WHITE PAPER

Seasonal Savings

Nest Labs, Inc.
April 2013

Seasonal Savings: Heating season field trial results and simulation results for cooling season

1. Introduction

The Nest Learning Thermostat Seasonal Savings™ feature identifies opportunities to save customers energy without sacrificing comfort. It automatically adjusts the temperatures in Nest's schedule over several weeks and eventually creates a schedule that uses 5-10% less heating and cooling, on average.

Seasonal Savings is highly personalized and uses the Nest thermostat's knowledge of each customer's temperature preferences and occupancy patterns to optimize their schedules. Users can adjust the temperature or their schedule at any time and aren't locked into the schedule that Seasonal Savings creates.

Seasonal Savings is available at the beginning of each heating and cooling seasons. For this paper, we ran a heating season trial with Nest beta testers in March 2013 to assess the effectiveness of Seasonal Savings and people's reaction to it. We then used data from our heating trial as well as weather projections to estimate savings for different parts of the country and for the cooling season.

Highlights:

- After Seasonal Savings, our field trial participants used 5-10% less heating. Based on heating results, we simulated similar results for cooling schedules.
- The temperatures in users' schedules became 1.5ºF more efficient on average after Seasonal Savings. This factors in both the changes that Seasonal Savings made and those that users made themselves.
- 80% of people decided to keep their new schedule after Seasonal Savings was done.
- Only 9% of people thought their new Seasonal Savings adjusted schedule was not as comfortable as their old one.

2. Heating season field trial methods

2.1 Heating trial coverage

To qualify for the trial, Nest Learning Thermostats had to be in Heat or Heat • Cool mode, actively heating in the week prior to the Seasonal Savings trial, and connected to Wi-Fi.

This trial was presented to participants on March 3, 2013, and they were given 7 days during which they could start.

45 States were represented in the field trial, with a distribution similar to the US population.

Seasonal Savings could be terminated altogether by changing modes (going from heating to cooling, for example), or choosing “STOP Seasonal Savings” from the Settings menu.

454 thermostats qualified for Seasonal Savings during the heating season. 86 of these did not complete the Seasonal Savings trial:

- 61 thermostats ended Seasonal Savings by switching from Heat to Cool
- 3 turned Auto-Schedule off or on, thereby ending Seasonal Savings.
- 2 stopped Seasonal Savings before it was done and chose to revert back to their original schedule.
- 20 stopped Seasonal Savings before it was done - but chose to keep their new schedule.

The remaining 368 thermostats completed the Seasonal Savings trial. For the remainder of this paper, we’ll focus on these thermostats (“devices”).

2.2 Typical schedule changes

Each device’s schedule changed slowly over 2-3 weeks. Exactly how long Seasonal Savings lasts depends on variants like user interaction and occupancy patterns. Here’s what users experienced:

- The nighttime temperature began adjustments on the first day and was adjusted the most during the Seasonal Savings trial.
- Temperature changes while people were home - like in the mornings and evenings - took place later in the Seasonal Savings process. These adjustments were also smaller than those done at night.
- Seasonal Savings is designed to respect the user’s adjustments, so when the user changed the temperature while Seasonal Savings was running, Nest learned and sometimes slowed or stopped Seasonal Savings’ automatic temperature changes for them.
- This means that the user had the full freedom to change their schedule. For this study, all the changes they made are incorporated in the overall analysis, and resulting schedules include changes made by the user.

2.3 Savings computation

To calculate the savings that resulted from Seasonal Savings, we created a model to predict how many hours of heating and cooling each Nest Learning Thermostat would have used without Seasonal Savings.

A large sample of devices was used to build and validate the model. Over 10,000 devices running heat in winter 2012 and running cooling in summer 2012 were used.

The device data was used to fit the following statistical model:

$$Heat\_Runtime = a * Temp\_target + b * Temp\_outside + c$$

- For any given day, *Heat_Runtime* is the total minutes of time that Nest commanded heat to be on.
- *Temp_target* is the time-normalized room temperature set point.
- *Temp_outside* is the average outside temperature for that day.
- The model fit is good: the estimated coefficients have small standard errors of 0.2 to 1.2%.

With the trained model data, different *Temp_target* can be used to predict the *Heat_runtime*.

