White Paper

Nest Learning Thermostat Efficiency Simulation for the U.K.

Nest Labs
April 2014

Introduction

This white paper gives an overview of potential energy savings using the Nest Learning Thermostat in the United Kingdom. The Nest Thermostat offers easy-to-use, energy-efficient features, programs itself and automatically turns down the temperature when users are away or asleep.

This paper presents an estimate of the expected energy savings based on simulations of different house types, climates, locations and user behaviors in the UK. The Nest Learning Thermostat balances energy savings and comfort for the simulations reflected in this paper. This white paper makes assumptions of households with moderate energy consciousness. All estimates are just estimates and don't guarantee specific energy savings from using a Nest Thermostat. Your actual energy savings will depend on factors beyond Nest's control such as your boiler, house construction and weather.

The simulations compare the estimated annual energy usage of homes operating under a variety of heating schedules, ranging from schedules with a constant 20°C temperature, to schedules with deep temperature setbacks for two significant periods per day (similar to having a programmer or timer) and during holiday periods. Depending on the user's house, climate, existing schedule and which features they use, the savings on their heating bill may range from 4% to 29%. This can result in annual savings ranging from £ 9 to £ 353.

When the Nest Thermostat launched in the U.S., a white paper was published based on simulations of potential energy savings. Six months later, the white paper was revised with data from real customer schedules and usage. The revision found that potential savings were even greater than those simulated in the first edition of the white paper. As more data becomes available, this white paper will be revised to reflect the latest findings.

Energy-saving features

The Nest Learning Thermostat offers several features that help users save energy: Auto-Schedule, Auto-Away, Time-to-Temperature, True Radiant, the Nest Leaf, Energy History and Report, and remote control using the Nest app.

Auto-Schedule

The Nest Thermostat automatically learns customers' schedules and preferences based on their selected temperatures. Through the automatic learning algorithm, the thermostat creates a setback schedule that uses a lower temperature setting when people are away or asleep, providing energy savings without compromising comfort.

Auto-Away and Away mode

Auto-Away detects when users leave the house, whether for several hours or several days. Sensor data is interpreted by algorithms to provide a confidence determination of the home's occupancy. When the confidence level is high, Auto-Away overrides the existing schedule to save energy. During Away periods, the heating setpoint (target temperature) is reduced to a user-selected value where efficiency gains can be realized. Away mode can also be set manually on the thermostat, or remotely using the Nest apps.

Even if Auto-Away is deactivated, customers can use remote control to save energy while out of the house.

Time-to-Temperature

The Time-to-Temperature feature calculates and displays in real-time an estimated time to reach the set temperature. People often set a very high temperature hoping to hurry their heating, but this behavior is inefficient. Time-to-Temperature assures the customer and discourages wasteful behavior.

True Radiant

True Radiant uses Time-to-Temperature to decide when heating should begin, in order to reach desired temperatures according to the Nest Thermostat's schedule. The learning algorithm accurately determines when to turn on heating to reach the right temperature at the right time, based on information about the home, the heating system and the weather. This feature can save a significant amount of energy.

Leaf

The Nest Thermostat encourages users to select energy-efficient temperatures by displaying a green Nest Leaf icon whenever those settings are reached. Efficient temperatures are specific to each household, based on the home, schedule and habits of the family.

Energy History and Report

Energy History displays a comparison of the last ten days of heating usage to a running ten day average, letting users know how much they used and why. By revealing the factors affecting their energy consumption, Energy History helps users understand how they can save even more energy.
Nest Energy Report is a monthly email sent to each customer with a connected Nest Thermostat that summarizes the previous month's heating usage, providing tips on saving energy. By comparing users to their peers, and to their own usage from month to month, customers are encouraged to be more efficient.

Methods

In order to analyze the energy savings that a Nest Thermostat might provide a user in the United Kingdom, simulations accounted for different house types and different climate regions. Energy usage for typical setpoints was simulated for a standard thermostat and for the Nest Learning Thermostat, taking advantage of its energy-saving features. Comparing these two simulations provides an estimate of the savings that different users might achieve.

