Comfort and Load Control:
It's Getting Hot in Here – But is the Utility to Blame?

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ABSTRACT

DLC of air conditioners (ACs) is an important demand response measure. The measure cycles ACs off for portions of time during a control event. These programs allow the utility to avoid capacity costs and also reduce energy prices by reducing demand. Customers may experience discomfort during control events. However, during a prolonged heat wave, how much of that discomfort is due to the control event and how much of it would have occurred anyway? How is the control strategy likely to affect comfort and savings?

A situation in the summer of 2011 provided a controlled experiment to help answer this question. Temperatures soared to nearly 105 F degrees over a three day period. A sample of participants had meters installed for an impact analysis. This group was controlled over two days. On the third day, the transmission operator called an event that triggered control of all participants of the program. However, because the metered sample had already been controlled the previous two days, they were excluded from the more general control event over concerns that they might drop out of the program and the metered data points would be lost. This situation created a natural experiment to compare the two groups to see if comfort was influenced by AC control.

Analysis showed that no statistical difference in perceived comfort levels between the controlled and uncontrolled customers. Analysis of the control strategy indicated the adaptive algorithm used was unlikely to affect comfort levels, but would contribute significantly to overall savings.

Introduction

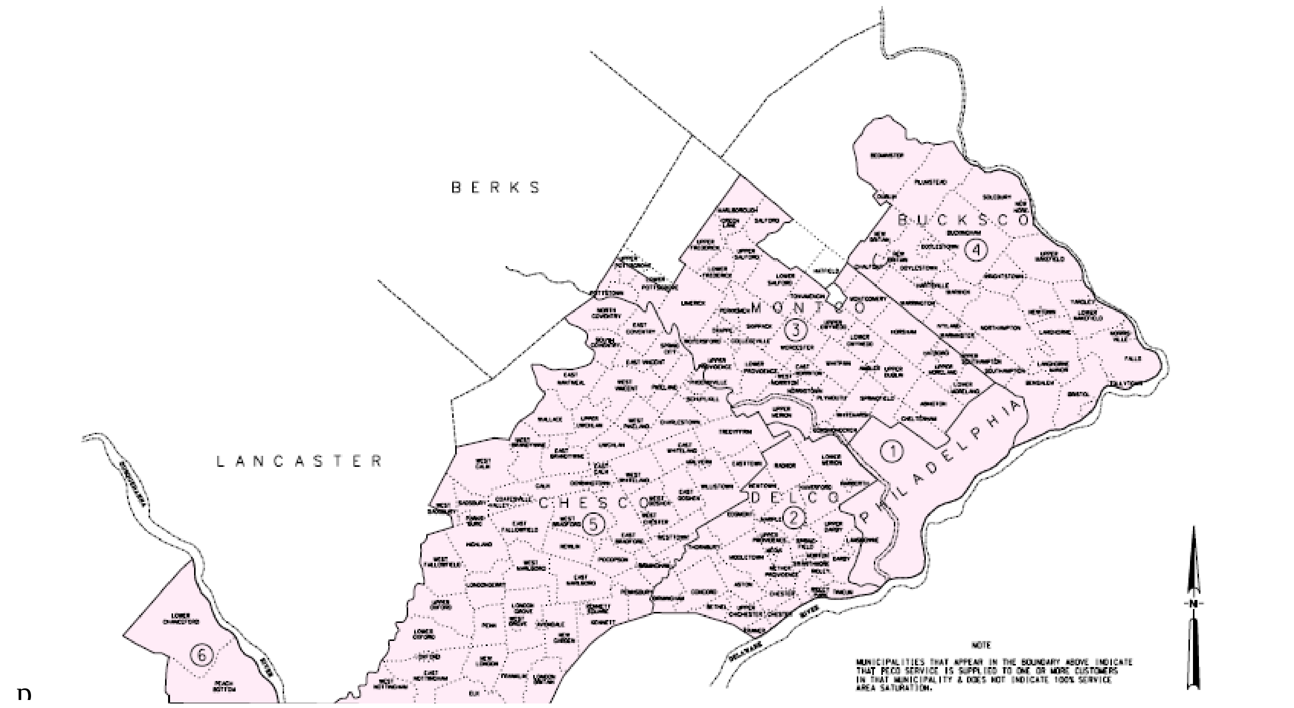
Direct load control (DLC) of air conditioners is an important demand response measure for many utilities. The measure cycles air conditioners off for portions the time during a control event. These programs allow the utility to avoid capacity costs and also reduce energy prices by reducing demand. Customers may experience discomfort during control events. However, during a prolonged heat wave, how much of that discomfort is due to the control event and how much of it would have occurred anyway? How is the control strategy likely to affect comfort and savings?

