Disaggregation: The Holy Grail of Energy Efficiency?

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Two Big Problems

1. Significant low-cost energy savings can be made in the residential and commercial sectors, but these savings have not been achievable to date.

2. Billions of dollars are being spent to install smart meters, yet the energy saving and financial benefits of this infrastructure – without careful consideration of the human element – will not reach its full potential.

Solution: We propose strategically marrying these problems, using disaggregation algorithms, to solve both. Is this possible?
What are the benefits of appliance specific data?

• A review of ~40 studies on feedback demonstrate reductions in energy use, with the magnitude depending on the type of feedback. (taken from Ehrhardt-Martinez, Donnelly, & Laitner, 2010).

• [A note that many of the studies that informed this were small populations – those with larger and more representative samples typically showed about half the savings for each bar.]

• There is a limited amount of appliance-specific work to date – shown in the purple bar - but it shows greater energy reductions than non-specific feedback.

• The appliance-specific feedback studies to date have not pushed the bounds of how this information can be used, however. The right-most bar has been added to illustrate that disaggregation and its associated services (diagnostics, recommendations, channeling to programs, new behavioral techniques, targeted marketing, etc.) could be pivotal in achieving greater electricity savings; they could also be used to achieve energy savings in gas use.

• Several papers estimate a potential of up to around 20% energy savings in the residential sector, and sizeable savings in commercial as well. (taking market penetration into account) (Gardner and Stern 2008; Laitner, Ehrhardt-Martinez, and McKinney 2009)
We think the last bar on the previous slide might be quite high particularly because appliance specific information not only provides feedback, but it can be used to provide automated, personalized recommendations about what should be done, and when appliances are malfunctioning (seen in the box in the middle of this diagram). Then households can be channeled into specific programs (e.g., audits, appliance repair and replacements), & barriers to taking action can be addressed – through apps, etc.

We explain this in much more detail in our paper: http://peec.stanford.edu/docs/behavior/research/disaggregation-armel.pdf
Those points are illustrated in the top rows in this table. In addition, we think that appliance specific information can provide many other benefits:

• In obtaining Commercial Energy Savings

• To help facilitate energy efficiency appliance innovations. (For appliance innovations – the Better data should help (a) in the redesign appliances for energy efficiency, (b) to improve standards, and (c) to back up appliance EE marketing)

• In Building Research and Design, to Improve building simulation models, which will then improve design and operational efficiency, and enable auto-commissioning. (Clarifies why predicted (i.e., modeled) and actual building energy use are discrepant, and guide future improvements.)

• For Strategic, specific, energy efficiency marketing

• In Program Evaluation, to enable the evaluation of efficiency & conservation programs that weren’t quantifiable previously, and to draw stronger causal links between programs and their savings.

• For Contractor and Building Performance Ratings – energy data affords performance based metrics, ratings, and incentives for contractors and buildings (and these could impact real estate value)

• And finally, for improved load forecasting, as well as improved Economic Modeling and Policy Recommendations (due to increased specificity)
How can we get appliance specific data?

So far, consumers have only had one option of getting appliance specific data – that is by using plug level hardware.

In the future, smart appliances may also communicate their power consumption. However, both these methods use hardware for each plug to monitor individual appliances. This is an expensive approach and does not scale very well.

Software based disaggregation instead uses just the whole home energy data and provides a scalable and cost effective approach. The hardware needs to only sense the power at one point and the software does the rest. Until now, the whole house data was only available through consumer purchased sensors like TED, Blueline and various others. The cost is around $200+ and sometimes installation is tough.

Smart Meters solve that problem and present the most cost effective and lowest installation effort option (from the consumers perspective – since utilities are investing into Smart Meters anyways).

*The take-home is that: We can get much higher penetration in the population if we do disaggregation using smart meter hardware, than with any other method.*
By appliance, I also mean end-use, etc.
So what are the disaggregation algorithm requirements, and can smart meters satisfy these?

Let’s start with the data requirements:

Disaggregation can be done using different sampling frequencies – e.g., 1 hour data currently from smart meters, 1min-1sec data that can come from the HAN. And higher sampling frequencies from other hardware, or future versions of smart meters. Here we display the appearance of the data at the different frequencies, the types of data analyzed by the algorithms, and the number and type of appliances that algorithm can identify.

As we increase the sampling frequency, we can detect more appliances – only base and variable load from hourly, ~10 from 1min-1sec data, and up to 100 discrete appliances with MHz data.
Can Smart Meter Hardware meet these Data Needs? We’ve analyzed the various smart meter components and the sampling frequency supported by those components. This allowed us to determine not only what smart meters could currently do, but also what would need to be upgraded to sufficiently improve their capabilities for the algorithms, and the associated cost.

