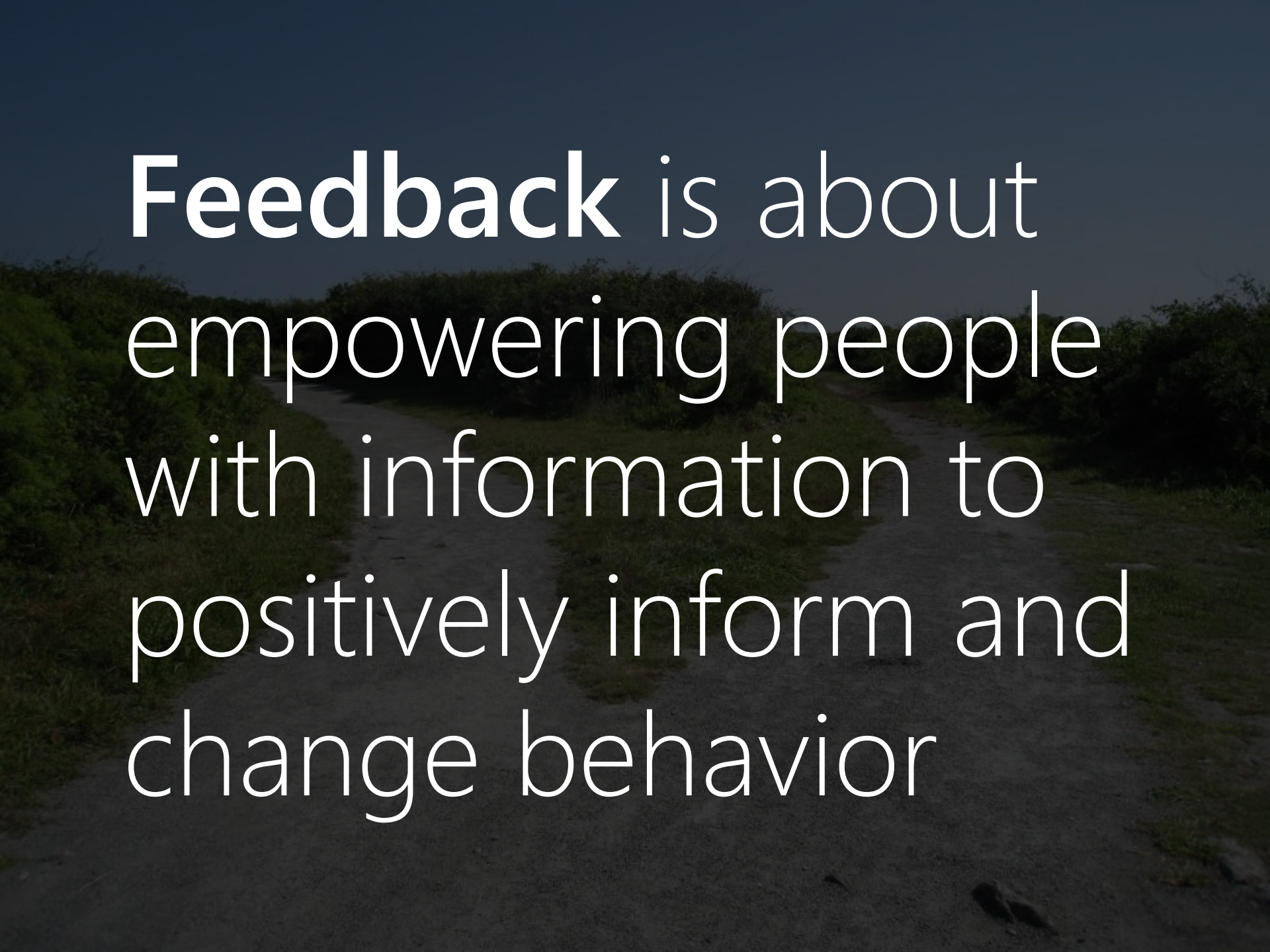


A perspective view of a two-lane road with a double yellow line receding into the distance. The road is paved with asphalt and the yellow paint is worn in places. The background shows a dark, wooded area.

Moving Beyond Line Graphs

@jonfroehlich

The background is a dark, moody photograph of a dirt path or road that recedes into the distance, flanked by dense, dark green bushes and trees. The lighting is low, creating a sense of mystery and depth. The text is overlaid in a clean, white, sans-serif font, centered horizontally and vertically.

Feedback is about
empowering people
with information to
positively inform and
change behavior

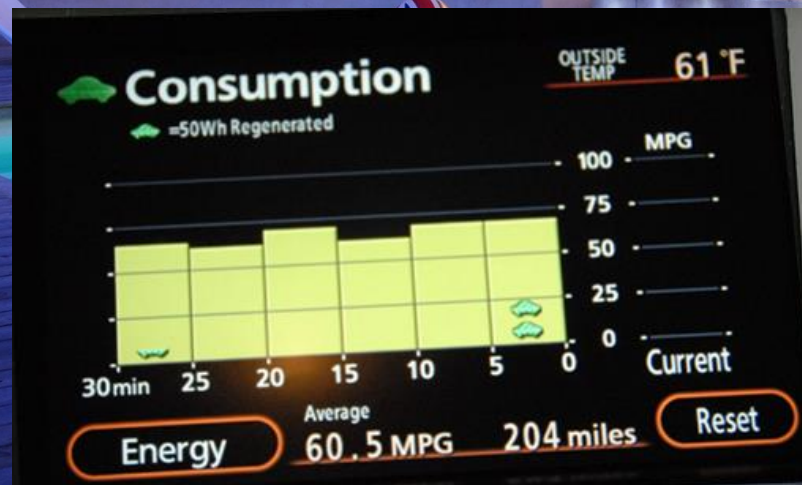
the prius effect?



why is the **prius** effective?

- Immediate
- Simple
- Educates
- Constrained environment
- Reason to care
- Informs only one action

the prius effect?

