

Personal Energy Analytics: Successes, failures and challenges

Lyn Bartram
 School of Interactive Arts + Technology
 Simon Fraser University
 lyn@sfu.ca



Human Centered Systems for Sustainable Living



Background

- Computer scientist
 - Information visualization, personal visual analytics
 - Information and computational systems for sustainable living
- My team:
 - Architects, engineers, computer scientists, designers, psychologists
- Our collaborators
 - Energy utilities, urban planners, green tech companies, building developers and designers, trades, community gardeners, social scientists....



Human Centered Systems for Sustainable Living

SFU



SCHOOL OF INTERACTIVE
ARTS + TECHNOLOGY

Overview (and provocation)

- Chapter 1: Frame the problem
 - Energy, humans and behaviour
- Chapter 2: Data, feedback and design mismatches
 - Are we asking the right questions?
 - Are we collecting (all) the right data?
 - Are we operating under [correct, reasonable, effective] assumptions?
- Chapter 3: The role NILM research [does, can, might] play
 - Discretionary use
 - Trust and agency



Overview (and provocation)

- Chapter 1: Frame the problem
 - Energy, humans and behaviour
- Chapter 2: Data, feedback and design mismatches
 - Are we asking the right questions?
 - Are we collecting (all) the right **data**?
 - Are we operating under [correct, reasonable, effective] **assumptions**?
- Chapter 3: The role NILM research [does, can, might] play
 - Discretionary use
 - Trust and agency

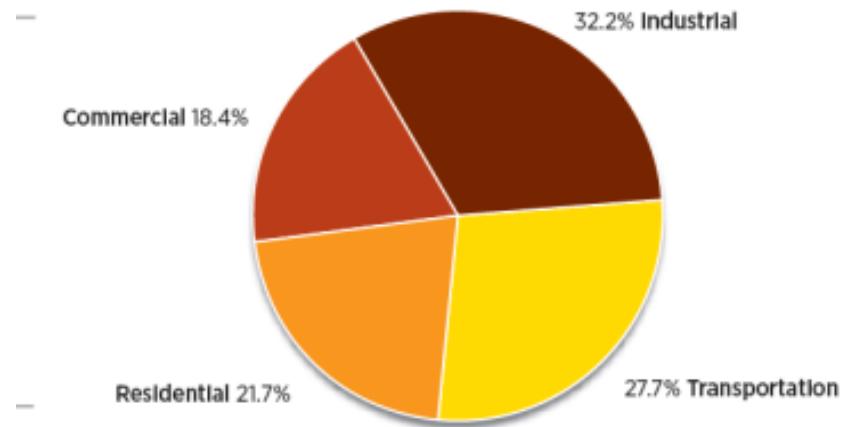


Human Centered Systems for Sustainable Living

Buildings use significant energy

- Buildings in the US accounted for 40% energy consumption in 2013
 - ~22% residential

U.S. Energy Consumption, 2013: 97.4 Quadrillion Btu



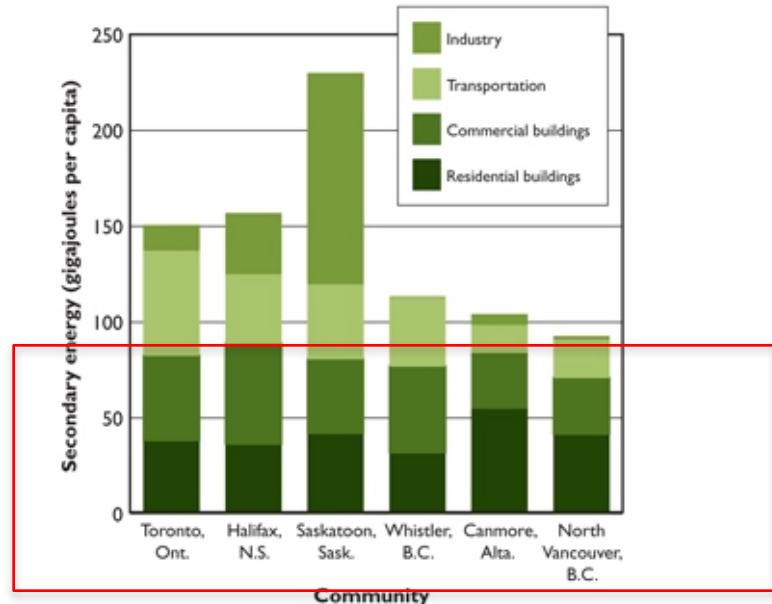
U.S. Department of Energy, Energy Information Administration



