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White paper

# Thermostat cycling vs. temperature offset, customer comfort and load reduction analysis

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## Executive summary

Utilities are increasingly implementing residential demand control programs that rely on Programmable Controllable Thermostats (PCTs) to address peak load, procurement economics, and improve overall reliability of the power system.

PCTs are typically deployed using either Thermostat Cycling or Temperature Offset methods to manage the energy consumed by Heating, Ventilation and Air Conditioning (HVAC) systems. Tests have shown that Thermostat Cycling is more efficient as it provides benefits to both the consumer and the utility. From a utility perspective, cycling provides predictable demand reduction over multiple hours of control. For customers, the periodic cycling of the HVAC system improves comfort by moderating the rate of temperature rise and reducing humidity.

## Introduction

Peak demand control is a proven tool that has been used by utilities for many years to address energy management challenges and improve the reliability of the power system. Peak demand control involves reducing system load during periods of high usage. This reduces supply costs, which are particularly high at times of peak usage, and also increases reliability by preventing any possible system overload.

Peak demand control programs for residential customers typically use either switches or PCTs to control the energy consumed by Heating, Ventilation and Air Conditioning (HVAC) systems.

To help determine how PCTs can deliver the optimum balance between the amount of load shed and the customers' comfort, this paper examines the two distinct ways they can be used in residential demand control programs. The first is called "Temperature Offset" and, as the name suggests, it uses a temperature offset to remotely raise the current set point during the period of time that the utility initiates its demand response program to reduce load. This period of time is also referred to as a "control event". While this simplifies temperature control and maximizes load shed for short periods of time,[1] it affects customer comfort and provides a variable load for the utility to manage.

The second method, referred to as "Thermostat Cycling", involves sending a command that cycles the HVAC system to lower the operating duty cycle and reduce energy consumption during a control event. In contrast to Temperature Offset, Thermostat Cycling curtails the HVAC system for a period of time and allows it to then run for a second period of time. If the cycling strategy includes an Adaptive Algorithm to handle oversized compressors, Thermostat Cycling can improve both customer comfort and load shape for control events for multiple hours.

To demonstrate how Thermostat Cycling and Temperature Offset impact load control and customer comfort, this paper details the results of a residential peak demand control program conducted in a hot Southwestern climate.

1. The offset amounts to 100 percent of cycling strategy of the compressor plus curtailment of the circulating fan, until the offset temperature is reached. The circulating fan will be off when the compressor is off if the thermostat is set in the AUTO mode. The fan would remain on if the fan is set ON at the thermostat. The AUTO mode of operation is the most widely observed method.

# Temperature offset

Temperature Offset raises the thermostat set point by a fixed amount, typically 4°. The compressor and circulating fan are subsequently switched off until the new set point is reached and, at that time, the thermostat returns to normal operation at the new, higher temperature level.

To determine how Temperature Offset impacts load shed performance and customer comfort, this section will examine a large number of homes at a temperature equal to the average summer peak temperature for three different control events, each lasting three hours. The data from each site will include the interior temperature at the end of each hour and the duration of compressor run-time during that hour.