This paper presents results of an analysis of a controlled DLC experiment that explores these questions.

Overview of the DLC Program

The program is sponsored by PECO Energy Company (PECO). PECO, an energy delivery subsidiary of Exelon Corporation, is headquartered in Philadelphia. PECO is the largest electric and natural gas utility in Pennsylvania, serving approximately 1.6 million electric customers and 494,000 natural gas customers in southeastern Pennsylvania. Approximately 90% of PECO's customers are residential and the remaining 10% are commercial and industrial. Figure 1 presents a map of the PECO service territory.

Figure 1. Map of PECO Service Territory



Source: PECO

The program is part of a comprehensive portfolio of energy efficiency and demand reduction programs, developed by PECO in collaboration with key stakeholders to meet aggressive energy and peak demand reduction goals set by Pennsylvania Act 129 of 2008[1].

The PECO Smart A/C Saver Program is a DLC program for residential customers. The program is based on the installation of digital control units (switches) on qualified residential air conditioners. Participants are incented at the rate of $120/year ($30 in each of the four summer months per installed device).

The PECO Smart A/C Saver switch is controlled via public VHF paging networks and only activated at times of high energy usage, during the summer months of June through September. Conservation events may occur on selected summer afternoons, between noon and 8 p.m. During peak summer hours, control signals can be sent to reduce air-conditioning load by cycling the compressor 50 percent within each home. The program is designed to provide demand response during PECO’s top 100 hours of system peak loads.

During control events, participants’ air conditioners are controlled using an adaptive algorithm. The adaptive algorithm records the compressor runtime, or duty cycle, in the hour before the event, then reduces the duty cycle by half during event hours (Comverge 2010). For example, if the duty cycle was 75% in the hour prior to the event (that is, the compressor ran for 45 minutes), the adaptive algorithm reduces the duty cycle to a maximum of 37.5% during event hours (22.5 minutes). A simpler algorithm, the simple switch method, caps the duty cycle at 50% during event hours, regardless of whether the air conditioner was running the full hour or not at all.

On July 21 and July 22, 2011 the PECO service area experienced a record breaking heat wave. PECO received many complaints from program participants regarding discomfort from heat. PECO asked Navigant to explore how the program was affecting discomfort. PECO also asked Navigant to explore the effects of the adaptive algorithm on discomfort and savings.

1 The Act sets mandatory targets for electric distribution companies in Pennsylvania, requiring reductions in energy use of 3% of energy and 4.5% of demand over four years

The Effects on Comfort

PECO did not control all customers during the heat wave. This provided the opportunity for a natural experiment. The program implementer installed 100 meters on a group of 79 customers for the purposes of measurement and verification (the "M&V Sample"). PECO called a control event for the M&V Sample on Wednesday, July 20, and Thursday, July 21. On July 22, the regional transmission organization, PJM, called a control event for utility customers across the region. The PECO program manager did not want to control the M&V Sample for the third day in a row out of fear that these customers would drop out of the program and the valuable metering points would be lost. Consequently, on Friday, July 22, all program participants excluding the M&V Sample experienced an event. This situation provided the evaluators with a natural experimental design. Navigant conducted a survey, shortly after the heat wave, of two groups:

1. 46 customers in the M&V Sample and
2. 260 other participants ("the Participant Sample")

The survey explored issues related to comfort levels and also characteristics of air conditioning operation and of the homes.

