$12 to $24. Therefore, the per-PEV infrastructure costs will run to between $25 and 50 for long-term and short-term volumes respectively. Assuming 2030 PEV installed base volume to be about 10 million vehicles, the cost of deploying Smart Grid infrastructure will approach $250 million ($25 per unit times 10 million vehicles) in 2030.

Table 7-7
Cost of Vehicle to Grid Converter

Technology	Total Units	Units	% Sat	Cost/ Unit Low $	Cost/ Unit High $	Total Cost Low-High $M
Vehicle to Grid Power Converter	30,000,000	Number of vehicles	50	300	500	4,500-7,500

Communication Upgrades for Building Automation

Today, over one-third of the conditioned and institutional buildings in the U.S. have some form of energy management and control systems installed (EPRI 101883). Automated demand response (ADR) can be accomplished by communicating to advanced building energy management systems using an Internet-communicated signal or some other form of direct link. Legacy systems deployed today lack this capability. Open automated demand-response (Open-ADR) involves a machine-to-machine communication standard that provides electronic, Internet-based price and reliability signals linked directly to the end-use control systems or related building and automated control systems (EPRI 1016082). The building automation system is pre-programmed to reduce load according to the messages it receives, and it may also provide real-time energy consumption information back to the utility or service provider.

Employing Open-ADR presumes the building has an advanced EMS system. There are two cost components that enable the building to respond to DR signals. The first is enable the building's EMS to receive the DR signals. In some cases, this might mean upgrading the software, and in other cases, this might mean installing a "simple client" whose only purpose is to receive the DR signals and pass them on to the EMS system. One of the features of Open-ADR is to allow very simple and inexpensive clients to be built that can interface to existing EMS systems via dry-relay contacts. Dry relay contacts seem to be the near-universal interface mechanism for EMS systems.

The second and perhaps largest cost component is the programming of load control strategies in the EMS. The cost is primarily one of manpower that involves audits of loads in the facility and specialized knowledge of how to convert the EMS to implement load control strategies. Auditing building use and load characteristic is not a trivial exercise. In this regard, the simple response levels sent as part of an Open-ADR signal can be used. In many cases, it is more convenient for the facility manager to think in terms of "normal, moderate, and high" response levels instead of prices or specific dispatch commands. Also, it is not insignificant that if the engineers set up their load control strategies based upon simple levels, then they can more easily move between different programs without the need to reprogram their EMS system.

The study team estimated that by 2030 some 5% of the 20,178,151 commercial buildings would be upgraded to the level of complete energy automation at a cost of $5,000 to $20,000 per building. The total Smart Grid cost is estimated between $5–20 billion.

Table 7-8
Cost of Communication Upgrades for Building Automation

Technology	Total Units	Units	% Sat	Cost/ Unit Low $	Cost/ Unit High $	Total Cost Low–High $M
Communication Upgrades for Building Automation	20,178,151	Number of buildings	5	5,000	20,000	5,045-20,180

Electric Energy Storage

Advanced lead-acid batteries represent the most prevalent form of electric energy storage for residential, commercial and industrial customers wanting to maintain an uninterruptible power supply (UPS) system. In the future stationary lithium-ion batteries may also be deployed for use in consumer premises.

As shown in Table 7-9, commercial and industrial systems can supply power for up to 8 hours at 75% efficiency, and maintain performance through more than 5000 cycles. Residential versions typically involve two hour duration at 75% efficiency and 5000 cycle performance.

Table 7-9
Electric Energy Storage Options for Customers

Application	Technology option	Capacity (MWh)	Duration (hours)	Efficiency %	Total cycles	Cost $/kW
Residential	Advanced lead-acid	0.8	8	75%	5000	2300-2400
Commercial & Industrial	Advanced lead-acid	10	2	75%	5000	2200-2400

Both standby and online UPS technologies are available. The online UPS is ideal for environments where electrical isolation is necessary or for equipment that is very sensitive to power fluctuations. Although once previously reserved for very large installations of 10 kW or more, advances in technology have permitted it to now be available as a common consumer device, supplying 500 watts or less. The online UPS is generally more expensive but may be necessary when the power environment is "noisy" such as in industrial settings, or for larger equipment loads like data centers, or when operation from an extended-run backup generator is necessary.

In an online UPS, the batteries are always connected to the inverter, so that no power transfer switches are necessary. When power loss occurs, the rectifier simply drops out of the circuit and the batteries keep the power steady and unchanged. When power is restored, the rectifier resumes carrying most of the load and begins charging the batteries, though the charging current may be limited to prevent the high-power rectifier from overheating the batteries and boiling off the electrolyte.

The main advantage to the on-line UPS is its ability to provide an electrical firewall between the incoming utility power and sensitive electronic equipment. While the standby and Line-Interactive UPS merely filter the input utility power, the Double-Conversion UPS provides a layer of insulation from power quality problems. It allows control of output voltage and frequency regardless of input voltage and frequency.

The study team estimated that by 2030 roughly 1.8 GW of on-site back-up storage will be installed in commercial and industrial facilities at a unit cost of $2300 to 2400/kW. An additional 2.8 GW of battery storage for residential backup applications will be installed at an average unit cost of $2200 to 2400 kW.

Table 7-10
Cost of Electric Energy Storage

Technology	Total Units	Units	% Sat	Cost/ Unit Low $	Cost/ Unit High $	Total Cost Low–High $M
Integrated PV Inverter	10,000	kW of distributed PV	100	800	1000	8.0-10.0
Consumer Energy Management System	143,928,676	Number of	10	150	300	2,159–4,318
In Home Displays	143,928,676	Number of	20	50	100	1,439–2,878

Summary of Customer Costs

The cost to bring the customer interface of the electric infrastructure up to Smart Grid performance levels so that it can support a broad array of customer services–ranging from DR-ready appliances to V2G charging–is estimated at $24 to $44 billion, as shown in Table 7-11. This cost does not include the sizeable investment that will be made by customer in appliances, PHEVs, HVAC equipment, and the like.

Table 7-11
Smart Grid Costs for Customers

Technology	Total Units	Units	% Sat	Cost/ Unit Low $	Cost/ Unit High $	Total Cost Low–High $M
Integrated PV Inverter	10,000	kW of distributed PV	100	800	1000	8.0-10.0
Consumer Energy Management System	143,928,676	Number of	10	150	300	2,159–4,318
In Home Displays	143,928,676	Number of	20	50	100	1,439–2,878
Grid-Ready Appliances	143,928,676	Number of	40%	10	20	222–443
Vehicle to Grid Power Converter	30,000,000	Number of vehicles	50	300	500	4,500–7,500
Communication Upgrades for Building Automation	20, 178,151	Number of buildings	5	5,000	20,000	5,045–20,180
Industrial & Commercial Storage for Backup	1,800,000	kW	100	2,300	2,400	4,140–4,534

Table 7-11 (continued)
Smart Grid Costs for Customers

Technology	Total Units	Units	% Sat	Cost/ Unit Low $	Cost/ Unit High $	Total Cost Low–High $M
Residential Storage for Backup	2,800,000	kW	100	2,200	2,400	6,160–6,720
Ongoing System Maintenance						
Total Cost Customer						**23,672-46,368**
Allocated to Existing Customers						**20,386-39,932**
Allocated to New Customers						**3,286-6,436**

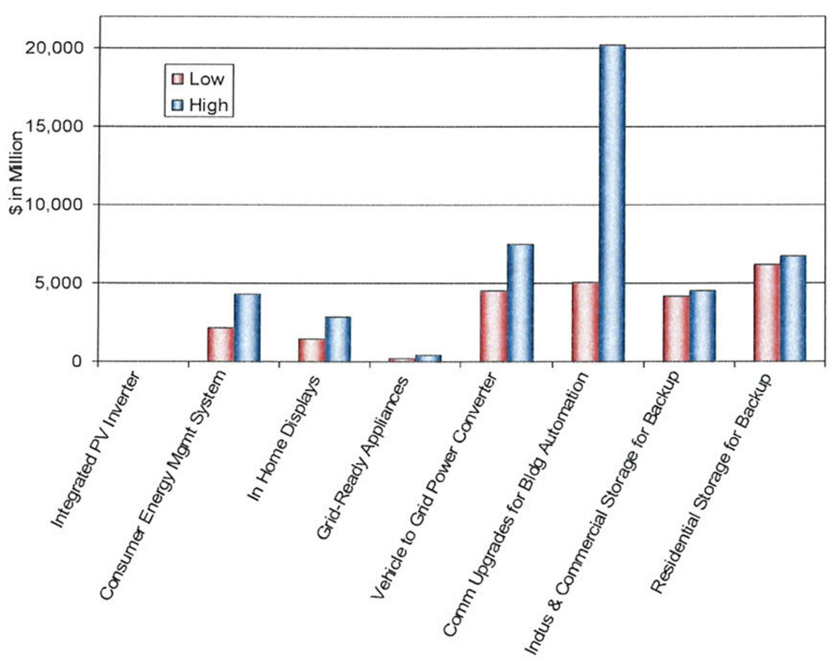

Figure 7-2
Consumer Costs for a Smart Grid

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Appendix A: Notes Pertaining to Table 4-5: List of Smart Grid Benefits

Facilitating Plug-In Electric Vehicles (PEVs)

Hi Band Estimate – EPRI's Prism analysis estimates a potential CO_2 emissions reduction in 2030 of 9.3% as a result of electricity displacing gasoline and diesel to fuel a substantial portion of the vehicle fleet. EPRI bases this estimate on the assumption that plug-in electric vehicles (PEVs) are introduced to the market in 2010, consistent with product plans of many automakers, and the rapid growth of market share to almost half of new vehicle sales within 15 years. Net emissions reduction estimates from the increasing market share of PEVs are based on research by EPRI and others (EPRI/NRCD, 2007), factoring vehicle miles traveled, carbon savings from gasoline not burned, and the trend for the electric system to become "cleaner" – i.e., for an increasing share of power generation to emit less or no CO_2.

EPRI Prism analysis assumptions:

- 100 million PEVs in the fleet by 2030; and
- Fraction of non-road transportation applications (e.g., forklifts) represents three times the current share by 2030.

PEV Low Band – The PEV low band used the results of the EPRI-NRDC study from 2007 and, somewhat arbitrarily, attributed up to 20% of the carbon savings to the presence of a Smart Grid. The reasoning was that a Smart Grid is an enabling factor, but not the sole determining factor, in the market growth of PEVs. PEV-to-Smart Grid interface-related incremental costs, which run about $25 to $50 per vehicle (on- and off-board, $50 short term, $25 long term, and only include the PLC and PLC/X interface chipset BOM costs). So the incremental cost estimate is $250 million.

Facilitating Electrotechnologies

The 2009 analysis estimates a potential CO_2 emissions reduction in 2030 of 6.5% as a result of electric technologies displacing traditional use of primary energy consumption for certain commercial and industrial applications. Electrotechnology research (EPRI/ELEC, 2009) indicates that there are applications through which net reductions in CO_2 emissions can be achieved.

This projection is based on replacing significant use of direct fossil-fueled primary energy with relatively de-carbonized electricity for a range of possible applications, e.g., heat pumps, water heaters, ovens, induction melting, and arc furnaces. It is assumed that 25% of these electro technologies are facilitated by the Smart Grid. A total of 4.5% or primary energy supplied by fossil fuels is replaced by electricity by 2030.

Facilitating Renewable Energy Resources

Hi Band Estimate – EPRI's 2009 analysis estimates a potential CO_2 emissions reduction in 2030 of 13% as a result of substantially increased deployment of renewable generation facilitated by the Smart Grid. This assumes the penetration of diverse renewable generation resources based on consideration of existing and potential state and federal programs, cost and performance improvements, and grid integration challenges. This assumption corresponds to 135 gigawatts (GW) by 2030 consisting of ~100 GW new wind; ~20 GW new biomass; and ~15 GW other technologies including solar. The average new generation over 20 years will be equal to 67.5 GW corresponding to a reduction in 3.41 Billion tons of CO_2 at \$50 per ton or \$172 billion.

Low Band Estimate – The renewables low band estimate was based on 100 additional GW of renewable capacity. Of that, 50 GW was assumed to be wind power. Assuming a 61% load factor, 267 billion kWh of additional energy would be by wind. The study attributed 50% of the realization of this energy from wind to the resolution of the intermittency challenge of wind, and then further, attributed up to 50% of the credit for resolving the intermittency challenge to the presence of a Smart Grid. The rationale used was that Smart Grid is not the sole criterion for such large-scale wind integration, but it is a critical component. The study then applied the estimated CO2 intensity of generation in 2030 to get the 37 MMtons figure.

Table A-1
Environment Benefits From Renewables, PEVs and Electrotechnologies: High Band Estimates

	Technology	% Savings	20-Year Savings (@ ramp 0 to 100%)		
			Total	%Attribute to Smart Grid	\$ @ \$50/Ton
Gross CO_2 in 2030	Additional Renewables	13	3.431E+09	100	1.72E+11
263,900,000 Million	PEV	9.3	2.454E+09	100	1.23E+11
Metric Tons	Electrotech	6.5	1.715E+09	25	2.14E+10

Table A-2
Low-Band Estimates of PEVs and Renewables (EPRI)

	Million Tons Co_2 (2030)		Total (over 20 years)		$B @ $50/Ton	
	Low	High	Low	High	Low	High
Renewables	19	37	190	270	9.5	18.5
PEVs	10	60	100	600	5.0	30.0

Table A-3
Value of PEVs: High Band

			$B	
			Low	High
Value of PEVs as a grid support technology*	50% of 30 million vehicles in 20 years	$1,500 per vehicle	11.3	11.3

*Wellinghoff, 2008

Expanded Energy Efficiency

EPRI provides estimates of benefits of expanded energy efficiency not included in its 2004 report in a subsequent study (EPRI 1016905). This is shown in Table A-4.

Table A-4
Value of Expanded Energy Efficiency

Type	Billion kWh (2030)		Value $ (@ 7¢/kWh)		Co2 Reduction Mill. Metric Ton		Value @ $50/Ton	
	Low	High	Low	High	Low	High	Low	High
Continuous commissioning	2	9	140M	630M	1	5	50M	250M
Energy efficiency benefits from demand response	0	4	0	280M	0	2	0	100M
Feedback	40	121	280M	847M	22	68	1100M	3400M
Total	42	134	420M	1757M	23	75	1150M	3750M

Related T&D capital savings can be calculated using the following assumptions

- 25% Load Factor and T&D Savings $ 800/kW = 2030 savings range from $ 1B to $ 3B

AMI Benefits

Table A-5
Edison SmartConnect™ Cost Benefit Information and U.S. Estimate

Benefits	Amount ($M)
Meter Services	$3,909
Billing Operations	187
Call Center	96
Transmission & Distribution Operations	92
Demand Response – Price Response	1,044
Demand Response – Load Control	1,242
Conservation Effect	828
Other	39
Total Benefits	**$7,437**

Southern California Edison (SCE) filings to the California Public Utilities Commission (CPUC) Proceedings: D.08-09-039, A.08-06-001; A.08-07-021 estimated benefits for several AMI attributes over a 20-year period including: Meter Services = $3,909 million; Billing Operations = $1,187 million; and Call Center = $96 million. Estimate made using SCE estimates of $4,874,890 customers and total U.S. estimated customers in 2030 of 142,121,652.

Table A-6
Southern California Edison Company Estimates of AMI Attributes

	$	$/Meter	Potential Benefit	Estimated Benefit
Meter services	3,909,000,000	801.8642	1.13962E+11	91,169,817,193
Billing operations	187,000,000	38.35984	5,451,763,819	4,361,411,055
Call center	96,000,000	19.69275	2,798,766,453	2,239,013,162
Total SCE meters	4,874,890			
Total U.S. meters	142,121,652			

Avoided Generation Investment from EE and DR

The Brattle Group estimates (Brattle, 2008) for the period 2010 to 2030 of avoided generation cost investment due to energy efficiency and demand response to be between $129 billion and $242 billion.

Table A-7
Avoided Generation Investment from Energy Efficiency and Demand Response (Brattle, 2008)

	Low	High
(Avoided) generation investment due to EE/DR	(192)	(242)

Energy Storage Benefits

Table A-8
Storage Benefits by Attribute (20 years) (EPRI 1017813 and Sandia, 2010)

Type	$Million	
	Low	High
Improved Asset Utilization		
Electric Energy Time Shift	4,936	7,367
Electric Supply Capacity	3,239	8,908
Load Following	16,354	32,561
Area Regulation	1,236	1,519
Electric Supply Reserve Capacity	1,915	2,634
Voltage Support	497	1,326
Transmission Support	221	937
Transmission Congestion Relief	19,745	33,743
Total	**48,142**	**88,995**
T&D Capital Savings		
T&D Upgrade Deferred	8,257	21,421
Renewables Capacity Firming	6,483	17,828
Wind Integration – short	958	2,865
Wind Integration – long	7.662	22,911
Total	**23,360**	**65,024**

Table A-8 (continued)
Storage Benefits by Attribute (20 years) (EPRI 1017813 and Sandia, 2010)

Type	$Million	
	Low	High
Electricity Cost Savings		
TOU Energy Cost Management	96,855	139,502
Demand Charge Management	18,245	58,976
Total	**115,100**	**198,478**
Reliability		
Substation On-Site Power	55	791
Reliability	1,731	19,774
Power Quality	700	21,026
Total	**2,485**	**41,591**
Environmental		
Renewables Integration	9,871	14,733
Total	**9,871**	**14,733**
Total All Storage	**198,959**	**408,821**

Table A-9
Distributed Generation Transmission Capacity Assumptions

Distributed Generation	Core Value
Capacity per participating customer (kW)	3.0
Grid connected PV systems	70000
Penetration growth rate	10.0%
Capacity factor	15.0%
Capacity reduction per kW – Transmission	0.45 kW
Total reduction 2010 – 2030	**$27 Billion**

Electrification Energy Benefits

Table A-10
Reduced Net Energy Required by Electrification (EPRI 1014044 and 1018871)

	High Case	Low Case
2030 decrease in quadrillion BTUs	5.32	1.71
2010-2030 decrease in quadrillion BTUs	53.2	17.1
Value @ $6.000 per million BTUs	$319.2M	$102.6M

Table A-11
Electric Sector Carbon Dioxide Emissions (AEO, 2009 Updated)

	Million Metric Tons is 2030
Petroleum	41
Natural gas	365
Coal	2222
Other*	12
Total	**2639**

*Includes emissions from geothermal power and non-biogenic emissions from municipal waste.

The Electric Power Research Institute Inc., (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

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A technical and behavioral field assessment

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TABLE OF CONTENTS

REPORT SUMMARY

OVERVIEW

This report summarizes an investigation of electricity savings opportunities in Minnesota homes related to home electronics and other plug-in devices. After 30 years of research and program efforts, much is known about large energy users in the home such as space heating: much less is known about the collection of so-called plug-load devices that includes everything from televisions to toasters—due in no small part to the very diversity and rapid evolution of this class of devices. This study seeks to address that gap for Minnesota homes, with an emphasis on prospecting for low- and no-cost energy savings opportunities for these devices.

The study relies on extensive metering and interview data for 50 Minnesota owner-occupied households that were recruited from a 1,000-household telephone survey and a 260-household mailed appliance survey. These samples were geographically and demographically stratified and are weighted to reflect the larger population of Minnesota homes. The data collection occurred in four rounds between December 2008 and October 2009, to help ensure that the results were seasonally balanced. The telephone and mailed appliance surveys provided additional insights, as well as an opportunity to verify the representativeness of the 50 homes.

We bring these technical and behavioral threads together to identify the most promising opportunities and program strategies for mitigating electricity waste among this category of electricity-using devices.

FINDINGS

How much electricity do residential plug-in devices use?

We estimate that plug-in devices (excluding major appliances and lighting) consume about 15 to 30 percent of the typical home's electric usage. Home electronics (televisions, computers and audio equipment—and their associated peripherals) make up about half of this usage. Space heaters, dehumidifiers and other portable space conditioning equipment make up about another quarter.

Many of these devices use electricity all the time for such functions as display clocks and remote control response. We estimate that such "standby" electricity consumption among plug-in devices accounts for about 20 percent of the electricity used by these devices, or about 4 percent of home electricity use (this figure does not include standby electricity used by hard-wired devices, major appliances and other devices that were not part of the scope of this study).

What savings opportunities exist for these devices?

Based on the usage patterns we found during this study, we considered five low- and no-cost ways that people can reduce the electricity used by plug-in devices:

- Enabling computer power management
- Manually unplugging devices that draw standby power when not in use

- Manually turning off devices that are left on but not used
- Using "smart" power strips to eliminate standby power consumption of peripherals (e.g., a DVD player) when the main device (e.g. television) is turned off
- Using timers to eliminate electricity use by devices that are only used at certain times of the day

We scoured the metering data from about 700 devices in the 50 homes looking for opportunities in the above categories that would save at least 25 kWh per year.

After extrapolating from devices that we metered to the full population of devices in Minnesota homes, we estimate that there is an average of 300 to 600 kWh per year worth of savings opportunities per home related to these strategies. Not all of these savings are realistically achievable given varying levels of homeowner interest and imperfect implementation of strategies, especially those that require habitual action. When these factors are taken into account, a more realistic (though speculative) behaviorally-adjusted estimate of the average savings potential per home is about half of the technically feasible figure above.

These averages belie a large range: among individual homes in the study, the estimated savings potential ranged widely, from nearly nothing to 1,500 kWh per year, depending on how many and what kinds of devices people had in their homes.

COMPUTER POWER MANAGEMENT—A SIGNIFICANT OPPORTUNITY

The single most important opportunity that we identified is computer power management, which accounts for about 40 percent of the (behaviorally-adjusted) savings potential. The data we collected show that about two-thirds of desktop computers in homes are either left on all the time or are idle for long periods each day. Moreover, 80 percent of desktops do not have sleep/hibernate enabled for the computer (most are set to put the monitor to sleep, however).

Our analysis—which was based on metering data as well as occupancy-sensor data showing when someone was at the computer—suggests that simply enabling sleep/hibernate mode for these computers could reduce electricity use among these systems by about 50 percent (nearly 300 kWh per year). In other words, in two of every three Minnesota homes, a simple change to computer settings could reduce home electricity use by about 3 percent.

Further, we found that many homeowners were unaware that their computers were not configured optimally to conserve electricity use, and we found a high level of willingness to implement more aggressive power management. Indeed, in nearly half of the cases where we identified this as an opportunity, the homeowner immediately implemented it with no active encouragement on our part—and the limited follow-up that we conducted suggest that most or all have readily stuck with the new settings.

While our study stopped short of measuring savings from actual implementation of this strategy, the facts that this no-cost, one-time opportunity is highly prevalent, appears to offer substantial electricity savings, and is apparently embraced with enthusiasm by many, suggests that it is highly worthy of pursuit.

OTHER SAVINGS OPPORTUNITIES

About 30 percent of savings potential (but half of the opportunities) are related to unplugging devices when not in use to eliminate standby power consumption. Among the homes we studied, the majority of these opportunities arose for four devices:

- Compact stereo systems that drew 20 watts or more continuously and were rarely used;
- Older CRT televisions that drew 10 watts or more of standby power;
- Computer printers drawing 4 to 8 watts of standby power that were typically used for only a few minutes a week; and,
- TV peripherals, particularly VCRs and VCR/DVD players that were rarely used.

We also identified a number of opportunities related to turning off devices that were clearly left on for inordinate lengths of time. While some of these opportunities were related to televisions, stereo receivers and other home electronics devices, unattended or inappropriate use of devices like space heaters and dehumidifiers also played a role. Altogether, we estimate that these opportunities account for about 10 percent of savings potential.

Timers offer a relatively low-cost way to de-power devices on a regular basis, and we considered these for applications such as cable and satellite set-top boxes, computer networking equipment and tool chargers. Set-top boxes make up a full quarter of TV-related electricity use, and are notable in that they are always "on" with no easy way to turn them off. However, people were generally reluctant to consider putting these on timers, due to concerns about ability to recover settings and (in some cases) the desire to record shows off-hours. Nonetheless, we did identify some promising applications for timers, and estimate that these make up about 10 percent of savings potential.

"Smart" power strips promise to eliminate standby electricity consumption by de-powering peripherals for TVs, computers and audio equipment when the main device is turned off. Smart power strip opportunities make up about 10 percent of the savings that we identified, though some of what we classified as a manual unplugging opportunity could also be a smart power strip application.

How can energy efficiency programs best address these opportunities?

A substantial share of our study households were interested in saving energy. The energy-saving opportunities they were inclined to implement face two primary barriers that programs could help to overcome. They are:

- households lack good, easy-to-use information on which of **their home's** devices truly matter;
- households don't know what practices would make a real difference.

Much of the energy-saving information to which Minnesotans—or Americans generally—are exposed is fairly general in nature. Households hear a barrage of energy-saving tips; everything from "lower your thermostat" messages from utilities to "get new windows" commercials by remodeling firms. For plugged-in devices, households know that turning off equipment is good practice, but they get little feedback on which devices use the most energy when operated or which ones use significant amounts of energy when they are simply attached to a power source. Finding out takes more effort than most households are willing to invest.

