ELECTRIC POWER RESEARCH INSTITUTE

A Framework for Assessing the Net Benefits of Home Area Networks to Enable Demand Response

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Technical Update, December 2010

EPRI Project Manager
B. Neenan

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

THE FOLLOWING ORGANIZATION PREPARED THIS REPORT:

Electric Power Research Institute, Inc.

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Electric Power Research Institute (EPRI)
3420 Hillview Avenue
Palo Alto, California 94304-1338

Principal Investigators
S. Mullen
B. Neenan,

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PRODUCT DESCRIPTION

Results and Findings

The report describes an assessment of the value homeowners might realize from the installation of a Home Area Network (HAN) to facilitate demand response program participation. A HAN accommodates the flow of information to and from network nodes each associated with a device or element of the household's electric system. Communication among devices and the EMS can be accomplished through wireless, wired, or power line carrier media that define and make operational the HAN. One way to get consumers more involved in managing electricity use is to reduce the time and effort required to change how they use electricity.

Challenges and Objectives

The application of the HAN valuation framework was done under a hypothetical set of conditions (rate structure, prices, system peak periods, end-use load shapes, etc.) which were selected to illustrate its application. The value of curtailments enabled by the HAN was tied to payments that ISO/RTOs make for such resources. These values vary considerably over time and across markets. Additionally, a more comprehensive analysis, using this framework, would more fully characterize the conditions under which HAN investments are remunerative to consumers. A more focused analysis, honing in on a specific market and customer circumstances, will provide more locally insightful findings.

Applications, Values, and Use

The framework is offered to assist in portraying the conditions under which HANs might gain wide-spread consumer acceptance. A utility could employ the framework to establish the avoided costs associated with a HAN-enabled load management strategy. HAN technology suppliers can use the framework to establish cost goals for the technology they develop.

EPRI Perspective

EPRI is exploring all avenues by which household loads can be employed to reduce electricity costs. That includes understanding how demand response provides value when it can be fully integrated into the operation of the electric system, and using that value stream to identify technically feasible and economically sensible ways to extend load control from traditional devices such as AC units, hot water heaters, and pool pumps to some, or perhaps all, of the electric devices typically found in households. This report provides a perspective on those possibilities.

Approach

The value of HAN as demand response resources was modeled by characterizing how household loads correspond to demand response needs. A daily (summer peak) load profile was established for 28 end uses of a household in the South Atlantic region of the U.S. The loads were then sorted into groups according to the degree of technology required to manage them under representative demand response program protocols. The first group included technologies that are already used extensively without the benefit of HAN technology. The others were assumed to require a HAN with various degrees of sophistication and cost. The increased cost of control was compared to the addition revenues attributed to the additional load under control.

Keywords
Demand response
Home area networks
Cost/benefit analysis
Load control

ABSTRACT

EPRI conducted an analysis to provide insight into the value of a Home Area Network (HAN) to a household. A HAN accommodates the flow of information to and from network nodes each associated with a device or element of the household's electric system and devices. This collectivization of household devices facilitates managing the whole house load under demand response program protocols, and provides opportunities for additional payments to the household. EPRI conducted an analysis to see if the added stream of benefits attributed to a HAN justified its costs.

The findings are mixed. Under conditions where demand response produces high payments for curtailments, the HAN investment can be recouped from the marginal payments it produces in a year or so. However, at demand response curtailment payments typical of what is offered today, the investment has a long payback time. The payback would be faster if HAN costs come down, which might be the case when the technology matures and is produced in large scale. Moreover a HAN may provide the household with other services that improve the value of electricity or reduce the electric bill, which would contribute to the benefits and hasten payback.

A daily (summer peak) load profile was established for 28 household end uses typical of the South Atlantic region of the U.S. The loads were then sorted into groups according to the degree of technology required to manage them under representative demand response program protocols. The increased cost of control was compared to the addition revenues attributed to the additional load under control.

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INTRODUCTION

The Invisibility of Electricity Consumption

Managing electricity use effectively is challenging even when prices vary only routinely and modestly, because the value of the service delivered from electric devices changes over time and varies across household members. It requires continuously collecting state-of-use information from multiple devices (the average home has over 50 plug loads and hard-wired devices), and processing that information in light of wants, needs, and obligations to inform an implicit decision process. Moreover, once that is accomplished, it remains for someone (or several) in the household to carry out the requisite change of state of use of those devices affected by the decision.

Most U.S. households are served under rates that change infrequently, and the terms of service do not involve any outside agent's helpful or authoritative intervention. Households cope by devising general electricity usage behavioral rules that take into account the cost and the realized value. The result is a low level of ongoing involvement, driven by well-established but inconspicuous behaviors and habits that are subject to episodic change, rendering usage doubly invisible (Burgess and Nye 2010). Most consumers actively participate in all forms of auctions and negotiated transactions for relatively paltry benefits, participation on eBay for example. However, few undertake commensurate involvement with household energy usage, which might produce substantial returns to the time and investment committed.

Striving to get consumers to manage what they neither observe nor acknowledge largely has been an exercise in futility. Recently, researchers have turned attention in two different directions to overcome the inertia embedded in household electricity consumption routines and habits. One seeks to break the cognitive log jam by providing consumers with better and actionable information about when and how they use electricity. The goal is to pierce and influence the social and cultural practices of the household so that electricity usage decisions are made based on more pertinent information about cost and value (Hargreaves et al., 2010, EPRI 1018987, 2009).

The other strives to surmount the difficult job of fostering behavioral modification by replacing the need for continuous decision making (in the face of changing usage levels and inducements to change them) with an automated control system that requires making only periodic decisions about electricity use.

The role and impact of feedback mechanisms is described elsewhere (EPRI 1018985, 2009, ACEEE, 2010: Hargreaves et al., 2010). The focus in what follows is on the economic efficacy of household electricity control systems: Is it cost effective for a household to purchase equipment that enables extensive control over household electricity end uses?

