The DABE
Climate Control & Energy Monitor

Becky Hurwitz & Daniel Perry

Information Visualization I247
Spring 2010 Final Project Report
Professor Cecila Aragon
GSI Ljuba Miljkovic

Our Motivation

Programmable thermostats are designed to help people with energy savings, yet studies have shown that people with programmable thermostats can in fact use as much if not more energy than those with non-programmable thermostats. One of the primary reasons for lack of energy savings is the poor display of information on the thermostat interface.[1]

The DABE Climate Control and Energy Monitor is much more than just a thermostat, it offers a complete home energy display monitor that allows users to make intelligent decisions about their energy use. The device incorporates real and historic data from the utility company giving users simple ways to maximize energy efficiency by showing current energy costs and consumption rates and accounting for government recommendations for energy efficiency. The device is designed to integrate directly with the smart metering system of users' local utility company and provide real time feedback on users' energy usage.

Our Project Specifications

The DABE device's informational displays are based on four primary principles that we have determined as important to effective thermostat use and energy usage behavior.

Key Principles of DABE'S Information Display:

1) Users need a simple and effective way to set and compare their temperature settings with Energy Star recommended settings.
2) Users need a simple and effective way to view their program schedule and temperature settings.
3) Users can be motivated by energy cost.
4) Users can be motivated by comparisons with their neighbors.

Supporting Research for Key Principles:

1) Research has show that some of the biggest challenges in ensuring that thermostats achieve effective energy savings are the proper temperatures in setback and set-forward temperatures in "away" and "sleep" modes.[2] Energy Star energy savings calculations are based on a temperature difference of eight degrees setback from normal home temperatures (for heating) when users' are away or sleeping. While these setback (for heating) and set-forward (for cooling) temperatures are factored into the default temperatures when the user first installs the thermostat, these temperatures do not figure into every day settings considerations.

2) Based on qualitative interviews we conducted among six programmable thermostat owners as well as a national survey among 81 respondents, we determined that users were rarely updating their scheduled settings reducing potential energy savings. Among survey respondents **89%** identified never to almost never changing their program schedule for weekday and weekend settings. Peoples' schedules and temperature

---

[1] Nevis, M., and Pigg, S. "Programmable Thermostats that Go Berserk? Taking a Social Perspective on Space Heating in Wisconsin" 1999.; Cross, D., and Judd, D. "Automatic Setback Thermostats: Measure Persistence and Customer Behavior" 1997.

[2] Plourde, A. , "Programmable Thermostats as Means of Generating Energy Savings: Some Pros and Cons. " University of Alberta. 2003..

preferences vary based on season and lifestyle yet the information display and interface for programming schedules and temperatures was simply too cumbersome for people to update their schedule.

3) Cost can be a motivating factor in determining energy usage but there is often no way for thermostat users to compare utility cost to their temperature settings. According to our national survey of 81 thermostat owners, **42%** of respondents ranked saving money on energy as more important than comfort or environmental concerns in determining usage behavior.

4) Competition and comparison with neighbors within the same region can motivate energy usage behavior. Studies done with Sacramento Municipal Utility District and Puget Sound Energy have shown that information regarding energy usage in relation to ones' neighbors led to a 1.5% to 2.1% decrease in energy usage.[3]

Device Considerations & Specifications:

The DABE Climate Control Device and Energy Monitor was a graphical prototype conceived as being 5" wide by 4" in height. If built in full, the screen would be a full-color LCD touchscreen interface.

The device has three different types of information views that account for different key decisions and motivational behaviors for energy usage. These types of displays are:

Ambient Display Energy Comparison:

The default screen for the times when the user is not actively engaging with the thermostat is an ambient display displaying users' current energy usage in relation to their neighbors (within a 25 mile radius). Thermostats are installed in private homes, sometimes in well-trafficked and highly visible places like hallways. This view is for quick comprehension and alert about *real time conditions*. It should catch the attention of the user and should *alert them through visual cues* that a user should change their energy consumption. It should be based on data that a user is willing to act on.

Scheduling and Temperature Settings Screen:

The scheduling interface provides an easy way for users to set a schedule and clearly shows users how their programmed settings compare to Energy Star temperature recommendations. These guidelines state that a user should set the thermostat to an energy-saving temperature (low temperatures for heating, high temperatures for cooling) for long periods of time (at least 8 hours) each day. The key information to display on this screen is time of day and desired temperature. This display should also show temperature settings that will help users save money calculated using Energy Star guidelines.

---

[3] Ayres I, Raseman, S., Shih, A. "Evidence from Two Large Field Experiments that Peer Comparison Feedback Can Reduce Residential Energy Usage." NBER, September, 2009.

Usage Analysis Displays:
A third view is the usage analysis tools. This is not a single screen, but a series of screens to view historical usage data. A user can view monthly gas and electricity usage disaggregated and compared to other neighbors.

Information Display Best Practices:
We draw on best practices in information visualization for design and usability for this dashboard-type display. In his paper, "Dashboard design for real-time situation awareness", Stephen Few enumerates best practices for dashboard design. Our design for the DABE CCD takes these recommendations into consideration while rejecting some of the recommendations that are not fitting for the specific functions of our displays.

Our device, similar to Few's ideal dashboard is meant to give users "situation awareness" – a "perception of the environment", "comprehension of its meaning", and "the projection of that understanding into the future to anticipate what might happen."[4] We relate real time energy conditions and settings to projected costs. Few also emphasizes ways in which designers can use flicker to notify users of crucial changes in their data.[4] This concept has been carefully incorporated into the ambient screen for the DABE CCD which uses changes in color and sizing to indicate important changes in energy usage.

While Few stresses the importance of a dashboard as a single screen display, given the size of a thermostat display and the context of where it is used, we create a device with multiple screens. In Few's examples a user benefits from a single screen view because they are more able to compare the information and to decide to act or not accordingly. While we considered this analysis we decided that displaying all of the key information on a single screen of such as small size would simply be too overwhelming for the average user. This conclusion was supported by our early rounds of user testing in which users expressed confusion when there was multiple views of information on a single screen.

Our Process

We proposed a design based on a review of current energy and thermostat research, current energy dashboard designs and our original research conducted for Lawrence Berkeley National Labs (LBNL). This research included in-person semi-structured interviews, a national online-survey, and usability testing with leading commercial brand thermostats.

Display Considerations:
In our research, participants found programmable thermostats confusing. Participants expressed confusion and uncertainty about how to use thermostats and frustration at an inability to confirm settings. Additionally, participants were unfamiliar with Energy Star guidelines for efficiency.

---

[4] Few, S. "Dashboard design for real-time situation awareness." Inova Solutions. 2003.

Information as Motivation:

We found that users were interested in saving money on energy bills[5] and that users are willing to use less energy when shown data about nearby household energy usage.[6] The key principles for the DABE information display were related to relevant design consideration (Figure 1).

.

Feedback/Findings	Relevant design change
Users are confused about how to set schedules	Create a simple method for users to set a schedule
Users are unaware of guidelines for setting the most energy efficient schedules	Clearly indicate Energy Star guidelines to users as they set schedules and give users a method for acting on these guidelines
Users are willing to act on cost savings	Clearly indicate to users how their thermostat settings effect their energy costs Clearly indicate when energy costs are high (during peak hours)
Users are willing to act on knowledge of neighbor's energy usage	Indicate comparison of user's consumption and neighbors'

Figure 1. Early research findings and design implications.

Some commercially available digital thermostats and ambient energy displays, like the Energy Joule in *Figure 1,* display current household energy usage rates and energy costs. Ambient displays can alert users to real time conditions, and if coupled with a thermostat user interface and smart meter data, could be a successful way to monitor energy usage.

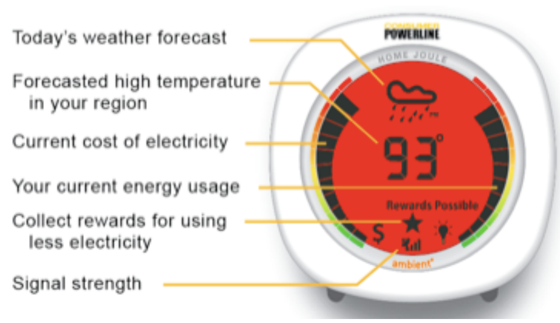


Figure 2. An annotated image of the Ambient Energy Joule

While devices like the Energy Joule show that energy usage can be displayed in a simple and aesthetically appealing manner it has several notable shortcomings. The current energy usage is shown as a scale but the comparison is unclear. Namely, the bars are not shown in relation to

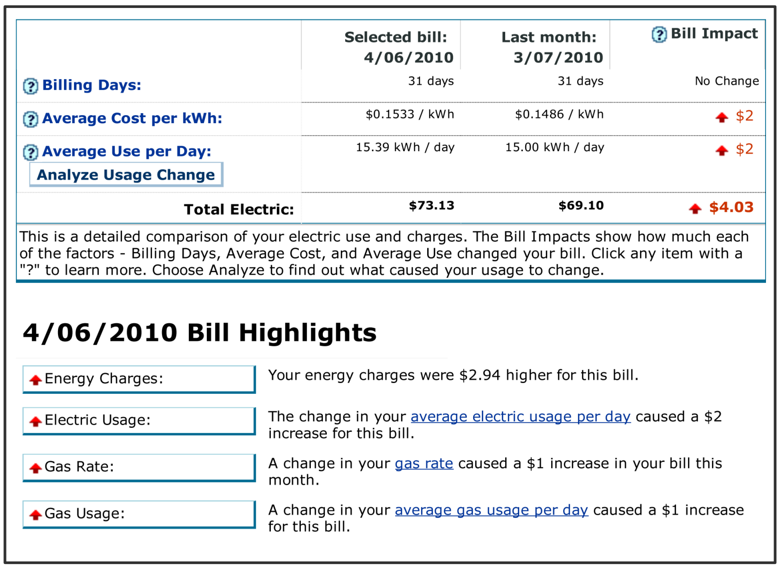
---

5 In our nationwide online survey, of 81 respondents, 42% responded saving money on energy bills was more important to them than how their energy usage effects the environment and feeling comfortable.

6 "When customers received information on the energy consumption of their neighbors, average energy use declined by 1.2 to 2.1 percent." Ayers, I., Rasement, S., Shih, A. (2009). Evidence from Two Large Field Experiments that Peer Comparison Feedback Can Reduce Residential Energy Usage. *NBER Working Paper No. 15386*.

anything. The use of area and size of the current cost and usage bars is also unclear in the Energy Joule. The bars at top are larger than the bars as bottom suggesting that they might be more important. In our design we wanted to be as consistent as possible in showing relationships to energy usage. While we did use separated bars for the ambient display of the DABE CCD we made sure that the comparisons were clearly noted on the display.

Our design considerations were also influenced by the information currently viewable in PG&E's online accounts. Online account holders can log onto the company website to view summaries from historical billing and usage data (Figure 3). A user views these tools online and cannot necessarily act immediately on the information as they may be away from their thermostat. Our design incorporates some of the same information, but on the thermostat itself so that a user can act immediately. We explored graphical displays of usage information that would offer faster comprehension.



	Selected bill: 4/06/2010	Last month: 3/07/2010	? Bill Impact
? Billing Days:	31 days	31 days	No Change
? Average Cost per kWh:	$0.1533 / kWh	$0.1486 / kWh	$2
? Average Use per Day: Analyze Usage Change	15.39 kWh / day	15.00 kWh / day	$2
Total Electric:	$73.13	$69.10	$4.03

This is a detailed comparison of your electric use and charges. The Bill Impacts show how much each of the factors - Billing Days, Average Cost, and Average Use changed your bill. Click any item with a "?" to learn more. Choose Analyze to find out what caused your usage to change.

4/06/2010 Bill Highlights

Energy Charges:	Your energy charges were $2.94 higher for this bill.
Electric Usage:	The change in your average electric usage per day caused a $2 increase for this bill.
Gas Rate:	A change in your gas rate caused a $1 increase in your bill this month.
Gas Usage:	A change in your average gas usage per day caused a $1 increase for this bill.

Figure 3. Snapshot of PG&E account summary tools.

We also considered bar and line graphs for displaying historical data. Figure 4 is an example of a chart showing total energy costs by month in the year 2009. A user can easily compare monthly data and can accurately estimate costs from this chart. We spoke with users and found that they were most interested in monthly data as they are accustomed to considering utility costs on a monthly basis.

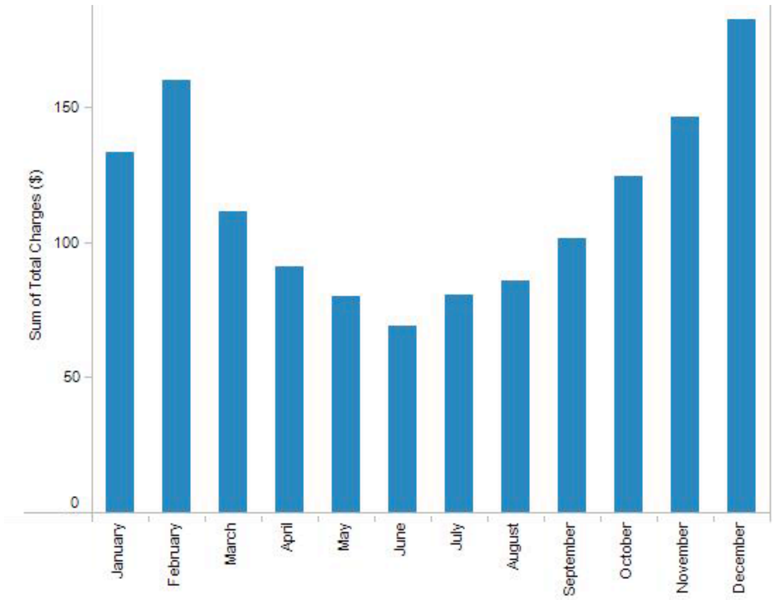


Figure 4. A bar graph showing 2009 monthly energy costs for a PG&E account.

We also examined the way PG&E plotted energy usage relative to temperature to determine whether this was a helpful comparison for our device. Figure 5 is a line chart plotting monthly energy costs and average outdoor temperatures. This chart is problematic in that there are two different scales measured on the y-axis. These are money and temperature. Strengths of this format are easy comparison, especially when data is plotted in contrasting colors.

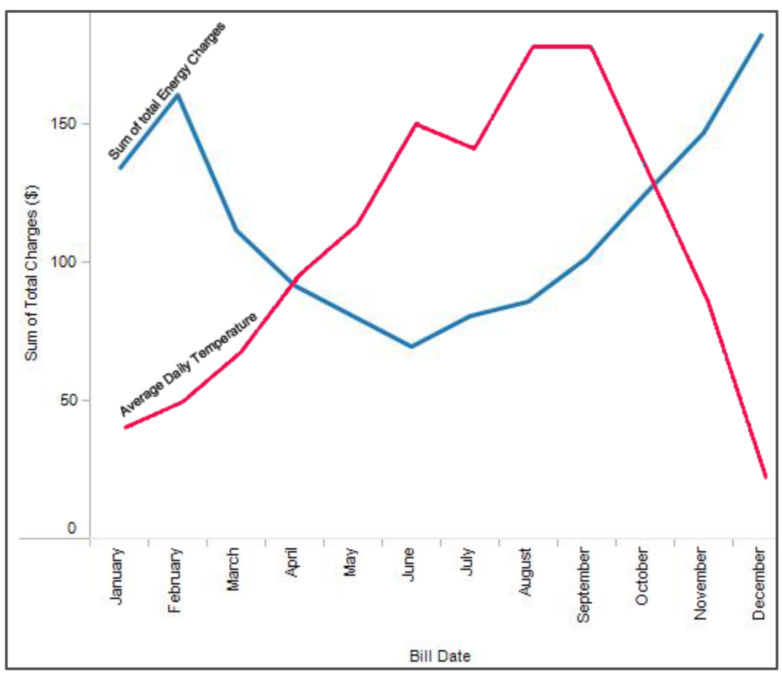


Figure 5. A line chart plotting monthly energy bill costs against average outdoor temperature in the year 2009.

Our Data Sets

Our project utilized data for 2009 for:

- Residential energy usage in kWh and therms (from a PG&E electricity bill)
- Residential energy cost in dollars (from a PG&E electricity bill)
- Bay Area temperatures
- Variable energy costs throughout the day (from PG&E peak energy schedule)

If the DABE CCD and Energy Monitor were actually implemented it would utilize real time data from a utility's smart metering system. This would include continually updated information on electric usage in kilowatts and gas usage in kilowatts. We were unable to attain appropriate real time data sets for our purposes so we utilized data from two PG&E San Francisco customers. We pooled data on energy usage, cost and temperatures to examine relationships between a variety of possible energy determinant factors (Figure 2).

Bill Date	Avg Daily Tem	Total Charges	Avg. $/Day	Gas Charges (
4/6/10	55	$141.58	$2.21	$68.45
3/7/10	54	$138.64	$2.24	$69.54
2/2/10	51	$186.29	$3.12	$103.09
12/31/09	49	$182.29	$3.92	$113.72
12/2/09	56	$146.54	$1.78	$58.81
11/1/09	61	$124.55	$1.19	$34.55
10/2/09	66	$101.28	$0.73	$21.90

Figure 7: Data collected in excel to compare average temperatures and energy charges.

We also conducted an exploration of the data using Tableau Software tool to establish important comparative relationships and understand what visual comparison might be important to users (Figure 8).

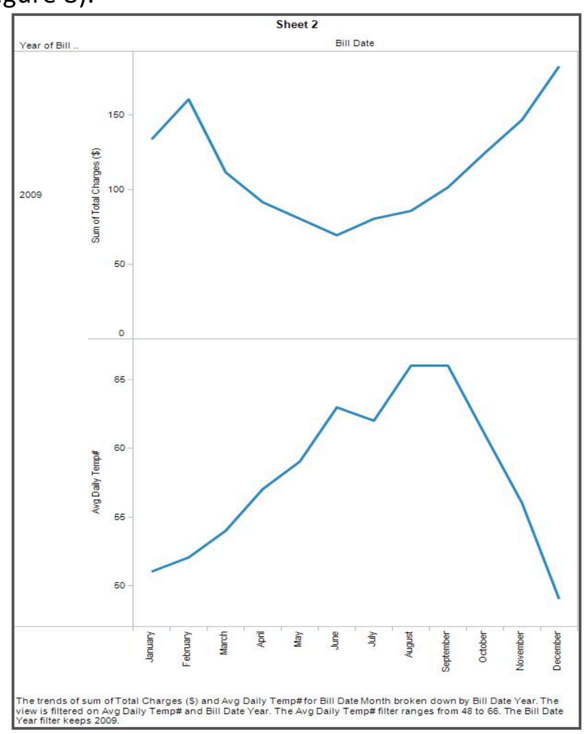


Figure 8: Exploratory graph comparing monthly utility charges to temperatures.

Early Prototypes

We went through several rounds of exploratory prototypes to determine what information regarding energy usage, time and temperature should be viewable in the DABE display. Based on our research findings, we created several simple mock-up of what our thermostat schedule setting screen might include using Balsamiq software (Figure 9). A user can set a time and temperature and can view suggested temperatures plotted on a graph along with these settings

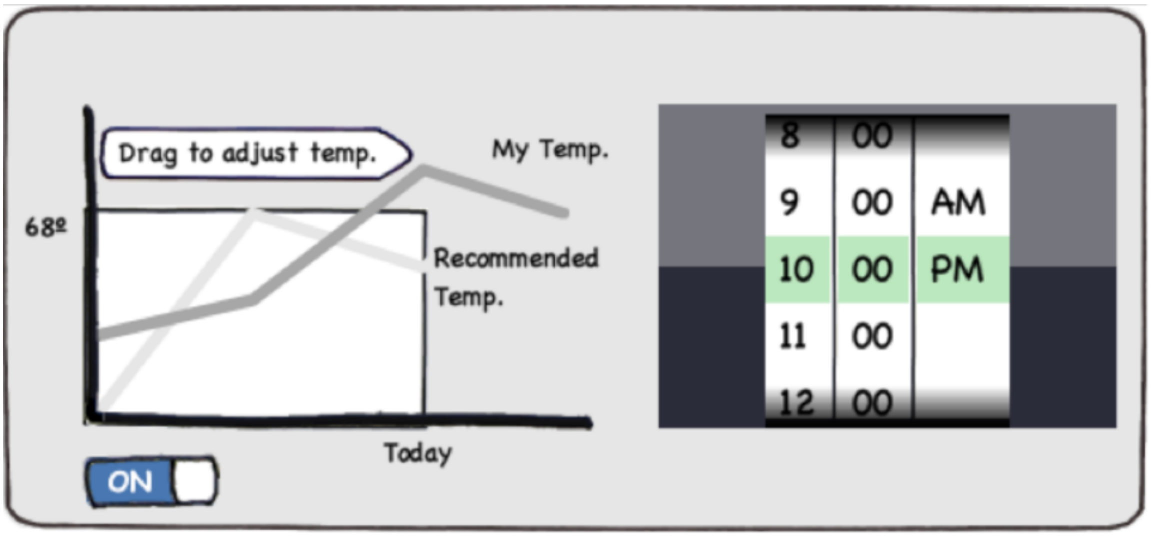


Figure 9. Rough mock-up of thermostat showing programmed temperatures plotted against recommended temperature (based on peak energy cost).

Low-Fidelity Prototype:

We developed and tested a low-fidelity prototype using Balsamiq, Photoshop, and PowerPoint (Figure 10). We tested the usability of this prototype, asking two graduate student users to perform a cognitive walk-through with to set a schedule. We also tested for comprehension of energy and cost visual tools.

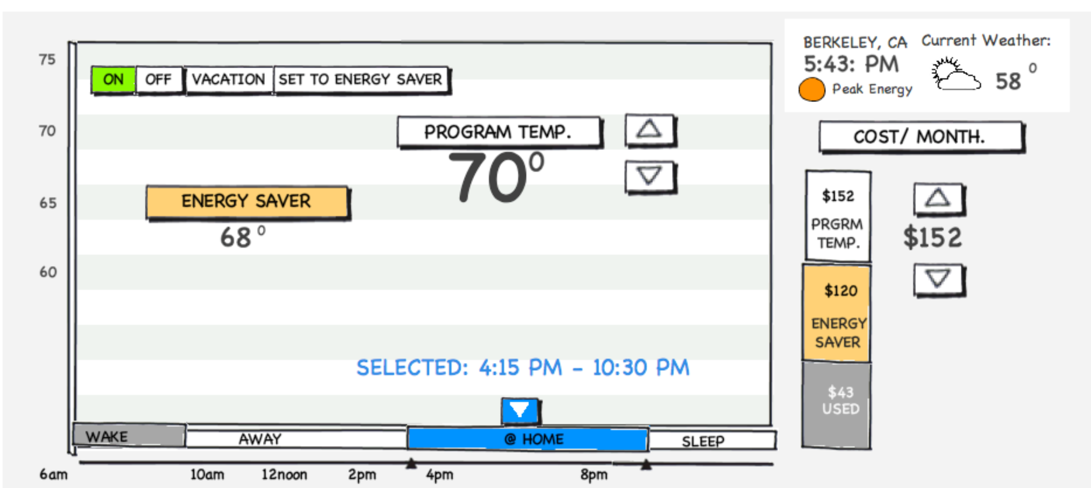


Figure 10. Screenshot from our low fidelity prototype showing scheduling screen

In this prototype, a user can set a schedule, choosing times when she is home, away, asleep, and waking up. She can also adjust the temperature for a heating and cooling by pressing the up and down arrows. Energy saver is a tool we created that evaluates the most efficient neighboring users and suggests temperatures that will help a user to achieve the same level of energy efficiency.

This thermostat displays cost information in one vertical bar. The grey area represents the current energy bill of the user this month. The white is the projected bill, calculated based on usage so far. The orange area shows the projected bills of the most efficient users in the neighborhood. A user can adjust arrows at the cost to set a target bill cost. When a user adjusts the temperature, the thermostat calculates estimates for monthly costs and redraws the orange bar and dollar value. When a user adjusts the target cost, the thermostat calculates temperature settings required to reach the target cost and sets and redraws the schedule accordingly.

There were numerous important findings from this first round prototype with design implications that we incorporated into future versions of our displays (Figure 11). Users identified that the reference to peak energy times was confusing and our basic comparative display did not provide clear enough information regarding "Energy Saver" mode.

Feedback/Findings	Relevant design change
Utility companies like PG&E provide some tools for analyzing usage data online	Provide similar tools on a thermostat so a user can act on the information immediately
Users are accustomed to monthly utility bills	Display historical information as monthly data
Line charts make comparison easy	Display information for users to compare as line charts
Interface buttons move as users change the program temp	Separate buttons from dynamic graphics; do not change location of buttons
Users ask if daily weather can be plotted in the schedule window	Consider plotting weather outside on the schedule area
Users are confused about what Energy Saver means	Define Energy Saver on the device
It is not clear that Energy Saver compares a user's usage to neighbors	Consider reassigning Energy Saver as Energy Star recommendations for lowering temp (during heating season) or raising temp (during cooling season) for at least 8 hours a day; compare users to neighbors in a different display
Users confused about meaning of peak hours icon	Consider a different representation of peak hours
Users are uncomfortable with monthly billing costs showing by default	Represent costs without dollar values if costs show by default; consider different default displays

Users want to see a set of information on every screen including scheduled temperature and inside temperature	Display some content on all screens including scheduled temperature and inside temperature

Figure 11. Low fidelity research and user testing findings and design implications.

Prototype Refinement

Based on user testing and feedback from our presentation, we made a considerable number of changes to the initial design. We began our redesign process with a new round of sketching by hand and in Photoshop.

In this set of sketches, all screens show the temperature inside the house, the temperature set by the user, the temperature outside, the time of day, and the user's estimated usage costs for the month compared with E-saver cost projections. Additionally, the thermostat displays a label that indicates whether a user is overriding a scheduled setting or is currently using a scheduled setting.

Figure 12 is a sketch of a default screen design displaying both schedule settings and cost. This screen will show whenever a user is not actively engaging in setting the schedule or usage analysis tools. A quick glance should let a user know if the user should change their consumption at the moment.

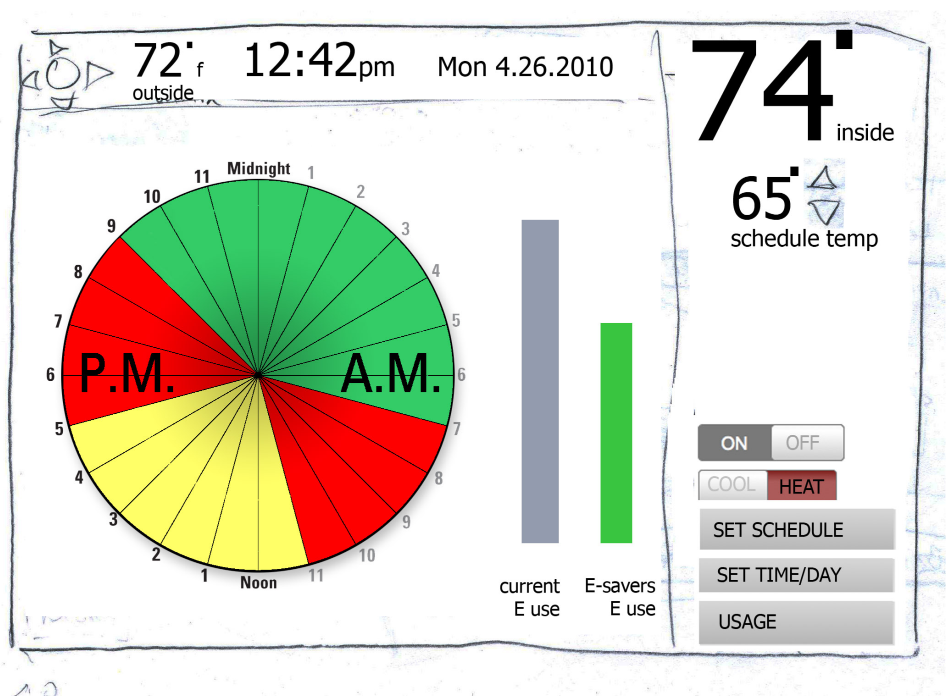


Figure 12. Mock-up of the default screen showing times and cost comparison.

