Switches or Stats: Who Wants What?
A Comparison of Switches and Web-enabled Programmable Thermostats
for Mass Market Demand Response

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INTRODUCTION

How do regular switches compare to Web-enabled thermostats for controlling residential air-conditioning load in a northern climate? What impacts do each of the technologies have on the utility load curve? What difference do they make on the customers' experience of the control event?

To answer these questions, and many more, WPSC conducted a Residential Thermostat Pilot during the summer of 2005. Web-enabled programmable thermostats were installed in 86 residential homes. The existing Help Direct Load Control program, which uses regular switches, was also extensively tested in conjunction with this pilot. WPSC's system-wide Automated Meter Reading (AMR) meters were used to collect hourly data on 1,170 of these customers. Impact evaluations were done to compare the effects of different control strategies for the switches and the thermostats. Data was also collected on customers' notice and comfort levels during the load control tests.

TEST GROUPS

There were five test groups in the Thermostat Pilot. Groups 1, 2 and 3 were samples of customers from WPSC's Help Direct Load Control program. Groups 4 and 5 were test participants who received Web-enabled programmable thermostats.

Table 1
Summary of Information on Test Groups

Group	Technology	Com-mun-ication	Control Tests	# of Control Hours	Rate Incentive	# of Customers in the Group
1	Regular switch	FM	100% Load Shed for 1 hour	10	$32 credit	647
2	Regular switch	FM	25%, 50%, or 67% Cycle-off for 4 or 7 hours	47	Cycling only No credit	523
3	Adaptive Cycling switch	Paging	25%, 50%, or 67% Cycle-off for 4 or 7 hours	47	$32 credit	23

Group	Technology	Com-mun-ication	Control Tests	# of Control Hours	Rate Incentive	# of Customers in the Group
4	Web-enabled programmable thermostat	Paging	4, 6, or 8-degree temperature ramp-up for 4 or 7 hours with or without a pre-cool period. Customer can opt-out	82	None	23
5a	Web-enabled programmable thermostat	Paging	Customer choice (most were 100% load shed). Customer can opt out	101	3 –tier TOU with Critical Peak Pricing	30
5b	Web-enabled programmable thermostat plus orb to communicate price periods					33

AIR-CONDITIONING LOADS IN WISCONSIN

Given the different natures of the five test groups, it is important to have an understanding of potential differences in each group's use of Air-Conditioning (AC). Different underlying AC use patterns could cause differences in measurements of impacts from control events that have nothing to do with differences in control technologies or strategies.