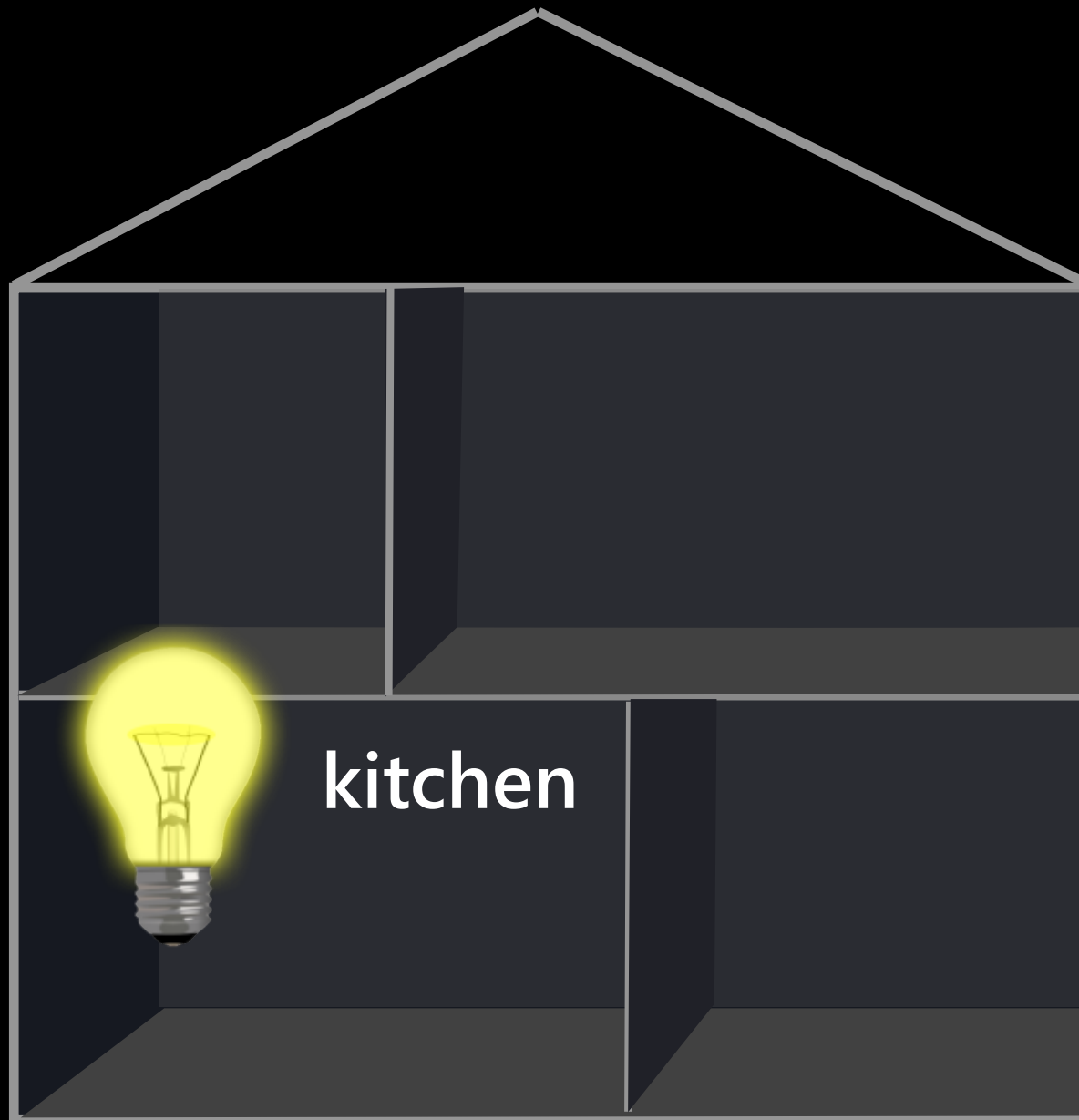


A group of people, likely a wedding party, are posed on stone steps. The image is semi-transparent, with a large white number '1976' centered over it. The group includes men in suits and women in dresses. The clothing is characteristic of the mid-1970s, such as wide lapels, patterned scarves, and specific shoe styles. The overall tone is formal and commemorative.

1976



Kohlenberg et al., *J. of Applied Behavior Analysis*, 1976



Kohlenberg et al., *J. of Applied Behavior Analysis*, 1976

the **lightbulb** effect?

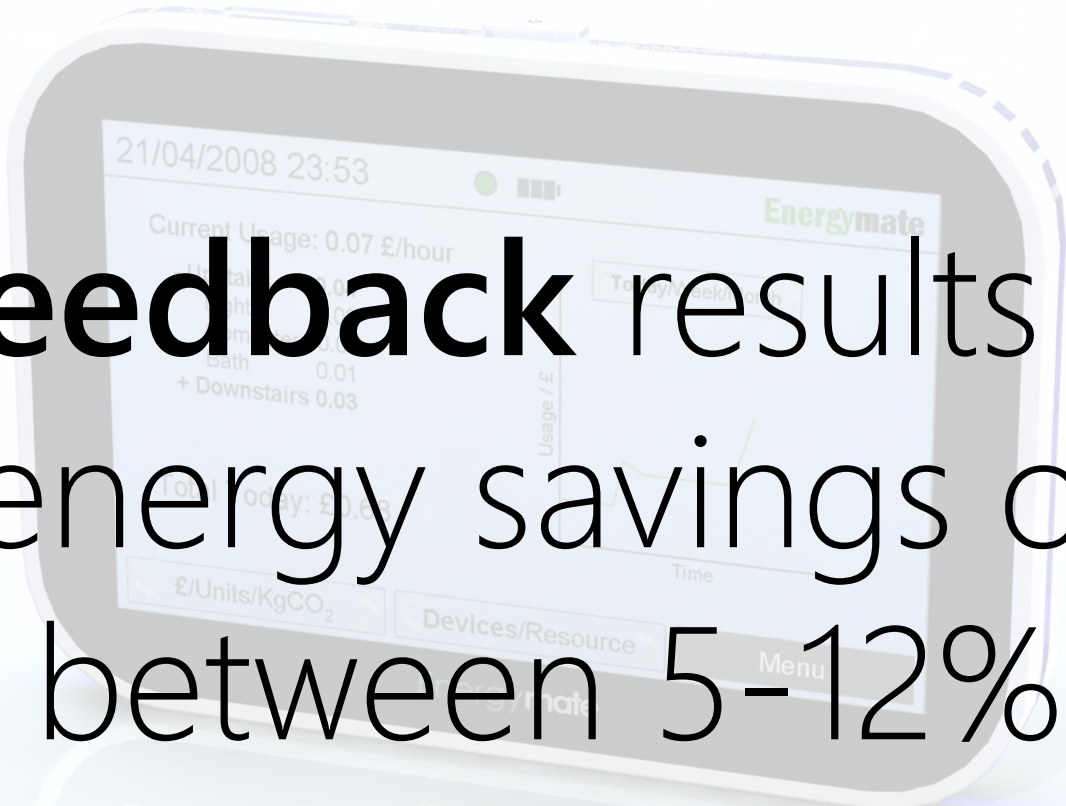
- Immediate
- Simple
- Educates
- Constrained environment
- Reason to care
- Informs only one action

the **lightbulb** effect?

- Immediate
- Simple
- Educates
- Constrained environment
- Reason to care
- Informs only one action

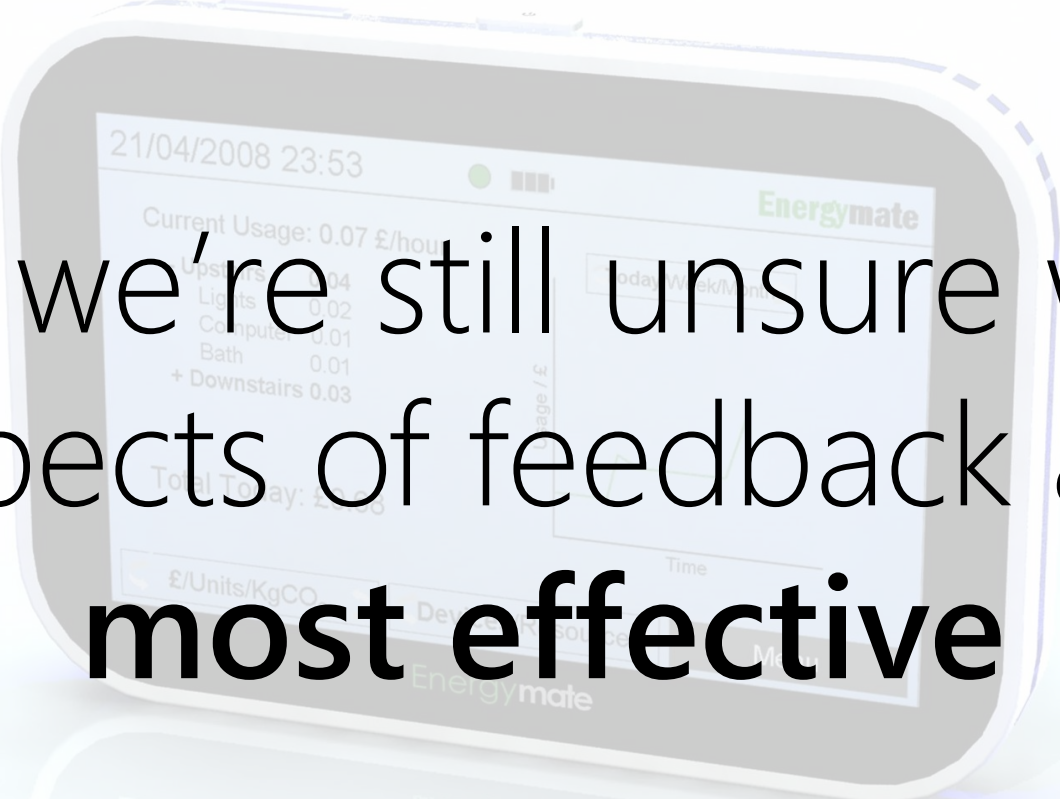
A photograph of three young women, likely teenagers, looking down at their smartphones. The woman on the left is wearing a red sleeveless top and has braces. The woman in the middle is wearing a white tank top. The woman on the right is also wearing a white tank top and has her hair down. The image is dimmed, and the year '2010' is overlaid in large white text in the center.

