Modeling the Potential Savings of an Air Conditioner Reset Demand Response Program

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Executive summary
This report discusses the results of a model that simulates Allegheny Powers Electricity Price Response Pilot Program. This demand response program increases the setting on the thermostat of residential customer's air conditioners when the wholesale market price reaches a certain minimum value. This way the program reduces the electricity demand for that period. The model is written in Visual Basic 6.0 and makes use of Excel to import historical data from and export output into. The simulations showed that the program reduces the fluctuation in a customer's bills for the period that the program is active. Whether this is true for the entire year depends on whether the customer's demand is heating dominated or cooling dominated. Results also show that though the program is successful from a reduction of peak demand point of view this currently is not the case for the utility: the economical success depends on the overhead costs associated with the installation and operation of the hourly demand meter. With advancements in the technology and economies of scale these costs should go down and the program should become economically feasible.

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Introduction

Utilities are looking for ways to reduce the peak demand. In this section I'll explain why and also why demand response is considered a good option.

The electricity sector in the United States is currently undergoing significant restructuring of its regulation. This has not affected rural cooperatives or municipally-owned utilities, but has had a big effect on private power companies, which produce about three quarters of all electricity in the U.S.In the past the utilities were state regulated. Utilities were guaranteed a small profit, and thus costs were always covered by the benefits. A key aspect of the restructured industry has been the development of wholesale power markets, in which the price of electricity can vary greatly. In most states private utility companies are still bound by state regulations as far as a rate cap is concerned: the electricity rate they charge their customers may not exceed a certain limit. There are however times when this rate cap doesn't cover the costs at which the utility buys their electricity in the wholesale market.

In the current electricity sector, most distribution companies don't own enough generating capacity to meet the peak demand in their service area. They may have been required to sell off their generation assets as a part of restructuring, or may simply not own enough peaking capacity to meet load on peak demand days. For the demand that exceeds this base load, the utility is forced to buy electricity on the wholesale market. On the wholesale market the prices go up when demand is high. This is not only due to the economic principle of supply and demand but also because the higher the demand the higher the production cost of each extra unit of electricity.

The generators that produce electricity to meet base load are operating 24 hours per day. When demand is higher than base load, new generators are put on line. These shoulder units operate a large part of the day, but are turned on and off on a daily basis. For even higher demand, the so-called peak-demand, even more generators have to be called upon. These peaking units are operated only a few hours per day. The price per unit of electricity produced for these peaking units is considerably higher than those of base load and shoulder units because of three reasons:

First, since the capital of a generator can only be written off over the period that the generator is operational, in the case of peaking units the capital per unit of electricity generated is very high.

Second, these generators are more often than not old gas or oil fired generators. The fuel prices for gas and oil are considerably higher than those for other fuels, like coal, new gas, hydro, and nuclear.

Third, the efficiency of these old gas and oil fired generators is lower than that of the generators used for base and shoulder load, which means more fuel is needed per unit of electricity output.

Because of this higher price per unit of electricity for the top of the peak demand, the average price of electricity during peak periods is higher than during off peak hours. As a result the price at which the utility generates or buys electricity varies from hour to hour.

However, state regulations require utilities to sell this electricity at a flat rate. This prevents the utilities from passing the varying prices on to their customers. As a result a utility typically make less or even loses money at times when demand is at a peak. It is therefore in the interest of the utility to have a lower and shorter peak demand. Another reason for this so called peak shaving is adequacy (a form of reliability). Adequacy relates to the existence of sufficient facilities within the system to satisfy the consumer load demand.[1] By lowering the peak demand, this peak is more easily met. This means the adequacy requirement goes down, which means lower costs.

A way of lowering the peak demand is demand response. A definition of demand response is given by the Peak Load Management Alliance:

Demand response in electricity is defined as load response called for by others and price response managed by end-use customers.

By means of the price response some of the volatility of the prices in the wholesale markets is passed through to the retail market. A price response can be real-time pricing, dynamic pricing, coincident peak pricing, time-of-use rates and demand bidding or buyback programs. The load response can be a variety of actions: direct load control of equipment (e.g. air conditioners), partial or curtailable load reductions, and complete load interruptions. Another way of saying it is that demand response occurs when customers reduce or shift electricity use in response to signals or to programs specifically designed to induce such actions.[2] Demand response programs are most often focused on customers whose demand is flexible and changeable at the customer's own discretion. The electricity they use is low-value-added and they are thus easier convinced to reduce demand during peak demand periods.[3]

In the past, consumers had no incentive to react to the changes in prices, because for them there were no changes. The utilities were not allowed to pass the fluctuations through to their customers and so the rate these customers face was always the same, regardless of the actual price of generation. Now the price situation is still the same, but utilities are no longer guaranteed that costs are recovered. So now they have an interest in controlling the costs. The way they try to do so is by giving customers an incentive to change their demand, by either reducing it or switching it from a peak period to an off peak period. This changes the relationship between the utility and its customers, which up till now could be seen as two one-way streets: the utility provides electricity on demand, the customer pays the bill sent by the utility. Now the customer can have a more active role. Most of these demand response programs involve new devices in the home. Customers have to operate these themselves. So far hardly any research has been done on this new human-technology interaction in the electricity sector, and not much is known about it. To get a grasp of the real potential of demand response, more research has to be done in this field. Research can also show what different forms of DR do for customers and whether the results are the same for every customer. This will make it easier for regulators who have to protect the public to make decisions about DR programs. Now the danger is that they will not allow changes in fear for negative results.

[1] Billington, R. and L. Wenyuan. (1994)
[2] Malme, R. et al (2002)
[3] Sioshansi, F. and A. Vojdani (2001)

In order to get a better idea of the different types of DR available, I did some preliminary research on what has already been done. One of the programs is an air conditioner reset program that Allegheny Power started in 2001. This overview is given in the first chapter. The second chapter further discusses the workings of APs air conditioner reset DR program. I made a model based on this program, which is discussed in Chapter 3. After this chapter come the results of the model (Chapter 4). Chapter 5 is a discussion of ways to improve both the model and the actual DR program, and is followed by suggestions for future research (Chapter 5).

What has already been done / What is being done?

Before restructuring, several efforts were made to change customer's demand. These program were then called "Demand Side Management" or DSM. Since utilities were guaranteed to recover their costs, they had no real interest in getting succesful results. Now, because regulators don't guarantee retrieval of made expenses any more, the utilies really have something to gain from succesfull demand response (DR). These DR programs causes a sharp decrease in the cost of service because it lowers the amount of expensive peak power that must be purchased. It also give a signal to electricity producers that when price of peak power goes up too much, demand will go down. This works even when the demand is not reduced but only switched to an off peak period, because then purchasing of the same amount of power is lower. In the long run, DR programs cause the system to have flatter peaks and thus less capacity will be needed to serve them, reducing the cost of the system. In addition, DR programs can reduce overall demand somewhat.

These programs differ in several characteristics, like whether the utility or the customer changes the demand, and the type of incentive to change demand (information and/or monetary reward). In this section I will discuss four programs, which can be placed in different parts of the spectrum made up by the aforementioned characteristics. The programs that will be discussed are Puget Sound Energy's (PSE) Personal Energy Management program, Avista Utilities (AU) All Customer Electric Energy Buy-Back Program, the Baltimore Gas and Electric Company's (BGE) Energy Saver Switch program, and Allegheny Powers (AP) Electricity Price Response Pilot Program. Because of the residential focus of this report I will only look at the residential customers although some of these programs involve(d) industrial customers as well.

PSE first conducted an experiment where it only provided information by means of online information about a participant's electricity use of the last seven days. The participants, a total of 150,000, were billed according to a price structure with two on peak and two off peak periods. The result of the program was a 5% reduction in electricity use.[4]

After this PSE started its *Personal Energy Management program*, which consisted of charging the participants with time of day pricing (also called time of use or TOU pricing) and providing online information on electricity use. Through 2001, 300,000 residential customers were participating in this PEM program. The time of day pricing has four periods and is in effect Monday through Saturday. Peak rates: are charged from 6am to 10am and from 5pm to 9pm, a mid-day shoulder rate from 10am to 5pm,

[4] Pugit Sound Energy website (2001)

and a low off-peak rate from 9pm to 6am and one for Sunday (see figure 1).[5] PSE claims the program (which combines both information and pricing) to be responsible for a 5 to 6% shift from on peak to off peak consumption, and a 85% satisfaction among participants (9% dissatisfation). One of their surveys reports that 90% of the customers that have time of day pricing adjust their energy consumption. The Personal Energy Management program is still running and PSE is trying to get more people to participate.[6]

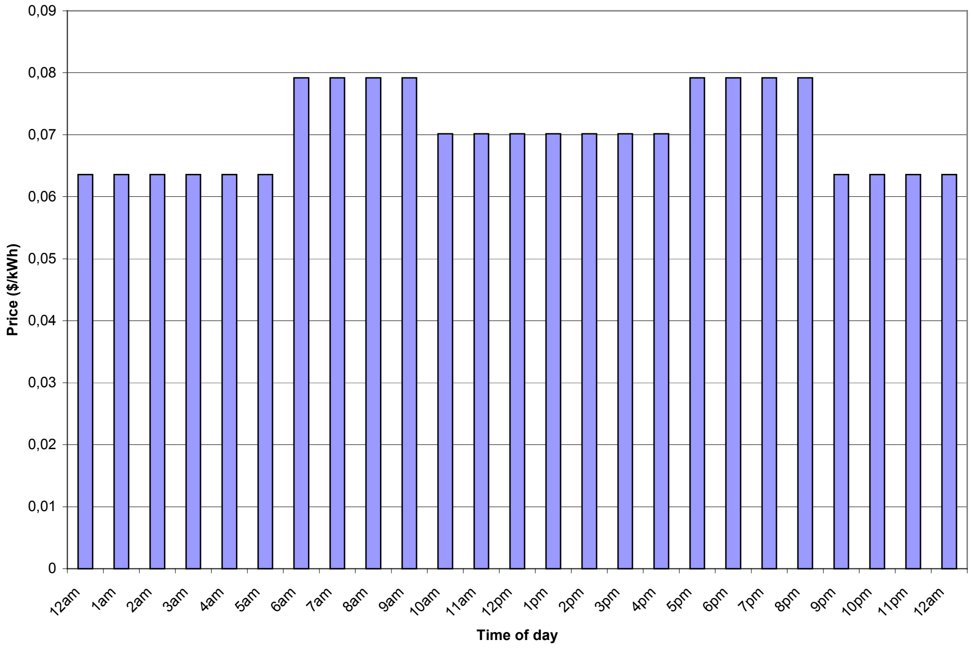

Figure 1 PSEs time of day price distribution for Monday through Saturday.

AU's *All Customer Electric Energy Buy-Back Program* was not so much initiated to switch consumption from on to off peak periods as to reduce overall peak demand. The program was based on a monetary incentive and the customers themselves decided whether or not to participate.

Avista started the program in May 2001 because the wholesale prices for electricity were about ten times higher (at $475/MWh) than the rates they were allowed to charge. To reduce the losses they were enduring, AU gave their customers 5 cents for each kilowatt-hour saved above a 5% (of lasts years' bill) minimum. The only feedback customers got was in the way of the monthly bill, which showed the reduction achieved in the previous month. (For more about Avista's Buy-Back Program see Appendix A.)