Buildings use significant energy

- Depending on the area, they are a primary consumer
 - Canadian study of community energy use, 2006

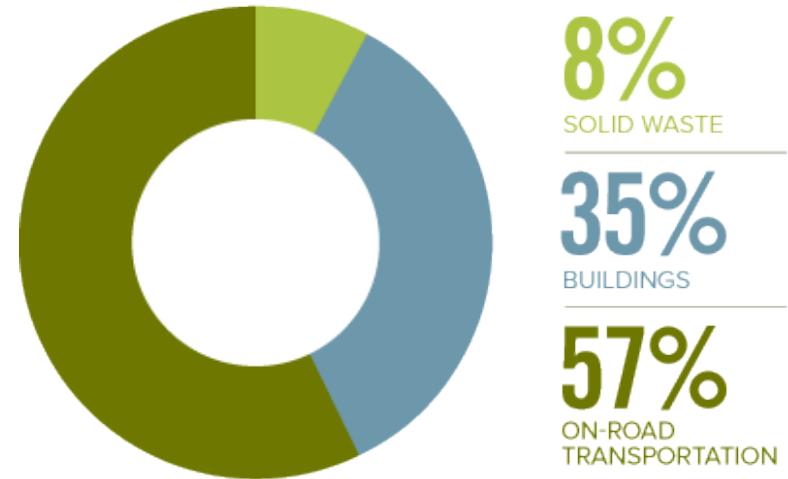
Figure 2. Energy use in Selected Communities



Natural Resources Canada, Energy resources, 2008

Emissions

2010 GHG EMISSIONS SOURCES



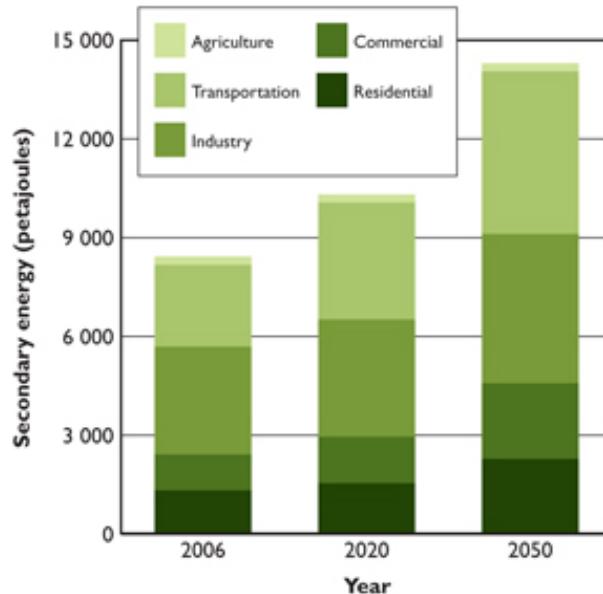
Source: Ministry of Environment, 2010 Community Energy and Emissions Inventory