In summary, current meters like those being installed in the CA IOU territory can get roughly 10s data once they open the HAN. If we want to get higher frequency data than that – say around 60Hz which affords more useful data characteristics - we likely will have to do some data compression inside the meter which will require a firmware upgrade (‘remote software’ upgrade).

If, for new meter installations, we want to get above say 2kHz, we’ll need to use better hardware than what the CA IOUs are currently putting in. It’s worth noting that the communication bandwidths will not support the higher frequencies, so either very high compression, or disaggregation itself, will need to be performed on the meter. The required changes would most likely cost ~$10 per meter.
Where can we run the actual disaggregation algorithms?

The algorithms could be run on a device in the home or in the cloud in the near future.

Note that many of the meters currently being installed use zigbee. The implication is that for both options 1 & 2, an extra piece of $30+ hardware is required in the home, just to convert the data from zigbee to wifi. Thus, it may make sense for new meters to use low power wifi to avoid this extra cost and hassle.

Further in the future, it may make the most sense to do disaggregation on the meter – because very high frequency data is difficult to send wirelessly.
Recommendations
Note on improving compression and disaggregation algorithms

• To allow improved data frequency, and improve robustness, accuracy, and number of appliances identified by the algorithms, while reducing frequency, processing, and training requirements.

• The frequency range of 1 second to 15 kHz is of particular importance, given that insufficient algorithmic work has been performed to date in this range, and this range could be achievable in meters.

• Develop high-yield data compression algorithms to enable the use of 1 second to 2 kHz data on current meters, and up to 15 kHz data on future meters.
Consumers today need to purchase a ZigBee gateway/router device to receive data from their Smart Meters which costs money and effort to install. Most consumers already have Wifi access points. Using IEEE 802.11x compatible radios in the Smart Meter for Home Area Network instead of IEEE 802.15.4 (used by ZigBee) would eliminate the need for buying the extra hardware and enable users to use the existing Wifi network to read the data off their Smart Meters. Removing this barrier should significantly increase penetration of data use (or use of apps that pull the data).

A couple of additional notes:

1. It is possible that 10s data will be sufficient to provide accurate identification of a fair number of appliances, but we’re not certain at this point given the algorithms are still in the early stages of development. We should know in a year or two whether this data is sufficient.

2. If you want to play it on the safe side, to reap the potential benefits from smart meter data, I’d recommend supporting up to 15kHz data on a meter. Although this may cost up to $10 per meter, if you choose a meter that uses wi-fi rather than zigbee, they you’ve save your utility or customers $30, which more than makes up for the $10.
Regarding the last two points:

- Disaggregation developers should contribute use case specifications and requirements to the standards process...So forthcoming communications technologies are better suited for disaggregation

- Federal agencies and PUCs should demand improved transparency about meter specifications...And enable universities to test real meters to establish actual constraints. Currently, some of the relevant meter specifications are proprietary. Large public expenditures are going towards the smart grid, and there is great potential for innovation and consumer benefit, but this is likely to go unrealized without greater transparency.

In summary, disaggregation may be the lynchpin to realizing large-scale, cost-effective energy savings in residential and commercial buildings. To date, these “$20 on the sidewalk” energy savings have been onerous to collect, but disaggregation offers an opportunity for significant automation. Smart meters, given their widespread roll-outs, and ability to circumvent cost and effort barriers, offer an opportunity for quick, sweeping market penetration of sensing hardware required for disaggregation. There are a number of research, meter, and policy steps needed to realize the application of disaggregation with smart meters, but all are tractable within a relatively short time frame. Further, this work could clear the way for similar energy disaggregation work on gas, water, and transport. We are optimistic this work will progress, along with its anticipated benefits.
DISAGGREGATION: THE HOLY GRAIL OF ENERGY EFFICIENCY?

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This paper aims to address two timely energy problems. First, significant low-cost energy reductions can be made in the residential and commercial sectors, but these savings have not been achievable to date. Second, billions of dollars are being spent to install smart meters, yet the energy saving and financial benefits of this infrastructure – without careful consideration of the human element – will not reach its full potential. We believe that we can address these problems by strategically marrying them, using disaggregation. Disaggregation refers to a set of statistical approaches for extracting end-use and/or appliance level data from an aggregate, or whole-building, energy signal.

In this paper, we explain how appliance level data affords numerous benefits, and why using the algorithms in conjunction with smart meters is the most cost-effective and scalable solution for getting this data. We review disaggregation algorithms and their requirements, and evaluate the extent to which smart meters can meet those requirements. Research, technology, and policy recommendations are also outlined.

For the complete report: