system peak				
summer	kW	0.01	0.01	
winter	kW	0.04	0.04	
Total switchable demand at peak				
summer	MW	6.6	8.2	15
winter	MW	27	33	60

We then added the savings to obtain the statewide fuel switching potential, with respect to total electricity, equivalent baseload, and peak. This is summarized in Table 8-5.

9. DISPATCHABLE OPTIONS: DEMAND-SIDE MEASURE DATA BASE

A. INTRODUCTION AND OVERVIEW

Advantages and Disadvantages

Dispatchable demand-side options for the residential sector have special appeal for the utility planner. These strategies offer reliable, controllable opportunities for shifting residential load to off-peak times. In addition to day-to-day flexibility, i.e., loads can be shifted when needed, these options also provide a valuable way to shed large amounts of load under emergency capacity shortage conditions. Consumers also benefit from load management options. In some cases customers have been happier with their load management system than they were prior to their participation. Some strategies become permanent (and valuable) fixtures of the home. Thermal storage, for example, is a major heating device and the prospect of replacement with a new, conventional heating system is costly and poorly justified if the current system adequately meets comfort needs and carries the added bonus of an annual cash incentive.

Among the disadvantages of demand-side load control is the degree of uncertainty as to the time-frame over which the load will remain dispatchable. Homeowners or renters may move from the service area or decide to no longer participate. Utilities reduce this uncertainty by arranging for multi-year contracts with customers. Customers also may choose to "lighten" their use of the load control, e.g., switch to a briefer cycling period. Incentive levels need to remain attractive to the customer. The extent of the uncertainty is also a function of the technology in question. Water heater cycling poses an almost imperceptible disruption for the customer and thermal storage for space heating only defers the *time* of energy demand not the *availability* of heat. In contrast, air conditioning control can cause discomfort for the occupant.

The need for concern about these reliability issues is lessened by the existence of large waiting lists and low drop-out rates in existing programs. As long as the supply of newcomers equals or exceeds the rate of attrition, there is no loss of load management capability. In addition, we have found that necessary levels of participation are far lower than the number of households eligible for each of the four programs we analyzed.

Program Design: Technical and Cost Considerations

Evaluating the performance of dispatchable demand-side options is complex, both at the micro and macro levels. It is necessary to understand the typical home's load shape, and program-wide performance is a function of weather, coincidence of participant demands, and system load shape at various times of the day and year. Common to all options is a characteristic "payback spike," the growth in load from the participants once control is relinquished by the utility. Sometimes the payback spike is simply equal in magnitude to the interrupted load. In other cases the payback spike is greater or less than the deferred load. Typically deferred energy use is made up at the payback time; in most cases changes in total electricity consumption integrated over the day or year are slight.

Cost-effectiveness analyses must incorporate the technical factors just described, as well as properly allocate cost components such as program management. (Utilities with several direct control activities typically share administrative costs among several programs.) Cost data reported by utilities with small demonstration programs are of course higher than those anticipated for a large-scale effort.

This follows from the higher cost of non-mass-produced products, high program start-up costs, and extra hours spent by contractors unfamiliar with the new technologies. Another important factor is the way in which cash incentives are made available to the participants. Typically this is done in the form of a time-of-use (TOU) rate or demand charge corresponding to the load control time periods. In other cases the rebate simply takes the form of a bill reduction. In our analysis we adopt the rebate approach due to the significant initial costs of TOU metering plus the on-going cost of meter reading, maintenance, repairs, and issuing bills. Detroit Edison's central estimate for the equipment and installation cost for a time-of-use meter is $215. If, for example, the meter is used in an air conditioner load shedding program that allows a diversified load shift of 2.1 kW per household, $102/kW is added to the cost of conserved peak power. Estimates for the additional costs of annual meter reading, billing and incidental repairs are roughly $7/year. The 20-year net present value of this cost is $50/kW. For a smaller load shift, e.g., water heater control with only 0.5 kW load shed, the extra costs would be $430/kW and $204/kW, respectively.

Given a large enough incentive the customer can repay the capital cost with their rebates; however the utility may instead make the capital investment and offer correspondingly lower rebates. The utility retains a large degree of choice in the design of the incentive or rate structures.

Selected Assessments and Results

In the following pages we analyze four dispatchable demand-side options that have been successfully used to shift many megawatts of peak demand by utilities in the U.S. and Europe. Figure 9-1 shows the base case system load curves during winter and summer peak days in Michigan. Below, we briefly define the four strategies and summarize the results of our analysis.

- *Demand subscription* involves interruption of the entire load of a home when demand exceeds a pre-agreed level. The participant is free to choose which loads they wish to shed or defer to restore power. Southern California Edison will soon reach the 4,000 customer level. Using SCE's eligibility criteria, 230,000 customers in Michigan could be eligible for such a program; at 2.8 kW per customer, the technical potential load shift is then 640 MW. The cost of conserved peak power is $266/kW.

- *Thermal storage* is a space-heating strategy in which thermal mass is electrically heated during off-peak periods for recovery during on-peak heating hours. Over 500,000 units were sold in Europe last year. The number of eligible single-family Michigan customers is 40,000; at 4.9 kW per customer, the technical potential load shift is then 200 MW. The cost of conserved peak power is $981/kW.

- *Water heater cycling* facilitates load shifting via radio-controlled interruption devices. Detroit Edison currently has 155,000 water heater cycling customers; Consumers Power has none. An additional 150,000 electric water heating customers are eligible throughout Michigan; here, at 0.6 kW per customer, the technical potential load reduction is 86 MW. The cost of conserved peak power is $928/kW.

- *Air conditioner load shedding* also employs radio controls. Over 140,000 Michigan homes would be eligible; here the potential is 308 MW (an average of 2.2 kW per customer). The cost of conserved peak power is $245/kW.

Tables 9-1 and 9-2 provide more detail on the system-wide technical performance and cost effectiveness of these four load management approaches as well as household-level performance. In addition, for each technology we have prepared a detailed worksheet describing our key assumptions and disaggregating total costs according to equipment and installation, rebates, and operation and maintenance.

In our analysis we use the following conventions: transmission and distribution losses are 15%. In the cases where payback spikes create a new system peak we curtail participation.* Rebates for the thermal storage and cycling programs are set at the levels currently offered to DE's water heater cycling customers (savings are attained through TOU rates); demand subscription rebates are those used in SCE's program. We neglect program administrative costs because they are a relatively small component of program cost and available data are difficult to evaluate in view of aggregation of start-up research costs, widely different program scales and simultaneous operation of multiple programs. The cost of conserved peak power is calculated for a 20 year time horizon with a 3% discount rate as in the rest of this report.

* A payback attenuation factor may also be applied to represent staggering the restoration of power to the participating customers. Here we assume no staggering.

Table 9-1. Assumptions for Demand-Side Options Analysis

END USE	MAXIMUM DIVERSIFIED COINCIDENT DEMAND	SEASON	DIVERSIFIED LOAD SHIFT @ METER (kW)	PAYBACK SPIKE @ METER (%)	INSTALLATION & CAPITAL COST ($ 1985)	ANNUAL O&M COST ($ 1985)	REBATE LEVEL ($ 1985)
DEMAND SUBSCRIPTION	—	S	2.4	100%	140	negl.	$40/yr
(sources)	—	—	SCE	SCE	SCE	DE	SCE
THERMAL STORAGE	4.3	W	4.3	490%	4,000	$25	$30/yr
(sources)	CP	—	CP	Mf'r	Mf'r	DE	DE
WATER HEATER INTERRUPTION	0.5	S	0.5	250%	87	negl.	$30/yr
(sources)	CP	—	CP	CP	DE	DE	DE
AIR CONDITIONER LOAD SHEDDING	2.12/1.72	S	2.12/1.72	120%	87	negl.	$30/y
(sources)	DE/CP	—	DE/CP	CP	DE	DE	DE

Table 9-2. Summary of Dispatchable Demand-Side Options:
Technical Performance and Cost Effectiveness

STRATEGY	PARTICIPANTS	LOAD SHIFT (MW)	CAPITAL COST ($1985/kW)	$CCPP_{20}$,3% ($1985/kW)	$CCPP_{20}$,7% ($1985/kW)
Demand Subscription					
Consumers Power (base case)	78,261	216	51	266	203
Detroit Edison (base case)	153,541	423	51	266	203
Thermal Storage—SF homes only, 53%					
Consumers Power (base case)	27,030	134	815	981	933
Detroit Edison (base case)	13,780	68	815	981	933
Water Heater Interruption					
Consumers Power (base case)	59,619	34	151	928	704
Detroit Edison (base case)	89,897	52	151	928	704
Air Conditioner Load Shedding					
Consumers Power (base case)	64,799	128	44	270	203
Detroit Edison (base case)	73,943	180	36	219	164
Case I: 20 minute cycling periods					
Consumers Power	111,000	73	132	809	614
Detroit Edison	221,000	180	107	656	498
Case II: 40 minute cycling periods					
Consumers Power	97,198	128	66	404	307
Detroit Edison	110,970	180	54	328	249

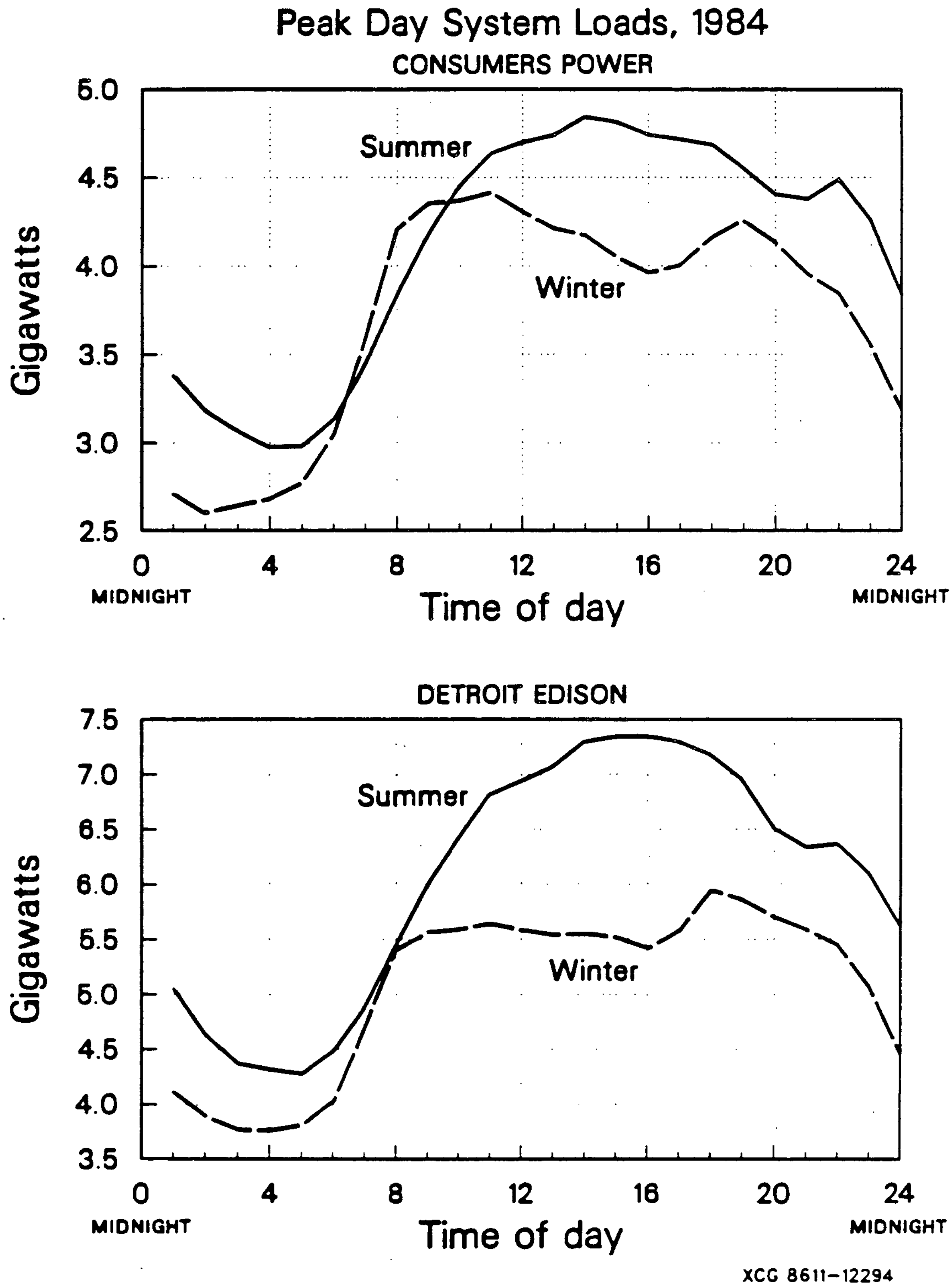

Peak Day System Loads, 1984
CONSUMERS POWER
Summer
Winter
Gigawatts
5.0
4.5
4.0
3.5
3.0
2.5
0
4
8
12
16
20
24
MIDNIGHT
Time of day
MIDNIGHT
DETROIT EDISON
Summer
Winter
Gigawatts
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
0
4
8
12
16
20
24
MIDNIGHT
Time of day
MIDNIGHT
XCG 8611-12294

Figure 9-1

B. DEMAND SUBSCRIPTION SERVICE

END-USE:	Air conditioning, water heating, lighting, clothes washing and drying, dishwashing
FUEL:	Electricity (peak power)
TECHNOLOGY:	Demand Subscription

GENERAL DESCRIPTION

Technology and Program Features

Load control strategy. Demand subscription (DS) is a relatively new form of load control. It differs from common interruptible/curtailable (I/C) rates programs in that the combined whole house load is targeted, rather than one specific end-use such as air conditioners or electric water heaters. Thus the customer can choose which load(s) to defer to avoid load interruption. DS programs offer cash incentives to homeowners who volunteer to allow a pre-agreed level of load interruption during utility peak demand periods. Like I/C programs, DS lends itself to combinations of incentive structures that combine time-of-use rates and demand charges. By properly selecting the time periods during which demand may be interrupted, the utility can defer electricity demand to off-peak periods without reducing overall sales.

How the program works. Activated by broadcasting a radio signal to the participant's meter, demand subscription is highly dispatchable and reliable. If loads exceed the demand threshold, power is interrupted until the load is reduced. The load interruption must coincide with the system peak, although not necessarily with the customer peak. Demand interruption poses less of an inconvenience to the household if it does not occur during the customer's peak demand. The duration of interruption is a function of the final system peak when interrupted customers come back on-line. Following the demand interruption period, customers begin to "payback" the deferred energy use. If these payback times are staggered then not only will the load be shifted but it will be leveled as well. Optimally, the system peak at payback equals the program-based system peak. The appearance of a new system peak at the payback time indicates over-subscription (see Figure 9-2 for a graphic representation of optimal participation rates).

The activities most likely to be shifted are air conditioning, ironing, dishwashing, vacuuming and cooking. In their time-of-use rate experiment, TVA customers shifted laundry 82% of the time, dishwashing 60%, and cooking 31% (TVA 1984).

To mitigate against customer inconvenience in the current SCE program, a "Customer Alert Device" is plugged into any household 120 Volt outlet, producing an audible tone and light signal when the service is in effect (SCE 1985). A red light indicates that the customer has exceeded their subscription power level, providing a two-minute opportunity for the customer to curtail some of their load before service is interrupted. Once power has been interrupted the customer has the option to "reset" the device (green light) and turn off some appliances in order to restore power. If the customer is away from home, the entire house load is interrupted, but power will be automatically restored in thirty minutes.

Hardware components. Whole-house demand interruption devices are similar in principle to those used for water-heating or air-conditioning interruption. They may be retrofitted onto the existing meter without modifications to the house wiring. (The dimensions of units installed by Southern California Edison are only 5" x 5" x 6 ").

Technology status and availability of hardware components. Devices useful for individual appliance control are available commercially and may be able to be applied to the entire house load. Southern California Edison contracted a subsidiary electronics firm to develop the units for its program. In I/C programs, many utilities (Detroit Edison in particular) have assembled the necessary interruption equipment from readily available components.

Status of current programs. Here we summarize the status of various DS/IC programs as reviewed in (EPRI 1985). We also report on the current status of Southern California Edison's DS program.

As of 1983, two utilities (SCE and Texas P&L Co.) were conducting residential DS programs for a total of 2,280 customers, SCE being the larger of the two. In 1985, SCE had 3,000 customers on demand subscription. SCE's approach employs a remotely activated control that disconnects the entire service if the load exceeds the contracted level during a demand limiting period, while the Texas program limits load to a prescribed level at all times. Potomac Electric Power and Virginia E & P Co, both investor-owned utilities, had DS proposals pending as of 1983. The EPRI study did not indicate the target sector.

Three investor-owned utilities (Black Hills P & L Co., Minnesota P & L Co., and Philadelphia Electric Co.) have residential interruptible/curtailable programs, one dating to before 1974. One utility had between 5 and 10% of its customers on the rate as of 1983. Six publicly-owned utilities (Fort Collings L&P, James Valley Electric, Lansing Board of W &L, Richland Electric Coop, United Power Association, and Vermont Electric Coop) reported having experimental residential I/C rates. Eligibility is typically contingent upon the customer having some minimum amount of load. Utility plans may specify a maximum amount of system-wide interruptible load for the customer class. In some cases there are required time commitments of five or more years.

The California Public Utilities Commission (CPUC) authorized a *second* SCE demonstration of the Demand Subscription Service (DSS) in August 1983, although Edison had sought approval for a full-fledged program. SCE's intention was for the rates to become mandatory for all new homes. The CPUC wanted to further investigate the need for demand savings due to high reserve margin forecasts and to settle questions concerning equity and selection bias in the first demonstration. In the coming year, SCE will be initiating a third phase with 1,200 new customers. The current SCE test investigates four incentive levels, four climate zones, and two control strategies. Eligibility is confined to customers using 1,200 kWh or more during three months over the period of May through October. A small group of <800 kWh/month customers is also included.

Arizona Power has a program whereby customers receive utility zero-interest loans to finance a load controlling device. The customers pay demand charges and a discounted energy rate, and hence can reduce their monthly costs by shifting load.

PROGRAM EXPERIENCE

The most well-documented application of DS is the current Southern California Edison (SCE) experiment, which began in 1980. Three groups were tested: high use, >1,200 kWh/month, >800 kWh/month, and 400-800 kWh/month customers. Figure 9-2 shows the impacts on SCE's high usage customers from the program. The following discussion is based on the experience of that company.

Program Impacts

Subscription and Incentive levels. High use customers subscribed to an average 4 kW (non-coincident) demand reduction. For the low usage (400-800 kWh) group, a maximum demand level of 1 kW was set. In SCE's program, four incentive strategies were applied to subgroups of participating customers; (1) a graduated \$5/\$7 per kW per month below the current peak demand, (2) a fixed \$5/month-kW incentive, (3) a fixed \$3/month-kW incentive and (4) a demand charge (\$4/kW) and a 2½ cents per kWh energy rate discount. In conjunction with these incentives, two dispatch strategies were tested, (1) a six-hour period between noon and 6 p.m. and (2) floating four-hour periods during this 6-hour time window. The interr-uptions were limited to 15 days over the six warm months of the year. Incentives were paid for each month regardless of whether an interruption occurred.

Average savings per rebate. The average load reduction (diversified) was 2.4 kW (2.7 kW including T&D savings) per >800 kWh and >1200 kWh customers in a typical weather year. Air conditioner saturations were very high in both groups (70%). Differences in load shift behavior as a function of rebate level were not statistically significant. Diversified savings for low-use (400-800 kWh/month) were substantially less than one kW. SCE found the program too restrictive to these customers.

The very significant *diversified* savings found by SCE for high usage customers are explained by two factors: the high air conditioner saturation among them, with an average diversified demand at system peak of about 2 kW, and the complete shut-down of all service for some customers (e.g. people that aren't home).

Payback spike. SCE observed that following the 4-hour load interruption period, the participating customers will gradually come back on-line with a load equivalent to that they had shifted, reaching a new peak roughly two hours after the utility relinquishes control. We refer to the payback time as that time the load actually reaches the payback spike; this falls roughly two hours after the load interruption has ceased. If the activation periods are staggered, the payback spike can be reduced.

Impacts on energy consumption. SCE found that changes in energy consumption caused by the program are negligible. This is to be expected, since the demand interruption is limited to a maximum of 15 days per year.

Equipment reliability and service life. The hardware necessary for demand interruption has been in use by utilities for many years now. Detroit Edison has found that water heater interrupt devices installed in 1968 typically required replacement in 10-15 years. Advancements in solid-state electronics since the 60s have made available technologies that can be expected to last well through the 20 year planning horizon.

Experiments by SCE and Detroit Edison investigated the reliability of load interruption hardware. SCE noted some occurrences of "minor communication problems" when the solid state recorders were installed near phone lines. Modifications are now being made to solve these problems. DE's 1979 tests revealed that a significant fraction of the devices did not operate properly. However, considering their age at the time and the recent advances in control technology, we can expect much higher reliability with future equipment.

Special problems. Households move every 5 to 10 years and it is not certain that the subsequent occupants will remain on the program. Original customers may also decide to discontinue participation. Contractual agreements, ensuring that the home will remain on the program for a fixed number of years have been used by utilities engaged in I/C programs. The indication for other demand-limiting programs is that, with adequate promotion, waiting lists are more than sufficient to maintain a constant level of participation without the complication of contractual agreements with customers.

Costs of Demand Subscription

Equipment cost. The prototypical interruption equipment used by SCE is expected to achieve costs comparable to those of conventional I/C hardware once produced in sufficient volume. Some indication of expected equipment cost can be found in the utilities' own studies on I/C options. Detroit Edison, for example, reports the cost of purchasing and installing its air conditioner and water heater control devices as $87 ($1985) (Detroit Edison, 1986). The company assumes prices to remain unchanged for the following decade, escalating at 5%/year thereafter. DE's extensive use of water heating control has resulted in maintenance costs of only $0.25/year per unit (Detroit Edison, 1986).

Program rebate costs. We consider annual rebate costs, assuming an annual incentive payment of $5/kW-month or $40 per participating customer for the 4 month (May through August) demand subscription season. The net present value of these payments over 20 years is $595 per customer at a three percent real discount rate ($424 at seven percent).

Costs of Conserved Peak Power

To establish a lower limit for the cost of this option, we base our cost calculations on an overall one-time program cost of $140 per participant, including equipment and installation. SCE staff sees this figure as a reasonable cost target for an expanded program. The peak power savings per customer are assumed to be the same as in the case of SCE, i.e. 2.7 kW diversified including system losses. This figure seems to be attainable for significant numbers of customers in Michigan as well. Considering all costs, the minimum cost of conserved peak power (i.e. for high usage customers) is then $266/kW (or $203 for a seven percent discount rate).

TECHNICAL AND ACHIEVABLE POTENTIAL

General

Eligible customers. Based on a threshold consumption of more than 800 kWh per month during the peak summer months, approximately 19% of Michigan's customers would be eligible for the program. However, participation levels of this magnitude would create new system peaks during the payback time thereby lowering the overall efficacy of the program. By iterating at various participation rates up to the upper limit of all eligible customers, we arrived at optimal subscription levels, i.e. minimizing the cost of conserved peak power and maximizing the number of participants. Using this approach, optimal participation rates are 78,000 customers in CP's service area and 154,000 customers in DE's (based on 1984/85 customer numbers). Another method for determining potential participants is to target customers with central air conditioners, since they are most likely to show high energy use in the summer period. This criteria would apply to nine percent of CP's customers and to 24% of DE's customers, respectively. (70% of the SCE participants had air-conditioners.)

Figure 9-3 shows Consumer Power's load curve for >1,200 and >800 kWh/month customers. Diversified demands during the summer afternoon peak period for the two customer classes are 3.6 and 3.2 kW, respectively, hence the savings of 2.4 kW for the two high-use groups in the SCE test seems attainable if customers shut off their air conditioners. For most households, demand subscription would thus have a very similar effect as an air-conditioner load-shedding program, making these two programs mutually exclusive for most homes.

Care would have to be taken to exclude customers on present or planned demand interruption programs such as DE's air conditioning or water heating interruption programs. It should be noted that savings from demand subscription are similar in magnitude and cost to those achieved with interruptible air conditioning programs although DS is probably preferable to customers because of the choice they retain over which load will be interrupted during peak times.

Maximum Potential Scenario

In 1984, the contribution to the summertime system peak of the residential class was 1,101 MW for CP and 2,307 MW for DE. We adopt SCE's 2.7 kW/household savings estimate. Our calculations are based on 1985 customer numbers and peak demands. Due to the flatness of CP's and DE's demand profiles surrounding their peak periods, large DS programs would require long demand interruption periods to avoid creating a new system peak during the payback time and to most optimally level the system load during payback. This can also be accomplished by dividing the participants into two groups and designating one for interruptions before the peak and the other for interruptions after the peak.

The optimal load shift for all CP participating customers is 216 MW and the program-based system peak is reduced from 4,840 to 4,624 MW; the corresponding savings for a DE program is 424 MW (see the worksheets for calculation details).

CUMULATIVE INVESTMENT AND PROGRAM COSTS ($1985)

Investment. The initial capital investment of $140 per home results in a $11 million cost for CP and a $21 million cost for DE.

Program Costs. The 20-year net present value of annual rebates of $5/household-kW-month totals $47 million for CP and $91 million for DE.

Conclusions. Equipment and installation costs represent 23% of total costs, rebates 77%. For each utility, a demand subscription program may conserve power at a cost of $51/kW for the hardware and $266/kW for all costs combined. The total cost for a seven percent discount rate is $203/kW.

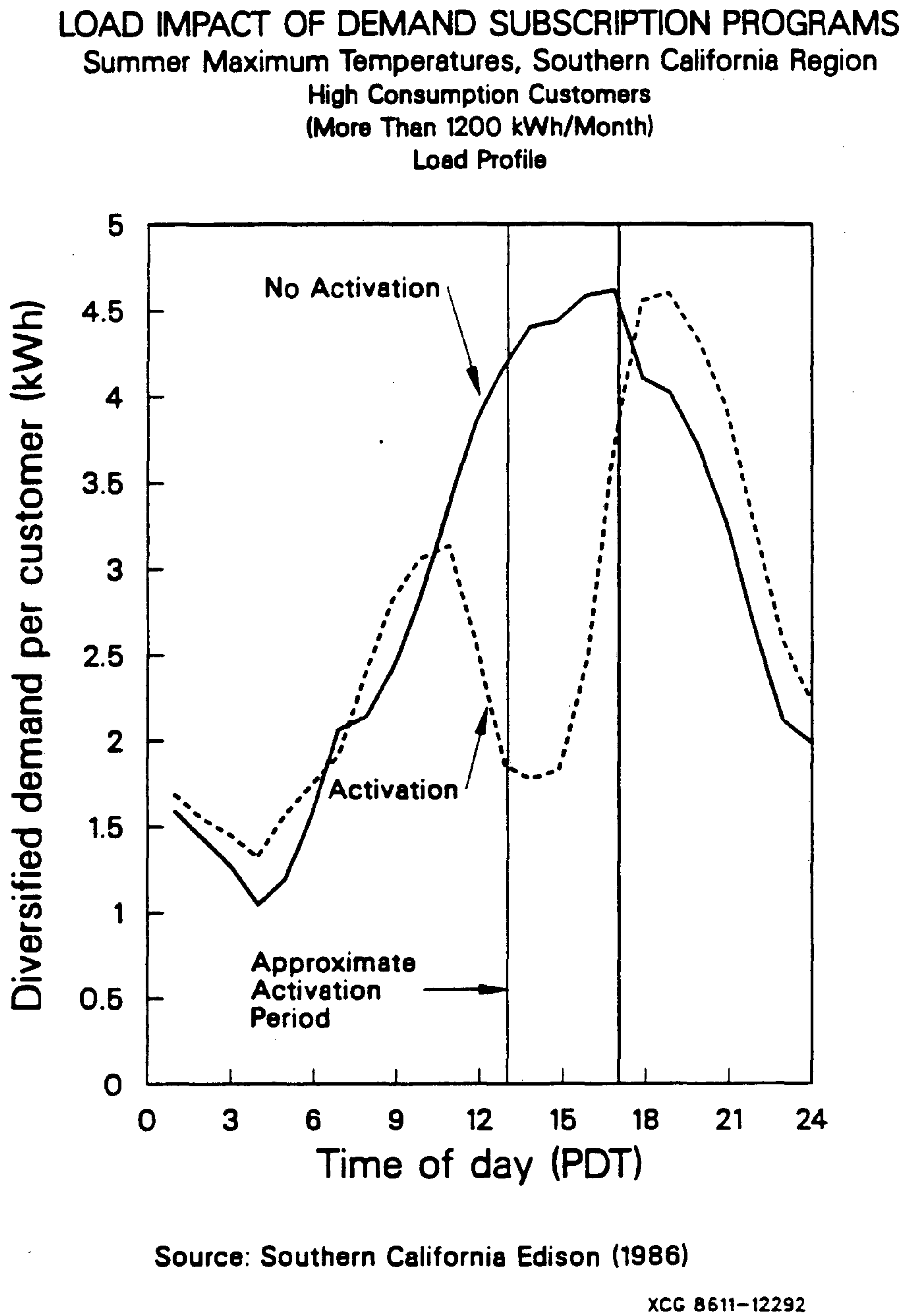
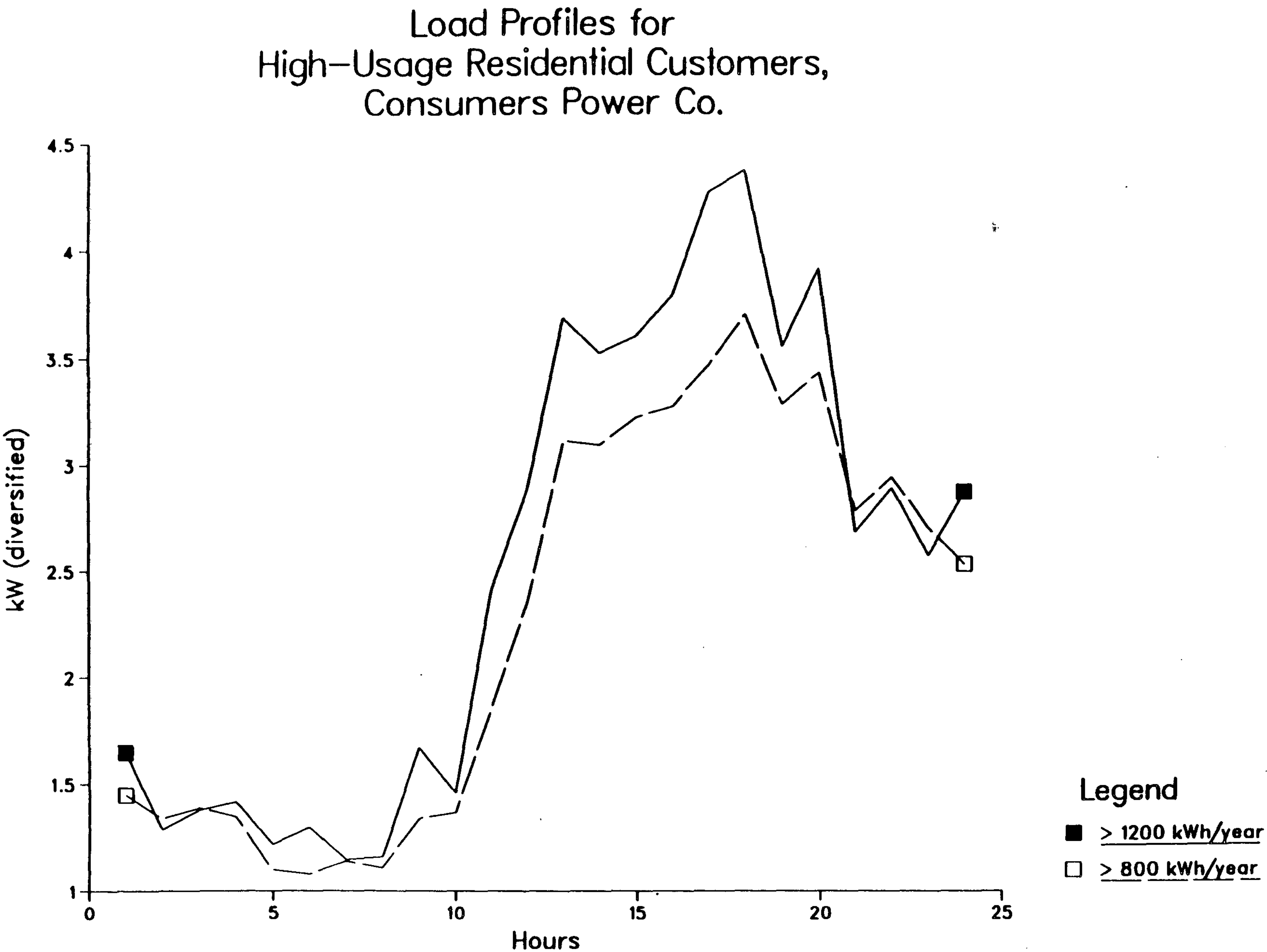

LOAD IMPACT OF DEMAND SUBSCRIPTION PROGRAMS
Summer Maximum Temperatures, Southern California Region
High Consumption Customers
(More Than 1200 kWh/Month)
Load Profile
Diversified demand per customer (kWh)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
No Activation
Activation
Approximate Activation Period
0
3
6
9
12
15
18
21
24
Time of day (PDT)
Source: Southern California Edison (1986)
XCG 8611-12292

Figure 9-2

Figure 9-3


Load Profiles for
High–Usage Residential Customers,
Consumers Power Co.
kW (diversified)
4.5
4
3.5
3
2.5
2
1.5
1
0
5
10
15
20
25
Hours
Legend
> 1200 kWh/year
> 800 kWh/year

C. AIR CONDITIONER INTERRUPTIBLE SERVICE

END-USE:	Air Conditioning
FUEL:	Electricity (peak power)
TECHNOLOGY:	Air Conditioner Load Shedding

GENERAL DESCRIPTION

Technology and Program Features

Load control strategy. Interruptible air conditioning service enables a utility with summer peaking problems to instantly shed electric load by cycling residential cooling equipment via radio control. The load reduction may be achieved by one of two methods, cycling or shedding. The appeal of load shedding is that interruptions, although greater in scale, occur less often. California utilities limit them to 15 days per year. In this analysis we will focus mainly on the load shedding approach.

Hardware components. Simple compressor control devices are retrofitted onto existing air conditioners and customers are offered a rate discount for separately-metered electricity used by the air conditioner as an incentive to participate.

How the program works. Radio controls must be attached to each air conditioner that is to be controlled. Unless the program also employs TOU rates (and therefore separate metering) only one visit to the home will be required. Thereafter control is accomplished remotely. In a cycling program, brief (15-20 minute) outages are applied to all participants over a multi-hour period, resulting in perhaps a 25% decrease in the system peak for the participants. In a load shedding program, the entire load of all customers is shed simultaneously, resulting in a 100% decrease in the participants' demand for that end use. If customers are not to be placed on TOU rates then a single rebate check is issued (or bill credit applied) each year, versus a separate air conditioning bill each month.

Technology status and availability of hardware components. Air conditioner interruption devices are commercially available. However, utilities may also assemble the necessary equipment with ''off-the-shelf'' components.

Status of current programs. California utilities are among the most active in the U.S., currently serving 150 - 200,000 customers.

Detroit Edison has also given considerable attention to direct control of residential air conditioning, although their program is not as large. Their use of this load management strategy dates back to December 1976. Less than four years later the program was made available to all customers. Participation had grown to 38,600 (roughly 10% of all central air-conditioning customers) by late summer 1985.

Under DE's program, air conditioning may be interrupted for up to 20 minutes per hour, but no more than eight hours in any given day. Customers surveyed in 1986 were overwhelmingly satisfied with service under the program. Eligible non-participating customers surveyed were typically unaware of the availability of the program.

Reports were released by Detroit Edison in 1978, 84, and 86. The 1986 assessment, requested by the Michigan Public Service Commission, found that doubling the current interruption period would be unacceptable for some customers, the incremental cost of special wiring posed a barrier to customer acceptance, and costs were expected to exceed benefits during the 1986 to 2000 period. Their conclusion regarding new customers was that that capacity savings would be unnecessary until the mid 1990's—a decade before the end of the MEOS planning horizon. Alternate rate structures, although they may decrease participation, may allow for the cost-effective deferral of new capacity additions in the late 1990s.

Eighty percent of the polled DE eligible customers felt that 20 minute interruptions would be acceptable, whereas slightly more than 30% felt 40 minutes would be acceptable.

Pacific Gas and Electric Company has also conducted an air conditioning control study. The load drop achieved by the 24,400 participants was 15.25 MW, or 0.63 kW per household (PGandE, 1983). Currently, there are 51,600 customers, 10,000 of which are "shed" customers, i.e., 4-hour per day continuous interruption and long waiting lists.

In 1984, a typical summer in Texas, Texas Power and Light tested two methods or air conditioning control on 30 homes (Schneider and Thedford, 1986). With a 20-minute/hour cycling pattern, both the local control and direct control devices reduced demand by roughly 0.65 kW at an outdoor temperature of 100°F. Savings were observed to be proportional to temperature. Oversized units attained lower demand savings because they are already cycling at regular intervals. Indoor temperatures were raised roughly 2°F during control periods; it was found that the opportunity to participate in the program improved customers' attitudes towards the utility. One in thirty customers reported being less comfortable than during the previous summer without the controls. Only three customers chose not to continue into a second year of control: one had an undersized air conditioner, another was moving, and a third who concerned about damage to the air conditioner.