In the beginning the utility achieved their goal of reducing losses. However, all through the duration of the program the wholesale market prices went down and in the end were lower then the 5 cents per kilowatt-hour that they offered customers for not consuming. At this point the AU no longer benefited from the program and wanted to terminate it. For this they needed approval from the state PUCs. The Idaho Commission approved while the Washington Commission denied.

Over the course of the five months that the program lasted the percentage of customers achieving the threshold rose from 35% the first month to a high of almost 68% in August after it went down slightly and ended with 57% in the last month. The

[5] Pugit Sound Energy website (2001)
[6] Brandon, C. (2002)

customers received a total of almost $4.2 million for a total reduction of almost 83.6 million kilowatt-hours on top of the five-percent threshold. In the sense of reduced consumption, the monetary incentive was a big success.[7]

The third program that will be mentioned is the *Electricity Price Response Pilot Program* that Allegheny Power started in 2001. AP installs a programmable thermostat for the air conditioner. This thermostat looks like a regular programmable thermostat with an extra indicator light. They then send a signal to this thermostat when wholesale electricity prices are at premium levels, changing the setting upwards. The signal also turns on a light on the thermostat to inform the customer that a price event is occurring. Now the customer has a choice: he/she can either leave the setting the way the utility set it and collect a monetary incentive or they can override the signal. In the Electricity Price Response Pilot Program the customer has the choice whether to participate or not but the utility decides when events happen.[8]

The last program being discussed here is an example of a program where participants have no say over the way the program is run once they sign up for it: the *Energy Saver Switch* program of the Baltimore Gas and Electric Company (BGE). The main objective is to lower demand. The way this is achieved is to install a radio-controlled device on the participants' air conditioners. The device is turned on by the BGE when demand is exceptionally high. It turns the outdoor condenser unit of the air conditioning system off and on with fifteen-minute intervals. Because the indoor fan continues to run during the interruption of the condenser, air is still being circulated. During the summer participants receive $ 10 per month of their electricity bill to compensate for the inconvenience.[9]

In the summer of 2001 BGE had 243,990 Energy Saving Switches installed, which reduced total summer load by 239.1 Megawatt.[10]

The workings of APs Electricity Price Response Pilot Program

Because past DSM programs were not taken all that seriously, and demand response is a relatively new thing that has not often been done before, it is unknown what the precise effects of it are. The goal of this research is to get a better idea of the workings of an air conditioner reset DR program and to calculate the potential changes in customer bills and utility costs and benefits due to it. Before we can do that, we have to get a clear picture of how an air conditioner reset DR program works. The program that is used for this is APs Electricity Price Response Pilot Program.

The program is based on the assumption that increasing the setting on customer's air-conditioners can save electricity. A signal will be sent out when the wholesale market price of electricity is at a premium. For some wholesale electricity markets, such as the Pennsylvania-New Jersey-Maryland Interconnection (PJM), this will be the Locational Marginal Price (LMP). In order to save electricity on the air-

[7] Avista Corporation (2001)
[8] Mader, M. (2002)
[9] Baltimore Gas and Electric Company (2001)
[10] Peak Load Management Alliance (2002)

conditioner (AC), the AC has to be using electricity in the first place. This is the case when the outside temperature is sufficiently high.

This gives rise to the question: what is sufficiently high? To be able to answer this question we have to have a look at the way an AC works.

The workings of an air-conditioner

Assume it's 74^{O}F outside as well as inside the house. When the thermostat is set at 70^{O}F, the compressor of the AC will turn on to lower the inside temperature. When the inside temperature reaches 69^{O}F, the compressor will turn off. Now due to heat exchange with the outside, the temperature inside will start rising. When it reaches 71^{O}F, the compressor will turn on again until the inside temperature is down to 69^{O}F, etc. (The actual temperature band an air conditioner will cycle over can be varied.) Note that at very high temperatures, an air conditioner may not be able to reduce the inside temperature down to the lower set point (due to high heat transfer through the building's shell) and the compressor will operate continuously, holding the temperature steady at, say, 72 ^{O}F.

Three different phases can be discerned, coinciding with three ranges of outside temperature: in the first phase, when the outside temperature is lower than the setting of the AC, the compressor is not working at all. The second range starts when the outside temperature is higher than the setting. Now the compressor of the AC is working an increasing percentage of the time in order to keep the inside temperature at the setting. The upper limit of this range is the outside temperature at which the compressor has to work 100% of the time to get the inside temperature down to the desired setting. The third phase is when the outside temperature is too high for the AC to cope with; the inside temperature will continuously be above the setting, even though the compressor is working all the time.

This inside temperature distribution is shown in Figure 1 for two different temperature settings, i.e. 70 and 74^{O}F. (Note: Figures 2 and 3 are for illustration purposes only, they are not based on measured values. Also, the calculations presented here are based on the assumptions built into these figures, such as a linear response in Figure 3, and the choice of 100 ^{O}F as the point at which the compressor starts to operate continuously.)

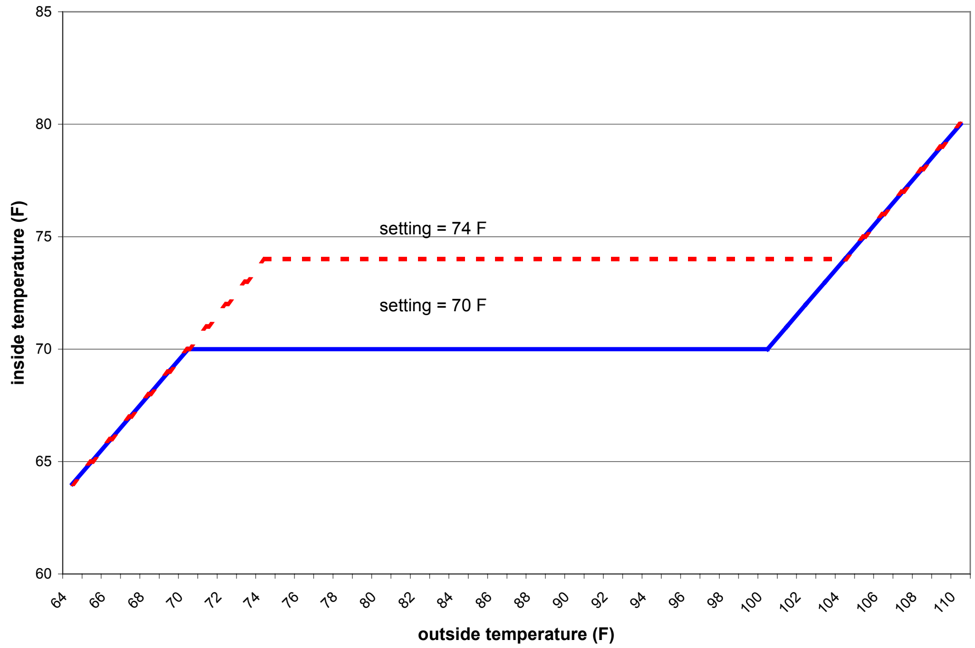

Figure 2 Illustration of temperature inside as a function of outside temperature for two thermostat settings. Figure is not based on measured values.

What are the consequences of this phenomenon for air conditioning reset DR programs? It limits when they will work. In the first temperature range the compressor is not working at all. Since the AC uses no electricity, no electricity can be saved. With the outside temperature in the second range, increasing the temperature setting will decrease the percentage of the time the compressor is working. Therefore in this temperature range electricity can be saved. Temperatures in the third range can be divided in two ranges. In the first one, starting at the temperature where the compressor has to work 100 percent of the time, increasing the setting will make it possible for the AC to reach this new setting, without working quite all the time. However when, for instance, the setting is increased four degrees, this range is also only four degrees. When the outside temperature is even higher, the AC will not reach the setting, even after the increase. From this temperature onwards, no electricity will be saved. All this is visualized by Figure 2, which shows the percentage of the time the compressor is working on the outside temperature, for the same two settings as Figure 1. Suppose 70^{O}F is the initial setting, and 74^{O}F the one after increase. For these temperature settings the range of outside temperatures for which changing the setting decreases the electricity consumption of the AC is when the dotted line is lower than the blue line in Figure 2. This means that the compressor is working a smaller percentage of the time with the increased setting than it is in the initial setting. In this case electricity can be saved when the outside temperature ranges from 70 to 104^{O}F. The savings are assumed to be approximately the same over this entire range.

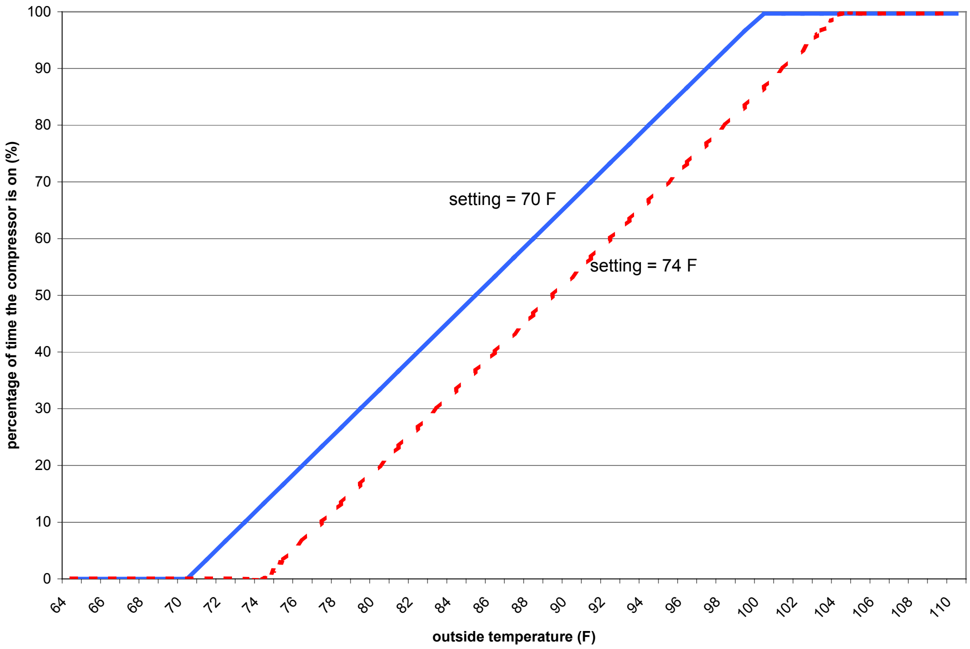

Figure 3 Illustration of the workings of the compressor of an air conditioner as a function of outside temperature for two thermostat settings. Figure is not based on measured values.

Factors influencing an event

We now know the two criteria for an event in air-conditioning reset DR programs:

- the wholesale price being paid by the utility for power, often called locational marginal price (LMP): for the utility lowering demand is only useful when the LMP exceeds the rate customers pay for it; and
- the outside temperature.

When these two criteria are met, an event is called. The effect of this event is influenced by several other factors. These factors will now be discussed by going through what happens after an event is called.

A signal that temporarily increases the setting of the thermostat is sent to all participating customers. Customers can either do nothing and that way accept the change or override it to lower it back to the original setting. The amount of electricity that is saved depends on the size of the increase. How much money the customers save depends on the rate structure the utility uses and the incentive they receive per event. For the utility the savings also depend on the locational marginal price, at which they would have bought the peak electricity.

