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ESTIMATING RESIDENTIAL ELECTRICAL DEMAND FOR SOUTHEASTERN MINNESOTA

BY

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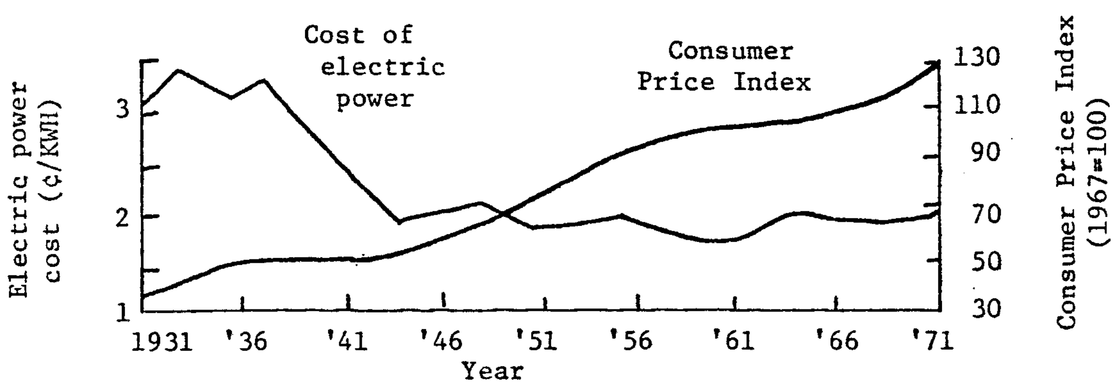
M. M. Dalton and K. W. Easter*

Forecasting electrical energy demand has always been an important function of utility managers. Because construction of a new facility takes about seven years (4)**, demand must be anticipated at least that far in advance. Prior to 1970 the cost of producing electrical energy was falling in real terms (Figure 1 (4)) while demand for electricity was growing at an annual average rate of about 7 percent (4). While forecasting was important, there was relative certainty that demand would increase steadily over time. Effective forecasts were obtained by simply extrapolating past consumption trends.

FIGURE 1. The average cost of electric power and the cost of living during the period 1931 to 1971.



Since the early 1970's, due to increased fuel and capital costs and longer construction time requirements, the cost of producing electrical energy has increased, leading to increased prices. Consumers have responded by adjusting their consumption habits so that the average annual growth in consumption has dropped to about 5 percent or less (4). The increase in capital costs have increased the costs of an inaccurate forecast. Changing

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*The authors are research assistant and professor in the Department of Agricultural and Applied Economics. We would like to thank Lee Martin, Carole Yoho, Thomas Stinson and Jean Kinsey for reviewing the bulletin.

**Numbers in brackets refer to references listed at the end of this paper.

consumption patterns have brought more uncertainty to the forecasting process. This increased uncertainty combined with an even greater need for accuracy, has led utility managers to investigate alternative forecasting techniques.

Two of the most common forecasting alternatives are the aggregate model and the end use model. The aggregate model relates some measure of electricity consumption (annual KWH consumed, KWH consumption per capita, or KWH consumption per household) to variables thought to affect consumption, through the use of statistical regression techniques. For example, consumption may be regressed on population, income, the price of electricity, and the price of competing fuels to estimate regression coefficients for each variable. The coefficients are assumed to determine the relationship between consumption and each of the variables so that changes in the independent variables can be used to forecast changes in consumption. However, the longer the forecast period, the less the degree of accuracy. An individual utility company may be able to disaggregate consumption into sectors (residential, commercial and industrial) to achieve a higher degree of accuracy in forecasting total demand. When forecasting demand for a geographic region served by several utilities, such disaggregation is not possible unless customer categorization is consistent across utility companies.

The end use model is a summation of electricity consumption by end uses. In modeling residential consumption, the appliance stock and annual energy consumption per appliance are determined for 1980 and forecasted to 1995; then the product of the number of appliances times the annual energy consumption per appliance are summed for all types of appliances, for each year. Some utilities have developed end use models but because of the enormous data requirements, most prefer aggregate models. According to one source (12) end use models have not yet been shown to be more accurate than other models. However, end use models provide a framework for considering appliance efficiency improvements and the implementation of other specific conservation measures such as building performance standards. So, while utility managers may think that the costs of end use models are not worth the increase in accuracy, policy makers and planners may find such models valuable for examining the potential effectiveness of various conservation policies. Once a particular policy is implemented, the end use model can be used to evaluate the impacts of the policy on future electrical energy consumption.

In this study the end use model is used to forecast residential electrical energy demand and incorporate the appliance efficiency improvements, which may result from the Department of Energy's proposed appliance efficiency standards. A set of scenarios was developed for the purpose of comparing various levels of efficiency improvements. The report is divided into six sections. The first section presents the Department of Energy's proposed standards, while the second discusses the end use model. The scenarios are described in section three which is followed by the fourth section with a discussion of the results. The last two sections consider Minnesota's energy conservation policies and evaluate the end use model.

Appliance Efficiency Standards

The National Energy Conservation Policy Act of 1978 (NEPCA) mandated the establishment of energy efficiency standards for 13 major appliances.

Nine of the 13 appliances were given priority: ranges, refrigerator-freezers, water heaters, clothes dryers, window air conditioners, central air conditioners, space heaters, furnaces, and freezers. For these nine, NEPCA mandated that the standards be established no later than December 1980. In June 1980, the Department of Energy proposed minimum energy efficiency levels for eight of the nine appliances.[1/]

In developing the standards, the Department of Energy first established two 'baseline' scenarios. These scenarios estimate the appliance efficiency improvements that would take place in response to higher energy prices and the relatively low cost of energy efficiency improvements in the appliances. The two scenarios are a high price baseline, in which there is a 2.5 percent real annual increase in electricity prices and a 3.0 percent real annual increase in the prices of other fuels; and the low price baseline, in which there is a 1.0 percent real annual increase in the price of electricity and a 1.5 percent real annual increase in the prices of other fuels.[2/] As would be expected, there is a more rapid decline in energy consumption per appliance in the high price baseline.

Minimum standards for both 1981 and 1986 have been proposed by the Department of Energy. The 1981 standards are, with the exception of those pertaining to central air conditioning, no improvement over the 1980

1/ To date no standards have been set for space heating equipment because the Department of Energy anticipated that a major design option improving efficiency was going to be available soon. Although no standards were set for electric furnaces, standards were set for other types of furnaces.

2/ The two price scenarios were used in the Oak Ridge National Laboratory Residential Energy Use Model to evaluate the market adjustments of consumer and producer response to higher prices.

efficiency levels. This is not surprising since it would be unreasonable to expect instantaneous compliance.

The 1986 standards were developed in three levels; level one being the least stringent and level three the most stringent (see Table 1). Although level three was designated for implementation, in March 1981 the Department of Energy stated that it would "not prescribe proposed energy efficiency standards for major household appliances pending review of the analysis upon which the standards would be based".[3/] Given the present administration's expressed desire to eliminate many current regulations and allow market forces to bring about adjustments, it is unlikely that the standards will ever become regulation at level three. More likely, the standards will either be imposed at a less stringent level, or they will be eliminated entirely. For this reason, the standards scenarios were developed to evaluate the energy consumption resulting from setting the standards at less stringent levels one and two.