The TP&L direct control system uses existing telephone lines to carry the interruption signals. This "power line carrier" (PLC) system allows not only for air conditioner control but for gathering load data, temperature data, and for metering. In this case, the PLC was programmed to limit interruptions during the period 1 to 9 PM. The network of homes on the controls are centrally controlled, enabling random, non-coincident interruption patterns. The local control system is placed in series with the thermostat and has pre-selected levels of cycling. In the experiment, the air conditioners were cycled off for 4½ out of every 10¼ minutes during the control hours.

PROGRAM EXPERIENCE

Program Impacts

Impacts on daily load shapes from air conditioner cycling and shedding are compared in Fig. 9-5, based on data of Pacific Gas and Electric Co.

Incentive levels. Detroit Edison provides a 2 cent per kWh incentive—or roughly $30/year. The Consumer Power experiment offered a $24/year incentive. In CP's air conditioner cycling experiment, 64% of the participants noted that they would continue on the program even without the incentive.

Average savings per rebate. Diversified demand for air conditioning could be reduced from 3 kW to 1.6 kW for a 40-minute/hour interruption or 0.6 kW for a 20-minute interruption—assuming average daily temperatures of >80°F. With load shedding, 3 kW would be shiftable in this instance.

Payback spike. Consumers Power found that the payback spike varied according to the duration of interruption, averaging 120% for afternoon interruptions.

Impacts on energy consumption. With interruptions limited to 15 days per year, as is typically the case in California, annual energy use reductions will be negligible. Energy reductions *for the control days* were estimated at about five percent.

Equipment reliability and service life. In Detroit Edison's experience, meters and controls have had high reliability. They estimate that less than one percent of the units now in the field are defective. California utilities have a 3%/year repair rate. Improvements in electronics since 1967 indicate that lifetimes of modern control hardware should be quite long.

Special problems. Crucial to the success of air conditioner interruption is that customer loads are highly coincident. Based on technical savings and economics, CP determined that if the interruption lasts fifteen minutes and the customer-class load factor (maximum diversified demand at system peak/average noncoincident demand) is less than 75% the program will not be successful. The load factor for CP is 48%. To maximize savings, we adopt load shedding as the load management method of choice for Michigan.

Costs of Air Conditioner Control

Equipment and installation cost. The current installation cost for Detroit Edison's equipment is $112 for the radio controls and a meter. An additional cost of $175 was required for the extra wiring costs for the meter and air conditioner. This cost is unnecessary in our analysis because we do not rely on time-of-use rates as the means of awarding the rebate.

In the earliest DE demonstration, a separate air conditioner meter was not installed. Instead the interruptible rate reduction was applied to all consumption. Reinstatement of this approach would facilitate a substantial cost reduction.

Program operation and rebate costs. Common to Michigan and California programs, annual rebates are $30 per participating customer. The net present value, per customer, of these payments over 20 years is $446 at a three percent discount rate.

Costs of Conserved Peak Power: Load Shedding

The diversified central air conditioning demand for Consumers Power customers is 1.72 kW at system peak, 2.12 kW for Detroit Edison. For the load shedding approach, the capital cost for CP (with installation) is then $44/kW and the total cost is $270 ($203 for a 7% discount rate), for DE, $36/kW, $219/kW, and $164/kW are the corresponding values.

TECHNICAL AND ACHIEVABLE POTENTIAL

General

With cycling programs, only a fraction of the load is shifted because relatively few air conditioners are being interrupted at any given moment. The potential is vastly larger for load shedding programs. California utilities are moving in this direction. Currently 20% of PGandE's residential air conditioning control customers are on load shedding.

In the future all new participants will use load shedding. Longer interruption periods are bound to attract fewer customers but the savings per customer are three or more times larger than those for the cycling approach. Here, we assess load shedding and provide a comparison to 20- and 40-minute load shedding schedules in Table 9-2.

Eligible fraction. Of Consumers Power customers, 111,000, or 10%, have central air conditioning. For Detroit Edison, 376,000 customers, or 23%, are eligible. In both cases this level would create too large a payback spike. For DE 74,000 participants are optimal, for CP, 65,000 participants.

Maximum Potential Scenario

In 1984, the contribution to summertime system peak of the residential class was 1,011 MW for CP and 2,307 MW for DE. Based on diversified savings of 1.76 kW per CP customer and 2.12 kW per DE customer the respective potentials are 128 and 180 MW for load shedding. Our calculations are based on 1985 customer numbers and peak demands.

CUMULATIVE INVESTMENT AND PROGRAM COSTS ($1985)

Investment. The initial capital investment of $87 per home results in a $5.6 million cost to CP and a $6.4 million cost for DE.

Program Costs. The 20-year net present value of annual rebates of $30/household-year totals $29 million for CP and $33 million for DE ($1986). Equipment and installation costs represent 19% of the total, and rebates 81%. maintenance 16%.

Conclusions. In our analysis, load shedding proves to be the most attractive and viable strategy. For CP and DE, central air conditioner load shedding programs conserve power at a cost of $44/kW and $36/kW for the hardware/installation and $270/kW and $219/kW for all costs combined (or an average of $180 at a seven percent discount rate). The costs differ slightly for the two utilities because the diversified demands for residential air conditioning are not identical. For Detroit Edison, cycling programs with interruption times of 20 minutes results in an average CCPP of $732/kW; 40 minutes results in a CCPP of $366/kW. System load reductions are greatest for the load shedding approach.

Figure 9-4

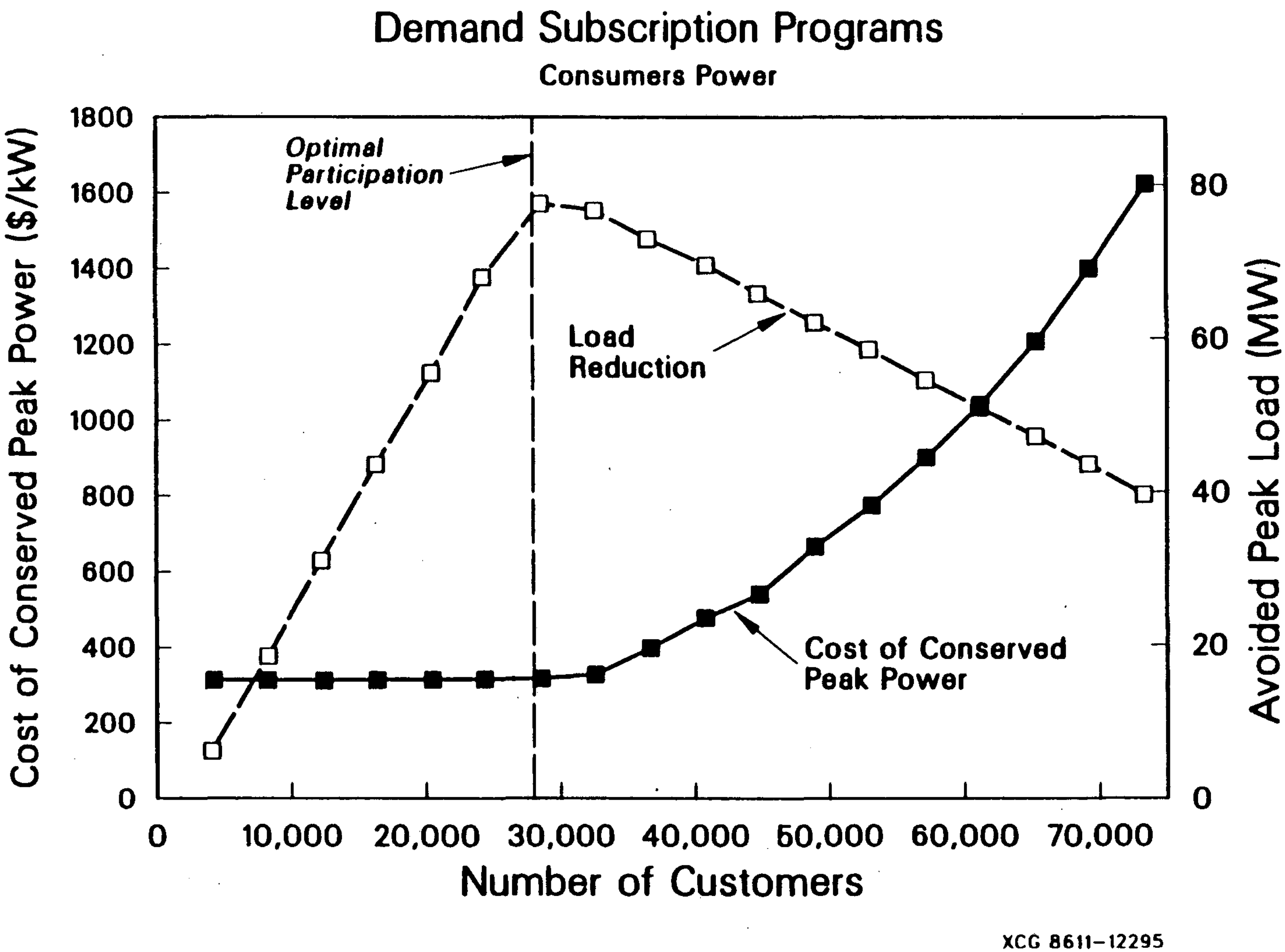
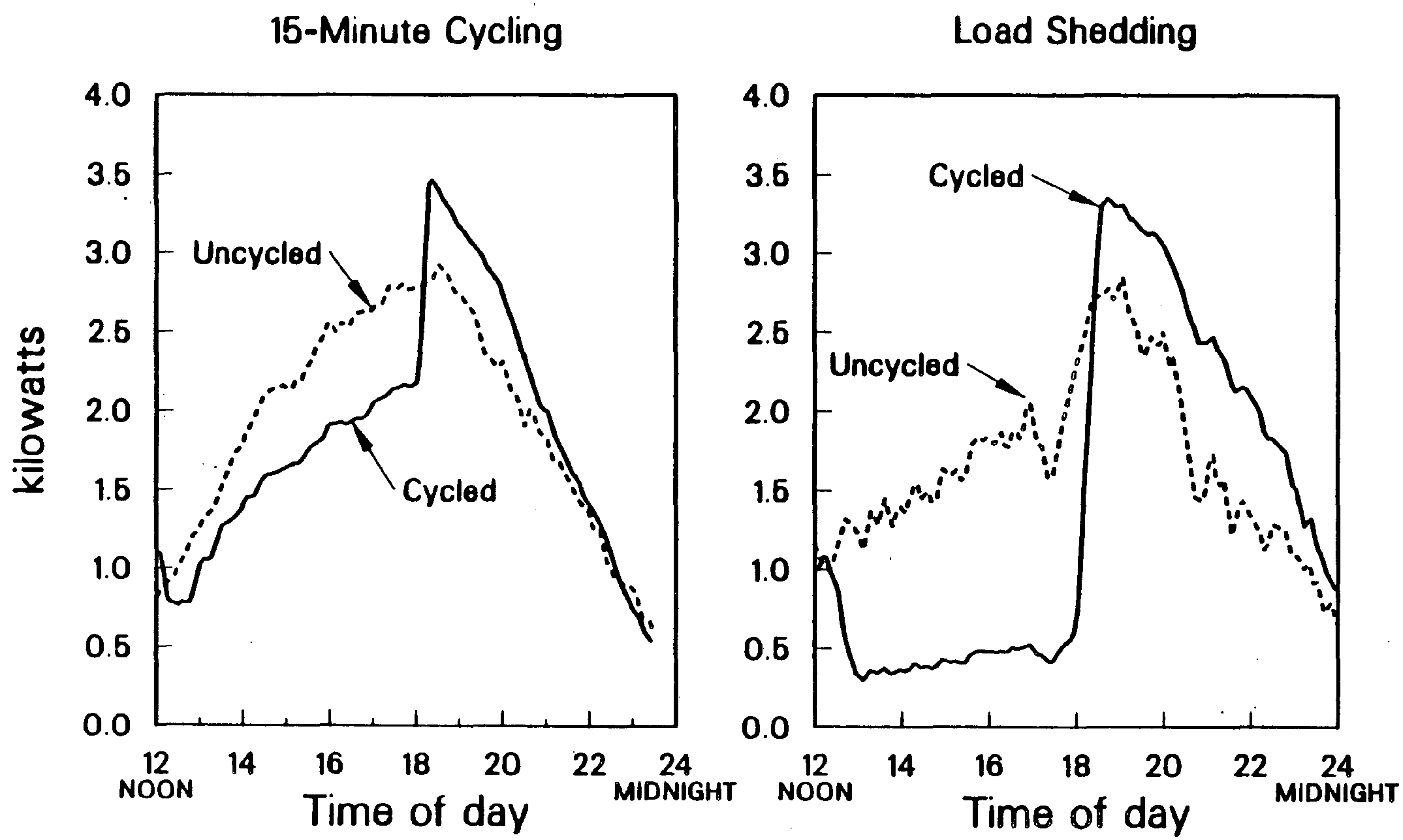

Demand Subscription Programs
Consumers Power
Cost of Conserved Peak Power ($/kW)
Avoided Peak Load (MW)
Number of Customers
Optimal Participation Level
Load Reduction
Cost of Conserved Peak Power
0
200
400
600
800
1000
1200
1400
1600
1800
20
40
60
80
10,000
20,000
30,000
40,000
50,000
60,000
70,000
XCG 8611-12295

Figure 9-5

LOAD IMPACTS OF RESIDENTIAL AIR CONDITIONER CONTROL PROGRAMS



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LOAD IMPACT WORKSHEET: Technical Potential

UTILITY:	Consumers Power
TECHNOLOGY:	Demand Subscription
END USES:	A/C, WH, L&A
DISCOUNT RATE:	3.00%
1. BASELINE DATA:	
Subscription Level	2.00 kW
Average Diversified Load Shift (system level)	2.76 kW
Average Diversified Load Shift (at the meter)	2.40 kW
Payback Fraction	100%
Payback Spike	2.76 kW
Duration of Control	8 hours
Time of Payback Spike (delay = 2 hours)	8:00 PM
Change in Energy Consumption (% of annual use	0.30%
2. PROGRAM COST ($1985 per participating customer):	
Rebate Level	$5 /kW
Number of Months in Operation	4 months
Annual Rebate	$40
NPV 20 year Rebate	$595
Equipment & Installation Cost	$140
3. PENETRATION:	
Eligibility Criteria:	Electricity use > 800 kWh/month
Eligible Fraction	18.50%
Number of Available Households	1,217,000 households
Target population	78,261 households
4. SYSTEM-WIDE IMPACTS:	
Baseline System Peak (August 1984 2:00 PM)	4,840,000 kW
Baseline System Demand at Payback Time	4,408,000 kW
Maximum Shiftable Load	432,000 kW
Load Shift for All Participating Customers	216,000 kW
Program-based System Peak at 2:00 PM	4,624,000 kW
Payback Spike Attenuation	1.00
Payback Spike	216,000 kW
Program-Based System Demand At Payback Time	4,624,000 kW
Net Load Reduction	216,000 kW
5. PROGRAM COST-EFFECTIVENESS ($1985):	
Total Capital Costs	$10,956,522
NPV of 20 Annual Rebates	$46,572,965
----> Cost of Conserved Peak Power (capital cost)	$51 /kW
----> Cost of Conserved Peak Power (total cost)	$266 /kW

LOAD IMPACT WORKSHEET: Technical Potential

UTILITY:	Detroit Edison
TECHNOLOGY:	Demand Subscription
END USES:	A/C, WH, L&A
DISCOUNT RATE:	3.00%
1. BASELINE DATA:	
Subscription Level	2.00 kW
Average Diversified Load Shift (system level)	2.76 kW
Average Diversified Load Shift (at the meter)	2.40 kW
Payback Fraction	100%
Payback Spike	2.76 kW
Duration of Control	8 hours
Time of Payback Spike (delay = 2 hours)	8:00 PM
Change in Energy Consumption (% of annual use)	0.30%
2. PROGRAM COST ($1985 per participating customer):	
Rebate Level	$5 /kW
Number of Months in Operation	4 months
Annual Rebate	$40
NPV 20 year Rebate	$595
Equipment & Installation Cost	$140
3. PENETRATION:	
Eligibility Criteria:	Electricity use > 800 kWh/month
Eligible Fraction	18.50%
Number of Available Households	1,635,000 households
Target population	153,541 households
4. SYSTEM-WIDE IMPACTS:	
Baseline System Peak (August 1984 3:00 PM)	7,350,000 kW
Baseline System Demand at Payback Time	6,502,000 kW
Maximum Shiftable Load	848,000 kW
Load Shift for All Participating Customers	423,772 kW
Program-based System Peak at 2:00 PM	6,926,228 kW
Payback Spike Attenuation	1.00
Payback Spike	423,772 kW
Program-Based System Demand At Payback Time	6,925,772 kW
Net Load Reduction	423,772 kW
5. PROGRAM COST-EFFECTIVENESS ($1985):	
Total Capital Costs	$21,495,685
NPV of 20 Annual Rebates	$91,371,862
----> Cost of Conserved Peak Power (capital cost)	$51 /kW
----> Cost of Conserved Peak Power (total cost)	$266 /kW

D. WATER HEATER INTERRUPTIBLE SERVICE

END-USE:	Water heating
FUEL:	Electricity (peak power)
TECHNOLOGY:	Water Heater Interruption

GENERAL DESCRIPTION

Technology and Program Features

Load control strategy. Interruptible water heating service enables a utility with summer and/or winter peaking problems to shift load by cycling off residential water heaters via radio control. In addition to load shedding capabilities, interruptible service enables the utility to rapidly shed large amounts of load in the event of emergency capacity shortages. Among the many direct control strategies, this is the least disruptive for the home occupant. A well-insulated water heater cools off at the rate of only one degree per hour.

Detroit Edison is the industry leader, operating until recently the largest U.S. program with 155,000 customers. In contrast, Consumers Power has no program in place, although in their analysis the Rates and Research Department (now the Market Research and Pricing Department) recommends increased use of this strategy (Consumers Power, 1980). Successful water heater cycling depends on a high level of coincidence in use among customers and with the system peak.

Hardware components. The on/off signal may be provided either by a timeclock or radio signal. In addition to the control hardware, a separate time-of-use (TOU) meter may be installed to measure electricity used by the water heater.

How the program works. The simple control devices are retrofitted onto the existing water heater and customers are offered a rebate or rate discount for electricity used by the appliance as an incentive to participate. The target population are those households with electric water heating. TOU rates are often provided as an incentive to participate and take advantage of the inexpensive off-peak electricity, but rebates may also be made directly without introducing a new tariff.

Technology status and availability of hardware components. Devices used by the Michigan and California utilities to control air conditioners and water heaters have been constructed in-house as well as purchased from manufacturers (e.g. Motorola). Flexibility increases as one moves from the pre-set timeclock designs to sophisticated radio-control systems which allow remote control and sensing of demand.

Status of current programs. Michigan utilities are among the most active in the U.S. Detroit Edison has pursued direct control of residential water heating. Their use of this load management strategy dates back to 1934 when clock timers were used to interrupt water heaters for four hours per day. In 1968, DE shifted to radio control technology which allowed increased flexibility in their phasing and timing of load shedding. Under DE's program, water heating may be interrupted for up to four hours. Until recently, more than 200 interruptions were conducted each year. Customers surveyed in 1980 were satisfied with service under the program (none experienced shortages of hot water) nine out of ten felt that water heating control should be an option for all customers.

DE's 17-year old radio-control system is wearing out. Their 1981 study (DE 1978) estimated that 15% of the controls were inoperative and an additional 18% were unreliable. The Company found that it was cost effective to refurbish the existing units but that it is not recommended for widespread use until reserve margins drop below current levels.

Consumer Power's evaluation states that "control of residential water heating would provide the greatest potential for load reduction, on a continuous basis, of the three [air conditioning, water heating, and space heating] experimental controls." (Consumers Power, 1980)

Pacific Gas and Electric Company also has conducted an experiment. Their program was serving 2,150 customers as of May 1983. Interruption periods of nearly six hours, longer than those used in Michigan, are used during summer months. PGandE found that the demand payback occurs 30-45 minutes after control is discontinued. Due to a high diversity in customer demand, PGandE has not found radio control of water heaters to be cost effective and has discontinued their program.

PROGRAM EXPERIENCE

Program Impacts

Impacts on the daily load profile of water heating customers are shown in Fig. 9-6, based on Consumers Power data.

Incentive levels. In Consumer Power's experiment, 59% of the participants noted that they would continue on the program even without the $24/year incentive. An additional 20% would continue with the incentive. PGandE has attracted customers with a $2/month bill reduction. Their annual dropout rate has been 8.7%.

Average savings per rebate. Although the non-coincident demand of electric water heaters in Michigan is very high—up to 7 or 8 kW—the average coincident demand is closer to 3 kW and the diversified demand (the measure of potential savings) at system peak is only about 0.5 kW. This circumstance strongly undermines the cost-effectiveness of direct water heater control.

Payback spike. Consumers Power found that the payback spike varied according to the duration of interruption, averaging 150% of the interrupted load for one hour interruptions and 190% for four-hour interruptions, with loads reaching their new peak roughly two hours after power is restored. As with any load interruption scheme, it may be necessary to stagger the reinstatement of customer service in order to insure that payback spikes do not exceed the baseline system peak.

Equipment reliability and service life. In Detroit Edison's experience, the controls have had high reliability. Nonetheless, the system is nearing two decades of operation and is in need of refurbishment. The Company estimates a 1½ to 2½ percent per year failure rate. Advancements in circuitry since the 60s should extend reliable lifetimes to 20 years.

Socio-economic characteristics of participants. Consumers Power assessed customer demographics in their Electric Water Heating Load Study (Consumers Power 1985). They found that heads of households ranged in age from 35 to 44 years with annual incomes from $10,000 to $15,000. Only eleven percent had air conditioning. Thirty two percent of the households had two occupants.

Costs of Water Heater Control

Equipment cost. In Detroit Edison's water heater control refurbishment study, the cost of control units is estimated at $67 ($1985) plus one hour of labor ($20), for a total installed cost of $87 (Detroit Edison, 1981).

Program rebate costs. Annual rebate payments are assumed to be $30 per participating customer as is common for most direct control programs today. The net present value, per customer, of the rebate payments over 20 years is $446 at a three percent real discount rate.

Costs of Conserved Peak Power

Installed equipment costs are assumed to be $87, as was the case in DE's water heater refurbishment study. We base our savings potential on estimates of 0.58 kW at system peak. The capital cost is then $151/diversified kW and the total cost is $928/kW ($704 for a 7% discount rate). These values apply to both utilities.

TECHNICAL AND ACHIEVABLE POTENTIAL

General

Eligible fraction. The electric water heating saturation in Consumers Power service territory is 33.5% or 411,970 customers; in Detroit Edison's territory the saturation is 9.9% or 164,600 customers. 155,000 DE customers currently have interruptible water heating. Only 59,600 CP customers and 89,900 DE customers can be on the program without causing new system peaks at the payback time.

Maximum Potential Scenario

In 1984, the contribution to summertime system peak of the residential class was 1,011 MW for CP and 2,307 MW for DE. Based on diversified savings of 0.58 kW per customer the potential for CP is 34 MW and 52 MW for DE. Our calculations are based on 1985 customer numbers and peak demands.

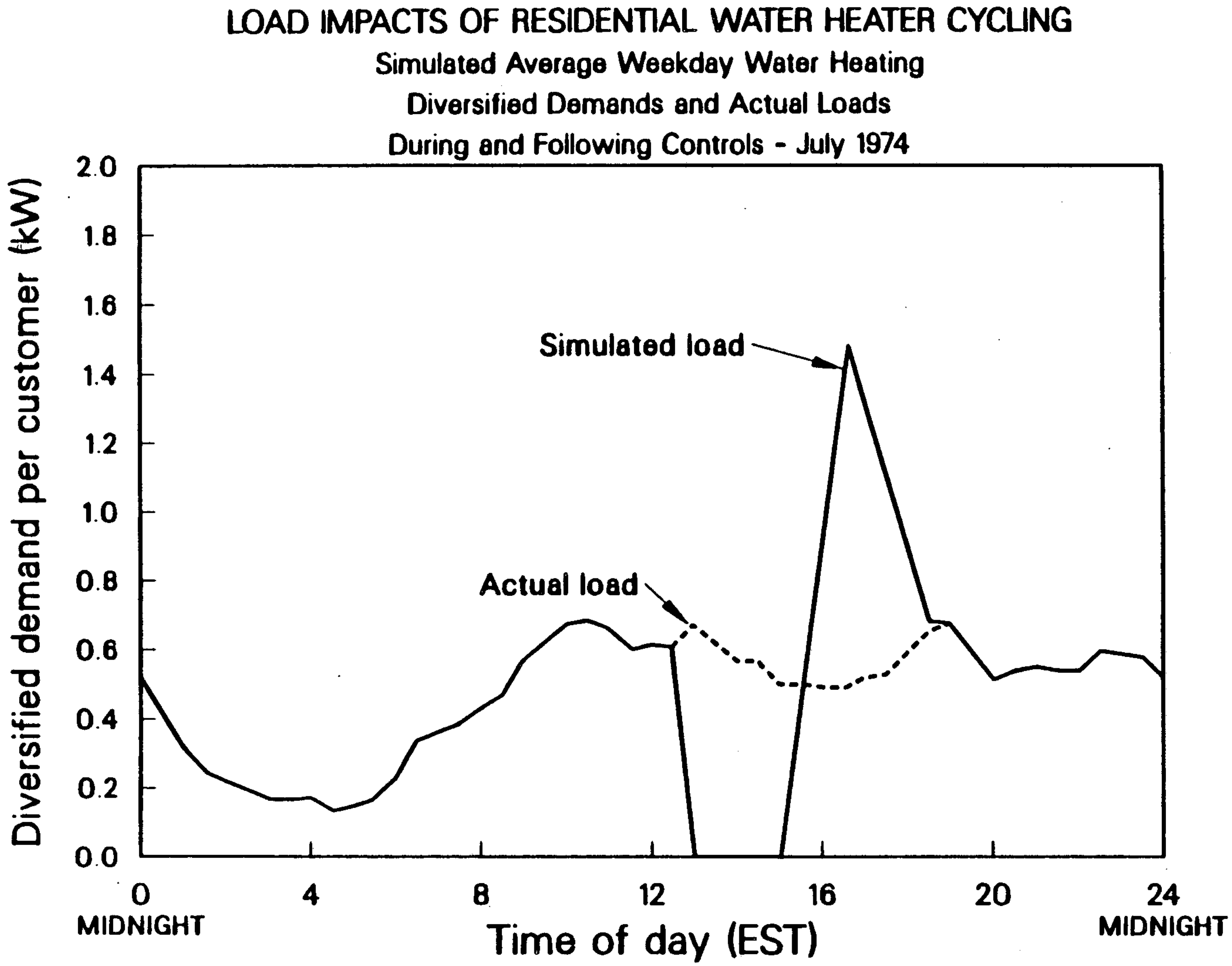
CUMULATIVE INVESTMENT AND PROGRAM COSTS ($1985)

Investment. The initial capital investment of $87 per home results in a $5 million cost to CP and a $8 million cost for DE.

Program Costs. The 20-year net present value of annual rebates of $30/household-year totals $27 million for CP and $40 million for DE ($1986).

Conclusions. An interruptible water heating program conserves power at a cost of $151/kW for the hardware/installation and $928/kW for all costs combined ($704/kW at a seven percent discount rate).

Figure 9-6



Source: Detroit Edison Co., 1974-75 water heating load study

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LOAD IMPACT WORKSHEET: Technical Potential

UTILITY:	Consumers Power
TECHNOLOGY:	Water Heater Interruption
END USES:	Water Heating
DISCOUNT RATE:	3.00%
1. BASELINE DATA:	
Maximum Div'd Demand @ System Peak (summer)	0.50 kW
Average Diversified Load Shift (system level)	0.58 kW
Average Diversified Load Shift (at the meter)	0.50 kW
Payback Fraction	250%
Duration of Control	4 hours
Time of Payback Spike	5:00 PM
Payback Spike (delay = 1 hour)	1.44 kW
Change in Energy Consumption (% of annual use)	0.00%
2. PROGRAM COST ($1985 per participating customer):	
Annual Rebate	$30
NPV 20 year Rebate	$446
Equipment & Installation Cost	$87
3. PENETRATION:	
Eligibility Criteria:	Electric Water Heating
Number of Available Households	411,970 households
Target population	59,619 households
4. SYSTEM-WIDE IMPACTS:	
Baseline System Peak (August 1984 2:00 PM)	4,840,000 kW
Baseline System Demand @ Payback Time	4,720,000 kW
Maximum Shiftable Load	120,000 kW
Load Shift for All Participating Customers	34,281 kW
Program-based System Peak at 2:00 PM	4,805,719 kW
Payback Spike Attenuation	1.00
Payback Spike	85,703 kW
Program-based System Demand at Payback Time	4,805,703 kW
Net Load Reduction	34,281 kW
5. PROGRAM COST-EFFECTIVENESS ($1985):	
Total Capital Costs	$5,186,887
NPV of 20 Annual Rebates	$26,609,580
---> Cost of Conserved Peak Power (capital cost)	$151 /kW
---> Cost of Conserved Peak Power (total cost)	$928 /kW

E. THERMAL STORAGE

END-USE:	Space heating
FUEL:	Electricity (peak power)
TECHNOLOGY:	Thermal Storage

GENERAL DESCRIPTION

Technology and Program Features

Load control strategy. Residential thermal storage (TS) systems use ordinary resistance electric heating elements to charge a storage medium such as water, brick, or phase-change materials with heat during off-peak hours. On-peak heating is provided by fans or pumps that deliver heated air, normally through the existing heating distribution system. Time-of-use rates or flat rebates are used as incentives to participants.

Thermal storage systems for residences have been used for load-leveling by European utilities in England, West Germany, Ireland and Switzerland. The combination of residential thermal storage and time-of-use (TOU) rates in Europe dates from the 1950s, motivated initially by the desire to convince gas customers to switch to electricity as a less expensive heating fuel alternative. Today, individual 3 kW room units are most common, with sales of 520,000 units (1500 MW) in 1984 alone. More than 1.5 million customers are on the time-of-use rates.

Although the Michigan utilities are currently summer-peaking, we consider this technology in the event that future demand management and energy conservation strategies might ultimately shift the annual peaks to winter.

How the program works. Thermal storage systems are installed in owner-occupied new or existing homes. Room units replace electric resistance heaters and central units replace ducted or hydronic central heating systems. After charging for an 8-hour period, the units can provide 16 hours of heat. The charging elements are activated by outdoor temperature sensors, with controls to avoid large spikes in demand. Pre-set time clocks can also be used to activate the charging elements. The capital costs may be paid either by the utility or by the homeowner.

As with any load management strategy, load during the system peak is reduced (fully eliminated in the case of TS) and shifted to an off-peak period several hours later. At this time, the on-peak load reduction reappears in the system load as a "payback spike." The payback spike can be flattened by staggering the time at which participating households come back on-line. For a small number of participants, the payback spike does not affect the system peak and hence staggering becomes unnecessary.

Hardware components. The core of thermal storage units tested by Consumers Power contained olivene bricks, which can reach a maximum temperature of 1,382°F (CP 1979). The units were heavily insulated and built-in safety devices prevent over-heating. If the units are located in basement areas, heat losses must be accounted for during sizing. Units are available in sizes from 1.7 to 30 kW storage. Central units may contain 90 cubic feet of storage area, and typically weigh 3,000 lbs, or 130 lbs/square foot. The room units attain surface temperatures of roughly 150°F. If the utility so chooses, a time-of-use meter is also incorporated in the system configuration.

Technology status and availability of hardware components. Large scale use of residential thermal storage systems has been underway in Europe since the 1950s. Experiments in the U.S. date back to the late 1970s. The literature identifies four U.S. manufacturers and one importer of European units.

The Tennessee Valley Authority began a thermal storage experiment in the summer of 1979 (TVA 1984). Seventy-five systems were purchased from three manufacturers. The Megtatherm, Inc. system was based on pressurized water, the OEM Products system used eutectic salts for thermal storage, and the Tennessee Plastics (TPI), Inc. system used ceramic brick for the storage medium. The TPI units were designed after the systems designed by the experienced English firm, Creda.

Utility programs. We have identified thermal storage programs conducted by fifteen utilities. Eight were in the TVA region, one in Michigan, one in New York, and five in Vermont and Maine. Customers are generally very pleased with their thermal storage systems. Of the customers with the ceramic brick TPI units, 95% rated them either good or excellent; 100% felt that the units heated their homes adequately; half had no difficulties with the equipment whatsoever. Of customers with individual units, 80% found their new heating systems superior to their old ones; 17% said they had less maintenance; and 11% said that they provided *better* heat.

One of the earliest U.S. programs was initiated by Consumers Power in the winter of 1978. The ten-installation project grew out of their TOU experiments, and employed units developed by a U.S. manufacturer in cooperation with the experienced English firm, Creda. Time clocks were used to activate the charging elements between 11 PM and 7 AM. TOU rates were available to the participants between the hours of 9:00 PM and 9:00 AM. Satisfied owners felt that the heaters were cost-effective. Consumers Power concluded that the systems operated reliably, maintained comfort, and shifted significant loads.

Forty-five homes installed individual room units for a test program overseen by Argonne National Laboratory (Argonne, 1982). Among five small utilities in Vermont and Maine, 358 customers already had thermal storage systems. They installed 1-3 kW of traditional electric resistance heating in the buildings as well. They encountered very few problems with installation, maintenance, or defective components. This study included a mid-day boost to raise heat for customers. The experience in England, however, has been that such practices can gradually lead to the creation of a new system peak at this time.

In the TVA experiment, data were collected from the summer of 1979 until May 1982 (TVA, 1984). Large storage water heaters, charged only during off-peak hours and controlled by time-of-day meters, were also installed in each home. The TOU rates were 4 cents per kWh off-peak and 5.1 cents per kWh on-peak—a very small price ratio compared with other TOU programs around the country. Control customers remained on the standard rates. The solid-state meters recorded consumption in the on- and off-peak periods and housed the controls for the thermal storage equipment. The timeclocks within meters were found to be accurate, with battery power capabilities in the event of power interruptions. The meters were simple for utility staff to operate, taking only one minute to program. The homes were instrumented and data acquired on loads for the entire home, thermal storage unit, and water storage tanks. Another program evaluated hydronic systems in fifty Long Island homes (ORNL 1983).

PROGRAM EXPERIENCE

Program Impacts

Program impacts as found in Consumers Power's thermal storage experiment are shown in Fig. 9-7.

Incentive levels. Annual bill reductions for TVA participants ranged from $130 to $330 as derived from TOU rates. These rebates had to be large enough to provide a reasonable return to homeowners buying their thermal storage systems.

Consumers Power offered TOU rates of 2.7 cents per kWh. Customers attained three to four year paybacks. In cases where the TS units are purchased by the utility, little or no incentive should be necessary given that the new units replace aging existing heating systems and that improved heating service is likely.

Average savings per customer. Per-customer savings are by definition equivalent to the diversified demand for electric space-heating. A valuable characteristic of the thermal storage approach is that peak demand is not highly dependent on temperature because charging occurs off-peak when temperatures are relatively moderate.

Argonne reported 5 kW/customer diversified savings. Notably, the thermal storage systems, if used to replace all the direct heating units in the utility, would raise their system load factor from 0.69 to 0.82.

In the TVA trials, typical off-peak electricity consumption for the homes increased from 65 to 84%. Load reductions during peak hours on the peak winter day were between 8.2 and 9.3 kW per home. The storage water heaters achieved additional load reductions of 1.7 kW.

Payback spike. The Argonne experiment resulted in diversified payback spikes of 20 kW at midnight on the day of system peak, versus 5 kW for the control customers. The use of timers or direct control can increase the utilities control over the shape of payback spikes. The cost of these controls should be similar to those identified in the demand subscription analysis, or roughly $140 per customer.

Impacts on energy consumption. The TVA study did not observe increased electricity use in the test homes, except perhaps due to losses resulting from the placement of storage chambers in unheated basements. In the Argonne study, consumption for the control homes was typically well below that of the thermal storage homes. Increases in monthly electricity consumption (off-peak) were as high as 50%, but on average the difference was closer to 25%. The increased consumption may be useful for "valley-filling" during the nighttime hours.

Equipment reliability and service life. Equipment reliability was generally acceptable to the participants in the studies we reviewed. Manufacturers claim that there is little or no need for maintenance of room units and the field studies confirm that maintenance requirements were negligible. For those tests involving large, central units, maintenance costs were roughly $100 per unit per year. The one exception was the phase-change system tested by TVA, where "chronic" maintenance problems (and higher first cost) made the OEM systems far less attractive than the more conventional units. For the ceramic brick system, TVA found that the most common problem was that the solid-state circuit board controller would sometimes fail, requiring replacement. Infrequent service included replacement of the hydraulic core limit. TS systems can be expected to have useful lifetimes similar to those of conventional central heating systems.

Special considerations. Sizing is a very important factor in optimizing program technical- and cost-effectiveness. The design of TOU rates is important because it fixes the amount of time available to inexpensively charge the storage medium. A ten hour charging period would allow for a 16 kW system whereas an 8 hour charging period would require a 20 kW system. Oversizing, however, results in higher first costs, larger payback spikes and the possibility of unwanted heating via heat loss into the living space during non-heating hours. In general, the unit size is the product of a sizing factor (typically between 1.25 and 2.5) and the design heat loss of the building. Both the TVA and Argonne reports provide useful sizing methodologies.

Characteristics of the existing home must be taken into consideration in choosing between central or individual units. Existing hydronic or forced air systems are more adaptable to central systems, while existing electric resistance heating is more logically replaced with individual room units.