Besides these event-specific factors, there are also other factors that have their effect for either the participants or the utility or both; the one-time costs of installing the hourly meter, the costs for operation and maintenance of this meter, and the one-time incentive customers receive for joining the program.

To summarize, the success of the program depends on several factors, which can be divided in four different types: factors directly related to the program, technical factors, factors related to the customers, and external factors.

Program factors:
- cost of installing the hourly meter;
- cost of operation and maintenance of the meter;
- the incentive customers receive for joining the program;
- the incentive customers receive for accepting each event;
- the increase in setting that a signal causes;
- rate structure.

Technical factors:
- The standard temperature setting of the thermostat;
- The maximum differential between inside and outside temperature at which the air-conditioner still meets the set temperature.

Customer factors:
- total number of customers;
- fraction of customers that participates in the program (participation rate);
- fraction of events that gets accepted by participants (acceptance rate);
- the individual demand.

External factors:
- outside temperature;
- wholesale price, or locational marginal price (LMP).

Differences between customers

Thermostat setting

Earlier in this chapter the working of an air-conditioner was explained. In this explanation 70^{O}F was taken as the standard setting. But what if a customer doesn't have 70^{O}F as his or her standard setting?

Then the usable range of outside temperatures will be different. For example, a shift in setting of 5^{O}F will cause an equals shift in the range; so with a setting of 75^{O}F the range will be 75 to 109^{O}F. As a result, for consumers that have their thermostat set at a higher temperature, outside temperature has to be higher in order to save electricity.

Allegheny Power has sent out a questionnaire in which they ask at what temperature people have set their thermostats. In table 1, the distribution of customers over five temperature ranges is given in both absolute numbers and percentage of the total. In total, 222 people that have a programmable thermostat responded.

Taking the data in the table as a valid distribution of all participating customers has the following implications for the model: with an outside temperature of 70^{O}F, savings can be achieved at 32% of all participants, since it's not warm enough for the other customers' air-conditioners to be working yet. At higher outside temperatures of 75, 80 and 85^{O}F, the percentage of customers that can save energy is 74, 98 and 100% respectively.

Table 1 Distribution of thermostat settings over customers.

Setting	Absolute	Percentage[11]
≤ 70	74	32
71 – 75	92	41
76 – 80	54	24
81 – 85	4	1.8
86 –	0	0

[11] The percentages don't add up to 100% due to rounding off.

Demand

Different customers have different demands. For instance, a two-person household in general has a higher electricity demand than a one-person household, e.g. because of more laundry. Because of this difference the overall influence of the program on a customers electricity demand will be different for every customer.

The model

The model allows for estimations of the energy and economic effects of the Allegheny Power DR program. It is written in Microsoft Visual Basic 6.0 and makes use of Microsoft Excel to retrieve historical data (LMP, temperature and demand) and to write the results.

The model simulates the AP air conditioning reset DR program for the year 2001. First, various parameters (discussed below) are set to define a model run. The model then determines which hours in 2001 would result in an 'event' , based on the criteria of LMP and temperature. Then, for the hours when the criteria for calling an event are met, the model calculates the potential savings, based on the demand data and the factors discussed earlier. These savings are calculated in both kilowatt-hours and dollars, for both the utility and the customers. Several different features of the DR program (such as the electricity tariff) can be varied manually to perform sensitivity analyses.

The data

Before actually feeding data into a model, it is good to have a close look at this data. In this case, it makes sense to do a preliminary examination of both the outside temperature and the Locational Marginal Price (LMP), because these are the two parameters that determine whether an event is called or not. It also seems wise to look at the data that is the biggest parameter for the size of the savings per event: the demand data. A preliminary examination gives a rough indication of the results that can be expected. Also, a preliminary examination might show that it is of no use to run the model for some period(s) because either LMP or the outside temperature does not reach the minimum level required for an event. By reducing the number of data points to be run by the model, processing time can be saved without losing important information.

Criteria for an event

Both the outside temperature and the Locational Marginal Price (LMP) have to exceed a certain value for an event to be called. These minimum values are 70^{O}F and 100 $/MWh. When only one meets the minimum value while the other is below its minimum value, no event is called. It thus makes sense to find out for which hours of 2001 both criteria are met.

The LMP used for this model are the hourly integrated real-time LMP values in dollars per megawatt-hour for PJMs Western Hub for the year 2001.[12] This is the price Allegheny Power pays for the peak demand and is thus the amount of money saved for each megawatt-hour not spent. All hours, 103 in total, when the minimum value for LMP is met are contained in the period from January 3rd till August 8th.

[12] PJM Interconnection L.L.C.

The historical temperature data that was used for this model is not the optimal data. It should be the temperature at the same place as the demand data is from. This data however was not available at the time of this project and an approximation had to be used. This is the hourly mean dry bulb temperature in round degrees Fahrenheit for the Pittsburgh International Airport for the year 2001.[13] The period that encompasses all hours with a temperature of 70^{O}F or higher starts at February 25th and ends on December 5th. 1741 hours meet the minimum value for temperature.

When these two datasets are analyzed at the same time the period that contains all the hours when both criteria are met at the same time turns out to be from April 9th till September 3rd, a 148 days period. These results are shown in table 2.

Table 2

Hours with: LMP ≥ 100 $/MWh	Temp. ≥ 70^{O}F	Period in Julian hours (out of 8760)	in dates Start	End	Length (in days)
103 (100%)		43 – 5823	01 / 02	08 / 31	242
	1741 (100%)	1335 – 8128	02 / 25	12 / 05	284
97	97	2364 – 5901	04 / 09	09 / 03	148

Demand data

The original demand data provided by Allegheny Power is hourly data for 63 different residential customers for the year 2001 who had high-resolution meters installed and for whom demand data at one-hour increments was available (although there were some missing data points). These customers had an average demand varying from 0.394 to 3.69 kilowatt-hour per hour, with a standard deviation varying from 0.40 to 3.9. The average and standard deviation are positively correlated ($p < .000$). A distribution for both is given in Figure 4.

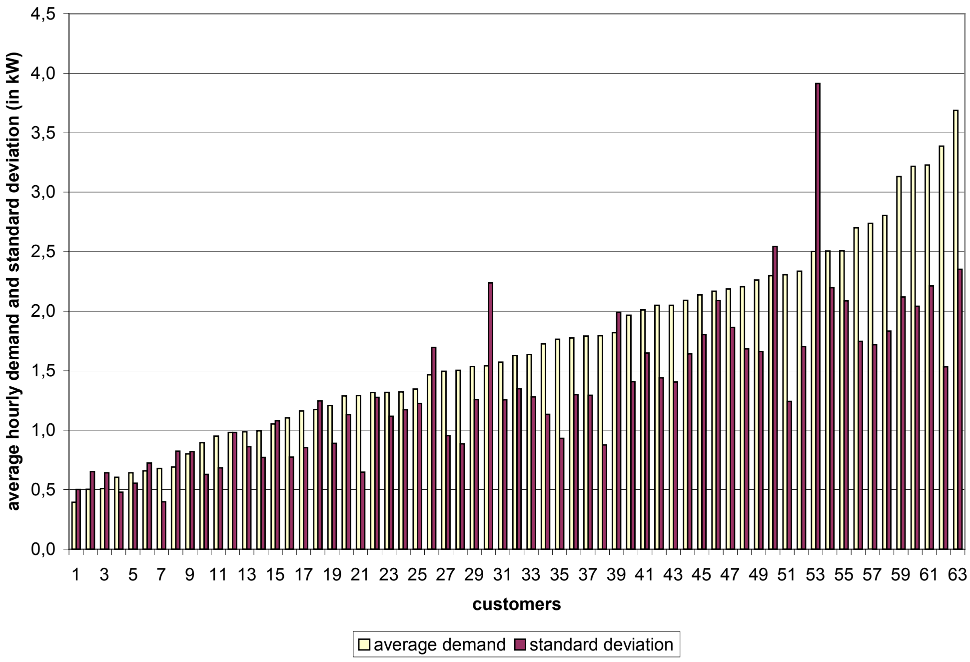

Figure 4 Average hourly demand and standard deviation for all 63 customers.

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Running the model for all these customers would take a lot of time. Instead it is also possible to run the model for a customer with an average demand and for two customers with extreme demands; one minimum demand and one maximum demand. This varying of values is called a parametric analysis and gives a good picture of the savings that can be expected. When you know the percentage of customers whose demand can be approximated by the minimum demand, and also for the average and maximum demand, you can calculate the total savings for the entire customer base based on the parametric analysis. The three customers used for this parametric analysis are: Annie, whose average electricity demand is minimal (0.394 kWh); Barend, who has an average electricity demand (1.73 kWh); and Carla, whose electricity demand is maximal (3.69 kWh).

For these three customers the hourly data is incomplete, just like for the other sixty customers. Most of the data is missing in the periods from March 3rd till April 26th and October 11th till November 26th. Because of this the model can't run for these periods. Figure B.1 in Appendix B shows the demand data for Annie, Barend, and Carla.

So now when we combine these preliminary examinations the final period for which the model is to be run is the months May through September.

Different scenarios

The model is made in such a way that many factors can be changed to define a scenario. For instance, the number of events the customer will accept and the number they will override can be varied, due to differences, for instance, in customer awareness. To test the importance of this factor, the model can be run several times and changes in energy demand or economics can be determined.

To analyze what the savings can be with different values of the factors involved, the model has to be run for different combinations of values. As was mentioned before, this is called a parametric analysis. First, the external factor minimum LMP will be changed. For these different minimum LMPs the savings will be calculated when varying the thermostat setting and the rate structure. Two rate structures are used, one flat rate of 0.0644 $/kWh and a three-tier rate structure with high and low season rates (see Table 4). All these values lead to the following 24 scenarios that will all be run for all three selected demand types:

Table 3 The different scenarios with their specific values.

Scenario	LMP (in $/MWh)	Thermostat setting (in ^{O}F)	Rate structure *
1a	100	≤ 70	flat
1b	100	≤ 70	3-tier
1c	100	71 – 75	flat
1d	100	71 – 75	3-tier
1e	100	76 – 80	flat
1f	100	76 – 80	3-tier
1g	100	81 - 85	flat
1h	100	81 - 85	3-tier
2a	90	≤ 70	flat
2b	90	≤ 70	3-tier
2c	90	71 – 75	flat
2d	90	71 – 75	3-tier
2e	90	76 – 80	flat
2f	90	76 – 80	3-tier
2g	90	81 - 85	flat
2h	90	81 - 85	3-tier
3a	80	≤ 70	flat
3b	80	≤ 70	3-tier
3c	80	71 – 75	flat
3d	80	71 – 75	3-tier
3e	80	76 – 80	flat
3f	80	76 – 80	3-tier
3g	80	81 - 85	Flat
3h	80	81 - 85	3-tier

Table 4 The prices in the 3-tier rate structure (in $/kWh).