Study Area and Model

The study area is an 18 county region in the southeastern corner of Minnesota (see Figure 2). The area is fast growing, more urban than rural yet not as urbanized as the Twin Cities metro area. It is served by 31 utility companies of which 14 are municipals, two are investor owned, and the remaining are members of one of three rural cooperatives. Aggregate electricity consumption statistics were computed under the assumption that the service area of each utility has remained constant. Since 1977,

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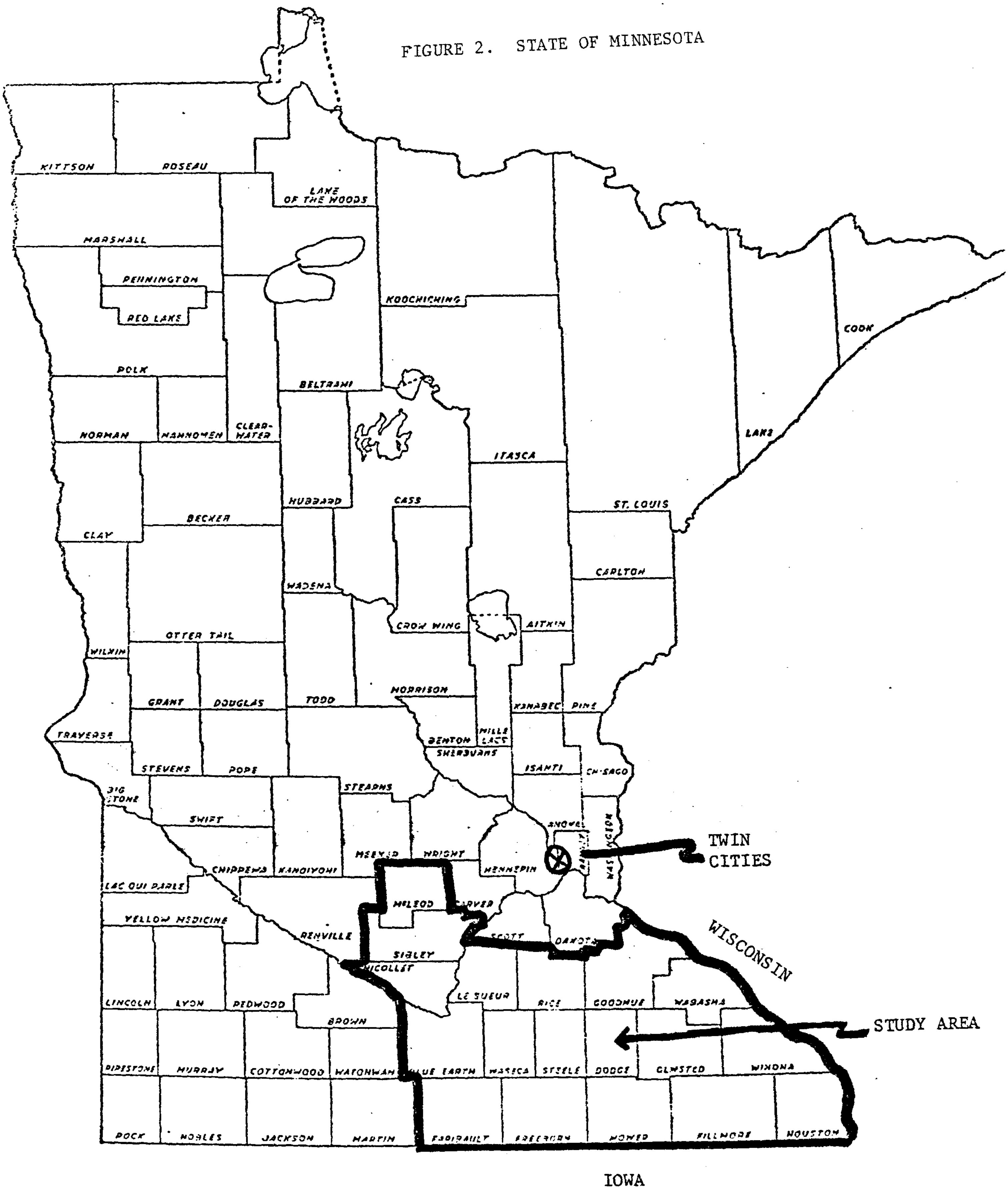
3/ Energy Insider, Volume 4, United States Department of Energy, March 2, 1981.

TABLE 1. PERCENTAGE IMPROVEMENT IN EFFICIENCY BY 1986 OVER 1980 USAGE LEVELS

Appliance	Level One	Level Two	Level Three
Central Air Conditioning	15.65	28.75	52.5
Room Air Conditioning	21.0	29.69	32.7
Water Heaters	10.0	14.65	15.81
Clothes Dryers	13.15	16.92	19.02
Kitchen Range	10.7	15.6	16.61
Refrigerator/Freezer	24.7	65.0	133.10
Freezer	38.1	111.0	161.5

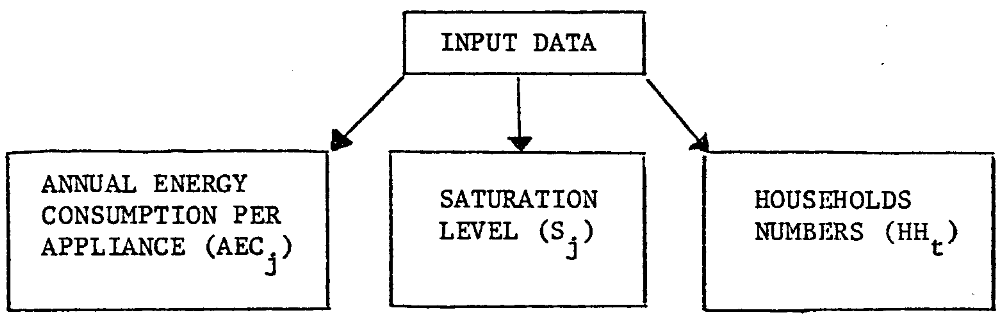
SOURCE: U.S. Department of Energy, Economic Analysis, June 1980: DOE/CS.0169.

FIGURE 2. STATE OF MINNESOTA



utilities have been required to report deliveries by county so that in the future the validity of such an assumption can be verified. The delivered KWH of each utility serving only the 18 county area were added to the KWH delivered inside the study area by companies serving customers both inside and outside the study area. These fractional figures for companies serving customers inside and outside the study area were constant for 1977 and 1978.

The model for residential end use is shown below (2):



Therefore, electricity consumption (EC) for a particular year would be:

$$EC_t = \sum_{j=1}^{M} (AEC_j \ (S_j \ X \ HH_t))$$

where: t = time (1980-1995)
$j = 1 - M$
M = total number of appliances under consideration

While the model is conceptually very simple, obtaining accurate and reliable data is a major obstacle to using such a model. Detailed surveys could be done by personal interview or by mail for households in the study area to obtain the necessary information. Budget constraints limit the surveying of each household so that it is necessary to work with sample surveys and secondary data.

The first step in utilizing the model is to determine present electricity consumption. Then future consumption is estimated using the Department of Energy's market adjusted efficiency improvements. Finally estimates are made of future consumption by incorporating the proposed standards into the energy use per appliance, and changing the appliance stock according to the service life of each appliance. The data used in the model are described below.

Households

The projected number of state households (1980-2000) was obtained from the State Demographer's Office. There are two estimates of the projected number of state households, shown in Table 2. The medium estimate assumes that the persons per household will drop more quickly after 1990 when the birth rate is expected to reach its peak. The high estimate is based on the national projections of changes in persons per households, with which Minnesota has historically kept pace.

TABLE 2. ESTIMATES OF NUMBERS OF HOUSEHOLDS IN MINNESOTA (1000's)

	Medium Estimate		High Estimate	
Year	Persons per HH	HH	Persons per HH	HH
1980	2.77	1423	2.75	1433
1985	2.65	1536	2.60	1566
1990	2.55	1645	2.50	1678
1995	2.50	1721	2.45	1756
2000	2.45	1792	2.40	1829

Since the study area is only 18 counties and not the entire state, a method of disaggregating the state data was necessary. To estimate the future number of households in the study area, the current number of households in the study area was increased at each of the two rates of increase of household formation implicit in the state household projections.[4/] The resulting estimates for the future number of households in the study area are shown in Table 3. To check the credibility of these figures the study area households as a proportion of the state households was computed since 1970. These were compared to the medium and high estimates respectively. The study area households have been a constant 14.55 percent of the state

TABLE 3. ESTIMATES OF NUMBERS OF HOUSEHOLDS IN STUDY AREA

Year	Medium Estimate	High Estimate
1980[5/]	207177	207177
1985	223606	226403
1990	239504	242591
1995	250545	253871
2000	260843	264432

4/ Rate of Increase of Household Formation.

Year	Medium Estimate	High Estimate
1980-85	.0793	.0928
1985-90	.0712	.0715
1990-95	.0461	.0465
1995-2000	.0412	.0416

5/ The 1980 estimate is the same for both assumptions. It is based on county population information from the State Demographer's Office.

households. The medium estimate of study area households maintain this percentage proportion, while the high estimate of study area households lowers the share to a constant 14.46 percent of the total state household to the year 2000. Forecasts based on each assumption were done to test for sensitivity of the household component. The high household estimate resulted in a consumption level about 1.5 percent higher than the medium household estimate. The high estimate was used so that final growth rates in consumption would have an upward bias and not be underestimated.