Discomfort Level on Thursday and Friday

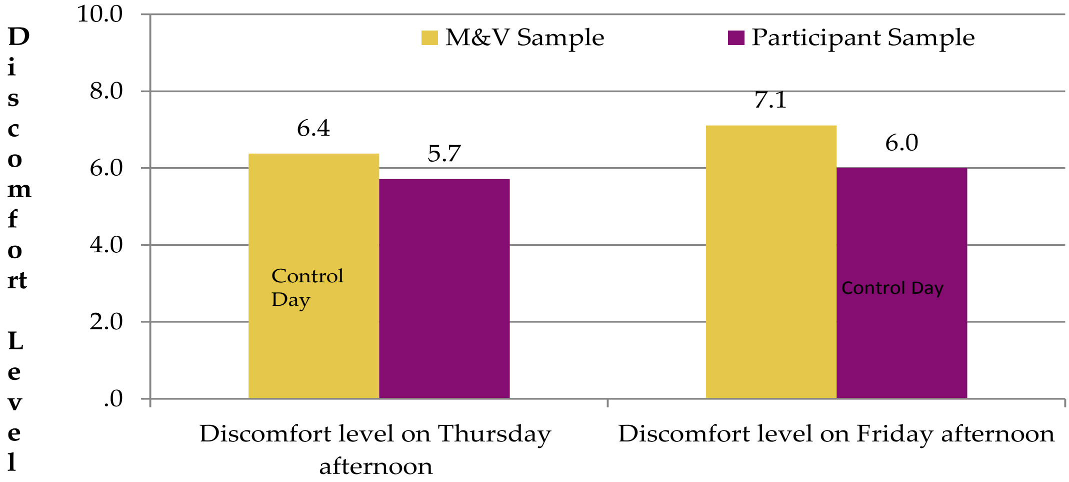
Navigant asked survey respondents: "What was your discomfort level, on a scale of 0 to 10 where 0 is no change in comfort and 10 is extremely uncomfortable?" The scale in this question, 0 to 10, increases as discomfort rises.

As shown in Figure 2, customers reported that discomfort rose between Thursday and Friday. The largest rise in discomfort between Thursday and Friday is reported by the M&V Sample. The discomfort measure rose from 6.4 on Thursday afternoon to 7.1 on Friday afternoon. Even though the M&V Sample was not controlled on Friday, their perception was one of increased discomfort. Participant Sample discomfort rose from 5.7 to 6.0 on the discomfort scale. Compared to the Participant Sample, the M&V Sample has a slightly higher level of satisfaction during both days. None of these differences are statistically significant.

The M&V Sample experienced more discomfort on Friday when they were not controlled than on Thursday when they were controlled. And although Friday was a hotter day than Thursday, the Participant Sample was only slightly less comfortable on Friday than they were on Thursday.

As expected, on Thursday when the M&V Sample experienced a control event, they were less comfortable than the Participant Sample who did not experience a control event. On Friday, the opposite occurred. The Participant Sample experience a control event and the M&V Sample did not. The relationship between the M&V Sample and the Participant Sample remained the same on both days. The M&V Sample still reported less comfort than the Participant Sample. The Participant Sample was only slightly less comfortable on Friday compared to Thursday, even though it was a control day for them.

Figure 2. Discomfort Levels Were Not Significantly Related to Control Event



Source: Navigant analysis.

Details of Customer Discomfort

Sixty percent of all survey respondents were comfortable in their home on Thursday, July 21. Those who became uncomfortable started noticing their change in comfort around 3:30 in the afternoon, although times ranged from 1:00 PM to 7:00 PM. Thirteen survey participants in the M&V Sample and seven participants in the Participant Sample were asked what was causing the discomfort in their homes. A majority (55%) said high temperatures were causing the discomfort compared to only 25% who blamed their discomfort on the humidity.

Again, most customers, 62%, were comfortable during the afternoon of July 22 during the control event. Those who were uncomfortable began noticing the home heating up around 3:00 PM on Friday afternoon - slightly earlier than on Thursday afternoon. The earlier mean time was due to five participants who noticed the heat at 1:00 PM or earlier. Times ranged from 12:00 PM to 7:00 PM. Of the eighteen survey participants who were uncomfortable in their home on Friday, over half of them mentioned the high temperature and over 20% mentioned the high humidity as the cause of their discomfort.

M&V customers who were not aware of the Thursday control event were more satisfied with the comfort of their home than those who indicate they were aware of the event. Almost 80% of survey participants who were not aware of the event expressed high levels of satisfaction with the comfort level of their home. In comparison, only 60% of M&V survey participants who were aware of the event were highly satisfied with their comfort level. M&V customers who did not know for sure whether they knew about the event were moderately satisfied with the comfort level in their home. These differences are significant at the 0.02 level according to Pearson's Chi Square test.