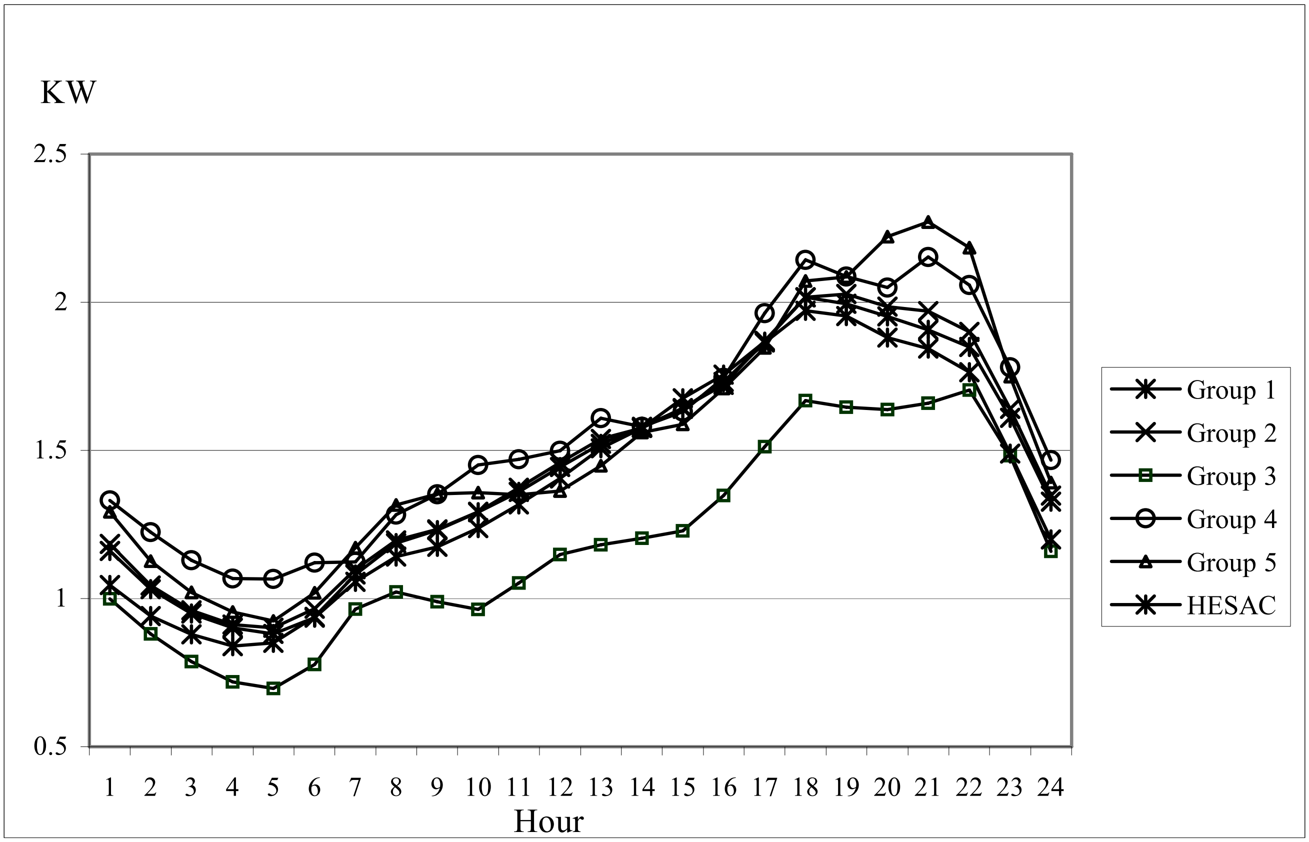
Air-conditioning leaves a significant mark on hourly electric load curves which makes it possible to compare the average electric load curves for each of the five groups to understand any differences in AC use that may exist.

Chart 2 shows that four of the test groups had very similar patterns, and they were all close to the pattern of residential customers with air-conditioning that were not on any load control program. This ended the argument on whether or not all Direct Load Control participants were 'free riders', i.e. – people who didn't use their air-conditioning much so they didn't care if it was turned off or not.

Group 3 was the only group with a different load pattern. Their loads were much lower. The cause of this difference is unknown. However, this is one of the smallest test groups, having only 23 customers. Results for this group, the Adaptive Cycling Switch test group, should be used with caution.

All of the groups show that evening use is considerably greater than daytime use due to more people at home during those hours.

Chart 2
Average Weekday Load for Each Group



Note: HESAC is a random sample of 1500 residential customers with air-conditioning.

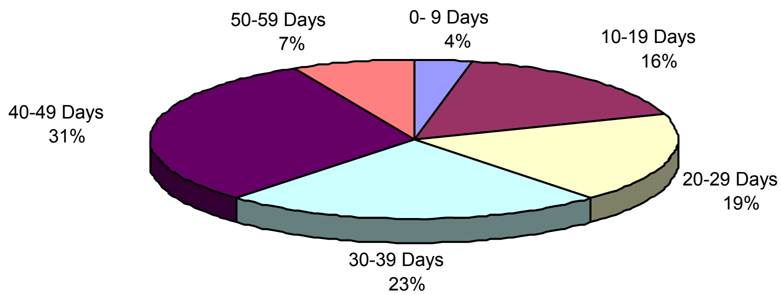
The richness of the hourly data collected from the thermostats allowed us to answer other long-standing questions specifically about air-conditioning use in Wisconsin. The thermostats collected hourly indoor temperature data as well as hourly run times for the air-conditioner.

How many days are air-conditioners running during a summer?

During the summer of 2005, it varied from 0 days to 59 days, with half of the customers using it for at least 40 days. Based on NOAA Green Bay weather station data, during the summer of 2005 there were 14 days where the Composite Temperature Humidity Index (CTHI) was greater than 10 for eight hours, 43 days where the CTHI was between 0 and 10, and 27 days with CTHI < 0 (indicating no need for AC). Based on this information, it looks like 20% of customers only turn on their AC when it is very hot and 7% leave it on all summer. Everyone else is somewhere in between.