The classification of households into type is not essential. The necessity for housing type classification is entirely dependent on the type of appliance saturation information. For example, if saturation data are classified by housing type, then there would be reason to disaggregate into housing type. In this study current appliance saturations are classified by housing type for only one utility company for one year. The saturation forecasts for that utility are not classified by housing type. Therefore, no classification by housing type was done. This does not mean that the ability to disaggregate by housing type is not superior. Motivations for appliance purchases differ depending on whether the consumer lives in a house, apartment, or mobile home, and whether the consumer is an owner or a renter. The inability to disaggregate into housing type is not expected to seriously bias the analysis, since single family homes comprise 70 percent of the study area and are expected to comprise 67 percent of the study in 1995. Mobile homes make up 5 percent of households currently and are expected to make up 4 percent in 1995.

Appliance Saturation

Appliance saturation is defined as the percent of households possessing at least one of a particular appliance at a given point in time. Ideally, the estimates of saturation are made by extensive and thorough surveys of each household in the particular area under study. Five of the utility companies serving the study area have provided saturation estimates based on their own surveys. Some of the utilities disaggregate their own service areas into districts so that there are eleven saturation estimates for the region (see Table 4).

From the existing data, a 'utility average saturation' must be developed for the study. Other available estimates are for the entire country or for a large geographic region, such as a census region. Three of these estimates are shown on Table 5 along with the saturation estimates provided by the study area utilities. Tansil's estimates (18) and forecasts are based on a variety of assumptions for each appliance.[6/] His 1980 estimates, done in 1976, are the most outdated of the three outside estimates.

[6/] Projections of air conditioning saturations are based on regional increases in air conditioning in households from 1960-70 and the installation of central air conditioning in new homes. Projections of electrically heated households are taken from the 1970 National Power Survey based on the assumption that 40 percent of new dwellings constructed in the 1971-80 decade will be all electric, and 50 percent in the 1981-90 will be all electric. Projections of clothes dryers are based on assumption that electric clothes dryers will be installed in 50 percent of new homes from 1971-80 and 60 percent of new homes from 1981-90 and the conversions will equal new installations. Projections of electric ranges based on the assumption that they will be installed in 50 percent of new homes from 1971-80 and 60 percent of new homes from 1981-90 and that there will be two-thirds as many conversions as new installations. Projections of freezers based on the 1960-70 growth in households with freezers.

TABLE 4. SATURATION ESTIMATES BY APPLIANCE FOR 1979

Estimate: Company	Estimate: Division	Electric Range	Refrig.-Freezer	Freezer	Dish-washer	Water Heater	Clothes Dryer	Dehumid-ifier	Window AC	Central AC	Space Heater[b]	Furnace
		- Percentage -										
Dairyland Power	Freeborn	61	83	74	28	64	63	33	21	8	21	8
	People's	60	95	80	38	57	69	33	23	13	22	8
	Tri Co.	60	95	80	29	67	61	27	20	7	26	8
Interstate Power	Albert Lea		107[a]	70	32	26	47	48	35	27	14	3
	Chatfield		109	68	24	48	57	40	28	13	16	7
Basin Coop	Renville Sibley	74	112	118	30	80	70	35	34	12	46	10
CPA	Region 2	75	100	84	50	62	72		19	22	5	9
	Region 3	76	100	82	33	80	70		21	12	8	19
	Region 4	71	100	89	39	78	75		33	23	8	12
NSP	Hiawatha	70	113	64	34	48	62	47	43	19	11	6
	Keystone	59	100	60	39	30	57	41	38	24	10	4
John Tansil (U.S.)[c]		47	100	34		33	40		36	18		16
Merchandising (U.S.)		70	100	45	42				55			
Midwest Research (Central Region)		35		51	44	10	40		41	47		24
Utility Average Saturation		61.5	100	75	37	39	49	30	34.5	21.5	11.3	5.2

a/ Figures over 100% reflect homes having more than one appliance.

b/ Space heater refers to portable electric heaters used to heat spaces smaller than an entire housing unit.

c/ Saturation estimates are for 1980.

Merchandising is the most widely quoted source of saturation information. The source of their data is utility companies. *Merchandising* requests saturation information from utility companies but provision of the information is voluntary. When the information is provided there is no standard way in which it is gathered. Some utilities may use a statistical sampling technique while others use guesswork. In the 1978 Midwest Research Institute Study (MRI) (11), appliance saturations were estimated for the nation and for census regions, where the estimates would be expected to be different regionally. Their information was based on reported saturation rates from utilities in central cities of the United States, and from their own survey responses. Of these three outside estimates, the MRI study is the most accurate since it was based on statistical sampling techniques. However, since there are saturation estimates available from local utilities, a composite utility average saturation (UAS) was developed to make use of this local information.

To develop the UAS county households were assigned saturation rates according to the fraction of the county's electrical needs supplied by a given utility.[7/] As mentioned before, the fraction of county electrical needs supplied by a particular company is known for 1977 and 1978 and was constant for those two years. The appropriate saturation rate was multiplied by the number of households served by a particular

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# HOUSEHOLDS IN COUNTY I (from State Demographer's Office)	x	THE FRACTION OF COUNTY I's ELECTRICAL NEEDS SUPPLIED BY COMPANY J (1977, 1978)	=	THE # OF HOUSEHOLDS TO WHICH SATURATION RATE J IS TO BE APPLIED

company to obtain the appliance stock associated with each company. Then the total appliance units were summed across companies to obtain the total number of each appliance currently existing for the study area. Finally, an average saturation was obtained by dividing the estimate of the total number of appliances by the 1980 estimate of households in the study area to obtain the Utility Average Saturation (see Table 5). It should be noted that because the municipal companies serving the area did not have saturation information available, the appropriate Northern States Power (NSP) district information was used for the municipal service areas. Northern States Power serves predominantly urban customers and so do the municipals, whereas the rural customers are served by the rural cooperatives. For this reason, the NSP estimates were the most heavily weighted saturation estimates.

The utility average saturation provides an estimate of present saturation, but one must still predict future saturation. Saturation forecasts are a critical component of this type of analysis. Two possible estimating procedures are linear regression and a logistic equation. The linear regression technique can be used to extrapolate past saturation trends or to relate saturation to relevant variables such as households, income, and the price of electricity. The problem with this technique is that the most complete set of past data is available only from *Merchandising* and the quality of that data is suspect because of the inconsistencies and uncertainties in how the data was collected. Still, this technique is a common one. Cooperative Power Association used this method to forecast saturation. Their model is described in Appendix A.

TABLE 5. PROJECTED SATURATION: UTILITY AVERAGE PLUS CHANGE HYPOTHESIZED BY NSP

Appliance	UAS 1980[a/]	NSP 1980	NSP 1995[b/]	% increase 1980-95	1995 UAS[c/]
Electric Range	61.5	60.6	73.5	21.3	74.6
Refrigerator-Freezer	100.0	100.0	100.0	0.0	100.0
Freezer	75.0	49.0	50.0	2.0	76.5
Dishwasher	37.0	42.3	44.7	5.7	39.0
Water Heater	39.0	25.0	25.0	0.0	39.0
Clothes Dryer	49.0	48.3	66.3	37.3	67.3
Dehumidifier	30.0	34.4	34.0	-.4	30.0
Window Air Conditioner	34.5	45.0	40.0	-12.5	30.2
Central Air Conditioner	21.5	21.0	25.0	19.0	25.6
Space Heater	11.3				
Furnace	5.2	2.1	5.2	147.6	12.8

a/ From Table 4.

b/ Northern States Power's Assumptions:

- Saturations of window air conditioners is expected to decline because of the large number of single family and mobile homes switching to central air or not installing air conditioning.
- The rise is central air conditioning is expected to increase because of the increasing number of single family homes built new with central air conditioning or old homes retrofitted.
- The saturation of electric water heaters is expected to remain constant because new homes will be adopting electric where gas is unavailable and retrofits will be from electric to gas where possible.
- Remaining saturations were developed for NSP by DRI. DRI used an econometric forecasting equation based on past NSP data which had as independent variables state income, real price of electricity, price of appliances, index of growth of customers and a moving real average of real price of natural gas. Information was obtained by the Minnesota Public Research Interest Group (MPRIG) and provided to this study.

c/ 1995 UAS is the 1980 UAS plus the increase hypothesized by NSP. For example, the 1995 saturation of freezers was calculated in the following way:
((.02)(75)=1.5) + 75 = 76.5.
So, the percent increase from 1980 to 1995 = ((NSP 1995/NSP 1980) - 1) and this increase was then applied to the utility average saturation.