As such, we found the greatest opportunity for programs to help households reduce their load from plugged in devices is educational in nature. Well-designed consumer education with specific and narrow messages from credible sources can help to overcome some of the awareness gap. We think that a consumer educational campaign to promote computer power management may be the single most effective step programs can take to reduce so-called plug load. This report suggests some content for these messages.

Beyond power management, we also discuss program opportunities involving:

- additional messaging on devices with consistently high standby loads and easy household strategies to plug these "energy leaks";
- helping motivated households investigate their own home-specific savings opportunities; and
- adding a "plug load protocol" to energy audits and other investigative visits to homes of people with an interest in saving energy, saving money or reducing waste.

INTRODUCTION

Governments, utilities and others are under increasing pressure to effect reductions in energy use due to concern about global climate change. As a result, end-uses of electricity that have in the past not been a major focus of efficiency efforts are being looked at more closely by policy-makers and program implementers seeking to meet mandates for energy savings.

One of these areas of interest is the diverse array of devices that are plugged into sockets in homes. Conventional wisdom holds that home electronics and other such plug-load devices are a significant and growing part of electricity consumption in an increasingly connected and gadget-hungry society.

To be sure, interest in these devices is not new: the issue of standby power consumption by home appliances dates back to the early 1990s (e.g. Meier 1993). As a consequence, the federal government now maintains an active role in promoting the manufacture and purchase of efficient home electronics and other plug-in home appliances through its Energy Star program. And recently, the state of California accomplished another first by enacting standards for active power consumption of televisions. But these efforts are targeted at the efficiency of new devices and do not address questions about what, if anything, can be done to avoid wasted energy use among devices that are already in homes.

This is partly a problem of lack of data. Compared to the body of knowledge about other home energy uses, such as heating, cooling and refrigeration, less is known about how much electricity is used—and more importantly, wasted— by the myriad smaller plug-in devices in homes. Efforts to characterize and quantify energy use by "miscellaneous" home devices date back at least to the mid 1980s (see Meier et al. 1992), but field data have been hard to come by. The most extensive study in the U.S. to date was conducted in 2005 by Ecos Consulting (Porter et al. 2006). That study sought to get a more accurate estimate of miscellaneous electricity use in California homes, and parse this by device type and mode of operation.

This study seeks to build on the foundation that Ecos and others have created by adding to the body of data about energy use by plug-in devices in homes, in this case targeted at a different region of the country. We also seek to shift the emphasis to *savings opportunities* for these devices in homes. This emphasis is in keeping with the goals of the funders for this study, which are the State of Minnesota under its Conservation Applied Research and Development Grants (CARDG) program and Minnesota Power Company. Specifically, the goals of the CARDG program are to:

- accelerate the development and adoption of new energy efficient technologies and strategies in Minnesota;
- identify new conservation improvement program opportunities for electric and natural gas utilities in Minnesota; and,
- enable the state to achieve its statutory energy conservation goals.

In this context, we considered it important that a research study directed at residential plug-load be focused in ways that are most useful for regional, state and local program efforts to save energy. For that reason, we chose to assess the potential for savings from strategies that seek to save energy used by appliances that are already in homes.

The goals of this study are thus to:

1. characterize plug-load electricity use in Minnesota homes;
2. assess the extent of savings opportunities for these devices in these homes;
3. identify specific no- and low-cost ways for people to save energy among these end-uses; and,
4. propose broadly how these opportunities might be addressed by programs that operate at the regional, state or local level.

Before diving into the details of the study, it is useful to pause to more precisely define what we mean here by plug-in devices. Speaking to the difficulty in characterizing this class of home energy using devices, our definition is as much about what is not included as it is about what is included: we considered all devices that plug into a standard 120V outlet other than lighting and major home appliances like refrigerators and clothes washers. Our emphasis was on home entertainment and computing electronics—televisions and their peripherals, computers and peripherals and audio systems—which the Ecos study found to dominate electricity consumption among plug-in devices.

We did include electric space heaters, dehumidifiers, room air conditioners and other portable HVAC devices in the scope of our study. These deserve a special call-out for a couple of reasons. First, the approach that we used (see Method) was not well-suited for accurately estimating annual usage by these highly seasonal devices: this makes our estimates of usage and savings opportunities in this sub-category more tenuous than those for, say, televisions. Second, the saturation and use of these devices are obviously strongly related to climate: readers from regions with climates that differ strongly from Minnesota's long winters will need to take this into account in interpreting our results. For this reason, we have tried to provide key results in ways that allow these regionally-specific HVAC devices to be separated from other classes of devices.

Finally, we did make one important exception to the no-major-appliances rule: we decided to devote a small amount of effort at gathering data and talking to people about secondary refrigerators and stand-alone freezers. These are highly prevalent in Minnesota homes, and are worthy of some attention even if it meant a digression from our main focus. We include a short section covering our findings on these appliances in this report.

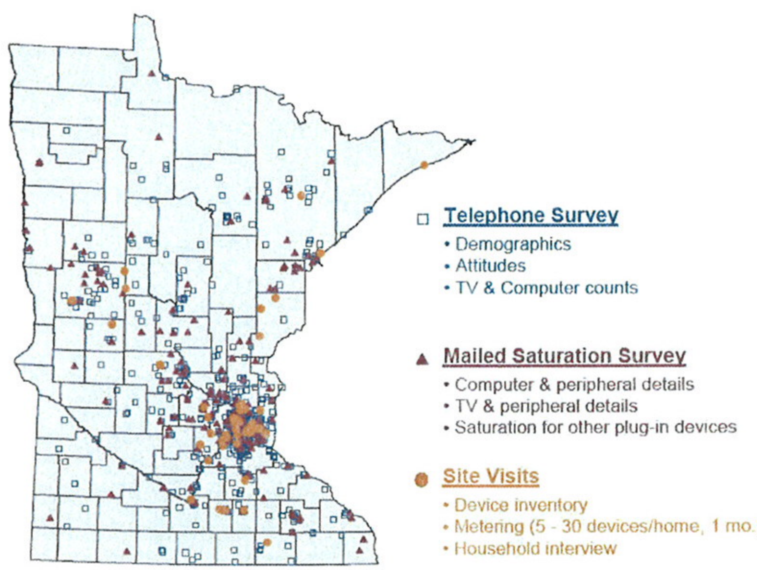
METHOD

The study relied on three nested levels of data that we collected for Minnesota homes in 2009:

- A telephone survey completed by 1,013 Minnesota households;
- A mailed appliance survey completed by 260 households; and,
- On-site data collection and interviews involving 50 households.

All three levels of data collection occurred in four separate rounds (to help ensure seasonal balance), starting in December 2008 and ending in October 2009, and were geographically and demographically stratified to help ensure that the final weighted samples were statistically representative of the population of Minnesota homes (Figure 1). Appendix A provides more details about the sampling and stratification process for the study.

FIGURE 1, GEOGRAPHIC DISTRIBUTION OF STUDY PARTICIPANTS.



TELEPHONE SURVEY

The telephone survey was used both as an initial recruiting tool for the other data collection efforts as well as to gather information on demographics, attitudes and saturation of key devices on a large sample of Minnesota households.[1] The survey was geographically and demographically stratified (see Appendix A). Each round of the survey targeted about 150 households in a core geographic region around the Twin Cities, and 100 households in one of four outlying regions. Though the study was focused mainly on homeowners (which make up about 70 percent of Minnesota households), we also collected data from some rental households: the final sample size was 837 homeowners and 176 renters.

Survey respondents were first posed a number of attitudinal questions, only some of which were clearly energy-related.[2] The interviewer also posed some fairly simple questions about home electronics, such as the number of TVs and computers in the home.

The interviewer then asked the respondent whether he or she would be willing to participate in a mailed appliance-related survey that would "help the State of Minnesota and the state's utilities better serve customers." Respondents were offered a $10 Visa gift card for participating in the appliance survey. Nearly 90 percent of respondents agreed to participate in the mailed follow-up survey.

Telephone-survey respondents were also told at this time that, in addition to the mailed appliance survey, the study was seeking "households for an in-home study of how much electricity various appliances use," for which a participation incentive of a $100 Visa gift card would be provided. About 40 percent of the telephone survey respondents said that they would be willing to participate in the on-site portion of the study (another 10 percent requested more information about the study).

MAILED APPLIANCE SURVEY

At the completion of each round of the telephone survey, we sub-sampled respondents that had indicated willingness to participate in the mailed appliance survey and sent these households a paper survey with much more detailed questions about their home appliances, particularly home electronics holdings (see Appendix F). This phase of data collection also involved demographic and geographic response quotas.

We mailed 462 surveys across the four rounds, and received 260 responses (209 homeowners and 51 renters), giving a 56 percent response rate. This survey provided us with more detailed information about home appliances for a moderately-sized sample that we could use to supplement (and cross-check) the subsequent in-home data. The appliance survey respondents also served as the recruiting pool for the in-home data collection.

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[1] The telephone survey was implemented by the Blackstone Group using a commercially available listed sample of Minnesota households.

[2] See Appendix E for the complete instrument.

IN-HOME DATA COLLECTION

At the most detailed level, we visited 50 Minnesota homes (homeowners only) and conducted three types of data collection:

1. we inventoried all (visible) plug-in devices in the home at the time of the initial site visit;

2. we installed meters on selected devices to record electricity consumption for a month-long monitoring period; and,

3. at the end of the monitoring period—and coincident with removal of the meters—we conducted a detailed interview with the household.

Device Inventory

The device inventory occurred at the beginning of the initial site visit. We simply went from room to room and recorded all plug-in devices. As part of the protocol, we also noted the room in which the device was located, what other devices it was connected to (e.g. a DVD player connected to a television) and whether the device was plugged in at the time. We noted (with the assistance of the homeowner) devices that were routinely power switched via a switched wall outlet or power strip.[3]

The inventory included the main living areas of the home, plus basements and garages. We did not inventory devices that appeared to be in "deep storage" areas, and some homes had shops with numerous power tools that we did not separately inventory (we did take note of all cordless tool chargers however). We also photographed many items and captured nameplate data for televisions and a few other types of devices when that was readily accessible.

Metering

After inventorying the appliances in the home, we selected devices for metering. On average, we metered 16 devices per home, but this ranged from 5 to 30 in individual homes. We gave first priority to home electronics, focusing on television- and computer-related equipment, but also gave a high priority to dehumidifiers and other portable HVAC devices.

We also targeted idiosyncratic devices that looked like they might use a lot of electricity or have an energy-savings opportunity. We did devote some meters to devices (such as alarm clocks) that were unlikely to have a savings opportunity, but would help us characterize total plug-load electricity use. Finally, we asked the homeowners if there were any devices they were interested in having metered: usually we had already covered any devices of interest to them, but we did fulfill a few additional requests by monitoring devices like irons and hair dryers.

[3] In a small number of instances, the homeowner did not allow us to enter parts of the home: in these cases, we relied on self-reports of devices in those areas.

After deducting a small number of cases where the metering data turned out to be unusable for one reason or another, we obtained useful data for 705 of the 1,612 devices that we inventoried (Table 1).[4,5]

TABLE 1, INVENTORIED AND METERED DEVICES.

	Number Inventoried	Number Metered	Percent metered
Audio equipment	196	95	48%
Portable device chargers[a]	140	33	24%
Clocks	93	7	8%
Computers	72	59	82%
Computer peripherals	127	101	80%
Exercise equipment	8	5	63%
Gaming devices	19	13	68%
Personal hygiene devices	37	4	11%
Household devices[b]	47	14	30%
Portable HVAC	118	46	39%
Kitchen appliances	134	23	17%
Musical instruments	5	3	60%
Networking equipment	58	35	60%
Office equipment	39	11	28%
Telephone	72	13	18%
Tools	20	2	10%
TVs	150	110	73%
TV peripherals	169	105	62%
Utility devices[c]	72	10	14%
Other	36	16	44%
Overall	1,612	705	44%

[a] except laptop chargers, which are included under Computers
[b] e.g., vacuums, sewing machines, irons
[c] e.g., CO detectors, baby monitors

[4] We also later inferred the presence of a small number (41) of important devices that we did not observe, but were reported as present by the homeowner on the appliance survey. These were mainly seasonal HVAC devices (dehumidifiers, space heaters and dehumidifiers), but also included 9 laptop computers and 5 television sets.

[5] These figures exclude the 48 secondary refrigerators and freezers that we metered as part of our side investigation.

The meters that we installed (WattsUp Pro) recorded time series data on each device for 27 days before their on-board memory filled. The meters were configured to record watt-hours of electricity use every six minutes, as well as the minimum and maximum wattage during the 6-minute interval.[6] (Appendix C provides more detail about the metering and compilation of these data.)