The summer of 2005 was a typical summer based on the number of days that reached CTHI greater than 10 (approximately 87 degrees). Compared to other summers, 2005 had more occurrences of high CTHI levels that lasted throughout the night creating several long, unbroken spells of high heat lasting for 24 hours or more. However, temperatures never exceeded 95 degrees so it was not an extreme temperature year.

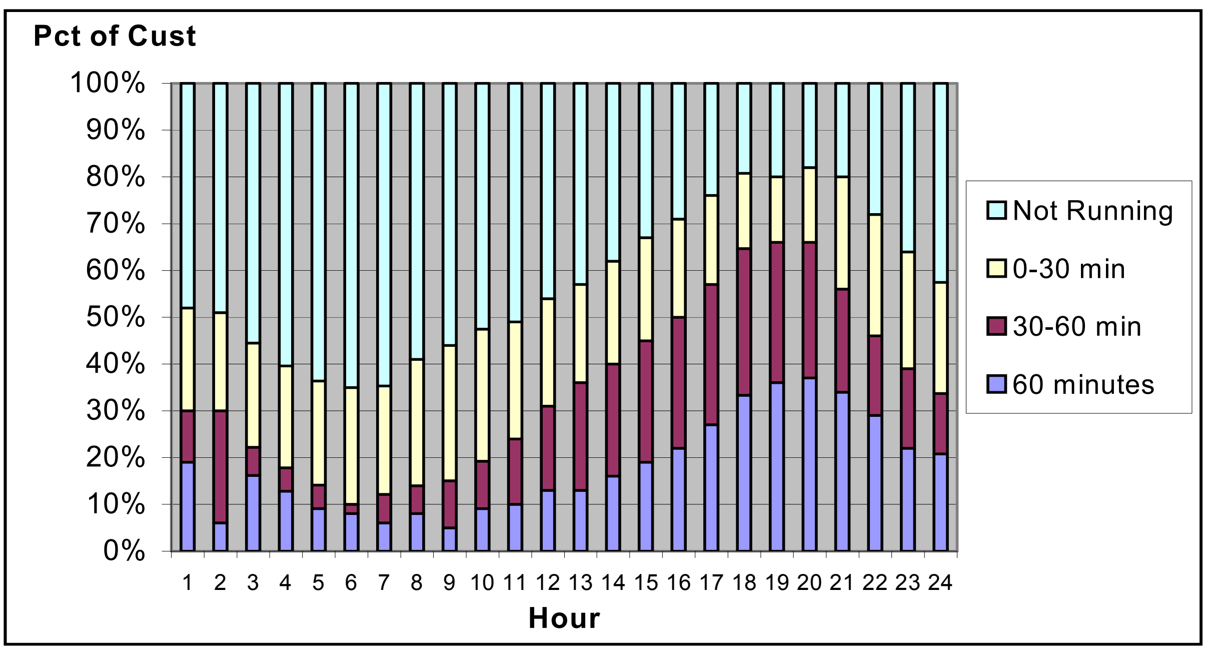
Chart 3
No. of Days Customers Use AC During Summer 2005



How many air-conditioners are running at different times on very hot days?

While everyone's AC may be running on very hot days, the chance that it will be running during a particular hour varies greatly. The data shows that the lowest use is from 5:00 to 6:00 a.m. when only 35% of AC are running, while the highest use is from 7:00 to 8:00 p.m. when 82% are running.

Chart 4
Percent of Customers with Different AC Run Times
On the Four Hottest Non-Control Days of Summer 2005



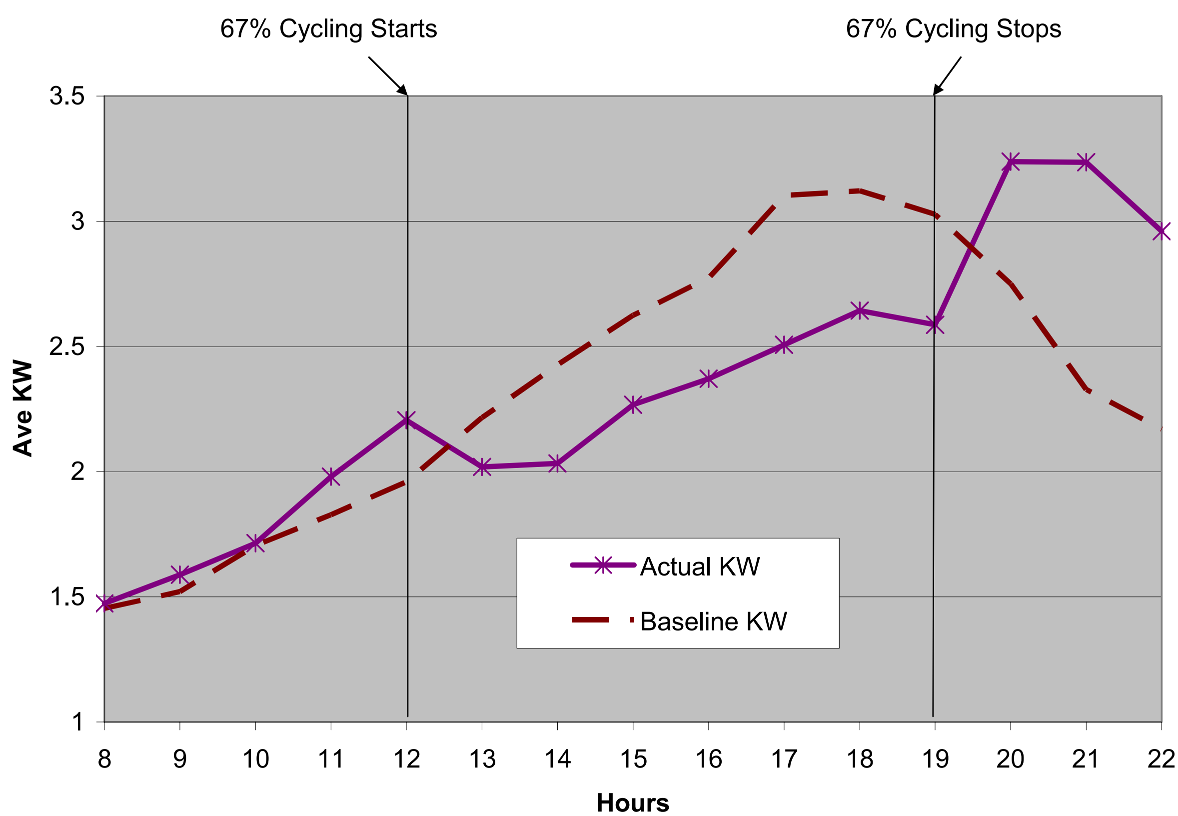
Over the last ten years the WPSC system peak seems to be moving to later in the day. Occasional noon peaks are being replaced with occasional 5 p.m. peaks. This increases the chances that a residential customers' AC will be on and the opportunity to 'free-ride' decreases.

RESULTS – LOAD IMPACTS

Many different control strategies were tested on many different days. Details of load impacts for each test and each day are shown in the full report which is available from the author.

As an example, here are the results of two tests conducted on the same day, August 1. One test was on the switches and one test was on the thermostats. August 1 was one of the hottest days during the summer of 2005, reaching a CTHI of 13 (approximately 90 degrees).

Chart 5: Test Group 2 – Regular Switches
67% Off Cycling Test
August 1, 2005 - 12:00 to 7:00 p.m.



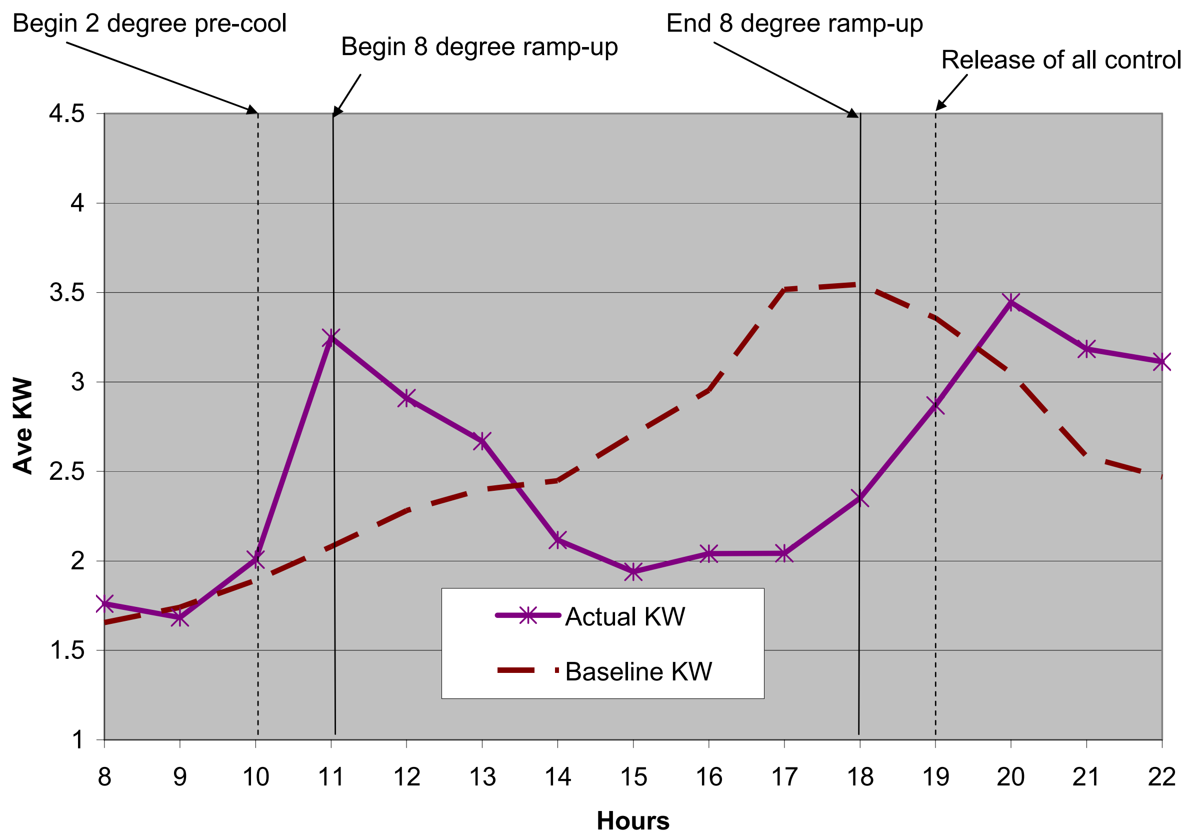
The baseline kw in this chart represents what the average load would have been expected to be for this particular group of customers if the control event had not been called. The baseline is developed by building individual load models for each customer. Regression is used to develop weekday hourly load models based on the Time of Day and the CTHI.

KW = f(Time of Day, CTHI)

Using this method, Chart 5 indicates that the average impact from 67% control on August 1 was 0.4 KW. Sixty-seven percent off was the most severe cycling strategy tested during the summer.

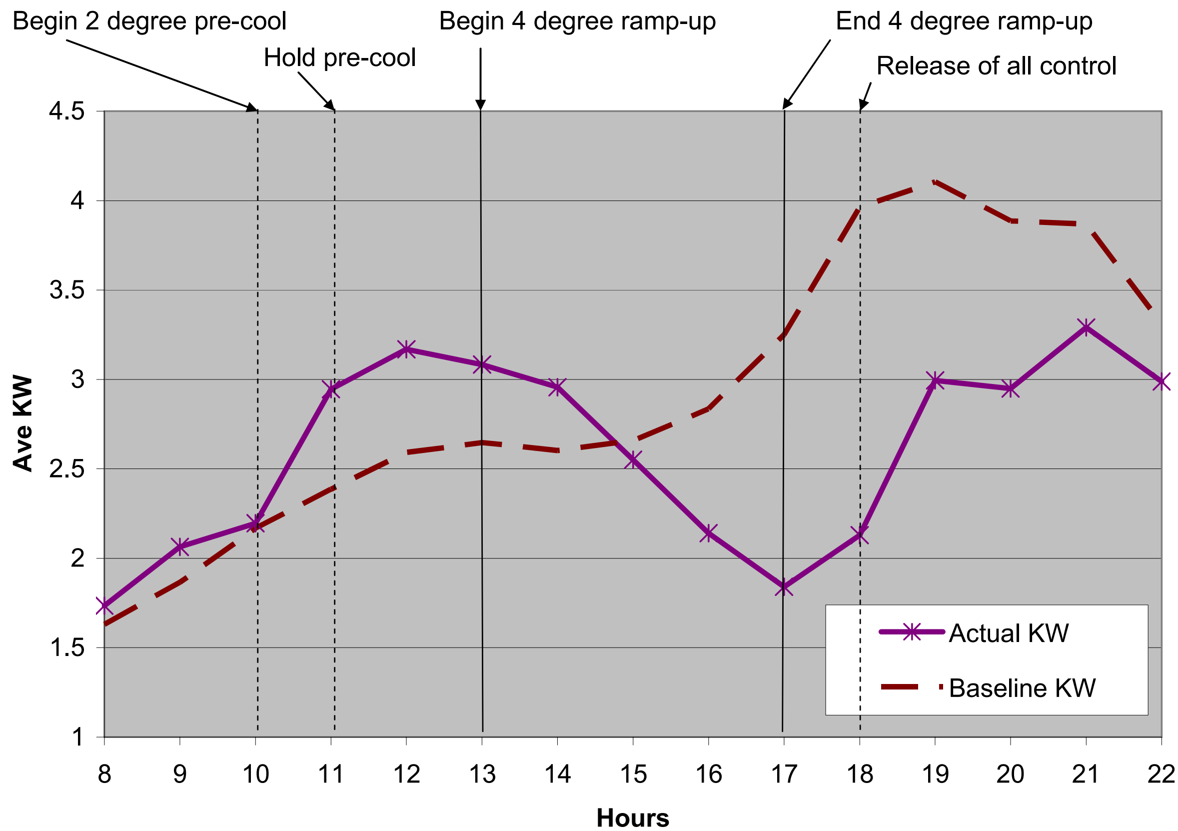
Similarly, August 1 was one of the most severe tests for the thermostat group. Group 4, which did not have individual control over their own load response strategy, was given a one-hour 2 degree pre-cool beginning at 10:00 a.m., followed by an 8 degree temperature ramp-up. The ramp-up was gradual over the seven hour control period, allowing indoor temperature to increase by about one degree per hour. Chart 6 shows the load impacts for this strategy.