		Summer (June-August) & Winter (December-February)	Spring (March-May) & Fall (September-November)
On-Peak	Mon-Fri; 8am-6pm	0.10103	0.08103
Shoulder-Peak	Mon-Fri; 6pm-10pm	0.06103	0.05603
Off-Peak	all other hours	0.04603	0.04603

Besides the factors that are varied, several factors stay the same for all the scenarios (see Table 5 below). It must be noted that the savings per event-hour depend on the demand in that particular hour: for customers with low demand it often occurs that their hourly demand is lower than 3 kWh. Therefor no 3 kWh can be saved by an event. When this is the case, the savings are assumed to be the total demand. E.g. when demand is 6.2 kWh or higher, the savings are assumed to be 3 kWh. When demand is 2.0 kWh, the savings are assumed to be 2.0 kWh.

Table 5 Factors that stay the same for all scenarios.

Factor	Value
Change in setting caused by event	4^{O}F
Savings per event per hour	3 kWh or lower*
Maximum differential at which the air conditioner still meets the setting	30^{O}F

Results

All 24 scenarios were run by the model for each of the three customers for the months of May through September. Appendix C contains an example of an output file that the model produces in Excel format. In Appendix D all output is comprised into three tables. The simulation runs on an hourly basis, but results in Appendix D are reported on an aggregated basis, by month and annually. Table D.1 shows the monthly demand for the three periods (on peak, shoulder peak, and off peak). Table D.2 contains the monthly bill for each customer using both the flat rate and the three-tier rate structure. And Table D.3 has all the monthly savings per customer per thermostat setting per minimum LMP, organized per period.

Before looking at the effects in kilowatt-hours and in dollars for the customer and the utility I will look at the number of hours per month for which the LMP and outside temperature both meet the criteria. These are shown in Table 6. The table already gives an indication of the differences in effect between the combinations that can be expected. When you look at the different thermostat settings, you see that with an increase in setting temperature, the number of events go down. This makes sense when you realize that a thermostat set at a higher temperature works a smaller percentage of the time (see also Figure 3). Lowering of the minimum wholesale market price (the LMP) causes an increase in events, because now the range of accepted LMPs is larger.

Table 6 Number of events per months for each combination of minimal LMP and thermostat setting.

Min. LMP:	100 $/MWh				90 $/MWh				80 $/MWh			
Thermostat setting (^{O}F):	Up to 70	71 - 75	76 - 80	81 - 85	Up to 70	71 - 75	76 - 80	81 - 85	Up to 70	71 - 75	76 - 80	81 - 85
April	9	5	3	0	12	7	3	0	16	10	3	0
May	1	1	0	0	3	3	0	0	6	5	1	0
June	0	0	0	0	0	0	0	0	3	2	2	1
July	10	7	3	3	15	12	6	5	20	17	11	8
August	40	40	32	23	43	43	35	24	51	50	42	28
September	0	0	0	0	1	0	0	0	1	0	0	0
Total:	60	53	38	26	74	65	44	29	97	84	59	37

Savings in kilowatt-hours

The first question that is of interest is how many kilowatt-hours are saved each month. Figure 5 shows the savings for Carlas for all the combinations of personal thermostat setting and minimum LMP. This figure shows us three things. First, most of the savings occur in the On peak period (8am till 6pm). Second, savings are lower when the thermostat is set at a higher temperature. And third, savings increase when the minimum LMP is lowered. All these things are true for each customer as will be shown in the next sections.

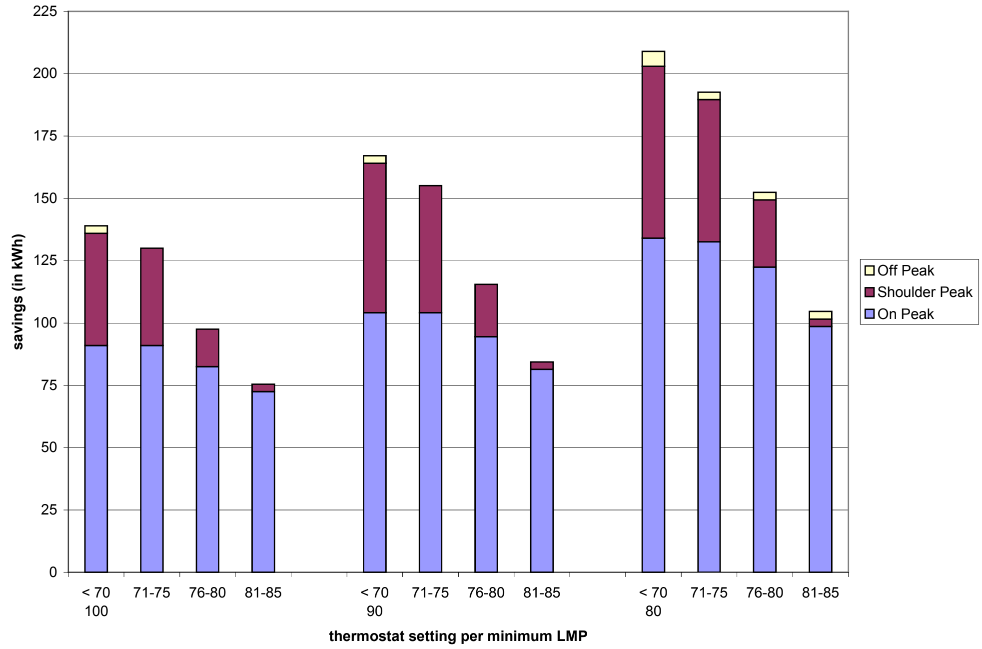

Figure 5 kWh savings over 2001 for Barend for each different combination of thermostat settings and minimal LMP.

Savings per period

Table 7 shows the savings for all three the customers for those months that were put into the model using a minimum LMP of 100 $/MWh, and a thermostat setting of up to 70^{O}F. The on peak period (8am till 6pm) is responsible for 65 to 72% of the savings. This was to be expected since demand is generally higher in this period than in the other two periods, and because it is the time of day when the temperature is highest. During the shoulder peak period about 30% of all savings are made, even though it is only four hours per weekday.

Table 7 Savings in kilowatt-hours for each customer in each of the period in the three tier structure, given a minimum LMP of 100 $/MWh and a thermostat setting of up to 70^{0}F.

Customer:	Annie			Barend			Carla		
Peak period:	On	Shoul-der	Off	On	Shoul-der	Off	On	Shoul-der	Off
May	0.2	0.0	0.0	0.5	0.0	0.0	3.0	0.0	0.0
June	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
July	1.4	0.8	0.1	15.0	12.0	3.0	15.0	12.0	3.0
August	7.2	2.7	0.0	75.5	33.0	0.0	87.0	33.0	0.0
September	0.0	0.0	0.0	0.5	3.0	3.0	0.0	0.0	0.0
Total:	8.8	3.4	0.1	91.1	45.0	3.0	105.0	45.0	3.0
Part of total savings:	72%	28%	0%	65%	32%	2%	69%	29%	2%
Part of total demand:	1.30%	0.94%	0.01%	3.03%	2.10%	0.06%	1.43%	1.03%	0.03%

Carla and Barend save more than ten times as much electricity as does Annie. This is not surprising because they also have higher demands than Annie does. It's like cleaning a muddy puddle: when it's really muddy it's easy to make it cleaner. But when it's nearly clean, making it cleaner is hard. Likewise, when demand is high, saving is easy, while when demand is already low, saving is harder. Another reason for this difference in savings is an assumption made about the savings per hour: savings per event-hour are assumed to be 3 kWh, unless demand is lower. In that last case the savings are the same as the demand. Annie's demand is often lower than this 3 kWh while that of Barend and Carla is higher. These last two thus both save 3 kWh even though their total demands are quite different (see the savings in percentages of total demand reported on the last line of Table 7).

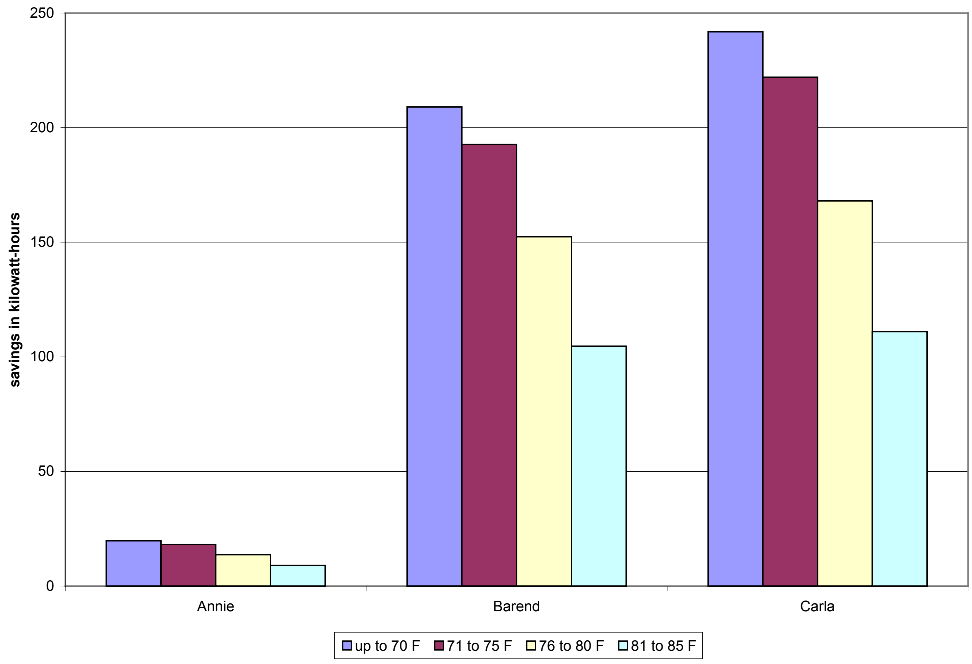

Figure 6 kWh savings over 2001 for each user for different thermostat settings at a minimal LMP of 80 $/MWh.

Savings per thermostat setting

This difference between customer-savings is also shown in Figure 6 that shows the savings in kilowatt-hours per customer per year given the different thermostat settings. What this figure clearly shows is that savings are lower when the thermostat setting is lower. This decrease in savings when the setting is increased is about the same for each customer. Another way to make this clear is to calculate the amount of savings relative to the lowest setting, up to 70^{O}F. This is done in Table 8 and it shows that the savings indeed go down with about the same percentage regardless of the size of the average demand.

Table 8 Savings in percentage of the setting 'up to 70^{O}F' at a minimum LMP of 80 $/MWh.

Setting (^{O}F)	Annie	Barend	Carla
≤ 70	100	100	100
71 – 75	92	92	92
76 – 80	69	73	69
81 – 85	45	50	46

Savings per minimum LMP

Doing the same for the different minimum LMPs, with a thermostat set at a temperature up to 70^{O}F, gives the following picture. The savings increase when the minimum LMP is lowered, again at pretty much the same rate for all customers.

Table 9 Savings in percentage of the minimum LMP of 100 $/MWh at a setting 'up to 70^{O}F'.