A Confluence of Technology and Behavioral Modification

One way to get consumers more involved in managing electricity use is to reduce the time and effort required to change how they use electricity. If usage decisions can be conveniently categorized so they are implemented based on current information, and that information can be readily collected and processed, then some, perhaps many, consumers will purchase and operate such a system. Specifically, they might install and operate a Home Area Network (HAN), an electronic information network that is connected to an Energy Management System (EMS), a decision processor. The HAN accommodates the flow of information to and from network nodes each associated with a device or element of the household's electric system. Nodes can be hard-wired devices that account for substantial portions of electricity used, like the HVAC system, a pool pump, lighting circuits, or smaller plug loads, like TVs, entertainment centers, and a multitude of chargers. Communication among devices and the EMS can be accomplished through wireless, wired, or power line carrier media that define and make operational the HAN.

An EMS is an intelligent device that acts as the coordinator for the devices that comprise the HAN. There are a variety of household EMS devices already commercially available, with numerous new devices entering this burgeoning field. An EMS maintains user-defined rules for when appliances and other household loads should turn on or off, or adjusts operation such as dimming of lights, changing the thermostat set-point, or shifting to low power "energy saving" modes on appliances where applicable. These rules can be based on:

(a) the price of electricity at a particular instance of time (e.g., when it exceeds some threshold);

(b) current conditions (e.g., the time of day a household service is typically expected to run); or

(c) response to a command to do so from an external agent (e.g., a curtailment order from a curtailment service provider).

The EMS can be thought of as the brain, making decisions based on exigent conditions viewed in light of a predefined instruction set, with the HAN serving as the neural system that conveys information about the state of the nodes, delivers commands, and verifies their receipt and enactment. The human analogy ends there. This system is not an autonomous or self-purposed organism. Its purpose is to optimize household electricity consumption better than the household can do so in its absence. Achieving that result requires understanding how the household members use and value electricity, establishing ways for them to negotiate differences in value systems, and establishing a holistic household utility function that establishes the relative value under different system states and executes pre-established operational decisions.

To achieve this functionally, both a HAN and an EMS are required. For simplicity of exposition, herein we will refer to a HAN, which includes both the HAN and EMS elements.

The Value of a HAN

Each piece of household electrical equipment (node on the system) has unique operating characteristics that offer varying degrees of possibility for employing control strategies. Each device delivers utility or value to the household based on its operating status when services are desired. To maximize household utility, these values must be continuously or periodically compared to the cost of and availability of electricity to ascertain which devices deliver what level of service and when. The greater the degree of control provided by the HAN, the greater the number of devices consumers are likely to surrender control of.

Characterizing household utility requires developing a fundamental relationship between when device services are made available and the value the household attributes to the total amount of electricity consumed. That is beyond the scope of this exposition; others are exploring ways to develop and quantify such relationships.[1]

Herein we undertake a more modest goal. To establish the value of a HAN for the application of demand response based on its value to the household; in particular, what it might expect to be paid for controlling loads based on system, rather than household, circumstances. In effect, we assume that consumers are willing to transfer control of when they use devices as long as there is a net income gain in the form of a reduced electricity bill.

This is an incomplete characterization of household consumption decision processes because it fails to account for the tradeoffs among the consumption of all goods that are involved. Not only are there other potential benefit streams for HAN from the consumer perspective, but additional benefits when viewed from the utility or societal perspectives. The valuation framework presented here characterizes the net benefits to consumers from a HAN as an enabler of demand response, As such, it serves as a first approximation of what consumers might be willing to pay for a HAN system.

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[1] See for example EPRI 1016844, Section 4.

2
A HAN VALUATION FRAMEWORK

Residential loads increasingly determine the level and timing of utility and regional peak electricity supply requirements. Expanding the generation fleet and electric delivery system to meet these short-duration demands raises electricity costs (and hence retail rates) disproportionately. Such investments are economically efficient if consumers realize value at least equal to the cost. However, flat retail rates mask the true cost, raising concerns about the wisdom of continuing to meet peak loads by investments in low-utilization assets.

An intuitively compelling solution is to correct the pricing distortion by replacing uniform, average cost-based rates with prices that more accurately reflect the cost of supply; time-of-use rates or electricity prices that change daily or even hourly. However, less than five percent of residences pay time-varying rates. The cost of implementing these services, along with perceived customer reluctance to accept price variability, are the most commonly offered explanations as to why.

Energy efficiency programs typically reduce overall electricity consumption, but influence peak usage proportionately less because many devices operate primarily or consistently at other than peak times. A more selective load management strategy is needed to effectively reduce peak load growth. Some utilities have focused on controlling the devices that contribute most to peak load— central air conditioning (AC), pool pumps, electric water heaters, and electric baseboard heating elements. They share several common characteristics: they typically are running during peak load periods; each draws at least 1/3 kW when operating; their usage is to some degree discretionary; and at least one is present in most residences, and some homes have two or three.

HAN technology provides a means for centrally and systematically controlling almost any household device. Individual devices are connected to a central receiver and logic processor located in the home and under the control of the homeowner. Each can be managed according to a user-defined script that reflects its availability (operating profile) and value. Even the most discretionary loads may be available for control at certain times (for example, only some of the peak hours) while operating under specified availability rules (how long and how often it can be shut off).

Systematically organizing end uses according to their value in service, using a HAN, may represent a diversified and deep source of dispatchable resources. But, the extent of the resource has not been demonstrated. It remains to show that the benefits households expect exceed the costs of acquiring a high degree of dispatchability. This potential will be revealed through pilots and other field trials. But, it is useful to provide guidance to how those pilots are designed and evaluated so they contribute to an improved understanding of the value of a HAN (EPRI 1018985, 2010).

Methodology

The general framework devised to value HAN control capabilities is illustrated in Figure 2-1. On the left is the characterization of the household and its electric devices and when they are used.