Comparing the original schedule (manifested into *Temp_target*) and the resulting schedule after Seasonal Savings results in estimated savings which is computed using:

$$Estimated\_savings\% = 1 - \frac{Heat\_Runtime\ (after\ seasonal\_savings)}{Heat\_Runtime\ (before\ seasonal\_savings)}$$

3. Heating season field trial results

3.1 Schedule changes

On average, Seasonal Savings dropped the mean temperature for all users by 1.5˚F. This is equivalent to reducing their entire day/week schedule by 1.5˚F. Looking at the charts below, we can see that users who adjusted the temperature during Seasonal Savings saw a smaller drop in their average temperatures, while those who allowed it to run uninterrupted saw the temperatures in their schedules fall an average of 1.74˚F with a single set point maximum change of 3.8˚F.

Table 1 shows the average maximum/minimum/mean temperatures from all the device’s 7-day schedules. These temperatures were captured right before and right after Seasonal Savings and include schedules that Seasonal Savings adjusted with no interruption and schedules that were adjusted by the user, either to be more or less efficient. The mean temperature is normalized by time.

All devices (368)	Maximum (ºF)	Minimum (ºF)	Mean (ºF)
Before SS	69.38	63.35	66.67
After SS	68.56	60.95	65.00

Table 1: All schedule temperatures before and after Seasonal Savings

Tables 2 and 3 show the average maximum/minimum/mean temperature for two subgroups:

- Table 2: Users who didn't adjust the temperature while Seasonal Savings was actively adjusting a set point. The mean fell by 1.74˚F for these users.
- Table 3: Users who did adjust the temperature while Seasonal Savings was actively adjusting a set point, thus changing the schedule that resulted. These users experienced an average reduction of 0.97˚F across their schedule.

Devices completed with SS schedule (262)	Maximum (ºF)	Minimum (ºF)	Mean (ºF)
Before SS	69.34	63.52	66.52
After SS	68.37	60.73	64.78

Table 2: Users who did not adjust the temperature while Seasonal Savings was running.

Devices with user modification (106)	Maximum (ºF)	Minimum (ºF)	Mean (ºF)
Before SS	69.46	62.86	66.37
After SS	68.99	61.27	65.40

Table 3: Users who did adjust the temperature while Seasonal Savings was running.

Finally, in Table 4, we calculate that the temperature would have fallen by 1.99˚F if all devices had completed Seasonal Savings without any manual adjustments during times when set points were being adjusted by Seasonal Savings.

Simulated All Devices SS schedule (368)	Maximum (ºF)	Minimum (ºF)	Mean (ºF)
Before SS	69.38	63.35	66.50
After SS	68.36	60.31	64.51

Table 4: Simulated data if there were no manual adjustments by users.

4. Heating season simulation results for different climate regions

The table below (Table 5) shows how much runtime (hours of heating) falls with every 1˚F that you lower the target temperature. It uses the linear model described above and shows both regional averages and the US national average.

Climate	Runtime reduction per °F decrease	Runtime reduction with Seasonal Savings (including user adjustments)	Runtime reduction with Seasonal Savings (excluding user adjustments)
Very-Cold	3.5%	5.3%	7.1%
Cold	4.0%	6.1%	8.1%
Mixed-Dry	6.9%	10.4%	13.8%
Mixed-Humid	4.1%	6.1%	8.1%
Marine	4.3%	6.4%	8.5%
Hot-Dry	4.2%	6.4%	8.4%
Hot-Humid	3.4%	5.0%	6.7%
Overall	**4.1%**	**6.2%**	**8.2%**

Table 5: How much heating runtime changes for every 1˚F decrease in the target temperature

From the trials, the average temperature reduction due to Seasonal Savings was 1.5˚F. This translates to a savings range of 5.0% (Hot-Humid) to 10.4% (Mixed-Dry).

As stated earlier, the simulated average temperature drop due to Seasonal Savings when users did not make manual adjustments was 1.99˚F. Therefore, it can be shown that manual adjustments account for a 24.6% [(1.99˚F-1.5˚F)/1.99˚F] reduction in savings.

5. Cooling season simulation results for different climate regions

Since a cooling Seasonal Savings trial had not been run at the time of this paper, we conducted a simulation. We looked at devices that were cooling in August 2012 and calculated what the results would be if we applied Seasonal Savings to those schedules. Then we applied the damping effect (24.6%) found from user adjustments in the heating trial.

As with the heating simulation, the cooling simulation is based on cooling runtime estimations that take into account the target temperature and outdoor temperature. This computation was done for different climate zones, just like the heating simulation. The table below (Table 6) shows the regional and US national average for how much runtime falls with every 1˚F you increase the target temperature.

