Electric Rate Structures for Thermal Energy Storage Evaluation

May 1991

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ELECTRIC RATE STRUCTURES FOR
THERMAL ENERGY STORAGE EVALUATION

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SUMMARY

Future electric rate structures are critical to thermal energy storage (TES) technologies that are specifically designed to take advantage of electric energy costs that vary depending on the magnitude, duration, and timing of power demand (e.g., cool storage). In fact, rate structure characteristics may affect the TES system design and operating approach as well as economic feasibility. The objective of this study, conducted by the Pacific Northwest Laboratory^(a) for the U.S. Department of Energy, was to define reference electric utility rate structures to be used in technical assessments of TES technologies.

Electric rate structures were characterized for residential, commercial, and industrial sectors. A range of conditions for several alternative rate structures was identified for each sector to capture the variability of likely conditions. Individual rate structure characteristics include demand charges and energy charges applicable during different months of the year, days of the week, and hours of the day.

It seems imprudent to conduct technical assessments based on a single generic rate structure because of the current and expected future variability in electric rate structures and the impact of the rate structure on the design and economic feasibility of TES technologies like cool storage. Rather, multiple utility rate structure scenarios representing the range of expected conditions are more appropriate.

The rate structure data developed in this study are intended for use in site-generic studies of TES technologies like cool storage where the demand for the service provided by the technology is driven entirely by the characteristics of the rate structure. Site-generic studies should consider the range of conditions and alternative rate structure types possible within each sector. Studies based on only one type of rate structure and/or one set

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of conditions will have limited value for determining the potential feasibility of a TES concept. Whenever site-specific studies are conducted, the actual rate structure for the local utility should be used. Average electric power cost data, which combine demand and energy charges into a single \$/kWh value, are appropriate for evaluating technologies that are insensitive to rate structure details.

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1.0 INTRODUCTION

In general, future energy costs have a significant impact on the economic feasibility of thermal energy storage (TES) technologies and their cost and performance requirements for competing with alternative technologies. In particular, future electric rate structures are critical to TES technologies that are specifically designed to take advantage of electric energy costs that vary depending on the magnitude, duration, and timing of power demand (e.g., cool storage). Such technologies are described as having a "derived demand," because the demand for the service provided by these technologies is driven entirely by the characteristics of the rate structure.

Rate structures vary considerably from state to state, among utilities, and between residential, commercial, and industrial sectors. The character of the rate structure may affect TES system design and operating approach as well as economic feasibility. For example, a load-shifting strategy is promoted by time-of-use rates while a load-leveling strategy is promoted by flat demand charges.

The objective of this study was to define reference electric utility rate structures to be used in technical assessments of TES technologies. The study was conducted by the Pacific Northwest Laboratory^(a) for the U.S. Department of Energy. Electric rate structures were characterized for residential, commercial, and industrial sectors. A range of conditions for several alternative rate structures was identified for each sector to capture the variability of likely conditions. Individual rate structure characteristics include demand charges and energy charges applicable during different months of the year, days of the week, and hours of the day.

Sections 2 and 3 define the general approach used in this study and the response received from several representatives of the electric utility industry regarding future electric rate structures. Sections 4 and 5 numerically characterize alternative rate structures. Section 6 presents future electric energy cost escalation rates.

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2.0 GENERAL APPROACH

The organizations listed below were consulted to determine what, if anything, had already been done to characterize future electric utility rate structures and to seek advice on prudent electric rate assumptions for evaluating TES technologies such as cool storage.

- Electric Power Research Institute
- Edison Electric Institute
- Energy Information Administration
- Utility Data Institute
- National Regulatory Research Institute
- National Association of Regulatory Utility Commissioners
- Casazza, Schultz, and Associates.

A literature search was also conducted to identify relevant publications. The information gathered was reviewed to determine if an adequate characterization of future rate structures had already been completed.

No satisfactory assumptions or analyses were found to have been developed, so the next step taken was to characterize rate structures amenable to the use of TES. The number of different types of rate structures employed by utilities is almost limitless, but can generally be grouped into the following categories

- flat energy charge
- flat energy charge with flat demand charge
- time-of-use energy charge
- time-of-use energy charge with flat demand charge
- time-of-use energy charge with time-of-use demand charge
- interruptible/curtailable
- real-time pricing.

The general trend in rate structures is away from simple, non-varying rates toward rates that more closely match a utility's cost of supplying power at any specific point in time. Demand charges, time-of-use rates, and

seasonal variations in demand charges and time-of-use rates are all oriented towards producing a better match between price and the supply cost. Real-time rates are an extension of the two- or three-period time-of-use concept. For example, rates might change hourly and their value known with certainty only 24 hours in advance. Thus, utilities employ a broad range of rate structures and are likely to continue to do so in the future.

A compilation of current electric rate structures was acquired. Rate structures that might present an opportunity for using TES were identified for residential, commercial, and industrial customers for each utility. This includes all of the rate structures discussed earlier except for flat energy charge. The rate structure characteristics listed below were collected as applicable to each rate structure type.

- demand charges
- energy charges
- summer season
- winter season
- peak days, peak hours
- mid-peak days, mid-peak hours
- off-peak days, off-peak hours.

Rate structure data were grouped according to the general classifications identified above. Within each group, the range, average, and standard deviation of the numerical characteristics were calculated.

The above analysis established the frequency of use and variability of rate structures employed by the majority of the utility industry. The statistical analysis was repeated for those utilities currently promoting the use of TES systems. These utilities are presumably more progressive in rate structure design and implementation and should be more representative of future rate structures for the entire industry. However, comparison of rate structure data for the two groups showed no significant differences when comparing statistics for the same rate structure type.

Recent literature pertaining to future electric rate structures was reviewed to identify innovative rate structures such as real-time pricing and interruptible/curtailable schedules that may become more common in the future. The rate structures were quantitatively characterized to the extent possible and their impact on the technical and economic feasibility of TES technologies was qualitatively addressed.

The information obtained from completing the above activities was used to develop reference rate structure characteristics for residential, commercial, and industrial sectors. Multiple rate structures were developed for each sector to cover the range of likely future conditions.

3.0 INDUSTRY CONTACTS

The consensus of opinion offered by electric utility representatives was that no generic future utility rate structures had been developed and that this would be very difficult to do. Establishing a single national composite would be almost impossible, if not foolhardy. Alternative recommendations were to develop generic regional rate structures, to consider several alternative rate structures, and to focus on utilities currently promoting TES because these utilities were more likely to be progressive leaders and representative of the future. Specific comments from representatives of the Electric Power Research Institute (EPRI) and Edison Electric Institute (EEI) are described below. Representatives from the other organizations listed in the previous section were contacted, but did not provide any insight on future electric rate structures.

Ron Wendland of EPRI suggested that the trend is definitely toward more use of demand charges and time-of-use rates, even in the residential class. Reduced metering costs are one driving force. Eventually, Mr. Wendland expects real-time pricing (at 1-hour intervals) to be used in conjunction with energy management systems, which react to energy pricing information and control household loads accordingly. Mr. Wendland also noted that EPRI has stayed away from establishing proposed or generic rates because it is a sensitive issue for utilities. In addition, composite or generic rates are of limited value to individual utilities.

Eric Ackerman of EEI believed it would be very difficult to generalize about rate structures. Any single rate structure would be relatively meaningless. Mr. Ackerman suggested we consider developing several regional rate structures rather than one national composite or complete case studies for several different rate structures. Mr. Ackerman noted that interruptible and semi-interruptible power schedules are becoming more popular in the Northeast, which is already facing power shortages.

Phil Hanser of EPRI expected future electric rate structures to involve time-of-use rates, real-time pricing, various classes of interruptible power,

demand and energy charges, and load factor rates. Mr. Hanser sees much more flexibility in rate structures in the future. Mr. Hanser also noted that rate structures are so variable, it would be extremely difficult to generalize. EPRI recognizes this is a problem for technology developers, but there is no easy solution. If the utilities are interested in having technologies such as cool storage develop, they are going to have to work towards developing more standard, less volatile rate structures. Mr. Hanser suggested examining alternative rate structures to see how much different parameters could be varied and still maintain economic feasibility.

Tim Yau of EPRI also confirmed the lack of any composite or generic rates. Mr. Yau noted that some utilities have no current interest in promoting thermal energy storage and their rate structures reflect that. That's why some flat energy rates still exist, especially in the residential sector. However, future rate structures could be considerably different. Once a utility decides it's in their interest to promote thermal energy storage, new rate structures will quickly be put in place. For these reasons, using an average or composite of all current rate structures would be a poor proxy of the future. Mr. Yau suggested focusing on utilities currently interested in promoting thermal energy storage if an average, or composite, or range of rate structures for evaluating thermal energy storage is needed. Utilities currently promoting thermal energy storage are typically industry trend setters or at least have given some thought as to how thermal energy storage could benefit them and what type of rate structures need to be employed. Mr. Yau believes that rate structures for these utilities are much more likely to be representative of the future and certainly much more relevant for evaluating thermal energy storage concepts.

4.0 STANDARD RATE STRUCTURE CHARACTERIZATION

The Electric Rate Book (Casazza, Schultz, and Associates 1989) was reviewed to identify the following rate structure types (if used) for residential, commercial, and industrial rate sectors for each utility: 1) flat demand and energy charges, 2) time-of-use (TOU) energy charges, 3) flat demand charges and TOU energy charges, and 4) TOU demand and energy charges.

The Electric Rate Book presents abstracts of rate schedules for 110 investor-owned electric utilities providing service to residential, commercial, and industrial customers. The utilities included provide service to about 95% of all customers served by investor-owned utilities and about 75% of all electricity customers in the United States.

Residential rate structures are specifically identified as such by title in the Electric Rate Book. Rate structures applicable to commercial and industrial customers follow in order, although they are not usually specifically identified as being commercial or industrial. Therefore, rules-of-thumb were established for classifying a nonresidential rate structure as commercial or industrial.

The key distinguishing service features of the nonresidential or general service rate structures are the minimum and/or maximum monthly peak kW demand limits and the voltage service level. In fact, most general service rate structures could be applicable to either commercial or industrial customers, depending on the actual power requirements of an actual business. Thus, some judgment is required to identify commercial and industrial rate structures from those listed in the Electric Rate Book. The following general rules were applied:

1. Secondary or lower voltage service levels were defined to be applicable to commercial customers.
2. Primary or higher voltage service levels were defined to be applicable to industrial customers.
3. Rate structures applicable to peak demands less than 1000 kW were defined as commercial, and rate structures applicable to peak demands greater than 1000 kW were defined as being industrial.

Application of the above rules still required some judgment, however, because the rate structures for any specific utility were rarely segregated exactly at the 1000-kW power level and several voltage service levels might apply to the same basic rate structure. Each of the nonresidential or general service rate structures was reviewed for each utility before making a decision on which to identify as commercial and industrial. Looking at the whole group helped establish a sense for the overall rate structure logic.

Rate structure characteristics identified in Section 2 were collected for each rate structure identified in the Electric Rate Book, as applicable. Within each classification, the range, average, and standard deviation of the numerical characteristics were calculated. The statistical analysis was applied to data from all of the utilities identified for each rate structure and for the subset of innovative utilities. In general, no significant differences between the two groups were found.

Marginal cost data for the last kW or kWh purchased were recorded, where a tiered rate structure existed, except when the last tier was a penalty rate for exceeding the intended service level of the rate structure. For example, if the rate structure was for power demands less than 100 kW, the rate for exceeding 100 kW was not quoted. Rather, the rate for the last increment below 100 kW was quoted. Fixed customer charges were ignored because they are not part of the marginal cost. The demand charge quoted was based on the actual demand rather than any other type of demand, such as the distribution demand.

Many variations of the general rate structure types can be found. The rate structures selected for characterization represent the most common configurations and/or those that were considered to be fundamentally different. Minor variations were not characterized. For example, several TOU rate structures also have mid-peak or shoulder rate periods and rates; but these data were ignored because their number was small and a three-period TOU rate structure was not considered to be so different from a two-period TOU rate structure that it warranted separate characterization.

4.1 RESIDENTIAL SERVICE

Rate structure data were collected and generic rate structures developed for three different residential service rate structure types: TOU energy charges, flat demand and energy charges, and TOU demand and energy charges. No residential rate structures based on flat demand and TOU energy charges were identified.

Rate structures based on TOU energy charges were found to be offered by 60 of the investor-owned utilities included in the Electric Rate Book. Composite statistics for this rate structure are presented in Table 4.1. Reference rate structure characteristics suggested for TES evaluations are shown in Table 4.2. Baseline conditions were set equal to the average conditions shown in Table 4.1. Peak and off-peak rates for this rate structure and sector were found to be positively correlated, i.e., higher peak rates were generally associated with higher off-peak rates. Therefore, conditions for the high and low cases were set equal to a one standard deviation increase and decrease, respectively, from the peak and off-peak energy charges for the baseline case.

Rate structures based on flat demand and energy charges were found to be offered by only five of the investor-owned utilities included in the Electric Rate Book. This set was considered too small to be representative of the potential population, so the raw data were adjusted to develop the reference rate structures. The adjustment was based on the ratio of average rates for the five utilities compared to all utilities for the TOU energy charges structure. Composite statistics for this rate structure are presented in Table 4.3. Reference rate structure characteristics suggested for TES evaluations are shown in Table 4.4. Baseline conditions were based on the average conditions shown in Table 4.3, but adjusted as described above. In general, little correlation was seen between demand charges and energy charges for this rate structure and sector, except for extreme cases, which were negatively correlated. Therefore, conditions for the high and low cases were set equal to a one standard deviation increase and decrease, respectively, from the demand charges for the baseline case, with energy charges remaining constant.

**TABLE 4.1. Composite Rate Structure Statistics;
Residential TOU Energy Charges**

<u>Characteristic</u>	<u>Average</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Standard Deviation</u>
Summer months	May-Sept	April	November	-
Number of summer months	5	3	8	1
Winter months	Oct-April	October	June	-
Number of winter months	7	3	8	1
Peak days	Mon-Fri	Mon-Fri	Mon-Fri	-
Number of peak days	5	5	5	0
Summer peak hours	9am-8pm	6am	12pm	-
Number of summer peak hours	11	6	15	3
Winter peak hours	8am-8pm	6am	12pm	-
Number of winter peak hours	12	3	15	3
Summer peak energy (\$/kWh)	0.1280	0.0702	0.3684	0.0538
Summer off-peak energy (\$/kWh)	0.0377	0.0060	0.0785	0.0197
Winter peak energy (\$/kWh)	0.1053	0.0489	0.1410	0.0250
Winter off-peak energy (\$/kWh)	0.0377	0.0060	0.0797	0.0199

**TABLE 4.2. Reference Rate Structure Statistics;
Residential TOU Energy Charges**

<u>Characteristic</u>	<u>Baseline</u>	<u>Low</u>	<u>High</u>
Summer months	May-Sept	May-Sept	May-Sept
Winter months	Oct-April	Oct-April	Oct-April
Peak days	Mon-Fri	Mon-Fri	Mon-Fri
Summer peak hours	9am-8pm	9am-8pm	9am-8pm
Winter peak hours	8am-8pm	8am-8pm	8am-8pm
Summer peak energy (\$/kWh)	0.1280	0.0742	0.1818
Summer off-peak energy (\$/kWh)	0.0377	0.0180	0.0574
Winter peak energy (\$/kWh)	0.1053	0.0803	0.1303
Winter off-peak energy (\$/kWh)	0.0377	0.0178	0.0576

TABLE 4.3. Composite Rate Structure Statistics;
Residential Flat Demand and Energy Charges

<u>Characteristic</u>	<u>Average</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Standard Deviation</u>
Summer months	May-Sept	May	October	-
Number of summer months	5	4	6	1
Winter months	Oct-April	October	May	-
Number of winter months	7	6	8	1
Summer demand (\$/kW)	7.78	4.25	10.79	2.65
Winter demand (\$/kW)	6.27	4.25	7.66	1.45
Summer energy (\$/kWh)	0.0289	0.0165	0.0437	0.0092
Winter energy (\$/kWh)	0.0252	0.0165	0.0367	0.0066

TABLE 4.4. Reference Rate Structure Statistics;
Residential Flat Demand and Energy Charges

<u>Characteristic</u>	<u>Baseline</u>	<u>Low</u>	<u>High</u>
Summer months	May-Sept	May-Sept	May-Sept
Winter months	Oct-April	Oct-April	Oct-April
Summer demand (\$/kW)	9.07	5.98	12.16
Winter demand (\$/kW)	7.31	5.62	9.00
Summer energy (\$/kWh)	0.0344	0.0344	0.0344
Winter energy (\$/kWh)	0.0300	0.0300	0.0300

Rate structures based on TOU demand and energy charges were found to be offered by only six of the investor-owned utilities included in the Electric Rate Book. This set was considered too small to be representative of the potential population, so the raw data were adjusted to develop the reference rate structures. The adjustment was based on the ratio of average rates for the six utilities compared to all utilities for the TOU energy charges structure. Composite statistics for this rate structure are presented in Table 4.5. Reference rate structure characteristics suggested for TES evaluations are shown in Table 4.6. Baseline conditions were based on the