On the right is the characterization of demand response opportunities based on programs offered by several ISOs/RTOs (IRC 2009). The boxes in the center define the methodology used to estimate the marginal value of household device control and to access the program opportunities, through a HAN.

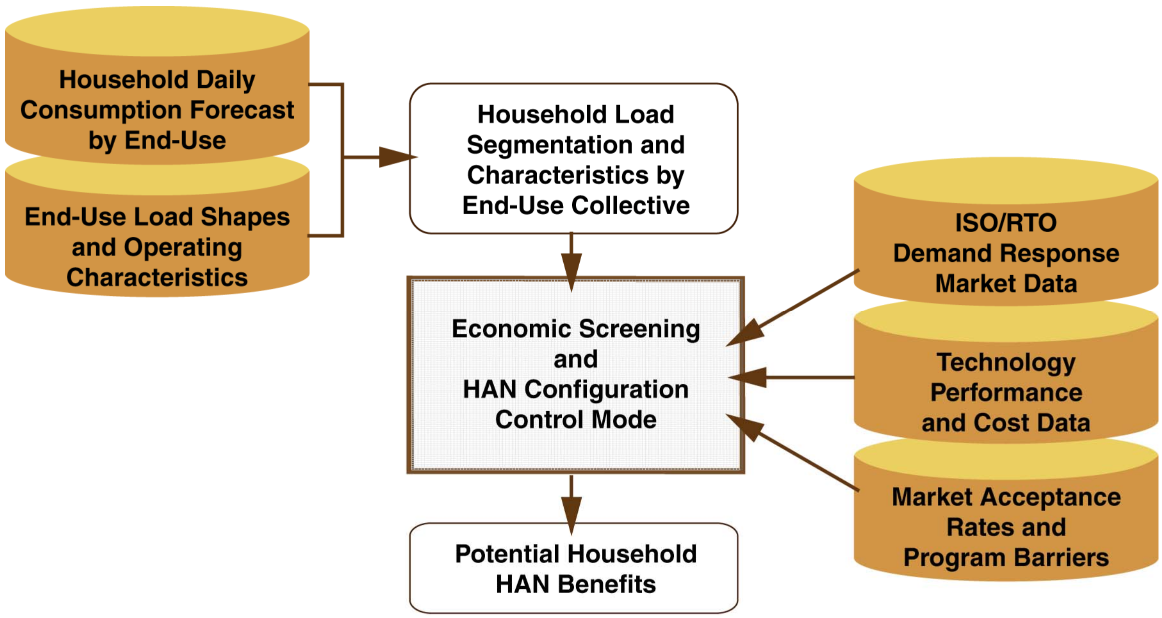

Figure 2-1
HAN Valuation Framework Methodology

Estimating HAN Value

Three levels of end-use control classes are constructed to facilitate establishing HAN potential. Traditional utility-controlled demand response is used as a base case. It is comprised of devices for which there is extensive experience in demand response programs, most of which involve some form of externally imposed load control. Two additional control classes are constructed and evaluated to illustrate the marginal impact of HAN technology. These three levels of end-use control classes are discussed in detail in Section **Error! Reference source not found.**. Section 4 describes how the value of a HAN is illustrated using proxy revenue streams.

3

HAN POTENTIAL CHARACTERIZATION

The technical potential for demand and energy reduction within a household is determined using a representative daily load profile and HAN configurations with increasing control capabilities. Technical potential describes all the end uses in the household. There will be variability in the specific end-use equipment, its consumption, and load shape across households, and as such the framework allows users to tailor the valuation to households that are representative of their customers. Figure 3-1 illustrates the process used to establish the household's demand response technical potential, as described below.

Household end uses and load shapes. A household load shape is specified based on the temporal operating characteristics of household loads. Each piece of end-use equipment has unique operating characteristics, which involve changes in typical usage profiles.

Grouping end uses. The end uses within a household are grouped into end-use collectives according to similarities in their load profiles and corresponding control opportunities identified for each. For instance clothes washers, dryers, and dishwashers are grouped together because they all have periodic user-initiated operating cycles, and they require no standby power consumption.[2]

kWh and kW reduction potential. The reduction potential for these end-use collectives is established based on their operating modes, taking into account control limitations due to the nature of their use. The reduction potential of each end-use collective is characterized by the total energy (kWh) and the maximum and average demand reduction (kW).

HAN configuration control modes define increasing household monitoring and load control capabilities using local appliance-level operating information available via a HAN. The control opportunities within each end-use collective and the resulting reduction potentials are matched with the appropriate HAN control class to determine the technical potential within the household.

Base Demand Response. Demand response implemented as utility-controlled direct load control (DLC) determines the base load reduction potential within a home absent HAN technology. This has been historically accomplished through one-way communication with end-use controllers to decrease system demand during peak or emergency events. In some cases, the homeowner can override the control action by pressing a button, which may result in notification of the action to the program operator. This simple system has been deployed on millions of AC units (over 780,000 in Florida alone[3]), hundreds of thousands of pool pumps (primarily in Florida and California), water heaters, and resistance space heating devices.

HAN-Enabled Demand Response. Many DLC programs rely on expected load reductions that are derived from experience, which adds a source of variation that undermines its value. AMI

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[2] Units with digital displays may have standby power consumption.

[3] Florida Power and Light On Call® Savings Program website. http://www.fpl.com/residential/energy_saving/programs/oncall.shtml

and HAN could allow two-way communications between households and the utility or system operator so that it has knowledge of available demand response resources before it calls upon them to curtail, and it can monitor actual end-use response.[4]

In addition, a HAN system can aid the consumer in responding by providing a means to perform load control locally and responsibly. Two levels of HAN control are considered to characterize the marginal value added with more sophisticated control configurations.