Socio-economic characteristics of participants. Customers in the TVA experiment were affluent. Over 90% had homes with three or more bedrooms, 34% had microwave ovens, and 66% owned separate freezers.

Costs of Thermal Storage

Equipment and maintenance costs. The capital cost of the 15 kW Consumers Power system was $1,492 ($1985). Installation added $732. In the TVA study, the cost of the most reliable unit was $1,900 plus $2,088 for installation. The high installation costs reflect, in part, the learning time spent by the contractors, removal of existing systems, and installation of the storage water heaters. Distribution system costs are exogenous to the evaluation because thermal storage systems use existing ductwork or hydronic heating coils. Costs reported for new homes may be less than those for retrofit applications, although this was not borne out in the Argonne experience. Maintenance costs were roughly $10 per month, probably higher than todays costs by a factor of five due to improvements in equipment design and circuitry.

We assume a cost of $25/year for maintenance, higher costs may occur in the first year or two while "commissioning" the system. The net present value of these maintenance costs is $413. An Ohio firm, TPI, currently imports the Creda units in a range of sizes. Based on discussions with TPI, we adopt $200/kW as a realistic estimate of capital and installation cost.

Program rebate costs. A fair assumption is that the utility gives the thermal storage equipment to the consumer and that there is no additional incentive in the form of a rebate. We consider the conservative case, however, of a $30/year incentive, the level of demand-control programs currently operating in Michigan and California. The rebate may be provided through a direct payment or TOU rates. The net present value of this rebate is $446/customer, that of a $20 rebate is $330.

Costs of Conserved Peak Power

We estimate that a typical electrically heated single family home in Michigan has a diversified demand of 4.3 kW during winter peak (at the meter), or 4.9 kW at the system level. With a fraction in use of 0.64, the non-coincident demand becomes 6.72 kW. Adding a sizing factor of 2.0 and a 50% oversizing margin, we arrive at a 20 kW system size. At $200/kW capacity, which shifts far less than 1 kW of demand, the capital and installation costs cost is $4,031. Adding annual maintenance costs brings the cost of conserved peak power to $815/kW ($1985). The addition of a $30/year incentive raises the CCPP to $981/kW, including capital, maintenance and incentive costs.

The results are, of course, highly sensitive to the diversified power savings. The utilities should investigate the applicability of thermal storage to electric heating customers with higher-than-average demand, i.e., targeted to high-use customers, the cost-effectiveness of thermal storage can increase substantially.

TECHNICAL AND ACHIEVABLE POTENTIAL

General

Eligible fraction. Based on the criteria that participating customers must currently be using electric space heating, 1.6% of DE's customers and 4.2% of CP's qualify. This corresponds to 51,000 participants in CP's service area and 26,000 participants in DE's. In our base case only single-family homes, 53% of the customer base, participate. Encouraging the use of room units will encourage adoption of the electrically-heated "warm rooms" strategy.

Maximum Potential Scenario

In 1984, the contribution to wintertime system peak of the residential class was 977 MW for CP and 1,600 MW for DE. Across the entire residential sector in Michigan, diversified heating loads are 2.3 kW for CP and 3.6 kW for DE. Our calculations indicate that single-family dwellings have at-the-meter loads of 4.3 kW.

The load shift attained is 133 MW for all eligible CP customers, and 68 MW for eligible DE customers. For 1984 winter conditions, their program-based system peaks are reduced to 4,284 and 5,881 MW, respectively.

CUMULATIVE INVESTMENT AND PROGRAM COSTS ($1985)

Investment. The initial capital investment of $4,031 per home results in a $108 million cost for CP and a $56 million cost for DE.

Program Costs. In the case of rebates, 20-year net present value of annual rebates of $30/household-year totals $12 million for CP and $6 million for DE. Maintenance costs add another $10 million for CP and $5 million for DE, or $75/kW.

Conclusions. The results are sensitive to demand savings and rebate levels. More detailed analyses must be conducted by the utility to yield more precise estimates of potentials. Thermal storage systems conserve power at a cost of $815/kW for the capital and installation costs and $981/kW including ongoing maintenance. For a seven percent discount rate, the CCPP is $933. The annual rebate may not be necessary if the thermal storage system is paid for by the utility.

LOAD IMPACT WORKSHEET: Technical Potential	
UTILITY:	Consumers Power
TECHNOLOGY:	Thermal Storage
END USES:	Space Heating
DISCOUNT RATE:	3.00%
1. BASELINE DATA:	
Average Diversified Load Shift (system level)	4.94 kW
Average Diversified Load Shift (at the meter)	4.30 kW
Fraction in Use	0.64
Sizing Factor	2.00
Thermal Storage System Size	20.16 kW
Payback Spike	23.18 kW
Duration of Control	16 hours
Time of Payback Spike (delay = 5 hours)	12:00 AM
Change in Energy Consumption (% of annual use)	10.00%
Saturation of Single-Family Homes	53%
2. PROGRAM COST ($1985 per participating customer):	
Annual Rebate	$30
NPV 20 Year Rebate	$446
Equipment Cost + Installation	$200 /kW
Total Installation Cost	$4,031
Annual Operation & Maintenance Cost	$25
3. PENETRATION:	
Eligibility Criteria:	Electric Space Heating
Number of Available Households	51,000 households
Target Population	27,030 households
4. SYSTEM-WIDE IMPACTS:	
Baseline System Peak (January 1984 11:00 AM)	4,418,000 kW
Baseline System Demand at Payback Time	2,721,000 kW
Maximum Shiftable Load	1,697,000 kW
Load Shift for All Participating Customers	133,663 kW
Program-based System Peak at 7:00 PM	4,284,337 kW
Payback Spike Attenuation	1.00
Payback Spike	626,547 kW
Program-Based System Demand At Payback Time	3,347,547 kW
Net Load Reduction	133,663 kW
5. PROGRAM COST-EFFECTIVENESS ($1985):	
Total Capital Costs	$108,964,688
NPV of 20 Annual Rebates	$12,064,144
NPV of 20 years Operation & Maintenance Costs	$10,053,454
----> Cost of Conserved Peak Power (capital cost)	$815 /kW
----> Cost of Conserved Peak Power (total cost)	$981 /kW

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10. ENVIRONMENTAL IMPACTS

Waste Disposal Impacts of Appliance Rebate Programs

We briefly present a back-of-the envelope discussion of the waste disposal impacts of the assumed appliance efficiency programs. Our conclusion is that the impact of these programs amounts to less than 1 percent of Michigan's solid waste disposal tonnage.

Outside of the bounty program for second refrigerators it is not clear that more appliances will be retired in the study period in response to demand-side programs. Industry has consistently argued that future efficiency standards will *reduce* sales, because consumers will react to higher first costs rather than to lower life cycle costs. If this view is correct then rebate programs might have no greater effect than reinstituting the original sales and retirement volumes that would have been achieved without demand-side programs.

Surveys of appliance rebate program participants that specifically addressed the question of early retirement found that participants generally do not time their appliance purchase on the basis of the rebates.

The one rebate program for which an additional disposal need will definitely arise is the bounty program for inefficient second refrigerators. Such a program would create a one-time increment of additional "junk". For a bounty program, the order of magnitude of the additional disposal needs is very small. Assuming 0.8 million second refrigerators and 3.2 million first units, and a reduction in second refrigerator life from 6 to 3 years, the number of units that would be disposed of annually would increase by 3.3 percent or 133,000 units. Some fraction of this volume will be recycled, another fraction will be crushed and compacted before disposal. Assuming no recycling, the weight of these refrigerators, at 200 lbs. average shipping weight, is about 12,000 tons. The total annual waste disposal in the state of Michigan is 10 million tons/year. Thus, the increase in disposal tonnage from the rebate program would amount to 0.12 percent.

Chlorofluorocarbon Impacts of Insulation

One of the potentially most significant environmental impacts of demand-side measures such as better refrigerators and building shells that may use polyurethane foam insulation is the related release of climate-sensitive chlorofluorocarbons. Demand-side measures bring with them a strong reduction in other climate-sensitive emissions, notably CO_2. We were unable to assess the net impact of these reductions and possible CFC emission increases.

Fortunately, substitutes for these materials are easily available in building insulation applications, where space considerations are not as restrictive as in refrigerator equipment insulation. In the latter case, evacuated panels are a possible solution. These are currently under development by the major manufacturers. With increasing certainty about the ozone-depleting impacts of CFCs, legislation can be expected that will further restrict and regulate the use of these chemicals. A major chemical manufacturer has announced that a substitute can be provided if the price of the CFCs is forced to rise by about a factor of five. Michigan's MEOS project should monitor developments in this area and ensure that its demand-side programs in the building sector do not add to the current emission levels.

Air Quality Considerations

Recent research has suggested that poor indoor air quality may be responsible for a variety of ailments and illnesses (Turiel 1985). The principal pollutants are radon, formaldehyde, volatile organic compounds, and carbon monoxide. Each causes significantly different biological reactions. For example, formaldehyde irritates the eyes and upper nasal passages and causes headaches. Long term exposure to radon can cause lung cancer. However, it is difficult to design epidemiological studies capable of associating a risk to different concentrations of each chemical. A major problem is that cigarette smoking -- both active and passive -- overwhelms any health effects from other indoor pollutants. Moreover, only recently have sampling techniques become cheap enough to permit long-term monitoring of these pollutants (EA&R 1986). So better estimates of health risk, based on more houses and longer sampling periods, will soon be available.

Radon appears to be an average indoor health risk in Michigan homes relative to other states. The Terradex Corp., the largest analyzer of radon samples has processed 44 radon samples from Michigan homes (Energy Design Update 1985). Since most homes had multiple samples, the survey represents significantly fewer than 44 homes. Of these, about 23% of the samples were above the EPA warning level. However, the survey was strongly biased towards houses suspected of having high radon concentrations, so these early results must be treated with great skepticism.

Since MEOS deals only with electrically-heated homes, carbon monoxide and combustion-generated pollutants are not present in significant quantities. Formaldehyde and other volatile organics from building materials, furniture, and household chemicals will be present in unpredictable quantities. Of course, cigarette smoke is by far the greatest indoor pollutant, both in concentration of pollutant and number of homes affected.

The goals of energy conservation and indoor air quality conflict when conservation measures reduce the amount of fresh air circulating in the building. Fresh air serves to remove (or at least dilute) the air pollutants. On the other hand, fresh outside air must be conditioned -- either heated or cooled -- which requires energy. Heating the fresh air typically accounts for 20 - 30% of a building's heating load, but can be as much as 40% in a leaky building.

U.S. houses have traditionally relied on air infiltration, that is, the unintentional entry of air through cracks and open doors and windows, to provide sufficient fresh air. Improved building techniques have resulted in sealing many of the inadvertent leaks in the building shells. In addition, new building materials and furniture have greater amounts of some pollutants. As a consequence, sufficient air flow must be designed rather than taken for granted. Ventilation systems must be installed in houses having low infiltration rates. These systems replace the stale, polluted indoor air with (presumably) fresh outside air. Ventilation systems coupled to air-to-air heat exchangers will recover some of the heat and reduce energy loss. Typically 60%, and sometimes as much as 90%, of the heat in the exhaust air can be recovered, so the energy savings can be substantial (BPA 1986).

Heating costs and indoor air quality depend on the air exchange rate. But there is considerable uncertainty regarding typical long-term infiltration rates. Short term (on the order of minutes) measurements made with blower doors find higher infiltration rates than that with long-term (on the order of months) results from passive samplers. In a preliminary analysis, Bonneville Power Administration found that the average air change rate for current practice homes was about 0.6 based on blower doors but only 0.3 with passive samplers. A careful reconciliation has not yet been undertaken.

We incorporate in our building shell retrofit savings estimates only a limited amount of weatherstripping and sealing, equivalent to 10 percent of total savings. Where significant indoor air pollution problems from sources such as Radon exist, these might require the installation of a forced ventilation system irrespective of the level of air tightness.

For new houses, we assumed that the house would be built to a low infiltration standard through use of a vapor barrier, but included an air-to-air heat exchanger in the cost of a low infiltration package. Over twenty models of residential heat exchangers are available in the US (EA&R 1985, Energy Design Update 1986). The recovered heat can also be used to heat water rather than incoming fresh air (Gehring 1986). A small heat pump uses the warm exhaust air as a heat source. Small, controllable vents in the windows provide the fresh incoming air. The exhaust air heat pump system has the advantage that the incoming and outgoing air streams do not need to be carefully balanced and tends to be less susceptible to fluctuations in building conditions. Of course, the exhaust air heat pump system has drawbacks, too, including satisfactory matching of exhaust air flow with heat recovery coils.

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APPENDIX A

END-USE RESULTS, CONSUMERS POWER AND DETROIT EDISON

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Water Heating:

Air Conditioning:

Space Heating:

Scenario Forecasts of UEC and GWh by End-Use—Examples:

EXPLANATION OF SCENARIO TABLE NOMENCLATURE

The tables showing the scenario calculations in this appendix are organized with the same basic nomenclature as the MEOS forecast. The first letter denotes the end-use, using the same abbreviations as the MEOS forecast. These are basically self-explanatory. For example, H stands for space heating, R for refrigerator, etc.

The next two letters preceeding the hyphen denote the utility company: CP for Consumers Power, and DE for Detroit Edison. Where only one letter is shown before the hyphen, the table refers to the two service territories combined.

The letter behind the hyphen denotes the type of data contained in the table. A stands for GWh figures, B for winter peak demand, C for summer peak demand, and D for program costs.

Total yearly savings are not previous year savings plus new sales, due to retirements and behavior function effects (e.g. change in household size).

Totals in these tables may not add exactly due to rounding.

Table M-A:

Scenario of potential electricity savings 1984-2005,

CP and DE territories combined, GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	MEOS Forecast GWh	MEOS Forecast Index	Program Scenario GWh	Program Scenario Index	Technical Potential GWh	Technical Potential Index	Savings over MEOS (GWh) From New Sales Prog	Savings over MEOS (GWh) From New Sales TechP	Savings over MEOS (GWh) Total Yearly Prog	Savings over MEOS (GWh) Total Yearly TechP
1984	12484	12484	100	12484	100	12484	100	0	0	0	0
1985	12545	12528	99	12527	99	12523	99	2	5	2	5
1986	12603	12560	99	12553	99	12547	99	-4	2	6	12
1987	12655	12578	99	12561	99	12553	99	-4	6	12	22
1988	12661	12535	99	12416	98	11175	88	85	1328	116	1360
1989	12669	12490	98	12186	96	9810	78	244	1753	304	2581
1990	12661	12420	98	11810	93	8701	68	448	2071	612	3718
1991	12640	12334	97	11300	89	8288	65	644	1558	1037	4047
1992	12621	12250	97	10777	85	7863	62	754	1667	1471	4387
1993	12608	12171	96	10263	81	7460	59	849	1738	1909	4710
1994	12602	12101	96	9774	77	7185	57	933	1784	2325	4915
1995	12604	12082	95	9629	75	6922	54	791	1833	2504	5105
1996	12611	11972	94	9338	74	6684	53	834	1878	2631	5288
1997	12610	11887	94	9127	72	6394	50	891	1949	2760	5491
1998	12626	11814	93	8944	70	6128	48	930	2001	2870	5687
1999	12675	11785	92	8809	69	5922	46	963	2010	2972	5864
2000	12734	11788	92	8727	68	5787	45	982	1988	3059	5998
2001	12812	11803	92	8672	67	5674	44	1016	2021	3132	6129
2002	12871	11793	91	8598	66	5545	43	1035	2025	3196	6249
2003	12929	11790	91	8529	65	5444	42	1062	2048	3262	6342
2004	12988	11784	90	8450	65	5323	40	1104	2098	3336	6466
2005	13044	11781	90	8373	64	5195	39	1124	2108	3408	6587
Total	279253	266678	95	225747	80	175705	62	14683	33869	40924	90962

Table M-B:

Scenario of potential winter peak power savings 1984-2005,

CP and DE territories combined, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast MW	MEOS Forecast Index	Program Scenario MW	Program Scenario Index	Technical Potential MW	Technical Potential Index	Savings over MEOS (MW) From New Sales Prog	Savings over MEOS (MW) From New Sales TechP	Savings over MEOS (MW) Total Yearly Prog	Savings over MEOS (MW) Total Yearly TechP
1984	2359	2359	100	2359	100	2359	100	0	0	0	0
1985	2372	2367	99	2360	99	2358	99	6	8	5	8
1986	2395	2382	99	2371	98	2367	98	7	11	10	14
1987	2413	2393	99	2378	98	2372	98	11	17	15	22
1988	2428	2399	98	2362	97	2076	85	28	317	34	322
1989	2443	2406	98	2328	95	1791	73	66	394	80	612
1990	2454	2407	98	2252	91	1518	61	118	452	155	888
1991	2466	2407	97	2146	86	1470	59	165	279	261	939
1992	2475	2407	97	2037	82	1421	57	185	300	370	991
1993	2486	2410	96	1926	77	1378	55	205	318	479	1035
1994	2497	2409	96	1823	73	1338	53	223	334	589	1070
1995	2509	2408	95	1784	71	1305	52	172	347	524	1105
1996	2524	2412	95	1759	69	1274	50	184	362	652	1137
1997	2530	2408	95	1726	68	1233	48	197	379	683	1171
1998	2544	2407	94	1701	66	1203	47	203	392	707	1204
1999	2558	2411	94	1682	65	1172	45	215	402	729	1234
2000	2576	2416	93	1668	54	1153	44	224	409	747	1254
2001	2596	2427	93	1660	63	1136	43	233	419	765	1288
2002	2608	2427	93	1646	63	1116	42	241	426	784	1311
2003	2624	2434	92	1633	62	1101	41	344	250	893	1145
2004	2639	2434	92	1618	61	1078	40	352	273	907	1171
2005	2652	2439	91	1604	60	1052	39	359	284	923	1202

Table M-C:

Scenario of potential summer peak power savings 1984-2005,

CP and DE territories combined, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	2498	2498	100	2498	100	2498	100	0	0	0	0
1985	2521	2521	100	2520	99	2520	99	0	0	0	0
1986	2511	2506	99	2503	99	2503	99	1	1	2	2
1987	2496	2486	99	2479	99	2479	99	2	2	8	8
1988	2480	2463	99	2436	98	2281	91	13	168	25	183
1989	2463	2438	98	2386	96	2101	85	31	219	54	339
1990	2448	2416	98	2323	94	1928	78	51	256	92	482
1991	2433	2389	98	2251	92	1833	75	70	220	140	559
1992	2419	2363	97	2173	89	1735	71	84	233	189	632
1993	2405	2342	97	2100	87	1636	68	96	239	243	705
1994	2402	2331	97	2040	84	1574	65	102	235	289	753
1995	2401	2317	96	2001	83	1517	63	94	239	316	799
1996	2402	2307	96	1974	82	1468	61	98	240	333	839
1997	2403	2294	95	1942	80	1414	58	103	246	352	879
1998	2404	2284	95	1915	79	1358	56	108	254	370	927
1999	2412	2279	94	1894	78	1314	54	111	253	386	965
2000	2423	2279	94	1880	77	1280	52	113	248	400	1001
2001	2433	2279	93	1864	76	1235	50	119	264	415	1047
2002	2437	2271	93	1851	75	1187	48	121	261	426	1086
2003	2445	2266	92	1833	74	1174	48	123	268	435	1092
2004	2450	2261	92	1819	74	1161	47	127	272	440	1098
2005	2451	2254	91	1805	73	1144	46	129	269	447	1106

Table M-D:

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

CP and DE territories combined.

Year	Technical Potential Investment Costs ($M)		Program Scenario Costs ($M)						Discounted Ratepayer Costs ($M)			
			Administration		Rebate		Ratepayer		3% Discount Rate		7% Discount Rate	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	453	453	2	2	16	16	18	18	11	11	10	10
1989	458	911	5	7	31	47	36	54	19	29	16	26
1990	469	1380	6	13	57	114	73	127	32	62	27	52
1991	201	1581	9	22	97	211	106	233	39	101	31	83
1992	211	1792	9	31	108	319	117	350	37	138	28	112
1993	216	2008	9	40	118	437	127	477	34	172	25	137
1994	200	2208	9	49	123	560	132	610	30	202	21	158
1995	207	2415	4	53	69	629	73	682	14	216	10	168
1996	198	2613	4	57	67	696	71	753	12	227	8	175
1997	200	2813	4	61	70	766	74	827	10	238	6	182
1998	210	3023	2	63	56	823	59	886	7	245	4	186
1999	208	3231	2	66	55	878	57	943	6	250	3	189
2000	189	3420	2	68	49	927	51	995	4	255	2	192
2001	179	3599	1	69	7	934	8	1003	1	255	0	192
2002	172	3772	1	71	7	941	8	1011	1	256	0	192
2003	179	3951	1	72	4	945	5	1016	0	256	0	192
2004	203	4154	2	73	4	949	6	1022	0	256	0	193
2005	203	4357	2	75	4	953	5	1028	0	256	0	193
Total	4355.92		74.57		952.72		1027.42		256.35		192.7	

Table CP-A:
Scenario of potential electricity savings 1984-2005,
Consumers Power, GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/ Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	5828	5828	100	5828	100	5828	100	0	0	0	0
1985	5862	5855	99	5861	99	5859	99	-4	-2	-4	-2
1986	5880	5864	99	5869	99	5866	99	-11	-8	-6	-3
1987	5931	5899	99	5905	99	5901	99	-16	-11	-7	-2
1988	5946	5888	99	5836	98	5193	87	35	677	52	695
1989	5961	5882	98	5733	96	4672	78	119	956	148	1310
1990	5963	5865	98	5562	93	3993	66	219	1162	294	1863
1991	5960	5823	97	5325	89	3801	63	328	968	498	2022
1992	5958	5794	97	5085	85	3607	60	395	1036	706	2184
1993	5982	5786	96	4866	81	3431	57	462	1100	921	2355
1994	5960	5734	96	4617	77	3281	55	509	1109	1118	2463
1995	5962	5701	95	4485	75	3144	52	470	1150	1216	2555
1996	5966	5669	95	4380	73	3014	50	501	1184	1287	2656
1997	5971	5642	94	4288	71	2889	48	529	1215	1354	2752
1998	5985	5619	93	4208	70	2776	46	554	1246	1409	2843
1999	6004	5607	93	4146	69	2690	44	573	1251	1458	2916
2000	6033	5611	93	4107	68	2632	43	587	1242	1502	2978
2001	6085	5633	92	4092	67	2595	42	609	1262	1543	3038
2002	6110	5629	92	4059	66	2547	41	615	1255	1571	3084
2003	6138	5630	91	4027	65	2506	40	631	1267	1604	3121
2004	6164	5632	91	3994	64	2461	39	652	1288	1638	3170
2005	6189	5632	91	3955	63	2402	38	666	1300	1676	3230
Total	131836	126213	95	106228	80	80988	61	8421	20647	19978	45218

Table CP-B:
Scenario of potential winter peak power savings 1984-2005,
Consumers Power, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	1136	1136	100	1136	100	1136	100	0	0	0	0
1985	1143	1141	99	1139	99	1138	99	1	3	1	3
1986	1152	1148	99	1146	99	1143	99	2	4	3	5
1987	1166	1159	99	1154	98	1151	98	2	5	4	8
1988	1173	1163	99	1146	97	1000	85	11	160	15	165
1989	1186	1171	98	1133	95	859	72	30	211	40	310
1990	1189	1171	98	1096	92	726	61	55	248	75	445
1991	1197	1174	98	1048	87	704	58	79	176	125	472
1992	1202	1174	97	998	83	679	56	91	188	178	498
1993	1213	1183	97	950	78	660	54	104	202	229	523
1994	1214	1178	97	900	74	639	52	114	206	280	540
1995	1220	1179	96	878	71	622	50	96	216	300	560
1996	1228	1182	96	863	70	605	49	102	224	317	577
1997	1231	1180	95	850	69	586	47	108	231	332	594
1998	1240	1183	95	839	67	574	46	111	238	345	609
1999	1245	1185	95	830	66	560	44	117	242	356	622
2000	1253	1189	94	825	65	552	44	121	246	363	637
2001	1266	1198	94	823	66	546	43	127	252	374	649
2002	1272	1199	94	817	64	540	42	129	253	384	559
2003	1280	1203	93	812	63	533	41	227	80	485	482
2004	1287	1204	93	804	62	525	40	229	86	491	494
2005	1293	1208	93	799	61	514	39	231	92	497	509

Table CP-C:
Scenario of potential summer peak power savings 1984-2005,
Consumers Power, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast MW	MEOS Forecast Index	Program Scenario MW	Program Scenario Index	Technical Potential MW	Technical Potential Index	Savings over MEOS (MW) From New Sales Prog	Savings over MEOS (MW) From New Sales TechP	Savings over MEOS (MW) Total Yearly Prog	Savings over MEOS (MW) Total Yearly TechP
1984	915	915	100	915	100	915	100	0	0	0	0
1985	923	923	100	924	100	924	100	0	0	0	0
1986	923	922	99	922	99	922	99	-1	-1	-1	-1
1987	931	926	99	926	99	926	99	-1	-1	0	0
1988	933	924	99	916	98	838	89	5	83	8	86
1989	935	924	98	903	96	764	81	15	120	21	161
1990	936	922	98	883	94	694	74	26	148	38	226
1991	932	913	97	853	91	659	70	38	138	60	256
1992	929	903	97	821	88	622	66	47	146	83	283
1993	930	902	96	794	85	588	63	56	155	108	313
1994	926	894	96	766	82	566	61	60	150	129	327
1995	926	889	96	748	80	547	59	61	155	140	341
1996	927	885	95	738	79	528	56	65	158	147	356
1997	928	880	94	724	78	506	54	69	166	156	373
1998	928	876	94	711	76	483	52	73	171	164	393
1999	931	873	93	701	75	464	49	76	171	171	407
2000	936	873	93	694	74	451	48	77	168	179	422
2001	943	876	92	691	73	440	46	80	172	185	436
2002	945	873	92	686	72	427	45	81	171	189	446
2003	950	873	91	681	71	422	44	83	173	193	452
2004	954	872	91	676	70	418	43	85	175	196	455
2005	955	872	91	671	70	411	43	87	175	199	460

Table CP-D:
Annual and Cumulative costs of demand side resources (1985$), 1984-2005,
Consumers Power.

Year	Technical Potential Investment Costs ($M) Annual	Technical Potential Investment Costs ($M) Cumulative	Program Scenario Costs ($M) Administration Annual	Administration Cumulative	Rebate Annual	Rebate Cumulative	Ratepayer Annual	Ratepayer Cumulative	Discounted Ratepayer Costs ($M) 3% Discount Rate Annual	3% Discount Rate Cumulative	7% Discount Rate Annual	7% Discount Rate Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	216	216	1	1	9	9	10	10	8	8	7	7
1989	220	436	3	4	17	26	20	30	13	21	11	18
1990	223	659	3	7	35	61	38	68	23	44	19	38
1991	94	753	4	12	49	109	53	121	30	74	24	61
1992	98	851	5	16	54	164	59	180	30	104	23	84
1993	106	957	5	21	59	223	64	244	29	133	22	106
1994	84	1042	5	26	61	283	65	309	27	160	19	125
1995	94	1136	2	28	38	321	41	350	15	176	10	135
1996	95	1231	2	31	38	359	40	389	14	189	9	144
1997	102	1333	2	33	37	396	39	429	12	202	8	152
1998	108	1441	1	34	27	423	29	457	8	210	5	157
1999	106	1547	1	36	27	450	28	485	7	217	4	161
2000	97	1645	1	37	24	474	26	511	6	223	3	165
2001	74	1719	1	38	4	478	5	516	1	224	1	165
2002	71	1790	1	39	4	482	5	520	1	225	0	166
2003	74	1864	1	39	2	483	2	522	0	225	0	166
2004	88	1952	1	40	2	485	3	525	0	225	0	166
2005	90	2042	1	41	2	487	3	528	0	225	0	166
Total	2041.21		40.59		486.37		527.34		225.33		166.2	

Table DE-A:
Scenario of potential electricity savings 1984-2005,
Detroit Edison, GWh ~~indices~~ based on Frozen Efficiency = 100.

Year	Frozen (GWh/ Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	6656	6656	100	6656	100	6656	100	0	0	0	0
1985	6683	6673	99	6666	99	6664	99	6	7	6	7
1986	6723	6696	99	6684	99	6681	99	7	10	12	15
1987	6724	6677	99	6656	98	6652	98	12	17	19	24
1988	6716	6647	98	6580	97	5982	89	50	651	64	665
1989	6708	6608	98	6453	96	5338	79	125	797	156	1271
1990	6698	6565	98	6248	93	4708	70	229	909	318	1855
1991	6680	6511	97	5975	89	4487	67	318	590	539	2025
1992	6663	6456	96	5692	85	4256	63	359	631	765	2203
1993	6626	6385	96	5397	81	4029	60	387	636	988	2355
1994	6642	6367	95	5157	77	3904	58	424	675	1207	2462
1995	6642	6331	95	5044	75	3778	56	321	683	1288	2550
1996	6646	6303	94	4958	74	3670	55	333	694	1344	2632
1997	6639	6246	94	4839	72	3505	52	362	734	1406	2739
1998	6641	6196	93	4736	71	3350	50	376	755	1461	2844
1999	6671	6178	92	4663	69	3232	48	390	759	1514	2948
2000	6701	6177	92	4620	68	3155	47	395	746	1557	3020
2001	6727	6170	91	4580	68	3079	45	407	759	1589	3091
2002	6761	6164	91	4539	67	2998	44	420	770	1625	3165
2003	6791	6160	90	4502	66	2938	43	431	781	1658	3221
2004	6824	6152	90	4466	65	2862	41	452	810	1698	3295
2005	6855	6149	89	4418	64	2793	40	458	808	1732	3357
Total	147417	140465	95	119519	81	94717	64	6262	13222	20946	45744

Table DE-B:
Scenario of potential winter peak power savings 1984-2005,
Detroit Edison, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	1223	1223	100	1223	100	1223	100	0	0	0	0
1985	1229	1226	99	1221	99	1220	99	4	5	4	5
1986	1243	1234	99	1226	98	1224	98	5	7	7	9
1987	1247	1234	98	1224	98	1221	97	10	13	11	14
1988	1253	1236	98	1216	97	1076	85	17	158	19	157
1989	1257	1235	98	1195	95	932	74	36	183	40	302
1990	1265	1236	97	1156	91	792	62	63	204	80	443
1991	1269	1233	97	1097	86	766	60	86	103	136	467
1992	1273	1233	96	1039	81	742	58	94	112	192	493
1993	1273	1227	96	976	76	716	56	101	116	250	512
1994	1283	1231	95	923	71	699	54	110	127	309	530
1995	1289	1229	95	906	70	683	52	76	132	324	545
1996	1296	1230	94	896	69	669	51	82	138	335	560
1997	1299	1228	94	876	67	647	49	89	148	351	577
1998	1304	1224	93	862	66	629	48	92	154	362	595
1999	1313	1225	93	852	64	612	46	98	160	373	612
2000	1323	1227	92	843	63	601	45	102	163	384	627
2001	1330	1229	92	837	62	590	44	106	167	391	639
2002	1336	1228	91	829	62	576	43	112	173	400	652
2003	1344	1231	91	821	61	568	42	117	180	408	663
2004	1352	1230	90	814	60	553	40	123	187	416	677
2005	1359	1231	90	805	59	538	39	128	192	425	693

Table DE-C:

Scenario of potential summer peak power savings 1984-2005,

Detroit Edison, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW) From New Sales		Savings over MEOS (MW) Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	1583	1583	100	1583	100	1583	100	0	0	0	0
1985	1598	1598	100	1596	99	1596	99	1	1	1	1
1986	1588	1584	99	1581	99	1581	99	3	3	4	4
1987	1565	1560	99	1553	99	1553	99	4	4	8	8
1988	1547	1539	99	1520	98	1443	93	9	86	17	97
1989	1528	1514	99	1483	97	1337	87	16	99	33	178
1990	1512	1494	98	1440	95	1234	81	25	108	54	256
1991	1501	1476	98	1398	93	1174	78	33	83	80	303
1992	1490	1460	97	1352	90	1113	74	38	86	106	349
1993	1475	1440	97	1306	88	1048	71	39	85	135	392
1994	1476	1437	97	1275	86	1009	68	42	86	160	426
1995	1475	1428	96	1253	84	970	65	34	85	176	458
1996	1475	1422	96	1236	83	940	63	33	82	186	483
1997	1475	1414	95	1218	82	908	61	34	80	196	506
1998	1476	1408	95	1204	81	875	59	35	82	206	534
1999	1481	1406	94	1193	80	850	57	36	82	215	558
2000	1487	1406	94	1186	79	829	55	36	80	221	579
2001	1490	1403	94	1173	78	795	53	40	92	230	611
2002	1492	1398	93	1165	78	760	50	40	90	237	639
2003	1495	1393	93	1152	77	752	50	41	95	242	640
2004	1496	1389	92	1143	76	743	49	42	97	245	643
2005	1496	1382	92	1134	75	733	48	42	94	248	646

Table DE-D:

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

Detroit Edison.

Year	Technical Potential Investment Costs ($M)		Program Scenario Costs ($M) Administration		Program Scenario Costs ($M) Rebate		Program Scenario Costs ($M) Ratepayer		Discounted Ratepayer Costs ($M) 3% Discount Rate		Discounted Ratepayer Costs ($M) 7% Discount Rate	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	237	237	1	1	7	7	7	7	6	6	5	5
1989	238	475	2	3	14	21	16	24	11	17	9	14
1990	246	721	3	6	32	53	35	59	22	38	18	32
1991	107	828	4	10	49	101	53	112	29	68	23	56
1992	113	941	4	15	54	156	59	170	30	97	23	79
1993	110	1051	4	19	59	215	63	234	29	127	21	100
1994	116	1166	4	24	63	277	67	301	28	155	20	120
1995	113	1279	1	25	31	308	32	333	12	167	8	128
1996	102	1382	1	26	29	337	31	364	11	177	7	135
1997	98	1480	2	28	33	370	35	398	11	188	7	142
1998	102	1582	1	29	29	399	30	428	9	196	5	147
1999	101	1683	1	30	28	428	29	458	8	204	4	151
2000	92	1775	1	31	25	453	25	484	6	210	3	155
2001	105	1880	1	31	3	456	4	487	1	211	0	155
2002	101	1981	1	32	3	459	4	491	1	211	0	156
2003	106	2087	1	32	2	461	3	494	0	212	0	156
2004	115	2202	1	33	2	464	3	497	0	212	0	156
2005	113	2215	1	34	2	466	3	500	0	213	0	156
Total	2214.71		33.58		465.35		499.58		212.83		156.32	

Table R-A: Refrigerators

Scenario of potential electricity savings 1984-2005,

CP and DE territories combined, GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	→MEOS Forecast GWh	→MEOS Forecast Index	Program Scenario GWh	Program Scenario Index	Technical Potential GWh	Technical Potential Index	Savings over MEOS (GWh) From New Sales Prog	Savings over MEOS (GWh) From New Sales TechP	Savings over MEOS (GWh) Total Yearly Prog	Savings over MEOS (GWh) Total Yearly TechP
1984	4415	4415	100	4415	100	4415	100	0	0	0	0
1985	4435	4430	99	4430	99	4430	99	0	0	0	0
1986	4455	4437	99	4437	99	4437	99	0	0	0	0
1987	4463	4422	99	4422	99	4422	99	0	0	0	0
1988	4463	4391	98	4381	98	4283	96	9	128	9	128
1989	4460	4355	97	4325	96	4096	91	19	131	30	257
1990	4439	4292	96	4229	95	3883	87	33	140	63	399
1991	4417	4229	95	4115	93	3679	83	50	151	112	550
1992	4402	4173	94	3996	90	3447	78	64	175	176	725
1993	4389	4121	93	3880	88	3230	73	65	166	241	890
1994	4373	4068	93	3773	86	3108	71	64	163	295	959
1995	4353	4010	92	3667	84	2984	68	68	167	343	1026
1996	4332	3954	91	3572	82	2862	66	68	169	380	1092
1997	4299	3868	89	3449	80	2686	62	79	199	418	1184
1998	4277	3793	88	3340	78	2520	58	86	211	452	1274
1999	4279	3746	87	3258	76	2389	55	79	196	487	1358
2000	4291	3730	86	3221	75	2322	54	58	147	508	1408
2001	4317	3723	86	3193	73	2281	52	61	151	531	1462
2002	4337	3709	85	3157	72	2192	50	62	152	554	1520
2003	4360	3704	84	3126	71	2127	48	63	155	577	1575
2004	4385	3692	84	3077	70	2025	46	82	200	617	1668
2005	4412	3687	83	3034	68	1929	43	77	191	653	1758
Total	96353	88949	92	82497	85	69716	72	1087	2992	6446	19233

Table R-B: Refrigerators

Scenario of potential winter peak power savings 1984-2005,

CP and DE territories combined, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast MW	MEOS Forecast Index	Program Scenario MW	Program Scenario Index	Technical Potential MW	Technical Potential Index	Savings over MEOS (MW) From New Sales Prog	Savings over MEOS (MW) From New Sales TechP	Savings over MEOS (MW) Total Yearly Prog	Savings over MEOS (MW) Total Yearly TechP
1984	473	473	100	473	100	473	100	0	0	0	0
1985	474	474	100	474	100	474	100	0	0	0	0
1986	478	475	99	475	99	475	99	0	0	0	0
1987	477	473	99	473	99	473	99	0	0	0	0
1988	477	469	98	468	98	457	95	1	14	1	12
1989	477	467	97	464	97	438	91	2	14	3	29
1990	474	459	96	453	95	417	87	4	15	6	43
1991	473	451	95	440	93	393	83	5	16	11	59
1992	470	447	95	429	91	369	78	7	19	18	79
1993	469	442	94	414	88	347	73	7	18	26	95
1994	467	434	92	405	86	332	71	7	18	32	102
1995	465	428	92	392	84	319	68	7	18	37	110
1996	463	424	91	383	82	307	66	7	18	41	116
1997	459	414	90	369	80	286	62	9	21	45	126
1998	459	406	88	358	77	270	58	9	23	49	136
1999	458	401	87	349	76	255	55	8	21	52	144
2000	461	400	86	345	74	249	54	6	16	54	151
2001	462	399	86	342	74	241	52	6	16	55	156
2002	464	396	85	338	72	234	50	7	16	59	163
2003	466	396	84	335	71	227	48	7	16	61	168
2004	470	395	84	328	69	216	45	9	21	66	178
2005	472	394	83	325	68	206	43	8	20	70	188

Table R-C: Refrigerators

Scenario of potential summer peak power savings 1984-2005,

CP and DE territories combined. MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast MW	MEOS Forecast Index	Program Scenario MW	Program Scenario Index	Technical Potential MW	Technical Potential Index	Savings over MEOS (MW) From New Sales Prog	From New Sales TechP	Total Yearly Prog	Total Yearly TechP
1984	592	592	100	592	100	592	100	0	0	0	0
1985	594	594	100	594	100	594	100	0	0	0	0
1986	597	595	99	595	99	595	99	0	0	0	0
1987	598	592	98	592	98	592	98	0	0	0	0
1988	598	589	98	588	98	571	95	1	17	1	18
1989	597	583	97	579	96	549	91	3	18	4	35
1990	594	576	96	569	95	521	87	4	19	8	53
1991	592	567	95	553	93	493	83	7	20	15	74
1992	590	559	94	535	90	463	78	9	23	23	98
1993	588	552	93	519	88	432	73	9	22	33	120
1994	586	546	93	505	86	415	70	9	22	40	129
1995	584	538	92	491	84	400	68	9	22	46	138
1996	582	530	91	479	82	384	65	9	23	51	146
1997	577	519	89	462	80	360	62	11	27	56	158
1998	574	509	88	449	78	337	58	11	28	61	171
1999	573	500	87	437	76	320	56	11	26	66	182
2000	574	499	86	432	75	311	54	8	20	68	189
2001	579	499	86	428	73	303	52	8	20	72	196
2002	580	496	85	424	73	293	50	8	20	75	204
2003	585	496	84	420	71	285	48	8	21	79	212
2004	589	495	84	413	70	270	45	11	27	83	222
2005	591	495	83	407	68	258	43	10	28	88	235

Table R-D: Refrigerators

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

CP and DE territories combined.