A logistics equation can be used to interpolate the values for the years in between the present and some future year. For example, if the 1980, 1995, and terminal saturation estimates are available, the following formula can be used to compute the appliance saturation for 1985 and 1990 (12).[8/]

$$\text{Saturation}_t = \frac{\text{Terminal Saturation}}{1 + c\, e^{-k(t-1980)}}$$

where:

Terminal Saturation = the maximum achievable saturation value for a particular appliance

Base Saturation = the base year (1980) saturation

$$c = \frac{\text{Terminal Saturation} - \text{Base Saturation}}{\text{Base Saturation}}$$

$$k = \frac{\left(\ln\left(\frac{\text{Terminal Saturation} - \text{Base Saturation}}{\text{Base Saturation}}\right)\right)}{15} - \frac{\left(\ln\left(\frac{\text{Terminal Saturation} - \text{1995 Saturation}}{\text{1995 Saturation}}\right)\right)}{15}$$

e = base of the natural log

ln = natural log

Saturation in 1995 can be estimated by assuming a particular rate of growth in present saturations. For example, the rate of change of saturation hypothesized by Northern States Power between 1980 and 1995 can be applied to the 1980 Utility Average Saturation. The resulting 1995 saturation rates computed in this way are shown in Table 5. Assuming the trends fore-

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[8/] For more detailed explanation of model see The Technical Potential for Conservation in Reducing Residential Electrical Energy Demand, M. M. Dalton, Department of Agricultural and Applied Economics, University of Minnesota, Appendix E.

cast by Northern States Power are plausible, this is one way to compute 1995 saturations for appliances.

Another way is to devise a set of assumptions about future installations and conversions of appliances. Purely for illustrative purposes, assume that 75 percent of new households are equipped with dishwashers and that 50 percent of existing homes not having dishwashers acquire them between now and 1995. This would result in a 1995 saturation for dishwashers of 74 percent.

Once the 1995 saturations have been determined, the terminal saturations must be estimated to use the logistics formula. As mentioned, NRDC (14) assumes this to be 100 percent although this may not be legitimate for all appliances. For example, dehumidifiers and air conditioners will not have a terminal saturation of 100 percent, since all homes will not need them. An alternative is to assume some percentage increase in appliance saturation and designate that as the terminal saturation. In the case of ranges and water heaters, the terminal saturation of electric appliances could be assumed to be those households that do not have natural gas available. However, the preference for a type of appliance may be motivated by something other than availability of fuel alone, such as convenience or initial capital expense. For example, a person may prefer an electric range even if natural gas is available, because an electric range has a self cleaning option not available on gas ranges.

Terminal saturation values can also be obtained by assumption, and a range of values used to test the sensitivity of the saturation component. This was the method used by the Energy Systems Research Group (19). In the prepared testimony (19) it is stated that the figures they used were based on guidelines obtained through examination of a variety of studies involving saturations.

Future saturation rates were developed for each year of the forecast period using the model described in Appendix B. Two sets of assumptions were developed for saturations: the low saturation case and the high saturation case shown in Table 6. They were formulated after close examination of those used by the Energy Systems Research Group.

With the exception of refrigerator-freezers, dishwashers, space heaters, furnaces, and window air conditioners, the low case 1995 saturation levels were computed using the growth rate in saturation between 1980 and 1995 that was hypothesized by Northern States Power for its Minnesota Service Area.[9/] Saturation of refrigerator-freezers was set at 100 percent throughout the forecast period. While it will probably be higher, due to homes with more than one refrigerator, how much higher is uncertain. However, this conservative figure does not affect the result significantly.[10/] The growth in saturation of dishwashers hypothesized by Northern States Power is 5.7 percent between 1980 and 1995, which would result in a 1995 saturation level of 39 percent. After speaking with several new home builders who indicated that dishwashers were a standard new home appliance, this figure seemed too low. A 55 percent saturation of dishwashers was used based on the conservative assumption that half of new households are equipped with a dishwasher and that 10 percent of present households not having a dishwasher acquire one. An 18 percent 1995 saturation rate for space heaters represent a 60 percent increase in saturation. The 12.8 percent

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[9/] The data were provided by the Minnesota Public Research Interest Group who obtained it from Northern States Power.

[10/] A 10 percent increase in refrigerator saturation increases 1995 refrigerator energy consumption by 2 percent, but this increases total 1995 refrigerator energy consumption by less than .5 percent.

TABLE 6. TWO SATURATION LEVELS BY APPLIANCE

Appliance	Low		High	
	1995	Terminal	1995	Terminal
Electric Range	74.6	80.0	80.0	95.0
Refrigerator-Freezer	100.0	100.0	100.0	100.0
Freezer	76.5	80.0	76.5	80.0
Dishwasher	55.0	70.0	65.0	80.0
Water Heater	39.0	50.0	70.0	90.0
Clothes Dryer	67.3	70.0	70.0	90.0
Dehumidifier	34.0	40.0	50.0	60.0
Window Air Conditioner	54.3	60.0	60.0	70.0
Central Air Conditioner	25.6	27.0	25.0	30.0
Space Heater	18.0	25.0	20.0	35.0
Furnace	12.8	20.0	20.0	30.0

saturation rate for furnaces is based on the saturation level hypothesized by both Northern States Power and the Minnesota Energy Agency. The 1995 saturation level for window air conditioners was set at the original level hypothesized by Northern States Power rather than their projected decline, which tends toward a downward bias.[11/]

The low terminal saturation levels were chosen after an examination of other studies utilizing this type of model. These terminal saturation levels were chosen to be above the 1995 saturation levels and to provide a low range estimate.

The high saturation estimates, for both 1995 and the terminal, were developed with the assumption that: (1) saturation of appliances would be higher than the low range for most appliances, and (2) that natural gas price would increase so rapidly that consumers would be induced to purchase electric appliances before the end of the gas appliance service life. This is an extreme case which primarily affects water heaters, ranges, clothes dryers, and furnaces.

The saturation levels for refrigerator-freezers and freezers is the same for both the high and low saturation cases. The reasoning for maintaining the 100 percent saturation for refrigerators was already discussed. The saturation of freezers was kept the same for both cases because of the already high level of saturation, which is due to the high saturation of freezers in the rural areas where the freezing of agricultural products is common.

[11/] In a study done by DRI for NSP, 1995 window air conditioner saturation was estimated at 54.3 percent. Later NSP revised this estimate (16) to 40 percent.

The low and high values for 1995 and terminal saturation were used to interpolate saturation values for each year from 1980 to 1995 using the model described in Appendix C.

Annual Energy Consumption Per Appliance

There are many estimates of KWH consumed annually per appliance. George (7) sent surveys to over 70,000 households to obtain data on appliance ownership, structural characteristics of the home, demographic information and electricity bills. He then used a multivariate regression model to estimate the annual energy consumption of each appliance. Such a technique is not possible in this analysis, since one of the limits has been the lack of detailed appliance data on appliance ownership.

Ten sets of estimates of annual energy consumption per appliance are available (see Table 7) (7). All of them, except for the Basin Coop and Northern States Power and MRI estimates are national averages. Basin and NSP are Minnesota averages and MRI is a Midwest regional average. The national average figures are acceptable for most appliances. Usage of some appliances, however, will vary by geographic location, such as air conditioners. For this reason, the Minnesota and Midwest regional estimates should be used for the window air conditioners, central air conditioners, water heaters, space heaters, and furnaces.

It is through energy consumption per appliance that all efficiency improvements are incorporated into the model. Values chosen for 1980 are shown below. Preliminary computations were done to test for the sensitivity of the 1980 values. A 10 percent increase in the 1980 initial values results in a 10 percent increase in consumption for 1995. Since NSP services the largest number of consumers in the area, its annual consumption figures

TABLE 7

ANNUAL ENERGY CONSUMPTION PER APPLIANCE (KWH/YR)

Appliance	NSP a/	Project Independence b/	MRI c/	MEA d/	NRDC e/	Edison Electric Institute f/	Merchandising g/	Tansil h/	Univ. Texas i/	Basin Coop
Electric Range	960*	1143	723		1108	1200	1200	1200	1113	1200
Refrigerator-Freezer	1450*	1084	1288	1000		1800	1480	1300	1084	1200
Freezer	1200*	1348	1365	1200	1103	1600	1480	1400	1172	1200
Dishwasher		352		360*	335	363	363	363	352	300
Water Heater	5400*	5626	4046	5400	4442	4219	4811		5567	3600
Clothes Dryer		938	1000*	750	916	993	993	993	938	1000
Dehumidifier				400*						300
Window Air Conditioner	450*		642			860	1389	2000	1377	600
Central Air Conditioner	1780*		1576					3560	2490	2000
Space Heater										600*
Furnace	12900*								10255	16400

a/ Sundin, 1980.
b/ Federal Energy Administration, 1974.
c/ Midwest Research Institute, 1978.
d/ Minnesota Energy Agency, 1980.
e/ Natural Resources Defense Council, 1980.
f/ Statistical Abstract of the United States, 1976.
g/ March 25, 1974.
h/ Tansil, 1976.
i/ University of Texas, 1976.

were used where possible. Otherwise MEA, MRI or Basin Coop estimates were used. Decreases in the late 1980 annual energy consumption per appliance figures shown in Table 8 were made throughout the 15 year forecast period according to the efficiency increases described under each scenario. For example, in the low price market induced efficiency scenario, electric ranges are 3 percent more efficient in 1995 so that 1995 annual energy consumption for an electric range is 931 KWH per year.