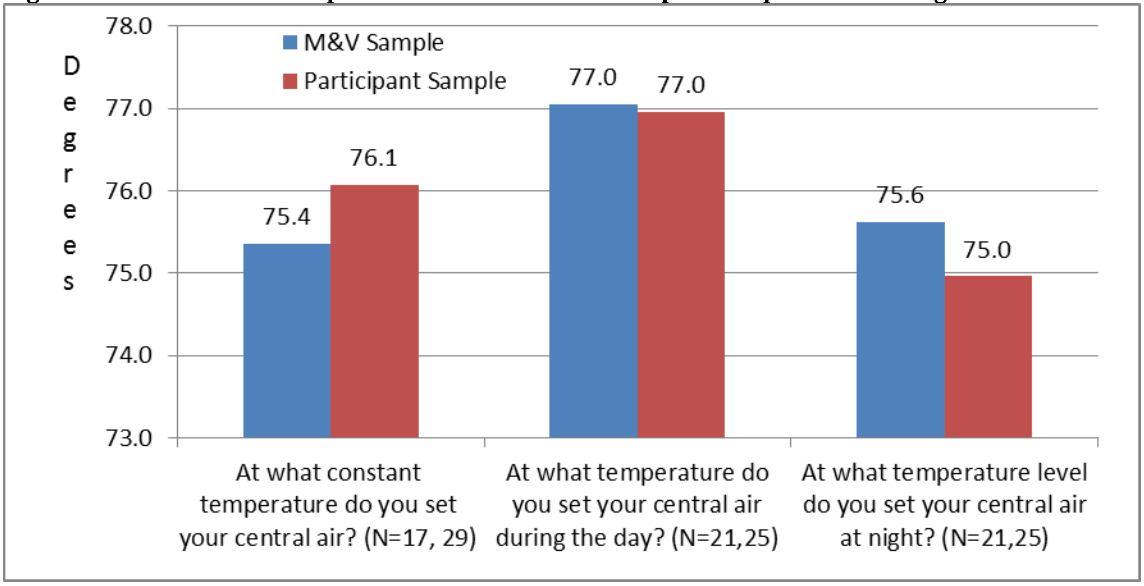
How Survey Participants Operate their Air Conditioners

Overall, about 43% of survey participants report they operate their central air conditioner manually. Fifty-seven percent said their air conditioner unit is programmed.

Survey participants who program their air conditioner are equally likely to keep their thermostat constant as they are to program the thermostat for different temperatures during the day and the evening, whether they are in the Participant or M&V Sample. A similar percentage set their controls to keep a constant temperature during the day and the evening as set different temperatures between daytime and night time (about 40%). Thirteen percent adjust the temperature as needed for comfort.

The selected M&V Sample of 79 customers set their constant temperature about one degree cooler than the overall Participant Sample. The Customers who program their thermostat for different temperatures during the day and the night, on average, lower their temperature in the evening about two degrees. Figure 3 presents these results. These differences are not statistically significant showing there are no differences in how customers in the two samples use their air conditioners during the day or at night.

Figure 3. Differences in Temperature Levels between Sample Groups Were Not Significant.