Year	Technical Potential Investment Costs ($M) Annual	Cumulative	Program Scenario Costs ($M) Administration Annual	Administration Cumulative	Rebate Annual	Rebate Cumulative	Ratepayer Annual	Ratepayer Cumulative
1984	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0
1988	8	8	0	0	1	1	1	1
1989	12	20	0	0	1	2	1	2
1990	18	38	0	1	3	4	3	5
1991	23	62	0	1	5	9	5	10
1992	28	89	1	2	9	18	9	20
1993	29	119	1	2	11	29	12	32
1994	33	152	1	3	11	40	12	43
1995	36	188	1	4	11	51	12	55
1996	36	225	1	4	11	62	12	66
1997	47	272	1	5	14	76	15	82
1998	48	319	1	6	15	91	16	97
1999	45	364	1	7	14	105	15	112
2000	30	395	1	8	9	114	10	121
2001	33	427	1	8	2	116	2	124
2002	32	460	1	9	2	117	2	126
2003	34	493	1	10	2	119	2	129
2004	51	545	1	10	2	121	3	132
2005	50	595	1	11	2	123	3	135
Total	594.79		11.41		123.2		134.62	

Table RCP-A: Refrigerators

Scenario of potential electricity savings 1984-2005,

Consumers Power Service Territory — GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/ Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	1847	1847	100	1847	100	1847	100	0	0	0	0
1985	1859	1857	99	1857	99	1857	99	0	0	0	0
1986	1855	1848	99	1848	99	1848	99	0	0	0	0
1987	1859	1840	98	1840	98	1840	98	0	0	0	0
1988	1854	1820	98	1817	98	1773	96	3	47	3	47
1989	1854	1808	97	1796	96	1713	92	6	46	10	92
1990	1847	1781	96	1759	95	1636	88	11	51	21	144
1991	1841	1757	95	1715	93	1552	84	20	61	41	206
1992	1841	1740	94	1671	90	1460	79	27	74	68	279
1993	1850	1731	93	1633	88	1378	74	30	77	98	356
1994	1837	1701	92	1581	86	1310	71	25	65	120	391
1995	1829	1678	91	1531	83	1244	68	29	72	143	431
1996	1821	1647	90	1484	81	1177	64	31	75	163	471
1997	1816	1623	89	1446	79	1118	61	31	78	178	506
1998	1814	1603	88	1412	77	1064	58	36	85	190	540
1999	1816	1588	87	1385	76	1020	56	33	81	202	569
2000	1823	1584	86	1372	75	994	54	22	58	211	590
2001	1840	1586	86	1365	74	973	52	25	60	222	613
2002	1849	1580	85	1351	73	946	51	24	58	231	636
2003	1859	1580	84	1340	72	923	49	26	62	240	655
2004	1868	1573	84	1317	70	878	47	36	88	256	694
2005	1880	1570	83	1296	68	831	44	37	92	274	739
Total	40559	37337	92	34662	85	29379	72	461	1228	2671	7959

Table RCP-B: Refrigerators

Scenario of potential winter peak power savings 1984-2005,

Consumers Power Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	198	198	100	198	100	198	100	0	0	0	0
1985	199	199	100	199	100	199	100	0	0	0	0
1986	199	198	99	198	99	198	99	0	0	0	0
1987	199	197	98	197	98	197	98	0	0	0	0
1988	198	194	97	194	97	190	96	0	5	0	4
1989	199	194	97	193	96	183	91	1	5	1	11
1990	197	190	96	188	95	175	88	1	5	2	16
1991	197	187	94	183	92	166	84	2	7	4	22
1992	196	186	94	179	91	156	79	3	8	7	31
1993	198	186	93	174	87	148	74	3	8	10	38
1994	196	181	92	170	86	141	71	3	7	13	42
1995	196	179	91	163	83	133	67	3	8	15	46
1996	195	177	90	159	81	125	64	3	8	18	50
1997	194	173	89	156	79	119	61	3	8	19	54
1998	195	172	88	152	77	114	58	4	9	21	58
1999	194	170	87	148	76	109	56	4	9	22	60
2000	196	170	86	147	75	107	54	2	6	22	63
2001	197	170	86	146	74	103	52	3	7	23	65
2002	198	169	85	146	73	101	51	3	6	25	68
2003	199	169	84	144	72	98	49	3	7	25	70
2004	200	168	84	140	70	93	46	4	9	28	74
2005	201	168	83	139	69	89	44	4	10	29	79

Table RCP-C: Refrigerators

Scenario of potential summer peak power savings 1984-2005,
Consumers Power Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	247	247	100	247	100	247	100	0	0	0	0
1985	249	249	100	249	100	249	100	0	0	0	0
1986	248	248	100	248	100	248	100	0	0	0	0
1987	249	246	98	246	98	246	98	0	0	0	0
1988	248	244	98	244	98	238	95	0	6	0	6
1989	248	242	97	240	96	230	92	1	6	1	12
1990	247	239	96	237	95	219	88	2	7	3	19
1991	247	236	95	231	93	208	84	3	8	5	28
1992	247	233	94	224	90	196	79	4	10	9	38
1993	248	232	93	218	87	184	74	4	10	13	48
1994	246	228	92	211	85	175	71	4	9	17	53
1995	246	225	91	205	83	167	67	4	10	19	57
1996	245	221	90	199	81	158	64	4	10	22	63
1997	244	218	89	194	79	150	61	4	11	24	68
1998	243	215	88	190	78	142	58	5	11	25	73
1999	244	212	86	186	76	136	55	4	11	27	76
2000	244	212	86	184	75	133	54	3	8	28	80
2001	247	213	86	183	74	130	52	3	8	30	82
2002	247	211	85	181	73	127	51	3	8	31	85
2003	249	212	85	180	72	124	49	3	8	33	89
2004	251	210	83	177	70	117	46	5	12	34	93
2005	252	211	83	174	69	111	44	5	12	37	99

Table RCP-D: Refrigerators

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,
Consumers Power Service Territory

Year	Technical Potential Investment Costs ($M)		Program Scenario Costs ($M)						Discounted Ratepayer Costs ($M)			
			Administration		Rebate		Ratepayer		3% Discount Rate		7% Discount Rate	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	3	3	0	0	0	0	0	0	0	0	0	0
1989	5	9	0	0	0	1	1	1	0	1	0	1
1990	8	16	0	0	1	2	1	2	1	2	1	1
1991	10	26	0	0	2	4	2	4	2	4	1	3
1992	12	38	0	1	4	8	4	8	3	7	2	5
1993	13	51	0	1	5	13	5	14	4	11	3	9
1994	14	65	0	1	5	17	5	19	4	15	3	11
1995	18	83	0	2	5	23	6	24	4	19	3	14
1996	19	102	0	2	6	28	6	30	4	23	3	17
1997	17	119	0	2	5	33	6	36	4	27	2	19
1998	17	136	0	3	5	39	5	41	4	31	2	22
1999	16	152	0	3	5	44	5	47	4	35	2	24
2000	13	165	0	3	4	48	4	51	3	37	1	25
2001	15	180	0	3	1	48	1	52	1	38	0	25
2002	14	194	0	4	1	49	1	53	1	38	0	26
2003	15	209	0	4	1	50	1	54	1	39	0	26
2004	22	231	0	4	1	51	1	55	1	40	0	27
2005	24	255	0	5	1	51	1	56	1	41	0	27
Total	254.71		4.85		51.49		56.34		40.57		26.95	

Table RDE-A: Refrigerators

Scenario of potential electricity savings 1984-2005,
Detroit Edison Service Territory — GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	MEOS Forecast GWh	MEOS Forecast Index	Program Scenario GWh	Program Scenario Index	Technical Potential GWh	Technical Potential Index	Savings over MEOS (GWh) From New Sales Prog	From New Sales TechP	Total Yearly Prog	Total Yearly TechP
1984	2568	2568	100	2568	100	2568	100	0	0	0	0
1985	2576	2573	99	2573	99	2573	99	0	0	0	0
1986	2600	2580	99	2580	99	2580	99	0	0	0	0
1987	2604	2582	99	2582	99	2582	99	0	0	0	0
1988	2609	2571	98	2564	98	2490	95	6	81	6	81
1989	2606	2549	97	2529	97	2388	91	13	85	20	165
1990	2592	2511	96	2470	95	2257	87	22	89	42	255
1991	2576	2472	95	2400	93	2127	82	30	90	71	344
1992	2561	2433	95	2325	90	1987	77	37	101	108	446
1993	2539	2390	94	2247	88	1855	73	35	89	143	534
1994	2536	2367	93	2192	86	1798	70	39	98	175	568
1995	2524	2335	92	2136	84	1740	68	39	95	200	595
1996	2511	2307	91	2088	83	1685	67	37	94	217	621
1997	2488	2246	90	2004	80	1567	63	48	121	240	678
1998	2463	2190	88	1928	78	1456	59	51	128	262	734
1999	2463	2158	87	1873	76	1369	55	46	115	285	789
2000	2468	2146	88	1849	74	1328	53	38	91	297	818
2001	2477	2137	86	1828	73	1288	51	38	91	309	849
2002	2488	2129	85	1806	72	1246	50	38	94	323	884
2003	2501	2124	84	1786	71	1204	48	37	93	337	920
2004	2517	2119	84	1760	69	1147	46	48	112	361	974
2005	2532	2117	83	1738	68	1098	43	40	99	379	1019
Total	55794	51612	92	47835	85	40337	72	836	1764	3775	11274

Table RDE-B: Refrigerators

Scenario of potential winter peak power savings 1984-2005,
Detroit Edison Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast MW	MEOS Forecast Index	Program Scenario MW	Program Scenario Index	Technical Potential MW	Technical Potential Index	Savings over MEOS (MW) From New Sales Prog	From New Sales TechP	Total Yearly Prog	Total Yearly TechP
1984	275	275	100	275	100	275	100	0	0	0	0
1985	275	275	100	275	100	275	100	0	0	0	0
1986	279	277	99	277	99	277	99	0	0	0	0
1987	278	276	99	276	99	276	99	0	0	0	0
1988	279	275	98	274	98	267	95	1	9	1	8
1989	278	273	98	271	97	255	91	1	9	2	18
1990	277	269	97	265	95	242	87	2	10	4	27
1991	276	264	95	257	93	227	82	3	10	7	37
1992	274	261	95	250	91	213	77	4	11	11	48
1993	271	256	94	240	88	199	73	4	10	16	57
1994	271	253	93	235	86	191	70	4	11	19	50
1995	269	249	92	229	85	186	69	4	10	22	64
1996	268	247	92	224	83	181	67	4	10	23	66
1997	265	241	90	214	80	167	63	5	13	26	72
1998	264	234	88	206	78	156	59	5	14	28	78
1999	264	231	87	201	76	146	55	5	12	30	84
2000	265	230	86	198	74	142	53	4	10	32	88
2001	265	229	86	196	73	138	52	4	10	32	91
2002	266	227	85	193	72	133	50	4	10	34	95
2003	267	227	85	191	71	129	48	4	10	36	98
2004	270	227	84	188	69	123	45	5	12	38	104
2005	271	226	83	186	68	117	43	4	11	41	109

Table RDE-C: Refrigerators

Scenario of potential summer peak power savings 1984-2005,

Detroit Edison Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast MW	MEOS Forecast Index	Program Scenario MW	Program Scenario Index	Technical Potential MW	Technical Potential Index	Savings over MEOS (MW) From New Sales Prog	Savings over MEOS (MW) From New Sales TechP	Savings over MEOS (MW) Total Yearly Prog	Savings over MEOS (MW) Total Yearly TechP
1984	346	346	100	346	100	346	100	0	0	0	0
1985	346	346	100	346	100	346	100	0	0	0	0
1986	349	347	99	347	99	347	99	0	0	0	0
1987	349	346	99	346	99	346	99	0	0	0	0
1988	350	346	98	344	98	333	95	1	11	1	12
1989	349	341	97	339	97	319	91	2	11	3	23
1990	347	337	97	332	96	302	87	3	12	5	34
1991	346	331	96	322	93	285	82	4	12	10	46
1992	343	328	96	311	90	267	77	5	14	14	60
1993	340	320	94	301	88	248	72	5	12	20	72
1994	340	318	93	294	86	240	70	5	13	23	78
1995	338	313	92	286	84	233	68	5	13	27	81
1996	337	309	91	280	83	228	67	5	13	29	83.
1997	333	301	90	268	80	210	63	7	16	32	90
1998	331	294	88	259	78	196	58	7	17	36	98
1999	329	288	87	251	76	184	56	6	16	39	106
2000	330	287	86	248	75	178	53	5	12	40	109
2001	332	286	86	245	73	173	52	5	12	42	114
2002	333	285	85	243	72	166	49	5	13	44	119
2003	336	284	84	240	71	161	47	5	12	46	123
2004	338	285	84	236	69	153	46	6	16	49	129
2005	339	284	83	233	68	147	43	5	13	51	136

Table RDE-D: Refrigerators

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

Detroit Edison Service Territory

Year	Technical Potential Investment Costs ($M) Annual	Technical Potential Investment Costs ($M) Cumulative	Program Scenario Costs ($M) Administration Annual	Administration Cumulative	Rebate Annual	Rebate Cumulative	Ratepayer Annual	Ratepayer Cumulative	Discounted Ratepayer Costs ($M) 3% Discount Rate Annual	3% Discount Rate Cumulative	7% Discount Rate Annual	7% Discount Rate Cumulative
1984	0	0	0	0	0	.0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	4	4	0	0	0	0	0	0	0	0	0	0
1989	7	12	0	0	1	1	1	1	1	1	1	1
1990	11	22	0	0	2	3	2	3	1	3	1	2
1991	13	35	0	1	3	5	3	6	3	5	2	4
1992	16	52	0	1	5	11	5	11	4	10	3	8
1993	16	68	0	1	6	17	7	18	5	15	4	11
1994	19	87	0	2	6	23	7	25	5	20	4	15
1995	19	106	0	2	6	29	6	31	4	24	3	18
1996	17	122	0	2	5	34	6	36	4	28	3	21
1997	30	152	1	3	9	43	10	46	7	35	4	25
1998	31	183	1	4	9	52	10	56	7	42	4	29
1999	29	212	1	4	9	61	9	65	6	48	4	33
2000	17	229	0	4	5	66	6	71	4	52	2	35
2001	18	247	0	5	1	67	1	72	1	53	0	35
2002	18	255	0	5	1	68	1	74	1	53	0	36
2003	19	284	0	6	1	70	1	75	1	54	0	36
2004	29	313	1	6	1	71	2	77	1	55	0	37
2005	27	340	0	7	1	72	2	78	1	56	0	37
Total	240 08		5 56		71 71		73 28		56 06		37 01	

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Table F-A: Freezers

Scenario of potential electricity savings 1984-2005,

CP and DE territories combined, GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	1551	1551	100	1551	100	1551	100	0	0	0	0
1985	1569	1568	99	1567	99	1567	99	2	2	2	2
1986	1591	1591	100	1586	99	1586	99	3	3	5	5
1987	1609	1610	100	1599	99	1599	99	4	4	9	9
1988	1601	1598	99	1579	98	1571	98	9	18	19	27
1989	1590	1583	99	1554	97	1536	96	10	19	29	47
1990	1578	1564	99	1523	96	1496	94	11	21	40	67
1991	1548	1523	98	1470	94	1432	92	12	24	55	92
1992	1512	1478	97	1409	93	1358	89	13	29	68	121
1993	1483	1433	96	1349	90	1279	86	16	33	84	154
1994	1457	1392	95	1293	88	1203	82	16	35	99	189
1995	1440	1359	94	1248	86	1137	78	15	34	113	222
1996	1429	1332	93	1207	84	1081	75	12	29	125	251
1997	1424	1307	91	1170	82	1028	72	13	31	138	282
1998	1423	1290	90	1140	80	980	68	12	30	149	310
1999	1433	1286	89	1131	78	961	67	6	16	154	326
2000	1444	1285	88	1125	77	944	65	6	16	160	342
2001	1460	1289	88	1124	76	932	63	6	14	165	357
2002	1470	1288	87	1118	76	919	62	5	13	169	368
2003	1479	1285	86	1110	75	902	60	5	16	175	384
2004	1491	1290	86	1113	74	898	60	4	10	179	393
2005	1501	1292	86	1109	73	885	58	5	16	182	406
Total	33083	31194	94	29073	87	26841	81	185	413	2119	4354

Table F-B: Freezers

Scenario of potential winter peak power savings 1984-2005,

CP and DE territories combined, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	166	166	100	166	100	166	100	0	0	0	0
1985	167	167	100	167	100	167	100	0	0	0	0
1986	170	170	100	170	100	170	100	0	0	0	0
1987	172	172	100	172	100	172	100	1	1	1	1
1988	171	171	100	169	98	168	98	1	2	2	2
1989	170	169	99	167	98	164	96	1	2	3	4
1990	168	167	99	163	97	161	95	1	2	4	7
1991	166	163	98	157	94	154	92	1	3	5	10
1992	163	159	97	150	92	146	88	1	3	7	13
1993	158	154	97	144	91	137	86	2	4	9	16
1994	156	149	95	138	88	129	82	2	4	10	20
1995	154	146	94	132	85	122	79	2	4	11	24
1996	154	142	92	130	84	116	75	1	3	13	26
1997	152	139	91	126	82	110	72	1	3	14	30
1998	153	139	90	121	79	105	68	1	3	17	33
1999	153	137	89	121	79	102	66	1	2	17	34
2000	155	137	88	121	78	101	65	1	2	17	37
2001	157	138	87	120	76	101	64	1	2	18	38
2002	157	138	87	119	75	98	62	1	1	19	40
2003	158	138	87	119	75	97	61	1	2	19	40
2004	160	138	86	119	74	97	60	0	1	19	41
2005	161	138	85	118	73	94	58	1	2	20	44

Table F-C: Freezers

Scenario of potential summer peak power savings 1984-2005,

CP and DE territories combined, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast MW	MEOS Forecast Index	Program Scenario MW	Program Scenario Index	Technical Potential MW	Technical Potential Index	Savings over MEOS (MW) From New Sales Prog	Savings over MEOS (MW) From New Sales TechP	Savings over MEOS (MW) Total Yearly Prog	Savings over MEOS (MW) Total Yearly TechP
1984	208	208	100	208	100	208	100	0	0	0	0
1985	211	211	100	211	100	211	100	0	0	0	0
1986	213	213	100	212	99	212	99	0	0	0	0
1987	216	215	99	214	99	214	99	1	1	2	2
1988	215	214	99	212	98	211	98	1	2	2	4
1989	213	213	100	209	98	206	96	1	3	4	7
1990	212	210	99	203	95	201	94	2	3	6	9
1991	208	204	98	198	96	192	92	2	3	7	.3
1992	203	198	97	189	93	182	89	2	4	9	15
1993	198	192	96	182	91	172	86	2	4	11	20
1994	195	187	95	174	89	161	82	2	5	13	25
1995	193	183	94	167	86	152	78	2	5	15	30
1996	192	179	93	162	84	144	75	2	4	17	34
1997	191	176	92	157	82	138	72	2	4	19	37
1998	190	172	90	153	80	131	68	2	4	20	42
1999	192	173	90	152	79	129	67	1	2	21	43
2000	194	172	88	150	77	126	64	1	2	21	46
2001	195	172	88	151	77	126	64	1	2	22	49
2002	196	172	87	150	76	123	62	1	2	23	50
2003	198	173	87	149	75	120	60	1	2	23	51
2004	200	174	87	149	74	121	60	1	1	23	53
2005	202	174	86	148	73	119	58	1	2	24	54

Table F-D: Freezers

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

CP and DE territories combined.

Year	Technical Potential Investment Costs ($M) Annual	Technical Potential Investment Costs ($M) Cumulative	Program Scenario Costs ($M) Administration Annual	Administration Cumulative	Rebate Annual	Rebate Cumulative	Ratepayer Annual	Ratepayer Cumulative
1984	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0
1988	2	2	0	0	0	0	0	0
1989	4	6	0	0	0	0	0	0
1990	7	13	0	0	0	0	0	1
1991	9	22	0	0	1	1	1	1
1992	12	34	0	0	2	3	2	3
1993	15	49	0	1	4	7	4	7
1994	17	66	0	1	4	11	4	12
1995	19	86	0	1	5	15	5	16
1996	18	104	0	1	4	19	4	21
1997	18	122	0	2	4	24	5	25
1998	18	140	0	2	4	28	4	30
1999	10	150	0	2	2	30	3	32
2000	10	160	0	2	2	33	3	35
2001	10	169	0	2	2	34	2	37
2002	8	178	0	2	1	36	2	38
2003	10	187	0	3	1	37	2	40
2004	5	193	0	3	2	39	2	41
2005	10	202	0	3	2	41	2	44
Total	202.21		2.86		40.9		43.73	

Table FCP-A: Freezers

Scenario of potential electricity savings 1984-2005,

Consumers Power Service Territory — GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	820	820	100	820	100	820	100	0	0	0	0
1985	831	831	100	831	100	831	100	1	1	1	1
1986	843	843	100	841	99	841	99	1	1	2	2
1987	858	858	100	854	99	854	99	2	2	4	4
1988	855	852	99	843	98	838	98	5	10	9	14
1989	850	844	99	829	97	818	96	6	11	15	26
1990	842	83[illegible]	98	811	96	794	94	6	12	21	38
1991	825	81[illegible]	98	782	94	759	92	6	13	29	51
1992	806	785	97	748	92	718	89	7	15	36	66
1993	791	762	96	718	90	678	85	9	18	45	84
1994	774	737	95	685	88	635	82	8	18	53	102
1995	763	718	94	659	86	599	78	8	18	60	119
1996	755	701	92	634	83	565	74	7	17	67	137
1997	750	686	91	612	81	532	70	8	18	75	155
1998	748	675	90	593	79	504	67	7	17	81	171
1999	751	672	89	588	78	495	65	2	6	83	177
2000	757	671	88	586	77	488	64	2	6	85	183
2001	766	673	87	586	76	483	63	2	6	87	190
2002	771	672	87	584	75	477	61	2	5	88	195
2003	776	669	86	578	74	467	60	2	8	91	203
2004	783	675	86	585	74	472	60	1	2	92	204
2005	789	678	85	584	74	467	59	2	7	93	210
Total	17503	16464	94	15351	87	14135	80	94	211	1117	2332

Table FCP-B: Freezers

Scenario of potential winter peak power savings 1984-2005,

Consumers Power Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	88	88	100	88	100	88	100	0	0	0	0
1985	88	88	100	88	100	88	100	0	0	0	0
1986	90	90	100	90	100	90	100	0	0	0	0
1987	92	92	100	92	100	92	100	0	0	0	0
1988	91	91	100	90	98	90	98	1	1	1	1
1989	91	90	98	89	97	88	96	1	1	2	2
1990	90	89	98	87	96	85	94	1	1	2	4
1991	89	87	97	84	94	82	92	1	1	3	6
1992	87	84	96	80	91	77	88	1	2	4	7
1993	84	82	97	76	90	72	85	1	2	5	9
1994	83	79	95	73	87	68	81	1	2	5	11
1995	81	77	95	70	86	65	80	1	2	6	13
1996	81	75	92	68	83	61	75	1	2	7	14
1997	80	73	91	66	82	57	71	1	2	7	17
1998	81	73	90	63	77	54	66	1	2	9	18
1999	81	72	88	63	77	53	65	0	1	9	18
2000	81	72	88	63	77	52	64	0	1	9	20
2001	82	72	87	63	76	52	63	0	1	9	20
2002	82	72	87	62	75	51	62	0	1	10	21
2003	83	72	86	62	74	50	60	0	1	10	21
2004	84	72	85	62	73	51	60	0	0	10	21
2005	85	72	84	62	72	50	58	0	1	10	23

Table FCP-C: Freezers

Scenario of potential summer peak power savings 1984-2005,

Consumers Power Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast MW	MEOS Forecast Index	Program Scenario MW	Program Scenario Index	Technical Potential MW	Technical Potential Index	Savings over MEOS (MW) From New Sales Prog	From New Sales TechP	Total Yearly Prog	Total Yearly TechP
1984	110	110	100	110	100	110	100	0	0	0	0
1985	112	112	100	112	100	112	100	0	0	0	0
1986	113	113	100	112	99	112	99	0	0	0	0
1987	115	115	100	114	99	114	99	0	0	1	1
1988	115	114	99	113	98	112	97	1	1	1	2
1989	114	114	100	112	98	110	96	1	2	2	4
1990	113	112	99	108	95	107	94	1	2	3	5
1991	111	108	97	105	94	102	91	1	2	4	7
1992	108	105	97	100	92	96	88	1	2	5	8
1993	106	102	96	97	91	91	85	1	2	6	11
1994	104	99	95	92	88	85	81	1	2	7	13
1995	102	97	95	88	86	80	78	1	2	8	16
1996	101	94	93	85	84	75	74	1	2	9	18
1997	100	92	92	82	82	71	71	1	2	10	20
1998	100	90	90	80	80	68	68	1	2	11	23
1999	100	90	90	79	79	66	66	0	1	11	23
2000	102	90	88	78	76	65	63	0	1	11	25
2001	102	90	88	79	77	65	63	0	1	12	26
2002	103	90	87	78	75	64	62	0	1	12	26
2003	104	90	86	78	75	62	59	0	1	12	27
2004	105	91	86	78	74	63	60	0	0	12	28
2005	106	91	85	78	73	63	59	0	1	12	28

Table FCP-D: Freezers

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

Consumers Power Service Territory

Year	Technical Potential Investment Costs ($M) Annual	Cumulative	Program Scenario Costs ($M) Administration Annual	Administration Cumulative	Rebate Annual	Rebate Cumulative	Ratepayer Annual	Ratepayer Cumulative	Discounted Ratepayer Costs ($M) 3% Discount Rate Annual	3% Cumulative	7% Discount Rate Annual	7% Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	1	1	0	0	0	0	0	0	0	0	0	0
1989	3	4	0	0	0	0	0	0	0	0	0	0
1990	4	8	0	0	0	0	0	0	0	0	0	0
1991	5	12	0	0	0	1	0	1	0	1	0	1
1992	6	19	0	0	1	2	1	2	1	2	1	1
1993	8	27	0	0	2	4	2	4	2	3	1	2
1994	9	36	0	1	2	6	2	6	2	5	1	4
1995	10	46	0	1	2	8	3	9	2	7	1	5
1996	10	56	0	1	2	10	3	11	2	9	1	6
1997	11	67	0	1	3	13	3	14	2	11	1	7
1998	10	77	0	1	2	15	3	16	2	12	1	8
1999	4	81	0	1	1	16	1	18	1	13	0	9
2000	4	85	0	1	1	17	1	19	1	14	0	9
2001	4	90	0	1	0	18	1	19	0	14	0	9
2002	4	94	0	1	0	18	0	19	0	14	0	9
2003	5	99	0	1	0	18	0	20	0	14	0	10
2004	1	99	0	1	0	19	0	20	0	15	0	10
2005	4	104	0	1	1	20	1	21	1	15	0	10
Total	103.52		1.45		19.7		21.15		15.09		9.9	

Table FDE-A: Freezers

Scenario of potential electricity savings 1984-2005,

Detroit Edison Service Territory — GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/ Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	731	731	100	731	100	731	100	0	0	0	0
1985	738	737	99	736	99	736	99	1	1	1	1
1986	748	748	100	745	99	745	99	2	2	3	3
1987	751	752	100	745	99	745	99	2	2	5	5
1988	746	746	100	736	98	733	98	4	8	10	13
1989	740	739	99	725	97	718	97	4	8	14	21
1990	736	732	99	712	96	702	95	5	9	19	29
1991	723	713	98	688	95	673	93	6	11	26	41
1992	707	693	98	661	93	638	90	6	14	32	55
1993	692	671	96	631	91	601	86	7	15	39	70
1994	683	655	96	608	89	568	83	8	17	46	87
1995	677	641	94	587	86	538	79	7	16	63	103
1996	674	631	93	573	85	516	76	5	12	58	114
1997	674	621	92	558	82	494	73	5	13	63	127
1998	675	615	91	547	81	476	70	5	13	68	139
1999	682	614	90	543	79	466	68	4	10	71	149
2000	687	614	89	539	78	456	66	4	10	75	159
2001	694	616	88	538	77	449	64	4	8	78	167
2002	699	616	88	534	76	442	63	3	8	81	173
2003	703	616	87	532	75	435	61	3	8	84	181
2004	708	615	86	528	74	426	60	3	8	87	189
2005	712	614	86	525	73	418	58	3	9	89	196
Total	15580	14730	94	13722	88	12706	81	91	202	1002	2022

Table FDE-B: Freezers

Scenario of potential winter peak power savings 1984-2005,

Detroit Edison Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	78	78	100	78	100	78	100	0	0	0	0
1985	79	79	100	79	100	79	100	0	0	0	0
1986	80	80	100	80	100	80	100	0	0	0	0
1987	80	80	100	80	100	80	100	0	0	1	1
1988	80	80	100	79	98	78	97	1	1	1	1
1989	79	79	100	78	98	76	96	1	1	1	2
1990	78	78	100	76	97	76	97	1	1	2	3
1991	77	76	98	73	94	72	93	1	1	3	4
1992	76	75	98	70	92	68	89	1	2	3	6
1993	74	72	97	68	91	65	87	1	2	4	7
1994	73	70	96	65	89	61	83	1	2	5	9
1995	73	69	94	62	84	57	78	1	2	5	11
1996	73	67	91	62	84	55	75	1	1	6	12
1997	72	66	91	60	83	53	73	1	1	7	13
1998	72	66	91	58	80	51	70	1	1	8	15
1999	72	65	90	58	80	49	68	0	1	8	16
2000	74	65	87	58	78	49	66	0	1	8	17
2001	75	66	88	57	76	49	65	0	1	9	18
2002	75	66	88	57	76	47	62	0	1	9	19
2003	75	66	88	57	76	47	62	0	1	9	19
2004	76	66	86	57	75	46	60	0	1	9	20
2005	75	66	86	56	73	44	57	0	1	10	21

Table FDE-C: Freezers

Scenario of potential summer peak power savings 1984-2005,

Detroit Edison Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	98	98	100	98	100	98	100	0	0	0	0
1985	99	99	100	99	100	99	100	0	0	0	0
1986	100	100	100	100	100	100	100	0	0	0	0
1987	101	100	99	100	99	100	99	0	0	1	1
1988	100	100	100	99	99	99	99	1	1	1	2
1989	99	99	100	97	97	96	96	1	1	2	3
1990	99	98	98	95	95	94	94	1	1	3	4
1991	97	96	98	93	95	90	92	1	2	3	6
1992	95	93	97	89	93	86	90	1	2	4	7
1993	92	90	97	85	92	81	88	1	2	5	9
1994	91	88	96	82	90	76	83	1	2	6	12
1995	91	86	94	79	86	72	79	1	2	7	14
1996	91	85	93	77	84	69	75	1	2	8	16
1997	91	84	92	75	82	67	73	1	2	9	17
1998	90	82	91	73	81	63	70	1	2	9	19
1999	92	83	90	73	79	63	68	1	1	10	20
2000	92	82	89	72	78	61	66	1	1	10	21
2001	93	82	88	72	77	61	65	1	1	10	23
2002	93	82	88	72	77	59	63	0	1	11	24
2003	94	83	88	71	75	58	61	0	1	11	24
2004	96	83	87	71	74	58	61	1	1	11	25
2005	96	83	86	70	72	56	58	1	1	12	26

Table FDE-D: Freezers

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

Detroit Edison Service Territory

Year	Technical Potential Investment Costs ($M)		Program Scenario Costs ($M)						Discounted Ratepayer Costs ($M)			
			Administration		Rebate		Ratepayer		3% Discount Rate		7% Discount Rate	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	1	1	0	0	0	0	0	0	0	0	0	0
1989	2	3	0	0	0	0	0	0	0	0	0	0
1990	3	5	0	0	0	0	0	0	0	0	0	0
1991	4	10	0	0	0	1	0	1	0	1	0	0
1992	6	15	0	0	1	1	1	2	1	1	1	1
1993	7	22	0	0	2	3	2	3	1	3	1	2
1994	9	31	0	0	2	5	2	5	2	4	1	3
1995	9	40	0	1	2	7	2	8	2	6	1	4
1996	7	47	0	1	2	9	2	10	1	7	1	5
1997	8	55	0	1	2	11	2	11	1	9	1	6
1998	8	63	0	1	2	13	2	13	1	10	1	7
1999	6	68	0	1	1	14	1	15	1	11	1	7
2000	6	74	0	1	1	15	1	16	1	12	1	3
2001	5	80	0	1	1	17	1	18	1	13	0	8
2002	5	84	0	1	1	18	1	19	1	13	0	9
2003	5	89	0	1	1	19	1	20	1	14	0	9
2004	5	93	0	1	1	20	1	21	1	15	0	9
2005	5	99	0	1	1	21	1	23	1	16	0	10
Total	98.69		1.41		21.2		22.58		15.57		9.83	

Table L-A: Lighting

Scenario of potential electricity savings 1984-2005,

CP and DE territories combined, GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	2117	2117	100	2117	100	2117	100	0	0	0	0
1985	2143	2136	99	2136	99	2136	99	0	0	0	0
1986	2174	2160	99	2160	99	2160	99	0	0	0	0
1987	2201	2180	99	2180	99	2180	99	0	0	0	0
1988	2226	2197	98	2208	99	1652	74	-9	545	-9	545
1989	2251	2214	98	2174	96	1099	48	51	570	40	1115
1990	2275	2231	98	2045	89	545	23	148	573	189	1688
1991	2301	2250	97	1832	79	551	23	231	11	419	1701
1992	2326	2266	97	1618	69	557	23	230	9	648	1710
1993	2348	2282	97	1403	59	562	23	231	10	879	1720
1994	2374	2300	96	1190	50	569	23	231	12	1110	1732
1995	2397	2315	96	1203	50	575	23	2	9	1113	1740
1996	2419	2329	96	1213	50	579	23	4	10	1115	1750
1997	2441	2344	96	1224	50	585	23	3	8	1119	1757
1998	2461	2354	95	1233	50	589	23	0	6	1120	1763
1999	2480	2366	95	1244	50	595	23	2	8	1122	1771
2000	2499	2375	95	1254	50	599	23	0	4	1122	1776
2001	2523	2391	94	1264	50	606	24	5	10	1125	1785
2002	2541	2399	94	1274	50	609	23	0	4	1125	1790
2003	2559	2408	94	1284	50	614	23	1	5	1126	1794
2004	2576	2415	93	1292	50	619	24	0	3	1123	1797
2005	2592	2423	93	1299	50	623	24	0	5	1123	1801
Total	52224	50462	96	34847	66	20721	39	1126	1802	15608	29735

Table L-B: Lighting

Scenario of potential winter peak power savings 1984-2005,

CP and DE territories combined, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	644	644	100	644	100	644	100	0	0	0	0
1985	652	648	99	648	99	648	99	0	0	0	0
1986	662	657	99	657	99	657	99	0	0	0	0
1987	669	662	98	662	98	662	98	0	0	0	0
1988	676	667	98	671	99	504	74	-3	165	-3	165
1989	684	673	98	661	96	335	48	16	173	12	338
1990	692	678	97	621	89	165	23	45	174	58	513
1991	699	684	97	556	79	168	24	70	4	127	516
1992	706	687	97	491	69	170	24	70	3	197	519
1993	713	693	97	425	59	172	24	70	3	266	521
1994	721	698	96	361	50	174	24	70	4	338	524
1995	727	702	96	364	50	175	24	1	2	338	527
1996	736	708	96	367	49	177	24	1	3	338	530
1997	741	711	95	371	50	178	24	1	2	340	532
1998	747	713	95	373	49	180	24	0	2	340	533
1999	753	718	95	377	50	181	24	1	2	341	535
2000	758	720	94	379	50	182	24	0	1	341	537
2001	766	725	94	383	50	184	24	1	3	342	541
2002	771	726	94	386	50	185	23	0	1	342	541
2003	777	729	93	389	50	188	24	0	2	342	542
2004	782	731	93	391	50	188	24	0	1	340	543
2005	786	735	93	393	50	190	24	0	1	340	546

Table L-C: Lighting

Scenario of potential summer peak power savings 1984-2005,

CP and DE territories combined, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast MW	MEOS Forecast Index	Program Scenario MW	Program Scenario Index	Technical Potential MW	Technical Potential Index	Savings over MEOS (MW) From New Sales Prog	From New Sales TechP	Total Yearly Prog	Total Yearly TechP
1984	156	156	100	156	100	156	100	0	0	0	0
1985	158	158	100	158	100	158	100	0	0	0	0
1986	160	159	99	159	99	159	99	0	0	0	0
1987	162	160	98	160	98	160	98	0	0	0	0
1988	164	162	98	162	98	122	74	0	40	0	40
1989	166	162	97	160	96	82	49	4	42	3	81
1990	168	164	97	150	89	40	23	11	42	14	123
1991	169	165	97	134	79	42	24	17	1	31	124
1992	171	166	97	119	69	42	24	17	1	47	124
1993	172	167	97	102	59	42	24	17	1	65	125
1994	174	168	96	86	49	42	24	17	1	82	126
1995	175	168	96	87	49	42	24	0	0	82	126
1996	177	170	96	88	49	43	24	0	1	82	126
1997	179	170	94	89	49	44	24	0	1	82	127
1998	180	172	95	89	49	44	24	0	0	82	128
1999	181	172	95	90	49	44	24	0	1	82	128
2000	183	172	93	91	49	45	24	0	0	82	128
2001	184	174	94	91	49	45	24	0	1	82	128
2002	186	174	93	93	50	45	24	0	0	82	128
2003	187	175	93	93	49	46	24	0	0	82	130
2004	188	175	93	93	49	46	24	0	0	82	130
2005	189	176	93	94	49	46	24	0	0	82	130

Table L-D: Lighting

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

CP and DE territories combined.