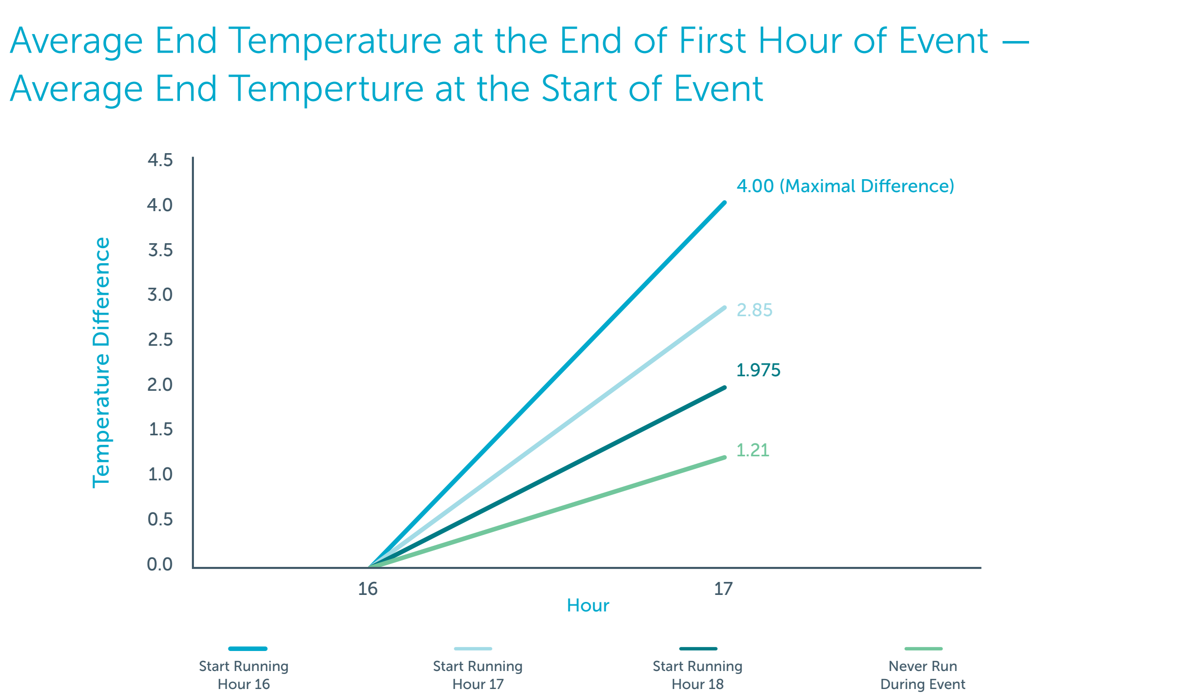
For these events, the thermostat set point was raised by 4° at 15:00. As the thermostat settings were raised, the compressor was held off until the interior temperature reached the higher set point. The dashed blue line in Figure 1 shows homes that rose 4° within the first hour of control. Since the compressors in these homes came on during the first hour of the event, it can be determined that the rate of rise was at least 4° per hour, but it is not possible to calculate the exact rate of temperature rise as readings were only available at the end of each hour.

This was repeated for homes where the compressor did not come on until the second hour. For these homes where the compressor came on during the second hour of the event,[2] the average temperature rise was 2.85° per hour.

The homes where the compressor did not come on until the third hour experienced a rise of 1.975° per hour. For some homes, the compressor did not come on at all during the event. These homes showed a temperature rise of 1.21° per hour.

The data clearly show when different groups would reach the 4° offset value where the air conditioning would turn on.

Figure 1 — Hourly rate of temperature rise for residences.



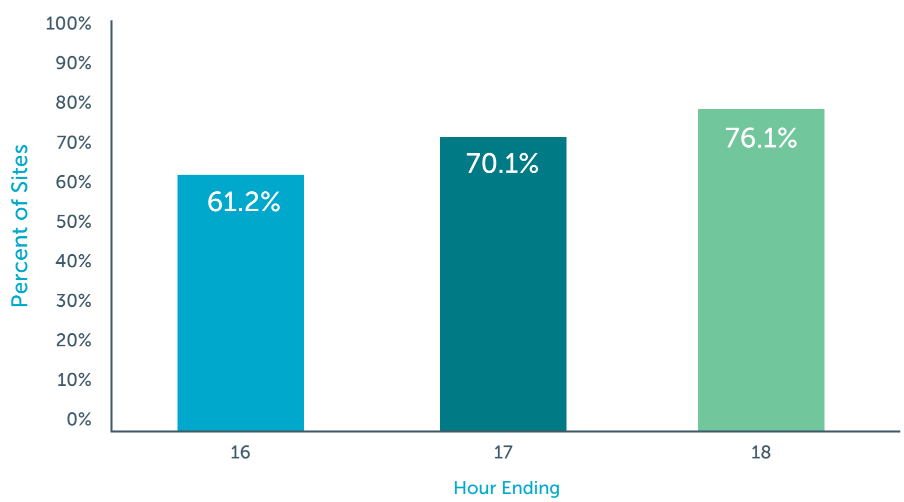

2. We look at the rise in the first hour because this data is unaffected by compressor run time and hence it gives us an unaffected end temperature.

# Temperature offset

To demonstrate what this means for today's power system, Figure 2 shows how the population can be divided into these groups. Interestingly, the majority of residences (61.2 percent) will rise 4° within the first hour of a control event and then remain at that new set point for the remainder of the event. Approximately 10 percent of compressors come on in the next hour and an additional 6 percent start in the third hour. The remaining 23.9 percent of the population had compressors that did not run in the hour prior to control and hence were eliminated from this analysis (estimated at 14 percent of the population), or did not experience a significant enough temperature rise for the compressor to be activated during the three-hour test period. Of note, while the rate of rise may be less when peak temperatures are not reached, the impact on the load would be the same, with a large initial load drop followed by a very small load contribution after the new offset period is reached.

Figure 2 — Over 60% of residences reached a 4° offset in the first hour.