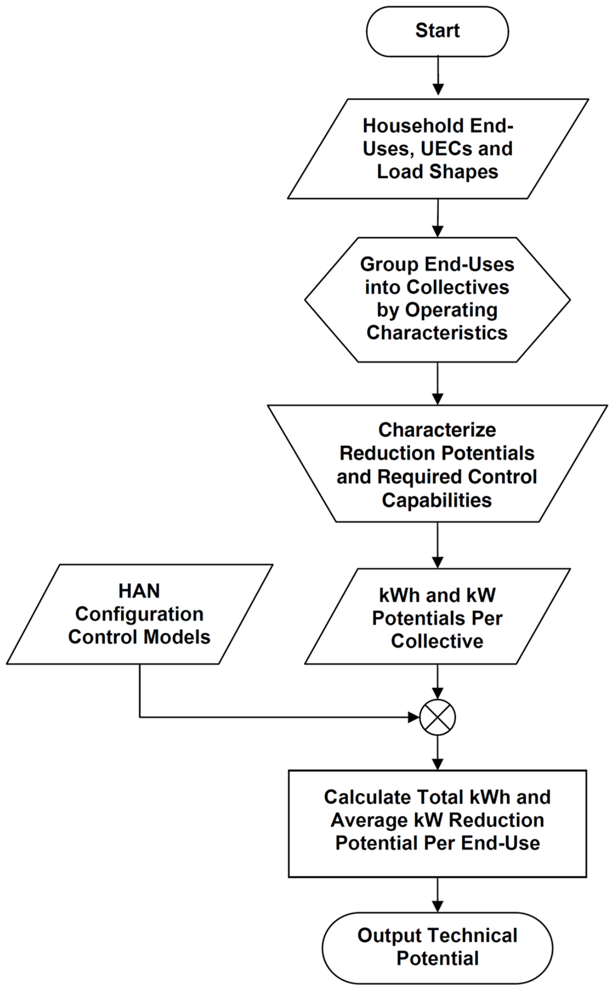

Figure 3-1
Methodology for Technical Potential Framework

HAN Level 1 is assumed to enable multi-level switching of end-use states based on household preferences and demand response incentives. For example, a central AC that has a variable speed compressor allows control by a set amount for a fixed duration when turn-on of other major appliances is sensed. Local operating information in the form of turn-on status notification for

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[4] This will likely be accommodated by an aggregator which would act as the point of contact for multiple smaller entities allowing operators to interact with a larger demand-side resource.

large appliances, or mode of operation for multi-level end uses is necessary to perform the additional load control.

HAN Level 2. Additional coordinated end-use switching is enabled through HAN Level 2 which includes all of the control capabilities of HAN Level 1, plus variable/multi-level end-use control and control of standby loads. Instead of the discrete reduction of AC compressor consumption for a fixed duration, the continuously variable compressor will be curtailed to the level needed to commensurate for curtailment shortfalls that arise from the operation of other loads, e.g., dishwasher, or clothes dryer. Level 2 allows greater flexibility in controlling household loads by using information about real-time consumption of specific loads, and allowing control to be adjusted based on how equipment is being used throughout the day. By including monitoring of all end-use devices more granular control decisions may be made.

Assigning end-use devices to categories and associating the dispatchability of each category to the degree of HAN control present characterizes the household as an upward sloping resource supply curve, which facilitates dispatching device categories based on the value of each.

4

ECONOMIC POTENTIAL FRAMEWORK

The value streams available from demand response in a home are dependent on the market value for the services they provide. To varying degrees, the ISOs/RTOs in North America have made accommodations to wholesale market operations to allow demand response to act as a system resource.5 These augment or in some cases displace conventional utility programs.

The load available for curtailment is specified for the base case demand response scenario and the two levels (1 and 2) of HAN-based end-use control. Both energy (kWh) and average and peak demand (kW) reductions are specified. Market prices for capacity and energy supply are used to calculate the associated financial benefits to the household. The result of this process is a set of value streams associated with each end-use category and level of end-use control class within the household. The economic potential framework is illustrated in Figure 4-1.

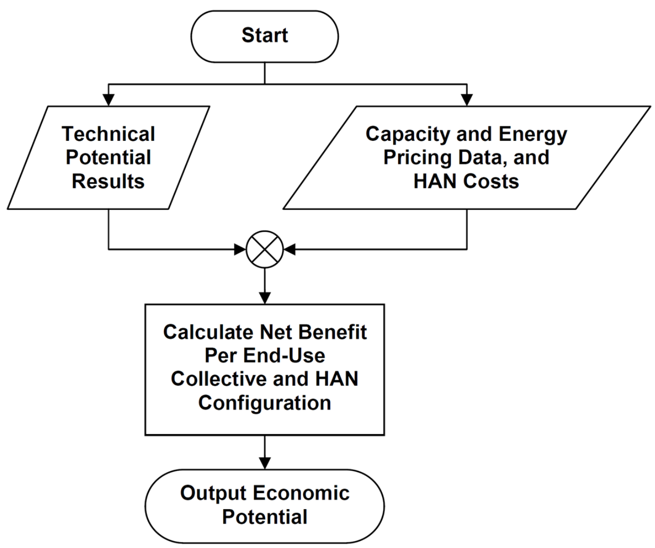

Figure 4-1
Methodology for Economic Potential Framework

Two categories of demand reduction supply are considered, capacity and energy. The benefit associated with capacity provision is determined by applying a $/kW-year capacity payment to the household's demand reduction capability, as defined by the three categories. The average demand reduction over the period of interest (event) was used to determine the basis for the capacity payment the homeowner receives.

Energy programs pay participants based on the level of energy reduction they undertake during events, which are times when market prices are high (or otherwise would be except for the

[5] ISO/RTO Council Markets Committee, October 16, 2007. Harnessing the Power of Demand: How ISOs/ RTOs Are Integrating Demand Response into Wholesale Electricity Markets

demand response). Energy program benefits are calculated using a specified $/kWh price that is applied to load reduced during event hours.

The economic potential represents the annual net benefit to homeowners. The cost of the HAN includes the central control unit, and any sensors and controllers needed to carry out the chosen control strategies. A simple annualized HAN cost is used within this study. The marginal annualized HAN cost is subtracted from the marginal annual capacity and energy payments attributable to HAN control to indicate the household net benefit.

5
FRAMEWORK APPLICATION

To demonstrate the application of the HAN valuation framework, a proxy household was constructed and its end-uses identified. End uses for a single-family home in South Atlantic defined the constituent load profiles. To gain insight into the marginal contribution of HAN technology, a summer peak day event (noon – 8:00 p.m.) was used to evaluate its ability to increase response to a capacity event, and several high wholesale price days served to evaluate the benefits of responding to energy events.

Household Load Profile Development

Based on household end-use categories for which data are available in EIA's *Annual Energy Outlook 2009* (*AEO2009*), baseline electric device load profiles were constructed for the home. Regional and national consumption data from *AEO2009* and EIA's Residential Energy Consumption Survey (RECS 2005) were used to determine the average daily electricity consumption for each of the end-uses.[6]

For space cooling, a split central AC system was assumed to be operating, including an AC fan. The unit was assumed to be operated to meet the thermostat set-point over the summer capacity event period, which is appropriate for the assumption that the event corresponds to a hot summer afternoon. The unit is modeled as a 3.5 ton unit with an energy factor of 2.5, which results in a load of approximately 5 kW.

AEO2009 reports consumption for several individual end-use equipment categories but they are too aggregated for the purposes herein. To isolate and characterize most end-use loads, EPRI employed a variety of secondary sources including device measurements EPRI is collecting as part of its Energy Efficiency Demonstration program.

The composite (of several sub-loads) load duration curves for each of the seven major end-use categories on a hot summer day are shown in Figure 5-1. The household draws a peak load of approximately 13,000 W between about 3:30 PM and 4:15 PM due to coincident operation of the clothes dryer, water heater, and central AC. This suggests that the peak load could be significantly reduced if operation of major appliances could be coordinated throughout the day.

End-Use Control Strategies

HAN end-use control strategies were specified for the control categories defined in Section 4. Some devices were assumed to never be available for control due to the nature of their use and issues such as security. For example, stove and oven use were exempted from control because their use is associated with highly ingrained and routine households behaviors that are not easily modified. Likewise, a homeowner is not likely to include its security system and digital alarm clocks in a demand response portfolio.

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[6] Energy Information Administration. "2005 Residential Energy Consumption Survey." Released 2008.

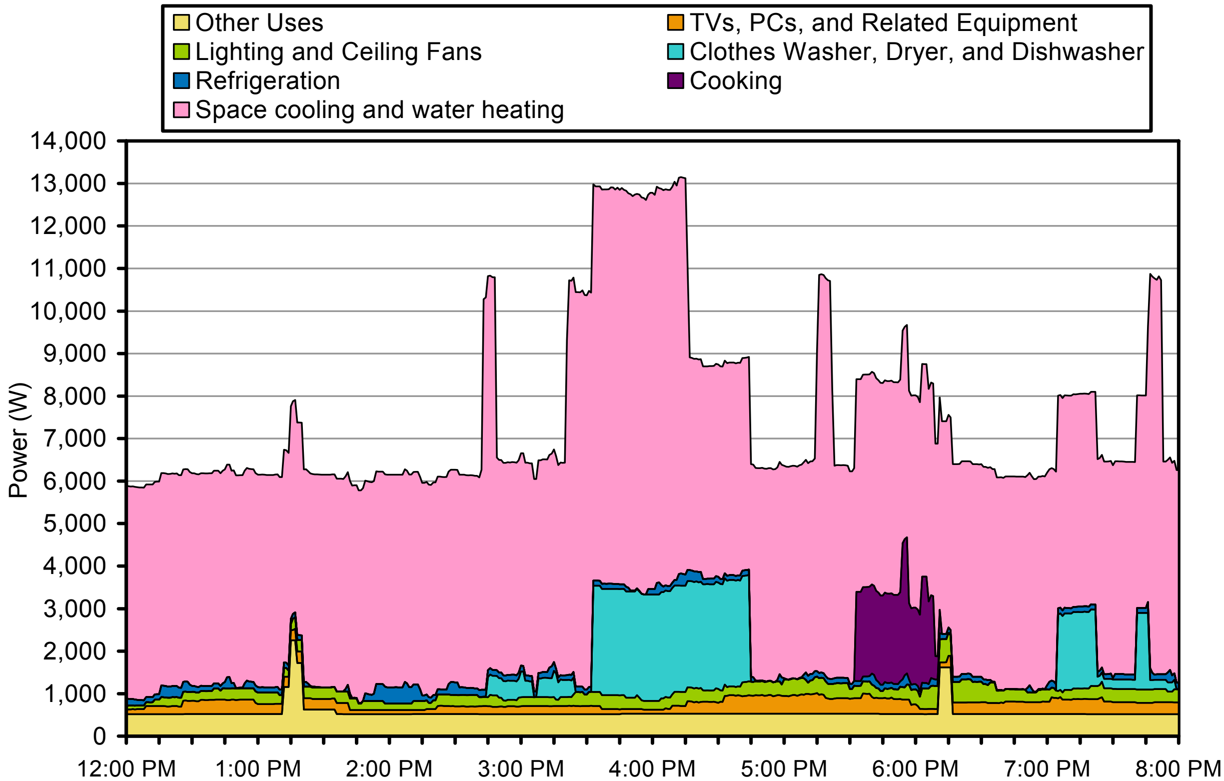

Figure 5-1
Composite Load Profile for Household between Noon and 8 p.m.

Table 5-1 describes the control capabilities which were associated with the three control categories to evaluate the technical and economic potential for the household. Each successive control level includes the control strategies of the lower levels.