2010



The background image shows a handheld device with a screen displaying energy usage information. The screen shows the date and time '21/04/2008 23:53' at the top. Below that, it says 'Current Usage: 0.07 £/hour'. There is a list of usage by room: 'Kitchen 0.01', 'Bath 0.01', and '+ Downstairs 0.03'. A line graph is visible on the right side of the screen, labeled 'Usage / £' on the y-axis and 'Time' on the x-axis. At the bottom of the screen, there are buttons for '£/Units/KgCO₂', 'Devices/Resource', and 'Menu'. The device is labeled 'EnergyMate' in the top right corner of the screen.

Feedback results in
energy savings of
between 5-12%



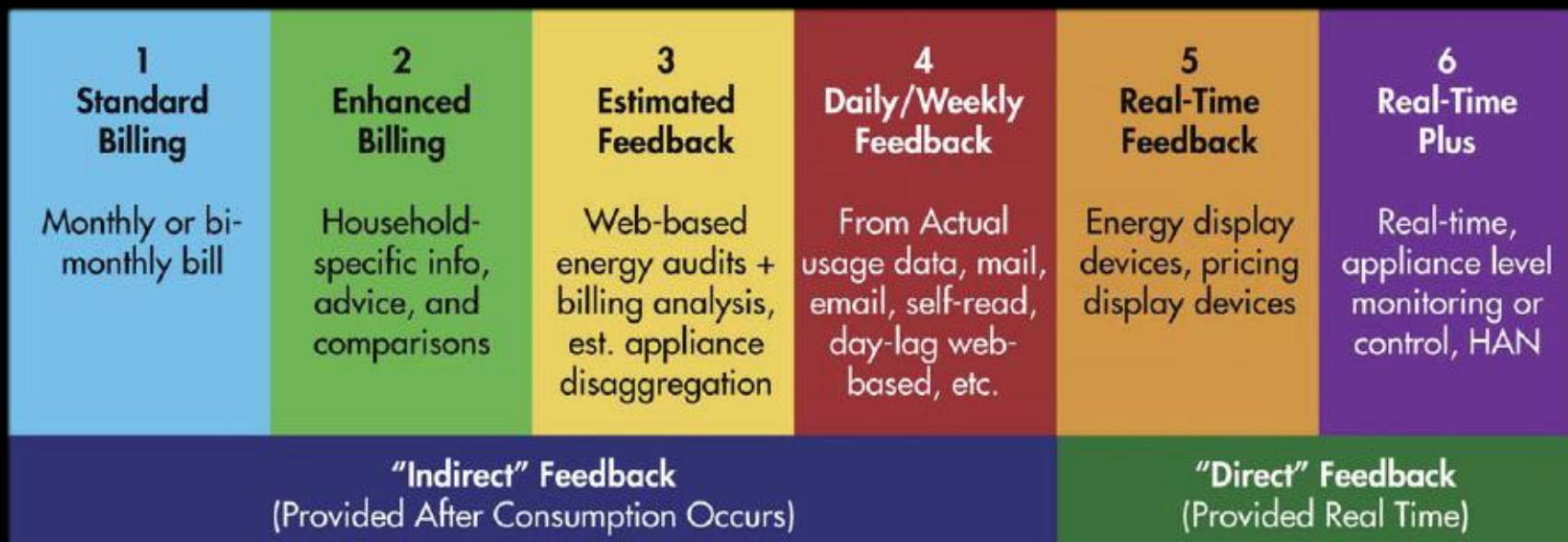
The image shows a handheld device with a screen displaying energy usage information. The screen shows the date and time as 21/04/2008 23:53. The title 'EnergyMate' is visible in green. The main display area shows 'Current Usage: 0.07 £/hour'. Below this, there is a list of energy-consuming items: 'Upstairs 0.04', 'Lights 0.02', 'Computer 0.01', 'Bath 0.01', and '+ Downstairs 0.03'. At the bottom of the screen, it says 'Total Today: £0.07'. The device has a blue and white casing. In the background, there are other similar devices, including a laptop and a tablet, all displaying the same 'EnergyMate' interface.