Year	Technical Potential Investment Costs ($M) Annual	Cumulative	Program Scenario Costs ($M) Administration Annual	Administration Cumulative	Rebate Annual	Rebate Cumulative	Ratepayer Annual	Ratepayer Cumulative	Discounted Ratepayer Costs ($M) 3% Discount Rate Annual	3% Cumulative	7% Discount Rate Annual	7% Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	206	206	1	1	6	6	7	7	5	5	5	5
1989	206	413	1	2	16	23	18	25	12	17	10	15
1990	206	619	4	6	43	65	46	71	29	46	24	38
1991	6	625	6	11	68	133	74	145	41	87	33	71
1992	6	631	6	17	73	206	79	223	40	127	31	102
1993	6	637	6	23	78	285	84	307	39	165	28	130
1994	6	643	6	28	84	368	89	396	37	202	26	156
1995	6	649	0	29	29	397	29	425	11	213	7	164
1996	6	655	0	29	29	426	29	455	10	223	7	171
1997	5	660	0	29	29	455	29	484	9	232	6	176
1998	5	665	0	29	29	484	29	513	8	241	5	181
1999	5	671	0	30	29	513	29	542	8	248	4	186
2000	5	676	0	30	29	542	29	572	7	255	4	190
2001	6	682	0	30	0	542	0	572	0	255	0	190
2002	5	687	0	30	0	542	0	572	0	255	0	190
2003	5	691	0	30	0	542	0	572	0	255	0	190
2004	4	696	0	30	0	542	0	572	0	255	0	190
2005	4	700	0	30	0	542	0	572	0	255	0	190
Total	698.85		29.71		541.73		571.42		254.89		189.53	

Table LCP-A: Lighting

Scenario of potential electricity savings 1984-2005,
Consumers Power Service Territory — GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/ Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	895	895	100	895	100	895	100	0	0	0	0
1985	904	901	99	901	99	901	99	0	0	0	0
1986	913	907	99	907	99	907	99	0	0	0	0
1987	929	920	99	920	99	920	99	0	0	0	0
1988	943	930	98	935	99	698	74	-3	232	-3	232
1989	956	940	98	923	96	465	48	22	243	16	475
1990	967	948	98	869	89	232	23	63	243	80	718
1991	979	957	97	779	79	234	23	98	5	178	723
1992	990	964	97	688	69	237	23	98	4	276	727
1993	1004	975	97	601	59	240	23	98	8	374	735
1994	1011	979	96	506	50	243	24	98	2	473	737
1995	1021	985	96	512	50	245	23	1	4	474	740
1996	1031	992	96	516	50	247	23	2	5	475	745
1997	1041	999	95	521	50	249	23	1	4	477	748
1998	1050	1004	95	525	50	251	23	0	3	477	751
1999	1058	1008	95	530	50	254	24	0	3	478	754
2000	1067	1013	94	535	50	256	23	0	2	478	757
2001	1079	1021	94	540	50	259	24	3	6	481	762
2002	1086	1024	94	544	50	260	23	0	1	480	764
2003	1094	1028	93	548	50	263	24	0	2	481	765
2004	1101	1031	93	552	50	265	24	0	1	479	766
2005	1108	1034	93	554	50	266	24	0	2	479	768
Total	22227	21455	96	14801	66	8787	39	477	770	6652	12667

Table LCP-B: Lighting

Scenario of potential winter peak power savings 1984-2005,
Consumers Power Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	272	272	100	272	100	272	100	0	0	0	0
1985	275	273	99	273	99	273	99	0	0	0	0
1986	278	276	99	276	99	276	99	0	0	0	0
1987	282	279	98	279	98	279	98	0	0	0	0
1988	286	282	98	284	99	213	74	-1	70	-1	71
1989	291	286	98	281	96	142	48	7	74	5	144
1990	294	288	97	264	89	70	23	19	74	25	218
1991	297	291	97	237	79	71	23	30	2	54	220
1992	300	292	97	209	69	72	24	30	1	84	221
1993	305	296	97	182	59	74	24	30	2	113	223
1994	307	297	96	154	50	74	24	30	1	144	223
1995	310	299	96	155	50	75	24	0	1	144	225
1996	314	302	96	156	49	76	24	1	1	144	226
1997	316	303	95	158	50	76	24	0	1	145	227
1998	319	304	95	159	49	77	24	0	1	145	227
1999	321	306	95	161	50	77	23	0	1	146	228
2000	323	307	95	162	50	78	24	0	1	145	229
2001	328	310	94	164	50	79	24	1	2	146	231
2002	330	310	93	165	50	79	23	0	0	146	231
2003	332	311	93	166	50	80	24	0	1	146	231
2004	334	312	93	167	50	80	23	0	0	145	232
2005	336	314	93	168	50	81	24	0	1	145	233

Table LCP-C: Lighting

Scenario of potential summer peak power savings 1984-2005,

Consumers Power Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	66	66	100	66	100	66	100	0	0	0	0
1985	67	67	100	67	100	67	100	0	0	0	0
1986	68	67	98	67	98	67	98	0	0	0	0
1987	69	68	98	68	98	68	98	0	0	0	0
1988	70	69	98	69	98	52	74	0	17	0	17
1989	71	69	97	68	96	35	49	2	18	1	35
1990	72	70	97	64	88	17	23	5	18	6	53
1991	72	71	98	57	79	18	25	7	0	13	53
1992	73	71	97	51	69	18	24	7	0	20	53
1993	74	72	97	44	59	18	24	7	1	28	54
1994	75	72	96	37	49	18	24	7	0	35	54
1995	75	72	96	37	49	18	24	0	0	35	54
1996	76	73	96	38	50	18	23	0	0	35	54
1997	77	73	94	38	49	19	24	0	0	35	55
1998	77	74	96	38	49	19	24	0	0	35	55
1999	78	74	94	39	50	19	24	0	0	35	55
2000	79	74	93	39	49	19	24	0	0	35	55
2001	79	75	94	39	49	19	24	0	0	35	55
2002	80	75	93	40	50	19	23	0	0	35	55
2003	80	75	93	40	50	20	25	0	0	35	56
2004	81	75	92	40	49	20	24	0	0	35	56
2005	81	76	93	40	49	20	24	0	0	35	56

Table LCP-D: Lighting

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

Consumers Power Service Territory

Year	Technical Potential Investment Costs ($M)		Program Scenario Costs ($M)						Discounted Ratepayer Costs ($M)			
			Administration		Rebate		Ratepayer		3% Discount Rate		7% Discount Rate	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	89	89	0	0	3	3	3	3	3	3	2	2
1989	89	178	1	1	7	10	8	11	7	9	6	8
1990	88	266	2	2	18	28	20	30	17	27	14	22
1991	3	269	2	5	29	57	32	62	27	53	21	43
1992	3	272	2	7	31	89	34	96	28	81	21	65
1993	4	276	2	10	34	122	36	132	29	109	21	86
1994	2	277	2	12	36	158	38	170	29	139	21	106
1995	3	280	0	12	12	171	13	183	9	148	6	113
1996	3	283	0	12	13	183	13	196	9	157	6	119
1997	2	285	0	13	12	196	13	208	9	166	6	124
1998	2	288	0	13	13	208	13	221	9	174	5	130
1999	2	290	0	13	12	221	13	234	8	183	5	134
2000	2	292	0	13	13	233	13	246	8	191	5	139
2001	3	295	0	13	0	233	0	246	0	191	0	139
2002	2	297	0	13	0	233	0	246	0	191	0	139
2003	2	299	0	13	0	233	0	246	0	191	0	139
2004	2	301	0	13	0	233	0	246	0	191	0	139
2005	2	302	0	13	0	233	0	246	0	191	0	139
Total	301.94		12.85		233.29		246.12		190.91		139.11	

Table LDE-A: Lighting

Scenario of potential electricity savings 1984-2005,

Detroit Edison Service Territory — GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	MEOS Forecast GWh	MEOS Forecast Index	Program Scenario GWh	Program Scenario Index	Technical Potential GWh	Technical Potential Index	Savings over MEOS (GWh) From New Sales Prog	Savings over MEOS (GWh) From New Sales TechP	Savings over MEOS (GWh) Total Yearly Prog	Savings over MEOS (GWh) Total Yearly TechP
1984	1222	1222	100	1222	100	1222	100	0	0	0	0
1985	1239	1235	99	1235	99	1235	99	0	0	0	0
1986	1261	1253	99	1253	99	1253	99	0	0	0	0
1987	1272	1260	99	1260	99	1260	99	0	0	0	0
1988	1283	1267	98	1273	99	954	74	-5	313	-5	313
1989	1295	1274	98	1251	96	634	48	29	327	24	640
1990	1308	1283	98	1176	89	313	23	85	330	109	970
1991	1322	1293	97	1053	79	317	23	133	8	241	978
1992	1336	1302	97	930	69	320	23	132	5	372	983
1993	1344	1307	97	802	59	322	23	133	2	505	985
1994	1363	1321	96	684	50	326	23	133	10	637	996
1995	1378	1330	96	691	50	330	23	1	5	639	1000
1996	1388	1337	96	697	50	332	23	2	5	640	1005
1997	1400	1345	96	703	50	336	24	2	4	642	1009
1998	1411	1350	95	708	50	338	23	0	3	643	1012
1999	1422	1358	95	714	50	341	23	2	5	644	1017
2000	1432	1362	95	719	50	343	23	0	2	644	1019
2001	1444	1370	94	724	50	347	24	2	4	644	1023
2002	1455	1375	94	730	50	349	23	0	3	645	1026
2003	1465	1380	94	736	50	351	23	1	3	645	1029
2004	1475	1384	93	740	50	354	24	0	2	644	1031
2005	1484	1389	93	745	50	357	24	0	3	644	1033
Total	29997	28997	96	20046	66	11934	39	649	1032	8956	17068

Table LDE-B: Lighting

Scenario of potential winter peak power savings 1984-2005,

Detroit Edison Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast MW	MEOS Forecast Index	Program Scenario MW	Program Scenario Index	Technical Potential MW	Technical Potential Index	Savings over MEOS (MW) From New Sales Prog	Savings over MEOS (MW) From New Sales TechP	Savings over MEOS (MW) Total Yearly Prog	Savings over MEOS (MW) Total Yearly TechP
1984	372	372	100	372	100	372	100	0	0	0	0
1985	377	375	99	375	99	375	99	0	0	0	0
1986	384	381	99	381	99	381	99	0	0	0	0
1987	387	383	98	383	98	383	98	0	0	0	0
1988	390	385	98	387	99	291	74	-1	95	-1	94
1989	393	387	98	380	96	193	49	9	99	7	194
1990	398	390	97	357	89	95	23	26	100	33	295
1991	402	393	97	319	79	97	24	40	2	73	296
1992	405	395	97	282	69	98	24	40	2	113	298
1993	408	397	97	243	59	98	24	40	1	153	298
1994	414	401	96	207	50	100	24	40	3	194	301
1995	417	403	96	209	50	100	23	0	1	194	302
1996	422	406	96	211	50	101	23	1	1	194	304
1997	425	408	96	213	50	102	24	0	1	195	305
1998	428	409	95	214	50	103	24	0	1	195	306
1999	432	412	95	216	50	104	24	0	1	195	307
2000	435	413	94	217	49	104	23	0	1	196	308
2001	438	415	94	219	50	105	23	0	1	196	310
2002	441	416	94	221	50	106	24	0	1	196	310
2003	445	418	93	223	50	108	24	0	1	196	311
2004	448	419	93	224	50	108	24	0	0	195	311
2005	450	421	93	225	50	109	24	0	1	195	313

Table LDE-C: Lighting

Scenario of potential summer peak power savings 1984-2005,

Detroit Edison Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	90	90	100	90	100	90	100	0	0	0	0
1985	91	91	100	91	100	91	100	0	0	0	0
1986	92	92	100	92	100	92	100	0	0	0	0
1987	93	92	98	92	98	92	98	0	0	0	0
1988	94	93	98	93	98	70	74	0	23	0	23
1989	95	93	97	92	96	47	49	2	24	2	46
1990	96	94	97	86	89	23	23	6	24	8	70
1991	97	94	96	77	79	24	24	10	0	18	71
1992	98	95	96	68	69	24	24	10	0	27	71
1993	98	95	96	58	59	24	24	10	0	37	71
1994	99	96	96	49	49	24	24	10	1	47	72
1995	100	96	96	50	50	24	24	0	0	47	72
1996	101	97	96	50	49	25	24	0	0	47	72
1997	102	97	95	51	50	25	24	0	0	47	72
1998	103	98	95	51	49	25	24	0	0	47	73
1999	103	98	95	51	49	25	24	0	0	47	73
2000	104	98	94	52	50	26	25	0	0	47	73
2001	105	99	94	52	49	26	24	0	0	47	73
2002	106	99	93	53	50	26	24	0	0	47	73
2003	107	100	93	53	49	26	24	0	0	47	74
2004	107	100	93	53	49	26	24	0	0	47	74
2005	108	100	92	54	50	26	24	0	0	47	74

Table LDE-D: Lighting

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

Detroit Edison Service Territory

Year	Technical Potential Investment Costs ($M)		Program Scenario Costs ($M)						Discounted Ratepayer Costs ($M)			
			Administration		Rebate		Ratepayer		3% Discount Rate		7% Discount Rate	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	117	117	0	0	4	4	4	4	4	4	3	3
1989	117	235	1	1	9	13	10	14	9	13	8	11
1990	118	352	2	3	24	37	26	40	23	35	19	30
1991	3	356	3	6	39	76	42	82	35	71	28	58
1992	3	359	3	10	42	118	45	127	37	107	28	86
1993	2	361	3	13	45	162	48	175	38	145	28	114
1994	5	365	3	16	48	210	51	226	39	184	28	141
1995	3	369	0	16	16	226	16	242	12	196	8	150
1996	3	372	0	16	16	243	16	259	12	208	8	157
1997	3	375	0	16	16	259	16	275	12	219	7	165
1998	3	378	0	17	16	275	16	292	11	231	7	172
1999	3	381	0	17	17	292	17	309	11	242	7	178
2000	3	384	0	17	17	309	17	325	11	252	6	184
2001	3	387	0	17	0	309	0	325	0	252	0	184
2002	3	390	0	17	0	309	0	325	0	252	0	184
2003	3	392	0	17	0	309	0	325	0	252	0	184
2004	3	395	0	17	0	309	0	325	0	252	0	184
2005	2	397	0	17	0	309	0	325	0	252	0	184
Total	396.91		15.36		308.44		325.3		252.45		184.06	

Table W-A: Water Heating

Scenario of potential electricity savings 1984-2005,

CP and DE territories combined, GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	2156	2156	100	2156	100	2156	100	0	0	0	0
1985	2131	2127	99	2140	100	2140	100	-12	-12	-12	-12
1986	2115	2110	99	2134	100	2134	100	-24	-24	-24	-24
1987	2112	2103	99	2141	101	2141	101	-37	-37	-37	-37
1988	2096	2083	99	2054	97	1590	75	29	493	29	493
1989	2087	2071	99	1965	94	1188	56	106	883	106	883
1990	2075	2054	98	1875	90	882	42	179	1172	179	1172
1991	2072	2047	98	1777	85	788	38	270	1259	270	1259
1992	2068	2039	98	1683	81	710	34	356	1330	356	1330
1993	2067	2036	98	1594	77	645	31	441	1390	441	1390
1994	2059	2023	98	1503	72	587	28	520	1436	520	1436
1995	2054	2013	98	1416	68	539	26	596	1474	596	1474
1996	2052	2007	97	1374	66	497	24	633	1510	633	1510
1997	2052	2001	97	1331	64	460	22	672	1541	672	1541
1998	2051	1995	97	1288	62	428	20	708	1567	708	1567
1999	2048	1988	97	1246	60	398	19	742	1590	742	1590
2000	2045	1981	96	1205	58	372	18	776	1609	776	1609
2001	2042	1975	96	1183	57	365	17	792	1609	792	1609
2002	2041	1968	96	1160	56	359	17	808	1608	808	1608
2003	2039	1961	96	1137	55	353	17	824	1608	824	1608
2004	2036	1954	95	1114	54	347	17	840	1607	840	1607
2005	2032	1946	95	1091	53	341	16	855	1605	855	1605
Total	45530	44638	98	34567	75	19420	42	10071	25215	10071	25215

Table W-B: Water Heating

Scenario of potential winter peak power savings 1984-2005,

CP and DE territories combined, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	343	343	100	343	100	343	100	0	0	0	0
1985	339	339	100	341	100	341	100	-1	-1	-1	-1
1986	337	337	100	340	100	340	100	-3	-3	-3	-3
1987	337	336	99	342	101	342	101	-5	-5	-5	-5
1988	334	333	99	327	97	254	76	5	79	4	79
1989	334	331	99	314	94	190	56	17	141	17	140
1990	331	328	99	300	90	141	42	28	187	28	187
1991	331	327	98	285	86	126	38	43	201	42	201
1992	331	325	98	269	81	114	34	57	212	56	213
1993	331	325	98	255	77	104	31	70	222	70	222
1994	329	324	98	241	73	94	28	83	229	.83	230
1995	329	322	97	227	68	87	26	95	236	96	236
1996	328	320	97	220	67	80	24	101	241	101	242
1997	328	320	97	213	64	73	22	107	246	107	246
1998	327	319	97	206	62	69	21	113	250	113	250
1999	327	318	97	199	60	64	19	118	254	119	254
2000	327	316	96	193	59	60	18	124	257	123	257
2001	327	316	96	190	58	58	17	126	257	127	257
2002	326	315	96	186	57	58	17	129	257	129	257
2003	326	314	96	182	55	57	17	224	80	224	71
2004	325	312	96	179	55	56	17	225	80	224	71
2005	325	311	95	175	53	54	16	225	82	225	72

Table W-C: Water Heating

Scenario of potential summer peak power savings 1984-2005,

CP and DE territories combined, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast MW	MEOS Forecast Index	Program Scenario MW	Program Scenario Index	Technical Potential MW	Technical Potential Index	Savings over MEOS (MW) From New Sales Prog	Savings over MEOS (MW) From New Sales TechP	Savings over MEOS (MW) Total Yearly Prog	Savings over MEOS (MW) Total Yearly TechP
1984	269	269	100	269	100	269	100	0	0	0	0
1985	266	266	100	268	100	268	100	-1	-1	0	0
1986	264	264	100	267	101	267	101	-2	-2	-2	-2
1987	264	263	99	268	101	268	101	-4	-4	-4	-4
1988	262	261	99	257	98	200	76	3	62	4	61
1989	262	259	98	247	94	149	56	13	110	13	110
1990	260	258	99	236	90	110	42	22	147	22	146
1991	260	257	98	224	86	99	38	33	158	33	158
1992	259	255	98	212	81	90	34	44	167	44	167
1993	260	256	98	201	77	81	31	56	175	56	174
1994	258	254	98	189	73	74	28	66	180	66	180
1995	258	253	98	179	69	68	26	74	186	75	185
1996	258	252	97	174	67	63	24	79	190	79	190
1997	258	251	97	168	65	58	22	84	194	84	194
1998	258	251	97	163	63	54	20	88	197	88	197
1999	258	250	96	157	60	50	19	93	200	92	199
2000	257	249	96	152	59	47	18	97	202	97	202
2001	257	248	96	149	57	47	18	99	202	99	203
2002	257	247	96	147	57	46	17	101	202	101	202
2003	257	246	95	143	55	44	17	103	202	103	202
2004	256	245	95	141	55	44	17	106	202	105	201
2005	255	244	95	138	54	43	16	107	201	106	201

Table W-D: Water Heating

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

CP and DE territories combined.

Year	Technical Potential Investment Costs ($M) Annual	Technical Potential Investment Costs ($M) Cumulative	Program Scenario Costs ($M) Administration Annual	Program Scenario Costs ($M) Administration Cumulative	Program Scenario Costs ($M) Rebate Annual	Program Scenario Costs ($M) Rebate Cumulative	Program Scenario Costs ($M) Ratepayer Annual	Program Scenario Costs ($M) Ratepayer Cumulative
1984	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0
1988	57	57	0	0	2	2	3	3
1989	57	114	0	1	2	5	3	6
1990	57	171	1	2	8	13	8	14
1991	52	223	1	3	8	20	8	23
1992	52	278	1	3	8	28	8	31
1993	52	328	1	4	8	35	8	40
1994	52	381	1	5	8	43	8	48
1995	52	433	1	6	8	51	8	56
1996	52	486	1	7	6	56	7	63
1997	52	538	1	7	6	62	7	69
1998	52	591	1	8	6	68	7	76
1999	52	643	1	9	6	74	7	83
2000	52	696	1	10	6	79	7	89
2001	0	696	0	10	3	83	4	93
2002	0	696	0	10	3	86	4	97
2003	0	696	0	10	0	86	0	97
2004	0	696	0	10	0	86	0	97
2005	0	696	0	10	0	86	0	97
Total	695.61		10.4		86.18		96.58	

Table WCP-A: Water Heating

Scenario of potential electricity savings 1984-2005,

Consumers Power Service Territory — GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	1428	1428	100	1428	100	1428	100	0	0	0	0
1985	1421	1418	99	1429	100	1429	100	-9	-9	-9	-9
1986	1413	1410	99	1429	101	1429	101	-19	-19	-19	-19
1987	1416	1410	99	1440	101	1440	101	-29	-29	-29	-29
1988	1413	1404	98	1391	98	1077	76	13	327	13	327
1989	1409	1398	98	1336	94	807	57	63	591	63	591
1990	1402	1388	99	1277	91	601	42	111	787	111	787
1991	1404	1387	98	1215	86	539	38	172	848	172	848
1992	1404	1385	98	1155	82	487	34	230	898	230	898
1993	1411	1389	98	1100	77	445	31	289	944	289	944
1994	1405	1381	98	1039	73	406	28	342	975	342	975
1995	1405	1377	98	982	69	374	26	394	1003	394	1003
1996	1404	1373	97	954	67	345	24	419	1028	419	1028
1997	1404	1369	97	925	65	320	22	445	1049	445	1049
1998	1403	1365	97	896	63	298	21	469	1067	469	1067
1999	1400	1359	97	867	61	277	19	492	1082	492	1082
2000	1398	1354	96	839	60	259	18	515	1095	515	1095
2001	1400	1354	96	827	59	255	18	527	1098	527	1098
2002	1396	1346	96	810	58	251	17	536	1095	536	1095
2003	1392	1339	96	793	56	246	17	546	1093	546	1093
2004	1388	1332	95	777	55	242	17	555	1090	555	1090
2005	1382	1323	95	760	54	238	17	564	1086	564	1086
Total	30898	30299	98	23668	76	13193	42	6622	17096	6622	17096

Table WCP-B: Water Heating

Scenario of potential winter peak power savings 1984-2005,

Consumers Power Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	243	243	100	243	100	243	100	0	0	0	0
1985	241	241	100	243	100	243	100	-1	-1	-1	-1
1986	240	240	100	243	101	243	101	-2	-2	-2	-2
1987	241	240	99	245	101	245	101	-4	-4	-4	-4
1988	240	239	99	236	98	183	76	2	56	2	56
1989	240	238	99	227	94	137	57	11	100	11	100
1990	238	236	99	217	91	102	42	19	134	19	134
1991	239	236	98	207	86	92	38	29	144	29	144
1992	239	235	98	196	82	83	34	39	153	39	153
1993	240	236	98	187	77	76	31	49	161	49	160
1994	239	235	98	177	74	69	28	58	166	58	166
1995	239	234	97	167	69	64	26	67	171	67	171
1996	239	233	97	162	67	59	24	71	175	71	175
1997	239	233	97	157	65	54	22	76	178	76	178
1998	238	232	97	152	63	51	21	80	181	80	181
1999	238	231	97	147	61	47	19	84	184	84	184
2000	238	230	96	143	60	44	18	88	186	87	186
2001	238	230	96	141	59	43	18	90	187	90	187
2002	237	229	96	138	58	43	18	91	186	91	186
2003	237	228	96	135	56	42	17	186	9	186	0
2004	236	226	95	132	55	41	17	185	9	185	0
2005	235	225	95	129	54	40	17	185	10	185	0

Table WDE-A: Water Heating

Scenario of potential electricity savings 1984-2005,
Detroit Edison Service Territory — GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/ Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	728	728	100	728	100	728	100	0	0	0	0
1985	710	709	99	711	100	711	100	-2	-2	-2	-2
1986	702	700	99	705	100	705	100	-4	-4	-4	-4
1987	696	693	99	701	100	701	100	-7	-7	-7	-7
1988	683	679	99	663	97	513	75	16	166	16	166
1989	678	673	99	630	92	381	56	43	292	43	292
1990	673	666	98	598	88	281	41	68	386	68	385
1991	668	660	98	562	84	249	37	98	411	98	411
1992	664	654	98	528	79	223	33	126	432	126	432
1993	656	646	98	494	75	200	30	152	446	152	446
1994	654	642	98	464	70	181	27	178	461	178	461
1995	649	636	97	434	66	165	25	202	471	202	471
1996	648	634	97	420	64	152	23	214	482	214	482
1997	648	632	97	406	62	140	21	227	492	227	492
1998	648	630	97	392	60	130	20	239	500	239	500
1999	648	629	97	379	58	121	18	250	508	250	508
2000	647	627	96	366	56	113	17	261	514	261	514
2001	642	621	96	356	55	110	17	265	511	265	511
2002	645	622	96	350	54	108	16	272	513	272	513
2003	647	622	96	344	53	107	16	278	515	278	515
2004	648	622	95	337	52	105	16	285	517	285	517
2005	650	622	95	331	50	103	15	291	519	291	519
Total	14632	14347	98	10899	74	6227	42	3449	8119	3449	8119

Table WDE-B: Water Heating

Scenario of potential winter peak power savings 1984-2005,
Detroit Edison Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	100	100	100	100	100	100	100	0	0	0	0
1985	98	98	100	98	100	98	100	0	0	0	0
1986	97	97	100	97	100	97	100	0	0	0	0
1987	96	96	100	97	101	97	101	0	0	0	0
1988	94	94	100	91	96	71	75	2	23	2	23
1989	94	93	98	87	92	53	56	6	40	6	40
1990	93	92	98	83	89	39	41	9	53	9	53
1991	92	91	98	78	84	34	36	14	57	13	57
1992	92	90	97	73	79	31	33	17	60	17	60
1993	91	89	97	68	74	28	30	21	62	21	62
1994	90	89	98	64	71	25	27	25	64	25	64
1995	90	88	97	60	66	23	25	28	65	28	65
1996	89	87	97	58	65	21	23	30	67	30	67
1997	89	87	97	56	62	19	21	31	68	31	68
1998	89	87	97	54	60	18	20	33	69	33	69
1999	89	87	97	52	58	17	19	35	70	35	70
2000	89	86	96	50	56	16	17	36	71	36	71
2001	89	86	96	49	55	15	16	37	71	37	70
2002	89	86	96	48	53	15	16	38	71	38	71
2003	89	86	96	47	52	15	16	38	71	38	71
2004	89	86	96	47	52	15	16	39	71	39	71
2005	90	86	95	46	51	14	15	40	72	40	72

Table WDE-C: Water Heating

Scenario of potential summer peak power savings 1984-2005,

Detroit Edison Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	71	71	100	71	100	71	100	0	0	0	0
1985	69	69	100	69	100	69	100	0	0	0	0
1986	68	68	100	68	100	68	100	0	0	0	0
1987	67	67	100	68	101	68	101	0	0	0	0
1988	66	66	100	64	96	50	75	2	16	2	16
1989	66	65	98	61	92	37	56	4	28	4	28
1990	65	65	100	58	89	27	41	7	37	7	37
1991	65	64	98	55	84	24	36	10	40	9	40
1992	64	63	98	51	79	22	34	12	42	12	42
1993	64	63	98	48	75	19	29	15	43	15	43
1994	63	62	98	45	71	18	28	17	45	17	45
1995	63	62	98	42	66	16	25	20	46	20	46
1996	63	61	96	41	65	15	23	21	47	21	47
1997	63	61	96	39	61	14	22	22	48	22	48
1998	63	61	96	38	60	13	20	23	49	23	49
1999	63	61	96	37	58	12	19	24	49	24	49
2000	63	61	96	35	55	11	17	25	50	25	50
2001	62	60	96	34	54	11	17	26	50	26	50
2002	63	60	95	34	53	11	17	26	50	26	50
2003	63	60	95	33	52	10	15	27	50	27	50
2004	63	60	95	33	52	10	15	28	50	28	50
2005	63	60	95	32	50	10	15	28	50	28	50

Table WDE-D: Water Heating

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

Detroit Edison Service Territory

Year	Technical Potential Investment Costs ($M)		Program Scenario Costs ($M)						Discounted Ratepayer Costs ($M)			
			Administration		Rebate		Ratepayer		3% Discount Rate		7% Discount Rate	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	16	16	0	0	1	1	1	1	1	1	1	1
1989	16	31	0	0	1	1	1	2	1	1	1	1
1990	16	47	0	0	2	3	2	4	2	3	2	3
1991	14	62	0	1	2	6	2	6	2	5	2	4
1992	14	76	0	1	2	8	2	9	2	7	1	6
1993	14	90	0	1	2	10	2	11	2	9	1	7
1994	14	105	0	1	2	12	2	13	2	11	1	9
1995	14	119	0	2	2	14	2	16	2	13	1	10
1996	14	134	0	2	2	16	2	17	1	14	1	11
1997	14	148	0	2	2	17	2	19	1	15	1	11
1998	14	163	0	2	2	19	2	21	1	16	1	12
1999	14	177	0	2	2	20	2	23	1	18	1	13
2000	14	191	0	3	2	22	2	24	1	19	1	13
2001	0	191	0	3	1	23	1	26	1	19	0	14
2002	0	191	0	3	1	24	1	27	1	20	0	14
2003	0	191	0	3	0	24	0	27	0	20	0	14
2004	0	191	0	3	0	24	0	27	0	20	0	14
2005	0	191	0	3	0	24	0	27	0	20	0	14
Total	191.37		2.86		23.67		26.53		19.97		14.09	

Table C-A: Air Conditioning

Scenario of potential electricity savings 1984-2005,

CP and DE territories combined, GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	1070	1070	100	1070	100	1070	100	0	0	0	0
1985	1080	1080	100	1079	99	1079	99	0	0	0	0
1986	1071	1070	99	1066	99	1066	99	4	4	5	5
1987	1058	1057	99	1048	99	1048	99	5	5	9	9
1988	1048	1046	99	1027	97	996	95	7	40	16	50
1989	1039	1034	99	1009	97	946	91	9	39	25	90
1990	1033	1027	99	990	96	898	88	11	39	36	128
1991	1026	1018	99	973	94	860	83	10	30	46	158
1992	1022	1011	98	955	93	822	80	11	30	56	191
1993	1017	1004	98	938	92	783	76	9	31	66	221
1994	1019	1007	98	933	91	765	75	7	21	72	242
1995	1024	1008	98	929	90	746	73	7	21	79	262
1996	1028	1010	98	924	89	731	71	5	18	86	279
1997	1031	1013	98	922	89	716	69	4	17	90	297
1998	1036	1014	97	919	88	697	67	6	21	96	318
1999	1043	1018	97	915	87	680	65	6	21	101	339
2000	1049	1021	97	914	87	663	63	5	20	106	358
2001	1052	1020	96	908	86	633	60	8	33	112	387
2002	1053	1016	96	900	85	604	57	8	31	115	411
2003	1053	1011	96	894	84	603	57	8	35	117	407
2004	1052	1006	95	889	84	603	57	8	35	116	403
2005	1051	1000	95	886	84	603	57	7	34	114	398
Total	22955	22561	98	21088	91	17610	78	146	525	1463	4953

Table C-C: Air Conditioning

Scenario of potential summer peak power savings 1984-2005,

CP and DE territories combined, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	1273	1273	100	1273	100	1273	100	0	0	0	0
1985	1292	1292	100	1289	99	1289	99	1	1	1	1
1986	1277	1275	99	1270	99	1270	99	4	4	5	5
1987	1256	1256	100	1245	99	1245	99	6	6	11	11
1988	1241	1237	99	1217	98	1177	94	8	48	19	60
1989	1225	1221	99	1191	97	1115	91	10	47	30	106
1990	1214	1208	99	1166	96	1056	86	12	45	42	151
1991	1204	1196	99	1142	94	1007	83	12	38	54	190
1992	1196	1185	99	1118	93	958	80	13	38	66	228
1993	1187	1175	98	1096	92	909	76	13	38	79	266
1994	1189	1176	98	1086	91	882	74	9	28	89	293
1995	1191	1175	98	1077	90	855	71	9	27	98	320
1996	1193	1176	98	1071	89	834	69	8	23	104	343
1997	1198	1178	98	1066	88	814	67	7	21	111	363
1998	1202	1180	98	1061	88	792	65	7	24	119	389
1999	1208	1184	98	1058	87	771	63	7	25	125	413
2000	1215	1187	97	1055	86	751	61	7	24	132	436
2001	1218	1186	97	1046	85	714	58	12	39	140	471
2002	1218	1182	97	1037	85	680	55	11	37	145	501
2003	1218	1176	96	1028	84	679	55	11	43	148	497
2004	1217	1172	96	1023	84	680	55	11	42	147	492
2005	1214	1165	95	1018	83	678	55	11	40	147	486

Table C-D: Air Conditioning

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

CP and DE territories combined.