Appliance Service Life

Estimates of the service life of appliances are shown in Table 9. An average of these figures is used for analysis. To check the plausibility of the resulting average, a small sample of appliance service life was taken of persons having above average and below average family sizes. The average of their responses was very close to the average calculated.

The number of appliances replaced in a particular year equals the initial number of appliances divided by the service life. This number of appliances is replaced each year until the initial stock is exhausted or entirely replaced. Where the service life of the appliance is less than the 15 years, later year replacement units are equal to the early year additions to stock plus replacements of old units. For example, since the service life of window air conditioners is ten years, replacements of window air conditioners in 1991 equal replacements and additions that were made in 1981.

Scenario Description

Five basic scenarios were developed: the baseline scenario, two market induced efficiency scenarios, and two appliance standards scenarios. In

TABLE 8. 1980 ANNUAL ENERGY CONSUMPTION PER APPLIANCE (KWH/YR)

Appliance	KWH/yr
Electric Range	960
Refrigerator-Freezer	1450
Freezer	1200
Dishwasher	360
Water Heater	5400
Clothes Dryer	1000
Dehumidifier	400
Window Air Conditioner	450
Central Air Conditioner	1780
Space Heater	600
Furnace	12900

TABLE 9. APPLIANCE SERVICE LIFE (YRS.)

Appliance	FEA a/	Lawrence Livermore b/	DOE c/	NRDC d/	Average
Electric Range	15	17	14	15	15.3
Refrigerator-Freezer	15	20	15	14	16
Freezer	21	25	20	18	21
Dishwasher	11	11			11
Water Heater	20	10	10	10	12.5
Clothes Dryer	13	11	14	12.7	12.7
Dehumidifier	10				10
Window Air Conditioner		10	10	10	10
Central Air Conditioner		17.5	14	15	15.5
Space Heater	8				8
Furnace		40	20		30

a/ Federal Energy Administration, 1974.
b/ Lawrence Berkeley Laboratory, 1978.
c/ U.S. Department of Energy, Consumer Products, Division, June 1980.
d/ Natural Resources Defense Council, 1980.

addition, two cases were estimated for each scenario: the low saturation and high saturation case. This makes a total of ten cases.

Baseline Scenarios

In the baseline scenarios there are no improvements in efficiency. Population and appliance saturation levels increase but annual energy consumption per appliance remains constant. This case represents the highest possible consumption given the population and saturation estimates, since in all other scenarios, annual energy consumption per appliance decreases over time due to efficiency improvements.[12/]

Market Induced Efficiency Scenario

The efficiency scenario imposes no standards but consumers, due to higher prices, purchase more efficient appliances and producers supply more efficient appliances. These efficiency improvements were estimated by the Department of Energy in developing the proposed standards. In their analysis, baseline forecasts were estimated to assess the probable market adjusted efficiency improvements if no standards were imposed (21). Two cases were developed: a low price case and a high price case. These

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12/ It must be noted that none of the scenarios incorporate assumptions about the market penetrations of solar technologies or heat pumps. Consultation with both the Minnesota Energy Agency and the Mid-America Solar Energy Research Center revealed that no reliable forecasts are available, but that present usage is quite small. Also, no thermal efficiency improvements were assumed for the forecast period since the quantitative relationship between such improvements and reductions in energy use is speculative. However, such improvements are likely to occur and will lower consumption figures.

were based on the Department of Energy's baseline price scenarios described earlier on page 4.

Fossil fuel prices have risen so fast in recent years and with more deregulation scheduled, it is not unreasonable to expect that prices of other fuels will rise at a real annual rate of 3.0 percent. In the last year, however, Northern States Power, the single largest supplier of electricity to the state, raised its price 12 percent, about equal to the annual inflation rate. The Minnesota Energy Agency projects that real prices of electricity will remain relatively stable through the forecast period (12). So, the low price appears to be more relevant for the electricity price increases, while the high price case is more reasonable for other fuels. If the price of other fuels rises at the rate indicated in the high price case, this could cause consumers to substitute electricity for other fuels. This substitution could raise demand and necessitate new and more costly capacity increases which would result in higher electricity prices. In short, both the high and low price cases developed by the Department of Energy could occur.

Efficiency improvements for each price scenario are shown in Table 10. Because the improvements are the result of market forces, they are evaluated as continuous, so that new units purchased in 1987 use less energy than those purchased in 1986. It must be emphasized that these scenarios do not include a lower hourly annual usage rate for appliances, but simply incorporate a technical change in design that result in a lower annual KWH usage rate. Because of this the resulting consumption figures represent an upper consumption level which may be further reduced by modifying behavioral usage patterns.[13/] The Department was not mandated to prescribe standards for the appliances showing no change in Table 10 and therefore no change was hypothesized for these appliances, though improvements may occur.

Standards Scenario

As was discussed earlier, it is doubtful that the appliance energy efficiency standards will ever be imposed. Clearly, the level 3 standards will not be imposed in the near future.[14/] For this reason, only level 1 and 2 standards are used to construct scenarios of energy consumption resulting from setting standards. The efficiency improvements estimated for level 2 are about twice that of level 1 by 1995 except for those showing no change (see Table 1).

Since these levels would be set by regulation, the impacts were evaluated in a discontinuous format. The 1980 usage levels were used until 1986, and from 1986 to 1995 the 1986 standard level was used. In actuality, if standards were imposed, efficiency may improve continuously from 1980 to 1986 due to competition among producers. The result would be that more efficient appliances would be placed in homes sooner and would effectively lower 1995 consumption figures.

[13/] There was no adjustment made for the possibility that higher efficiencies may result in a greater annual usage of appliances. Since there is no way to determine what the behavioral response will be, it is assumed that the upward bias built into the model will accommodate this effect.

[14/] The standards were developed in three levels: level 1 being the least stringent and level 3 the most stringent.

TABLE 10. PERCENTAGE IMPROVEMENT IN EFFICIENCY OVER 1980 USAGE LEVELS (CUMULATIVE) a/

	High Price Case			Low Price Case		
Appliance	1985	1990	1995	1985	1990	1995
Range	2.6	4.6	6.1	1.2	2.1	3.0
Refrigerator-Freezer	14.0	24.3	32.9	6.2	11.2	16.0
Freezer	12.7	21.9	29.5	5.6	10.2	14.5
Dishwasher		No Change			No Change	
Water Heater	4.2	7.2	9.8	1.8	3.3	4.8
Clothes Dryers	3.6	6.3	8.7	1.6	2.8	4.1
Dehumidifier		No Change			No Change	
Window Air Conditioner	7.5	16.6	22.8	3.8	9.6	13.6
Central Air Conditioner	8.0	12.5	16.7	4.6	7.0	9.5
Space Heater		No Change			No Change	
Furnace	8.0	12.9	16.8	5.1	8.5	11.4

a/ SOURCE: Reference 21, pp. 4-27 and 4-28.

Results

The 1995 consumption figures resulting from various scenarios are shown in Table 11. In the first column the MWH figures are consumption figures based on the appliances listed in Table 10. These appliances account for about 80 percent of residential electricity consumption on a national average.[15/] The second column is the total 1995 residential consumption (column one divided by .8). It is clear that future saturation levels play an important role in consumption. This can be seen by comparing scenarios which differ only by saturation level, such as one and two, five and six. The high saturation scenarios result in an average consumption 33 percent higher than the low saturation scenarios. This is primarily due to the increase in furnaces, window air conditioners and water heaters. The high price case scenarios result in a consumption level about 3.5 percent lower than the low price case.