This mockup screen includes a clock shaded in different colors to indicate when energy is most expensive during the day. It also includes two bars that represent energy costs and estimated energy costs if the user chooses the E-saver mode. If the time is an on-peak time and if current energy use is much higher than E-Saver estimated use, a user should change their current consumption.

One of our early versions of a scheduling screen shows interface buttons located in an area where they do not change position to reflect comments from our low fidelity prototype. This also shows a new approach to displaying user costs in three bars to the right hand side of the screen (Figure 13). These bars represent, from left to right, user's current energy costs for the month, projected monthly cost, and projected cost in the E-Saver mode.

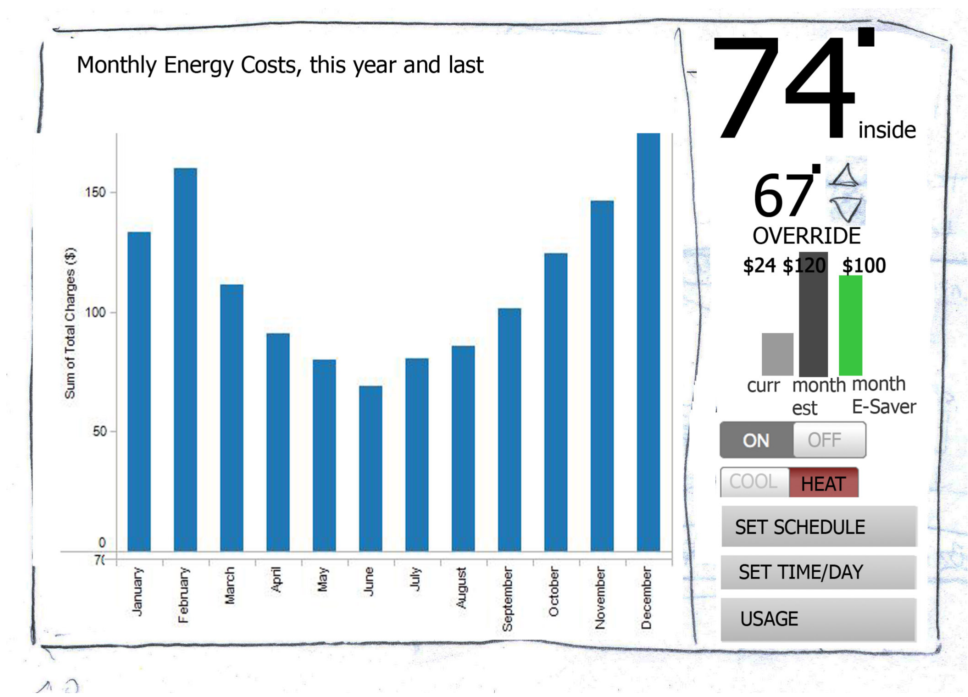


Figure 13. Mockup usage analysis screen with three bars of energy use on right.

We showed these screen mock-ups to the two graduate student users we had conducted initial user tests with and found that the display of peak hours was not dynamic enough and that the display of home/away settings needed to be simplified (Figure 14).

.

Feedback/Findings	Relevant design change
A static chart showing peak hours is too static, it is not an alert	Show real time data on the default screen
Setting periods as home/away should be very simple	Consider drag-and-drop setting

Figure 14. Sketch feedback and design implications

High Fidelity Prototype

Our high fidelity prototype is created using DrawPlus and Flash. Based on our research and usability with prior prototypes, we created a video demonstrating functionality of the thermostat dashboard (http://www.beckyhurwitz.net/ischool/thermovis/).

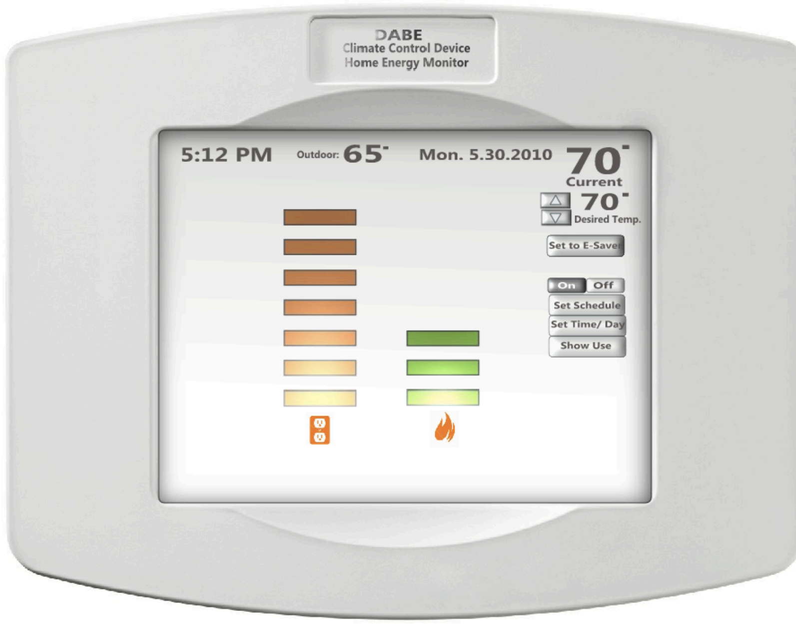


Figure 15. High fidelity prototype default screen

In this default screen (Figure 15), users have a quick view of their current electricity and gas usage. The graphic is a comparison of user consumption to neighbors' consumption. The graphic communicates usage comparison in color and magnitude. The bar grows taller and redder as a user's usage approaches the highest percentile of use and grows shorter and greener as a user's usage approaches the lower percentiles of use.

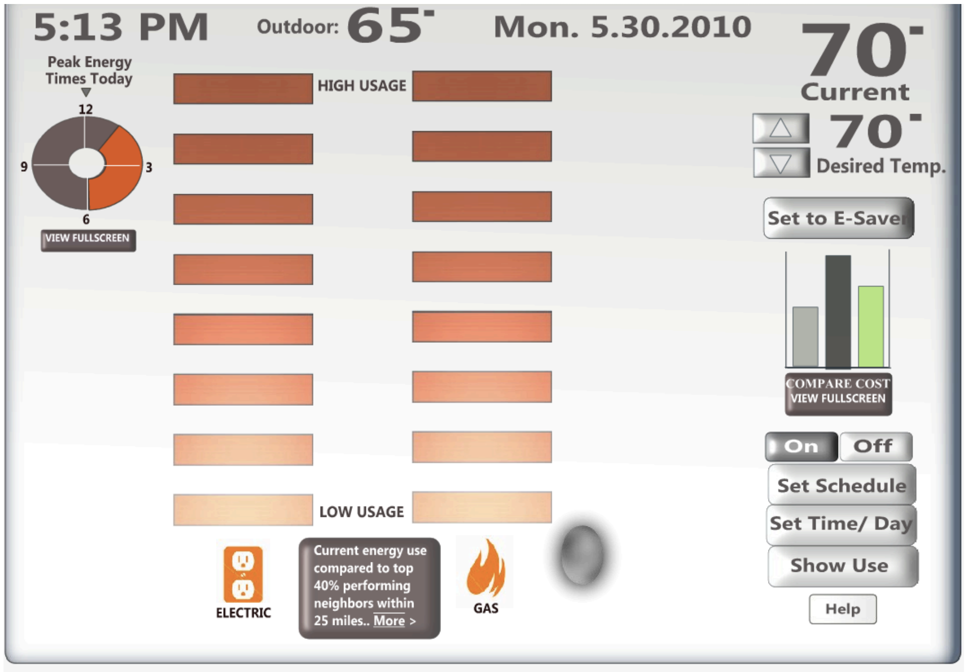


Figure 16. High fidelity prototype default screen with onscreen manual explanations

If a user touches the screen, onscreen descriptive text appears, showing labels and other information to explain the meaning of graphical elements and specific values. This screen (Figure 16) includes our redesigned peak time indicator. It is a clock face with peak hours highlighted in orange. It is located near the clock so that users can easily assess if the current time is a peak time.