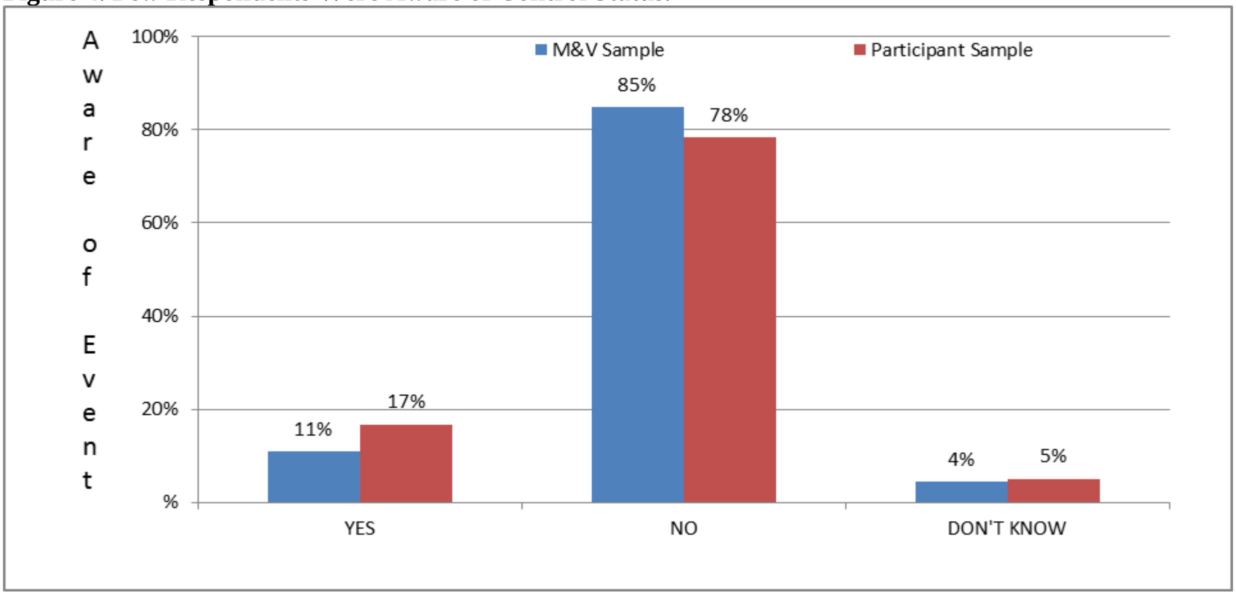


Source: Navigant analysis.

Awareness of the Thursday, July 21 Control Day and the Friday, July 22, Control Day

Only a small number of survey participants whether M&V or Participant Sample (11%, 17%), knew that it was a control day. In the Participant Sample, five checked the light on the control unit to confirm it was a control day, while two M&V Sample survey participants called customer call centers, as shown in Figure 4.

Figure 4. Few Respondents Were Aware of Control Status.



Source: Navigant analysis.

Demographics

Customer homes in both samples averaged about 2,350 square feet in size and were slightly less than 20 years old. Over half of the homes were wood frame (53%), almost one-third were brick or brick veneer (31%) and 16% were other masonry construction.

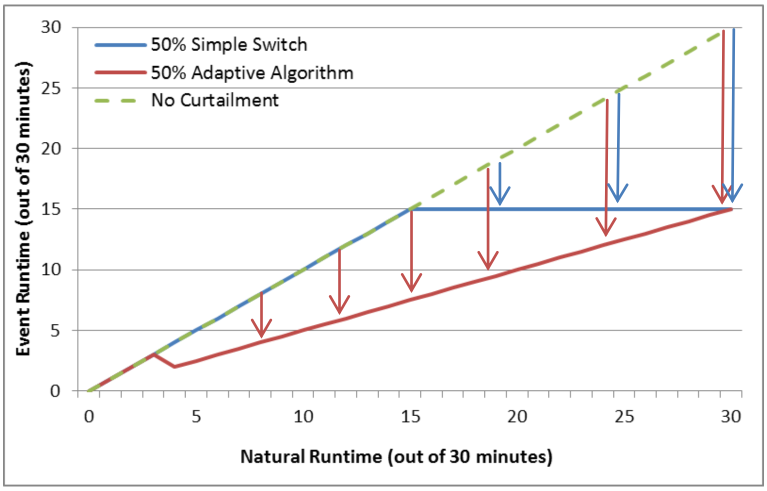
Survey participants with high satisfaction levels of comfort during a control event report smaller homes than participants with moderate or low satisfaction with the comfort level during a control event. Those with high satisfaction report mean square footage of 2,156 compared to 2,811 square feet for customers with low satisfaction and 2,952 square feet for customers with moderate satisfaction with the control event. These differences are statistically significant at the .02 level of significance. One theory is that smaller homes are more likely than larger homes to have an oversized HVAC system, which serves the customer well during a heat wave. To the extent that this occurred in the PECO service area, over-sized units would explain this difference in the level of satisfaction by the size of the home.

A similar pattern is seen for age of home. Program participants with high satisfaction report the oldest homes with an average of more than 37 years. Those with moderate satisfaction say their homes are about 22 years old and program participants with low satisfaction with the comfort of their home during a control event report homes about 27 years old. These differences are statistically significant at the .02 level of significance. One theory is that contractors in the past were more likely than current contractors to oversize the HVAC system which serves the customer well during a heat wave. To the extent that this occurred in the PECO service area, over-sized units would explain this difference in the higher levels of satisfaction by age of the home.

The Effect of the Adaptive Algorithm

The adaptive algorithm in use during the control event provides significant savings over a comparable simple switch method when the air conditioner is not running at full capacity, such as on days with milder weather conditions or for oversized units. On the hottest days, such as the heat wave, the difference in savings, and therefore discomfort, approach zero. As illustrated in Figure 5 below, the simple switch method results in no savings when the natural duty cycle is less than 50% (a runtime of less than 15 out of 30 minutes). On the other hand, the adaptive algorithm results in savings (corresponding to the red arrows) for nearly the entire range of natural duty cycles, with the exception of natural duty cycles below 10%. For natural duty cycles greater than 50%, the simple switch method results in savings (corresponding to the blue arrows), but these savings are less than savings resulting from the adaptive algorithm in every instance, except when the compressor was scheduled to run for the entire hour.

Figure 5: Compressor Runtimes, Adaptive Algorithm versus Simple Switch



Source: Navigant analysis.

This particular adaptive algorithm assumes that the duty cycle during the event hours would have been equal to the duty cycle in the hour before the event. Realistically, the duty cycle could likely increase with the length of the event. Continuing with our previous example, suppose the duty cycle in the hour before the event was 75%. The adaptive algorithm reduces the duty cycle to 37.5% during each event hour. However, suppose the natural duty cycle during the event hours increased to 80% in the first event hour, 85% in the second and third event hours, and 90% in the fourth and final event hour. In this case, by reducing the duty cycle to 37.5% during event hours, the adaptive algorithm is curtailing the unit by more than 50%. Alternative adaptive algorithms employ "learning" (Alexander, et al. 2008) by storing information about the unit's duty cycle on non-event days with extreme weather conditions. These algorithms essentially predict the natural duty cycle during each event hour and curtail the unit appropriately.

In an effort to quantify the difference in program savings from an adaptive algorithm compared to expected savings from a simple switch method, Navigant employed regression analysis to predict the natural duty cycle for each unit during the event hours. The difference between the observed and predicted duty cycles during event hours is the direct impact of the adaptive algorithm. Navigant compared the summer 2011 savings from the adaptive algorithm to the savings that would have occurred with the simple switch method. We calculated per unit savings[2] of 0.738 kW from the adaptive algorithm, while the simple switch would have reduced savings by 0.275 kW, or approximately 37%, under the same conditions. Note that the difference in savings from the two methods depends on the natural duty cycles of the units during event hours, which in turn depend on the weather conditions during the events (recall Figure 5). The events of summer 2011 were called during relatively mild weather conditions, when natural duty cycles were less than 100%, in addition to the heat wave. When program events are called during more extreme weather conditions such as the recent heat wave, Navigant expects minimal difference between savings and comfort from the two methods, based on the reduced differences in event run-time as natural run-time grows longer.

Conclusions

The analysis showed DLC control has little influence on customer comfort during a heat wave. Customers in the two samples are very similar in their comfort levels, in how they program their thermostats and in how they reacted to the two heat wave days. Navigant believes there is no

2 Savings calculated for the hour of 4-5pm and for a weighted THI of 83.1.

evidence for treating the M&V Sample differently from the Participant Sample during an event.

Knowledge of the event appears to increase discomfort during the event, especially for those customers in the M&V Sample. There is a fine line to walk here. PECO has a responsibility to meet the needs of customers who want to know when control events are happening but, overall, customer satisfaction is best served by keeping event information knowledge low key.

The adaptive algorithm provides significant savings relative to a simpler algorithm when natural duty cycles are significantly less than 100%. As natural duty cycles approach 100%, as we would expect during extreme weather conditions, the two algorithms are likely to provide similar savings. It is unlikely that the adaptive algorithm would have a significant effect on comfort during heat waves.

References

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