Year	Technical Potential Investment Costs ($M)		Program Scenario Costs ($M)					
			Administration		Rebate		Ratepayer	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1984	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0
1988	109	109	0	0	0	0	0	0
1989	109	218	0	0	0	0	0	0
1990	108	326	0	0	0	0	0	0
1991	95	420	0	0	0	0	0	0
1992	97	517	0	0	0	0	0	0
1993	97	614	0	0	0	0	0	0
1994	75	690	0	0	0	0	0	0
1995	75	765	0	0	0	0	0	0
1996	67	831	0	0	0	0	0	0
1997	61	892	0	0	0	0	0	0
1998	70	961	0	0	0	0	0	0
1999	73	1034	0	0	0	0	0	0
2000	72	1106	0	0	0	0	0	0
2001	111	1218	0	0	0	0	0	0
2002	108	1326	0	0	0	0	0	0
2003	113	1439	0	0	0	0	0	0
2004	113	1552	0	0	0	0	0	0
2005	112	1664	0	0	0	0	0	0
Total	1663.55		0		0		0	

Table CCP-A: Air Conditioning

Scenario of potential electricity savings 1984-2005,

Consumers Power Service Territory — GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	298	298	100	298	100	298	100	0	0	0	0
1985	300	300	100	300	100	300	100	0	0	0	0
1986	301	300	99	299	99	299	99	1	1	2	2
1987	303	303	100	300	99	300	99	2	2	3	3
1988	305	304	99	298	97	289	94	2	12	5	15
1989	307	306	99	298	97	279	90	3	12	8	27
1990	310	308	99	297	96	269	86	3	12	11	39
1991	308	305	99	292	94	258	83	3	8	14	47
1992	307	304	99	287	93	248	80	3	8	18	57
1993	307	303	98	283	92	237	77	3	10	20	66
1994	307	304	99	283	92	235	76	1	3	20	69
1995	310	305	98	284	91	233	75	1	3	21	72
1996	312	307	98	284	91	233	74	1	3	23	74
1997	312	308	98	283	90	227	72	1	6	24	81
1998	314	307	97	281	89	218	69	3	9	27	90
1999	316	308	97	278	87	209	66	3	9	29	99
2000	318	309	97	278	87	203	63	2	8	30	106
2001	321	310	96	277	86	195	60	2	10	32	115
2002	322	310	96	276	85	187	58	2	10	33	123
2003	324	310	95	276	85	187	57	2	11	34	122
2004	325	310	95	275	84	188	57	2	11	34	122
2005	326	309	94	275	84	189	57	2	11	34	121
Total	6853	6723	98	6302	91	5281	77	42	159	420	1450

Table CCP-C: Air Conditioning

Scenario of potential summer peak power savings 1984-2005,

Consumers Power Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	294	294	100	294	100	294	100	0	0	0	0
1985	298	298	100	297	99	297	99	0	0	0	0
1986	298	298	100	296	99	296	99	1	1	1	1
1987	301	301	100	298	99	298	99	2	2	3	3
1988	304	302	99	297	97	286	94	2	13	5	16
1989	306	305	99	297	97	277	90	3	13	8	28
1990	309	308	99	297	96	268	86	3	12	11	40
1991	307	305	99	291	94	256	83	3	9	14	50
1992	306	302	98	285	93	244	79	3	10	17	59
1993	306	303	99	282	92	233	76	3	10	21	69
1994	306	303	99	281	91	231	75	1	3	22	72
1995	308	304	98	281	91	230	74	1	3	23	75
1996	310	306	98	283	91	229	73	1	3	23	78
1997	312	307	98	281	90	222	71	2	7	25	84
1998	313	307	98	278	88	213	68	3	9	28	94
1999	314	308	98	277	88	205	65	3	9	30	103
2000	317	309	97	276	87	198	62	2	8	33	110
2001	320	310	96	275	85	190	59	3	10	35	120
2002	321	310	96	274	85	182	56	3	11	36	128
2003	323	310	95	273	84	182	56	3	12	37	128
2004	324	311	96	273	84	184	56	3	12	37	127
2005	324	310	95	273	84	184	56	3	11	37	126

Table CCP-D: Air Conditioning

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

Consumers Power Service Territory

Year	Technical Potential Investment Costs ($M)		Program Scenario Costs ($M)						Discounted Ratepayer Costs ($M)			
			Administration		Rebate		Ratepayer		3% Discount Rate		7% Discount Rate	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	32	32	0	0	0	0	0	0	0	0	0	0
1989	33	65	0	0	0	0	0	0	0	0	0	0
1990	32	97	0	0	0	0	0	0	0	0	0	0
1991	27	123	0	0	0	0	0	0	0	0	0	0
1992	27	151	0	0	0	0	0	0	0	0	0	0
1993	30	181	0	0	0	0	0	0	0	0	0	0
1994	10	190	0	0	0	0	0	0	0	0	0	0
1995	11	201	0	0	0	0	0	0	0	0	0	0
1996	10	211	0	0	0	0	0	0	0	0	0	0
1997	20	231	0	0	0	0	0	0	0	0	0	0
1998	27	258	0	0	0	0	0	0	0	0	0	0
1999	27	285	0	0	0	0	0	0	0	0	0	0
2000	24	309	0	0	0	0	0	0	0	0	0	0
2001	34	343	0	0	0	0	0	0	0	0	0	0
2002	35	378	0	0	0	0	0	0	0	0	0	0
2003	35	413	0	0	0	0	0	0	0	0	0	0
2004	35	448	0	0	0	0	0	0	0	0	0	0
2005	35	483	0	0	0	0	0	0	0	0	0	0
Total	482.87		0		0		0		0		0	

Table CDE-D: Air Conditioning

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

Detroit Edison Service Territory

Year	Technical Potential Investment Costs ($M)		Program Scenario Costs ($M)						Discounted Ratepayer Costs ($M)			
			Administration		Rebate		Ratepayer		3% Discount Rate		7% Discount Rate	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	76	76	0	0	0	0	0	0	0	0	0	0
1989	76	153	0	0	0	0	0	0	0	0	0	0
1990	76	229	0	0	0	0	0	0	0	0	0	0
1991	68	297	0	0	0	0	0	0	0	0	0	0
1992	70	367	0	0	0	0	0	0	0	0	0	0
1993	67	434	0	0	0	0	0	0	0	0	0	0
1994	65	499	0	0	0	0	0	0	0	0	0	0
1995	64	563	0	0	0	0	0	0	0	0	0	0
1996	57	620	0	0	0	0	0	0	0	0	0	0
1997	40	660	0	0	0	0	0	0	0	0	0	0
1998	43	703	0	0	0	0	0	0	0	0	0	0
1999	46	749	0	0	0	0	0	0	0	0	0	0
2000	48	797	0	0	0	0	0	0	0	0	0	0
2001	78	875	0	0	0	0	0	0	0	0	0	0
2002	74	948	0	0	0	0	0	0	0	0	0	0
2003	78	1026	0	0	0	0	0	0	0	0	0	0
2004	77	1104	0	0	0	0	0	0	0	0	0	0
2005	77	1181	0	0	0	0	0	0	0	0	0	0
Total	1180.68		0		0		0		0		0	

Table H-A: Space Heating

Scenario of potential electricity savings 1984-2005,

CP and DE territories combined, GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	1175	1175	100	1175	100	1175	100	0	0	0	0
1985	1187	1187	100	1175	98	1171	98	13	16	13	16
1986	1197	1192	99	1170	97	1164	97	14	20	21	27
1987	1212	1204	99	1171	96	1163	95	25	35	32	42
1988	1227	1220	99	1167	95	1103	89	41	104	53	117
1989	1242	1233	99	1159	93	1045	84	49	111	74	189
1990	1261	1252	99	1148	91	987	78	66	128	105	264
1991	1276	1267	99	1133	88	979	76	71	83	135	287
1992	1291	1283	99	1116	86	971	75	80	94	167	310
1993	1304	1296	99	1099	84	961	73	87	106	198	335
1994	1320	1311	99	1082	81	953	72	95	117	229	357
1995	1336	1327	99	1068	79	942	70	103	128	260	381
1996	1351	1340	99	1048	77	934	69	112	142	292	406
1997	1363	1354	99	1031	75	922	67	120	153	323	430
1998	1378	1368	99	1024	74	912	66	118	166	346	455
1999	1392	1381	99	1015	72	899	64	128	179	366	480
2000	1406	1396	99	1008	71	887	63	137	192	387	505
2001	1418	1405	99	1000	70	877	61	144	204	407	529
2002	1429	1413	98	989	69	862	60	153	217	425	552
2003	1439	1421	98	978	67	845	58	161	229	443	574
2004	1448	1427	98	965	66	831	57	171	243	461	597
2005	1456	1434	98	954	65	814	55	181	257	481	619
Total	29108	28886	99	23675	81	21397	73	2069	2922	5217	7472

Table H-B: Space Heating

Scenario of potential winter peak power savings 1984-2005,

CP and DE territories combined, MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	733	733	100	733	100	733	100	0	0	0	0
1985	740	739	99	730	98	728	98	8	10	7	10
1986	748	743	99	729	97	725	96	11	15	14	18
1987	758	750	98	729	96	723	95	17	23	20	27
1988	768	759	98	727	94	693	90	25	58	31	64
1989	778	766	98	722	92	664	85	31	64	45	101
1990	789	775	98	715	90	634	80	40	74	59	138
1991	797	782	98	707	88	629	78	45	56	75	153
1992	806	789	97	698	86	623	77	51	64	92	167
1993	815	796	97	688	84	616	75	56	72	108	181
1994	824	804	97	678	82	609	73	62	80	126	194
1995	834	810	97	669	80	602	72	68	88	143	208
1996	843	818	97	659	78	594	70	73	96	159	223
1997	850	824	96	647	76	586	68	80	105	177	237
1998	858	830	96	643	74	579	67	80	114	188	252
1999	867	837	96	636	73	570	65	87	124	200	267
2000	875	843	96	630	72	561	64	94	133	212	282
2001	884	849	96	625	70	552	62	99	141	223	296
2002	890	852	95	617	69	541	60	106	151	235	310
2003	897	857	95	608	67	532	59	112	160	247	324
2004	902	858	95	601	66	521	57	119	170	258	338
2005	908	861	94	593	65	508	55	126	179	268	352

Table H-D: Space Heating

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

CP and DE territories combined.

Year	Technical Potential Investment Costs ($M)		Program Scenario Costs ($M) Administration		Rebate		Ratepayer	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1984	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0
1988	69	69	1	1	6	6	7	7
1989	67	136	3	4	10	17	13	20
1990	70	206	1	5	13	30	14	35
1991	10	216	2	7	14	44	16	51
1992	10	226	2	8	14	58	16	66
1993	11	237	2	10	14	72	16	82
1994	10	247	2	11	14	86	16	98
1995	10	257	2	13	14	101	16	114
1996	10	267	2	15	14	115	16	129
1997	10	277	2	16	14	129	16	145
1998	10	288	0	16	0	129	0	145
1999	10	298	0	16	0	129	0	145
2000	10	308	0	16	0	129	0	145
2001	9	317	0	17	0	129	0	145
2002	8	325	0	17	0	129	0	146
2003	8	334	0	17	0	129	0	146
2004	8	342	0	17	0	129	0	146
2005	8	350	0	17	0	129	0	146
Total	349.72		16.89		128.92		145.88	

Table HCP-A: Space Heating

Scenario of potential electricity savings 1984-2005,
Consumers Power Service Territory — GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/ Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	540	540	100	540	100	540	100	0	0	0	0
1985	547	548	100	543	99	541	98	5	7	5	7
1986	555	556	100	545	98	542	97	7	10	10	13
1987	566	568	100	551	97	547	96	10	15	16	21
1988	575	578	100	552	96	518	90	16	49	26	60
1989	585	588	100	552	94	490	83	19	53	36	99
1990	595	598	100	549	92	461	77	25	57	50	137
1991	603	607	100	542	89	459	76	27	33	64	147
1992	611	616	100	536	87	457	74	30	37	80	157
1993	619	626	101	531	85	456	73	33	43	95	170
1994	626	632	100	523	83	452	72	35	46	110	179
1995	634	641	101	517	81	449	70	37	50	124	190
1996	642	649	101	508	79	447	69	41	56	140	201
1997	648	657	101	502	77	443	68	43	60	155	213
1998	656	665	101	501	76	441	67	40	65	165	224
1999	663	672	101	498	75	435	65	43	70	174	235
2000	670	680	101	497	74	432	64	46	75	183	247
2001	679	689	101	497	73	430	63	50	82	194	260
2002	686	697	101	494	72	426	62	52	86	208	271
2003	693	704	101	492	70	420	60	55	91	212	283
2004	699	711	101	488	69	416	59	59	96	222	294
2005	704	718	101	486	69	411	58	62	102	232	306
Total	13798	13940	101	11444	82	10213	74	735	1183	2496	3714

Table HCP-B: Space Heating

Scenario of potential winter peak power savings 1984-2005,
Consumers Power Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	335	335	100	335	100	335	100	0	0	0	0
1985	340	340	100	336	98	335	98	3	4	3	5
1986	345	344	99	338	97	336	97	5	7	6	8
1987	352	351	99	341	96	338	96	6	10	9	13
1988	358	357	99	342	95	324	90	9	28	14	33
1989	365	363	99	343	93	309	84	12	31	21	53
1990	370	368	99	340	91	294	79	15	33	27	73
1991	375	373	99	337	89	293	78	17	22	35	80
1992	380	377	99	334	87	291	76	19	25	44	86
1993	386	383	99	331	85	290	75	21	29	52	93
1994	389	386	99	326	83	287	73	22	31	60	98
1995	394	390	98	323	81	285	72	24	35	68	105
1996	399	395	98	318	79	283	70	26	38	77	112
1997	402	398	99	314	78	280	69	28	41	85	118
1998	407	402	98	313	76	278	68	27	45	90	125
1999	411	406	98	311	75	274	66	29	48	95	132
2000	415	410	98	310	74	271	65	31	52	100	139
2001	421	416	98	309	73	269	63	34	56	106	146
2002	425	419	98	307	72	266	62	36	60	112	153
2003	429	423	98	305	71	263	61	38	63	118	160
2004	433	426	98	303	69	260	60	40	67	123	167
2005	436	429	98	301	69	254	58	43	71	128	174

Table HCP-D: Space Heating

Annual and Cumulative costs of demand side resources (1985$), 1984-2005,

Consumers Power Service Territory

Year	Technical Potential Investment Costs ($M)		Program Scenario Costs ($M)						Discounted Ratepayer Costs ($M)			
			Administration		Rebate		Ratepayer		3% Discount Rate		7% Discount Rate	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1984	0	0	0	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0	0	0	0	0
1988	47	47	0	0	4	4	5	5	4	4	4	4
1989	47	93	2	2	7	11	9	14	8	12	7	11
1990	46	140	1	3	9	20	10	23	8	21	7	18
1991	7	147	1	4	10	30	11	34	9	30	7	25
1992	7	153	1	5	10	40	11	45	9	38	7	31
1993	8	161	1	6	10	49	11	56	8	47	6	38
1994	6	167	1	7	10	59	11	66	8	55	6	44
1995	7	174	1	8	10	69	11	77	8	63	5	49
1996	7	181	1	9	10	78	11	88	8	71	5	54
1997	7	188	1	11	10	88	11	99	8	78	5	59
1998	7	195	0	11	0	88	0	99	0	78	0	59
1999	7	201	0	11	0	88	0	99	0	78	0	59
2000	7	208	0	11	0	88	0	99	0	78	0	59
2001	8	216	0	11	0	88	0	99	0	79	0	59
2002	7	223	0	11	0	88	0	99	0	79	0	59
2003	7	229	0	11	0	88	0	99	0	79	0	59
2004	7	236	0	11	0	88	0	99	0	79	0	59
2005	7	243	0	11	0	88	0	99	0	79	0	59
Total	242.74		10.9		88.09		98.98		78.63		59.04	

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Table HDE-A: Space Heating

Scenario of potential electricity savings 1984-2005,

Detroit Edison Service Territory — GWh indices based on Frozen Efficiency = 100.

Year	Frozen (GWh/Year)	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (GWh)			
								From New Sales		Total Yearly	
		GWh	Index	GWh	Index	GWh	Index	Prog	TechP	Prog	TechP
1984	635	635	100	635	100	635	100	0	0	0	0
1985	640	639	99	632	98	630	98	8	9	8	9
1986	642	636	99	625	97	622	96	7	10	11	14
1987	646	636	98	620	95	616	95	15	20	16	21
1988	652	642	98	615	94	585	89	25	55	27	57
1989	657	645	98	607	92	555	84	30	58	38	90
1990	666	654	98	599	89	528	78	41	69	56	127
1991	673	660	98	591	87	520	77	44	50	71	140
1992	680	667	98	580	85	514	75	50	57	87	153
1993	685	670	97	568	82	505	73	54	63	103	165
1994	694	679	97	559	80	501	72	60	71	119	178
1995	702	686	97	551	78	493	70	66	78	136	191
1996	709	691	97	540	76	487	68	71	86	152	205
1997	715	697	97	529	73	479	66	77	93	168	217
1998	722	703	97	523	72	471	65	78	101	180	231
1999	729	709	97	517	70	464	63	85	109	192	245
2000	736	716	97	511	69	455	61	91	117	204	258
2001	739	716	96	503	68	447	60	94	122	213	269
2002	743	716	96	495	66	436	58	101	131	222	281
2003	746	717	96	486	65	425	56	106	138	231	291
2004	749	716	95	477	63	415	55	112	147	239	303
2005	752	716	95	468	62	403	53	119	155	249	313
Total	15312	14946	97	12231	79	11184	73	1334	1739	2721	3758

Table HDE-B: Space Heating

Scenario of potential winter peak power savings 1984-2005,

Detroit Edison Service Territory — MW indices based on Frozen Efficiency = 100.

Year	Frozen MW Peak	MEOS Forecast		Program Scenario		Technical Potential		Savings over MEOS (MW)			
								From New Sales		Total Yearly	
		MW	Index	MW	Index	MW	Index	Prog	TechP	Prog	TechP
1984	398	398	100	398	100	398	100	0	0	0	0
1985	400	399	99	394	98	393	98	5	6	4	5
1986	403	399	99	391	97	389	96	6	8	8	10
1987	406	399	98	388	95	385	94	10	13	11	14
1988	410	402	98	385	93	369	90	16	31	17	31
1989	413	403	97	379	91	355	85	19	34	24	48
1990	419	407	97	375	89	340	81	25	40	32	65
1991	422	409	96	370	87	336	79	28	34	40	73
1992	426	412	96	364	85	332	77	32	39	48	81
1993	429	413	96	357	83	326	75	35	43	56	88
1994	435	418	96	352	80	322	74	40	49	66	96
1995	440	420	95	346	78	317	72	43	54	75	103
1996	444	423	95	341	76	311	70	47	59	82	111
1997	448	426	95	333	74	306	68	51	64	92	119
1998	451	428	94	330	73	301	66	54	70	98	127
1999	456	431	94	325	71	296	64	58	75	105	135
2000	460	433	94	320	69	290	63	62	81	112	143
2001	463	433	93	316	68	283	61	65	85	117	150
2002	465	433	93	310	66	275	59	70	91	123	157
2003	468	434	92	303	64	269	57	74	97	129	164
2004	469	432	92	298	63	261	55	79	103	135	171
2005	472	432	91	292	61	254	53	83	109	140	178

Figure A-1

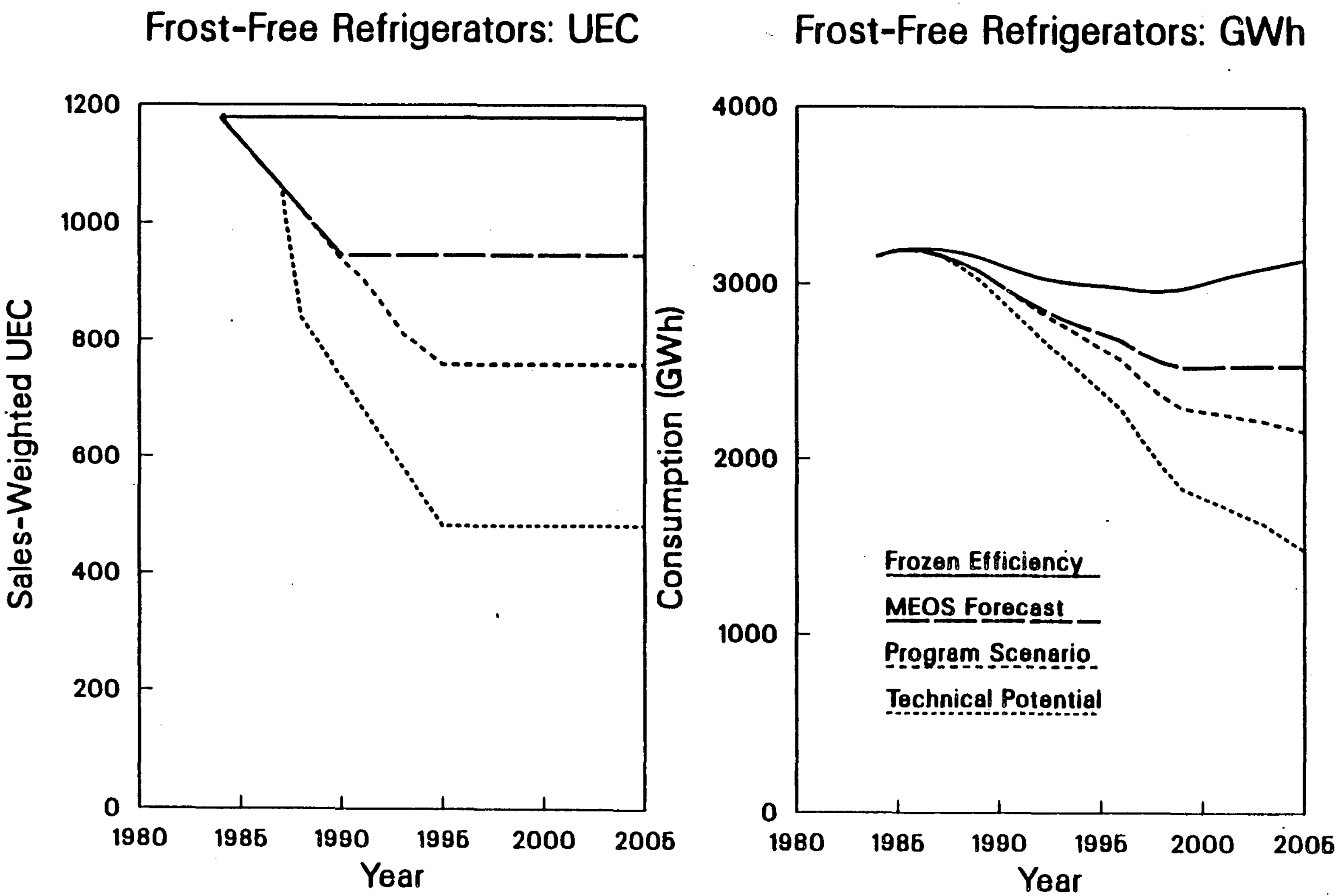

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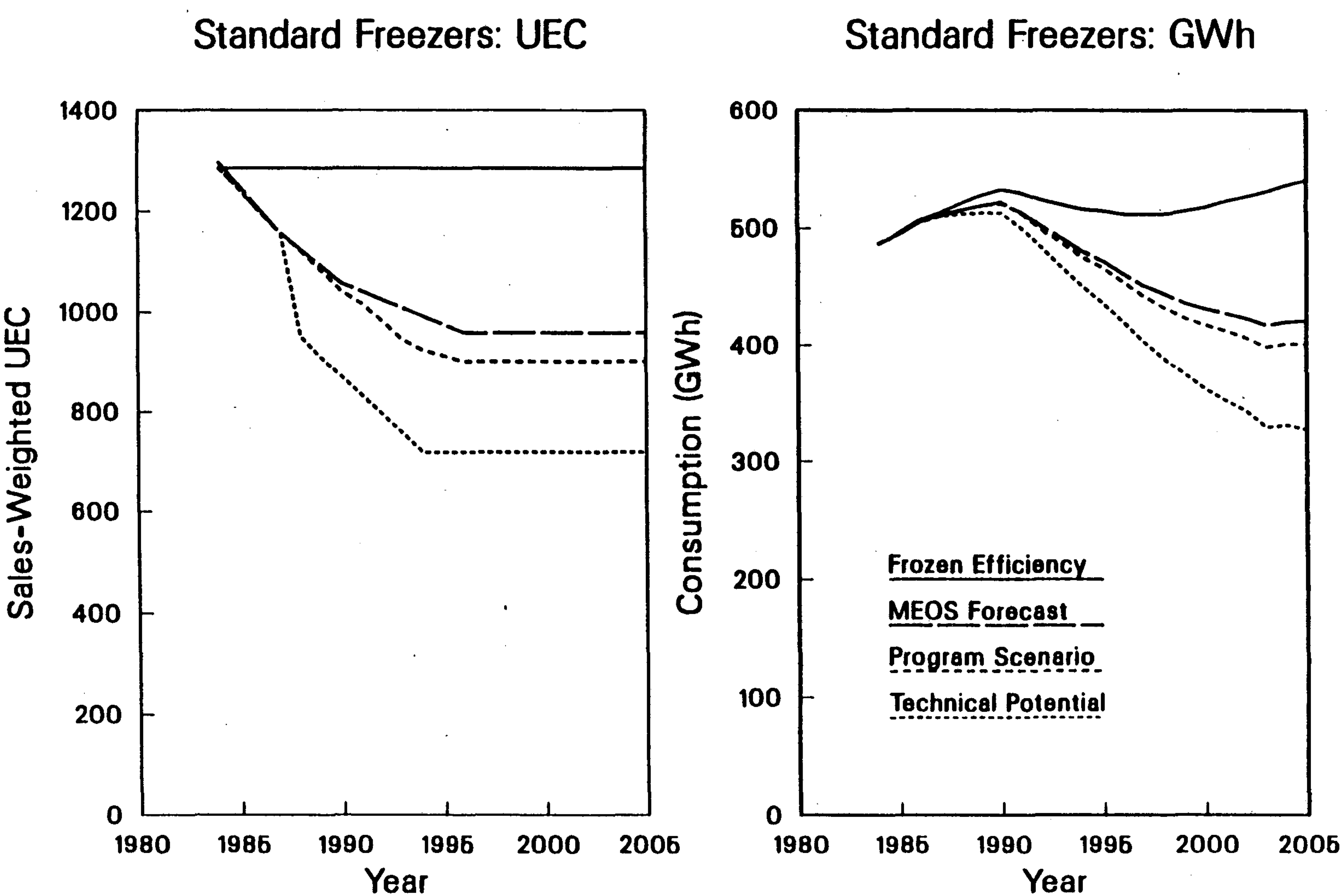
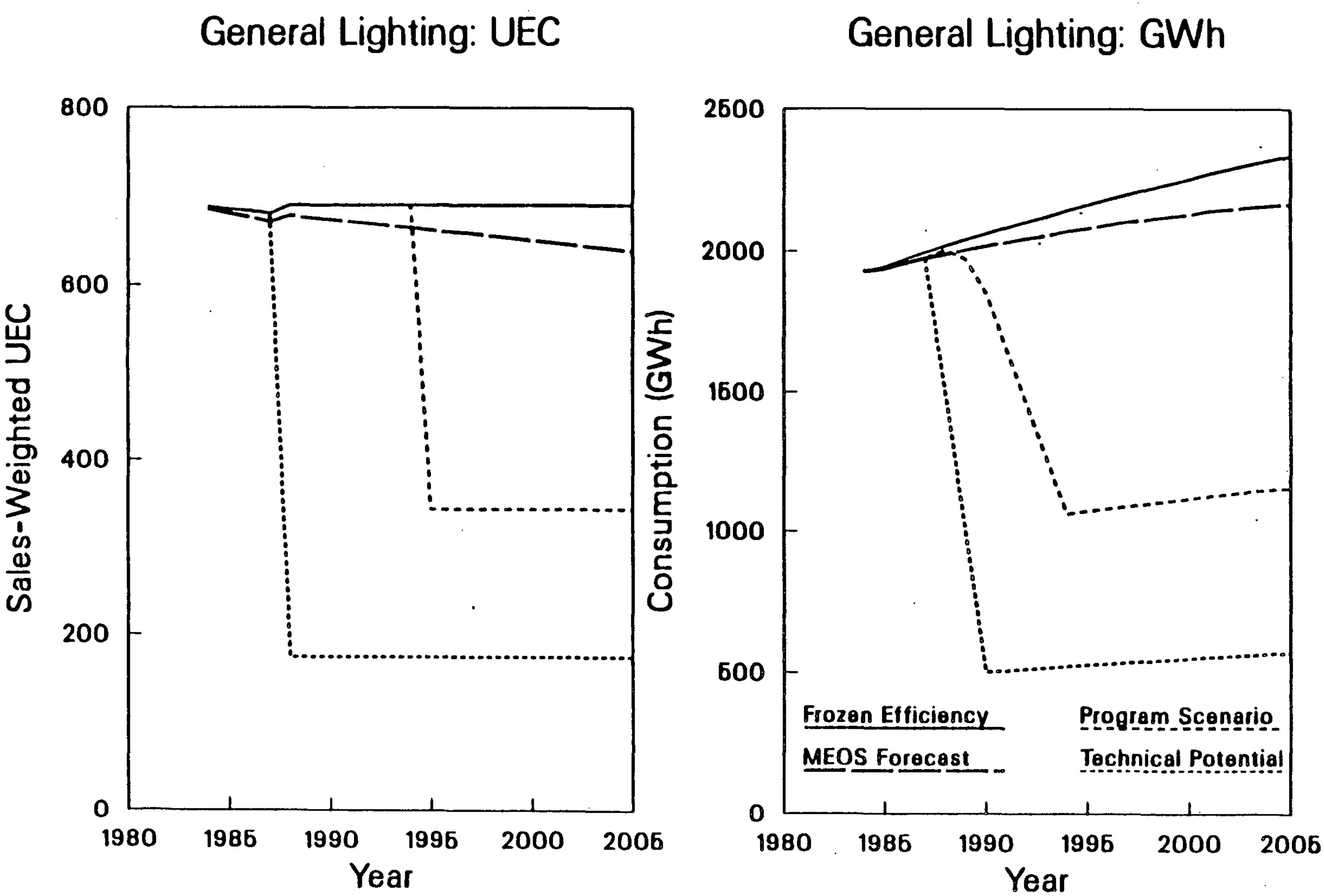
Figure A-2