**TABLE 4.5. Composite Rate Structure Statistics;
Residential TOU Demand and Energy Charges**

<u>Characteristic</u>	<u>Average</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Standard Deviation</u>
Summer months	May-Sept	May	October	-
Number of summer months	5	4	6	1
Winter months	Oct-April	October	May	-
Number of winter months	7	6	8	1
Peak days	Mon-Fri	Mon-Fri	Mon-Fri	-
Number of peak days	5	5	5	0
Summer peak hours	9am-8pm	9am	11pm	-
Number of summer peak hours	11	6	13	3
Winter peak hours	8am-8pm	6am	10pm	-
Number of winter peak hours	12	5	13	3
Summer peak demand (\$/kW)	7.21	5.20	10.88	1.91
Summer off-peak demand (\$/kW)	0.00	0.00	0.00	0
Winter peak demand (\$/kW)	4.55	3.06	8.24	1.75
Winter off-peak demand (\$/kW)	0.00	0.00	0.00	0
Summer peak energy (\$/kWh)	0.0452	0.0237	0.0616	0.0114
Summer off-peak energy (\$/kWh)	0.0304	0.0114	0.0384	0.0096
Winter peak energy (\$/kWh)	0.0429	0.0237	0.0533	0.0099
Winter off-peak energy (\$/kWh)	0.0304	0.0114	0.0384	0.0096

average conditions shown in Table 4.5, but adjusted as described above.

Demand and energy charges for this rate structure and sector were found to be positively correlated, i.e., higher demand charges were generally associated with higher energy charges. Therefore, conditions for the high and low cases were set equal to a one standard deviation increase and decrease, respectively, from the demand and energy charges for the baseline case.

4.2 COMMERCIAL SERVICE

Rate structure data were collected and generic rate structures developed for three different commercial service rate structure types: flat demand and

**TABLE 4.6. Reference Rate Structure Statistics;
Residential TOU Demand and Energy Charges**

<u>Characteristic</u>	<u>Baseline</u>	<u>Low</u>	<u>High</u>
Summer months	May-Sept	May-Sept	May-Sept
Winter months	Oct-April	Oct-April	Oct-April
Peak days	Mon-Fri	Mon-Fri	Mon-Fri
Summer peak hours	9am-8pm	9am-8pm	9am-8pm
Winter peak hours	8am-8pm	8am-8pm	8am-8pm
Summer peak demand (\$/kW)	10.73	7.89	13.57
Summer off-peak demand (\$/kW)	0.0	0.0	0.0
Winter peak demand (\$/kW)	6.77	4.17	9.37
Winter off-peak demand (\$/kW)	0.0	0.0	0.0
Summer peak energy (\$/kWh)	0.0315	0.0236	0.0394
Summer off-peak energy (\$/kWh)	0.0212	0.0145	0.0279
Winter peak energy (\$/kWh)	0.0299	0.0230	0.0368
Winter off-peak energy (\$/kWh)	0.0212	0.0145	0.0279

energy charges, flat demand and TOU energy charges, and TOU demand and energy charges. No commercial rate structures based on TOU energy charges only were identified.

Rate structures based on flat demand and energy charges were found to be offered by 78 of the investor-owned utilities included in the Electric Rate Book. Composite statistics for this rate structure are presented in Table 4.7. Reference rate structure characteristics suggested for TES evaluations are shown in Table 4.8. Baseline conditions were set equal to the average conditions shown in Table 4.7. In general, little correlation was seen between demand charges and energy charges for this rate structure and sector, except for extreme cases, which were negatively correlated. Therefore, conditions for the high and low cases were set equal to a one standard deviation increase and decrease, respectively, from the demand charges for the baseline case, with energy charges remaining constant.

TABLE 4.7. Composite Rate Structure Statistics;
Commercial Flat Demand and Energy Charges

<u>Characteristic</u>	<u>Average</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Standard Deviation</u>
Summer months	May-Sept	March	November	-
Number of summer months	5	4	8	1
Winter months	Oct-April	October	June	-
Number of winter months	7	4	8	1
Summer demand (\$/kW)	7.15	2.50	18.87	3.23
Winter demand (\$/kW)	6.29	2.00	10.08	2.34
Summer energy (\$/kWh)	0.0417	0.0062	0.0882	0.0221
Winter energy (\$/kWh)	0.0391	0.0079	0.0883	0.0201

TABLE 4.8. Reference Rate Structure Statistics;
Commercial Flat Demand and Energy Charges

<u>Characteristic</u>	<u>Baseline</u>	<u>Low</u>	<u>High</u>
Summer months	May-Sept	May-Sept	May-Sept
Winter months	Oct-April	Oct-April	Oct-April
Summer demand (\$/kW)	7.15	3.92	10.38
Winter demand (\$/kW)	6.29	3.95	8.63
Summer energy (\$/kWh)	0.0417	0.0417	0.0417
Winter energy (\$/kWh)	0.0391	0.0391	0.0391

Rate structures based on flat demand and TOU energy charges were found to be offered by only eight of the investor-owned utilities included in the Electric Rate Book. This set was considered too small to be representative of the potential population, so the raw data were adjusted to develop the reference rate structures. The adjustment was based on the ratio of average rates for the eight utilities compared to all utilities for the flat demand and energy charges structure. Composite statistics for this rate structure are presented in Table 4.9. Reference rate structure characteristics

TABLE 4.9. Composite Rate Structure Statistics;
Commercial Flat Demand and TOU Energy Charges