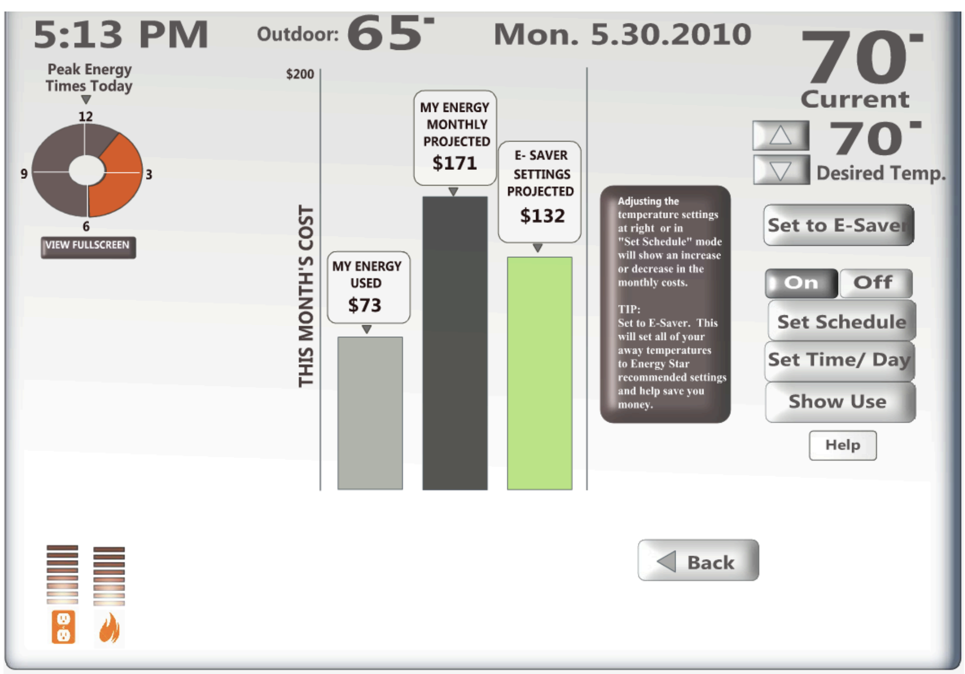


Figure 17. High fidelity prototype cost data with onscreen explanations

A user can view a larger version of the cost comparison by pressing on the "Compare Cost View Fullscreen" button (Figure 17). This is a large version of the aggregate and projected monthly costs proposed in our earlier prototype. When viewed in full screen, a user can see labels and specific dollar values.

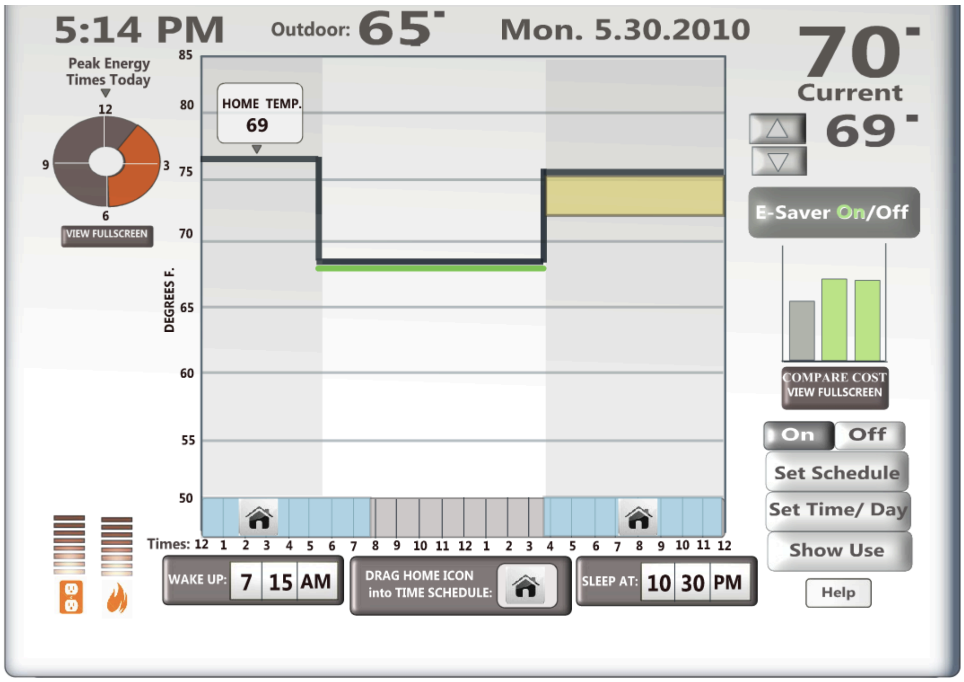


Figure 18. High fidelity prototype schedule interface

The schedule (Figure 18) is shown as an animate chart. The y-axis measures the temperature and the x-axis measures time of day. A user sees the full day's schedule including times marked for home, awake, and sleep setting temperatures.

Our high fidelity prototype schedule lets users set wake up and sleep times by scrolling number displays. A user drags an icon of a house on to the timeline to delineate times when she is home. The thermostat calculates Energy Star recommended temperatures and displays them as a green line. A user can select these recommended temperatures by turning E-Saver on.

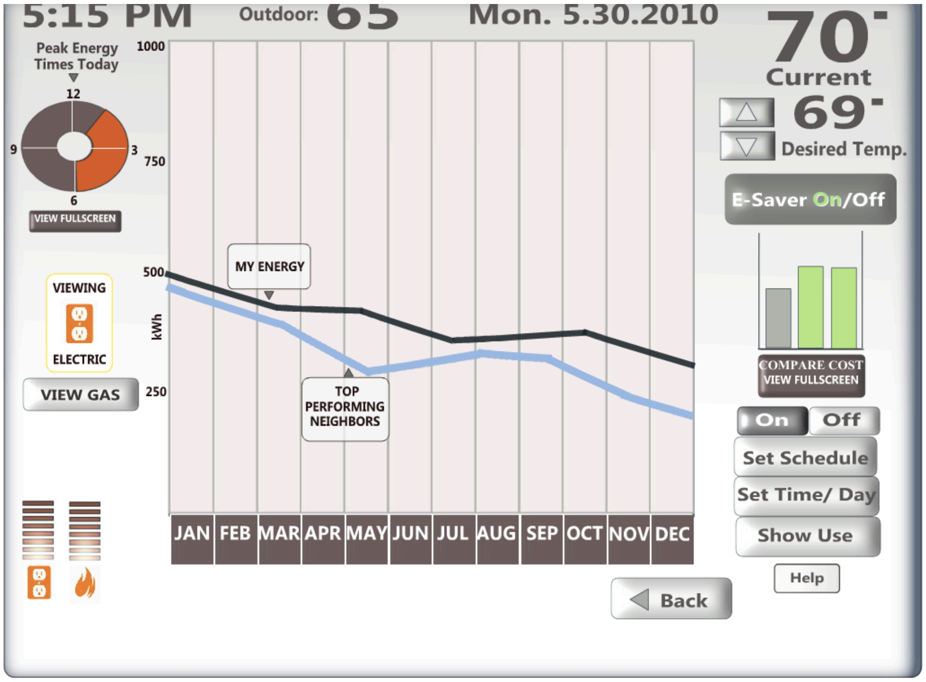


Figure 19. Higher fidelity prototype usage analysis screen.

This simple chart (Figure 19) lets users compare their usage to their most energy efficient neighbors. On this view, the user's information is plotted in grey and neighbors in blue. The y-axis measure cost in money and the x-axis measures time in months. A user can easily compare her use to a neighbor's at this granularity. Additional data is available measuring usage and costs in daily increments, but as billing is done in monthly cycles, users responded well to time periods of one month.

We conducted another round of user testing on two additional graduate students using slides in Power Point and "hotspot" interactions so users could get a sense of click-through functionality (Figure 20).

Figure 20: Round 2 User Testing on higher-fidelity prototype.

There were several important findings and design consideration we discovered after our second round of user testing's using a higher-fidelity prototype. These included challenges in conveying the comparative nature of the ambient screen showing users' energy usage in relation to their average neighbors, as well as confusion over the peak hour clock (Figure 21).

.

Feedback/Findings	Relevant design change
Users do not understand the underlying data and calculations in the default comparative display	Consider different designs or tool tips-style description
Users did not understand drag and drop	Consider other methods for labeling home/away periods
Users do not understand peak hours	Include information describing this as a tool-tip

Figure 20. Findings and Relevant Design considerations after 2nd round User Tests.

Final Prototype

In the final prototype, we paid particular attention to placement of objects on the screen. Content including time, date, temperature outside and temperature inside are displayed in the top horizontal section of the thermostat. This final prototype includes a new method for indicating peak rate time. When rates are non-peak levels, a circle near the time is green and the words "non-peak rate" appear. During peak hours, the indicator is filled with orange and the words "peak rate" appear.

Figure 21. Final prototype default display

We reduced the number of buttons displayed on the right hand side of the screen to include only buttons that a user may want to use frequently like the arrows to adjust the temperature and key function buttons for the climate control system "on" and "off." Buttons on the side of the screen also include buttons to view cost analysis and usage analysis. Buttons appear for setting a schedule and setting time and day when a user touches the thermostat.

A few observers expressed confusion about this display's comparison to neighbors' energy usage and we experimented with other possible ways to display the users' energy compared to the average of neighbors. One of these experimental designs is shown in Figure 22, where energy usage is shown as a continuous container. The data displayed in this exploration would also change colors as usage increased. We created this to test if people would understand the display. Users understood that green indicates positive and red negative information in this display, but some users were confused about what an empty container indicated. One user commented that red seemed negative but so did "emptiness" so this exploration was confusing.

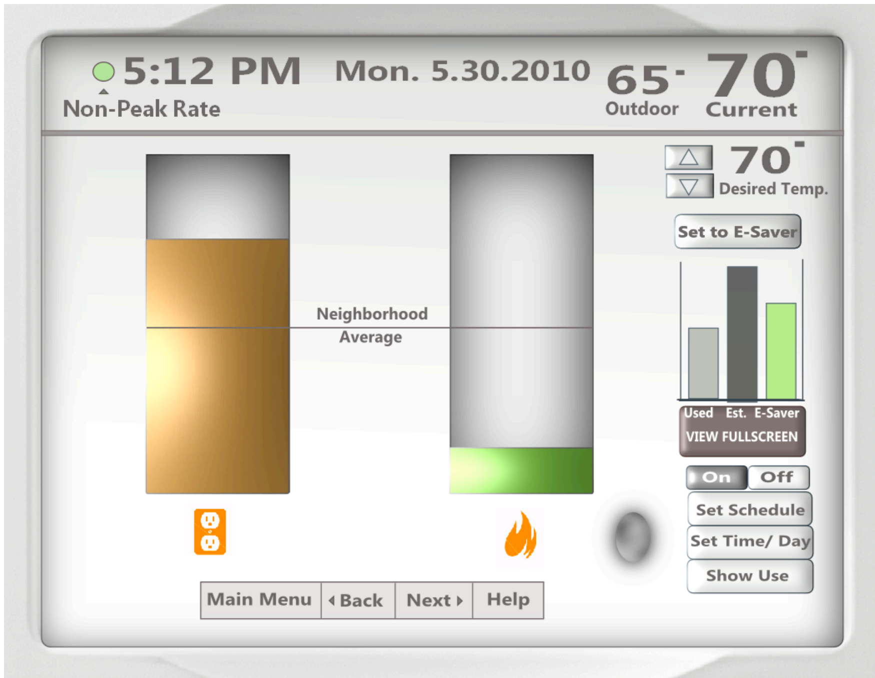


Figure 22. Design exploration default display.

The confusion regarding comparison to neighbors' usage compelled us to create a screen that explicitly shows average neighbors energy when the screen is touched. If a user touches the display while it is in the default screen, the thermostat loads a screen shown in Figure 23 that includes labels marking average neighbors' energy use.

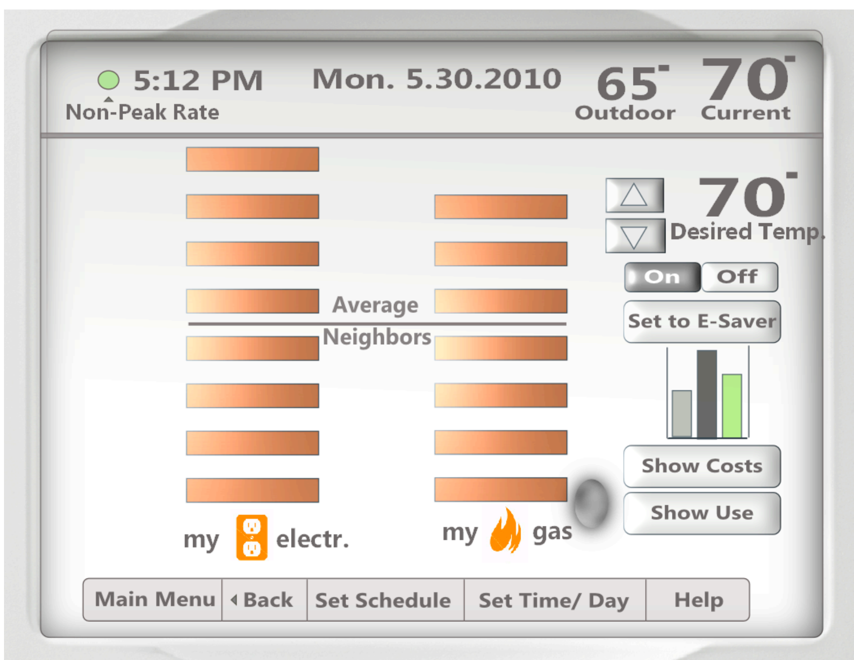


Figure 23. Default display with more information regarding where the average neighbors' usage was positioned on the display.