Human Centered Systems for Sustainable Living



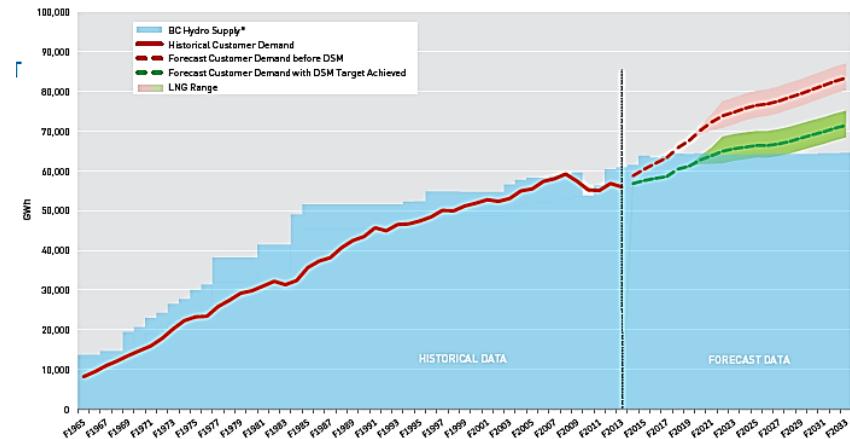
But that's not the scary part

Figure 3. Forecasted Growth in Community Energy Use



Natural Resources Canada, 2006

Electricity use is expected to increase by 40% over the next 20 years



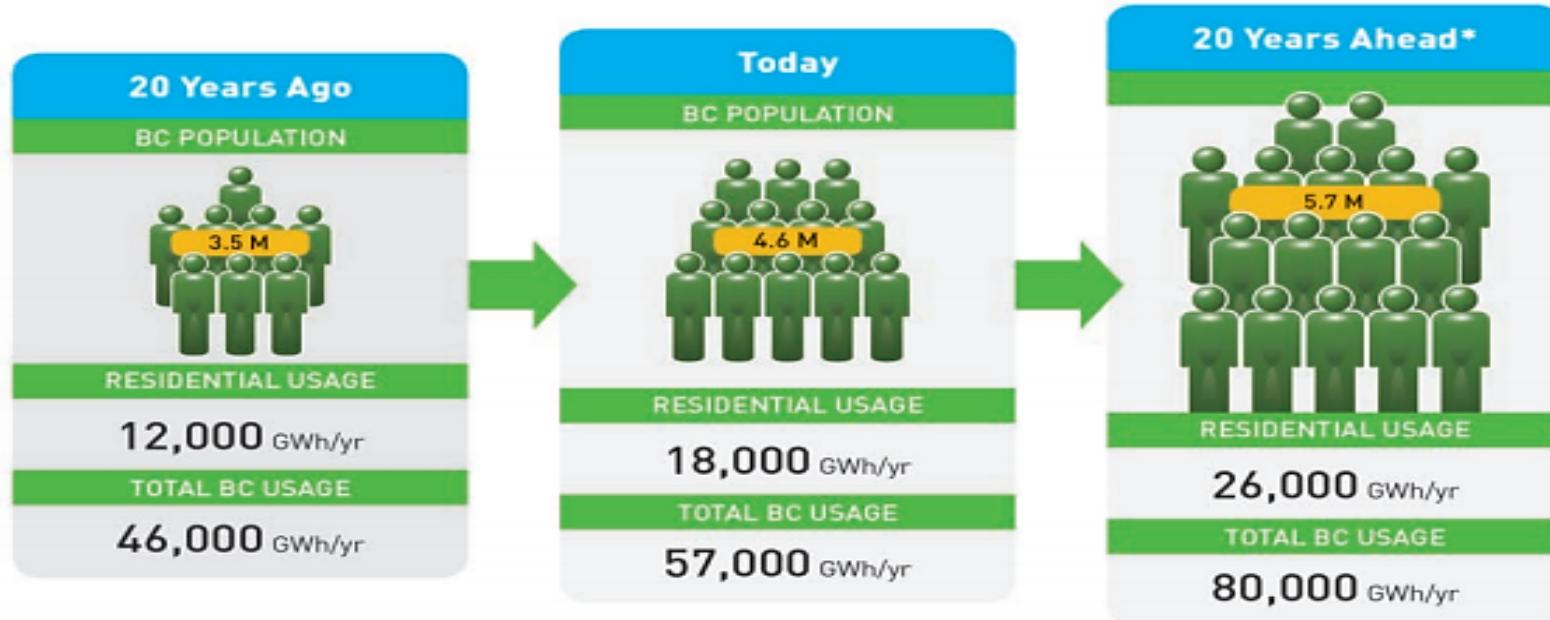
BC Hydro PowerSmart, 2014

Human Centered Systems for Sustainable Living



Chapter 1

Residential electricity use is expected to outpace population growth by 2:1



© BC Hydro

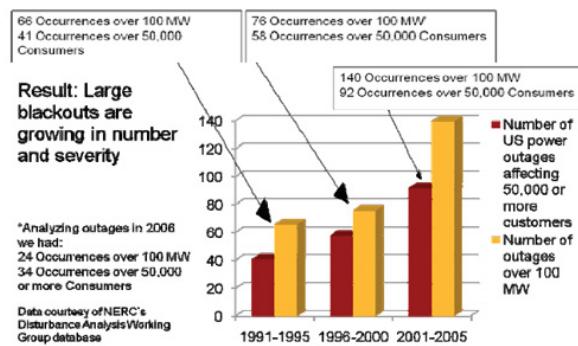


Human Centered Systems for Sustainable Living

Increasing demand for energy

- Reducing residential energy use is an important strategy in reducing our environmental footprint
 - How much we use (consumption)

**U.S. Electrical Outages Over 100 MW And Affecting Over 50,000 Consumers
(1991-2005)**



Residential energy indicators, 1990 and 2009



1990

- 2.8 people per household
- 116 m² of living space
- 9.9 million households
- 15 appliances per house