The results of scenarios in which there is appliance efficiency improvement are shown as a percentage reduction over the results of scenarios where there is no appliance efficiency improvement (see Table 12). In the market improved efficiency scenarios, if prices rise according to the low price case, 1995 consumption is 4.35 percent lower than if no improvement takes place at all. If prices rise according to the high price case, annual consumption in 1995 is 7.65 percent lower than if no improvement takes place at all. If prices rise according to the high price case, there is no substantial reduction in consumption achievable with standards level one

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[15/] Craig B. Smith, Efficient Electricity Use, Pergammon Press: New York, 1978.

TABLE 11. 1995 RESIDENTIAL CONSUMPTION

Scenario	1995 MWH for Included Appliances	Total Residential 1995 MWH
1) No efficiency improvement High Saturation	2910627	3638284
2) No efficiency improvement Low Saturation	2197597	2746996
3) Market improved efficiency High Saturation High Price Case	2691464	3364330
4) Market improved efficiency Low Saturation High Price Case	2026954	2533693
5) Market improved efficiency High Saturation Low Price Case	2791608	3489510
6) Market improved efficiency Low Saturation Low Price Case	2096000	2620000
7) Standards Level 1 High Saturation	2701153	3376441
8) Standards Level 1 Low Saturation	1998000	2497500
9) Standards Level 2 High Saturation	2301668	2877085
10) Standards Level 2 Low Saturation	1769246	2211558

NOTE: 1980 MWH consumption for included appliances equals 1491557. Total 1980 MWH consumption equals 1812572.

TABLE 12. REDUCTIONS IN RESIDENTIAL CONSUMPTION DUE TO PRICE INCREASES AND APPLIANCE EFFICIENCY STANDARDS

Scenario	Percent Reduction Over No Improvement
3) Market improved efficiency High Saturation High Price Case	7.5
4) Market improved efficiency Low Saturation High Price Case	7.8
5) Market improved efficiency High Saturation Low Price Case	4.1
6) Market improved efficiency Low Saturation Low Price Case	4.6
7) Standards Level 1 High Saturation	7.2
8) Standards Level 1 Low Saturation	9.0
9) Standards Level 2 High Saturation	20.9
10) Standards Level 2 Low Saturation	19.5

regardless of the saturation level. However, the standards level two result in an average reduction in consumption of 20.92 percent for the high saturation case, and a 19.5 percent reduction in consumption for the low case.

The compound growth rates associated with each scenario are shown in Table 13. With the low saturation scenarios, annual growth rates are 2.8 percent or less, while with the high saturation scenarios, growth rates range from a high of 4.6 percent (no efficiency improvement) to a low of 2.95 percent (standards level 2).

The most probable cases are scenarios 4 and 6 in which there are no mandated standards but rather market induced efficiency improvements. If prices rise according to the low price case, and the saturation level is low (i.e., no dramatic shift to electric appliances), the compound annual growth rate is 2.35 percent per year. If prices rise according to the high price case and the saturation is low, the compound growth rate is 2.1 percent per year.

In comparison, the Minnesota Energy Agency estimated residential electrical energy consumption.[16/] They forecast a compound growth rate of 2.26 percent for their estimate. Forecasts are not available for each utility serving the study area, but only from the larger municipals or parent companies.

16/ 1) demand estimates based on price assumptions
2) effects of current building codes
3) substitution of electric appliances for oil and gas appliances
4) increased appliance efficiencies
5) retrofits of existing homes
6) use of wood heat in electrically heated homes

Specific assumptions were not documented: Ref. 12.

TABLE 13. COMPOUND GROWTH RATES OF RESIDENTIAL ENERGY CONSUMPTION

Scenario	Compound Annual Growth Rates
1) No efficiency improvement High Saturation	4.6%
2) No efficiency improvement Low Saturation	2.8%
3) Market improved efficiency High Saturation High Price Case	4.05%
4) Market improved efficiency Low Saturation High Price Case	2.1%
5) Market improved efficiency High Saturation Low Price Case	4.3%
6) Market improved efficiency Low Saturation Low Price Case	2.35%
7) Standards Level 1 High Saturation	4.1%
8) Standards Level 1 Low Saturation	2.0%
9) Standards Level 2 High Saturation	2.95%
10) Standards Level 2 Low Saturation	1.125%

For the companies providing forecasts, compound 15 year residential electricity growth rates range from a low of 1 percent (Northern States Power) to a high of 1.75 percent (Cooperative Power Association). Since the forecasts were done in 1980 when the standards were proposed at level 3, the forecasts assumed a faster improvement in efficiency than was used in this study. Considering that the scenarios used less stringent standards levels and were designed to be biased on the high side, the results seem quite plausible.

Megawatt Capacity Cost

Growth rates are one way to compare the different scenarios, but decision makers are more often interested in the dollar figures attached to a particular growth in demand. In other words, the MWH demand figures must be translated into installed MW capacity figures necessary to meet MWH demand. The additional installed MW capacity can then be computed by subtracting existing 1980 MW capacity from the estimated MW capacity necessary to meet the 1995 demand. The cost of the additional capacity can then be computed by multiplying the necessary additional MW capacity by the cost of new capacity. To complete this process, two parameters must be determined: the annual load factor and the cost of new capacity.

Load factor (always less than 100 percent) is the ratio of the average demand in megawatt hours to the maximum or peak demand in megawatts times the number of hours in a year.[17/] The load factor gives an indication of how well demand for electricity is matched to peak demand. For example, peak

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17/ Load Factor (LF) = MWH/(MW(365x24)). To solve for peak MW demand: MW = MWH/(L.F.(8760)).

summer demand for electricity occurs during the hottest days of summer when most people use their air conditioners. While demand is not always that high, the megawatt capacity necessary to meet that demand must be available, even if it is not used. The higher the load factor, the better demand is matched to peak capacity, and the more even is the load.

In Minnesota, the peak demand occurs in the summer. While winter electric space heating requires a lot of electricity, the demand is more consistent. Therefore, summer load factors are higher than winter load factors. Load factors vary by customer class as well as by season. Commercial and industrial load factors are higher than residential load factors. The electricity demand is fairly consistent in the commercial and industrial sectors, whereas the residential sector demand is highest in the early morning and evening hours and relatively low during other periods.

Northern States Power reports summer residential load factors of 33.6 percent (1978), 37.2 percent (1979), and 37.6 percent (1980). There are no forecasts for residential load factors, although it is anticipated that they could rise due to load management practices and changing pricing policies. System load factors are forecast for the five major utilities serving the study area.[18/] The forecasts reflect an increase over the 1980 figures of about 1 or 2 percent. The system load factors are higher than the residential load factors because of the contribution of the industrial and commercial demand. Since this analysis concentrates on residential

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18/ 1980 Advance Forecast Report to the Minnesota Environmental Quality Board and the Minnesota Energy Agency, September 15, 1980; submitted by the Southern Minnesota Municipal Power Agency and the Minnesota/Wisconsin Power Suppliers Group.

demand only, the residential load factor is the appropriate statistic to use. Two residential load factors are used to provide a range for analysis: 35 percent and 40 percent. These are used to compute the megawatt capacity necessary to meet the megawatt hour demand projected in the scenarios and shown in Table 11.[19/]

Additional megawatt capacity must be added to the resulting megawatt figure to accommodate 'down time' and inefficiencies of plant equipment. Generating plants do not operate at 100 percent of their capacity for three reasons: (1) plants break down and need repair, (2) maintenance procedures require shut downs, and (3) mechanical and thermal limitations of conversion equipment. A 'capacity factor' is the ratio of megawatt hours generated by a particular plant to the capacity rating of that plant. In other words, it is the percent of a particular plant's rated capacity that is available for power generation. Capacity factors vary by the size of plant. The smaller plants tend to have higher capacity factors than larger plants while fossil fuel plants have larger capacity factors than nuclear plants.[20/] The capacity factor is important for either a single plant only, or a system of plants. In this study, the area is served by several utilities with many different types and capacities of plants. All utilities in the area belong to, or comply with, the regulations of the Mid-Continent Area Power Pool (MAPP).[21/] MAPP requires

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[19/] Capacity necessary to meet the megawatt hour demand =

$$\frac{\text{MWH demand}}{(\text{Load Factor} \times 8760)}$$

[20/] For statistical data see the Report on Equipment Availability for the Ten Year Period 1967-1976, Edison Electric Institution, Publ. No. 77-64.

[21/] Mid-Continent Power Pool (MAPP) is an organization of utilities that have interconnect agreements for the buying and selling of power.

that all members maintain a reserve capacity of 15 percent in excess of peak demand. While a 15 percent reserve would not be enough to accommodate the outages of a single plant, with many utilities and many plants interconnected, the risk of outages is spread so that in the aggregate an excess of 15 percent over peak demand is adequate. For this reason 15 percent reserve capacity is added onto the computed megawatt figure.