Characteristic	Average	Minimum	Maximum	Standard Deviation
Summer months	May-Sept	April	October	-
Number of summer months	5	4	7	1
Winter months	Oct-April	October	June	-
Number of winter months	7	4	8	2
Peak days	Mon-Fri	Mon-Fri	Mon-Fri	-
Number of peak days	5	5	5	0
Summer peak hours	8am-8pm	7am	11pm	-
Number of summer peak hours	12	8	16	3
Winter peak hours	8am-8pm	6am	11pm	-
Number of winter peak hours	12	8	16	3
Summer demand (\$/kW)	9.32	1.98	18.87	4.78
Winter demand (\$/kW)	7.47	1.98	9.82	2.48
Summer peak energy (\$/kWh)	0.0416	0.0246	0.0764	0.0173
Summer off-peak energy (\$/kWh)	0.0230	0.0062	0.0447	0.0116
Winter peak energy (\$/kWh)	0.0384	0.0246	0.0673	0.0147
Winter off-peak energy (\$/kWh)	0.0233	0.0081	0.0447	0.0113

suggested for TES evaluations are shown in Table 4.10. Baseline conditions were based on the average conditions shown in Table 4.9, but adjusted as described above. Demand and energy charges for this rate structure and sector were found to lack any strong correlation. Therefore, conditions for the high and low cases were set equal to a one standard deviation increase and decrease, respectively, from the demand charges for the baseline case, with energy charges remaining constant.

Rate structures based on TOU demand and energy charges were found to be offered by only 12 of the investor-owned utilities included in the Electric Rate Book. This set was considered too small to be representative of the potential population, so the raw data were adjusted to develop the reference rate structures. The adjustment was based on the ratio of average rates for

TABLE 4.10. Reference Rate Structure Statistics;
Commercial Flat Demand and TOU Energy Charges

<u>Characteristic</u>	<u>Baseline</u>	<u>Low</u>	<u>High</u>
Summer months	May-Sept	May-Sept	May-Sept
Winter months	Oct-April	Oct-April	Oct-April
Peak days	Mon-Fri	Mon-Fri	Mon-Fri
Summer peak hours	8am-8pm	8am-8pm	8am-8pm
Winter peak hours	8am-8pm	8am-8pm	8am-8pm
Summer demand (\$/kW)	9.56	4.66	14.46
Winter demand (\$/kW)	7.66	5.12	10.20
Summer peak energy (\$/kWh)	0.0616	0.0616	0.0616
Summer off-peak energy (\$/kWh)	0.0341	0.0341	0.0341
Winter peak energy (\$/kWh)	0.0569	0.0569	0.0569
Winter off-peak energy (\$/kWh)	0.0345	0.0345	0.0345

the 12 utilities compared to all utilities for the flat demand and energy charges structure. Composite statistics for this rate structure are presented in Table 4.11. Reference rate structure characteristics suggested for TES evaluations are shown in Table 4.12. Baseline conditions were based on the average conditions shown in Table 4.11, but adjusted as described above. Demand and energy charges for this rate structure and sector were found to be positively correlated, i.e., higher demand charges were generally associated with higher energy charges. Therefore, conditions for the high and low cases were set equal to a one standard deviation increase and decrease, respectively, from the demand and energy charges for the baseline case.

4.3 INDUSTRIAL SERVICE

Rate structure data were collected and generic rate structures developed for three different industrial service rate structure types: flat demand and energy charges, flat demand and TOU energy charges, and TOU demand and energy charges. No industrial rate structures based on TOU energy charges only were identified.

**TABLE 4.11. Composite Rate Structure Statistics;
Commercial TOU Demand and Energy Charges**

<u>Characteristic</u>	<u>Average</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Standard Deviation</u>
Summer months	May-Sept	April	October	-
Number of summer months	5	4	7	1
Winter months	Oct-April	October	May	-
Number of winter months	7	5	8	1
Peak days	Mon-Fri	Mon-Fri	Mon-Fri	-
Number of peak days	5	5	5	0
Summer peak hours	9am-8pm	7am	11pm	-
Number of summer peak hours	11	6	16	3
Winter peak hours	8am-8pm	6am	11pm	-
Number of winter peak hours	12	6	16	3
Summer peak demand (\$/kW)	6.99	4.22	11.40	2.09
Summer off-peak demand (\$/kW)	0.24	0.00	1.90	0.63
Winter peak demand (\$/kW)	5.80	3.70	8.00	1.27
Winter off-peak demand (\$/kW)	0.32	0.00	1.90	0.71
Summer peak energy (\$/kWh)	0.0438	0.0208	0.1275	0.0324
Summer off-peak energy (\$/kWh)	0.0215	0.0058	0.0541	0.0144
Winter peak energy (\$/kWh)	0.0276	0.0170	0.0391	0.0063
Winter off-peak energy (\$/kWh)	0.0187	0.0058	0.0399	0.0104

Rate structures based on flat demand and energy charges were found to be offered by 64 of the investor-owned utilities included in the Electric Rate Book. Composite statistics for this rate structure are presented in Table 4.13. Reference rate structure characteristics suggested for TES evaluations are shown in Table 4.14. Baseline conditions were set equal to the average conditions shown in Table 4.13. In general, little correlation was seen between demand charges and energy charges for this rate structure and sector, except for extreme cases, which were negatively correlated. Therefore, conditions for the high and low cases were set equal to a one standard deviation increase and decrease, respectively, from the demand charges for the baseline case, with energy charges remaining constant.