Chart 6: Test Group 4 – Thermostat
2 degree Pre-cool followed by 8 degree Temperature Rise
August 1, 2005 - 10:00 to 7:00 p.m.



WPSC system loads on hot days are high and relatively flat from noon to 6 p.m. Using the 2 degree pre-cool strategy helps keep customers comfortable, but could potentially increase system load during the early hours of the control period. To remedy this, a strategy was tested to move the pre-cool period earlier into the morning. Chart 7 is an example of the load impacts of this strategy.

Chart 7: Test Group 4 – Thermostat
2 degree Pre-cool with 2 hour Hold followed by 6 degree Temperature Rise
August 3, 2005 - 10:00 to 6:00 p.m.



On August 3, another hot day with outdoor temperatures reaching 90 degrees, the one-hour pre-cool period was followed by a two hour hold period where the lower indoor temperature was maintained until the start of the control period. This would allow shifting of the load spike to earlier in the day, but increased load during the beginning of the control period is still a concern. Careful work would have to be done on the timing of the pre-cool period and the beginning of the control period to create a new load shape that would not create a new system peak.

Table 8 summarizes the average kw impacts observed across all of the control events tested in Summer 2005 for the different technologies and control strategies.

Overall, the load impacts of Web-enabled thermostats have an equivalency to switches, although each technology has a different impact on the shape of the load curve. In general, a four-degree rise in temperature on a Web-enabled thermostat creates savings equal to 50% cycling on a regular switch. A six degree rise is equal to 100% load shed.

Table 8
Equivalent Load Impacts (Observed during Summer 2005)
KW per Customer

Equipment	25% Cycle-Off	50% Cycle-Off	67% Cycle-Off	100% Load Shed
Regular Switch	.09	.38	.36	.60
Adaptive Cycling Switch	.25	.41	.51	
Thermostat		.35 *4 degrees, 7 hours*		.70 *6 degrees, 7 hours*
		.40 *8 degrees, 7 hours, 2 degrees pre-cool*		.66 *100% Load Shed* **Price Response Option**

There is a strong relationship between weather (CTHI) and AC load. As CTHI increases, so does the average AC KW on the system. The average AC impacts observed during the summer of 2005 and reported in Table 8 correspond to an average CTHI of 11. For system planning purposes, these averages need to be extrapolated to expected impacts during peak day conditions. Using the baseline customer models for all of the test groups, the extrapolation predicts that the kw load impact per customer expected during a 100% load shed on a Net Design Peak day for WPSC is 1.3 kw. Net Design Peak is currently defined as hour ending 5:00 p.m. when the CTHI=17.5, which is roughly equivalent to 95 degrees. In half of our summers we reach a day that's 95 degrees; in half of our summers we don't.

It was also of note that 50% cycling on regular switches creates load reductions roughly equal to half of the 100% load shed impact. Previously it had been believed that this would not be true on the WPSC system because of significant oversizing of air-conditioners.