LMP ($/MWh)	Annie	Barend	Carla
100	100	100	100
90	129	120	122
80	159	150	158

Annual savings

The last three lines of Table 7 show the total savings per period for the entire year; the first line is in kilowatt-hours, the second in percentage of total savings, the last in percentage of the simulated total demand. Here it must be noted that, due to the missing data in the months March, April, October, and November the exact total demand could not be calculated. These months are left out of the calculation entirely. Because of this missing data, the savings in percentage of the total demand can be expected to be lower, though this is somewhat compensated by the savings in April that can not be calculated now. The overall savings are now 0.50%, 1.3%, and 0.66% for Annie, Barend, and Carla respectively. So even though Carla saves the most electricity in absolute terms, in percentages her and Annie's savings are very alike, while Barend saves most on a percentage basis. Lowering the LMP to a value of 80 $/MWh increases the current percentages to 0.79%, 2.0%, and 1.0% respectively. For every customer this is an increase in savings of 50 to 60%, which corresponds with the number of events for these months at these different minimum LMPs (51 events at 100 $/MWh and 81 at 80 $/MWh, see also Table 6).

Savings in dollars

Monthly bill

Some people hope and argue that air conditioner reset DR programs will diminish the fluctuation that characterizes customer bills. To see whether or not this is the case, the monthly bills have to be calculated both with and without the DR program. This is done using both the flat rate and the three tier rate structure. The monthly bills for Barend, who has an average electricity demand, are shown in Figure 7. His thermostat is set at a temperature up to 70^{O}F, and the minimum LMP for an event here is $100 per Megawatt-hour.

Note: no bill could be calculated for the months March, April, October, and November due to missing demand data. For the months where no events took place, the bill is the same with and without DR program.

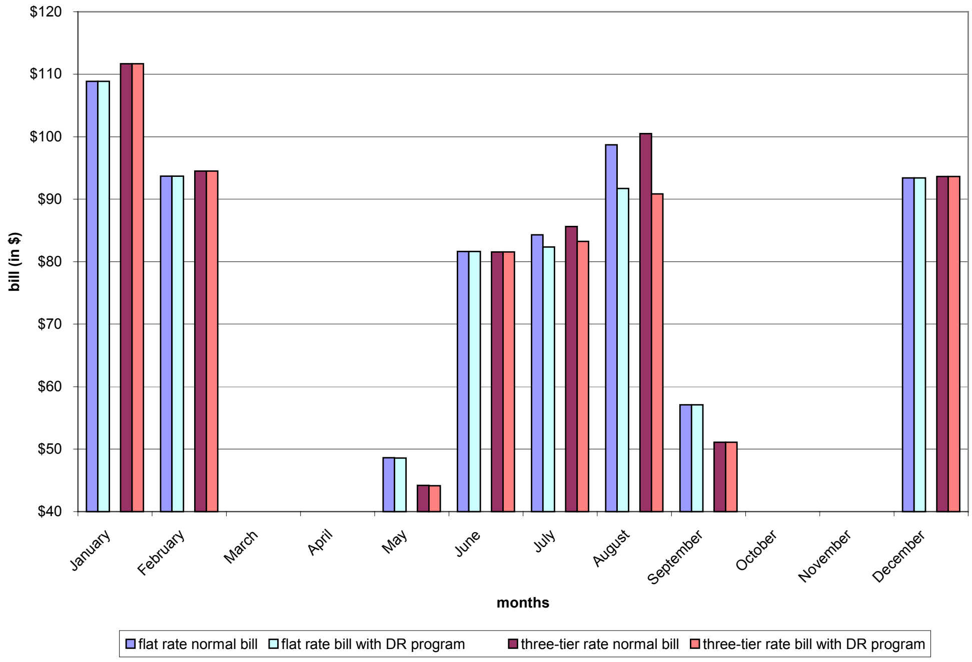

Figure 7 Monthly bills with and without DR for Barend (average demand) and the utility savings for both a flat rate and the three tier rate structure, using a 100 $/MWh minimum LMP and a thermostat setting of 'up to 70^{O}F'.

This Figure shows that for someone with an average demand like Barend the fluctuation in monthly bills is not diminished. Reason for this is that three of the four most expensive months are winter months and thus not susceptible for the air conditioner reset DR program. However, when you only look at the cooling season (May through September), the range (i.e. the difference between the most and the least expensive month) in bills has decreased. Without DR program it was $50 for the flat rate and $56 for the three-tier rate structure, with program it is only $43 and $47 respectively. The same picture arises when we look at Carla's monthly bills (Figure 8). The range goes down with $8 for the flat rate and $11 when the three-tier rate structure is used. The difference here is that for Carla the four most expensive months are all in the time that events are called. As a result of the DR program these expensive months get cheaper, and thus the range when taken over the entire year also decreases. Data shows that these results are not only true for the combination of a minimum LMP of 100 $/MWh and a thermostat setting of up to 70^{O}F, but for all combinations of LMP and thermostat setting.

The conclusion about the fluctuation has to be that when using the air conditioner reset DR program the fluctuation in monthly bills is decreased for the period that the program is active. Whether the range is decreased for the entire year depends on when usage of the customer is higher, during the heating or the cooling season.

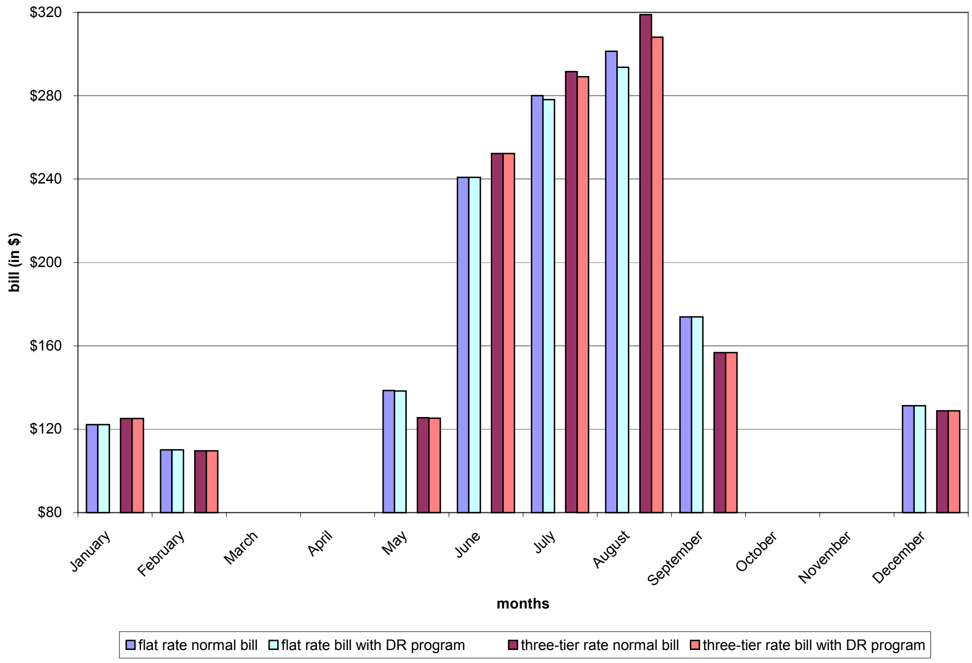

Figure 8 Monthly bills with and without DR for Carla (high demand) and the utility savings for both a flat rate and the three tier rate structure, using a 100 $/MWh minimum LMP and a thermostat setting of 'up to 70^{O}F'.

That at times the program can yield substantial savings is shown in August 2001. The savings in that month are 7.1 and 9.6 percent for Barend and 2.6 and 3.4 percent for Carla (for the flat rate and the three tier rate respectively). August 2001 was a warm month with an average temperature of 73^{O}F while the LMP was also high with an average of $48 (annual average over 2001 was $29). Periods with higher temperatures and/or higher LMP prices would yield even larger benefits.

Yearly bill

Table 10 shows the annual bills for every customer both with and without DR program and using the flat rate and the three-tier rate. The minimum LMP used here is 100 $/MWh and customers have their thermostat set at a temperature up to 70^{O}F. The bottom row of this table contains the annual savings in percentage of the customers normal bill.

Table 10 Annual bills with and without DR for each customer for both a flat rate and the three tier rate structure, using a 100 $/MWh minimum LMP and a thermostat setting of 'up to 70^{O}F'.

	Annie		Barend		Carla	
	flat	3-tier	flat	3-tier	flat	3-tier
normal	$ 160	$ 155	$ 666	$ 663	$ 1,498	$ 1,508
with DR	$ 159	$ 154	$ 657	$ 651	$ 1,488	$ 1,495
savings (in % of annual bill)	0.50	0.71	1.3	1.8	0.66	0.89

The first thing that catches the eye is the percentages in the flat rate case; these are precisely equal to the savings in percentage when looked at the kWh case. This is the way it should be since in the flat rate case every kilowatt-hour, saved or used, is worth the same 6.44 cents. More interesting in this table is the difference between the savings using the flat rate structure and the three tier rate structure. Using the three-tier rate structure increases the savings by 35 to 40%, depending on the demand.

Figure 9 visualizes Barend's savings per period for each combination of thermostat setting and minimum LMP. Again you can see that savings go down when the thermostat is set at a higher temperature and when the minimum LMP is higher.

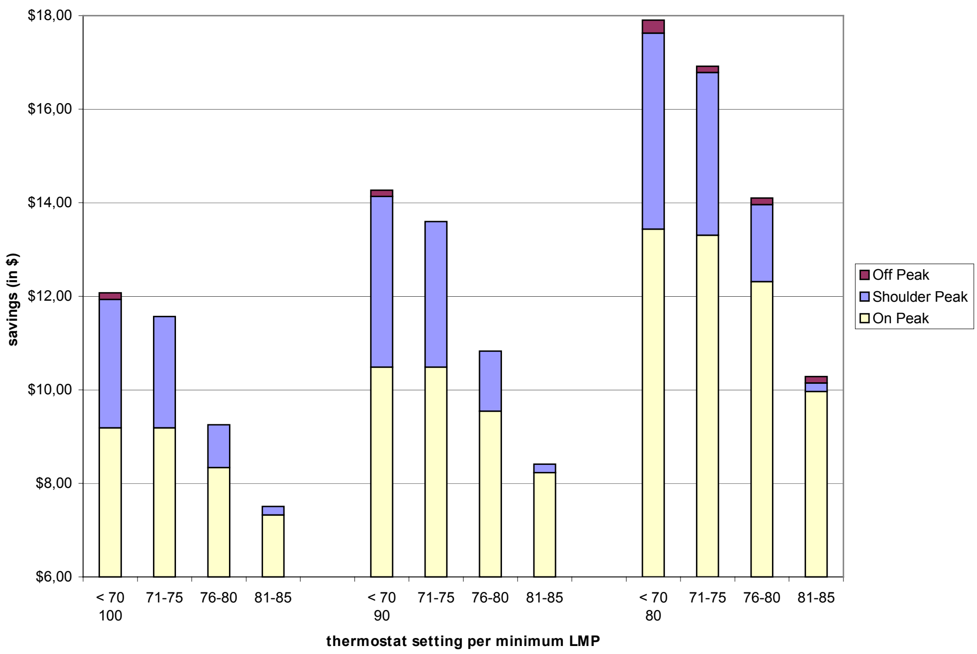

Figure 9 Annual savings for Barend for each combination of thermostat setting and minimum LMP.

Week with highest demand of the year

Demand Response programs are designed to bring down peak demand. To what extend does this specific program succeed in doing so? To answer this question I ran the model for all 63 customers for the week with the highest demand in the period that the program is operational. In this week from August 6 till 12, all customers together had a demand of 23.5 MWh, which consisted of 7.9 MWh in the on peak period, 4.9 MWh in shoulder peak, and 10.7 MWh in off peak. The average demand per customer, as well as the average savings that would have been achieved were the DR program installed are plotted in Figure 9. The total savings reduce demand by 23%. Because all savings occurred during the on peak period and the shoulder peak period, the proportional savings in these periods are far higher, 50% and 32% respectively.