But we're still unsure what
aspects of feedback **are**
most effective

low

data update frequency
cost to implement

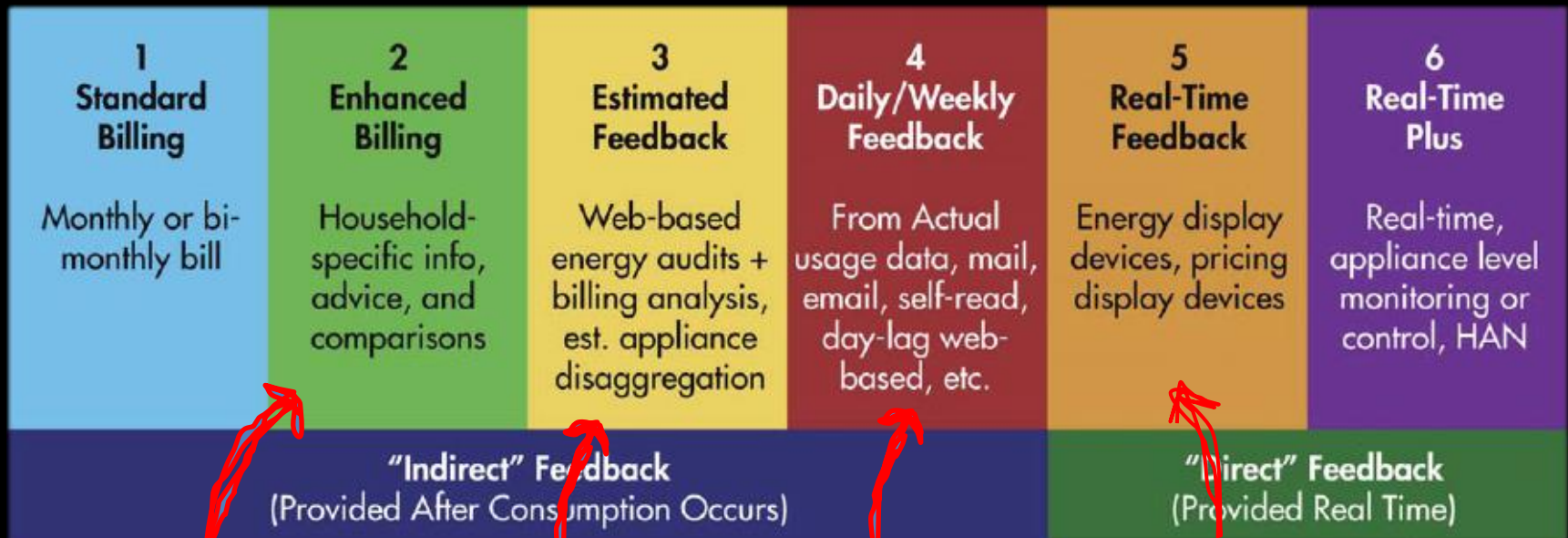
high



low

data update frequency
cost to implement

high



OPower

Energy Savvy.com

PG&E Website

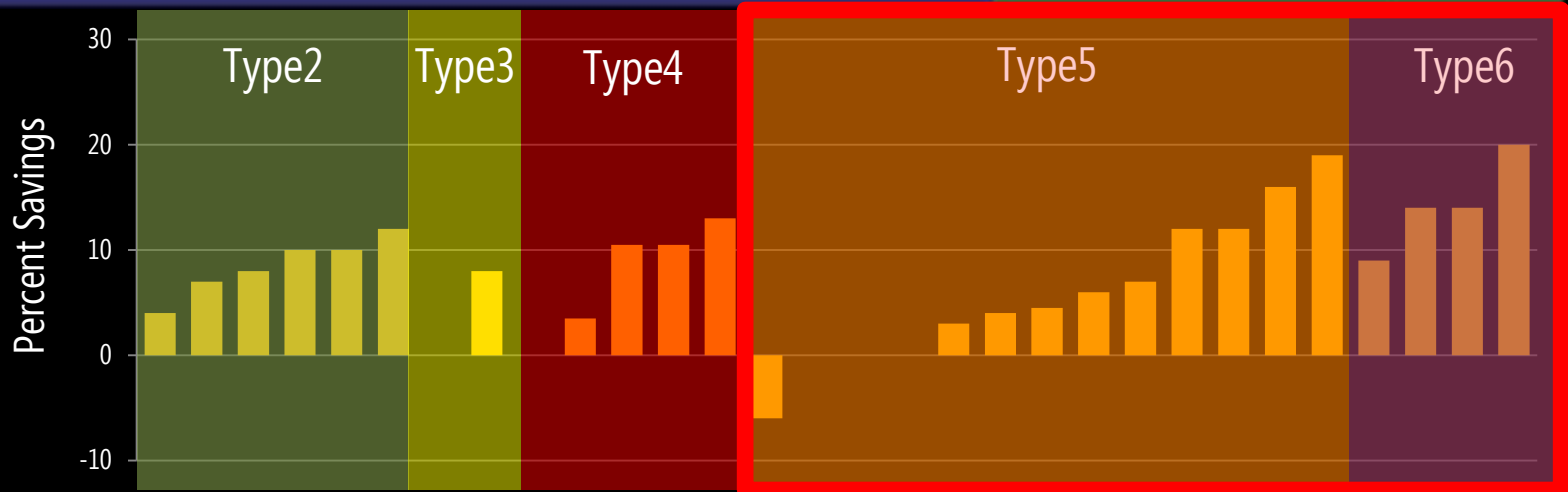
The Energy Detective

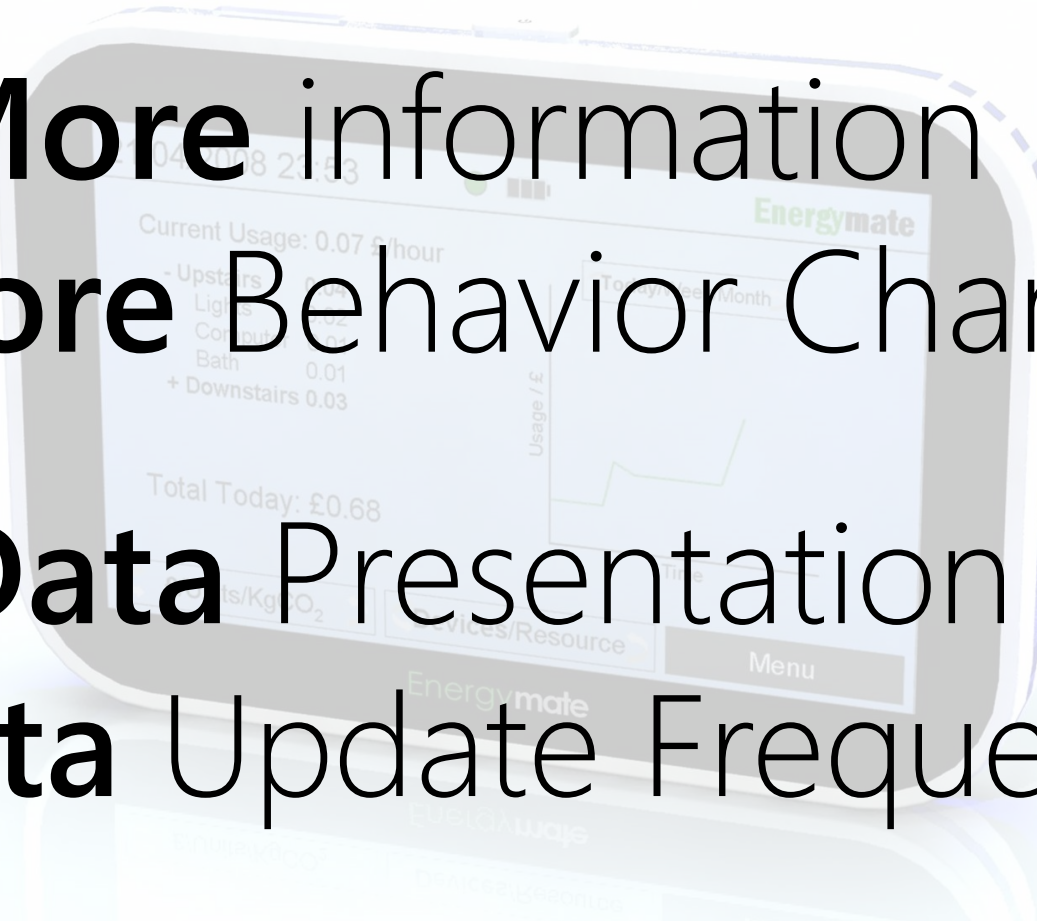
low

data update frequency
cost to implement

high

1 Standard Billing	2 Enhanced Billing	3 Estimated Feedback	4 Daily/Weekly Feedback	5 Real-Time Feedback	6 Real-Time Plus
Monthly or bi-monthly bill	Household-specific info, advice, and comparisons	Web-based energy audits + billing analysis, est. appliance disaggregation	From Actual usage data, mail, email, self-read, day-lag web-based, etc.	Energy display devices, pricing display devices	Real-time, appliance level monitoring or control, HAN
"Indirect" Feedback (Provided After Consumption Occurs)				"Direct" Feedback (Provided Real Time)	





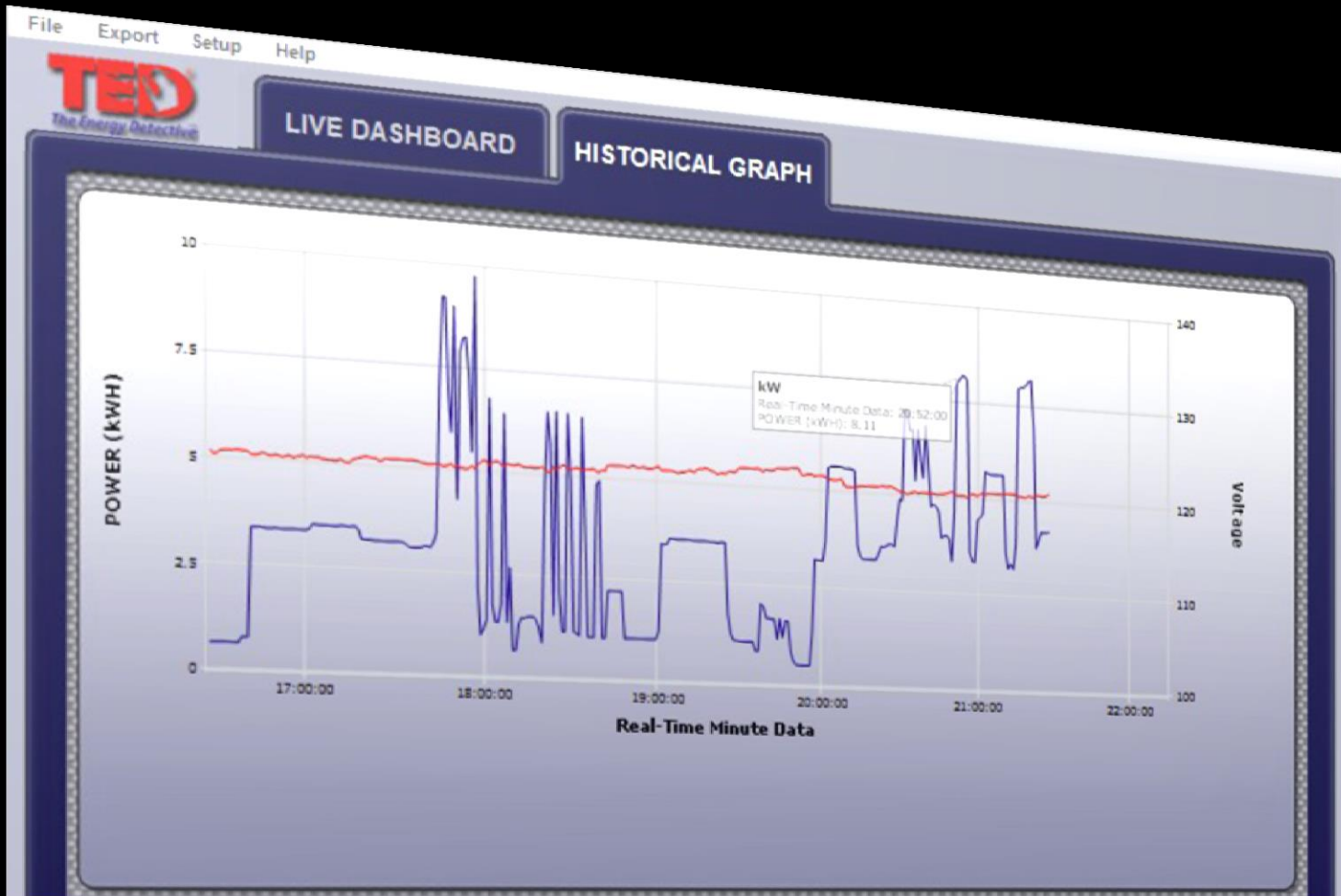
The background image shows a handheld device with a screen displaying energy usage information. The screen includes a clock at the top showing '2004-08-21 21:53'. Below the clock, it says 'Current Usage: 0.07 £/hour'. A list of usage categories is shown: 'Upstairs 0.02', 'Light 0.02', 'Comm 0.01', 'Bath 0.01', and '+ Downstairs 0.03'. A line graph titled 'Usage / £' shows a fluctuating trend. At the bottom of the screen, it says 'Total Today: £0.68'. The device has a 'Menu' button and a 'Services/Resource' button. The brand name 'EnergyMate' is visible on the screen.