Discussions with the Energy Center of Wisconsin and local heating installers revealed that AC are no longer oversized in WPS service territory. In the past, central AC units were oversized because they were operated like room AC units. They were off most of the time, but turned on when cool air was desired. The ability to cool down an overheated house quickly was important. Quick cooling with oversized AC units left houses clammy, however, because the short run-time was unable to remove the high humidity in the house. Over the years, preference for a less clammy environment, more energy-efficient building codes and a desire to reduce installation and operating costs has led to proper sizing and more constant use of AC. New systems are right-sized or under-sized, and most central air-conditioners on the WPSC system are new because of the recent rapid increase in the saturation of units.

Hourly run-time data downloaded from the thermostats verified this information (refer back to Chart 4).

RESULTS – CUSTOMER COMFORT LEVELS

Customer comfort during control events can be measured at two levels: first, if they noticed the event, and second, if their home stayed comfortable during the event. Customers in each of the five study groups received monthly surveys where they were asked to record their daily observations.

No special consideration was given to the question of whether or not anyone was home during the control periods. The test groups did not appear different from the general population in their mix of at-home and away-from-home (refer to Chart 2), so it was felt that the general comfort levels that were reported would relate to the entire population and could be used for program planning. Customers away-from-home return at a variety of hours throughout the day and could notice a control period if it had a significant impact on the indoor air temperature they find when they arrive home. Also, WPSC control periods frequently run into the early evening hours when most customers would be home even if they were away during the day.

Reported notice rates and comfort levels varied considerably among the groups.

Table 9
Summer 2005 Control Test Events
Comparison of Notice / Comfort Levels

Group	Average % that Notice	Average % Comfortable
Group 1 – 1 hr 100% Shed	8%	92%
Group 2 – Reg Switch Cycling	14%	89%
Group 3 – TrueCycle Cycling	0%	98%
Group 4 – DLC Thermostat	22%	69%
Group 5a – Price Response Thermostat – No Orb	33%	67%
Group 5b – Price Response Thermostat & Orb	40%	70%

Overall, notice levels were very low for the switches and comfort levels remained high, even for Group 2 which had experienced extended periods of cycling. This indicated that the load control system could be used more and customers would not be adversely impacted.

Notice was higher and comfort was lower for the thermostats. This is to be expected since they endured many more extended periods of 100% load shed. Also, the indicator that they were in a control period was on their indoor thermostat rather than on an outdoor switch box which made it easier to notice. If thermostat control events had been of similar intensity, it is expected that comfort levels would have matched comfort levels for switches, although notice rates may remain higher.

A look at individual days shows that comfort levels do correlate with the intensity of the events. Tables 10 and 11 show the individual daily information for the two groups that experienced the most variation in control events, Group 2 Switches and Group 4 Thermostats.

In general, the cycling events using switches in Group 2 were almost twice as noticeable and only slightly more uncomfortable than the one hour 100% load shed events in Group 1. On average, 14% of the customers noticed a control period and only 11% reported any discomfort. Of those who reported discomfort, 84% said that they were only slightly uncomfortable.

As expected, the highest notice and most discomfort are associated with the seven-hour, 67% cycle-off event on one of the hottest days of the summer. This extreme event was noticed by 24% of the customers and caused discomfort in 20% of the homes. The discomfort was not extreme, though, because 80% of those with discomfort reported that they were only slightly uncomfortable. It would seem that the impacts of even the most extreme cycling strategies are acceptable to almost all of the participating customers.

Table 10
Summer 2005 Control Test Events for Group 2 Switches
Notice / Comfort Levels

Date	Start Time	Duration (Hours)	Cycle-Off Percent	Average CTHI	Pct that Notice the Event	Pct that are Comfortable
July 13	11:00	7	25%	13.5	17%	91%
July 20	12:00	7	25%	7	9%	96%
July 25	1:00	4	50%	10.5	6%	94%
July 18	11:00	7	50%	11.3	13%	96%
July 15	1:00	4	50%	10.4	17%	87%
June 23	2:00	2	50%	13	12%	84%
August 3	3:09	1	50%	13.6	13%	83%
June 28	1:00	4	50%	12	12%	92%
August 1	12:00	7	67%	13.3	24%	80%
July 11	11:00	4	67%	10.3	13%	87%

Note: All control tests occurred on weekdays.