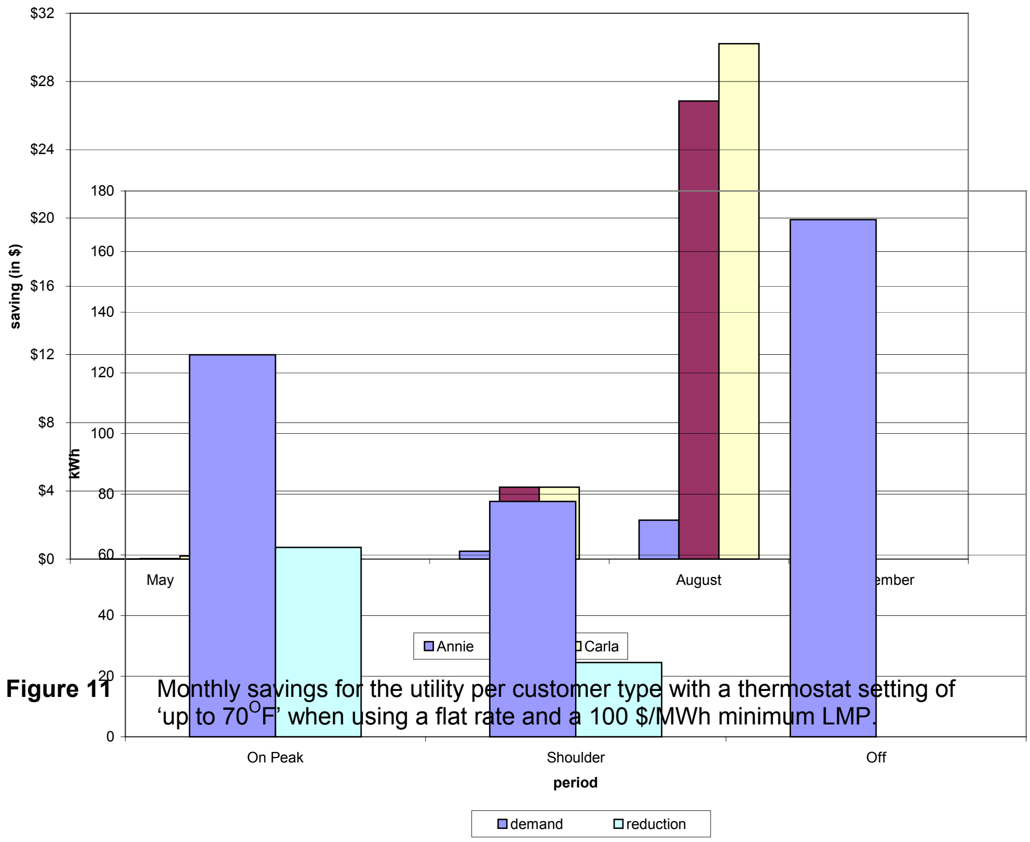

Figure 11 Monthly savings for the utility per customer type with a thermostat setting of 'up to 70^{O}F' when using a flat rate and a 100 \$/MWh minimum LMP.

Figure 10 Average original demand and reduction due to DR program in the week from August 6 till 12, 2001.

This week, where average temperature is almost 78^{O}F and average LMP is over 100 \$/MWh, shows that when both temperature and LMP are high the air conditioner reset DR program can greatly reduce peak demand.

Savings for the utility

We've now looked at the savings for all twelve different customers (3 different demand types, each with 4 different thermostat settings), for six different situations (3 minimum LMPs that can be used for 2 rate structures). But what are the savings for the utility? Figures 11 and 12 show the monthly savings that the utility achieves for each customer when using the DR program when they use the flat rate or the three-tier rate respectively. These savings are calculated by subtracting the difference in customer bill from the money saved on wholesale market costs.

What does this do for the utility implementing the air conditioner reset DR program? This depends on the utility's customer base and the other costs associated with the DR program.

First off, the total savings depend on the number of customers that join the DR program. This participation rate can be influenced by amongst others proper information and the way people are approached. Next, not all setting changes that the utility sends will be accepted by every customer. Sometimes people do mind the changes, e.g. because they have a party and want the people to be comfortable, or if there is a long series of events in a row due to a heat wave. The so-called acceptance rate is influenced by the know-how that customers have of the programmable thermostat used. If people don't know how to work the device, they will most likely just let it do its thing and by thus accept every event. When people think more about the short-term gain of comfort than they do about the long-term gain of a lower electricity bill, they will override most of the events. These and other human-technology interaction subjects have to be addressed in order to get a clear picture of the effects of the program. As was already addressed in the chapter with results the original setting of the thermostat is of direct influence to the savings a customer can achieve. Table 1 shows the distribution of thermostat settings in five-degree classes for the 222 respondents of the Allegheny Power questionnaire. This is a fair sample, but perhaps a more reliable distribution can be found when even more people are questioned. Nothing is known about the distribution of demand. When the distribution in minimal, typical, and maximum demand is determined this has to be combined with the setting distribution. This yields a final distribution of the total customers over all the twelve different customer types (e.g. minimal demand and '71-75^{O}F' or typical demand and 'up to 70^{O}F').

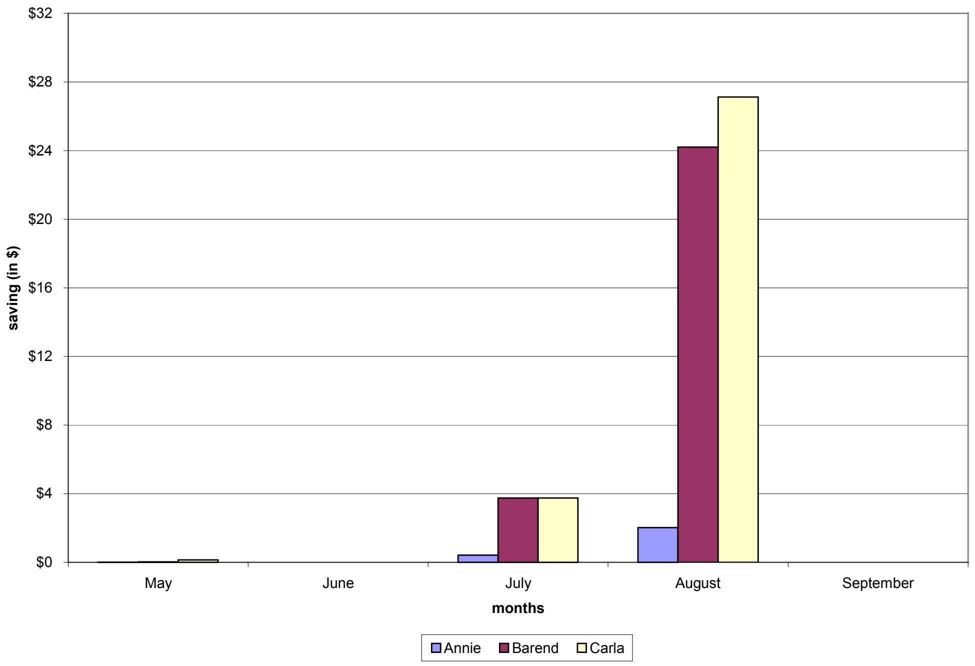

Figure 12 Monthly savings for the utility per customer type with a thermostat setting of 'up to 70^{O}F' when using the three-tier rate and a 100 $/MWh minimum LMP.

Another thing that is a major impact on the economical results of the program is the costs not related to events. Before the program can start, an hourly demand meter has to be installed at the customer's home. This costs money, for hardware and labor to install it. Besides this money that has to be spent on installation there's also the cost of annual operations and maintenance expenses (O&M), which partly reflect the software changes required at the utility's end to support the DR program. Then there often is a one-time incentive for customers to join the program. To find out whether or not a program like this is economically feasible for the utility, all these costs have to be put against the benefits of the money saved because of the lower demand. Allegheny Power provided some numbers regarding the costs of its Electricity Price Response Pilot Program.

Hourly meter:	$ 175
Labor:	$ 100
Rebate for joining:	$ 50
Annual O&M:	$ 180

The one time installation costs all add up to $ 325. Taking a five-year period to recover the invested costs at an interest rate of 6%, the annual cost of installation is $ 77.[14] Add to this the annual O&M of $ 180, and the total annual cost of the DR program comes at $ 257 per customer. As Table 11 shows, the annual savings for the utility don't come anywhere near this amount of money, and the figures in that table are only for the 'up to 70^{O}F' setting, while the other settings all have lower savings. On the one hand, the figures in Table 11 are on the low side because data for April is missing. On the other hand the data reported so far is all based on a 100% acceptance of events. I.e. all changes to the thermostat setting that are sent are accepted. Although no data is available on the acceptance and overriding of events, it can be assumed that not all changes are accepted.

With the figures reported here, the DR program is not remotely economically feasible. If however economies of scale apply to the installing and maintaining of the hourly meters, prices should when a large number of customers in the same area signs up for the DR program. Another route to an economic DR program would be through higher wholesale power prices during hot periods.

It is not unusual in DR programs for customers to receive an incentive per event they accept in the form of a rebate. The size of this rebate has to be such that the program is still economically feasible. Therefore the size of the rebate, if any, depends on the costs of installing and operating the meters, and the real total savings the utility achieves with the program. It can be argued that customers already save money because there demand goes down and thus they don't need an extra rebate. However, it might be necessary to offer a rebate per event as an extra incentive not to override but accept the change in setting.

[14] $U = P \times i / [1 - (1 + i)^{-n}]$
where U = annual cost, P = present value, i = interest rate, and n = recovery time

5. Discussion

The goal of project was to get a clearer picture as to the workings of an air conditioner reset DR program, its potential influence on customer bills and utility costs, and the benefits of it. As the first part of the previous chapter showed, the program certainly has the potential to save electricity. With the current data these savings were calculated to be around 1 percent of annual demand, with percentages of up to 10 percent in the warmest months. The financial success of the program greatly depends on the cost of installing and running the meters measure hourly demand. When the price of these devices comes down sufficiently this type of DR programs can be interesting from both the perspective of reducing peak demand as the economical perspective.

Some remarks have to be made concerning the data used for the model. Due to restrictions in available time and money some approximations had to be made. First, the temperature data used was not recorded at the houses for whose demand data was used. Since whether or not the air conditioner is turned on, and thus whether or not electricity can be saved, depends greatly on the outside temperature, it's important to use the most accurate temperature. The utility will probably also use one temperature for a bigger area, but the customers concerned should live in the vicinity of the place where this temperature is measured.

Demand data was only available for 63 customers. Picking users with a minimum, typical, and maximum demand from this small sample, as was done in this project, is a very rough approximation of actual residential demand. With a sample of 63 customers, each customers represents more than one percent of the all customers. This should be a lot less, and the sample should therefor be somewhere between 4 and 6 hundred customers.[15] Then also a valid distribution of demand can be determined (for x % of customers demand can be represented by minimum demand, y % by typical demand and z % by maximum demand). For these same customers the original thermostat setting has to be recorded. When both demand type and thermostat setting are known a possible correlation between these two can be found. I.e. maybe a bigger percentage of customers with a maximum demand has a thermostat settings at a temperature from 81 to 85^{O}F than is the case with customers with a typical demand.