## Percentage of sites with non-zero run time during hour



# Temperature Cycling

**The concept of cycling air conditioner compressors to achieve demand response is well established and is the standard method used for compressor mounted load control switches.**

Thermostat controls however deliver the flexibility to offer different operating modes (e.g., varying the programmed operation as a function of price and displaying the price on the thermostat), direct programmability to respond to price signals, and the potential for controlling the circulation fan of the HVAC system. These capabilities, combined with the potential to operate in a mode that cycles off both the compressor and the circulating fan for selected intervals in response to a load control initiation signal, give thermostat controls a significant advantage over compressor mounted switch-based programs.

Specifically, in relation to Temperature Offset, this mode of operation offers the following advantages:

- **Increased Customer Comfort:** Periodic running of the system is more comfortable for occupants as it decreases the rate of temperature rise over time.
- **Reduced Humidity:** Since the system is run periodically, the humidity does not increase as much as with temperature offset.
- **Predictable and Evenly Distributed Load Shed:** The load shed provided by this method of control is predictable and more evenly distributed over the control interval when compared to Temperature Offset, which is weighted for the initial period after control.
- **Accurate Forecasts:** With near real-time data from a monitoring and verification system, the hourly load sheds for Temperature Cycling can be more accurately forecasted than with Temperature Offset.

# Cycling with adaptive algorithm

An Adaptive Algorithm allows cycling times to be modified based on historical run time data and is more effective than applying a simple time-based algorithm for cycling (e.g., turn the HVAC off for 30 minutes and then allow it to run for 30 minutes).

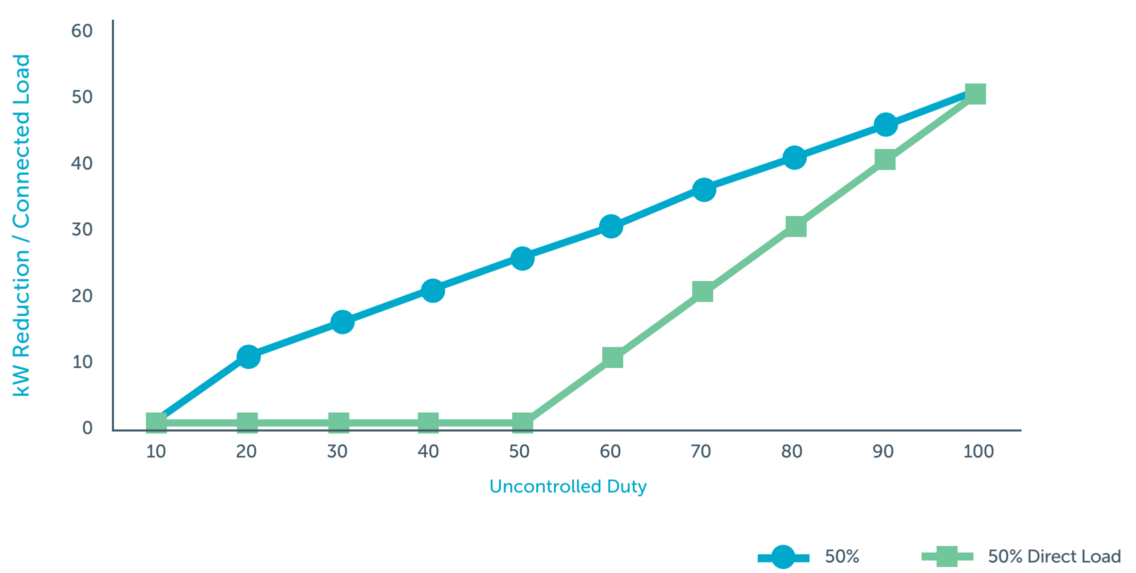
To accurately modify cycling times, an Adaptive Algorithm learns the compressor run time pattern and then compensates for it during a control event. This provides equitable load shed contribution from all participants for both oversized compressors and operations at temperatures below the maximum design temperature in an area. In both of these real-world scenarios, compressors will not run constantly and, with a simple 50 percent control strategy, the compressor will be held off for 30 minutes in an hour. If the compressor can maintain temperature during that hour by running for less than 30 minutes, the compressor will not contribute any load to the control event and the temperature will not rise in the home.

With an Adaptive Algorithm, the switch or thermostat monitors prior run time and compensates if the run time is less than the full hour. So if a compressor only runs for 30 minutes in an hour to maintain temperature, the algorithm for 50 percent cycling will take half of that run time and only allow the compressor to run 15 minutes per hour during the control event.

The problem with oversized compressors at a given temperature is illustrated in Figure 3, which shows data on compressor run time for an Adaptive Algorithm compared to a simple time-based solution. This figure shows that until the compressor runs 50 percent of the time, a non-adaptive solution provides no kW reduction, whereas the Adaptive Algorithm solution provides immediate kilowatt savings.