Out of the 50 respondents in Group 2, only two report that they would like to get out of the control periods because they were so uncomfortable. This occurs during the first week of August, one of the hottest weeks of the summer with the most severe control event. In fact, they want out every day during the first week of August, even though control events only actually happened twice. This would indicate that there will be drop outs if more extensive cycling is done, but there will not be many (2 out of 50, or 4%). Most likely they are people who are unhappy with the control program regardless of the control strategy.

Group 4 Thermostats in Table 11 show notice rates that are much higher and comfort levels that are much lower than they are for any of the groups with switches.

While the average comfort level of 69% for this group is lower than the average for other groups, it is not a fatal flaw for a thermostat program that would use less extreme control strategies. Even at the extremes that were tested, a majority of the customers maintained their comfort level. Of all days which were reported by customers as being uncomfortable, 66% of those were recorded as being only slightly uncomfortable. And this group of customers had the ability to opt-out of events that were too uncomfortable to endure.

Another factor of note is that this group of customers are not people who chose to be in a load control program. Rather, they are customers who were willing to try load control for one summer to help WPSC test the new thermostats. They also are a group with higher energy use, and probably higher AC use, than regular customers. Their reliance on the comfort that goes with AC is probably higher.

Table 11
Summer 2005 Control Test Events for Group 4 Thermostats
Notice / Comfort Levels

Date	Pre-cool Degrees	Pre-cool Duration (Hours)	Degrees Increase	Ramp-up Duration (hours)	Pct that Notice the Event	Pct that are Comfortable
June 23	0	0	4	4	23%	54%
July 13	0	0	4	7	33%	67%
July 18	0	0	6	4	42%	58%
August 9	0	0	6	7	18%	71%
July 15	0	0	8	4	25%	58%
July 11	0	0	8	7	33%	50%
July 25	2	1	4	7	8%	92%
June 24	2	1	6	4	15%	62%
August 1	2	1	8	7	24%	71%
June 28	2	3	4	4	15%	85%
June 27	2	3	4	7	23%	69%
August 3	2	3	6	4	24%	76%
July 20	2	3	8	7	8%	83%

Customers with thermostats can choose to opt out of control events as often as they want to. There is a risk to WPSC that customers in a thermostat program may collect an incentive payment but then opt out of most events and not provide the needed load impacts.

Data from other utilities with thermostat programs has shown low opt out rates. Data from the WPSC 2005 summer pilot confirms this. Opt-out rates were always low, ranging from 3% to 9% among the different groups.

Table 12
Opt-Outs in Thermostat Pilot

	Group 4 DLC Thermostats	Group 5 PR Thermostats	All Thermostats
Total Customers	23	63	86
No. who used Opt-outs	7	16	23
% of Cust who used Opt-outs	30%	25%	27%
Total No. of Control Hours	101	117	
Total Event Days	13	16	
Total Cust-Event Days *(No. of Cust times No. of Days)*	299	1008	1307
No. of Cust-Event Days Opted-out	26	35	61
% of Cust-Event Days Opted-out	9%	3%	5%
Average Opt-out Events per Customer who uses Opt-outs	3.7	2.2	2.7

CONCLUSIONS

A major finding of this study was that load impacts from a 50% cycling strategy with regular switches is roughly equivalent to the load impacts from a 4 degree rise with thermostat control. This equivalence was found in the northeastern Wisconsin climate.

While the average impacts are equivalent, the hourly impacts are very different between the two types of control. Switches create a constant impact over the control period, while thermostats with phased-in temperature ramp-up create an increasing impact over the control period. If the thermostats invoke an initial pre-cool before the event, they can actually cause increased loads during the beginning of the control period.

It was encouraging to see that neither 50% cycling events nor 4 degree temperature rises created significant notice or discomfort in customers' homes. This indicates that these strategies can be used frequently by utilities for load relief without adverse impacts on most customers.

The data shows that both technologies, switches and thermostats, can create similar load reductions with minimal customer impact. Given that a thermostat costs considerably more than a switch, the most reasonable investment for a northern utility would be in regular switches.

Additional study could be done on potential market penetration of Web-enabled thermostats because of their customer-friendly features such as opt-out and remote control. As the population becomes more Web-savvy, the Web-enabled thermostat may become a standard feature in all homes. If customers are willing to pay the difference between the switch and the thermostat, the thermostat would become a viable control technology for the utility.