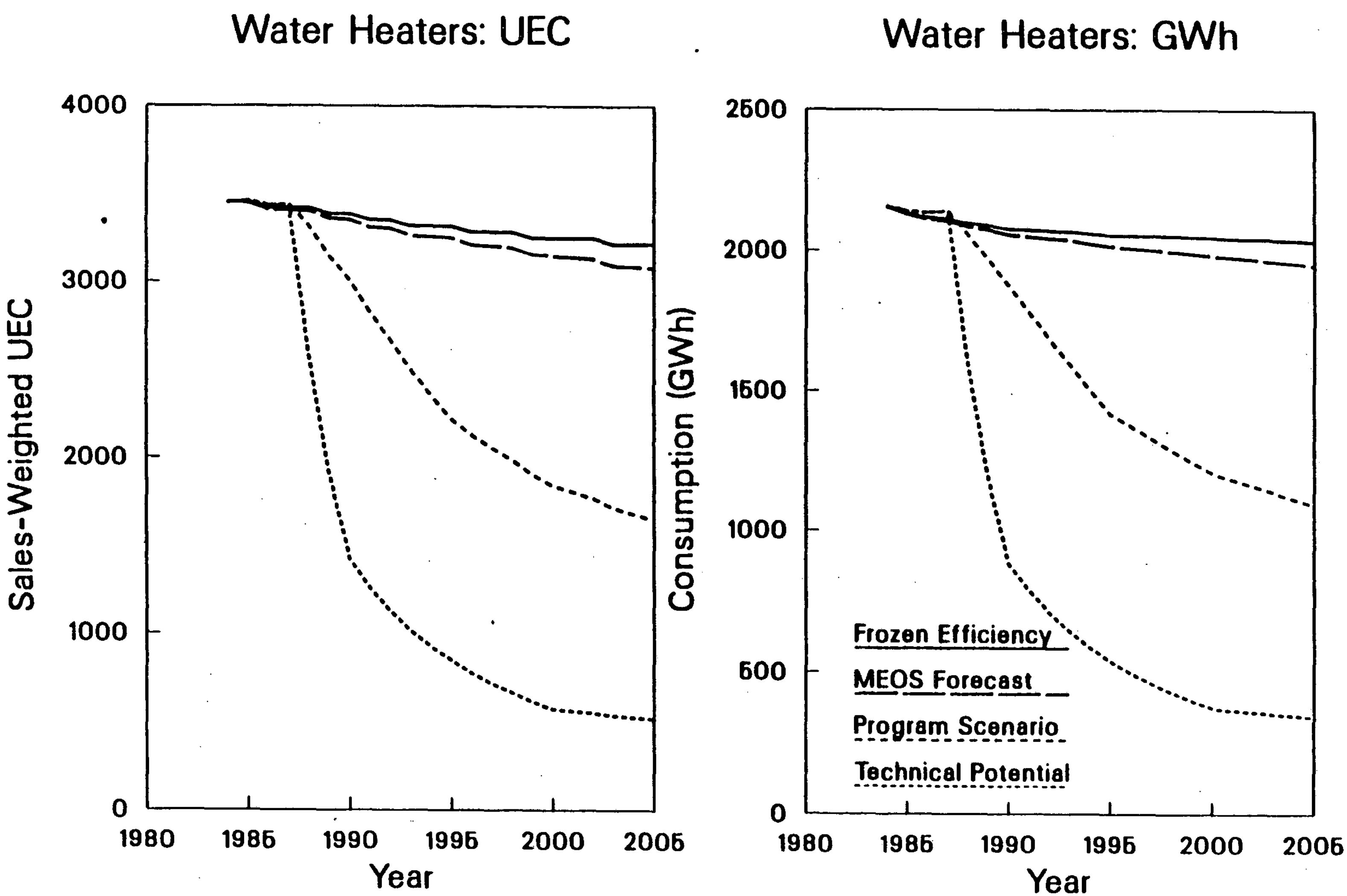
XCG 872-6766

Figure A-3



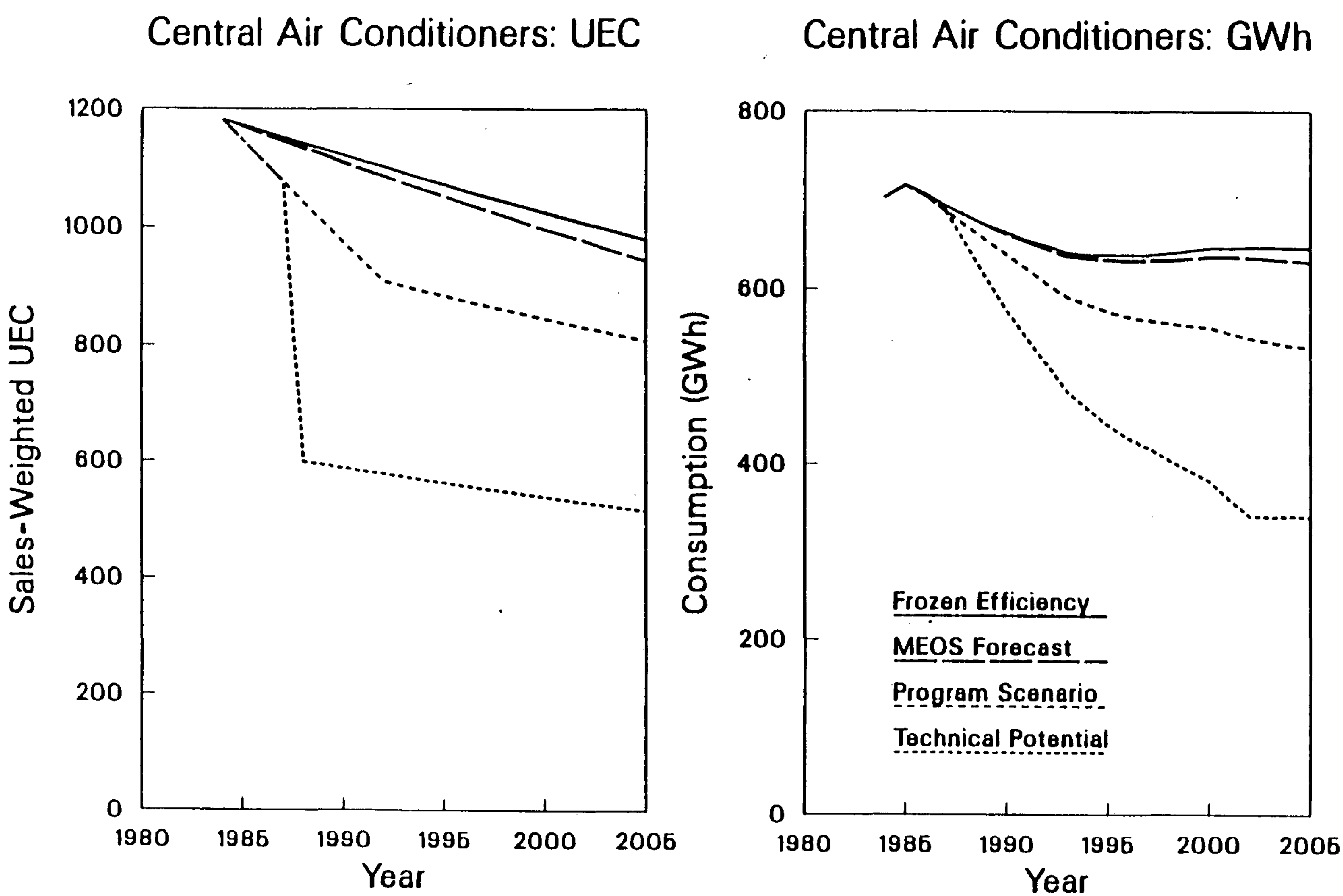
XCG 872-6764

Figure A-4



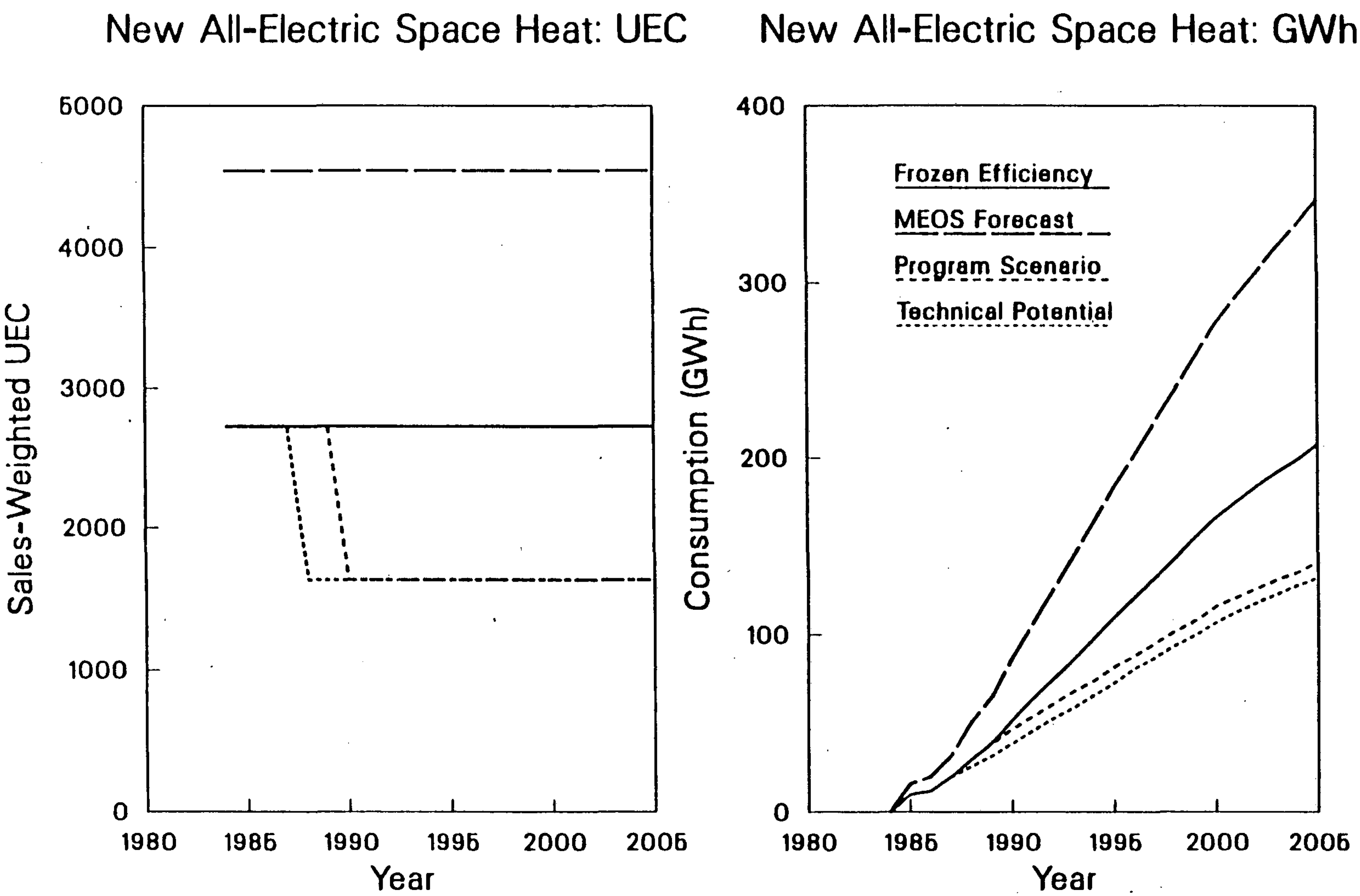
XCG 872-6767

Figure A-5



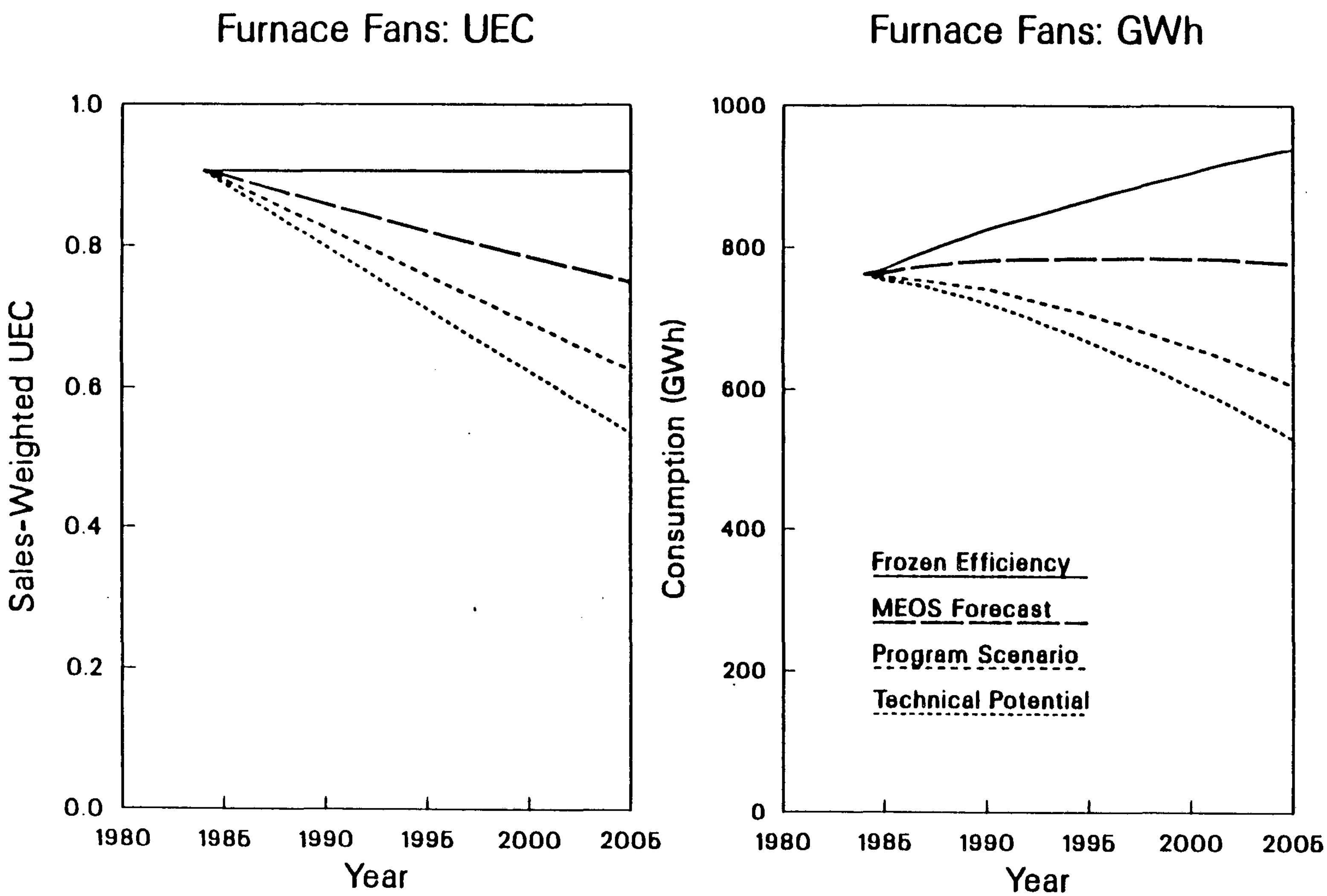
XCG 872-6760

Figure A-6



XCG 872-6762

Figure A-7



XCG 872-6763

APPENDIX B

HOURLY-TO-AVERAGE LOAD FACTORS AND FRACTION-IN-USE PROFILES

CONTENTS Page

Table B-1: Hourly to Average Load Profile for Refrigerators by Season

HOUR	SUMMER	WINTER	SPRING-FALL
01	1.011	0.805	0.860
02	1.011	0.805	0.860
03	1.011	0.805	0.860
04	1.011	0.805	0.860
05	1.011	0.805	0.860
06	1.035	0.805	0.860
07	1.059	0.824	0.880
08	1.176	0.842	0.900
09	1.176	0.936	1.000
10	1.176	0.936	1.000
11	1.176	0.936	1.000
12	1.176	0.936	1.000
13	1.176	0.936	1.000
14	1.176	0.936	1.000
15	1.176	0.936	1.000
16	1.176	0.936	1.000
17	1.176	0.936	1.121
18	1.176	0.936	1.681
19	1.448	1.152	1.231
20	1.448	1.152	1.231
21	1.448	1.152	1.231
22	1.346	1.071	1.145
23	1.225	0.999	1.068
24	1.011	0.805	0.860

Table B-2: Hourly to Average Load Profile for General Lighting by Season

HOUR	SUMMER	WINTER	SPRING-FALL
01	0.431	0.603	0.517
02	0.345	0.431	0.388
03	0.173	0.345	0.302
04	0.259	0.345	0.302
05	0.259	0.431	0.345
06	0.345	0.689	0.517
07	0.517	1.035	0.776
08	0.518	0.863	0.690
09	0.604	0.690	0.647
10	0.603	0.603	0.603
11	0.689	0.517	0.603
12	0.689	0.517	0.603
13	0.689	0.517	0.603
14	0.603	0.517	0.560
15	0.603	0.517	0.560
16	0.604	1.035	0.819
17	0.609	1.552	1.121
18	0.948	2.414	1.681
19	1.207	3.189	2.198
20	1.724	3.018	2.371
21	2.327	2.845	2.586
22	2.155	2.327	2.241
23	1.896	1.810	1.853
24	1.207	1.207	1.207

Table B-3: Fraction-in-use profile by type of day for electric water heaters, Consumers Power Co.

	SUMMER			WINTER			SPRING-FALL	
Hour	WKDAY	WKND	PEAK	WKDY	WKND	PEAK	WKDY	WKND
01	0.06	0.06	0.05	0.05	0.06	0.08	0.05	0.06
02	0.04	0.04	0.03	0.04	0.05	0.03	0.04	0.05
03	0.05	0.04	0.04	0.04	0.04	0.04	0.03	0.04
04	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.03
05	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.03
06	0.07	0.04	0.06	0.07	0.04	0.08	0.08	0.04
07	0.09	0.05	0.08	0.12	0.05	0.13	0.12	0.06
08	0.12	0.08	0.11	0.14	0.08	0.17	0.16	0.10
09	0.14	0.12	0.12	0.15	0.14	0.12	0.16	0.15
10	0.14	0.16	0.14	0.14	0.17	0.17	0.15	0.18
11	0.14	0.15	0.14	0.15	0.18	0.16	0.14	0.18
12	0.14	0.15	0.12	0.14	0.19	0.13	0.14	0.17
13	0.13	0.14	0.12	0.13	0.18	0.14	0.13	0.16
14	0.12	0.14	0.13	0.12	0.17	0.13	0.11	0.16
15	0.11	0.12	0.10	0.11	0.15	0.12	0.11	0.14
16	0.10	0.12	0.12	0.11	0.14	0.09	0.10	0.13
17	0.11	0.11	0.13	0.13	0.13	0.14	0.12	0.12
18	0.12	0.12	0.13	0.14	0.14	0.16	0.14	0.13
19	0.13	0.11	0.12	0.16	0.15	0.17	0.15	0.13
20	0.13	0.12	0.12	0.15	0.15	0.15	0.14	0.14
21	0.12	0.11	0.08	0.13	0.13	0.17	0.13	0.13
22	0.12	0.13	0.11	0.11	0.11	0.16	0.12	0.12
23	0.11	0.10	0.09	0.09	0.10	0.08	0.10	0.10
24	0.08	0.08	0.07	0.08	0.08	0.08	0.08	0.09

Table B-4: Fraction-in-use profile by type of day for electric water heaters, Detroit Edison Co.

	SUMMER			WINTER			SPRING-FALL	
Hour	WKDAY	WKND	PEAK	WKDY	WKND	PEAK	WKDY	WKND
01	.138	.126	.147	.174	.151	.157	.171	.155
02	.076	.073	.078	.109	.101	.096	.099	.096
03	.059	.057	.056	.077	.071	.075	.068	.069
04	.047	.046	.045	.063	.060	.063	.060	.063
05	.058	.048	.061	.064	.063	.070	.068	.060
06	.061	.053	.064	.082	.060	.089	.083	.059
07	.108	.061	.100	.133	.064	.130	.143	.065
08	.157	.089	.157	.206	.102	.221	.223	.111
09	.167	.151	.165	.226	.182	.234	.216	.180
10	.170	.185	.168	.223	.231	.235	.213	.231
11	.172	.203	.181	.213	.251	.218	.203	.241
12	.170	.199	.177	.196	.251	.200	.190	.233
13	.164	.189	.188	.188	.236	.188	.182	.223
14	.142	.170	.129	.174	.222	.168	.162	.206
15	.122	.147	.120	.162	.201	.150	.152	.190
16	.127	.139	.119	.157	.181	.170	.145	.177
17	.131	.134	.124	.165	.175	.172	.155	.167
18	.144	.137	.147	.177	.181	.187	.172	.172
19	.149	.142	.141	.179	.186	.172	.175	.171
20	.098	.125	.087	.089	.098	.101	.098	.126
21	.070	.103	.139	.060	.081	.058	.062	.093
22	.075	.095	.066	.084	.106	.091	.076	.102
23	.123	.109	.119	.177	.172	.182	.144	.135
24	.212	.159	.243	.243	.223	.258	.243	.206

Note: Profile reflects load control in the evening

Table B-5: Fraction-in-use profile by type of day for heat pump water heaters, Consumers Power Co.

	SUMMER			WINTER			SPRING-FALL	
Hour	WKDAY	WKND	PEAK	WKDY	WKND	PEAK	WKDY	WKND
01	0.08	0.08	0.12	0.11	0.14	0.02	0.08	0.09
02	0.05	0.06	0.03	0.07	0.12	0.02	0.06	0.09
03	0.05	0.06	0.04	0.07	0.08	0.14	0.07	0.07
04	0.06	0.06	0.05	0.07	0.08	0.01	0.07	0.08
05	0.08	0.08	0.07	0.07	0.07	0.04	0.07	0.09
06	0.12	0.09	0.20	0.11	0.08	0.28	0.12	0.08
07	0.15	0.09	0.25	0.24	0.08	0.14	0.26	0.09
08	0.21	0.16	0.00	0.35	0.13	0.37	0.36	0.17
09	0.20	0.20	0.18	0.27	0.20	0.23	0.26	0.19
10	0.21	0.25	0.19	0.23	0.31	0.18	0.19	0.29
11	0.24	0.29	0.13	0.24	0.35	0.22	0.21	0.36
12	0.24	0.29	0.18	0.22	0.32	0.10	0.23	0.34
13	0.20	0.29	0.14	0.18	0.32	0.26	0.19	0.33
14	0.15	0.20	0.11	0.18	0.30	0.13	0.16	0.27
15	0.14	0.23	0.10	0.18	0.27	0.17	0.16	0.24
16	0.15	0.21	0.12	0.19	0.24	0.26	0.16	0.24
17	0.21	0.18	0.14	0.27	0.25	0.09	0.20	0.25
18	0.23	0.18	0.15	0.33	0.25	0.30	0.27	0.25
19	0.20	0.17	0.17	0.32	0.25	0.34	0.29	0.22
20	0.19	0.17	0.05	0.28	0.23	0.24	0.26	0.23
21	0.21	0.22	0.30	0.23	0.19	0.21	0.23	0.19
22	0.21	0.20	0.27	0.18	0.17	0.24	0.20	0.20
23	0.17	0.15	0.17	0.15	0.14	0.07	0.17	0.14
24	0.12	0.12	0.14	0.13	0.11	0.11	0.13	0.12

Table B-6 Fraction-in-use profile by type of day for central air conditioners, Consumers Power Co., (Base: 3.58 kw average maximum non-coincident demand, non-interruptible).

Rate 200: Air Conditioning Central Units

Day Type	Temp °F	1 am	2 am	3 am	4 am	5 am	6 am	7am	8am	9am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 am
WEEKDAY	< 60	0.004	0.006	0.003	0.002	0.002	0.003	0.03	0.001	0.000	0.004	0.000	0.000	0.000	0.003	0.007	0.003	0.000	0000	0.002	0.002	0.001	0.007	0.005	0.004
WEEKDAY	60/62	0.013	0.008	0.015	0.013	0.014	0.011	0.07	0.008	0.007	0.020	0.014	0.016	0.008	0.003	0.000	0.000	0.000	0.000	0.000	0.010	0.015	0.007	0.010	0.016
WEEKDAY	63/65	0.038	0.031	0.017	0.038	0.023	0.029	0.023	0.011	0.006	0.005	0.003	0.005	0.014	0.040	0.022	0.003	0.000	0.000	0.017	0.030	0.017	0.024	0.025	0.034
WEEKDAY	66/68	0.034	0.029	0.037	0.019	0.018	0.030	0.032	0.022	0.014	0.023	0.017	0.022	0.009	0.004	0.005	0.038	0.028	0.028	0.023	0.012	0.023	0.037	0.050	0.053
WEEKDAY	69/71	0.112	0.117	0.095	0.093	0.094	0.095	0.088	0.077	0.028	0.020	0.019	0.003	0.024	0.020	0.011	0.009	0.010	0.008	0.015	0.036	0.035	0.053	0.083	0.121
WEEKDAY	72/74	0.156	0.159	0.175	0.127	0.127	0.097	0.087	0.099	0.081	0.038	0.045	0.043	0.031	0.037	0.044	0.027	0.016	0.024	0.035	0.049	0.080	0.103	0.188	0.183
WEEKDAY	75/77	0.232	0.196	0.140	0.167	0.070	0.070	0.060	0.080	0.130	0.120	0.067	0.071	0.069	0.071	0.050	0.064	0.057	0.050	0.068	0.086	0.143	0.226	0.249	0.243
WEEKDAY	78/80	0.360	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.110	0.130	0.134	0.103	0.084	0.067	0.087	0.105	0.136	0.153	0.147	0.165	0.242	0.332	0.291	0.280
WEEKDAY	81/83	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.110	0.178	0.163	0.162	0.139	0.112	0.122	0.111	0.123	0.193	0.265	0.399	0.410	0.520	0.000
WEEKDAY	84/86	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.310	0.256	0.240	0.246	0.248	0.264	0.318	0.398	0.445	0.437	0.000	0.000	0.000
WEEKDAY	87/89	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.405	0.372	0.412	0.374	0.439	0.463	0440	0.000	0.000	0.000	0.000
WEEKDAY	90/92	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.470	0.570	0.580	0.620	0.000	0.000	0.000	0.000	0.000
WEEKEND	< 60	0.002	0.002	0.000	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.002	0.000	0.000
WEEKEND	60/62	0.003	0.008	0.013	0.025	0.005	0.010	0.003	0.002	0.001	0.005	0.003	0.005	0.000	0.000	0.000	0.000	0.005	0.010	0.010	0.015	0.000	0.000	0.000	0.010
WEEKEND	63/65	0.028	0.020	0.015	0.010	0.022	0.021	0.016	0.010	0.004	0.003	0.000	0.000	0.007	0.010	0.005	0.010	0.020	0.020	0.020	0.000	0.000	0.020	0.025	0.017
WEEKEND	66/68	0.033	0.051	0.042	0.027	0.029	0.034	0.030	0.025	0.013	0.003	0.012	0.013	0.020	0.010	0.010	0.010	0.000	0.000	0.000	0.005	0.016	0.038	0.043	0.028
WEEKEND	69/71	0.123	0.097	0.103	0.093	0.083	0.058	0.058	0.063	0.030	0.012	0.010	0.013	0.010	0.005	0.000	0.007	0.015	0.020	0.018	0.017	0.096	0.047	0.060	0.087
WEEKEND	72/74	0.170	0.130	0.120	0.110	0.070	0.000	0.000	0.087	0.073	0.060	0.019	0.017	0.030	0.023	0.027	0.035	0.050	0.040	0.108	0.112	0.045	0.102	0.180	0.150
WEEKEND	75/77	0.200	0.000	0.240	0.220	0.220	0.180	0.160	0.000	0.107	0.100	0.107	0.050	0.045	0.040	0.037	0.46	0.101	0.116	0.083	0.076	0.133	0.185	0.000	0.320
WEEKEND	78/80	0.330	0.280	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.105	0.135	0.103	0.092	0.107	0.099	0.074	0.074	0.094	0.113	0.204	0.340	0.350	0.325
WEEKEND	81/83	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.130	0.205	0.175	0.145	0142	0.166	0.124	0.130	0.190	0.244	0.380	0.425	0.000	0.000
WEEKEND	84/86	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.210	0.295	0.330	0.040	0.040	0.196	0.265	0.313	0.500	0.465	0.000	0.000	0.000
WEEKEND	87/89	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.350	0.377	0.423	0.500	0.525	0.495	0.485	0.000	0.000	0.000	0.000
WEEKEND	90/92	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.410	0.440	0.000	0.000	0.000	0.000	0.000	0.000
PEAKDAY.	72/74	0.000	0.000	0.220	0.170	0.170	0.170	0.150	0.130	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PEAKDAY	75/77	0.300	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.220	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.440	0.370
PEAKDAY	78/80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.510	0.000	0.000
PEAKDAY	81/83	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.290	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.570	0.000	0.000	0.000
PEAKDAY	84/86	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.390	0.430	0.000	0.000	0.000	0.000	0.000	0.000	0.610	0.000	0.000	0.000	0.000
PEAKDAY	87/89	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.480	0.530	0.640	0.000	0.680	0.690	0.000	0.000	0.000	0.000	0.000
PEAKDAY	90/92	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.660	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table B-7 Fraction-in-use profile by type of day for room air conditioners, Consumers Power Co., (Base: 3.58 kw average maximum non-coincident demand, non-interruptible).

Rate 100: Air Conditioning Room Units

Day Type	Temp °F	1 am	2 am	3 am	4 am	5 am	6 am	7am	8am	9am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 am
WEEKDAY	<60	0.001	0.001	0.003	0.004	0.003	0.003	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WEEKDAY	60/62	0.009	0.008	0.007	0.007	0.006	0.007	0.007	0.003	0.001	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.008
WEEKDAY	63/65	0.025	0.015	0.007	0.013	0.016	0.023	0.016	0.010	0.005	0.001	0.003	0.002	0.000	0.000	0.004	0.007	0.007	0.007	0.007	0.000	0.000	0.008	0.015	0.014
WEEKDAY	66/68	0.014	0.016	0.023	0.026	0.009	0.016	0.025	0.016	0.008	0.003	0.003	0.006	0.003	0.004	0.013	0.010	0.008	0.000	0.000	0.004	0.018	0.012	0.021	0.031
WEEKDAY	69/71	0.058	0.063	0.052	0.055	0.060	0.076	0.049	0.039	0.011	0.011	0.006	0.003	0.007	0.000	0.001	0.004	0.014	0.010	0.010	0.019	0.012	0.009	0.035	0.063
WEEKDAY	72/74	0.114	0.118	0.129	0.092	0.097	0.081	0.068	0.067	0.032	0.009	0.020	0.013	0.007	0.010	0.009	0.009	0.010	0.012	0.023	0.025	0.014	0.031	0.105	0.129
WEEKDAY	75/77	0.159	0.146	0.132	0.143	0.060	0.060	0.040	0.040	0.058	0.048	0.015	0.021	0.019	0.019	0.014	0.019	0.036	0.034	0.026	0.024	0.073	0.117	0.187	0.208
WEEKDAY	78/80	0.460	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.083	0.059	0.027	0.030	0.026	0.044	0.053	0.069	0.086	0.089	0.082	0.116	0.220	0.204	0.253
WEEKDAY	81/83	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.065	0.079	0.071	0.069	0.056	0.068	0.083	0.089	0.102	0.144	0.244	0.283	0.500	0.000
WEEKDAY	84/86	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.155	0.139	0.125	0.139	0.152	0.163	0.172	0.225	0.253	0.287	0.000	0.000	0.000
WEEKDAY	87/89	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.265	0.243	0.262	0.216	0.261	0.268	0.320	0.000	0.000	0.000	0.000
WEEKDAY	90/92	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.290	0.380	0.460	0.460	0.000	0.000	0.000	0.000	0.000
WEEKDAY	<60	0.000	0.000	0.000	0.001	0.000	0.001	0.001	0.001	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000
WEEKEND	60/62	0.008	0.006	0.003	0.005	0.005	0.007	0.007	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.010	0.000	0.000	0.000	0.000
WEEKEND	63/65	0.018	0.005	0.010	0.010	0.014	0.023	0.020	0.008	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.010
WEEKEND	66/68	0.025	0.032	0.027	0.025	0.028	0.024	0.020	0.028	0.013	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.030	0.018	0.023
WEEKEND	69/71	0.058	0.048	0.038	0.050	0.057	0.050	0.018	0.067	0.028	0.011	0.007	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.064	0.011	0.040	0.052
WEEKEND	72/74	0.040	0.065	0.110	0.090	0.055	0.000	0.000	0.040	0.057	0.024	0.010	0.006	0.008	0.000	0.007	0.000	0.000	0.000	0.058	0.066	0.012	0.060	0.102	0.060
WEEKEND	75/77	0.120	0.000	0.200	0.120	0.100	0.060	0.050	0.000	0.033	0.037	0.035	0.017	0.025	0.012	0.013	0.014	0.380	0.053	0.054	0.042	0.080	0.073	0.000	0.235
WEEKEND	78/80	0.210	0.220	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.045	0.052	0.046	0.063	0.076	0.066	0.053	0.053	0.060	0.063	0.076	0.195	0.228	0.195
WEEKEND	81/83	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.055	0.075	0.063	0.067	0.090	0.103	0.078	0.075	0.088	0.116	0.210	0.205	0.000	0.000
WEEKEND	84/86	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.130	0.175	0.120	0.040	0.050	0.120	0.143	0.180	0.270	0.220	0.000	0.000	0.000
WEEKEND	87/89	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.235	0.240	0.247	0.235	0.235	0.235	0.235	0.000	0.000	0.000	0.000
WEEKEND	90/92	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.260	0.240	0.000	0.000	0.000	0.000	0.000	0.000
PEAKDAY	72/74	0.000	0.000	0.170	0.140	0.120	0.110	0.080	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PEAKDAY	75/77	0.210	0.160	0.000	0.000	0.000	0.000	0.000	0.000	0.080	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.480	0.420
PEAKDAY	78/80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.160	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.450	0.000	0.000
PEAKDAY	81/83	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.150	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.450	0.000	0.000	0.000
PEAKDAY	84/86	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.180	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.480	0.000	0.000	0.000	0.000
PEAKDAY	87/89	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.290	0.330	0.380	0.000	0.430	0.460	0.000	0.000	0.000	0.000	0.000
PEAKDAY	90/92	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.420	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table B-8 Fraction-in-use profile by type of day for central air conditioners, Detroit Edison Co., (Base: 4.07 kw average maximum non-coincident demand, non-interruptible).

AVERAGE WEEKDAY

Temp Range	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
To 65	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.05	0.05	0.03
66-70	0.12	0.12	0.09	0.07	0.08	0.06	0.04	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.02	0.04	0.07	0.07	0.13	0.15	0.19	0.19	0.16
71-75	0.21	0.19	0.17	0.15	0.13	0.11	0.09	0.07	0.03	0.03	0.04	0.03	0.02	0.04	0.07	0.05	0.10	0.10	0.16	0.26	0.27	0.27	0.26	0.24
76-80	0.32	0.30	0.27	0.24	0.14	•	0.20	0.11	0.10	0.06	0.05	0.08	0.08	0.06	0.08	0.10	0.13	0.21	0.25	0.38	0.43	0.46	0.42	0.38
81-85	•	•	•	•	•	•	•	•	0.14	0.16	0.12	0.14	0.18	0.15	0.16	0.20	0.22	0.36	0.48	0.50	0.51	0.46	•	•
86-90	•	•	•	•	•	•	•	•	•	•	0.24	0.26	0.28	0.33	0.28	0.33	0.41	0.49	0.62	0.63	•	•	•	•
91-95	•	•	•	•	•	•	•	•	•	•	•	•	0.33	0.36	0.48	0.51	0.59	0.53	•	•	•	•	•	•
96+	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	0.52	•	•	•	•	•	•	•

AVERAGE WEEKEND

Temp. Range	Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
To 65	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.03	0.04	0.03	0.03
66-70	0.10	0.07	0.08	0.08	0.06	0.04	0.04	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.02	0.02	0.02	0.09	0.12	0.12	0.16	0.15	0.13
71-75	0.23	0.20	0.26	0.09	0.08	•	0.07	0.03	0.03	0.03	0.02	0.01	0.01	0.02	0.00	0.02	0.08	0.13	0.13	0.21	0.33	0.34	0.39	0.37
76-80	0.21	0.14	0.14	0.15	0.15	0.16	0.11	0.09	0.09	0.05	0.05	0.07	0.08	0.06	0.09	0.06	0.09	0.16	0.23	0.40	0.43	•	0.37	0.37
81-85	•	•	•	•	•	•	•	•	0.08	0.15	0.12	0.10	0.16	0.16	0.18	0.22	0.26	0.28	0.47	0.51	0.35	0.33	•	•
86-90	•	•	•	•	•	•	•	•	•	0.12	0.17	0.24	0.21	0.24	0.29	0.37	0.46	0.46	0.53	•	•	•	•	•
91-95	•	•	•	•	•	•	•	•	•	•	•	•	0.35	0.40	0.45	0.44	0.50	0.57	•	•	•	•	•	•

Empty Temperature bins are displayed as •

Table B-9 Fraction-in-use profile by type of day for air-to-air heat pump fan load Consumers Power Co. (Base average maximum non-coincident demand

Rate 111: Air-to-Air heat Pump Fan Load

Day Type	Temp °F	1 am	2 am	3 am	4 am	5 am	6 am	7am	8am	9am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 am
WEEKDAY	-09/-07	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.670
WEEKDAY	-06/-04	0.000	0.000	0.000	0.000	0.000	0.000	0.740	0.710	0.720	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.680	0.690	0.000
WEEKDAY	-03/-01	0.000	0.000	0.000	0.720	0.720	0.730	0.000	0.750	0.000	0.690	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.640	0.660	0.000	0.000	0.000
WEEKDAY	00/02	0.680	0.710	0.725	0.750	0.735	0.730	0.737	0.720	0.717	0.670	0.660	0.000	0.000	0.000	0.000	0.000	0.000	0.670	0.650	0.000	0.000	0.650	0.660	0.000
WEEKDAY	03/05	0.680	0.705	0.725	0.715	0.710	0.710	0.000	0.000	0.000	0.730	0.620	0.625	0.635	0.000	0.000	0.660	0.660	0.000	0.630	0.650	0.640	0.660	0.635	0.613
WEEKDAY	06/08	0.630	0.680	0.700	0.695	0.715	0.710	0.720	0.680	0.000	0.730	0.720	0.000	0.620	0.625	0.630	0.640	0.680	0.630	0.000	0.620	0.625	0.000	0.000	0.000
WEEKDAY	09/11	0.648	0.658	0.673	0.682	0.692	0.705	0.705	0.687	0.668	0.653	0.645	0.680	0.000	0.000	0.620	0.000	0.000	0.600	0.610	0.000	0.000	0.610	0.610	0.640
WEEKDAY	12/14	0.650	0.660	0.676	0.682	0.710	0.710	0.710	0.693	0.670	0.643	0.645	0.635	0.605	0.570	0.570	0.600	0.630	0;620	0.603	0.620	0.628	0.652	0.618	0.610
WEEKDAY	15/17	0.602	0.624	0.640	0.652	0.668	0.680	0.685	0.662	0.650	0.630	0.610	0.583	0.610	0.620	0.610	0.633	0.630	0.590	0.600	0.606	0.603	0.608	0.608	0.598
WEEKDAY	18/20	0.600	0.610	0.645	0.644	0.668	0.688	0.653	0.650	0.620	0.640	0.608	0.604	0.575	0.552	0.613	0.618	0.602	0.588	0.589	0.591	0.583	0.603	0.600	0.583
WEEKDAY	21/23	0.570	0.577	0.608	0.625	0.638	0.653	0.672	0.652	0.620	0.620	0.605	0.590	0.590	0.588	0.553	0.570	0.590	0.580	0.588	0.580	0.607	0.550	0.523	0.545
WEEKDAY	24/26	0.563	0.580	0.598	0.608	0.604	0.613	0.612	0.614	0.607	0.582	0.565	0.542	0.533	0.520	0.533	0.540	0.559	0.570	0.555	0.540	0.541	0.572	0.547	0.552
WEEKDAY	27/29	0.500	0.539	0.545	0.565	0.574	0.591	0.595	0.572	0.549	0.551	0.552	0.535	0.518	0.550	0.513	0.533	0.553	0.518	0.503	0.515	0.509	0.515	0.506	0.499
WEEKEND	30/32	0.467	0.485	0.520	0.543	0.558	0.564	0.539	0.529	0.506	0.509	0.508	0.503	0.510	0.477.	0.40	0.462	0.472	0.483	0.476	0.485	0.480	0.499	0.498	0.481
WEEKEND	33/35	0.467	0.498	0.502	0.513	0.514	0.523	0.545	0.516	0.501	0.472	0.463	0.452	0.479	0.466	0.469	0.468	0.506	0.497	0.490	0.459	0.460	0.457	0.443	0.453
WEEKEND	36/38	0.432	0.440	0.437	0.454	0.443	0.478	0.473	0.452	0.433	0.415	0.374	0.381	0.381	0.401	0.418	0.458	0.458	0.393	0.382	0.389	0.405	0.406	0.398	0.399
WEEKEND	39/41	0.336	0.368	0.375	0.388	0.410	0.445	0.417	0.410	0.417	0.392	0.391	0.353	0.323	0.295	0.320	0.350	0.398	0.356	0.361	0.378	0.358	0.350	0.344	0.359
WEEKEND	42/44	0.360	0.290	0.250	0.317	0.350	0.375	0.380	0.360	0.330	0.310	0.280	0.344	0.342	0.319	0.319	0.310	0.318	0.332	0.342	0.331	0.330	0.323	0.340	0.293
WEEKEND	45/47	0.245	0.277	0.305	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.265	0.300	0.284	0.288	0.290	0.290	0.300	0.297	0.258	0.235	0.273	0.280	0.000	0.245
WEEKEND	48/50	0.280	0.310	0.330	0.330	0.000	0.000	0.000	0.000	0.000	0.240	0.270	0.260	0.285	0.180	0.210	0.215	0.247	0.223	0.290	0.280	0.250	0.225	0.233	0.260
WEEKEND	51/53	0.210	0.230	0.260	0.270	0.285	0.280	0.280	0.260	0.280	0.260	0.210	0.215	0.180	0.220	0.190	0.185	0.235	0.310	0.000	0.230	0.210	0.000	0.000	0.000
WEEKEND	54/56	0.000	0.000	0.000	0.000	0.000	0.330	0.340	0.320	0.000	0.000	0.000	0.000	0.200	0.000	0.250	0260	0.000	0.000	0.180	0.160	0.000	0.000	0.000	0.000
WEEKEND	57/59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.310	0.300	0.260	0.200	0.000	0.160	0.000	0.000	0.000	0.180	0.160	0.000	0.000	0.000	0.000	0.000
WEEKEND	>59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.180	0.165	0.150	0.140	0.150	0.145	0.210	0.180	0.180	0.130	0.130	0.130
WEEKEND	-15/-13	0.000	0.000	0.000	0.000	0.000	0.750	0.780	0.730	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WEEKEND	-12/-10	0.000	0.720	0.750	0.760	0.750	0.000	0.000	0.000	0.740	0.720	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WEEKEND	-09/-07	0.700	0.000	0.000	0.000	0.000	0.000	0.000	0.750	0.770	0.000	0.710	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WEEKEND	-06/-04	0.000	0.000	0.000	0.000	0.000	0.760	0.740	0.000	0.000	0.000	0.000	0.730	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WEEKEND	-03/-01	0.000	0.000	0.000	0.000	0.750	0.000	0.000	0.000	0.000	0.740	0.000	0.000	0.710	0.690	0.000	0.000	0.000	0.720	0.720	0.750	0.740	0.710	0.000	0.000
WEEKEND	00/02	0.690	0.720	0.755	0.780	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.700	0.700	0.730	0.000	0.000	0.000	0.000	0.650	0.705	0.690
WEEKEND	03/05	0.680	0.740	0.000	0.750	0.780	0.750	0.750	0.750	0.750	0.000	0.000	0.680	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.670	0.000	0.000	0.000
WEEKEND	06/08	0.000	0.000	0.000	0.000	0.750	0.730	0.730	0.720	0.740	0.730	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.660	0.650	0.000	0.000	0.670	0.595
WEEKEND	09/11	0.675	0.730	0.720	0.700	0.715	0.700	0.770	0.740	0.740	0.000	0.720	0.630	0.000	0.000	0.000	0.000	0.000	0.630	0.000	0.000	0.650	0.645	0.590	0.630
WEEKEND	12/14	0.570	0.630	0.670	0.000	0.000	0.740	0.705	0.705	0.690	0.680	0.630	0.680	0.620	0.580	0.000	0.000	0.610	0.000	0.630	0.636	0.000	0.580	0.620	0.000
WEEKEND	15/17	0.620	0.630	0.630	0.660	0.660	0.690	0.677	0.680	0.680	0.695	0.637	0.600	0.605	0.580	0.580	0.565	0.570	0.600	0.590	0.560	0.570	0.605	0.585	0.535
WEEKEND	18/20	0.617	0.603	0.623	0.620	0.637	0.645	0.650	0.640	0.634	0.000	0.640	0.580	0.553	0.517	0.538	0.563	0.585	0.590	0.585	0.617	0.617	0.600	0.580	0.000
WEEKEND	21/23	0.580	0.580	0.617	0.643	0.650	0.653	0.647	0.660	0.000	0.566	0.577	0.520	0.000	0.000	0.000	0.527	0.530	0.000	0.000	0.000	0.000	0.600	0.610	0.585
WEEKEND	24/26	0.566	0.577	0.590	0.588	0.610	0.617	0.610	0.623	0.633	0.610	0.523	0.558	0.503	0.482	0.488	0.580	0.530	0.530	0.537	0.533	0.544	0.540	0.537	0.539
WEEKEND	27/29	0.535	0.570	0.570	0.580	0.597	0.590	0.568	0.598	0.588	0.568	0.513	0.440	0.490	0.515	0.500	0.492	0.540	0.560	0.53	0.523	0.476	0.503	0.498	0.477
WEEKEND	30/32	0.464	0.502	0.517	0.520	0.522	0.538	0.547	0.525	0.530	0.504	0.533	0.490	0.413	0.400	0.435	0.000	0.520	0.470	0.412	0.433	0.490	0.440	0.408	0.440
WEEKEND	33/35	0.417	0.433	0.455	0.540	0.525	0.535	0.520	0.520	0.485	0.485	0.450	0.410	0.403	0.388	0.392	0.373	0.368	0.353	0.435	0.347	0.357	0.380	0.405	0.343
WEEKEND	36/38	0.385	0.417	0.437	0.463	0.455	0.480	0.480	0.480	0.445	0.390	0.410	0.398	0.400	0.375	0.275	0.275	0.330	0.365	0.347	0.330	0.334	0.332	0.350	0.390
WEEKEND	39/41	0.387	0.407	0.417	0.443	0.440	0.455	0.460	0.455	0.480	0.400	0.347	0.325	0.378	0.363	0.358	0.370	0.353	0.332	0.328	0.338	0.325	0.360	0.410	0.355
WEEKEND	42/44	0.370	0.350	0.380	0.360	0.405	0.440	0.450	0.460	0.000	0.370	0.380	0.310	0.312	0.325	0.313	0.318	0.330	0.315	0.310	0.307	0.327	0.333	0.330	0.380
WEEKEND	45/47	0.290	0.300	0.300	0.000	0.000	0.380	0.370	0.380	0.415	0.365	0.330	0.350	0.230	0.200	0.190	0.240	0.210	0.000	0.230	0.000	0.000	0.000	0.000	0.300
WEEKEND	48/50	0.000	0.000	0.000	0.290	0.290	0.000	0.000	0.000	0.000	0.000	0.340	0.300	0.170	0.230	0.230	0.230	0.210	0.210	0.000	0.170	0.000	0.000	0.000	0.170
WEEKEND	51/53	0.000	0.000	0.000	0.000	0.000	0.310	0.320	0.310	0.000	0.000	0.000	0.170	0.280	0.210	0.000	0.000	0.000	0.220	0.170	0.000	0.160	0.180	0.175	0.180
WEEKEND	54/56	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.300	0.225	0.180	0.000	0.000	0.000	0.180	0.180	0.200	0.000	0.000	0.000	0.180	0.190	0.000	0.000
WEEKEND	57/59	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.180	0.180	0.000	0.230	0.210	0.180	0.180	0.000	0.000	0.000	0.000	0.170	0.180	0.000	0.000	0.000	0.000
WEEKEND	>59	0.160	0.160	0.160	0.170	0.180	0.180	0.180	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.150	0.170	0.170	0.180	0.000	0.000	0.000	0.000	0.000	0.000
PEAKDAY	-03/-01	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.750	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PEAKDAY	00/02	0.730	0.740	0.770	0.750	0.750	0.740	0.760	0.000	0.730	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PEAKDAY	03/05	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.730	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PEAKDAY	06/08	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.720	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PEAKDAY	09/11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.680	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PEAKDAY	12/14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.630	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PEAKDAY	15/17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.620	0.000	0.000	0.000	0.600	0.620	0.000	0.000	0.000	0.000	0.000
PEAKDAY	18/20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.180	0.000	0.000	0.630	0.640	0.640	0.000	0.000	0.610	0.580	0.580	0.600	0.560