In this DR program the change that is made when an event is called is an increase in setting of 4^{O}F. For the savings per hour of increased setting I used 3 kilowatt-hour, which is an estimate made by Allegheny Power.[16] The exact figure is different for each customer and depends on the size of the house and the type of air conditioner. As mentioned earlier in the model, when hourly demand was lower than this 3 kilowatt-hour, the entire demand was said to be the savings. When demand was higher than this 3 kilowatt-hour, the savings were assumed to be 3 kilowatt-hour. This has to be researched, and it has to be determined whether there is a correlation with demand. It is plausible that people with a big house have both a high demand and a big air conditioner, while people with a smaller house have less demand and don't have a big air conditioner. The maximum differential of the air conditioner is taken to be 30^{O}F, while this is only an estimate not based on empirical evidence.

[15] Baarda, D.B. and M.P.M. de Goede (1998)
[16] Wojciechowicz, J. J. (2002)

6. Suggestions for future research

In this report several suggestions were made concerning research that has to be done that can greatly improve the reliability and validity of the model. These suggestions are summarized here.

Not much is known about the human-technology interaction involved in this type of DR program. Some of the questions that arise and that need to be researched are:

- How do the way people are approached and the information that is provided influence the participation rate?
- How do people respond to the programmable thermostat used in this program?
  - Does this response influence the acceptance rate of events?
- Is a rebate per event needed in order to get participants to accept the change in setting and, if so, how high does this rebate have to be?

There are some possible correlations between the different factors. Whether there really are correlations has to be researched. Some of the questions that come to mind are:

- Are the air conditioner characteristics correlated to the size of the house? (hourly savings achieved by 4^{O}F increase, the maximum differential)
- Is the size of the demand correlated to the size of the house?
- Is the size of the demand correlated to the original thermostat setting?

Another thing that has to be researched is the price of installing and operating the hourly meter.

Future research should also involve real data from air conditioner reset DR programs like Allegheny Powers Electricity Price Response Pilot Program. For the conclusions based on such research to be reliable and valid, more data about residential customers has to be known:

- demand data;
- original thermostat setting;
- size of house;
- size and type of air conditioner;
- air conditioners maximum differential.

Besides this customer data the temperature data from the area were participants are living should be used.

Expectations are that the demand for households that participate in DR programs will be lower than demand of non-participating households because of the changes in thermostat settings during periods of high outside temperature and premium wholesale prices. This translates into the following hypothesis:

H_1: Demand for households participating in air conditioner reset DR programs is lower than that for non-participating.

This hypothesis can be tested by comparing demand data for both groups of participants.

Results of several previous studies indicate that just by giving people information makes them perform better on several different tasks. Some of these studies concerned energy conservation tasks[17] and therefore a second hypothesis is formulated:

H_2: Demand for households participating in the Electricity Price Response Pilot Program is lower during the program than it was in corresponding periods prior to the program, when discounted for events and holidays.

This hypothesis concerns all demand besides that during which an event is called. Testing this hypothesis is complicated by external factors like the weather, which has to be accounted for.

[17] McCalley, L.T. (2002)

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Appendix A – Avista's Utilities Buy-Back Program

Why did Avista Utilities do it?

When the program started in May 2001, the utility had a hard time to find enough electricity to meet demand. The prices in the wholesale markets were 10 to 20 times those of a year before. Because Avista Utilities charged their customers a fixed price per kilowatt-hour, they were losing money (buying high & selling low).

The less electricity the utility sold, the less money they would loose. In order to do this they would have to get their customers to conserve electricity. However, because of the fixed price, customers had no incentive to try to use less electricity other than lowering their bill slightly. The buy-back gave customers an incentive; besides having a lower bill due to less electricity use, they even received money for the electricity they didn't use. This way the conservation saved them double money.

What it meant for the customer

If a customer reduced the amount of electricity he/she used with more than 5 percent compared to the same period last year, the customer received 5 cents per kilowatt-hour saved on top of that 5 percent. The price consumers paid for electricity was set on 5 cents per kilowatt-hour.

An example:

A customer used 1000 kWh in June 2000.

In order to receive a buyback the customer has to reduce his electricity consumption with 5 percent, which for him comes down to 50 kWh.

Now, in June 2001, the consumer uses 920 kWh. This is a reduction of 80 kWh, or 8 percent compared to last year. For the kilowatt-hours he saves in excess of the 50 kWh minimum he will receive a buyback. This buyback will be $1.50 (30 kWh x 5 cent/kWh).

Besides this buyback, the consumer also pays a smaller bill, since he reduced his consumption. The reduction will be $ 4.00 (80 kWh x 5 cent/kWh). All together, the customer saved $5.50 compared to June of last year.

What it meant for the utility

When the program started the wholesale market price of electricity was:

30 cents/kWh (according to Avista and WUTC)

The rate that Avista charged her customers was:

5 cents/kWh

This meant that every kilowatt-hour used cost the utility 25 cents.

In the program, every kilowatt-hour not used saved the utility these 25 cents. Every kilowatt-hour over the 5 percent of monthly use of last year per customer cost the utility 5 cents. This still meant a saving of 20 cents.

Back to the example:

A customer used 1000 kWh in June 2000.
This cost the utility $300, while it received only $50.

Now, in June 2001, the consumer uses 920 kWh. This costs the utility $276, and it receives $46 for it. The buyback costs the utility $1.50.

In total, this month it cost the utility only $228.50 compared to $250 last year. The avoided loss therefore comes to $21.50.

After two months (May-June 2001)

During the first two months of the program the prices in the wholesale market dropped to 10 cents per kilowatt-hour. This made the whole program less attractive, but Avista still saved money this way.

The customer awareness of the program was 80 percent.

In the first two months Avista returned $2.3 million. One third of the customers reduced their consumption with 5 percent; another one third used the same amount of electricity while the last one third used more than last year.

The overall electricity consumption went down with 43.6 million kilowatt-hours.

Because of the inconsistency of the prices in the wholesale market, the total amount of money that Avista saved can not be accurately calculated.

In order to make some rough calculation, I use the following:

Of the 43.6 million kilowatt-hours reduction, two fifth was saved in the first month of the program, and the other three fifth during the second month. I estimate the wholesale price of electricity to have been 30 cents per kilowatt-hour during the first month and 10 during the second. Combining these data, Avista saved $7.8 million by not producing. During this period however, they had to pay their customers $2.3 million, which makes the total amount of money saved by the buy-back program $5.5 million.

After four months (May-August 2001)

Avista paid their customers more than $6.5 million for their savings on electricity use. Customers saved 125 million kilowatt-hours.

The prices in the wholesale markets dropped to around 3 cents per kilowatt-hour.

Because of this drop in wholesale market prices the utility was not losing money on every kilowatt-hour used anymore, but could even make money on it again (buying real low – selling low). However, because of the buy-back program, they had to pay their customers for not using electricity. This reduced the amount of money they were making. Even worse: if customers would not conserve electricity, Avista would make more money.

So in the end, the reason to abort the buy-back program was not that they were not making money, but that they could make *more* money without the program. Avista had been losing money for quite a while and now needed every penny they could get.

Table A.1 Results of the Avista DR program per month.

Month	No. of Participants	Total MWh curtailed	Credits Paid	Avg. Credits per participant
May	40,225	16,013	$ 596,545	$ 14.83
June	107,510	47,450	$ 1,737,855	$ 16.16
July	109,667	45,283	$ 1,635,254	$ 14.91
August	141,158	66,418	$ 2,421,485	$ 17.15
September	101,582	43,471	$ 1,688,790	$ 16.62
October	56,822	23,115	$ 857,185	$ 15.09
Total	556,964	241,750	$ 8,937,114	$ 16.05

Note: All data is for 2001 and system-wide (WA and ID).
Source: WUTC

Appendix B – Demand distribution

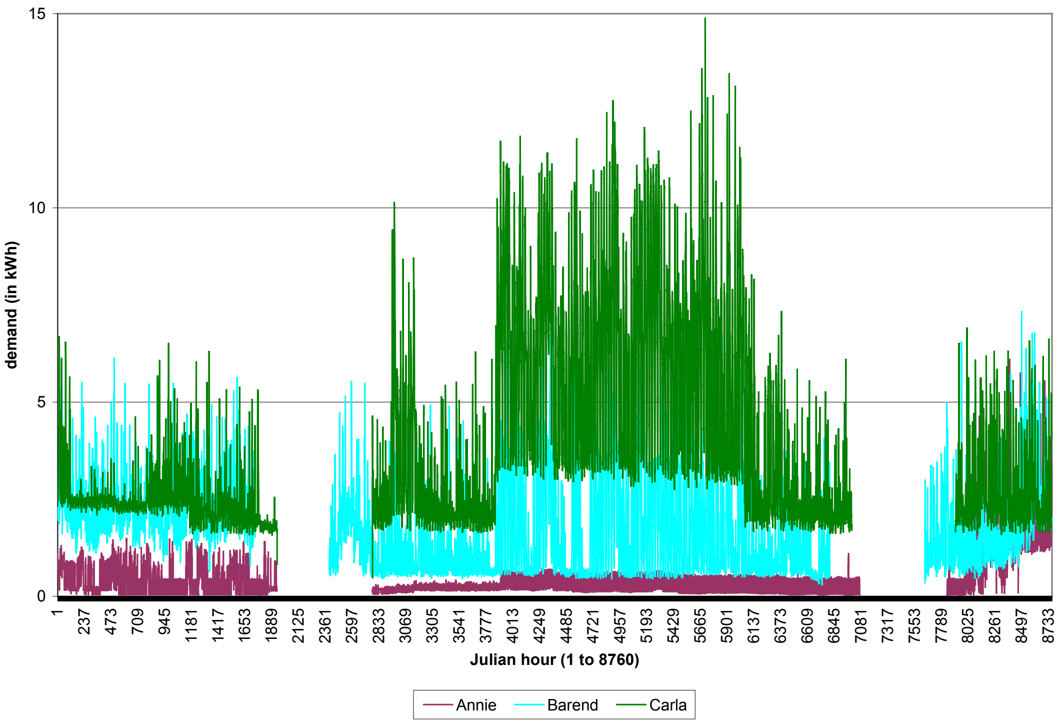

Figure B.1 Demand distribution for Annie, Barend, and Carla.