If a user selects "Show Costs", she sees this full screen version of the cost bar chart including a key and exact dollar value labels (Figure 24).

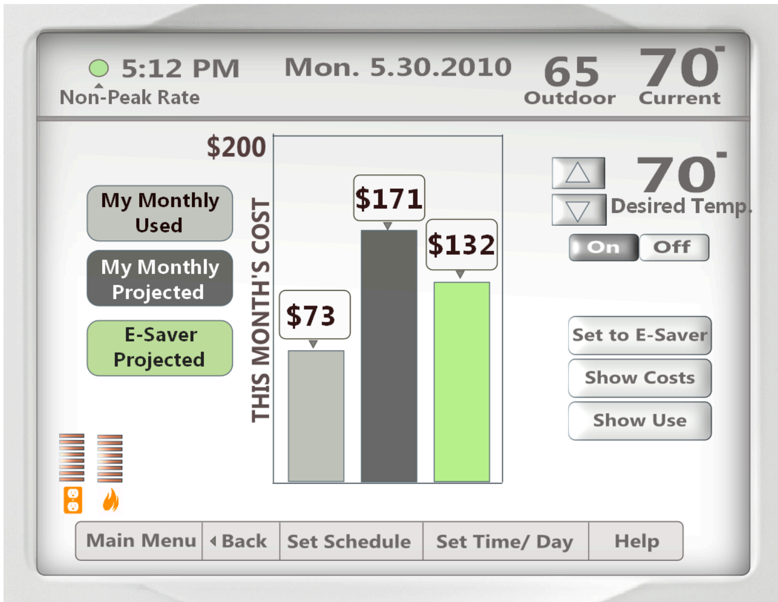


Figure 24. Final prototype Show Costs screen

This final scheduling screen includes different methods for choosing times. (Figure 25) Dragging and dropping the house icon was confusing to our users, so we have created a new method that lets users drag indicators labeled as wake, leave, return, and sleep. To set temperatures for a given segment, a user touches a part of the timeline and an indicator shows that a specific segment is selected. A user can then adjust the set temperature by pushing the up and down arrows. A magnifying glass effect helps a user to read the segment times better.

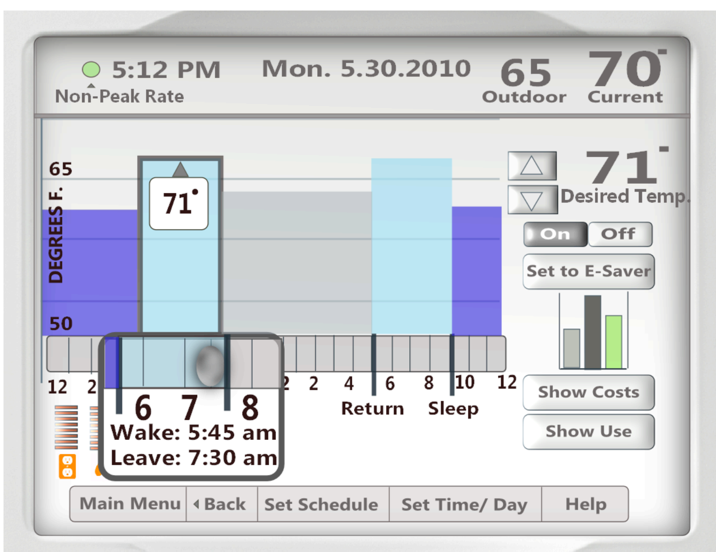


Figure 25. Final prototype schedule screen

Based on user testing with the considerable smaller dimensions we made considerable font changes for the usage analysis screens to ensure users obtain a quick and easy to read overview of their usage compared to their neighbors (Figure 26). Special attention was paid to the "My Energy" and "Top Performing Neighbors" markings, as well as numbers alongside the y-axis.

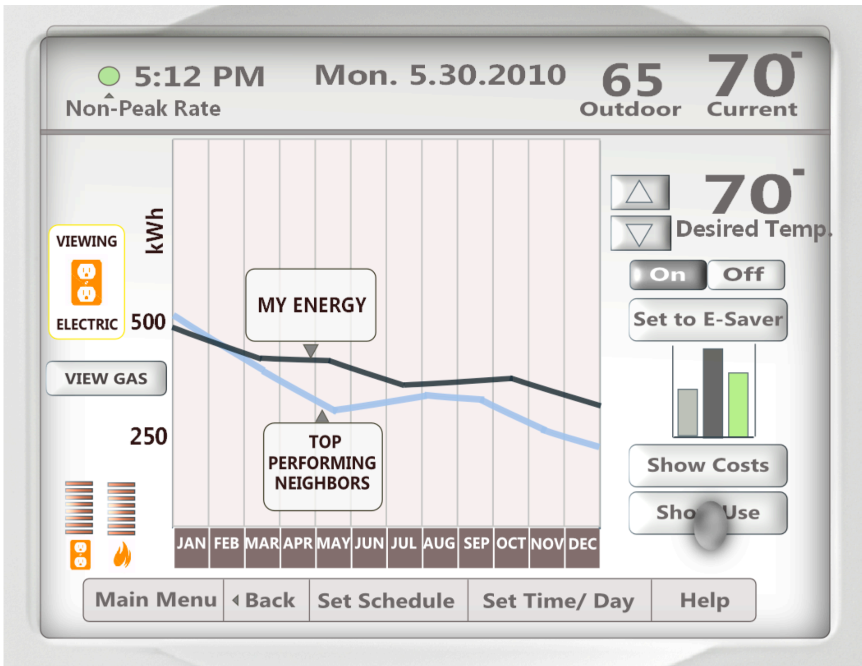


Figure 26. Final prototype usage analysis screen

Challenges and Further Exploration

Some of the greatest challenges in this design are combining the information display with interaction design. Future work in this area might include a Flash and ActionScript implementation that users can interact with more fully. We faced considerable challenges with the tools we used. DrawPlus, although a robust design tool, is an incredibly time consuming program for designing animation.

Further work includes more user testing and further refinement of this design. As users become more familiar with smart meters and data received from utility companies, we might consider using icons based on utility company iconography. Further testing will include onscreen manual refinement. At present, text is quite small. Some possible solutions will be to decrease the amount of text and to increase the font size.

Conclusions

Individual consumers want to save money on energy and the government wants to help consumers to be more energy efficient. Current programmable thermostats are designed poorly and government energy efficiency recommendations are not widely known among users. Users are willing to make decisions based on recommendations and cost savings, but currently this information is disaggregated from their thermostat and so is not immediately actionable.

The advent of smart metering will provide users and devices with more energy usage data. Many thermostat manufacturers are already creating designs to take advantage of the data available and to serve energy efficiency goals of consumers and the government. Ours is one attempt to fill this need and to take advantage of newly available data.