Figure B-1

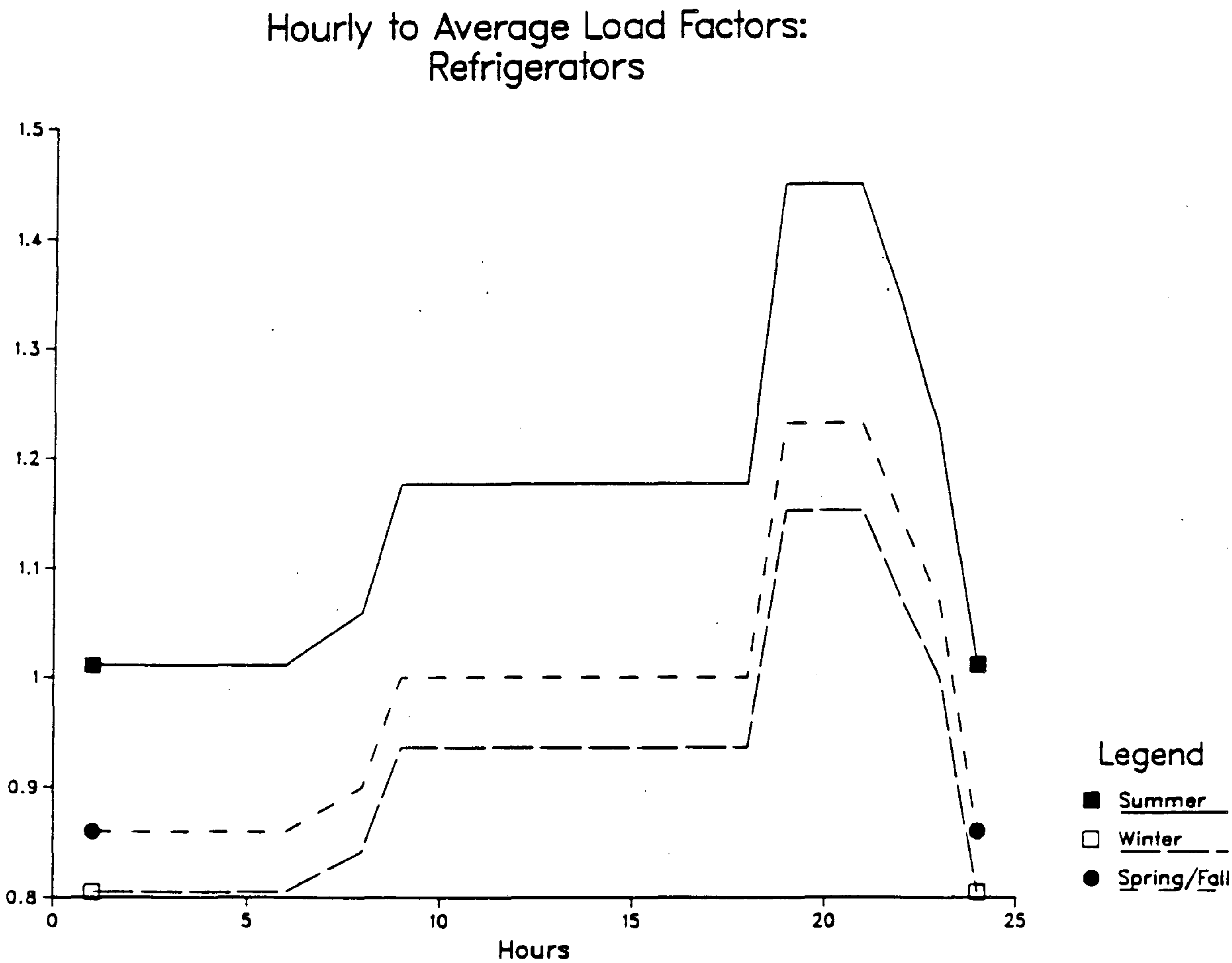

Hourly to Average Load Factors:
Refrigerators
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0
5
10
15
20
25
Hours
Legend
Summer
Winter
Spring/Fall

Figure B-2

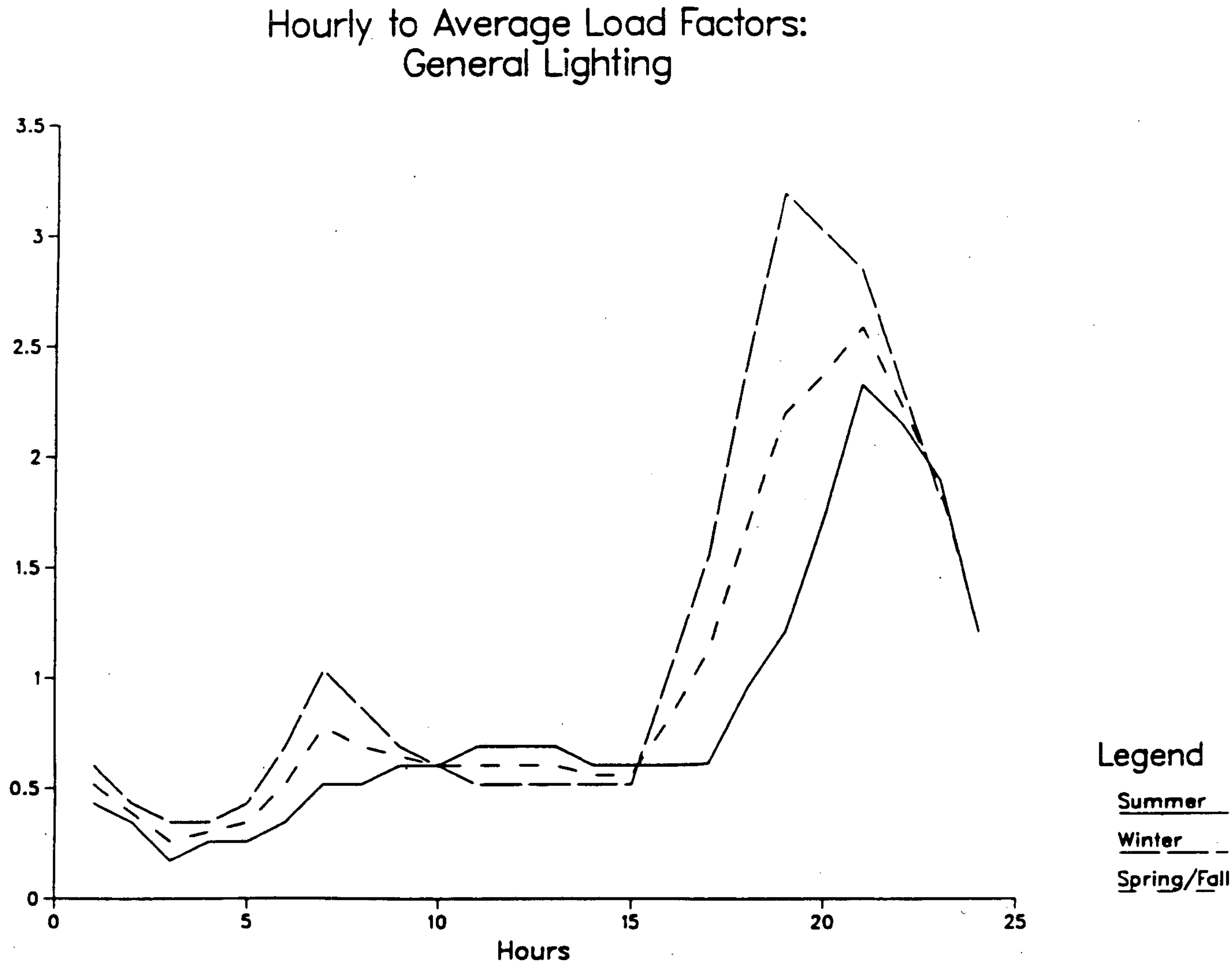
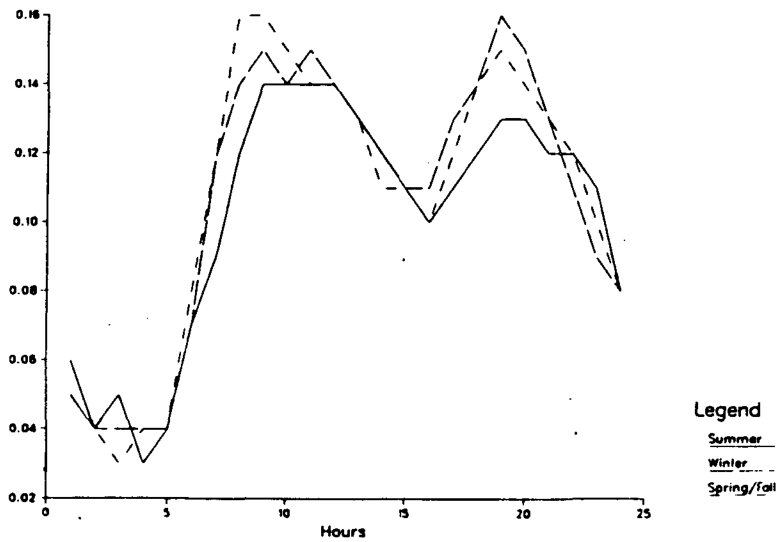
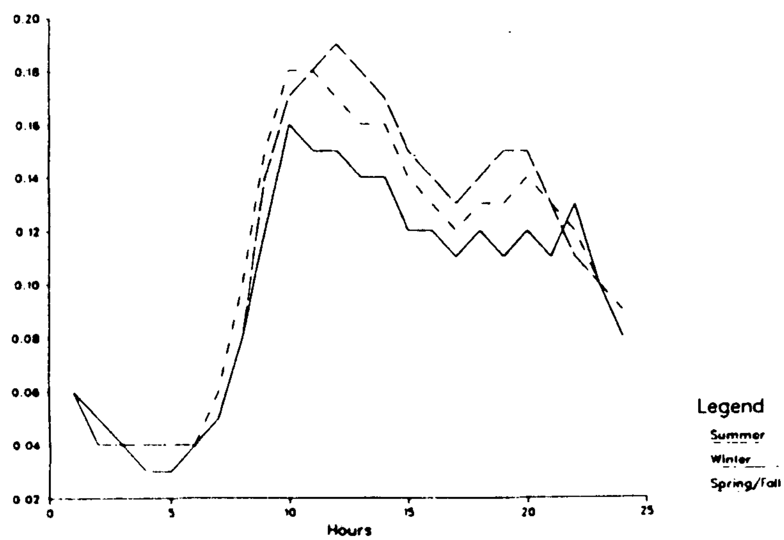

Hourly to Average Load Factors:
General Lighting
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
Hours
Legend
Summer
Winter
Spring/Fall

Figure B-3

Weekday Fraction–in–Use Profile:
Water Heaters, Consumers Power



Weekend Fraction–in–Use Profile:
Water Heaters, Consumers Power



Peak Day Fraction–in–Use Profile:
Water Heaters, Consumers Power

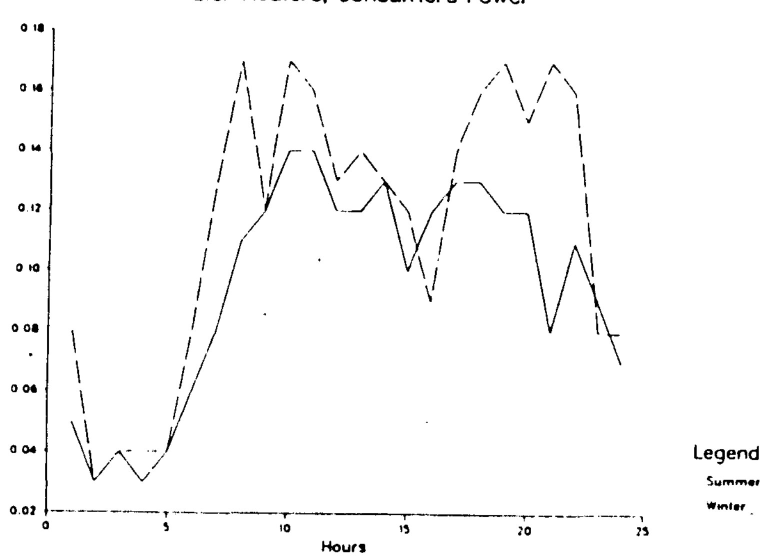
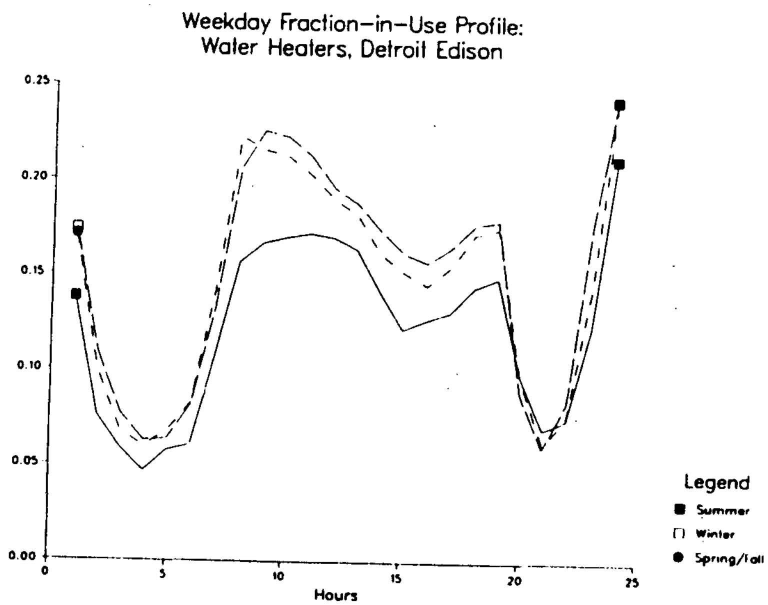
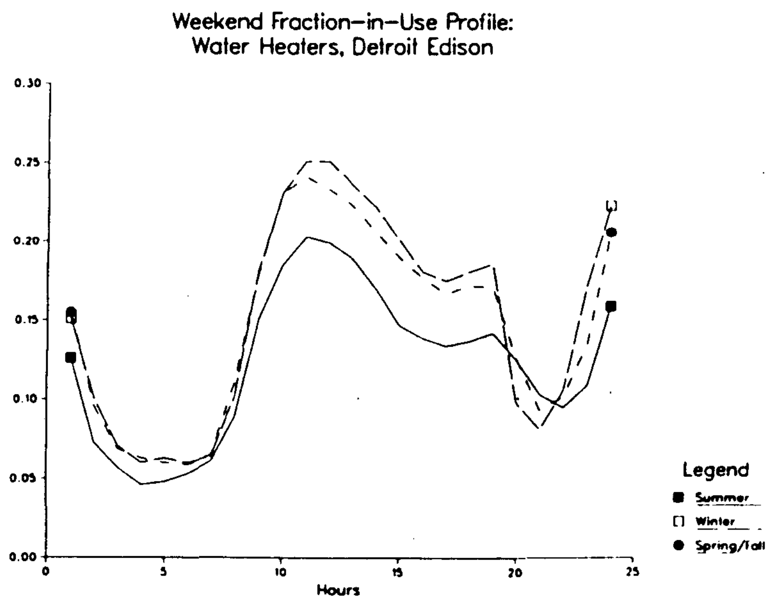


Figure B-4


Weekday Fraction-in-Use Profile:
Water Heaters, Detroit Edison
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
Hours
Legend
Summer
Winter
Spring/Fall


Weekend Fraction-in-Use Profile:
Water Heaters, Detroit Edison
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
Hours
Legend
Summer
Winter
Spring/Fall

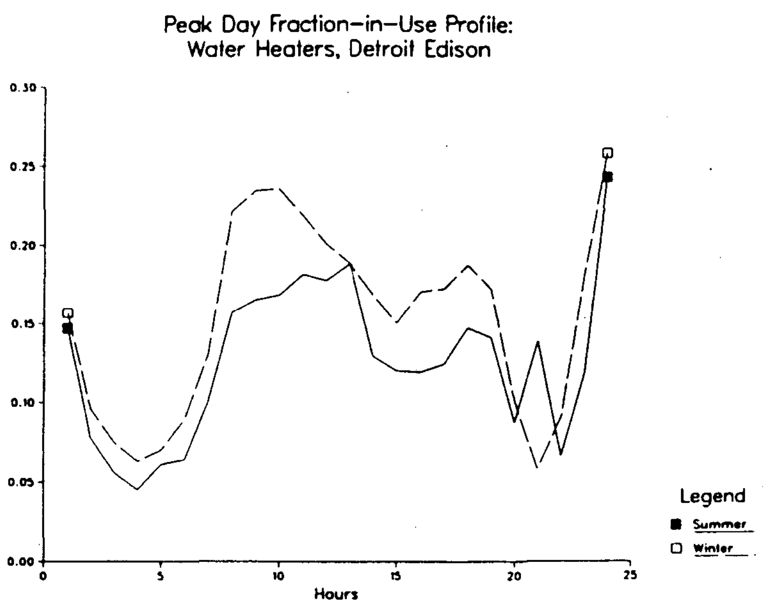
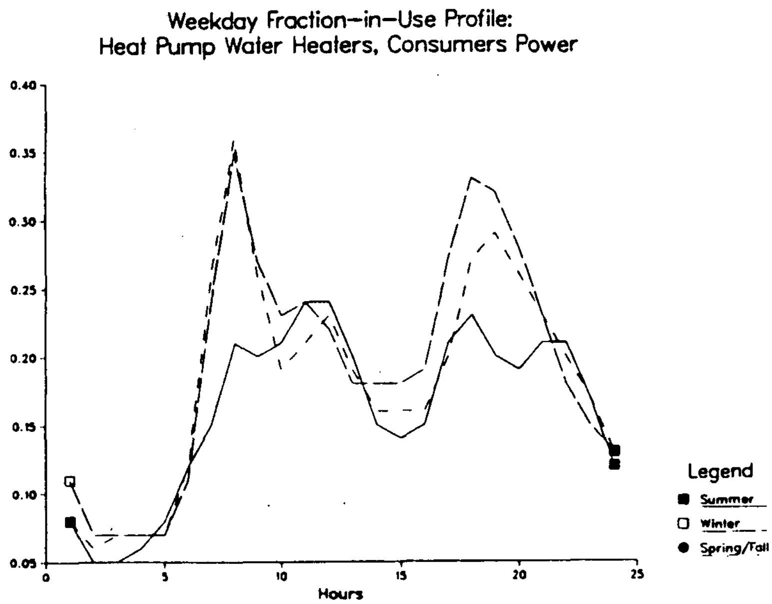
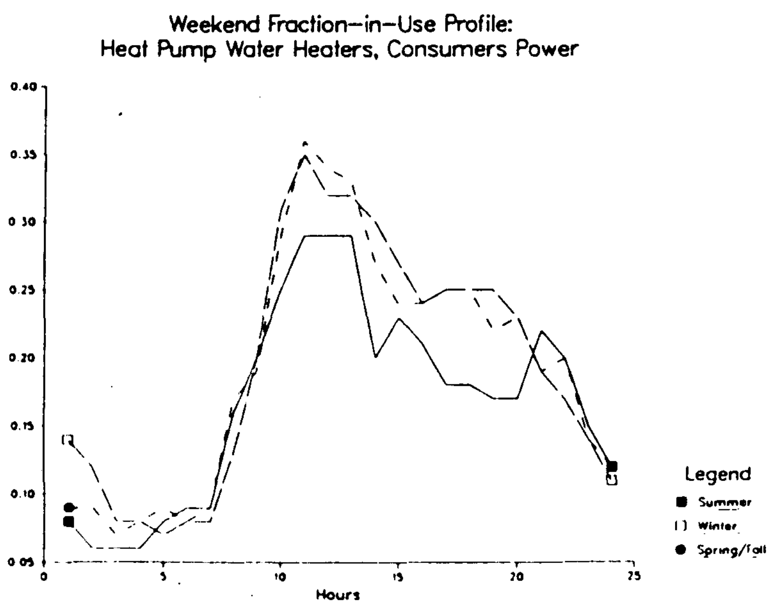

Peak Day Fraction-in-Use Profile:
Water Heaters, Detroit Edison
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
Hours
Legend
Summer
Winter

Figure B-5


Weekday Fraction-in-Use Profile:
Heat Pump Water Heaters, Consumers Power
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
5
10
15
20
25
Hours
Legend
Summer
Winter
Spring/Fall


Weekend Fraction-in-Use Profile:
Heat Pump Water Heaters, Consumers Power
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
5
10
15
20
25
Hours
Legend
Summer
Winter
Spring/Fall

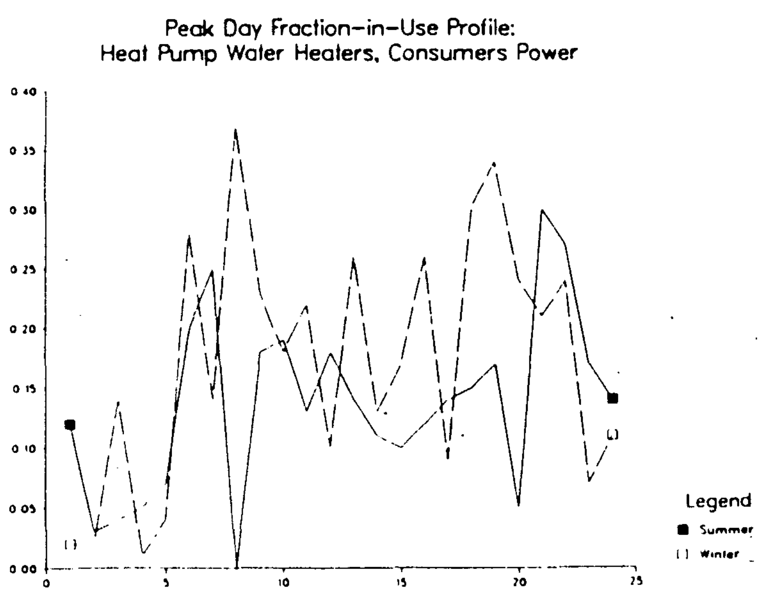

Peak Day Fraction-in-Use Profile:
Heat Pump Water Heaters, Consumers Power
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
Hours
Legend
Summer
Winter

Figure B-6

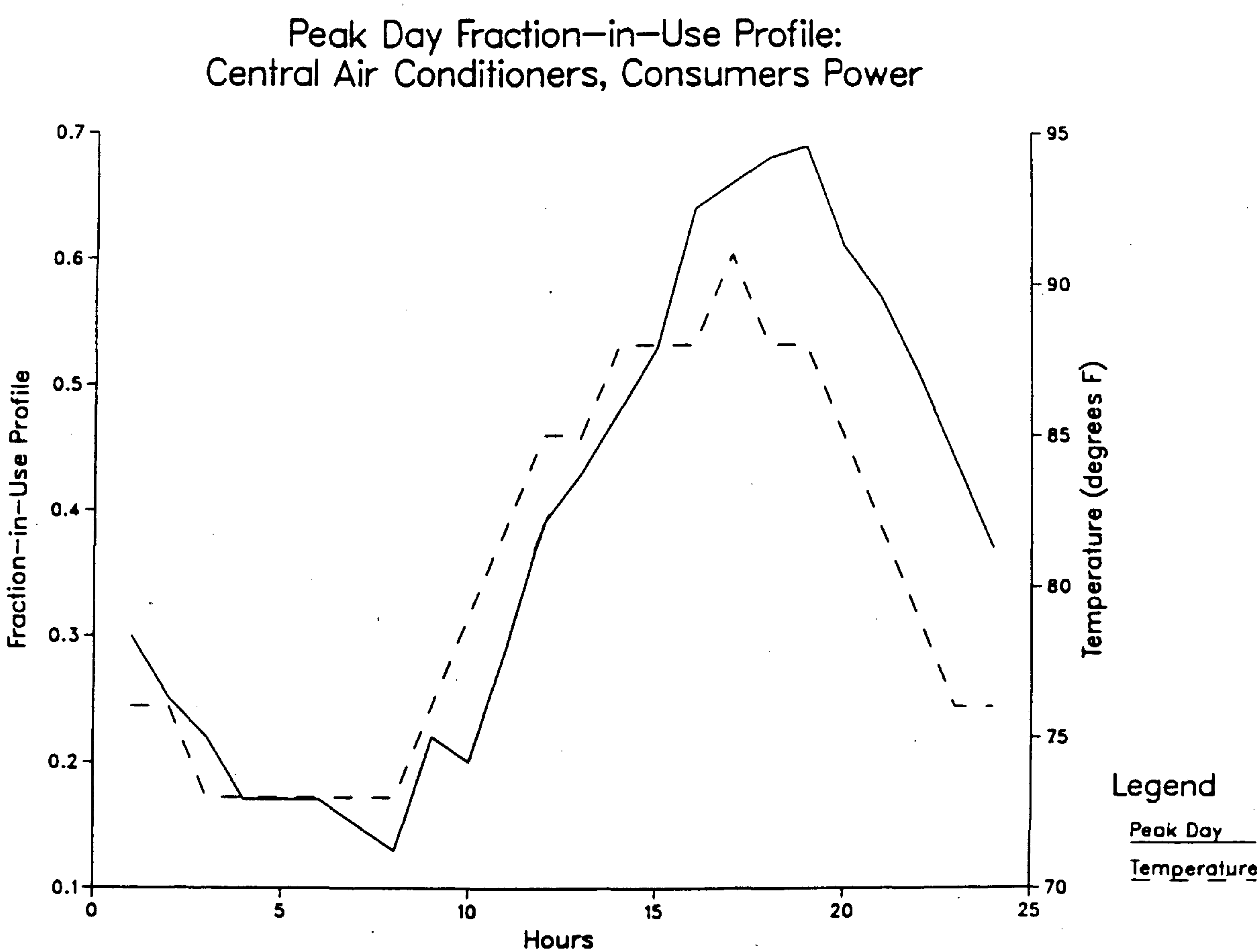

Peak Day Fraction–in–Use Profile:
Central Air Conditioners, Consumers Power
Fraction–in–Use Profile
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Temperature (degrees F)
95
90
85
80
75
70
0
5
10
15
20
25
Hours
Legend
Peak Day
Temperature

Figure B-7

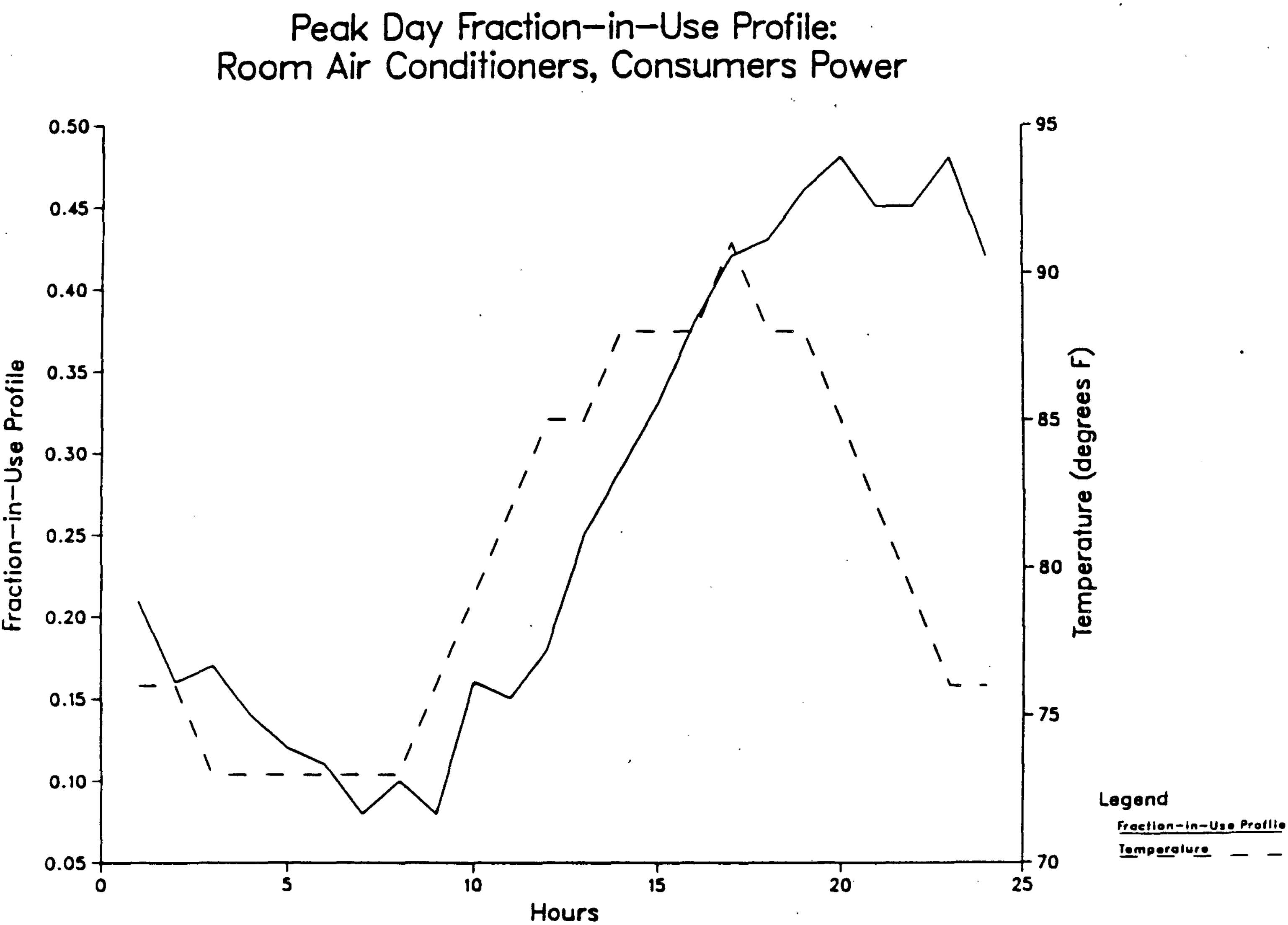
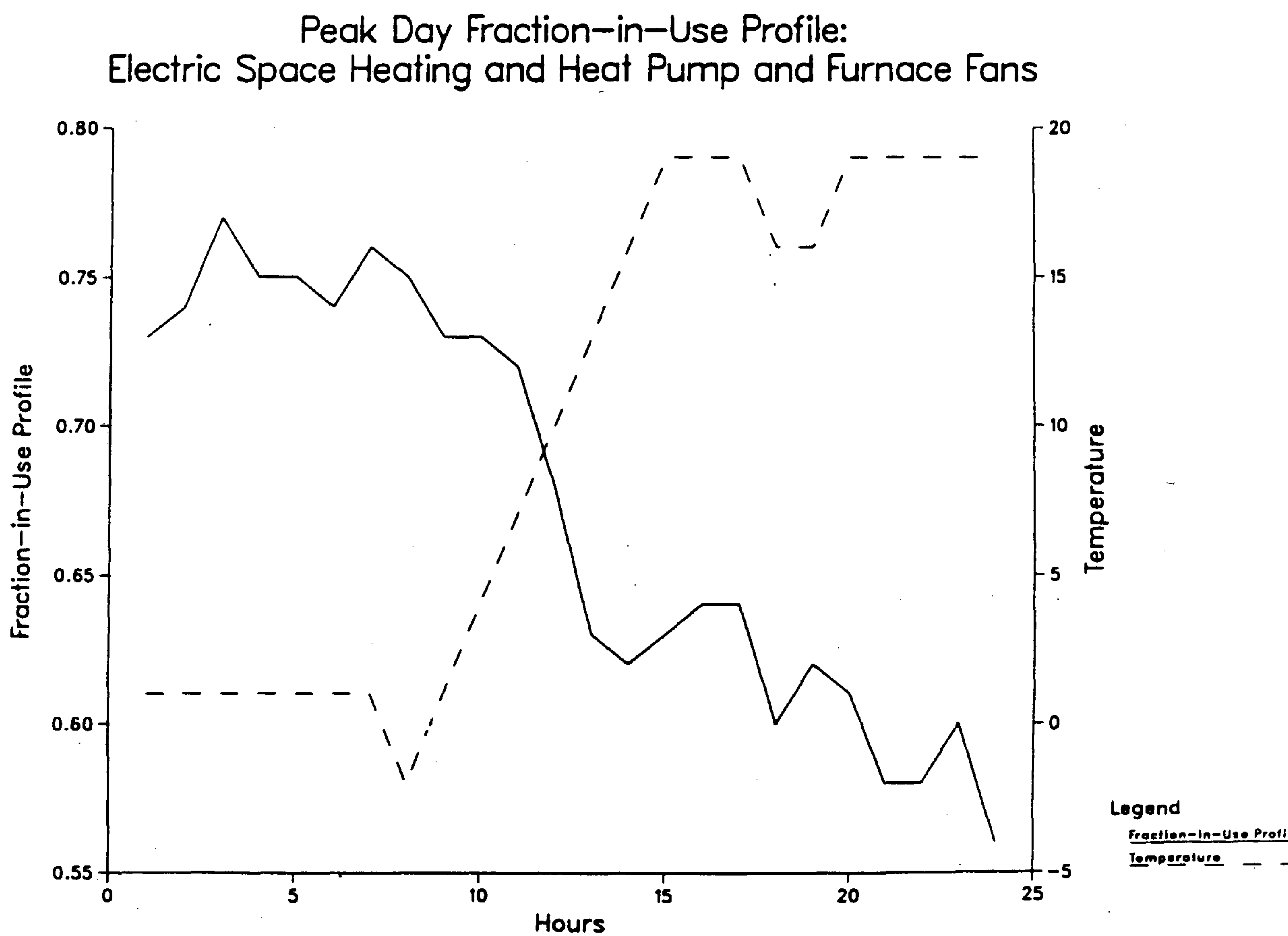

Peak Day Fraction-in-Use Profile:
Room Air Conditioners, Consumers Power
Fraction-in-Use Profile
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
Temperature (degrees F)
95
90
85
80
75
70
0
5
10
15
20
25
Hours
Legend
Fraction-in-Use Profile
Temperature

Figure B-8


Peak Day Fraction–in–Use Profile:
Electric Space Heating and Heat Pump and Furnace Fans
Fraction–in–Use Profile
Temperature
Hours
0.80
0.75
0.70
0.65
0.60
0.55
20
15
10
5
0
−5
0
5
10
15
20
25
Legend

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