Table 14 shows the estimated 1995 installed capacity needed to meet the total residential demand of the ten different scenarios. Column 1 and 2 are computed using the two estimates of load factor and the 15 percent reserve capacity.[22/] Column 2 shows the additions to 1980 megawatt capacity that would be necessary to meet the 1995 demand.[23/]

To translate the necessary megawatt capacity into dollar figures it is essential to have an estimate of the cost of new capacity. There are many different types of costs associated with power plant construction such as actual building costs, insurance, taxes, and interest charges. In addition, costs will vary depending on the type and size of plant to be built. In general, nuclear plants have the highest cost, and larger facilities have lower costs per megawatt than smaller plant. However, larger plants have higher costs of transmission and distribution than smaller plants.

22/ The 1995 megawatt hour demand of scenario 1 is 3638284 MW. Dividing this by the load factor multiplied by the hours in a year results in capacities for the scenario of 1187 MW and 1038 MW. Reserve capacity of 15 percent is then added onto each figure resulting in a high estimate of 1365 MW and a low estimate of 1194 MW.

23/ It is computed by subtracting the 1980 capacity (595 MW and 680 MW for the two load factors) from the necessary 1995 installed megawatt capacity of each scenario.

TABLE 14. NECESSARY CAPACITY AND INVESTMENT TO MEET 1995 RESIDENTIAL DEMAND

Scenario	Necessary 1995 Installed Megawatt Capacity		Necessary Additions to 1980 Megawatt Capacity		Investment Necessary For Capacity Addition (Millions of $)	
	HIGH a/	LOW b/	HIGH	LOW	HIGH	LOW
1) No efficiency improvement High saturation	1365	1194	685	599	1027.5	898.5
2) No efficiency improvement Low saturation	1030	902	350	307	525	460.5
3) Market improved efficiency High saturation High price case	1261	1104	581	509	871.5	763.5
4) Market improved efficiency Low saturation High Price case	950	831	270	236	405	354
5) Market improved efficiency High saturation Low price case	1309	1145	629	550	943.5	825
6) Market improved efficiency Low saturation Low price case	983	860	303	265	454.5	397.5
7) Standards level 1 High saturation	1266	1109	586	514	879	771
8) Standards level 1 Low saturation	937	820	257	225	385.5	337.5
9) Standards level 2 High saturation	1079	944	399	349	598.5	523.5
10) Standards level 2 Low saturation	829	726	149	131	223.5	196.5
1980 MW CAPACITY	680	595				

a/The high estimate is the result of using a load factor of .35
b/The low estimate is the result of using a load factor of .40

The average 1985 cost of installing coal generating plants in Minnesota is about $1 million per megawatt of installed capacity. This is based on the cost of Northern States Power's Sherco 3,800 MW coal plant, which is scheduled to come on line in 1985 at a cost of $800 million. However, if any new plants are built in the study area they will most likely be small coal fired facilities.

The Minnesota Energy Agency estimates 1990 costs of new capacity at $1.5 million per megawatt (see Table 15). The Energy Information Administration does not designate what size of plant the estimate is for. United Engineers cost estimate is for plants 800 MW or larger. Because the construction costs per MW are higher for smaller plants and these are the type most likely to be built, the highest cost estimate was used to estimate investment costs.

The investment necessary for capacity additions in column 5 and 6 of Table 14 are calculated by multiplying columns 3 and 4 by $1.5 million. The possible investment ranges all the way from $196.5 million to $1027.5 million.

There is not much difference in necessary investment between the high price market induced efficiency scenario and the standards level 1 scenarios. This suggests that it would be more cost effective to allow market price to rise than to institute standards at level 1. However, standards instituted at level 2 show a substantial decline in necessary investment and may well be worth implementing.

The saturation level makes a significant difference in the necessary megawatt capacity and therefore in the necessary investment to meet that capacity. If natural gas prices are allowed to rise substantially, then there may well be a significant shift towards electric appliances for space

TABLE 15. 1990 COST ESTIMATES OF COAL GENERATING PLANT CONSTRUCTION

Source	Estimate (Millions of $/MW)
Energy Information Administration[a/]	1.23
United Engineers[b/]	1.34
Minnesota Energy Agency[c/]	1.50

a/ Energy Information Administration, 1980 Annual Report to Congress, Vol. 3, March 18, 1981, p. 262.

b/ United Engineers and Constructors, Inc., Total Generating Costs: Coal and Nuclear Plants: Philadelphia, Pennsylvania, February 1979. (Costs shown are for low sulfur coal burning plants -- high sulfur plants have higher costs.)

c/ Discussion with D. Buller -- costs based on 1980 costs plus 8 percent annual escalation.

and water heating. In such a case, more capacity and investment will be needed to meet 1995 demands. Saturation is a difficult variable to manipulate so that legislators would find it hard to influence demand through this variable. Fisher and Kaysen[24/] found that "in general, net changes in the stock of appliances seem mainly to depend on changes in long run income or changes in population and in the number of households per capita. The price of electricity seems to have nearly no effect; the prices of appliances only relatively small ones." However, they did find that ranges and water heaters were exceptions in that the price of electricity did affect the saturation level. Therefore, for appliances requiring a lot of electricity, such as ranges, water heaters and furnaces, the price of electricity may be used to manipulate the saturation level, as well as the absolute usage level of appliances.

Minnesota Conservation Policies

Improved appliance efficiencies have been assumed to result from either market adjustments or from federally legislated standards. At the state level, attempts are also being made to induce consumers to purchase more efficient appliances. One such effort is a Minnesota statute passed in 1976. Another is Northern States Power Conservation Program 4: Rebate Incentives.

In 1976 the State of Minnesota adopted an Energy Code for new buildings based on the standards established in 1975 by the American Society of

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24/ F. M. Fisher and C. Kaysen, A Study in Econometrics: The Demand for Electricity in the United States, Amsterdam: North Holland Publishing Co., 1962, p. 5.

Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). Included in this code was a minimum energy efficiency ratio for air conditioners of 7.15 by 1980.[25/] Individual counties, excluding those in the Twin Cities Metropolitan Area, were given the option of not adopting the code. To date, 72 counties have not adopted the code, but this represents only 20.9 percent of the state's population.

Also in 1977, the Minnesota legislature changed the wording of a statute (1168120 Sub. 10), originally passed in 1976, requiring that "beginning January 1978 no new room air conditioner shall be sold or installed or transported for resale into Minnesota unless it has an energy efficiency ratio of 7.0 or higher."[26/] All counties must comply and do not have the option of rescinding. As legislators become more aware of the conservation gains possible with greater appliance efficiencies, this type of legislation could become more common.

In the fall of 1980, Northern States Power proposed to the Minnesota Public Services Commission a four part preliminary conservation program. Part 4 of the program is a rebate incentives program which offers rebates to residential electric customers to encourage the purchase of high efficiency major appliances.[27/] The plan has been submitted and approved by the Minnesota Public Service Commission and is now pending approval of the technical details (23). A one year demonstration project encompassing the Twin Cities Service Area is scheduled to begin in the summer of 1981.

25/ The average energy efficiency ratio proposed by DOE for 1981 is 7.15.

26/ The proposed DOE 1981 standard for room air conditioners is 6.65.

27/ There is a corresponding plan to induce consumer purchase of more efficient gas appliances so that there is no reason to assume that this program will induce consumers to switch from gas to electric appliances.

According to the plan description, "Northern States Power will rebate a portion of the additional purchase cost of an electric appliance having an energy efficiency greater than that of the average marketed appliance" (23). Rebates of up to $600 per customer will be given for the following appliances:

Room air conditioners
Central air conditioners
Water heaters
Refrigerator/Freezers
Freezers

The rationale of Northern States Power in devising the program is twofold. First, the reduction in peak demand on the system could potentially result in smaller additions to capacity. Second, they are hopeful that once the success of the program is demonstrated, the Public Services Commission will allow the company to earn a rate of return on the rebated amount.

The cost of the program for the entire system is estimated at approximately $460/KW. When compared to a present value of construction costs of about $620/KW for capacity additions, it is understandable why the utility is interested in promoting this program, especially if it can earn a rate of return on the expenses.