TABLE 4.12. Reference Rate Structure Statistics;
Commercial TOU Demand and Energy Charges

<u>Characteristic</u>	<u>Baseline</u>	<u>Low</u>	<u>High</u>
Summer months	May-Sept	May-Sept	May-Sept
Winter months	Oct-April	Oct-April	Oct-April
Peak days	Mon-Fri	Mon-Fri	Mon-Fri
Summer peak hours	9am-8pm	9am-8pm	9am-8pm
Winter peak hours	8am-8pm	8am-8pm	8am-8pm
Summer peak demand (\$/kW)	7.60	5.33	9.87
Summer off-peak demand (\$/kW)	0.0	0.0	0.0
Winter peak demand (\$/kW)	6.30	4.92	7.68
Winter off-peak demand (\$/kW)	0.0	0.0	0.0
Summer peak energy (\$/kWh)	0.0562	0.0354	0.0770
Summer off-peak energy (\$/kWh)	0.0276	0.0091	0.0461
Winter peak energy (\$/kWh)	0.0354	0.0273	0.0435
Winter off-peak energy (\$/kWh)	0.0240	0.0373	0.0107

TABLE 4.13. Composite Rate Structure Statistics;
Industrial Flat Demand and Energy Charges

<u>Characteristic</u>	<u>Average</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Standard Deviation</u>
Summer months	May-Sept	May	October	-
Number of summer months	5	4	6	1
Winter months	Oct-April	October	May	-
Number of winter months	7	6	8	1
Summer demand (\$/kW)	6.56	2.75	11.14	2.45
Winter demand (\$/kW)	6.22	2.50	11.14	2.46
Summer energy (\$/kWh)	0.0269	0.0028	0.0649	0.0137
Winter energy (\$/kWh)	0.0268	0.0028	0.0649	0.0137

TABLE 4.14. Reference Rate Structure Statistics;
Industrial Flat Demand and Energy Charges

<u>Characteristic</u>	<u>Baseline</u>	<u>Low</u>	<u>High</u>
Summer months	May-Sept	May-Sept	May-Sept
Winter months	Oct-April	Oct-April	Oct-April
Summer demand (\$/kW)	7.22	4.54	9.92
Winter demand (\$/kW)	5.96	3.75	8.20
Summer energy (\$/kWh)	0.0282	0.0282	0.0282
Winter energy (\$/kWh)	0.0256	0.0256	0.0256

Rate structures based on flat demand and TOU energy charges were found to be offered by 24 of the investor-owned utilities included in the Electric Rate Book. Composite statistics for this rate structure are presented in Table 4.15. Reference rate structure characteristics suggested for TES evaluations are shown in Table 4.16. Baseline conditions were set equal to the average conditions shown in Table 4.15. Demand and energy charges for this rate structure and sector were found to lack any strong correlation. Therefore, conditions for the high and low cases were set equal to a one standard deviation increase and decrease, respectively, from the demand charges for the baseline case, with energy charges remaining constant.

Rate structures based on TOU demand and energy charges were found to be offered by 26 of the investor-owned utilities included in the Electric Rate Book. Composite statistics for this rate structure are presented in Table 4.17. Reference rate structure characteristics suggested for TES evaluations are shown in Table 4.18. Baseline conditions were set equal to the average conditions shown in Table 4.17. No significant correlation between demand and energy charges was found for this rate structure and sector. Therefore, conditions for the high and low cases were set equal to a one standard deviation increase and decrease, respectively, from the demand charges for the baseline case and energy charges were held constant.

**TABLE 4.15. Composite Rate Structure Statistics;
Industrial Flat Demand and TOU Energy Charges**

<u>Characteristic</u>	<u>Average</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Standard Deviation</u>
Summer months	May-Sept	May	October	-
Number of summer months	5	4	6	1
Winter months	Oct-April	October	June	-
Number of winter months	7	6	8	1
Peak days	Mon-Fri	Mon-Fri	Mon-Fri	-
Number of peak days	5	5	5	0
Summer peak hours	8am-8pm	7am	11pm	-
Number of summer peak hours	12	8	16	2
Winter peak hours	8am-8pm	6am	11pm	-
Number of winter peak hours	12	5	16	2
Summer demand (\$/kW)	9.82	4.69	17.58	3.05
Winter demand (\$/kW)	8.33	3.81	10.65	1.88
Summer peak energy (\$/kWh)	0.0443	0.0284	0.0738	0.0153
Summer off-peak energy (\$/kWh)	0.0301	0.0045	0.0581	0.0142
Winter peak energy (\$/kWh)	0.0428	0.0111	0.0738	0.0174
Winter off-peak energy (\$/kWh)	0.0304	0.0067	0.0581	0.0140

**TABLE 4.16. Reference Rate Structure Statistics;
Industrial Flat Demand and TOU Energy Charges**

<u>Characteristic</u>	<u>Baseline</u>	<u>Low</u>	<u>High</u>
Summer months	May-Sept	May-Sept	May-Sept
Winter months	Oct-April	Oct-April	Oct-April
Peak days	Mon-Fri	Mon-Fri	Mon-Fri
Summer peak hours	8am-8pm	8am-8pm	8am-8pm
Winter peak hours	8am-8pm	8am-8pm	8am-8pm
Summer demand (\$/kW)	9.82	6.77	12.87
Winter demand (\$/kW)	8.33	6.45	10.21
Summer peak energy (\$/kWh)	0.0443	0.0443	0.0443
Summer off-peak energy (\$/kWh)	0.0301	0.0301	0.0301
Winter peak energy (\$/kWh)	0.0428	0.0428	0.0428
Winter off-peak energy (\$/kWh)	0.0304	0.0304	0.0304

TABLE 4.17. Composite Rate Structure Statistics;
Industrial TOU Demand and Energy Charges