More information !=
More Behavior Change
Data Presentation >
Data Update Frequency

Feedback du jour
line graphs



TED The Energy Detective



Google PowerMeter



Yello Strom



Wattson Holmes



Lucid Design Group



Microsoft Hohm





A man is seated at a desk in a dimly lit room, surrounded by numerous computer monitors. The screens display various data-heavy applications, including spreadsheets, charts, and a car image. The man is looking at one of the screens, and his posture suggests a state of intense concentration or fatigue. The overall scene conveys a sense of information overload and high cognitive demand.

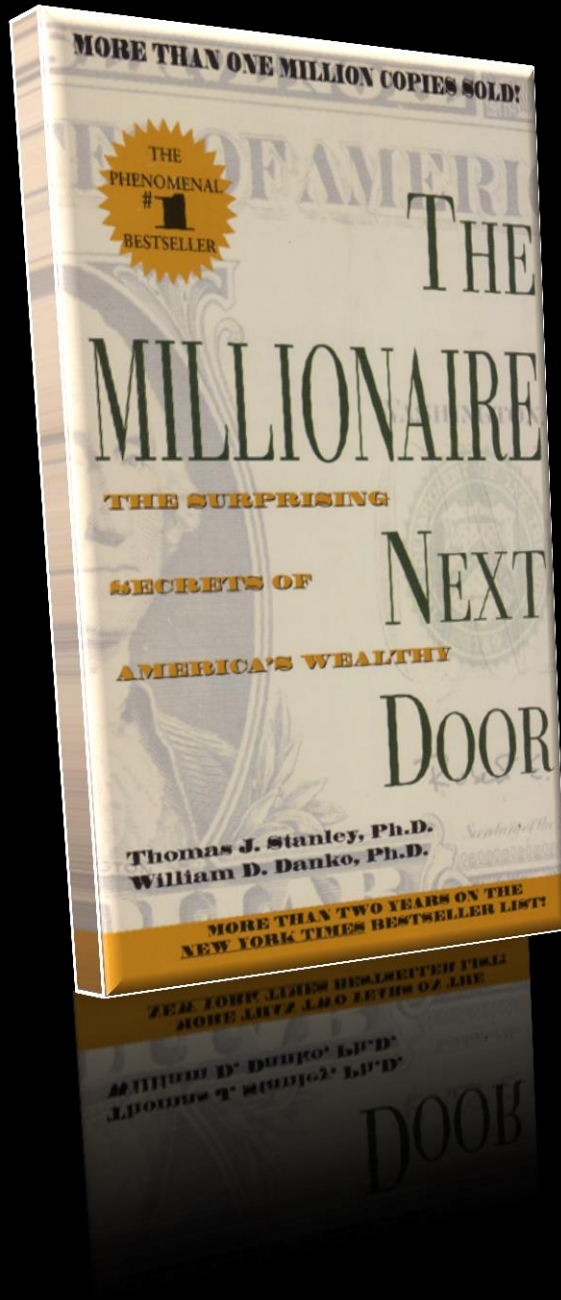
High **cognitive
burden** on person.
Why?



How much **time per day**
do we expect people will
spend exploring their
consumption behaviors?



How much **time per day**
do people spend
exploring their finances?



financially prudent

8.4 hrs/mo → 16.8 min/day

less financially successful

4.6 hrs/mo → 9.2 min/day

me (grad student)

0.5 hrs/mo → 1 min/day

A close-up, low-angle shot of a clock face. The clock has a light-colored, textured surface with dark Roman numerals. The hands are dark and ornate. The text "< 1 min" is overlaid in white, bold, sans-serif font. The clock face is slightly tilted, and the lighting is dramatic, with strong shadows.

< 1 min

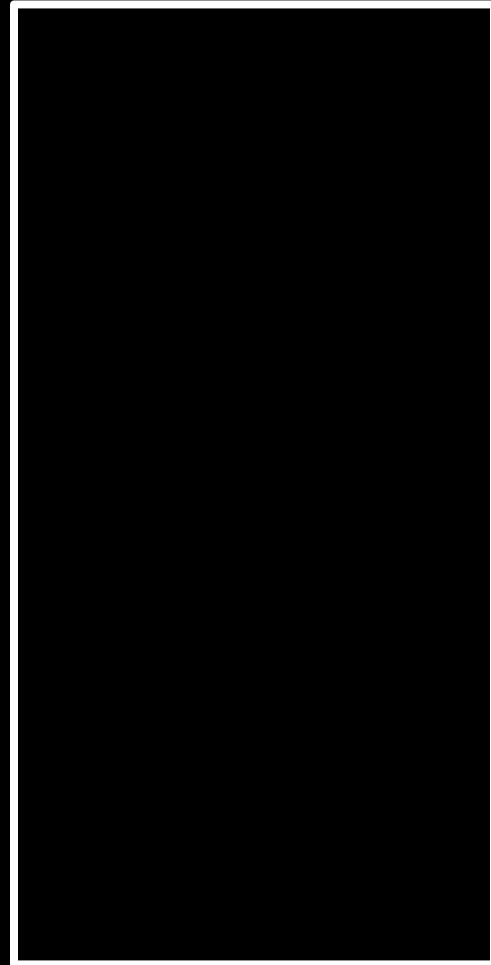
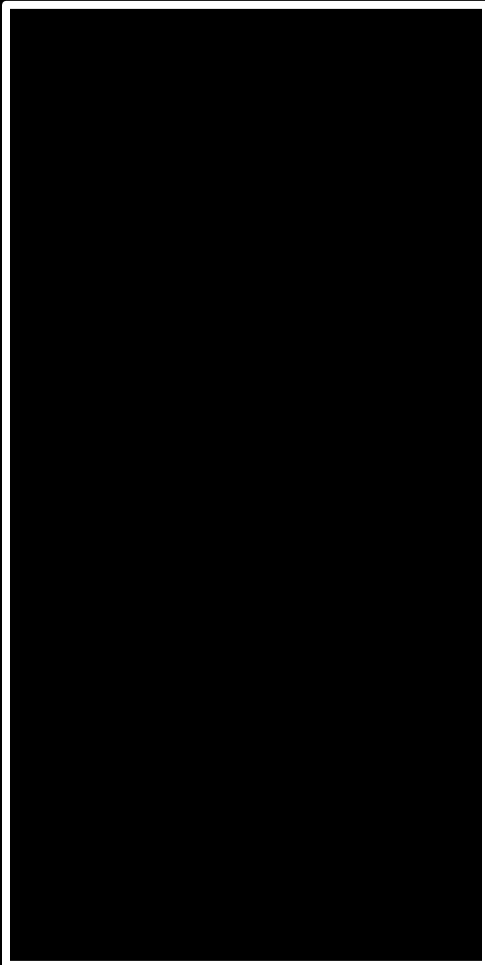
Line Graphs

How **actionable** is this information?