It has been suggested (14) that since the overall aim of such policies and programs is to reduce the use of costly future electricity, the most straightforward means to achieve this end is simply raising electricity prices to reflect the cost of new generation. Those who use more electricity would bear the burden of higher prices. However, an undue burden would fall on the poor. In a 1973 survey done by the Washington Center for Metropolitan Studies, it was found that even though low income groups use less electricity, they spend a greater percentage of their income on electricity than do high income groups.[28/] The survey also revealed that "the poor use more fuel (for heating) per square foot of housing than the lower middle and well-to-do".[29/] While payback periods on thermal insulating techniques are relatively short, the poor often do not have the initial capital to purchase and install insulation. There can be some relief for the poor through special loan programs. Northern States Power has proposed a low interest loan program in addition to their rebate program.

Conservation may also be achieved by simply changing the pricing structure. For example, elimination of declining block pricing[30/] and replacing it with constant block or increasing block pricing would induce conservation among those who use greater amounts of electricity without shifting a greater burden to the poor. Objections to such a change are usually made on economic efficiency grounds. That is, it is less expensive to deliver energy to the large user. Peak load pricing, in which customers are equipped with special meters and charged higher rates during periods of peak demand, is another alternative pricing structure that is under scrutiny by utilities. Peak load pricing helps reduce the amount of capacity that must be held in reserve for peak periods of the day. On the other hand, it may not be very effective in reducing the peak seasonal demands for heating and air conditioning.

28/ Energy Policy Project of the Ford Foundation, A Time to Choose, Ballenger Publishing Company, Cambridge, Massachusetts, 1974, pp. 116-123.

29/ Ibid, p. 121.

30/ Declining block pricing refers to a price structure in which higher blocks of electricity usage are charged lower rates. This is the most common pricing structure for electricity.

Evaluation of the End Use Model

To date, in Minnesota, end use models have only been used by utility companies in an effort to support their aggregate forecasts. One major difference between the state agency application and the utility company application of end use models is the delineation of the study area. The utility company models a service area which does not necessarily follow county or regional boundaries. The state or government agency looks at electricity consumption in a region or in the state. While the use of political boundaries make the population or household estimates easier to obtain, the saturation information may be difficult to obtain if there are several utilities serving the area.

Fortunately, in this study, there were current saturation estimates available from several utilities serving the area. In general, utility companies using aggregate models are resistant to collecting end use data because of the high cost of collection. Even most of those that do collect end use data do not continuously update the end use data. Therefore, for end use modeling to be a viable technique for a government or state agency, some mechanism for assembling and updating end use data must be developed. For example, the agency could subsidize the utility companies to collect the required information. On the other hand, utilities could simply be compelled to provide the information. In the residential sector, saturation data is in the most need of refinement.

Saturation and end use data should also be assembled on a region or state basis including a surveying of farm equipment. The data base should be updated at least every 5 years. This means that appliance data should be collected once or twice between census years. There are regional and national estimates available but they are not very useful for areas smaller than a Census region.

To obtain accurate estimates of average annual energy consumption per appliance, appliances could be metered in a sampling of homes over time to account for the effects of family size and seasonality. This would be costly, and it is doubtful that the improvements over the average estimates would be worth the costs for all appliances. However, it may be worth it for appliances whose use varies by climatic location, such as air conditioners. Also, in the commercial and industrial sectors, metering may be the only way to accurately measure actual technical improvement.

In the residential sector the end use model is quite satisfactory for evaluating future changes in electrical energy demand when one of the model components change. It is also an effective operational technique to apply to a geographic region rather than a utility service area. However, as scarce as end use data are in the residential sector, it is even more scarce in the industrial and commercial sectors. This would make it extremely difficult to utilize an end use model to evaluate potential policy impacts in the very sectors where the impacts could be the greatest. The remedy is data collection, similar to that described for the residential sector.[31/]

The ability to analyze the conservation potential in each sector could help speed up the political process. This kind of information is

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31/ An excellent review of a commercial end use model is given in Fazzolore and Smith's book which includes a description of the data used.

not only necessary to anticipate conservation potential, but also to measure the effectiveness of policies once they are implemented.

Summary

Three of the most common electrical energy forecasting methods are extrapolation, aggregate estimation, and end use models. In extrapolation, the past trend of consumption is simply extrapolated into the future. Aggregate estimation requires the use of statistical regression techniques in which consumption is a function of a set of variables such as population, income, price of electricity, etc. In end use models, consumption of electrical energy is estimated by summing up the consumption of various end uses of electricity such as ranges, water heaters and refrigerators. The number of each type of appliance is multiplied by the energy use of the appliance and the products are summed.

While aggregate estimation is the most commonly used method, it has limitations for evaluating conservation potential. If a price and time term are included in the model then conservation effects can be captured by the model. However, it will be impossible to determine whether the conservation is due to a curtailment of energy use or to the more efficient use of energy. An end use model, on the other hand, can be used to isolate future conservation effects of a technical change in the capital stock.

In this paper an end use model was developed to forecast residential electrical energy consumption for the southeastern region of Minnesota and to evaluate the impacts of the Department of Energy's proposed appliance efficiency standards. Because of the number of utilities serving the area, this end use model is somewhat more complicated than the usual approach of modeling a single utility's service area.

The data needed for the end use model are (1) number of households, (2) saturation of appliances, (3) annual energy consumption per appliance, and (4) appliance service life. Household data was obtained from the Minnesota State Demographer's Office. Since there are many utilities serving the area, a weighted average of saturation estimates was used for the 1980 saturation. The 1995 saturation values were selected after a close examination of existing studies and a logistics equation was used to interpolate the values from 1980 to 1995. Annual 1980 energy consumption per appliance were obtained from NSP, MEA, MRI and Basin Cooperative. Future energy consumption figures were obtained by decreasing the 1980 estimates according to the Department of Energy's (DOE) proposed standards. Appliance service life is the average number of years a particular appliance is in use. An average of available estimates was used for the analysis.

If consumers do not make a dramatic shift to purchasing electric appliances for which there are gas alternatives (water heaters, ranges, and furnaces), consumption growth rates are considerably lower than if such a shift occurs. If such a switch does occur, DOE's performance standards could be used to lower consumption.

If no such shift occurs, higher prices will continue to encourage conservation through the production and purchasing of more efficient appliances. In this case standards can be used to reduce consumption even further, but the bureaucratic and administrative costs must be carefully evaluated and compared to the cost savings of implementing standards.

Improvements in appliance efficiencies are being recognized as having an important conservation role. In 1976, the Minnesota legislature passed a statute requiring a minimum energy efficiency for air conditioners. Northern States Power Company, one of the largest utility companies in the study area will be conducting a demonstration project in the summer of 1981 in which rebates will be given to consumers for the purchase of more efficient appliances.

This all points to the need to improve appliance efficiency. End use models can provide a useful method for decision makers to analyze what the potential impacts of these improvements will be.

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APPENDIX A

The saturation model used by Cooperative Power Association is:

$$\ln(S_{it}/(1-S_{it})) = \sum_{j=1}^{k} \beta_j \ln X_j$$

where: i = appliance type

t = year

j = number of independent variables

S_{it} = saturation rate for households; appliance type i, year t

X_j = any of the independent variables included in the econometric model of saturation rate of appliance type i

j = regression coefficients

The model formulation constrains the saturation rate to be less than 100 percent. The independent variables used in the regression analysis were: lagged (one year) saturation; natural gas availability (percentage of households having natural gas available); the real price of propane and real household income.

APPENDIX B

The following saturation model was used by the Energy Systems Research Group (19) and the Natural Resources Defense Council (14).

$$Sat_t = \frac{\text{Terminal Saturation}}{1 + \frac{\text{Terminal Saturation - Base Saturation}}{\text{Base Saturation}} \cdot e^{-k(t-1980)}}$$

where: Sat_t = saturation of a particular appliance at time t

Terminal Saturation = the maximum achievable level of saturation for a particular appliance

Base Saturation = the initial year saturation (1980)

In the NRDC study the rate of change of saturation (k) was estimated using the following equation:

$$k = \frac{(\ln (\frac{\text{Terminal Saturation-Base Saturation}}{\text{Base Saturation}})) - (\ln (\frac{\text{Terminal Saturation}}{\text{1995 Saturation}}) - 1)}{15}$$

In the ESRG study k was estimated from historical data. What is not clear from the ESRD study is whether the historical data used was local data or some type of national or regional data.

The NRDC study assumed terminal saturation to be 100 percent for all appliances except refrigerators where it was assumed to be 120 percent. The 1995 saturation estimates were provided them by an outside study. The ERSG study assumed a particular range of values for the terminal saturation.

In this case it is felt that the formulation used by the NRDC is more suited to this analysis since it requires no historical data on the rate of change of saturation. However, it does impose an additional assumption on the system.