Appendix C – Example of output file

	total customers	0.10103	**On peak rate**	8	**start on peak**	182	**first day**
	participation rate	0.06103	**Shoulder peak rate**	18	**start shoulder peak**	212	**last day**
1.0	**acceptance rate**	0.04603	**Off peak rate**	22	**start off peak**	1.0	**Incentive per event**

Y324			**Total kWh saved**				**$ saved**			**kWh saved per event**											
LMP	**Setting**	**# events**	**On peak**	**Shoulder**	**Off peak**	**Total**	**customer**	**incentive**	**utility**	**savings per customer**											
100	up to 70	10	1.353	0.776	0.137	2.266	0.190	10.0	0.615	on peak	0.00	0.15	0.00	0.19	0.19	0.63	0.19	0.00	0.00	0.00	
										shoulder	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.19	0.19	0.19	
										off peak	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	71 - 75	7	1.353	0.388	0.000	1.741	0.160	7.0	0.553	on peak	0.15	0.00	0.19	0.19	0.63	0.19	0.00	0.00	0.00	0.00	
										shoulder	0.00	0.19	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	
										off peak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	76 - 80	3	0.532	0.000	0.000	0.532	0.054	3.0	0.136	on peak	0.15	0.19	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
										shoulder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
										off peak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	81 - 85	3	0.532	0.000	0.000	0.532	0.054	3.0	0.136	on peak	0.15	0.19	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
										shoulder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
										off peak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
90	up to 70	15	2.303	1.164	0.137	3.604	0.310	15.0	0.743	on peak	0.00	0.14	0.15	0.19	0.62	0.00	0.00	0.19	0.19	0.63	0.19
										shoulder	0.00	0.00	0.00	0.00	0.00	0.19	0.19	0.00	0.00	0.00	0.00
										off peak	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	71 - 75	12	2.303	0.776	0.000	3.079	0.280	12.0	0.681	on peak	0.14	0.15	0.19	0.62	0.00	0.00	0.19	0.19	0.63	0.19	0.00
										shoulder	0.00	0.00	0.00	0.00	0.19	0.19	0.00	0.00	0.00	0.00	0.19
										off peak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	76 - 80	6	1.482	0.000	0.000	1.482	0.150	6.0	0.226	on peak	0.14	0.15	0.19	0.62	0.19	0.19	0.00	0.00	0.00	0.00	0.00
										shoulder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
										off peak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	81 - 85	5	1.345	0.000	0.000	1.345	0.136	5.0	0.213	on peak	0.15	0.19	0.62	0.19	0.19	0.00	0.00	0.00	0.00	0.00	0.00
										shoulder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
										off peak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	up to 70	20	2.929	1.358	0.137	4.424	0.385	20.0	0.813	on peak	0.00	0.16	0.14	0.14	0.17	0.15	0.19	0.62	0.00	0.00	0.00
										shoulder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.19	0.19
										off peak	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	71 - 75	17	2.929	0.970	0.000	3.899	0.355	17.0	0.752	on peak	0.16	0.14	0.14	0.17	0.15	0.19	0.62	0.00	0.00	0.00	0.16
										shoulder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.19	0.19	0.00
										off peak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix D – Tables

Table D.1 Monthly electricity demand in kilowatt-hours for each customer without DR program
(The day and time of each period is shown in Table 5, months with no DC reset shown for comparison)

	Annie			Barend			Carla		
	On	Shoul-der	Off	On	Shoul-der	Peak	On	Shoul-der	Peak
January	91	57	202	534	300	856	604	302	992
February	58	32	162	438	231	786	480	303	926
March	-	-	-	-	-	-	-	-	-
April	-	-	-	-	-	-	-	-	-
May	53	27	108	222	170	421	639	412	1261
June	56	30	108	336	314	617	1261	720	1758
July	50	25	99	376	313	620	1433	836	2079
August	48	24	82	438	388	706	1646	864	2169
September	36	18	87	245	169	534	779	523	1596
October	-	-	-	-	-	-	-	-	-
November	-	-	-	-	-	-	-	-	-
December	289	151	606	417	260	773	520	427	1090
Total:	680	365	1454	3007	2144	5314	7362	4386	11872

Table D.2 Monthly bills for each customer without DR program
(The prices and times of the three tier rate structure is shown in Table 5)

	Annie		Barend		Carla	
	Flat rate	3 tier rate	Flat rate	3 tier rate	Flat rate	3 tier rate
January	$ 22.59	$ 22.02	$ 108.86	$ 111.66	$ 122.19	$ 125.07
February	$ 16.24	$ 15.28	$ 93.69	$ 94.51	$ 110.08	$ 109.64
March	-	-	-	-	-	-
April	-	-	-	-	-	-
May	$ 11.28	$ 10.17	$ 48.60	$ 44.19	$ 138.53	$ 125.48
June	$ 12.43	$ 12.40	$ 81.62	$ 81.54	$ 240.78	$ 252.25
July	$ 11.22	$ 11.16	$ 84.29	$ 85.63	$ 280.03	$ 291.51
August	$ 9.95	$ 10.11	$ 98.70	$ 100.48	$ 301.36	$ 318.91
September	$ 8.51	$ 7.53	$ 57.08	$ 51.08	$ 173.92	$ 156.79
October	-	-	-	-	-	-
November	-	-	-	-	-	-
December	$ 67.41	$ 66.34	$ 93.40	$ 93.62	$ 131.23	$ 128.82
Total:	$ 159.63	$ 155.01	$ 666.24	$ 662.71	$ 1,498.12	$ 1,508.47

Table D.3 Monthly savings in kilowatt-hours per customer, per minimum LMP, per thermostat setting.
(Note1, The months in which no events were called and for which data was missing are not reported)
(Note2. When using the flat rate, all savings occur in the 24-hour period. Savings in on peak, shoulder peak, and off peak period have to be added up.

			Annie			Barend			Carla		
Month	min. LMP ($/MWh)	setting (^{O}F)	On	Shoulder	Off	On	Shoulder	Off	On	Shoulder	Off
May	100	Up to 70	0.2	0.0	0.0	0.5	0.0	0.0	3.0	0.0	0.0
		71-75	0.2	0.0	0.0	0.5	0.0	0.0	3.0	0.0	0.0
		76-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		81-85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	90	Up to 70	0.6	0.0	0.0	1.6	0.0	0.0	9.0	0.0	0.0
		71-75	0.6	0.0	0.0	1.6	0.0	0.0	9.0	0.0	0.0
		76-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		81-85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	80	Up to 70	1.2	0.0	0.0	5.5	0.0	0.0	18.0	0.0	0.0
		71-75	1.1	0.0	0.0	4.8	0.0	0.0	15.0	0.0	0.0
		76-80	0.2	0.0	0.0	2.6	0.0	0.0	3.0	0.0	0.0
		81-85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
June	100	Up to 70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		71-75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		76-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		81-85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	90	Up to 70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		71-75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		76-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		81-85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	80	Up to 70	0.7	0.0	0.0	6.8	0.0	0.0	7.8	0.0	0.0
		71-75	0.4	0.0	0.0	6.0	0.0	0.0	6.0	0.0	0.0
		76-80	0.4	0.0	0.0	6.0	0.0	0.0	6.0	0.0	0.0
		81-85	0.2	0.0	0.0	3.0	0.0	0.0	3.0	0.0	0.0

Table D.3 (continued)

			Annie			Barend			Carla		
Month	min. LMP ($/MWh)	setting (^{O}F)	On	Shoulder	Off	On	Shoulder	Off	On	Shoulder	Off
July	100	Up to 70	1.4	0.8	0.1	15.0	12.0	3.0	15.0	12.0	3.0
		71-75	1.4	0.4	0.0	15.0	6.0	0.0	15.0	6.0	0.0
		76-80	0.5	0.0	0.0	9.0	0.0	0.0	9.0	0.0	0.0
		81-85	0.5	0.0	0.0	9.0	0.0	0.0	9.0	0.0	0.0
	90	Up to 70	2.3	1.2	0.1	24.0	18.0	3.0	24.0	18.0	3.0
		71-75	2.3	0.8	0.0	24.0	12.0	0.0	24.0	12.0	0.0
		76-80	1.5	0.0	0.0	18.0	0.0	0.0	18.0	0.0	0.0
		81-85	1.3	0.0	0.0	15.0	0.0	0.0	15.0	0.0	0.0
	80	Up to 70	2.9	1.4	0.1	36.0	21.0	3.0	36.0	21.0	3.0
		71-75	2.9	1.0	0.0	36.0	15.0	0.0	36.0	15.0	0.0
		76-80	2.1	0.2	0.0	30.0	3.0	0.0	30.0	3.0	0.0
		81-85	1.8	0.0	0.0	24.0	0.0	0.0	24.0	0.0	0.0
August	100	Up to 70	7.2	2.7	0.0	75.5	33.0	0.0	87.0	33.0	0.0
		71-75	7.2	2.7	0.0	75.5	33.0	0.0	87.0	33.0	0.0
		76-80	6.4	1.5	0.0	73.5	15.0	0.0	81.0	15.0	0.0
		81-85	5.4	0.3	0.0	63.5	3.0	0.0	66.0	3.0	0.0
	90	Up to 70	7.8	3.4	0.0	78.5	39.0	0.0	90.0	39.0	0.0
		71-75	7.8	3.4	0.0	78.5	39.0	0.0	90.0	39.0	0.0
		76-80	7.0	2.2	0.0	76.5	21.0	0.0	84.0	21.0	0.0
		81-85	6.0	0.3	0.0	66.4	3.0	0.0	69.0	3.0	0.0
	80	Up to 70	8.6	4.2	0.2	85.8	44.9	3.0	105.0	45.0	3.0
		71-75	8.6	4.1	0.2	85.8	42.0	3.0	105.0	42.0	3.0
		76-80	7.7	2.9	0.2	83.8	24.0	3.0	99.0	24.0	3.0
		81-85	6.5	0.3	0.2	71.6	3.0	3.0	78.0	3.0	3.0

Table D.3 (continued)

Month	min. LMP ($/MWh)	setting (^{O}F)	Annie On	Annie Shoulder	Annie Off	Barend On	Barend Shoulder	Barend Off	Carla On	Carla Shoulder	Carla Off
September	100	Up to 70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		71-75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		76-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		81-85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	90	Up to 70	0.0	0.5	0.0	0.0	3.0	0.0	0.0	3.0	0.0
		71-75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		76-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		81-85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	80	Up to 70	0.0	0.5	0.0	0.0	3.0	0.0	0.0	3.0	0.0
		71-75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		76-80	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		81-85	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Month	min. LMP ($/MWh)	setting (^{O}F)	Annie On	Annie Shoulder	Annie Off	Barend On	Barend Shoulder	Barend Off	Carla On	Carla Shoulder	Carla Off
Total (April through September)	100	Up to 70	8.8	3.5	0.1	91.0	45.0	3.0	105.0	45.0	3.0
		71-75	8.8	3.1	0.0	91.0	39.0	0.0	105.0	39.0	0.0
		76-80	6.9	1.5	0.0	82.5	15.0	0.0	90.0	15.0	0.0
		81-85	5.9	0.3	0.0	72.5	3.0	0.0	75.0	3.0	0.0
	90	Up to 70	10.7	5.1	0.1	104.1	60.0	3.0	123.0	60.0	3.0
		71-75	10.7	4.2	0.0	104.1	51.0	0.0	123.0	51.0	0.0
		76-80	8.5	2.2	0.0	94.5	21.0	0.0	102.0	21.0	0.0
		81-85	7.3	0.3	0.0	81.4	3.0	0.0	84.0	3.0	0.0
	80	Up to 70	13.4	6.1	0.3	134.1	68.9	6.0	166.8	69.0	6.0
		71-75	13.0	5.1	0.2	132.6	57.0	3.0	162.0	57.0	3.0
		76-80	10.4	3.1	0.2	122.4	27.0	3.0	138.0	27.0	3.0
		81-85	8.5	0.3	0.2	98.6	3.0	3.0	105.0	3.0	3.0