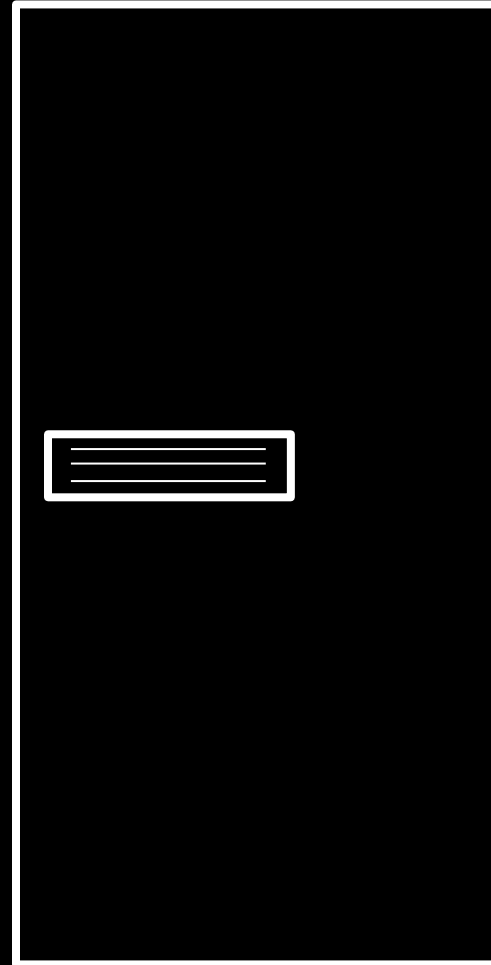
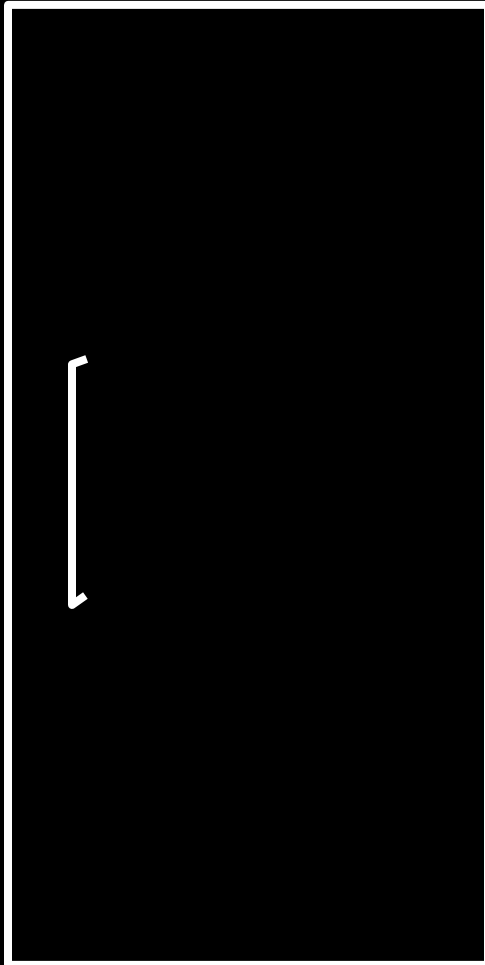




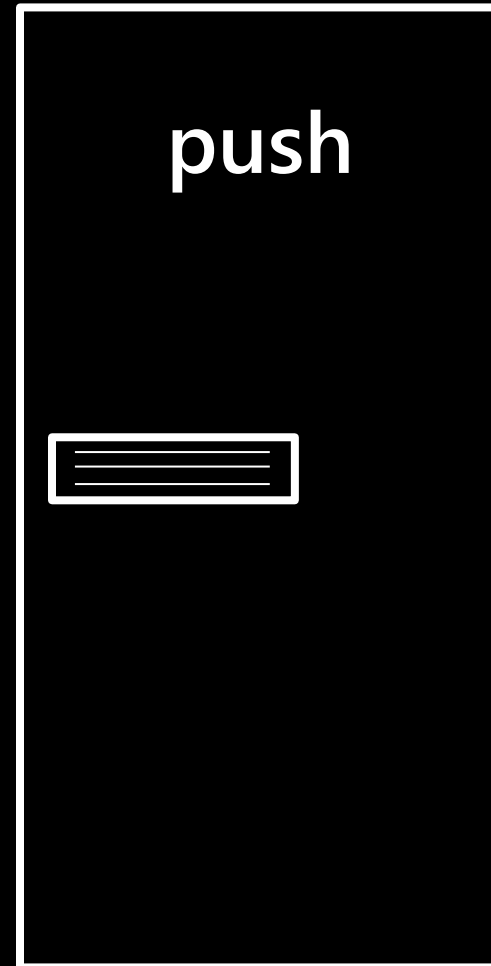
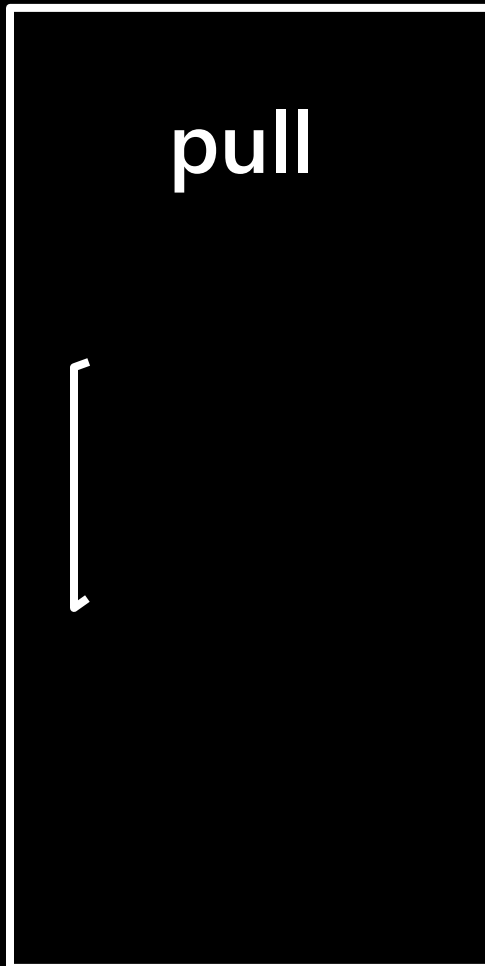
which door do i **push**,
which door do i **pull**?



which door do i **push**,
which door do i **pull**?



which door do i **push**,
which door do i **pull**?



which door do i **push**,
which door do i **pull**?







Norman door!

affordance refers to the perceived properties of a thing that determine just how that thing could possibly be used



don norman



*vertical
handle
cues pull
behavior*

PUSH

FAIL #1

PULL

FAIL #2

PULL

DUNK IT IN
DROP IT IN
SLURP IT UP

FAIL #3

PUSH



You can HAVE IT YOUR WAY® and pull if
you want, but this hinge is pretty slukbern.

AMERICAN
EXPRESS

Pull

FAIL #4

BURGER
KING



MIDVALE
SCHOOL FOR
THE GIFTED



WE CAN
BECAUSE
WE CAN
BY THE WAY
WE CAN





affordances affect our perception of use

can affordances change our **behavior**?



In-N-Out
Burger!

Battle of the Cans





Environmental protection



可回收物
Recyclable

纸类、玻璃、金属、塑料等

政府提倡使用的资源再生利用产品



愛我家园
Love our homeland



其它垃圾
Other waste

剩饭菜、瓜果壳、灰土等

政府提倡使用的资源再生利用产品



Battle of the Cans





Duffy, *Environment and Behavior*, 2010



Holes constrain
behavior and also
remind what is
recyclable





what

does this have to do with feedback?

Perceptual affordance refers to the perceived properties of a **thing** that determine how that **thing** is used

Vertical
handle
affords
pulling



Flat
textured
surface
affords
pushing!

Motivational affordance refers to the perceived properties of **information** that determine how that **information** is acted upon



Highly effective at stopping drivers

Motivational affordance refers to the perceived properties of information that determine how that information is acted upon

Information that affords an action



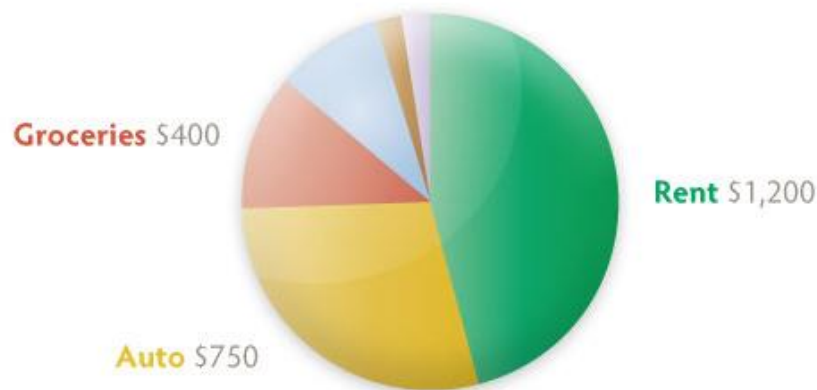
Highly effective at stopping drivers

the ^{free} best way to manage your money

"Best budgeting site" KIPPLINGER'S MAGAZINE

Editors' Choice Award PC MAGAZINE

"Top pick ★★★★★" MONEY MAGAZINE



New! Set, track and achieve your goals ▶

At-a-glance insights

We download and categorize your balances and transactions **automatically** every day— making it effortless to see graphs of your spending, income, balances, and net worth.