Simulation model

The thermostat energy simulation is a dynamic model based on the main principles of heat transfer and heating equipment performance, incorporating state-of-the-art research on building and equipment performance. The model simulates the heating requirements of a single-family home using typical-year hourly weather data files from 15 weather stations in the UK (downloaded from http://doe2.com/Download/Weather/NON-US/uk.zip).

The model simulates building heat transfer using a standard $U*A*dT$ approach, where U is the heat transfer coefficient; A is the surface area; and dT is the difference between the indoor and outdoor

temperatures. The model incorporates the effects of the thermal mass of the building skin and also of the interior contents using a lumped capacitance approach. Solar gain through windows is modeled from hourly solar data. Air infiltration is based on a detailed infiltration model that includes wind and stack effects using hourly wind speeds and indoor and outdoor temperatures. Heating equipment is modeled to include transient start-up effects, distribution system thermal lags (using a time constant approach), distribution losses and interactions between the heating output and building thermal mass. The model employs a 30-second time step and simulates a full year of operation (i.e., more than 1 million time steps per year), which allows for dynamic HVAC effects and provides for direct solution of the thermal model at each step based on lagged values without requiring iteration. This level of detail was employed in the simulation to reflect important system dynamics that could have an impact on the energy savings provided by differing thermostat control strategies.

Model parameters

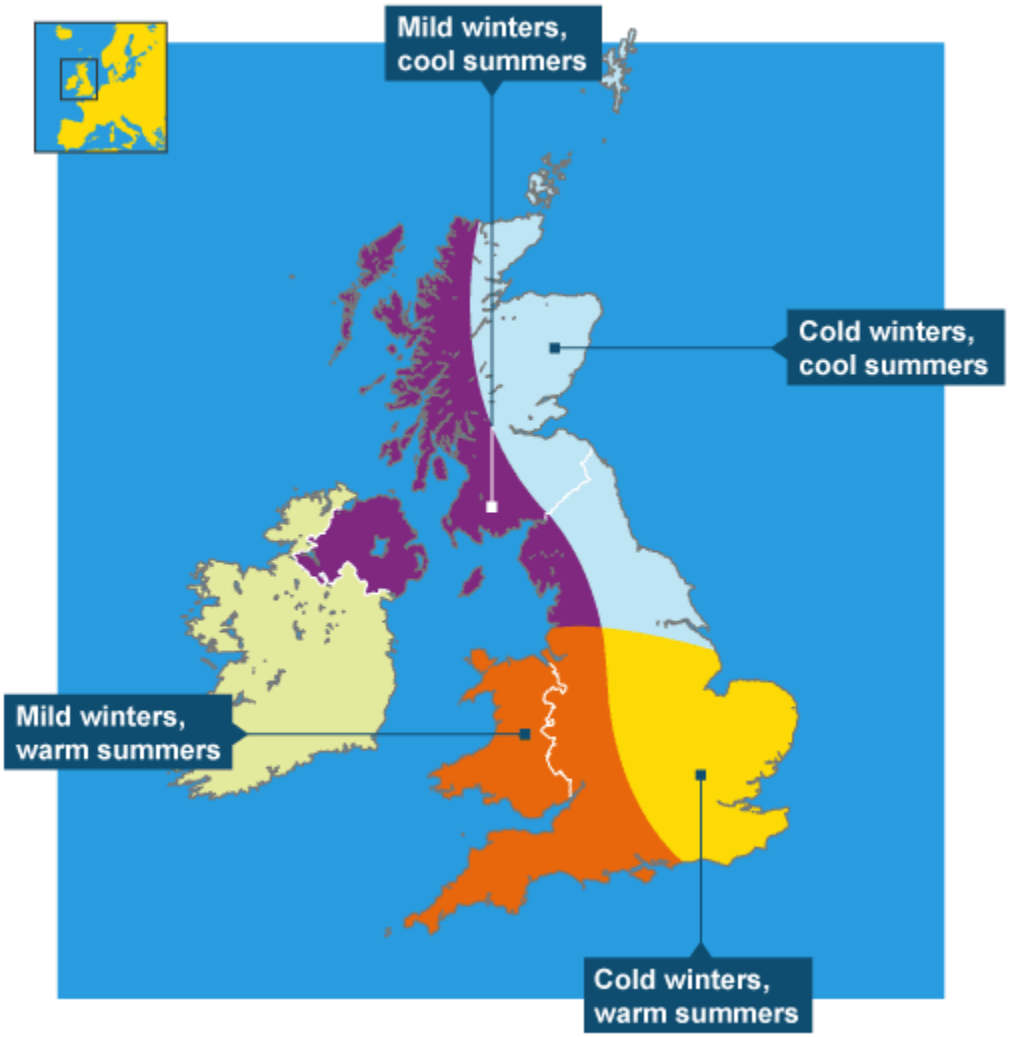
Climate regions

We ran the full set of simulations for four weather stations:

- London (Heathrow)
- Glasgow
- Aberdeen
- and Manchester.

These cities were chosen to represent the main four climate regions in the UK (Source: http://www.bbc.co.uk/bitesize/ks3/geography/physical_processes/weather_climate/revision/6/).

Figure 1: Climate regions in the UK



Prototype Home Configurations

Simulations were performed for three prototype home configurations:

- a 86 m² (925 ft²) detached home
- a 60 m² (645 ft²) semi-detached / end-terrace and mid-terrace home
- and a 46 m² (500 ft²) flat home.

The homes all had insulated walls (assembly U= 0.55 m²K/W) and some loft insulation (also U-0.55). The windows were assumed to be double pane (U-2.84) with window areas of 12.9m² for detached, 8.2m² for end-terrace, 7.5m² for mid-terrace and 4.6m² for the flat. The homes were assumed to be reasonably tight, using effective leakage areas to the exterior of 492 cm² for the detached home, 300 cm² for the end-terrace home, 278 cm² for the mid-terrace home and 80 cm² for the flat. The heating source was assumed to be a boiler with an 80% efficiency.

Definition of baseline

In this white paper, energy savings from the Nest Thermostat are calculated relative to two baseline schedules. The first baseline schedule has a constant setpoint temperature at 20°C throughout the

week. The second baseline schedule incorporates the effect of an external timer or programmer that prevents the heater from turning on between 22:00 and 05:00.

Pathways to energy savings

To show the Nest Thermostat's energy efficiency, four possible schedules were simulated, taking advantage of Nest's features. Each of these alternatives incorporates different combinations of schedule setpoint temperatures held throughout the year, as a result of the energy saving features.

1. 20°C baseline temperature with a 9°C setback for seven hours per night (10PM - 5AM)
2. 20°C baseline temperature with a 9°C setback for seven hours per night (10PM - 5AM) and during a two-week away period in mid-winter
3. 20°C baseline temperature with a 9°C setback for seven hours per night (10 PM - 5AM) and for nine hours per day (8AM- 5PM)
4. 20°C baseline temperature with a 9°C setback for seven hours per night (10 PM - 5AM), for nine hours per day (8AM- 5PM) and during a two-week away period in mid-winter

In the first example Nest assumes the use of Auto-Schedule to add a temperature setback during the night. The second schedule uses Auto-Away to reduce heat during a winter vacation. The third schedule uses Auto-Schedule and Auto-Away to reduce heating while residents are away during the day. The fourth schedule combines all of these advantages, with nighttime and daytime setbacks and the winter vacation setback.

Energy costs

Energy costs are assumed to be constant at 4.870p per kWh for gas (http://www.britishgas.co.uk/products-and-services/gas-and-electricity/our-energy-tariffs/Tariffs-A-Z.html).

Results

This section shows the results of the simulations and related estimates of energy savings. All estimates are just estimates and don't guarantee specific energy savings from using a Nest Thermostat. Actual energy savings will depend on factors beyond Nest's control such as boiler type, house construction and weather.

Savings

In Table 1, the energy savings (in kWh per year), as well as the cost savings (in GBP per year), can be found for the different pathways to energy savings provided in the previous section, compared to a baseline schedule with a constant setpoint temperature at 20°C. As the user adds setbacks and takes advantage of Nest's energy saving features, the savings increase.

Table 1: Energy Savings Compared to Constant 20°C Baseline

City	House Type	Baseline Usage For Heating (per year)	Night Setback Savings (per year)	Night Setback + Vacation Savings (per year)	Night + Day Setbacks Savings (per year)	Night + Day Setbacks + Vacation Savings (per year)
London	Detached (86m	19,390 kWh £ 944	2,544 kWh 13% £ 124	3,547 kWh 18% £ 172	4,387 kWh 23% £ 213	5,218 kWh 27% £ 254
	Semi-detached (60m	12,597 kWh £ 613	1,608 kWh 13% £ 78	2,280 kWh 18% £ 111	2,658 kWh 21% £ 129	3,223 kWh 26% £ 156
	End-terrace (60m	11,402 kWh £ 555	1,455 kWh 13% £ 71	2,075 kWh 18% £ 101	2,399 kWh 21% £ 117	2,919 kWh 26% £ 142
	Flat (46m	2,888 kWh £ 141	419 kWh 15% £ 21	619 kWh 21% £ 30	670 kWh 23% £ 33	835 kWh 29% £ 41
Glasgow	Detached (86m	24,277 kWh £ 1,182	3,213 kWh 13% £ 156	4,243 kWh 17% £ 206	5,646 kWh 23% £ 275	6,532 kWh 27% £ 318
	Semi-detached (60m	15,827 kWh £ 771	2,037 kWh 13% £ 99	2,724 kWh 17% £ 133	3,438 kWh 21% £ 168	4,032 kWh 25% £ 197
	End-terrace (60m	14,377 kWh £ 700	1,842 kWh 13% £ 90	2,472 kWh 17% £ 120	3,109 kWh 21% £ 151	3,653 kWh 25% £ 178
	Flat (46m	3,739 kWh £ 182	543 kWh 15% £ 26	727 kWh 19% £ 35	872 kWh 23% £ 42	1,033 kWh 28% £ 50
Aberdeen	Detached (86m	26,816 kWh £ 1,306	3,472 kWh 13% £ 169	4,475 kWh 17% £ 218	6,416 kWh 24% £ 313	7,251 kWh 27% £ 353

	Semi-detached (60m	17,514 kWh £ 853	2,205 kWh 13% £ 107	2,882 kWh 16% £ 140	3,879 kWh 22% £ 189	4,454 kWh 25% £ 217
	End-terrace (60m	15,927 kWh £ 776	1,993 kWh 13% £ 97	2,625 kWh 16% £ 128	3,513 kWh 22% £ 171	4,053 kWh 25% £ 198
	Flat (46m	4,273 kWh £ 208	594 kWh 14% £ 29	802 kWh 19% £ 39	1,026 kWh 24% £ 50	1,207 kWh 28% £ 59
Manchester	Detached (86m	23,134 kWh £ 1,127	2,976 kWh 13% £ 145	4,003 kWh 17% £ 195	5,497 kWh 24% £ 268	6,351 kWh 27% £ 310
	Semi-detached (60m	15,080 kWh £ 734	1,879 kWh 12% £ 91	2,569 kWh 17% £ 125	3,320 kWh 22% £ 161	3,902 kWh 26% £ 190
	End-terrace (60m	13,674 kWh £ 666	1,690 kWh 12% £ 82	2,334 kWh 17% £ 114	2,987 kWh 22% £ 146	3,526 kWh 26% £ 172
	Flat (46m	3,557 kWh £ 173	506 kWh 14% £ 24	717 kWh 20% £ 35	862 kWh 24% £ 42	1,045 kWh 29% £ 51

In Table 2 below, the energy savings in kWh per year, as well as the cost savings in GBP per year, can be found for the different pathways to energy savings provided in the previous section, compared to a baseline schedule with a constant setpoint temperature at 20°C, but with a timer preventing the heater from turning on between 22:00 and 05:00. This comparison demonstrates the savings possible for users who already have one setback, but could save further by taking advantage of the Auto-Away and Auto-Schedule features of the Nest Thermostat.

Table 2: Energy Savings Compared to 20°C with Nighttime Setback Baseline

City	House Type	Baseline + Night Setback Usage (per year)	Night Setback + Vacation Savings (per year)	Night + Day Setbacks Savings (per year)	Night + Day Setbacks + Vacation Savings (per year)
London	Detached (86m	16,846 kWh £ 820	1,003 kWh 6% £ 48	1,843 kWh 11% £ 89	2,674 kWh 16% £ 130
	Semi-detached (60m	10,989 kWh £ 535	672 kWh 6% £ 33	1,050 kWh 10% £ 51	1,615 kWh 15% £ 78
	End-terrace (60m	9,947 kWh £ 484	620 kWh 6% £ 30	944 kWh 9% £ 46	1,464 kWh 15% £ 71
	Flat (46m	2,469 kWh £ 120	200 kWh 8% £ 9	251 kWh 10% £ 12	416 kWh 17% £ 20

Glasgow	Detached (86m	21,064 kWh £ 1,026	1,030 kWh 5% £ 50	2,433 kWh 12% £ 119	3,319 kWh 16% £ 162
	Semi-detached (60m	13,790 kWh £ 672	687 kWh 5% £ 34	1,401 kWh 10% £ 69	1,995 kWh 14% £ 98
	End-terrace (60m	12,535 kWh £ 610	630 kWh 5% £ 30	1,267 kWh 10% £ 61	1,811 kWh 14% £ 88
	Flat (46m	3,196 kWh £ 156	184 kWh 6% £ 9	329 kWh 10% £ 16	490 kWh 15% £ 24
Aberdeen	Detached (86m	23,344 kWh £ 1,137	1,003 kWh 4% £ 49	2,944 kWh 13% £ 144	3,779 kWh 16% £ 184
	Semi-detached (60m	15,309 kWh £ 746	677 kWh 4% £ 33	1,674 kWh 11% £ 82	2,249 kWh 15% £ 110
	End-terrace (60m	13,934 kWh £ 679	632 kWh 5% £ 31	1,520 kWh 11% £ 74	2,060 kWh 15% £ 101
	Flat (46m	3,679 kWh £ 179	208 kWh 6% £ 10	432 kWh 12% £ 21	613 kWh 17% £ 30
Manchester	Detached (86m	20,158 kWh £ 982	1,027 kWh 5% £ 50	2,521 kWh 13% £ 123	3,375 kWh 17% £ 165
	Semi-detached (60m	13,201 kWh £ 643	690 kWh 5% £ 34	1,441kWh 11% £ 70	2,023 kWh 15% £ 99
	End-terrace (60m	11,984 kWh £ 584	644 kWh 5% £ 32	1,297 kWh 11% £ 64	1,836 kWh 15% £ 90
	Flat (46m	3,051 kWh £ 149	211 kWh 7% £ 11	356 kWh 12% £ 18	539 kWh 18% £ 27

Conclusion

The Nest Thermostat comes with a variety of energy-saving features that can help users be more efficient in their heating use. Simulations of energy usage with typical setpoint schedules were compared to those with setpoint schedules that users may receive from the Nest Thermostat's energy-saving features. Depending on the user's house, climate, existing setpoint schedule and active features, the savings on their heating bill may range from 4% to 29%, resulting in annual savings from £ 9 to £ 353.