<u>Characteristic</u>	<u>Average</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Standard Deviation</u>
Summer months	May-Sept	April	November	-
Number of summer months	5	4	8	2
Winter months	Oct-April	October	May	-
Number of winter months	7	4	8	2
Peak days	Mon-Fri	Mon-Fri	Mon-Fri	-
Number of peak days	5	5	5	0
Summer peak hours	8am-8pm	7am	11pm	-
Number of summer peak hours	12	7	16	3
Winter peak hours	8am-8pm	6am	11pm	-
Number of winter peak hours	12	3	16	4
Summer peak demand (\$/kW)	7.59	2.34	17.18	4.15
Summer off-peak demand (\$/kW)	0.45	0.00	3.37	0.94
Winter peak demand (\$/kW)	6.22	2.50	9.06	1.93
Winter off-peak demand (\$/kW)	0.45	0.00	3.37	0.95
Summer peak energy (\$/kWh)	0.0470	0.0207	0.0836	0.0196
Summer off-peak energy (\$/kWh)	0.0285	0.0059	0.0582	0.0141
Winter peak energy (\$/kWh)	0.0437	0.0173	0.0805	0.0201
Winter off-peak energy (\$/kWh)	0.0289	0.0059	0.0582	0.0150

**TABLE 4.18. Reference Rate Structure Statistics;
Industrial TOU Demand and Energy Charges**

<u>Characteristic</u>	<u>Baseline</u>	<u>Low</u>	<u>High</u>
Summer months	May-Sept	May-Sept	May-Sept
Winter months	Oct-April	Oct-April	Oct-April
Peak days	Mon-Fri	Mon-Fri	Mon-Fri
Summer peak hours	8am-8pm	8am-8pm	8am-8pm
Winter peak hours	8am-8pm	8am-8pm	8am-8pm
Summer peak demand (\$/kW)	7.59	3.44	11.74
Summer off-peak demand (\$/kW)	0.0	0.0	0.0
Winter peak demand (\$/kW)	6.22	4.29	8.15
Winter off-peak demand (\$/kW)	0.0	0.0	0.0
Summer peak energy (\$/kWh)	0.0470	0.0470	0.0470
Summer off-peak energy (\$/kWh)	0.0285	0.0285	0.0285
Winter peak energy (\$/kWh)	0.0437	0.0437	0.0437
Winter off-peak energy (\$/kWh)	0.0289	0.0289	0.0289

5.0 INNOVATIVE RATE STRUCTURE CHARACTERIZATION

A literature review was conducted to identify innovative rate structures being developed by utilities that might be commonly implemented in the future. Key sources of information are identified in the references (Ackerman 1989; Electric Power Research Institute 1989; Caves, Herriges, and Windle 1988; Fischer, Malko, and Wallace 1988; Wallace 1987). Several innovative rates are being used or considered by utilities. The information sources reviewed focused on the following rate structure classifications:

- constant discount for firm service
- indexing
- real-time pricing
- interruptible/curtailable rates.

Two of the four rate structures (real-time pricing and interruptible/curtailable) would promote or allow advantageous use of thermal energy storage equipment. Each of the rate structures is briefly described in the following paragraphs.

5.1 CONSTANT DISCOUNT FOR FIRM SERVICE

Constant discount for firm service is a discount for a firm load commitment offered to a customer or class of customers to promote economic development in distressed areas or to maintain a large customer that has lost business. The discounted rate is constant over a period of time (e.g., 1 year) and may be phased out over a longer period of time (e.g., 5 years).

Constant discount for firm service is a widely used rate. Of the 170 rates presented in Ackerman (1989), 78 are constant discount rates. Fifty-nine of the utilities offering constant discount offer the rate for economic development. Eleven utilities offer the discount rate to retain distressed industry loads. The remaining eight utilities provide discounted rates for load management, competitive load retention, or for self-generation deferral.

Because constant discount for firm service provides a flat rate for a firm load, the use of thermal energy storage is not encouraged. Companies

under this rate will pay a fixed price regardless of the timing of consumption.

5.2 INDEXING

Indexing adjusts the normal electric rate by an "index" that is calculated based on the profitability of the customer or on some competitive price index. Indexing, like constant discount for firm service, is provided to retain distressed industries on an exception basis. Only three cases of indexing are reported in Ackerman (1989) with prices adjusted according to the price of copper in Arizona, the price of aluminum in Ohio, and a competitive price index based upon 24 companies in Illinois. Indexing varies slowly over time. Therefore, thermal energy storage could not be beneficially applied.

5.3 REAL-TIME PRICING

Real-time pricing is an extreme application of time-of-use. Real-time pricing varies the price of electricity based on the actual cost to supply the load. Prices usually vary hourly with the prices released to the customers anywhere from 5 minutes to 1 day in advance. Price is a function of the utility forecasted hourly marginal charge and the customer contribution to the utility fixed cost.

Real-time pricing is currently (as of mid-1989) offered by only a few utilities. Innovative utilities offering real-time pricing include Jersey Central Power and Light, Niagara Mohawk, Pacific Gas and Electric, Southern California Edison, Tennessee Valley Authority, and Georgia Power. Georgia Power was the only case noted where residential customers were offered real-time pricing. Some other utilities offer real-time pricing as an add-on to time-of-use or interruptible/curtailable rates. Real-time pricing is usually offered to shift customer loads from high-cost peak times, but it can also be offered to sell low-cost marginal loads at reduced rates during off-peak times.

Real-time pricing is highly variable over time and, therefore, is a prime candidate for promoting thermal energy storage. A customer could plan

to use stored energy during periods of high prices. Unfortunately, because real-time pricing is so variable and dependent on the current conditions, quantitative pricing details were unavailable in any of the literature reviewed. The literature only provided a description of the customers, details on how and when prices were announced, and information as to what portion of a customer load was covered under real-time pricing. For these reasons, it was not possible to develop a reference real-time pricing rate structure. Future analyses involving these types of rate structures will have to incorporate their probabilistic nature.