We also targeted one computer center per home for more detailed metering: for these, we installed meters (on the computer and monitor) with additional memory that allowed us to capture data at a higher time resolution of 90 seconds. In addition, in these cases we also installed a portable occupancy sensor with a data logger to track when someone was at the computer.

At the end of the monitoring period, we returned to the site and retrieved the meters for download. Back at the office, we reviewed the data from each meter for signs of data anomalies and problems. We also assigned an active-mode wattage threshold for each metered device: we classified electricity use above this threshold to be active-mode power consumption, with electricity draw below the threshold classified as standby use—though this was sometimes difficult to accomplish unambiguously.[7]

Processing the data included removing data flagged as bad (which was only about 3 percent of what we recovered from the field), and condensing the time series data down to summary statistics that included annualized kWh, fraction of time in standby and active modes and average wattage in each mode. These statistical summaries formed the basis of our initial screening for energy saving opportunities

The cleaned time series data were extremely valuable for estimating savings for some strategies, and we developed algorithms to process the data to facilitate these estimates. For example, we developed a smart-power-strip algorithm that merged the time series data for a master device such as a TV with the data for the peripherals for that device, and simulated the impact of a smart power strip by setting the power draw for the peripherals to zero whenever the master device was not active.

Finally, at the end of the fieldwork, we checked each meter against a reference standard, and applied calibration corrections to the raw data.

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[6] Not all devices were metered with time series loggers. We also employed a small number of Kill-a-Watt meters that simply recorded elapsed hours and accumulated kWh for some lower priority devices. These were installed on 47 devices, and also used as a backup for the WattsUp Pro meters on some devices after we discovered that certain appliances with high transient loads (e.g. dehumidifiers and microwave ovens) sometimes corrupted the meters.

[7] The three types of devices that were problematic were: (1) printers, which were typically active for very brief and sporadic periods; (2) devices with multiple distinct power draws (we generally assigned anything above the lowest power draw as active-mode; and (3) devices such as cell phone chargers where the power draw even when active was very low. We also had to make decisions about whether devices that showed a flat power draw over the entire monitoring period were in standby (usually the case) or left on in active mode the entire time: we based these decisions on the power draw characteristics of other similar devices.

In-Home Interviews

The total meter pick up and interview process took from one to three hours reflecting the variation in number of meters, accessibility, ease of data collection, and occupant (and pet!) involvement.

Upon removing all the installed meters, we interviewed the designated or available household member(s).[8] The interviews lasted approximately twenty to sixty minutes and began with some general questions about the participants' attitudes and cognizance of energy. Starting with their perceptions of energy as an issue of societal or personal concern, it continued through such questions as the degree to which the household pays attention to energy issues, whether they do anything specifically to save energy in the home, what else they think they could do if they so chose, and where they could get more information. From there, we sought feedback on how likely the household would be to engage in various ways to save energy, including changing habits, using technological aides (like smart power strips), seeking feedback, and making one-time changes in equipment settings. Limited feedback on possible program strategies and likelihood of participation was sought.

After obtaining this feedback, we showed the interviewees our meter removal log sheet and walked them through the highlights of the usage we found in the home. At this point, we were essentially providing feedback to the house and were able to gauge how interested the household was in this information and what information was most interesting and/or surprising to them. Finally, the interviewer chose two to five of the most apparent energy-saving opportunities for plugged-in devices in that home, presented what the household could do to save energy and inquired how interesting these strategies seemed to the interviewee—as well as how likely they thought they would be to take these actions.

We approached these questions as conversations, and invited interviewees' honest reactions to the various strategies. We obtained a balance of positive and negative inclinations about the various strategies from most households, giving us confidence that we were receiving candid and thoughtful responses. These comments, along with participants' reports and interviewer observations about household practices, became the basis of our assessment of the likelihood that households would engage in the various technical savings opportunities we identified.

WEIGHTING

Although our sampling at all three stages of data collection was stratified on geographic region, housing tenure and across four demographic groups, the final samples were not perfectly representative of the Minnesota population. Also, later analysis revealed that our samples tended to skew somewhat toward older households and households with higher educational attainment. We developed case weights to correct for these differences (see Appendix A).

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[8] The interview guide is attached as Appendix F.

ELECTRICITY USAGE

By combining our device inventory with the metering data from the on-site data collection, we estimate that plug-in devices in Minnesota owner-occupied homes use an average of about 2,300 ± 700 kWh per year per home.[9] We estimate that this use makes up about 15 to 25 percent of all electricity use in single-family homes.[10]

Figure 2 shows how our point estimates of electricity use break out by device category and device. About 50 to 70 percent of the total (1,300 ± 400 kWh per year) is attributable to home electronics: TVs and their peripherals, computers and their peripherals and audio equipment. TVs dominate usage among home electronics due to a combination of their ubiquity (the average home has three sets), relatively high power consumption among home electronics devices, and frequency of use (the average TV that we monitored was used for about 4 hours per day). Desktop computers and their monitors also constitute a significant proportion of plug-in device usage.

Plug-in devices for heating, cooling or otherwise maintaining indoor comfort make up a significant proportion of the total. However, we monitored only about a dozen homes per season, and usage of these HVAC devices varies substantially. Consequently, our estimates of usage by these devices (about 600 ± 450 kWh/year) carry more uncertainty than other categories.

The data across all device types also suggest that about 20 percent of this electricity use is for standby mode, while 80 percent is consumed by devices that are in so-called active mode. Among home electronics (where we were best able to delineate standby versus active power consumption), standby consumption in mode dominates for devices such as printers and some audio equipment (Figure 3).

After allowing for climate differences, the above figures are somewhat higher than the California study conducted by Ecos in 2005, which found usage of 1,000 to 1,200 kWh per year per home for plug-in devices. After deducting the HVAC category, our estimate is about 1,700 ± 500 kWh per year per home, of which 40 to 50 percent is attributable to home entertainment (compared to 60% found for the California study), and 20 to 30 percent is attributable to computer-related devices (compared to 31 percent for the California study).

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[9] The stated uncertainty (here and elsewhere) reflects both sampling and imputation uncertainty, and represents an approximate 90% confidence interval. See Appendix D for more details.

[10] Data filed for 2007 by Minnesota utilities on the Federal Energy Regulatory Commission's Form 861 (Annual Electric Power Industry Report) shows average residential electricity use at 9,989 kWh per consumer. Since this includes residential accounts in apartment buildings that tend to use less electricity, average consumption for single-family, owner-occupied homes is likely somewhat higher. We estimate about 11,000 kWh per single family home.

FIGURE 2, POINT ESTIMATES OF ELECTRICITY USE BY PLUG-IN DEVICES IN MINNESOTA SINGLE-FAMILY HOMES, BY DEVICE CATEGORY (2,300 KWH/YEAR/HOME).

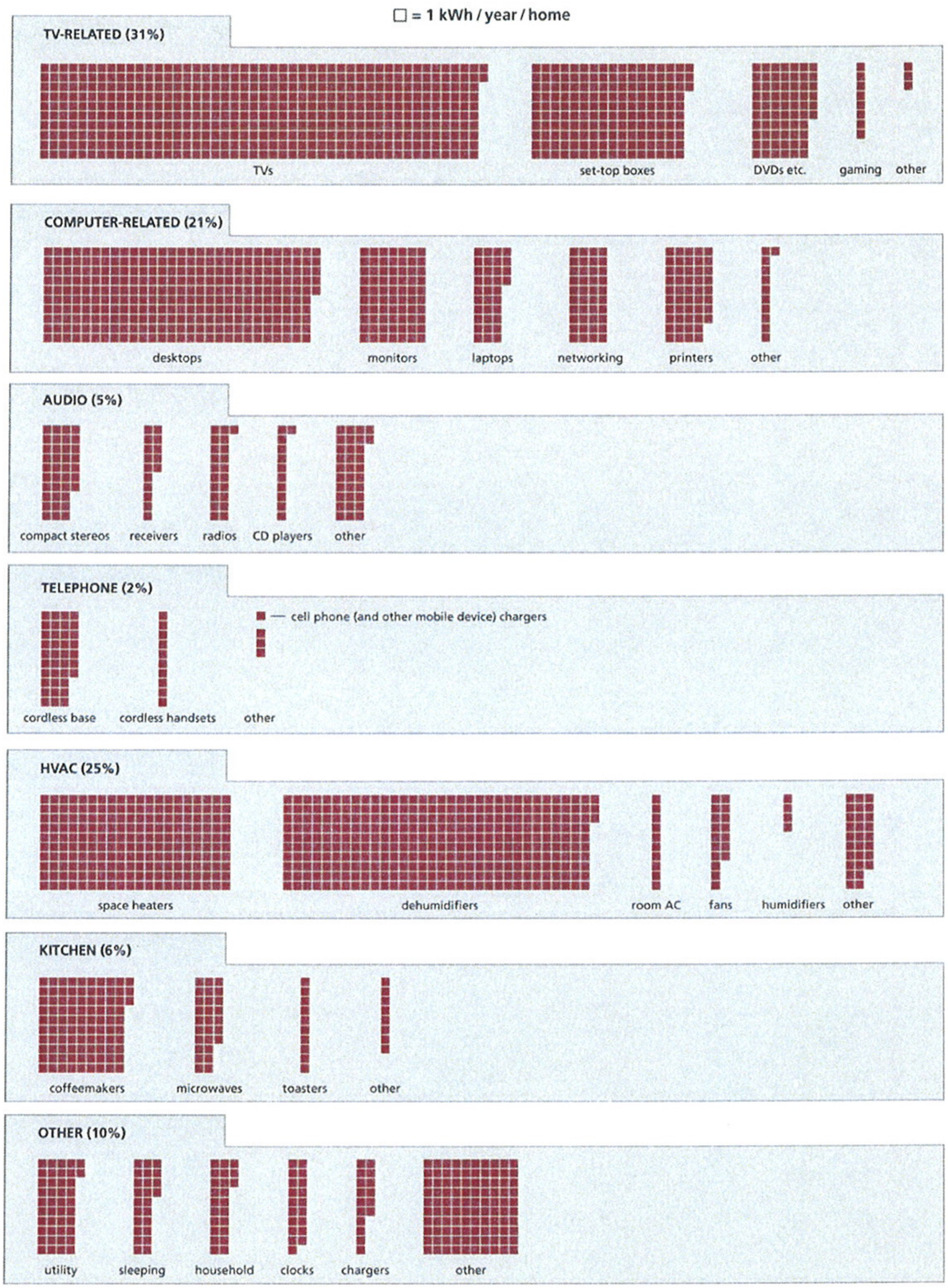
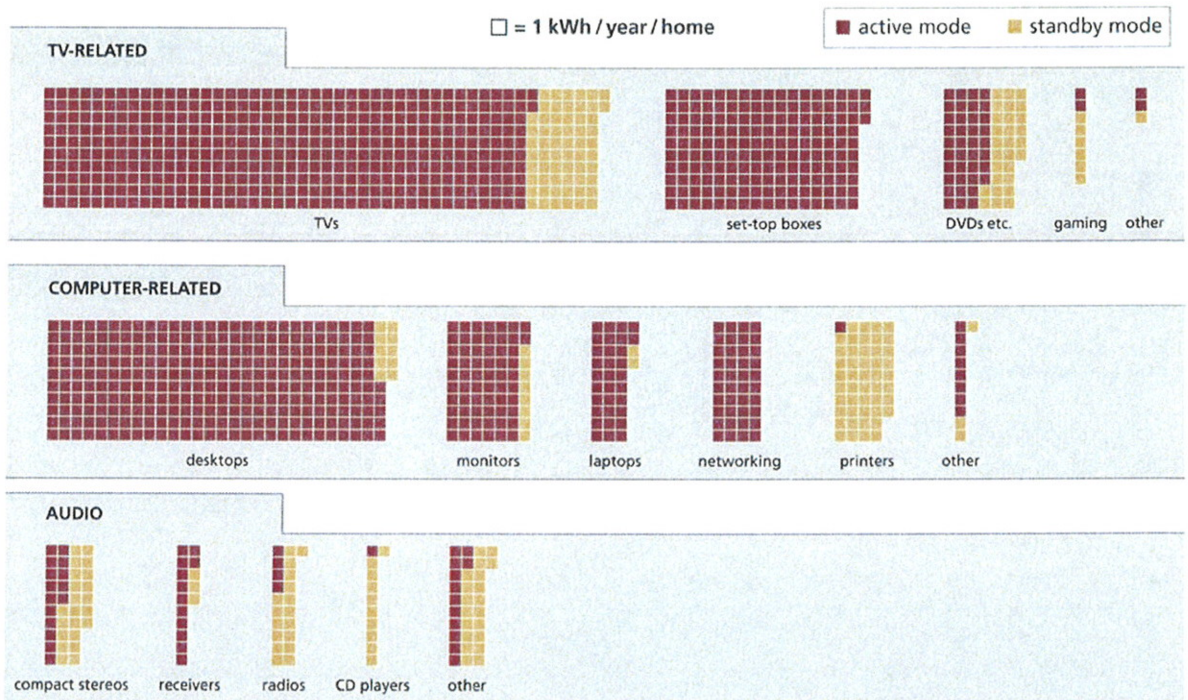


FIGURE 3, POINT ESTIMATES OF ACTIVE AND STANDBY ELECTRICITY USE FOR HOME ELECTRONICS.



ANALYSIS OF SAVINGS OPPORTUNITIES

The main goal of our study was to identify no- and low-cost things that people could do to reduce electricity consumption by plug-in devices, and quantify how much savings might be achievable in homes through these actions. In aggregate, the highest-potential opportunities can be expected to be found among devices...

1. ...that are common and use a lot of electricity;
2. ...that are commonly left on or use significant electricity even when turned off; and,
3. ...for which people are willing to take action to save electricity.

The survey and on-site device-inventory data that we collected helped us gauge the first item above. Close examination of the on-site metering data provided our basis for the second item. And the interviews with homeowners gave us insight into the third component above.

We considered five specific strategies for reducing electricity use by plug-in devices, but these boil down to two general categories: (a) turn off devices when not in use; and, (b) unplug devices that draw standby power to eliminate un-needed off-mode power consumption.[11]

TURN OFF WHEN NOT IN USE

We combed the metering data looking for devices that were left on for long periods of time. With one exception, it was not possible for us to know exactly when people were, for example, watching a metered television or listening to their stereo. Our identified savings opportunities thus derive from observations of inordinately long periods of active-mode operation (such as being left on overnight) that strongly suggested a device was left on and unused.

The exception to this is desktop computers. Here, we considered the question of unattended idling to be of sufficient importance that we deployed portable occupancy sensors that provided us with ancillary data about whether someone was sitting in front of the computer when it was on (see Appendix B for details).

UNPLUG TO ELIMINATE STANDBY POWER

Many devices draw power even when turned off. This may be for a clock display, for providing remote control functionality—or for other purposes, such as overnight downloading of programming information by cable and satellite set-top boxes. In addition, some devices simply "leak" electricity continually due to poor power supply design.

Opportunities for reducing off-mode electricity consumption arise from the combination of how much standby power the device draws, how frequently the device is used—as well as the extent to which users are willing to forgo any standby functionality provided and tolerate start-up hassles when power is restored to the device. It may be worthwhile to some people to unplug a device that is used frequently if

[11] Although in theory one could consider reducing electricity use by, say watching less television, or reducing how many plug-in devices are in the home, we did not take our analysis to this extreme.

it avoids a significant standby power draw. Conversely, it may not be a particular inconvenience to unplug devices that don't draw much standby power if they are rarely used. Some savings can be achieved with just about any device that draws standby power. In reviewing the metering data, we only called out savings opportunities that would amount to at least 25 kWh per year.

MANUAL AND AUTOMATED STRATEGIES

For both turning-off and unplugging opportunities, we considered automated as well as manual solutions—and gave preference to the former on the grounds that these will be applied much more consistently. We considered the following three technology-assisted strategies:

- Enabling power management settings on computers.
- Using a "smart" power strip to disconnect power to peripherals when a main device (such as a computer or television) is turned off.
- Using a timer to automatically disconnect a device from power at certain times of the day.

We also considered savings from simply remembering to turn off a device or unplug it when not in use.[12]

TECHNICAL VERSUS BEHAVIORALLY-ADJUSTED SAVINGS ESTIMATES

We identified about 200 savings opportunities among the roughly 700 devices that we metered in the 50 on-site homes.[13] For each savings opportunity that we identified, we estimated what we call the *technical* electricity savings; that is, the savings from perfectly implementing the strategy. For example, if we identified savings from unplugging a computer printer when it is not in use, our technical savings assume that the printer is always unplugged except when it is being used.

These technical savings estimates obviously don't account for human nature. They also don't account for whether people are interested in pursuing a strategy at all. To factor these in, we developed a high/medium/low set of behavioral probabilities (Table 2) that we applied to the technical savings estimate for each opportunity to give us a *behavioral* savings estimate; that is the savings that might be expected after factoring in both the level of interest that the household might have in pursuing a specific savings opportunity as well as forgetfulness for savings that rely on habitual actions.

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[12] Note that when we refer to manually unplugging devices, we don't generally mean physically pulling plugs from sockets (which most people would find burdensome): "unplugging" can be accomplished much more conveniently using a switched power strip. For hidden outlets, remote-control power strips or switches can be used (though with a small imposed parasitic electrical load).

[13] Similar to the imputation procedures that we used to estimate electricity use by devices that we didn't meter, we also imputed additional savings opportunities among unmetered devices (see Appendix D). Altogether, imputed savings opportunities account for about a third of our total estimated savings, and savings opportunities identified directly from metering data account for two thirds.

We based our behavioral assessments on the interview with the homeowner, as well as our own observations of the household. In some cases, we explicitly discussed the specific opportunity with household members as part of the interview.[14] In other cases, our assessments were based more generally on what the household members told us in the interview and our limited observations of the household. For example, we assigned lower behavioral probabilities for "unplug" opportunities in busy households that were not particularly concerned about wasted electricity compared to households that already showed attentiveness to wasted electricity. It is important to recognize, however, that these behavioral assessments are ultimately subjective estimates rather than observations of actual behavior.[15]

TABLE 2, BEHAVIORAL PROBABILITY ASSIGNMENTS.

	Requires habitual action?	
	No	Yes
High	85%	66%
Medium	50%	33%
Low	15%	0%

OVERVIEW OF SAVINGS OPPORTUNITIES

The results of our analysis suggests that there is an average of about 450 (± 180) kWh per year worth of technical no- and low-cost savings opportunities per home, representing 3 to 6 percent of total home electricity use and roughly 20 (±8) percent of consumption by plug-in devices. When our behavioral probabilities are factored in, these figures drop by about half.

Figure 4 graphically depicts what our analysis reveals about where these savings exist. Nearly a third of the technical savings (and about 40 percent of the behaviorally-achievable savings) that we estimated derive from a single strategy: computer power management. Manual strategies of unplugging and turning off devices together account for fully half of our estimated technical savings, but are diminished somewhat by our assumptions about people's willingness-and-forgetfulness in the behaviorally achievable estimates. Smart power strips and timers each account for about 10 percent of our estimated savings potential.

There are also important differences in the relative concentrations of savings across the opportunities. Relatively speaking, computer power management comprises a large amount of savings potential among a small number of devices, while the other strategies are characterized more by small savings over many devices (Table 3). If finding these savings opportunities is like prospecting for gold, then computer power management could be likened to gold nuggets, while other opportunities are more akin to low-grade ore.

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[14] We were able to get preliminary read-outs from the meters at the time they were collected, and could therefore sometimes immediately flag opportunities to cover during the post-metering interviews

[15] Actually, in some cases people did immediately implement a savings opportunity that we called out in the interview, which clearly indicated a high level of engagement and interest. However, our budget did not provide for systematic follow-up to see if the household continued to implement the strategy. We did however, follow-up with some households that implemented computer power management: see Computer Power Management.

FIGURE 4, ESTIMATED TECHNICAL (451 KWH/YR/HOME) AND BEHAVIORALLY-ADJUSTED (236 KWH/YR/HOME) NO/LOW-COST SAVINGS OPPORTUNITIES PER HOME, BY STRATEGY AND DEVICE CATEGORY.

TABLE 3, DISTRIBUTION OF OPPORTUNITIES AND SAVINGS BY STRATEGY.

Strategy	Percent of opportunities[a]	Percent of total estimated savings: Technical	Percent of total estimated savings: Behaviorally-adjusted
Computer power management	10 ± 5%	35 ± 10%	40 ± 15%
Unplug manually	50 ± 10%	30 ± 10%	30 ± 10%
Turn off manually	10 ± 10%	15 ± 20%	10 ± 20%
Timer	15 ± 5%	10 ± 5%	10 ± 5%
Smart power strip	15 ± 5%	10 ± 5%	10 ± 5%

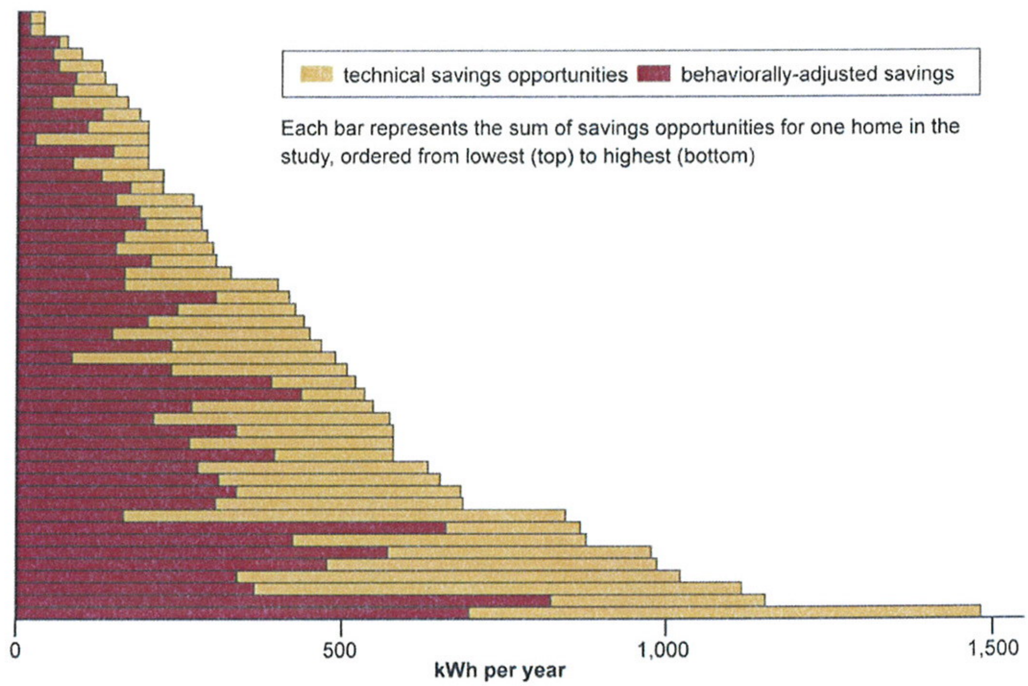
[a] For computer power management and smart strips, we considered each application to be a single opportunity (e.g., computer and monitor for the former); for the other strategies, we counted one opportunity per device.

Confidence intervals shown are approximate 90% confidence intervals accounting for sampling and imputation uncertainty.

All values are rounded to nearest five percentage points.

Similarly, as one might expect, the distribution of savings opportunities is not uniform across homes, but varies dramatically, ranging from nearly nothing to more than 1,500 annual kWh worth of savings opportunities (Figure 5). Not surprisingly, the extent of savings opportunities is well correlated with the number of devices in the home (which ranges from about 20 to 60): households with more devices tend to have more savings opportunities.

FIGURE 5, SAVINGS OPPORTUNITIES BY HOME.



In the sections that follow, we delve into types of savings opportunities in more detail, beginning with the one we find to be the most significant—computer power management.

COMPUTER POWER MANAGEMENT (40% OF IDENTIFIED SAVINGS POTENTIAL)

Computers are highly prevalent in Minnesota homes: our telephone survey suggests that there is an average of 0.84 desktop computers per single-family household in Minnesota and 0.56 laptop computers. We encountered 47 desktop computers in the 50 on-site homes, and we were able to individually meter the computer and monitor(s) for 42 of these.[16] Moreover, in 28 cases we were also able to deploy a portable occupancy sensor to record when someone was at the computer (see Appendix B).

The metering and occupancy-sensor data revealed four distinct ways that people operate their desktop computers:

- **Always on** (about 20% of systems) — these computers are simply left running continuously all the time (or nearly so).
- **Long idle periods** (about 40% of systems) — these systems are often left on for extended periods when no one is at the computer. A common scenario here is for the computer to be turned on in the morning and left on until bedtime, with sporadic use in the interim period. It is also not unusual for these systems to be left on overnight. Figure 6 exemplifies this pattern of usage.
- **Off when not in use** (about 25% of systems) — these computers are rarely left on for extended periods, and by all appearances are only turned on when they are actively being used.
- **Low use** (about 15% of systems) — these computers are simply not turned on very often.

Altogether, we found that almost 75 percent of desktop computer electricity consumption occurs when no one is in front of the computer. Computer power management offers a savings opportunity for the first two patterns of use above by automatically putting the computer into hibernation (no power draw) or sleep (low power draw) after a period of inactivity. We were able to check the power management settings on 32 desktop systems, and found that sleep/hibernate for the computer itself was not enabled in fully 80 percent of these. Contrast this with the power management settings for monitors, where sleep-mode after a set period (typically 20 minutes) was enabled in 80 percent of the cases. These observed usage and power-management settings are generally in line with another recent field study of home computer use (Chetty et al., 2009).

Indeed, the disparity between monitor and computer sleep settings may be part of the problem. We suspect that this is how most systems were set up out of the box, and that some people are lulled into a false sense of security because they see the more highly visible monitor turning off automatically. In fact, the monitor represents the minority of the system power draw (Figure 7), especially for the 50 percent of systems with LCD monitors.

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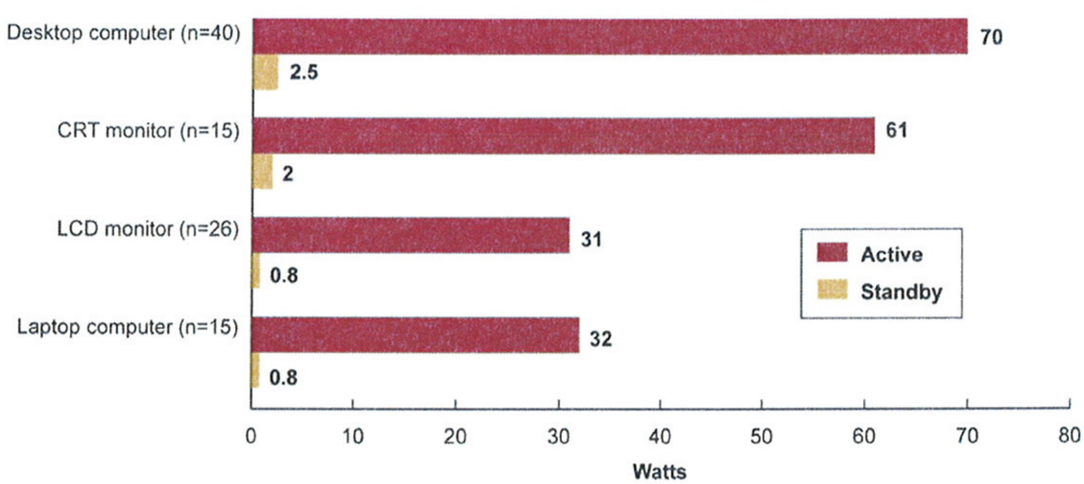
[16] We focus here on power management savings for desktop computers due to their higher electricity use, greater prevalence, and lower usage of power management features compared to laptops.

FIGURE 6, EXAMPLE (SITE 24) OF A DESKTOP COMPUTER WITH LONG IDLE PERIODS.

FIGURE 7, AVERAGE MEASURED POWER DRAW FOR COMPUTERS AND MONITORS.



To estimate the savings from power management, we developed an algorithm that drew upon the metering and occupancy data to estimate power management savings. The algorithm compares the actual metered electricity use of the computer and monitor to electricity use based on the assumption that power draw for both devices drops to their standby levels after a set delay period when no one is at the computer (as indicated by the occupancy sensor).[17] We used a commonly-recommended 30-minute standby/hibernate delay period for our savings estimates for our base estimates, but also explored how the projected savings vary with the delay period.[18]

Applying this algorithm to the metered computers in the study suggests that there are substantial savings to be had for the roughly two-thirds of computers that are left on all the time or for long periods (Table 4).

TABLE 4, USAGE AND ESTIMATED POWER MANAGEMENT SAVINGS FOR METERED DESKTOP COMPUTERS.

	Mean Electricity Use (kWh/yr)			Mean Estimated Power Management Savings[a]		
Operation Category	n[b]	Computer	Monitor(s)	n[c]	kWh/yr	Percent savings
Always on	10	552	83	9	396	67%
Long idle periods	14	371	92	8	213	42%
Off when not in use	11	90	26	7	10	9%
Not used much	7	16	29	4	2	4%

[a] Based on 30-minute standby/hibernate delay

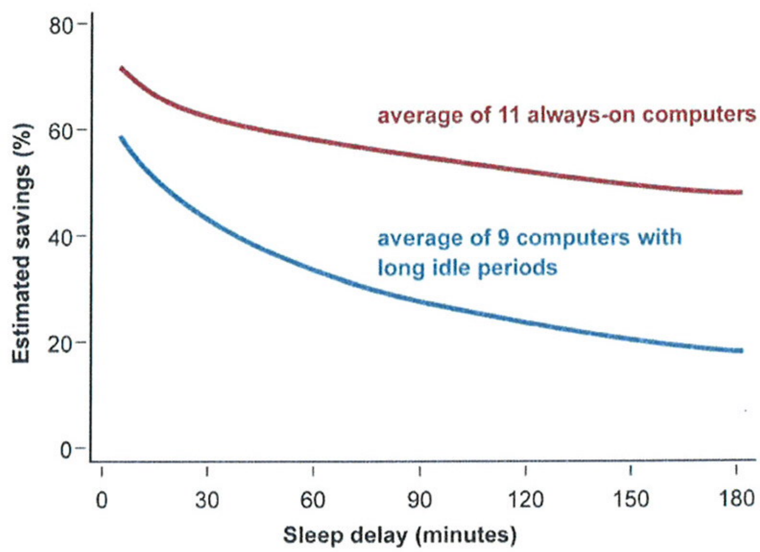
[b] Metered desktop computers

[c] Metered desktop computers with usable occupancy sensor data for estimating power management savings

[17] *Sleep* and *hibernate* are two different power management options available on most computers. *Sleep* retains data in the volatile memory, which allows the computer to go to sleep and reawaken very quickly—usually within seconds. However, if power to the computer is interrupted, unsaved files will be lost. *Hibernate* saves the existing session to the hard drive, thus eliminating the risk of lost data. But recovering from *hibernate* takes longer—generally a minute or so. (Some systems support a hybrid *sleep/hibernate* setting that provides both the fast re-start of *sleep* with the non-volatility of *hibernate*.) In terms of electricity consumption, while *hibernate* always reduces electricity consumption to near zero, savings from *sleep* mode can vary: newer computers draw only a few watts when asleep, but power consumption for older computers may be reduced only slightly in *sleep* mode.

[18] 30-minute standby/hibernate is recommended at www.climatesaverscomputing.org

FIGURE 8, ESTIMATED POWER MANAGEMENT SAVINGS VERSUS SLEEP DELAY.



We also used the algorithm to explore how the delay period might affect savings among always-on and long-idle-period systems (Figure 8). There is definite fall-off in our estimated savings as the delay period increases, particularly for long-idle-periods systems—but since more of our total power management savings derives from always-on systems, using a 60-minute off-delay instead of a 30-minute delay only decreases the estimated savings by about 15 percent.

Because these estimates are not based on actual before- and after- measurements of electricity consumption, there are technical factors that could mitigate the achievable savings. First, "sleep" mode for some older computers reduces power consumption only a small amount, though "hibernate" for these systems can achieve deep power reductions (albeit with slower wake-up times). Second, software (particularly virus checkers that also kick in after a period of inactivity) may interfere with entering sleep mode and reduce the achievable savings. More investigation or field metering is needed to assess the prevalence of these issues.

Nonetheless, based on our estimates, we identified 26 desktop power management savings opportunities (and 6 laptop opportunities) among the 50 homes where we conducted metering. We judged about half of these (12 of 26) as highly likely to be implemented by the homeowner, and assigned a "low" probability ranking to only four households (15%). In fact, 18 households in the study immediately implemented standby and/or hibernate for their systems when our post-metering interview revealed to them such a setting was available but disabled on their computer.[19]

To be sure, not everyone was interested in computer power management. About a dozen households told us directly that power management would not be a solution for them. Most of these indicated that they already turn their computer off or put it in a standby mode manually. In one household, the interviewee deferred to the main computer user; in another, the interviewee said she would set her personal computer to whatever standards her employer had for company computers. Finally, one participant with a home business was acting on the advice of his IT consultant in leaving the computer running all the time.

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[19] We later (January 2010) informally followed up with 10 of these households by e-mail: all six households that responded reported that they had maintained the settings with no problems. One household reported having actually shortening the delay period.

Nonetheless, the fact that so many households immediately implemented power management when the opportunity was pointed out suggests that the main barrier to widespread adoption is lack of awareness rather than lack of willingness. Combined with the fact that changing power management settings costs only a few minutes of time and does not require habitual action on the part of the household, our overall impression is that this strategy is highly worthy of pursuit.

These savings opportunities may be expected to fade over time as older computers are replaced with new systems with power management enabled by default: major manufacturers began shipping desktop computers with sleep enabled starting in 2006 and 2007.[20] We did not collect explicit data on the age of the computers we encountered in Minnesota homes, but we did ask (on the mailed appliance survey) about operating systems: of the 205 desktop systems reported to us, more than 70 percent were running Windows XP (66%) or an older operating system such as Windows 2000 or ME (5%). This is significant because Windows XP was supplanted by Windows Vista in 2007—at about the same time that manufacturers began shipping desktop computers with sleep mode enabled.

Note however, that even new computers can benefit from more aggressive power management settings: a desktop system purchased by a member of the research team in April 2010 from a major manufacturer was shipped with a two-hour sleep delay.

MANUALLY UNPLUG DEVICES (30% OF IDENTIFIED POTENTIAL)

Manually unplugging devices is in aggregate our second-highest ranking strategy for in-home savings from plug-in devices. But unlike computer power management, where the savings are concentrated in a small number of devices of a single type, the "unplug" category comprises a more diverse array of devices and generally smaller savings per opportunity. Four types of opportunities make up about 80 percent of this category:

- Some compact stereo systems that we monitored used a substantial amount of electricity. We metered 13 compact stereo systems (of 24 that we found in the 50 homes), and these used from 5 to 200 kWh/yr worth of electricity. Those on the high end of this scale drew 20 to 30 watts continuously, and in the field we sometimes found it difficult to tell if these devices were "on" or "off." Several homeowners expressed surprise at how much electricity their (mostly unused) compact stereos used: one of these was a single-occupant household that was already routinely unplugging all of his computer-related equipment and TV peripherals. Because of this, we considered these to be "unplug" opportunities.

- Older CRT television sets that draw 5 watts or more of standby power still make up about 20 percent of TVs in Minnesota homes. Unplugging these sets when not in use would yield an average of 60 kWh per year of savings. Since these tend to be analog sets that cannot receive the new digital-only broadcast signal without an external converter box, losing channel settings does

[20] Personal communication, Pat Tiernan, Executive Director, Climate Savers Computing Initiative, February 23, 2010.

not pose a barrier to unplugging them—though for the same reason, these may also be a disappearing species.[21]

- Computer printers are typically engaged in printing for only a few minutes per week, but draw an average of 4.5 watts the remainder of the time. Keeping these unplugged except when in use could be expected to save about 45 kWh per year on average.

- Some TV peripherals were not used at all during our month of metering and could be left unplugged most of the time. VCRs and (more prevalently) VCR/DVD combination players made up the bulk of these opportunities. At least some of these are probably legacy devices that are not used at all any longer.

Unplugging TV peripherals and computer printers could also be accomplished automatically with a smart power strip, which we discuss separately below. We classified most printers as an opportunity for manually unplugging rather than controlling automatically with a smart power strip, however, due to concern about adverse consequences from removing power to a printer without properly parking the print heads (see Smart Power Strips section). We classified never-used TV peripherals here as well on the grounds that the savings are larger and, if the devices are used less frequently than once a month, it would not be particularly burdensome to unplug them manually.

TURN OFF DEVICES (10% OF IDENTIFIED POTENTIAL)

To be sure, the metering data revealed cases of devices that were left on for inordinate lengths of time. We did observe instances of devices like DVD players that were used for a couple of hours and then left in an active/idle mode for days thereafter. We also observed five cases where televisions were routinely left on overnight, as well as three cases where stereo receivers were left on for most or all of the month-long monitoring period.

However, a significant portion of the opportunities in this category arose from unattended or inappropriate use of portable HVAC or other devices that used a significant amount of electricity. For example:

- We found a space heater in a basement bedroom that was running (controlled by its own thermostat) in late May to the tune of about 200 kWh per month. A guest had turned it on and left it running unbeknownst to the homeowner.

- One household left a boot dryer plugged in year round (the husband worked in construction). When asked about it, the homeowner reported that the instruction manual said that it should be left plugged in all the time. The operating instructions (which we downloaded later) actually said that the device may be left plugged in continuously. We metered the device as using about 700 kWh per year.

[21] The digital TV switchover occurred in the middle of our fieldwork, so our data present something of a mixed picture in terms of such things as the saturation of older TVs and digital-to-analog converter boxes.

- One household was drying clothes by hanging them indoors and running a dehumidifier to remove the moisture from the air.

- One household in our winter round was using an electric space heater and two heat lamps in their garage to keep their dogs warm while the owners were away during the day (the garage was open to the outdoors through a very loose dog door). These heaters were using more than 300 kWh per month of electricity. The owners had noticed the increase in their electric bill and were concerned, telling us that they had taken care to buy an "efficient" space heater (all electric space heaters are 100 percent efficient at turning electricity into heat).

TIMERS (10% OF IDENTIFIED POTENTIAL)

We considered the use of timers primarily for the following:

- Cable and satellite set-top boxes

- Computer networking equipment

- Tool chargers

CABLE AND SATELLITE SET-TOP BOXES

Our telephone survey data show that more than 80 percent of single-family homes in Minnesota subscribe to either cable or satellite TV. Although cable subscribers outnumber satellite subscribers by two to one, when it comes to counting set-top boxes in homes, satellite boxes account for about 85 percent of these. This apparent paradox is explained by the fact that while many cable subscribers can directly connect newer televisions to their cable service without a box, all satellite subscribers need at least one decoder box—and many have multiple boxes serving different TVs (we found up to four per home). Set-top boxes thus tend to be concentrated in households with satellite TV reception.

At an average of about 200 kWh of annual electricity use each, set-top boxes use a non-trivial amount of electricity: a household with four satellite boxes is looking at the equivalent of a refrigerator's worth of electricity use. Some draw an inordinate amount of power (we measured more than 50 watts in some cases, though the average was closer to 25 watts)—but the main driving force behind this usage is the simple fact that they are typically "on" all the time.

Because set-top boxes take some time to recover their settings and programming information, it is inconvenient to unplug these manually. We therefore considered a timer as a possible savings strategy here, on the grounds that at least *some* savings could be had if the box could be routinely powered down late at night after people have gone to bed, and then re-powered well before they want to watch television the next day.

We thus looked for the longest overnight period for each set-top box that would include less than five percent of the associated television viewing time (this varied, but in many cases turned out to be from about midnight to 6 AM). We excluded set-top boxes with recording capabilities, since people could be recording shows at any time of the day or night.

We estimated average savings of about 50 kWh per year from this application, consistent with a notion that they can typically be de-powered for about six hours per day.

Behaviorally, however, we gave this measure a low score in many cases. The interviews revealed that, for most people, concerns with retaining settings and programming information on their set-top boxes trump electricity savings. In fact, some people were so concerned about their "finicky" set-top boxes that they were reluctant to let us unplug the boxes long enough to install our meters.

Hence, although not feasible for most households, some satellite and cable customers told us they would consider using a timer to save energy on set-top boxes. Furthermore, one household with a metered satellite box began unplugging it manually overnight about halfway through our monitoring period (this was not prompted by us, but was perhaps inspired by the attention that was suddenly being paid to their devices). In the interview, the household members reported that this was not problematic for them: they simply plugged it back in each morning, and it recovered its settings within half an hour. For widespread application, however, savings for these devices may be more effectively pursued at the manufacturing level.

COMPUTER NETWORKING EQUIPMENT

Computer networking equipment—and here we refer to DSL modems, routers, access points, and all other devices that people use to connect to the internet and connect in-home computing equipment together—shares a couple of common characteristics with set-top boxes: (1) these devices are typically left on all the time (20 hours per day on average, to be precise), and (2) it often takes at least a few minutes to reconnect after losing power. We therefore considered timers as a savings strategy for these devices as well.

An important difference from set-top boxes is that while a set-top box typically serves only a single television, networking equipment is often connecting multiple computers (and sometimes other devices) to the internet, making it a more complicated proposition to decide when (and how) to turn it off. Also, the power draw for networking equipment is much lower: 5 watts is average, and none of the 31 devices that we metered drew more than 8 watts.

These factors make it difficult to find savings opportunities of at least 25 kWh per year among the average 1.2 pieces of networking equipment per Minnesota home. We identified a timer opportunity when we found multiple networking devices in a common location in a home that did not have laptops or other devices that might be connected to the internet at odd times.

TOOL CHARGERS

We found some tool (and also battery or other device) chargers in basements and garages that drew from 4 to 12 watts continuously for our month-long monitoring period with no evidence that the cordless device they served was used during that time. In these situations, a timer could be used to provide power to the charger for just a couple of hours per day, thereby ensuring that the device in question is adequately charged at all times, but avoiding much of the wasted electricity that likely arises from poor charger design for these devices.

SMART POWER STRIPS (10% OF IDENTIFIED POTENTIAL)

"Smart" power strips seek to reduce standby electricity consumption by peripheral devices. These have a socket for a primary device, such as a TV, plus additional sockets for peripherals that are used with the primary device (think of a DVD player here). When the smart power strip senses that the primary device is turned off, it automatically kills the power to the peripherals, thereby eliminating whatever standby power those devices might otherwise draw.

There are three main home applications for smart power strips: TV centers, computer centers and audio centers (Table 5). We inventoried these as part of the on-site data collection, and considered the savings from a smart power strip for each. In many cases, the estimated savings was well below our 25 kWh per year threshold, because there were few peripherals or the peripherals drew little standby power.

There were some additional factors that limited the circumstances where we considered a smart power strip strategy. Some audio systems play a dual role: they act as peripherals to a TV center, but also act as primary devices for listening to the radio or a CD, completely separate from TV viewing. The metering data we obtained in these situations suggested that in most cases, the audio system is engaged without the TV at least a few times a month. We therefore largely excluded receivers and their downstream audio-only components from TV smart-power-strip applications. There is a similar issue with computer networking equipment in homes with multiple computers.

TABLE 5, SMART POWER STRIP APPLICATIONS IN HOMES, BY TYPE OF CENTER.

	Type of Center[a]			All
	TV	Computer	Audio	Centers
Mean number per home	1.7	1.0	0.2	2.9
Mean number of peripherals per center	2.0	2.4	2.0	2.2
% of centers with savings opportunity of at least 25 kWh per year	53%	46%	0%	48%
Median estimated savings (kWh/yr)	29	24	18	24

[a] "Center" is defined here as a primary device (TV, computer or audio receiver) with at least one attached peripheral device.

For computer centers, printers and external speakers were the main peripherals that we encountered, and for the former we found that many draw non-trivial standby power (5 or more watts). However, there can be potential adverse consequences from killing power to a printer without first parking print heads by turning the device off—some printer manuals in fact explicitly warn against doing so. This, along with our observation that many printers are only used a few times a month, led us to prefer a manual unplugging strategy for these in most cases, under the presumption that users who manually disconnect a printer from power will turn it off first. This did still leave some computer-related smart-power-strip opportunities for speakers (which typically draw 4 to 6 watts and are often left on all the time) and other peripherals.

Computer centers also raise the conundrum that in many cases the logical primary device (the computer) is left running for inordinate periods. We keyed our savings estimates for computer centers off the operation of the monitor, which in most cases is configured to go into a sleep mode after a period of inactivity.

TELEVISIONS AND BRIGHTNESS SETTINGS

Although TVs represent a full 20 percent of plug-in device electricity use in Minnesota homes, they account for only about 10 percent of the savings we identified—mainly for unplugging older sets with high standby power draw, and turning off a few TVs that are routinely left on overnight.

Reducing the brightness settings on TVs could be another savings opportunity, since power draw generally increases with brightness. We had hoped to include this as a formal strategy, but found it too difficult to systematically check these settings in the midst of deploying and retrieving meters, checking computer power management settings, and conducting interviews with the occupants.

We were able to obtain brightness settings for 19 (of the 150) sets that we encountered. On a 0-100 scale, we recorded an average setting just above the mid-point (55), and only three of the 19 TVs (15%) had a brightness setting of 70 or higher. This cursory analysis does not fully incorporate the fact that newer sets typically have picture modes, such as "vivid" and "movie" that affect brightness and power consumption.[22] And our sample was dominated by older CRT sets (13 of 19).

If, as some suggest, new TVs are frequently shipped with an enhanced floor-display brightness setting, then there could be some additional savings potential from addressing brightness settings for these newer—and typically larger—sets. Our inventory and metering data suggest that although newer LCD and plasma sets account for only about a quarter of TVs in Minnesota homes, they account for more than half of TV electricity consumption. As an order-of-magnitude estimate, if active-mode power consumption for all 40-inch plus TVs could be reduced by 15 percent, the average savings would amount to about 30 kWh per year per home (across all homes), or about 6 percent of the total technical savings opportunities that we identified.

Another strategy might be to target reducing TV brightness settings in bedrooms, where viewing is typically later at night under less illumination. However, although a third of TVs in Minnesota homes are located in bedrooms, these represent only about 10 percent of TV electricity use.

One final note on TV brightness: some newer TVs have automatic brightness control, in that they sense the ambient light level and adjust their brightness setting accordingly. We encountered (and metered) two such units, both of which were 42-inch LCD sets of the same make and model. We observed active-mode power draw for these routinely drop from a full-output level of 150 watts to 100 watts—a 33 percent

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[22] For the three sets where we also obtained mode information, two were set to "vivid" or "bright" and one was set to "standard": the first two were also among the three that we scored as having high brightness.

decline—in the evening as ambient light levels dropped.[23] This suggests some technical promise for TV electricity savings, though not in the context of our exploration of no- and low-cost strategies.

TABLE 6, DISTRIBUTION OF TVS AND TV ELECTRICITY USE BY TYPE.

Type	Percent of units in homes	Average active-mode watts	Percent of aggregate TV electricity use
CRT	71%	70	38%
LCD	21%	115	39%
Plasma	4%	400	18%
Rear Projection	2%	NA	4%
Front Projection	2%	NA	<1%

A NOTE ON SECONDARY REFRIGERATORS AND FREEZERS

The main focus of our study excluded major appliances. But when we encountered a substantial incidence of secondary refrigerators and stand-alone freezers in study homes, we decided to devote some resources to looking at their energy use and people's willingness to eliminate under-utilized refrigerators and freezers.[24] This section documents that side trip.

As Table 7 shows, many Minnesota homes have secondary refrigerators and freezers. The more detailed data from the appliance survey indicates that about 12 percent of secondary refrigerators are compact (or dorm-sized) refrigerators. The appliance survey also suggests that about a third of secondary refrigerators and freezers (but only about a fifth of compact refrigerators) are located in garages.

TABLE 7, REFRIGERATOR AND FREEZER SATURATION IN MINNESOTA OWNER-OCCUPIED HOMES (TELEPHONE-SURVEY).

Number in home	Refrigerators	Stand-alone Freezers
0	0%	35%
1	68%	57%
2	28%	7%
3+	4%	1%

N=624 (homeowners only)

(Question posed in survey Rounds 2-4 only)

[23] We deployed light loggers to track ambient brightness for one TV per household in the first three rounds of the fieldwork.

[24] We did not, however, include these in our formal assessment of plug-load savings opportunities.

We found 59 secondary refrigerators and freezers in the 50 homes in the on-site portion of the study, and were able to meter many of these—as well as take a peek at their contents (Table 8).

TABLE 8, SECONDARY REFRIGERATORS AND FREEZERS IN ON-SITE HOMES.

	Refrigerator	Compact refrigerator	Freezer
Number found in home	13	12	34
...in garages or on porches	4	1	10
Number examined for contents	9	5	15
...less than ¼ full	4	2	4
...¼ to ½ full	2	1	2
...½ to ¾ full	1	2	0
...more than ¾ full	2	0	9
Number metered	13	12	34
...in garages or on porches	4	0	10
Annual kWh[a]			
Mean[b]	775	265	415
Range[c]	390 – 1,690	135 – 585	190 – 1,015

[a] from one month of metering

[b] Includes units in garages and on porches (which were relatively evenly distributed by season of monitoring).

[c] Excludes units in garages and on porches.

We assessed the savings opportunity for eliminating or unplugging units that appeared to be under-utilized. Of the 15 units that we observed to be half full or less, our interviews with the homeowners suggested a high likelihood that about a quarter (two freezers, one refrigerator and one compact refrigerator) could be eliminated. In addition, the household was amenable to unplugging an under-utilized unit in a third of the cases.

PROGRAM STRATEGIES

There is a long history of program efforts to increase the energy efficiency of homes in Minnesota and many other states, but these efforts have concentrated mostly on shell measures, large appliances, and lighting. Efficiency efforts for smaller plug-in appliances have centered on purchase decisions and standards for new devices. Existing devices have remained largely untouched by most programs other than an occasional encouragement to turn off or turn down equipment—efforts that are generally deemed not to be sufficiently effective to produce meaningful amounts of energy savings reliably. Are there effective ways for programs to help customers reduce the energy usage of the various plugged in devices in their homes?