Figure 3 — Adaptive Algorithm cycling provides significantly more load drop compared to time-based control.

## Comparison of kW reduction for 50% ADAPTIVE vs. 50% DIRECT CONTROL Percentage of Connected Load Reduced vs. Uncontrolled Duty



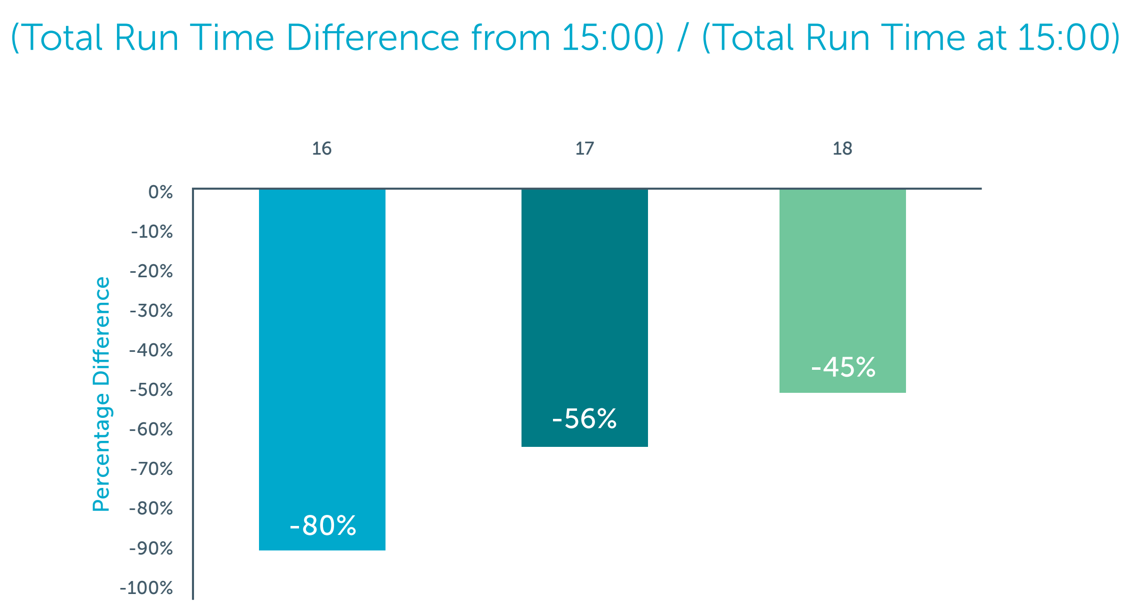
# Load shed for offset

Having evaluated some of the differences between Temperature Offset and Thermostat Cycling, this paper will now examine the actual load shed for each during peak demand control events.

Figure 4 shows the load shed for Temperature Offset over the course of the three-hour events, while Figure 5 shows a four-hour load drop for 50 percent adaptive cycling. The drop is plotted relative to a baseline of the load in the hour prior to the control event. Of note, the load shed for the Temperature Cycling is uniform throughout the duration of the event. This is very important for situations where the load shed is required over an extended period of time as this flat load shape enables the load drop to be accurately estimated over a period of time if the load in the prior hour is known.

Stated in another way, with Temperature Offset, the load drop for the population will vary from hour-to-hour and the extent of the variation will be difficult to estimate since it is dependent on factors such as the ambient temperature and the level of insulation. In contrast, with Adaptive Cycling, if the load in the prior hour is known (via monitoring and verification for example), then the load shed for the duration of the event is not strongly dependent on temperature and remains nearly constant throughout the event's duration.

Figure 4 — Load shed for Temperature Offset with Temperature Cycling decreases for each event hour and the drop is hard to predict.



# Conclusion

This paper demonstrates how Thermostat Cycling and Temperature Offset can be used in peak demand control programs to manage load shed performance and customer comfort and examines how the optimum balance can be achieved.

In summary, Temperature Offset provides a large initial load shed that decreases over time and is likely to maximize customer discomfort by rapidly increasing the interior temperature for the average household. In contrast, Thermostat Cycling delivers a lower and more predictable load shed that improves customer comfort for a longer period of time. The data also indicates that harder cycling would be possible for this population at the temperature analyzed.

Another important conclusion is that Thermostat Cycling without an Adaptive Algorithm allows for a high percentage of free riders who are unaffected by peak demand control programs and contribute little or no load.

Figure 5 — Adaptive Temperature cycling provides a flat, predictable load drop over a four-hour event.

(Total Run Time Difference from 15:00) / (Total Run Time at 15:00)