5.4 INTERRUPTIBLE/CURTAILABLE

Interruptible/curtailable rates provide customer discounts in the form of lower rates or credits for permission to curtail/interrupt load during periods of peak demands. Rates are dependent on the number of contracted interrupts/curtailments, contracted length of interrupts/curtailments, warning time, and contract lengths. The rate can be voluntary or nonvoluntary. Penalties are usually imposed as part of the nonvoluntary rate when the customer fails to interrupt/curtail upon request. The three major categories of interruptible/curtailable rates are:

- Industrial/Commercial Interrupt - the customer agrees to interrupt total demand upon request. Most of the interrupt programs have a penalty for noncompliance even if only to charge real-time prices for the interruptible loads.
- Industrial/Commercial Curtailable - the customer contracts for a firm load and a curtailable load. The curtailable load is everything in excess of the firm load. The rates charged are sometimes only for the curtailable load and sometimes for the entire load, depending on the utility. Most of the nonvoluntary rates impose a penalty for not complying to requested curtailments.
- Residential - the customer agrees to turn prearranged equipment (usually water heating, space heating, and/or space cooling) off during periods of peak demand. The utility has direct control over the equipment in most cases.

Tables 5.1 and 5.2 provide an overview of interruptible/curtailable rates. Many utilities offer some form of interruptible/curtailable rates. However, the literature reviewed often provided incomplete rate information. Table 5.1 displays industrial and commercial rate data from Caves, Herriges, and Windle (1988). Table 5.2 displays residential rates. Other innovative utilities, based upon reference to their efforts in the literature reviewed, include San Diego Gas and Electric and Niagara Mohawk Power.

To qualify for interruptible/curtailable rates in the commercial/industrial class, the customer must be willing to curtail several hundred to more than 1000 kW of demand. A 1000-kW curtailment agreement is typical. The interrupt period generally corresponds to the utility's peak demand period, or about 12 hours a day. The interrupt warning period varies considerably from less than 1 hour up to 1 full day; 1 to 2 hours is typical. The monthly credit was found to average about \$4/kW curtailed.

The variable features of interruptible/curtailable rates for the residential class make it difficult to discuss average conditions. Control of water heating equipment is common, as is heating and cooling equipment, and various combinations of these three equipment types. Utilities are usually allowed to curtail or interrupt service during the peak demand period, which may last up to 14 hours. For water heating control alone, energy rates were reduced by \$0.02 to \$0.04/kWh of water heating energy or a fixed credit of \$2 to \$5 per month was offered. Energy rate reductions for combined control of water heating and space heating equipment were similar. Credits for allowing utility control of heating and cooling equipment ranged from \$2 to \$16 per month, with higher credits associated with longer periods of utility control. The monthly credit should be roughly equivalent to the product of the utility's demand charge and the expected kW load reduction occurring during the peak demand period. To simplify metering requirements, most utilities apparently assume a standard size for residential heating, ventilation, and air conditioning and domestic hot water equipment.

TABLE 5.1. Industrial/Commercial Interruptible/Curtailable Rates

<u>Utility</u>	<u>Minimum Load Curtailed, kW</u>	<u>Interrupt Period, hr/day</u>	<u>Warning Period, hr</u>	<u>Monthly Credit, \$/kW</u>
Alabama Power	500	8	24	2.43
Baltimore Gas & Electric	2000	12	2	2.75
General Public Utilities Service	400	12	1	4.12
Illinois Power	1000	12	2	8.45
Pacific Gas & Electric	500	8	0.5	1.85
Public Service Electric & Gas of New Jersey	500		1	3.15
Wisconsin Power & Light	1000		1	4.55
Northern States	500		1	2.95
Public Service of Colorado			0.5	5.07
Iowa Electric Power & Light	1000			8.00
Average	822	10.40	3.67	4.33
Minimum	400	8.00	0.50	1.85
Maximum	2000	12.00	24.00	8.45
Standard Deviation	480	1.96	7.21	2.16

TABLE 5.2. Residential Interruptible/Curtailable Rates

<u>Utility</u>	<u>Equipment Controlled</u>	<u>Interrupt Period, hr</u>	<u>Rate Reduction, \$/kWh</u>	<u>Monthly Credit, \$</u>
Pennsylvania Power & Light	Water heating	10	0.0211	
Otter Tail Power	Water heating			2
Otter Tail Power	Water heating	14	0.0081	
Otter Tail Power	Water heating and heating	14	0.00985	
Otter Tail Power	Water heating and heating	24	0.0184	
Otter Tail Power	Water heating and heating	14	0.02025	
Minnesota Power	All		0.01985	
Indiana-Michigan	Water heating	14	0.03758	
Florida Power	Heating			3
	Cooling			2
Florida Power	Heating			9
	Cooling			6
Florida Power	Water heating	5		4.5
	Pool			3.5
Baltimore Gas & Electric	Cooling			10
Wisconsin Electric	Water heating			4.5
Southern California Edison	Cooling			16.2

6.0 ELECTRICITY ESCALATION RATES

The electric rate data presented in the above sections was current as of 1989. Cost escalation factors must be applied to electricity cost estimates prepared from these rate structures to project cost estimates in future years. Electricity end-use price projections presented in the Energy Information Administration's (EIA) Annual Energy Outlook (1990) for the years 1989 through 2010 were used to develop the relative price schedules presented in Table 6.1. The relative prices and average annual escalation rates are based on constant 1989 dollars that exclude the effects of general inflation. The relative price schedules were developed from EIA's base-case forecasts. Electricity price forecasts based on alternative world oil price scenarios are not significantly different.

TABLE 6.1. Future Relative Electricity Rates

<u>Sector</u>	<u>Year</u>						<u>Average Annual Escalation Rate 1989 - 2010</u>
	<u>1989</u>	<u>1990</u>	<u>1995</u>	<u>2000</u>	<u>2005</u>	<u>2010</u>	
Residential	1.000	0.990	0.999	1.024	1.059	1.077	0.35%
Commercial	1.000	0.990	0.996	1.024	1.062	1.082	0.38%
Industrial	1.000	0.990	0.979	1.017	1.075	1.104	0.47%

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