We now turn to program strategies that appear to be promising approaches for turning the potential savings into saved kilowatt-hours. We begin by identifying the barriers and program interventions that we think flow out of our research. Then, we discuss practical opportunities for utilities to incorporate these interventions in their program portfolios, as well as further research needed to facilitate program efforts to affect plug load usage and in-home energy practices. Finally, we close with some specific insights from our research that may be helpful to program designers.

BARRIERS

Understanding barriers that prevent more energy efficient choices and actions is the first step toward effective program design, so we begin our discussion of program strategies with an analysis of the barriers that need to be overcome.

All of the energy-saving opportunities we explored in this study were technically feasible, so the barriers to their implementation are primarily behavioral. That is, the obstacles that stand in the way of the energy-saving opportunities we discussed in the previous sections are inherently about the priorities, knowledge, habits, and choices of individual households.

Some of the barriers we encountered—such as lack of interest in saving energy, inconvenience, or a high hassle factor—are not easily addressed in programs addressing end-users. For example, the long recovery time for many television set-top boxes after they have been unplugged and the perceived hassle factor of getting set-top boxes working the first place will prevent many motivated households from cutting power to these devices. These kinds of barriers are often best addressed with product designers and manufacturers through equipment standards or through voluntary engagement with Energy Star and with regional energy efficiency collaboratives.

Other barriers, however, appear to be viable candidates for programs that target end-users directly. While these barriers vary across individual households, there are some common themes by type of savings opportunity. Many of these are informational in nature.

Lack of Awareness of Where the Best Opportunities Lie

We found widespread lack of awareness about which devices or practices use meaningful amounts of electricity and which do not, thereby making it difficult for motivated households to focus their attention on effective practices. People do know to turn off equipment, for example, but they do not know which devices use large amounts of electricity when left on and which do not. Hence, they don't know where to focus the limited amount of mental attention available for energy-saving actions amongst busy lives and competing issues vying for their consideration. Furthermore, awareness of standby energy usage is rather modest. Some form of this informational barrier applies to virtually every savings opportunity we identified.

Lack of Awareness of How to Save Conveniently

Even when people know what to do, they may not know how to take an action conveniently or effectively. For example, unplugging devices can be a hassle, but turning off a power strip or remote switch to cut power to devices is as easy as turning off the device itself. We found a few households that were using these strategies, but most seemed to have never thought of ways to make unplugging easier.

For one promising opportunity, in particular, people seem to need instructions on how to implement the energy-saving strategy. Our interviews suggest that there are significant numbers of households with desktop computers who do not know where to find power management settings and would benefit from clear and easy instructions or other assistance to check and change their settings.

Savings Requiring Repeated Actions

Strategies that require habitual action face an additional challenge. Habits are difficult to form and to break. Consequently, even motivated households are likely to forget to turn off or unplug devices if they need to do so manually unless they have already formed the habit. Furthermore, households whose members have differing preferences or priorities may find interpersonal dynamics within the household to be an additional hindrance. On the other hand, once habits are formed, they seem likely to acquire inertia and persist for some time.

Unintended Consequences and Ineffective Implementation

Finally, there are some strategies that could either reduce or increase energy consumption, depending on how they are implemented. The smart power strip presents a good example of a device that can be used to save energy conveniently, but that can also be used in a way that does the opposite. The idea behind the smart power strip is that it cuts power to accessories while the main device (such as a computer or television set) is turned off. Using the smart power strip this way eliminates standby power usage of the peripherals. However, households could also be tempted to leave the accessories turned on and rely on the power strip to cut power to them. That would leave peripherals running in "on mode" whenever the main device is turned on – whether or not they are being used. In some situations, this could increase energy usage in exchange for the convenience of turning the smart power strip into an automatic switch. Clear communication and instructions are particularly important in these cases so users understand the implications of different uses of the device.

PROMISING INTERVENTIONS

In the context of influencing people to save electricity used by plug-in devices, we think it is useful to think of possible interventions in terms of the intensity of their contact with individual households. We thus classify interventions into three groups:

Low touch interventions: On the one extreme, some behavior-change initiatives are mostly information based, using mass communication to inform large numbers of individuals and (we would hope) influence the choices and practices of a subset of that population in a meaningful way. Public service announcements on health issues and anti-smoking campaigns are examples of "low touch" interventions. Within energy efficiency, examples include energy saving tips inserted with utility bills and on utility web sites.

Medium touch interventions: Some behavior-change interventions provide information or other support in more interactive ways. Within the energy efficiency field, the traditional equipment rebate falls into this category. Rebate users are generally not anonymous to the program, but interaction can be as modest as the submission of a rebate form with proof or purchase. In some cases, utilities and programs use telephone call centers to provide general energy-saving advice or offer individualized energy usage reports. We classify all of these approaches as "medium touch" interventions.

High touch interventions: On the other extreme, some interventions require fairly extensive or customized contact with a targeted household. Home energy audits and direct install programs are examples of such "high touch" interventions. High touch approaches tend to provide greater energy savings per customer, but they can reach only a comparatively small number of customers. As such, targeting the most promising customer groups can be an important attribute of effective high touch programs.

Low Touch Plug Load Interventions

Getting households to enable computer power management for their desktop computers offers the single-best low touch program intervention arising from this study. Several characteristics make power management—which also happens to be the single largest opportunity we identified—amenable to low touch approaches:

- Widespread applicability – We estimate that about two thirds of Minnesota households have a desktop that does not have power management fully enabled and is regularly left running without being used.
- Easy to describe and identify – Program materials could be developed easily to pinpoint households to this savings opportunity without requiring households to do much investigating on their own.
- Can be made easy for households to implement – Enabling power management, for example, entails a mostly straight-forward sequence of steps that requires little pre-existing knowledge. Alternatively, power management can be enabled through a downloadable application.
- Subject primarily to informational barriers – The primary barriers we encountered for power management and several other opportunities described above were often informational. People had not enabled power management primarily because they were not aware of the feature, did not realize how much energy their computer used, or mistakenly thought their computer already shut down. All of these barriers can be overcome with information.

An educational campaign to motivate and enable households to implement power management is probably most effective if done as a focused, single-message program. As such, we think of power management as the primary low touch opportunity for programs interested in achieving savings from small plugged in devices in the residential sector.

However, low-touch approaches are also amenable to addressing other specific savings opportunities that are highly prevalent and can be easily communicated as a special call to action. An example might be a call to unplug little-used audio and video equipment, especially compact stereo systems, some of which "leak" a meaningful amount of electricity.

Medium Touch Interventions

Medium-touch interventions offer the opportunity to address a wider variety of appliances and savings opportunities, and could also support the efforts of low-touch methods among households that require more intervention or information than can be provided by mass communication. These interventions provide assistance to motivated households so they can identify and implement energy-saving opportunities in a personalized way but without incurring the expense of, say, an in-person visit to the home. These interventions offer a way to go beyond the targeted hit-list opportunities of "one-size-fits-all" mass communications to opportunities that vary more widely from home to home. They also provide a structured way for people to prospect for savings in their own home. We present three such interventions below.

One medium touch program approach to plug-in devices entails a power meter loan or distribution program or an alternate strategy that allows households to identify their own energy-saving opportunities. Encouraging interested households to explore their devices' energy usage provides an educational opportunity for the households. Tailored instructions could guide them to identify both high standby loads that could be reduced and high energy-using devices that are left running unnecessarily. Some power companies already place power meters in libraries so local residents can check them out. A power meter loan or distribution program could follow that model, or offer a discounted power meter for sale to households. Ideally, access to such meters would be combined with instructions for which devices are most likely to present energy-saving opportunities, guidelines for what wattage and kilowatt-hour levels constitute a good opportunity, and tips for what to do when one finds an opportunity. For example, the Roanoke Valley Cool Cities Coalition[25] has designed a "Kill A Watt Program" that includes some instructions along these lines. The technical findings from our study also constitute a good starting point for developing Minnesota-specific guidance.

A second medium touch program could motivate potentially interested households to investigate energy-saving opportunities by offering discounted or free technological aides that help save energy. Smart or regular power strips or remote switches could be offered by utilities, for example, in an effort to attract attention to the energy use from plug loads. These technological aides could be distributed with informational materials to help customers identify the most effective applications.

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[25] See www.rvccc.org.

A third medium touch program approach involves the use of a call center, hosted call-in radio program, or other source of remote assistance to households interested in saving energy in their home. Trained professionals could serve as a resource to households attempting any strategies advocated by a low touch program, such as power management, or walk customers through more complicated savings opportunities than can easily be implemented by some households, such as using timers to eliminate standby usage during times that a household is unlikely to use a particular device. In some cases, this on-call resource could provide the extra support needed for households to implement a simple strategy. In other cases, this resource might help an interested household apply a strategy in a more effective manner.

High Touch Program Opportunities

High touch program opportunities are those that involve a visit to the home or other fully customized assistance to households in identifying savings opportunities and implementing savings strategies. We do not foresee sending professionals to people's homes just to look for plug-load savings: the magnitude of the opportunities probably does not justify this expense, nor does identifying these opportunities require substantial technical expertise.

However, a formal plug-load audit component could serve as a very useful supplement to existing home audit programs that place professionals in people's homes for other reasons. An experienced professional's eye in the home could readily spot many of the savings opportunities we found, and bring these to the attention of a household that is likely already motivated to save energy.

Technical specialists may need to be trained to effectively communicate the opportunities to their clients, however. Simply presenting homeowners with monthly or annual dollar savings from addressing plug-load opportunities is unlikely to be effective, because the amounts are generally small. As we will discuss later in more detail, we found that notions of waste and comparative "social math" presentations of savings gained more traction among study participants. But households have different triggers, requiring careful listening and engagement with the customer. Hence, an effective plug load audit may be as much about communication as it is about knowing how to find savings opportunities.

Utility visits prompted by high bill complaints may offer another opportunity to help motivated households identify and take advantage of energy-saving opportunities. Homes that file high bill complaints probably have good savings opportunities among their plugged-in devices and a high motivation to save energy. Utility staff and contractors who visit homes of these customers could be trained to add a screening for energy-saving opportunities among plugged-in devices to their protocol and communicate their findings to the customer.

OPPORTUNITIES FOR UTILITY PROGRAMS

While all of these concepts show promise as interventions to motivate households, utilities and third-party energy efficiency programs need to take into account some additional considerations in their program design. For many utilities, a successful program needs to not only achieve savings, but to do so in a verifiable way while also fitting into an existing program portfolio and infrastructure.

While helping interested customers reduce their energy usage is a valued customer service, utilities need to be able to quantify the energy savings before they can count toward efficiency requirements and goals. The one-way information flow in most customer education campaigns (and other low touch programs) tends to relegate them to a supporting role that does not receive credit for any energy savings they might produce.

This study provides an indication of where the best opportunities lie, but does not take the place of careful assessment of implementation rates, persistence, and actual savings when households are encouraged (or facilitated in their efforts) to save plug load energy through actual programs. Surveys, interviews and before/after metering are likely needed to provide credible evidence of impacts and persistence of such programs. Carefully evaluated pilot programs can also provide more insight about the most effective ways to achieve the potential savings this study identified.

At the same time, utilities will need to fit plug load-oriented programs into existing portfolios of programs, so the implementation may vary from utility to utility. Many utilities already provide energy-saving tips with their bills, so this would offer one way to deliver messages to customers. How these messages are branded and framed will need to be consistent with the program's overall approach, however. In other cases, utilities offer rebates or other incentives for energy-saving gadgets, and this offers an opportunity to reinforce "unplug your gadgets" messages with an offering for power strips and remote switches, for example. Finally, programs that already include staff who visit homes of customers who are likely to be interested in saving energy may be able to add a protocol for identifying plug load savings opportunities based on the findings of this study.

GUIDANCE AND OBSERVATIONS FOR PROGRAM DESIGN

We close this section with some guidance and observations for program designers based on patterns in our field data and qualitative observations we made from the in-depth interviews with households about their devices and metering results. We begin with some general observations that would apply across all program efforts to address plugged-in devices and then discuss a few specific program areas.

Avoiding waste appealed to study participants

Although we know that cost is an important driver behind energy-saving actions for many households, our interviews revealed that avoiding waste and/or preserving resources also provide important motivators for the kinds of no- and low-cost actions that can reduce the load from plugged-in devices. We consider this to be an important insight because the purely financial benefits from reducing energy consumption from individual plugged-in devices is small and might seem insignificant to some households that could be motivated by other factors. For this reason, we presented relative energy usage and various "social math" ways of presenting energy usage data rather than emphasizing cost savings when we presented energy-saving opportunities to households.

Interestingly, we found that measures of wasted energy and relative comparisons caught participants' attention and appeared to be sufficient for many of them to want to take some energy-saving steps. Here are some examples of language we used in the interviews:

- "It looks like your computer system uses more electricity than any other device we metered."
- "We found four devices in your house that use more than five watts all the time just by being plugged in."