Free! Get started here ▶

analytics engine for personal spending

UNDERSTAND YOUR MONEY

VIEW YOUR ACCOUNTS IN ONE PLACE

SET GOALS AND BUDGETS

FIND INSTANT SAVINGS

SAFE AND SECURE

What the press is saying

Mint is the most incredible online application I have ever come across!! Unbelievable job - keep up the great work.

- COBY H, CALAIS, VERMONT [MORE ▶](#)

Money

Our Top Pick ★★★★★

The New York Times

Mint Has Helped Me Save



Valuable...
Easy to Use



Editors' Choice
★★★★★ 1/2

[MORE ▶](#)

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[Transactions](#)
[Budgets](#)
[Goals](#) new
[Trends](#)
[Investments](#)
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INSURANCE


[Auto Insurance](#)

[Life Insurance](#)

Tell us about your savings accounts, and we'll find the best new account for you.*

[Hide Profile](#)

Total Balance



\$ 12,500

Current APY



0.30 %

Interest Earned

\$37 per year

* Values displayed are averages from the Mint community. To see your own spending, [add a savings account](#) to your profile.

Filter Results

[Reset](#)

▼ Rates and Fees

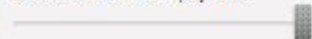
APY: > 0.00%



Minimum to Open: < \$5,000



No-Fee Balance: < \$5,000



Monthly Fee: < \$10.00



▼ Features

☐ Free ATM Withdrawals \$332

▼ Bank

☒ All BEST

☐ Ally Bank \$333

☐ American Express Bank, \$375

FSB

☐ BB&T \$18

☐ Bank of Oklahoma \$75

Estimate my savings over

1 year 2 years

3 years

Sallie Mae® High-Yield Savings Account

SallieMae®

Dream. Invest. Succeed.
[See Details](#)

APY
1.30 %

MINIMUM
TO OPEN
\$ 0

NO FEE
BALANCE
\$ 0

LOW BALANCE FEE
\$ 0

Your Three-Year Savings

\$375

[APPLY NOW ▶](#)

FDIC INSURED

[Show Savings Calculations](#)

Capital One InterestPlus Online Savings

Capital One Bank

[See Details](#)

APY
1.30 %

MINIMUM
TO OPEN
\$ 1

NO FEE
BALANCE
\$ 0

LOW BALANCE FEE
\$ 0

Your Three-Year Savings

\$375

[APPLY NOW ▶](#)

A large, faded Starbucks logo watermark is centered in the background. It features the iconic Siren (Mermaid) logo in the center, surrounded by the words "STARBUCKS" at the top and "COFFEE" at the bottom of a circular border.

How much **money** do I spend
per month on **Starbucks**?

[Overview](#)
[Transactions](#)
[Budgets](#)
[Goals](#)

new

[Trends](#)
[Investments](#)
[Ways to Save](#)

starbucks spending

February 2009 – November 2010

[This Month](#) [Last Month](#) [This Year](#) [All Time](#)


2 CHOOSE A GRAPH

Spending

Over Time

Income
Net Income
Assets
Debts
Net Worth

By Category
By Merchant
By Tag

 Search these transactions »

all GRAPHS TO TRY NEXT »
How is my net worth changing over time?

Spending Over Time

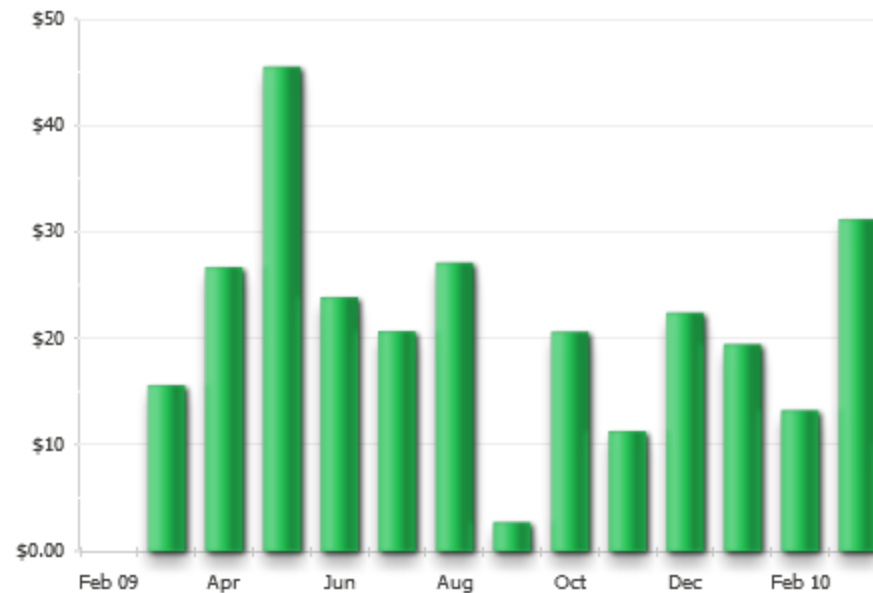
[Overview](#) > Starbucks

FILTER by CATEGORY or MERCHANT

 description: Starbucks


COMPARE to

▼ Select a comparison

■ Your Spending


Hiding: None (EDIT)

3 GET THE REPORT

MONTH

February

SPENDING

\$0.00

MOST SPENT

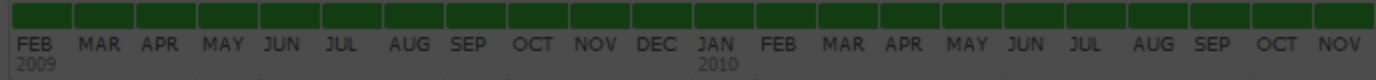
\$45 in May 2009

[Overview](#)
[Transactions](#)
[Budgets](#)
[Goals](#)
[Trends](#)
[Investments](#)
[Ways to Save](#)

1 SET YOUR TIMEFRAME

February 2009 – November 2010

[This Month](#)
[Last Month](#)
[This Year](#)
[All Time](#)



2 CHOOSE A GRAPH

Spending Over Time

[Overview](#) > Starbucks

FILTER by CATEGORY or MERCHANT

description: Starbucks

COMPARE to

▼ Select a comparison

Spending Over Time

Income By Category

Net Income By Merchant

Assets By Tag

Debits By Tag

Net Worth

This type of inquiry is **not possible** with current energy feedback systems; it needs to be.



Hiding: None (EDIT)

3 GET THE REPORT

MONTH

February

SPENDING

\$0.00

MOST SPENT

\$45 in May 2009

A faded cartoon illustration of the Scooby-Doo gang. From left to right: Velma is holding a spiral notebook and a pen; Fred is in the foreground wearing a green hat and a red and white striped shirt; Shaggy is in the center wearing a white shirt and a black bow tie; Scooby-Doo is behind him with his mouth open; and Daphne is on the right wearing a red dress and making a peace sign. They are all inside a transparent time machine with a large circular dial in the background.

Future

Feedback system provides
dissaggregated feedback

\$ 34.50 \$0.15/kWh
1265 kWh

Real Time Usage 682 Watts



Bedroom TV	<div></div>	300 W
Playstation 3	<div></div>	455 W
Cooking Range	<div></div>	1235 W
Lighting	<div></div>	750 W

Lighting	<div></div>	120 W
Cooking Range	<div></div>	1232 W
Playstation 3	<div></div>	422 W
Bedroom TV	<div></div>	300 W

image credit: sidhant gupta



Hot Water Heater
Consumes 19% of
Your House's Energy

Feedback system **suggests**
lowest effort actions for
greatest efficiency gain



**Replace Your Hot
Water Heater** with
a Tankless System
and Save \$250/yr



**You are losing
\$250/yr** by using
this water heater



< 1 min

See also: **CHI 2010** talk



See also: these two papers

<http://bit.ly/jonuw>

This paper was originally presented as a poster at the HCI, 2009 Workshop and subsequently released as a UIC Tech note 009-02-01.