The demand response-traditional direct load control involves the AC unit, the water heater, and a pool pump, which are assumed to already be controlled by an external agent pursuant to the program provisions. The homeowner already realizes benefits associated with these devices by participation in the demand response program, so the installation of a HAN adds no value in this portrayal; this assumption will be revisited later on.

The two HAN control strategies constitute opportunities to provide incremental benefit to the home owner for expanded load control capability. HAN Level 1 is comprised of devices that were assumed to be the most readily accommodating of control under demand response program provisions. An additional benefit from the central AC is realized, and the control of lighting and ceiling fans expands the load available for control by the HAN Level 1 system.

HAN Level 2 includes the additional AC control and adds management of TVs, set-top boxes and related equipment, along with dimming lighting and taking advantage of the cycling capabilities of the main refrigerator. These designations of load controllability were constructed to demonstrate how the HAN valuation framework works. Considerable behavioral research is needed to construct such categories, which in the end may differ among market segments, across markets, and among households.

Table 5-1
Household End-Use Control Strategies

End-Use	Control Opportunities
Demand Response: Traditional direct load control that does not require HAN	
Central AC	Reduce compressor operation to 50% duty cycle and keep fan running to circulate air while compressor is off.
Water heater and pool pump	Disable operation.
HAN Level 1: Enhanced direct end-use switching	
All traditional demand response control strategies	
Central AC	Reduce compressor speed to decrease power draw by 1,000 W for a preset amount of time with turn-on of dishwasher, clothes washer, and clothes dryer. The minimum draw will be 400 Watts for fan operation to keep air circulating.
Lighting	Turn off individual lights to reduce load 50%, not including ceiling fan lights.
Ceiling fans	Reduce speed by one level without turning any off.
HAN Level 2: Intelligent coordinated control of end-use devices	
All traditional demand response and Level 1 strategies.	
Central AC	Reduce continuously variable compressor speed to offset operation of the dishwasher, clothes washer, clothes dryer, coffee maker, and microwave. The minimum draw will be 400 W for fan operation to keep air circulating.
TVs, set-top boxes, PCs and related equipment, and miscellaneous electronics	Disable devices with standby draw, based on knowledge of typical operations, i.e., cut power to the cable box only when the TV associated with it is not operating.
Refrigeration	Disable auto-defrost cycle, peak times only.
Lighting	Dim all remaining lighting to 80%, including ceiling fan fixtures.

Incremental Load Reductions Attributable to HAN

HAN-based end-use control is summarized by the resulting average demand (kW) and total energy (kWh) reductions achieved over the capacity and energy events (always assumed to be declared during noon to 8:00 p.m.) under each of the three control strategies. The initial average hourly demand over event hours was calculated, and the end-use control strategies presented in Table 5-1 were applied to determine the base load reduction (without HAN) and the marginal demand (kW) reduction during each hour for each level of HAN control.

The baseline household demand profile where no end-use control is employed and the profiles after the application of the two HAN control categories (1 and 2) are shown in Figure 5-2. The plot of HAN Level 2 demand shown in Figure 5-2 represents the resulting household load profile after the base and both HAN control strategies described in Table 5-1 were applied.

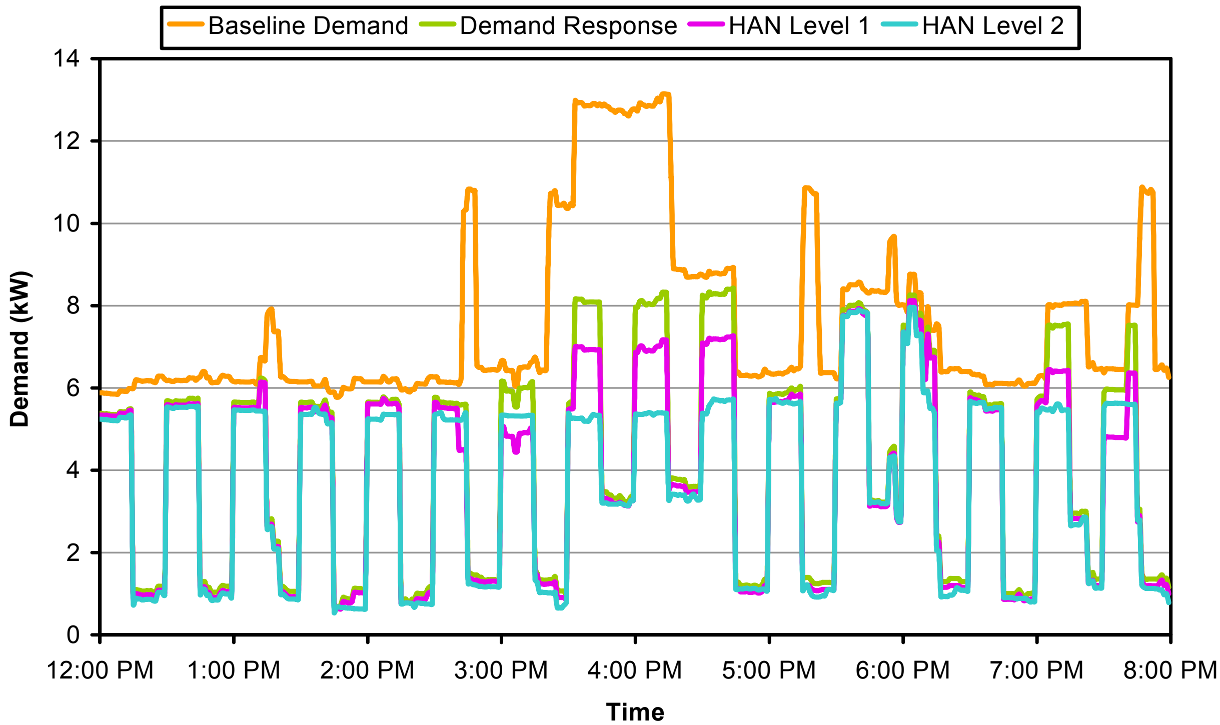

Figure 5-2
Comparison of Baseline Profile with Demand Profiles after Application of Three Levels of End-Use Control Strategies

The sequential addition of HAN 1 and HAN 2 control increases the total load under control and extends the amount of load reduced during the event. The most notable HAN impact is the cycling of the air conditioning compressor over the event period on fifteen minute intervals in HAN 1 and 2 control strategies. AC cycling is done to accommodate the use of other devices that are assumed to not be discretionary -- the over, clothes washer and dryer, and dishwasher -- but still achieve as constant a level of power reduction as possible throughout the event. The results of improved AC compressor operation are portrayed in Figure 5-2 by the Level 1 and Level 2 curves between 3:30 and 5:00 p.m.

The total and average reductions in household power consumption, associated with Base Demand Response and the two HAN categories are shown in Table 5-2, along with the cumulative reduction associated with HAN 1 and 2 technology deployment. Base Demand Response (comprised of AC, hot water heater, pool pump control) produces an overall reduction of 27.7 kWh, and a 4.7 kW reduction in event peak load. Periodic curtailment of the AC compressor accounts for about 66% of the total Base Demand Response reduction. Subsequent event load reductions from HAN Level 1 and 2 are small, approximately 9% and 6%, respectively.

Table 5-2
Technical Potential Energy and Demand Reductions for Three Levels of HAN Control over Eight Hour Period

Control Category	Total Energy Reduction (kWh)	Average Demand Reduction (kW)	Peak Demand Reduction (kW)
Base Demand Response	27.7	3.5	4.7
HAN Level 1	2.4	0.3	0.3
HAN Level 2	1.8	0.2	0.2
Cumulative	**32.0**	**4.0**	**5.2**

Note: Columns may not sum correctly due to rounding error.

Net Benefits of a HAN Investment

The net benefit of a HAN investment takes into consideration the stream of payments (capacity and energy) the household realizes from providing demand response resources, and the cost of acquiring and operating the HAN system.

Capacity payments. Demand response program participants receive a capacity payment, based on the kW reduction that substitutes for conventional generation in meeting the ISO/RTO installed capacity requirement. Historically, utilities have paid customers the avoided capacity cost for curtailable resources that reflect the corresponding savings in capital expenditures. While these are like-minded valuations conceptually, the nominal levels of such payments vary considerable based on market structure, market conditions, and how capacity is acquired.[7]

The range of capacity prices used in this study ($25, $50 and $75/kW-year) was chosen to be representative of recent capacity market clearing prices in northeast ISOs/RTOs. Table 5-3 shows the corresponding payment to the home owner under the Base Demand Response and Level 1 and Level 2 HAN control strategies for each of the three payment levels. The homeowner payments range from $86.70 ($25/kW/year from Base Demand Response) to $299.59 per year ($75/kW-year Level 2 HAN. Over 85% of the maximum possible payment (HAN Level 2) under the alternative ($/kW) levels is achieved by Base Demand Response. The incremental value of HAN Level 1 is just under 9% and Level 2 HAN adds an additional 6.5%.

Energy Payments. To illustrate what amount of benefits might be realized, three levels of summer event circumstances were specified. The first involves five days where prices during the event period (noon to 8:00 p.m.) are $.75/kWh. The second level includes the first, and an addition five days with prices at $.50/kWh. The last adds ten more days where prices are $.25/kWh. The homeowner is assumed to be paid at these rates for curtailments undertaken. The many event days may be atypical of today's wholesale (ISO/RTO) energy markets. However, critical peak pricing (CPP) rates have provision for this many events, and some involve prices that are twice as high as used herein.

[7] EPRI. December 2009. A Framework for Valuing Demand Response as a Capacity Adequacy Resource. EPRI 1017876.

Table 5-4 shows the resulting energy payments associated with each control strategy with three different bidding strategies. The first column represents bidding for only five days at a price of $0.75 per kWh. In each successive column the resource is bid for additional days where the market price is lower. As was the case for capacity benefits, Base Demand Response was assumed to be achieved without HAN technology, so only the incremental benefit associated with additional load reductions inures to Han Level 1 and Level 2.

The stream of cumulative annual benefits from energy payments ranges from $119 to $279 per year (Table 5-4), which is not far off of that was attributed capacity program curtailments. Again, benefits are largely attributive to Base Demand Response, which accounts for 87% of all payments.

Table 5-3
Annual Marginal Potential for Capacity Supply Payments for Three Levels of End-Use Control

Control Category	Average Demand Reduction (kW)	Capacity Payment		
		$25 per kW	$50 per kW	$75 per kW
Demand Response	3.5	$86.70	$173.40	$260.10
HAN Level 1	0.3	$7.58	$15.16	$22.74
HAN Level 2	0.2	$5.58	$11.17	$16.75
Cumulative	**4.0**	**$99.86**	**$199.73**	**$299.59**

Table 5-4
Annual Marginal Potential for Energy Supply Payments for Three Levels of End-Use Control

Control Category	Total Energy Reduction (kWh)	Energy Payment		
		0.75 $/kWh for 5 days	0.75 $/kWh for 5 days, 0.50 $/kWh for 5 days (total 10 event days)	0.75 $/kWh for 5 days, 0.50 $/kWh for 5 days, 0.25 $/kWh for 10 days (total 20 event days)
Demand Response	28	$104.04	$173.40	$242.76
HAN Level 1	2	$9.10	$15.16	$21.23
HAN Level 2	2	$6.70	$11.17	$15.63
Cumulative	**32**	**$119.84**	**$199.73**	**$279.62**

Note: Columns may not sum correctly due to rounding error. Each event day is comprised of eight event hours and curtailments accomplished are paid the specified $/kWh price.

Net Benefits Including HAN Cost

The net benefits to the household are calculated by subtracting the cost of the control technology employed. The costs associated with HAN Level 1 and Level 2 technology are specified in Table 5-5. Although intelligent home energy management systems are not generally available except through utility programs, the cost for similar in-home displays which provide energy consumption information and non-price based control is in the range of several hundred dollars. First, HAN investments are evaluated assuming the Base Demand Reponses is in place, or can be achieved without the added cost of a HAN. A second case attributes all energy payments to HAN technology to consider the possibility that responding 20 days a year is beyond what conventional load control systems can enable the homeowner to accommodate.

Table 5-5
Equipment Costs for HAN Levels 1 and 2

	HAN Level 1	**HAN Level 2**
Required Equipment	Central AC sensor and controller, ten lighting sensors and switches, three ceiling fan sensors and controllers, sensors for clothes washer, dryer, and dishwasher.	Additional sensors and switches for microwave and coffee maker, sensor for ceiling fan light fixture and dimmable controller, ten dimmable controllers for other lighting (replace on/off switches from Level 2), sensors and controllers for refrigerators, six sensors and switches for standby loads[b].
Central Control Unit	$500	N/A
Sensors	$51	$33
Switch – on/off	$70	$56
Controllers – dimmable or multi-level	$40	$130
Total HAN Cost	**$661**	**$219**
Equipment Lifetime	10 years	10 years
Annual HAN Cost	**$66.10**	**$21.90**

[a] Assumed ten total bulbs to be controlled and a maximum of five bulbs operating at once from noon to 8 p.m.
[b] Assumed six power strips or switches that could be opened to accommodate all non-kitchen loads consuming standby.

HAN as a Marginal Enabler

The net value to the household of the HAN system is derived using the value stream specified in Table 5-3 and Table 5-4 and the HAN cost provided in Table 5-5. Table 5-6 displays the resulting net values, where the total payment for the household is the sum of the energy and capacity payments for each level of end-use control. The capacity payments shown in Table 5-6 assumed a payment of $50 per kW-year. The range of Total Payments and Marginal Net Benefits reflect the three levels of economic event benefits; the low value associated with just 5 events a year, the high value with 20 events per year. The benefits and costs are marginal and represent the gain or loss that may be realized when moving from one Level of HAN control to the next.

Under the assumptions of this hypothetical construct, the incremental benefits from HAN Level 1 control are not sufficient to cover the costs of the HAN, resulting in a loss of between $22 (responding to 20 events) and $49 (responding to only five events per year). Level 2 control produces a slight positive net benefit ($10.48 per year), if 20 events are responded to. In years where prices are lower and economic response events few, the return on the HAN is negative.

Table 5-6
Net Benefits from Household Demand Response; Base Demand Response and HAN Level 1 and Level 2

Control Category	Total Payment	Annualized HAN Cost	Marginal Net Benefit
Demand Response	$ 190.74 - $ 502.86	$0	$190.74 - $502.86
HAN Level 1	$16.68 - $43.97	$66.10	(-$49.42) - (-$22.13)
HAN Level 2	$12.28 - $32.38	$21.90	(-$9.62) - $10.48

Note: Rows may not sum correctly due to rounding error.

HAN as an Energy Bidding Enabler

A second case is constructed assuming that realizing energy payments was achievable only with the use of Level 1 and Level 2 HAN control combined. The marginal net benefits for this case are shown in Table 5-7. Base Demand Response Benefits ($86-260) go down by 50% because in this portrayal they are comprised only of capacity payments. Annual energy event response benefits ($94-253) are attributed to HAN 2, which exceed the annual amortized system cost of about $88/year, and by a considerable amount in years where that are ten or more event days.

Table 5-7
Total Supply Payments for Three Levels of End-Use Control, Case 2

Control Category	Energy Payment	Annualized HAN Cost	Marginal Net Benefit
Demand Response	$86.70 - $260.10	$0	$86.70 - $260.10
HAN Level 2	$116.32 - $275.14	$88	$94.42 - $253.24

Note: Rows may not sum correctly due to rounding error.

6 SUMMARY AND NEXT STEPS

This document puts forward a framework to value the net benefits of HAN as an enabler of demand response from a consumer's perspective. The framework accounts for the costs borne by consumers to acquire and install the components of a HAN, as well as the capacity payments available to consumers that are enabled by the automation of HAN technology. The framework can be applied to any set of end use load assumptions, time-varying rate structures, and market structures for capacity payments or other incentives to consumers.

To demonstrate the application of this HAN-DR valuation framework, a representative South Atlantic household with typical end uses was constructed and hot summer day load profiles for all end uses developed. End uses were sorted according to their dispatchability, and those that have not been subscribed to conventional load control programs were sorted into two categories that were assumed to be enabled with two levels of HAN control. Capacity and energy payment streams were constructed to represent the payments available to a household that could reduce load when called up, or when high prices make doing so beneficial, respectively.

The results from this example suggest that where load control technology is already in place, justifying the incremental cost of HAN technology to augment response may be difficult. But, if the existing load control technology only enables the homeowner to participate in capacity programs, the extent to which HAN-based control opens opportunities for additional payments from responding to high prices makes it more cost-effective.

There may be additional benefits. A HAN system may induce participation by customers that reject traditional capacity-based demand response device controls because they are too rigid or do not offer event override capability. Finally, the homeowner may attribute part of the cost of a HAN to the value it receives from greater control of electricity use, which lower its bills, thereby making the overall investment more attractive.

The analyses presented herein are approximations to diverse household circumstances, market supply conditions that determine the payment for demand responsiveness, and presumptive assessments of what load households see as being discretionary. The next step is to develop a more complete framework and build a model for its application under a wide range of circumstances. Additional factors that need to be addressed to establish achievable potential include:

- Behavioral impacts and customer acceptance,
- Utility program impacts (e.g., program budget realities),
- Technology and infrastructure costs, and
- ISO/RTO demand response program requirements.

7
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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com