Climate	Runtime reduction per ºF increase	Runtime reduction with Seasonal Savings (including user adjustments)	Runtime reduction with Seasonal Savings (excluding user adjustments)
Very-Cold	5.6%	6.1%	8.1%
Cold	8.9%	9.8%	13.0%
Mixed-Dry	10.5%	11.5%	15.2%
Mixed-Humid	7.9%	8.7%	11.5%
Marine	7.0%	7.7%	10.2%
Hot-Dry	7.1%	7.8%	10.3%
Hot-Humid	11.0%	12.1%	16.0%
Overall	**9.1%**	**10.0%**	**13.3%**

Table 6: How much cooling runtime changes for every 1˚F increase in the target temperature

The smallest savings is seen in very cold climates, and is projected to be 6.1%. The largest savings will be seen in hot, humid climates, and will average out to 12%.

6. Survey results

One week after the trial ended, a survey was sent to the 368 participants who completed Seasonal Savings. 183 people responded to the survey.

a. 80% of people said they decided to keep the schedule Seasonal Savings had improved for them.

b. Only 9% of people said they are not as comfortable with their new schedule.

c. 86% of people said they felt they were in control the entire time Seasonal Savings was running. Only 1% of people said they felt they were not at all in control of the temperature.

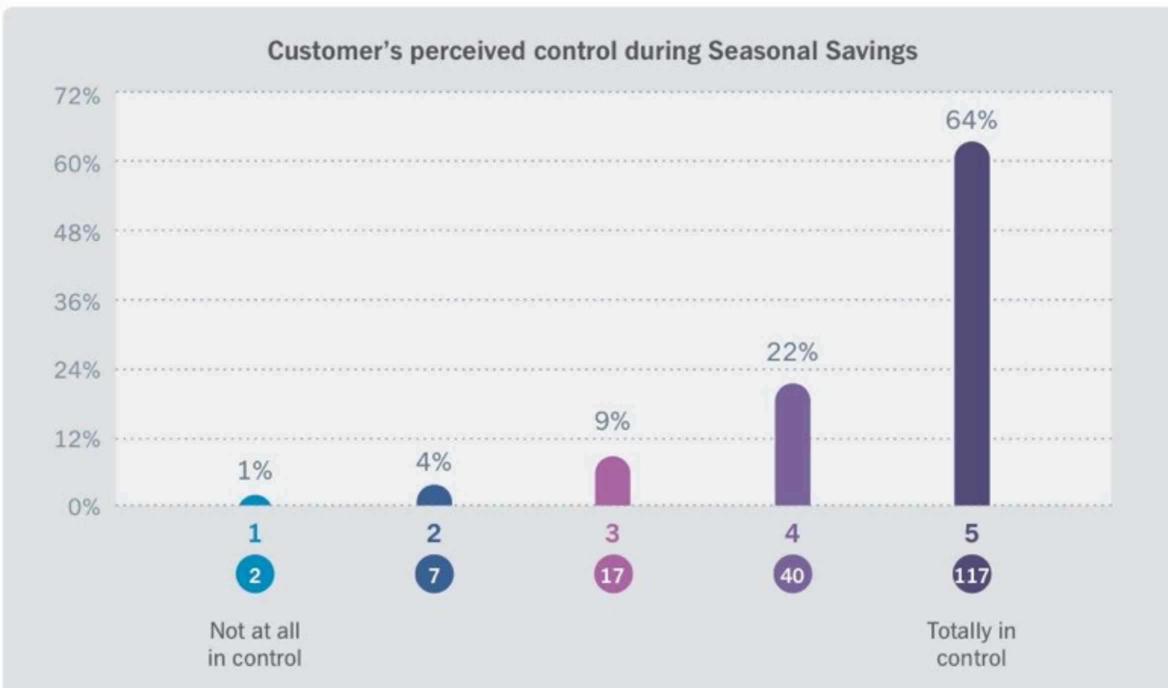

Figure 2: Customer's perceived control during Seasonal Savings

7. Conclusion

Overall, this field trial successfully saved energy for our users and kept them happy and comfortable.

After Seasonal Savings, our field trial participants used an average of 5-10% less heating and cooling with temperatures in their schedule changing only 1.5˚F on average. 80% of people decided to keep their new schedule after Seasonal Savings was done.