Promoting Energy Efficient Behaviors in the Home through Feedback: The Role of Human-Computer Interaction

Jon Froehlich

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Abstract

The consumption of energy is unlike most consumable goods. It is abstract, invisible, and untouchable. Without a tangible manifestation, home energy usage often goes unnoticed. Advances in resource monitoring systems will soon provide real-time data on electricity, gas, and water usage in the home. This will produce a tremendous amount of data that can be analyzed and fed back to the user—creating a rich space of opportunities for HCI research. This paper outlines common misconceptions of energy usage in the home, establishes the potential of feedback to change energy consumption behavior, and introduces ten design dimensions of feedback technology with which to build and evaluate future systems.

Keyword

Feedback

Introduction

The United States consumes one quarter of the world's energy resources, despite accounting for less than five percent of the world's population (US Department of Energy, 2002). The residential sector accounts for 21% of the nation's energy use and the average American household spends nearly \$2,000 on energy bills per year (US Department of Energy, 2006). Home energy and personal transport are the top two contributors of the average American's CO₂ emissions into the environment (Weber and Matthews, 2007), accounting for over 50% of their total carbon footprint. To date, the primary methods applied to improving energy efficiency and/or reducing energy usage have been technological and economic (Armell, 2008). For example, the production of hybrid or hydrogen vehicles has been emphasized as a major solution to CO₂ reduction and oil dependence. However, there is growing evidence that a human-centered, behavioral approach should also be pursued to educate, inform, and motivate energy efficient human behaviors.

In a study evaluating the energy consumption of 10 identical Habitat for Humanity all-electric homes outfitted with the same appliances and equipment, homes were found to exhibit a large range in energy consumption, with the most energy intensive home consuming 2.6 times more energy than the least (Parker et al., 2008). Indeed, it has been consistently found that energy use can differ by two to three times in identical homes, occupied by people with similar demographics (Socolow, 1978; Winett et al., 1979). Such findings reveal how differences in human behavior can significantly affect energy consumption and suggest that intervention strategies to promote sustainable behaviors could result in significant energy savings.

Yet, curtailing energy usage in the home is a difficult task. The consumption of energy—be it heating fuel or electricity—is unlike most consumable goods. It is abstract, invisible, and untouchable (Fischer, 2008). Without a tangible manifestation, home energy usage often goes unnoticed—unlike, for example, the decreasing amount of milk in the fridge, the increasing dullness of a razor blade, or a gas gauge nearing empty. Most people have no

The Design of Eco-Feedback Technology

Jon Froehlich¹, Leah Findlater², James Landay¹

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DUI Institute, University of Washington

{jfroehli, leahkf, landay}@uw.edu

ABSTRACT

Eco-feedback technology provides feedback on individual or group behaviors with a goal of reducing environmental impact. The history of eco-feedback extends back more than 40 years to the origins of environmental psychology. Despite its stated purpose, few HCI eco-feedback studies have attempted to measure behavior change. This leads to two overarching questions: (1) what can HCI learn from environmental psychology and (2) what role should HCI have in designing and evaluating eco-feedback technology? To help answer these questions, this paper conducts a comparative survey of eco-feedback technology, including 89 papers from environmental psychology and 44 papers from the HCI and UbiComp literature. We also provide an overview of predominant models of proenvironmental behaviors and a summary of key motivation techniques to promote this behavior.

Author Keywords

Eco-feedback, Environmental HCI, Reflective HCI, Survey

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

As environmental issues such as climate change, air pollution, and water scarcity become more salient in the global consciousness, so too have they become more active targets of research within HCI and Ubiquitous Computing [6, 19, 57]. One particularly popular form of environmental HCI research is the design and study of eco-feedback technology, which we define as technology that provides feedback on individual or group behaviors with a goal of reducing environmental impact (adapted from [39] and [28], see Figure 1 for examples). Despite this goal, few HCI eco-feedback studies have even attempted to measure behavior change. Although eco-feedback may be seen as an extension of research in *persuasive technology* [17], it actually extends back much further to over 40 years of research in environmental psychology. This leads to two interrelated questions: (1) What can HCI learn from Persuasion to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or to republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.
CHI 2010, April 10–15, 2010, Atlanta, Georgia, USA.
Copyright 2010 ACM 978-1-60558-029-9/10/04...\$10.00.



Figure 1. Examples of eco-feedback technology. (left-to-right) The Indotrip display uses sensors and living plants to provide feedback about recycling and waste disposal [29]. WaterNet provides ambient feedback information about water usage [3]. The UbiGreen Transportation Display semi-automatically senses and feeds back information about transportation to encourage green travel [19]. environmental psychology and (2) what should be the role of the HCI community in contributing to eco-feedback research? To explore these questions in detail, we present a review of the related environmental psychology literature as well as a comparative survey of eco-feedback studies in both HCI and environmental psychology.

Eco-feedback technology is based on the working hypothesis that most people lack awareness and understanding about how their everyday behaviors such as driving to work or showering affect the environment; technology may bridge this “environmental literacy gap” by automatically sensing these activities and feeding related information back through computerized means (e.g., mobile phones, ambient displays, or online visualizations). HCI and UbiComp researchers have built eco-feedback technologies for a variety of domains including energy consumption [28], water usage [3], transportation [19], and waste disposal practices [29].

Contributing to this growing interest in eco-feedback technology is the parallel advancement and availability of sensing systems for environmentally related activities (e.g., human activity inference [35]) and interactive displays to feedback this data (e.g., iPads and mobile phones). Such advances provide a rich space of opportunities for new types of eco-feedback that could not be considered in the past. Moreover, the next generation of resource measurement systems (often referred to as “smart meters”) will soon provide real-time (or near real-time) data on electricity, gas, and water usage in homes and businesses. This will produce tremendous amounts of data that can be

Best
Paper!

fresh off the presses:

SMART ENERGY SYSTEMS

Disaggregated End-Use Energy Sensing for the Smart Grid

This article surveys existing and emerging disaggregation techniques of energy consumption data and highlights signal features that might be used to sense disaggregated data in a viable and cost-effective manner.

Imagine an energy feedback system that displays not only total power consumption and cost, but also suggests specific cost-effective measures to improve energy efficiency. Such a system could report, for example, "Based on your energy consumption patterns, you could save \$360 per year by upgrading to a more efficient refrigerator, which would pay for itself after 21 months." The challenge in this scenario is how to sense end uses of energy to provide feedback at the individual device or appliance level. Emerging smart meters promise a tighter temporal coupling between energy usage and feedback (up to 15-minute sampling intervals). However, the focus still is on aggregate consumption, making it difficult for consumers to ascertain which devices or appliances are responsible for their energy usage. Disaggregated end-use energy data promises to transform the way residents, utilities, and policy

Jon Froehlich, Eric Larson, Sidhant Gupta, and Gabe Cohn
University of Washington

Matthew S. Reynolds
Duke University

Shwetak N. Patel
University of Washington

makers think about and understand how energy is consumed in the home. Our research team, as well as many other teams worldwide, is working toward a new generation of electricity, water, and natural gas measurement systems that are low cost, easy to

install, and, most important, capable of providing disaggregated data about consumption at the level of the individual appliance or device. Our team's contributions are focused on approaches for obtaining this disaggregated data from a single sensing point. Our vision is to provide high granularity resource-sensing systems for homes and businesses that will fundamentally transform how electricity, water, and natural gas are understood, studied, and ultimately consumed. This article focuses on electrical energy, but we've also developed systems for disaggregating water and gas usage (see the sidebar). All three of our systems share a common approach: they monitor side effects of resource usage that are manifest throughout a home's internal electricity, plumbing, or gas infrastructure.

Although our techniques should function in commercial and industrial sectors, we've concentrated so far on validating our methods in the residential sector, which presents many challenges. In addition to the significant amount of energy use and CO₂ emissions in the residential sector,^{1,2} there's a higher degree of decentralized ownership. Also, levels of self-interest and expertise in reducing energy consumption vary, compared with the industrial and commercial sectors. Perhaps more compelling, however, is that energy consumption can vary widely from home to home based simply on differences in individual behavior. Indeed, it has been found

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Moving Beyond Line Graphs

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