- 23 percent of occupied floor space cooled



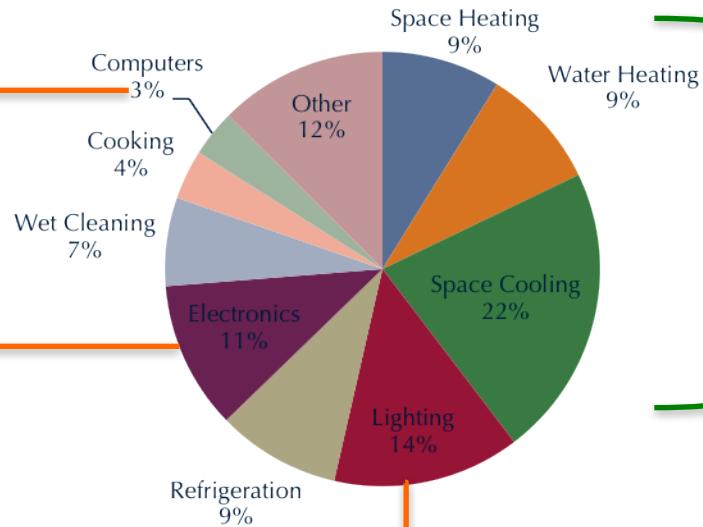
2009

- 2.5 people per household
- 129 m² of living space
- 13.4 million households
- 21 appliances per house
- 44 percent of occupied floor space cooled

Natural Resources Canada, 2009

Quick context: where we use energy

Residential Consumption by End Use, USA 2010.



Variable and hard to predict

Amenable to predictive modeling

US DoE, Building Energy Data Book, Table 21.5, 2012.



The rational premise

- It's all about use
(behaviour)
- So clearly, more
information will help



Factors that impede conservation behaviour
Kashani, Bartram, Woodbury 2012



Painful lessons 2..200

It's not just about information deficit

- The wrong kind of awareness
- Numerous environmental behaviour models

It's not just about adding more technology

- **data does not invoke action**
- Poor computational models of human use
- Deep lack of understanding in how we use our homes

Where and **when** is as important as **what**

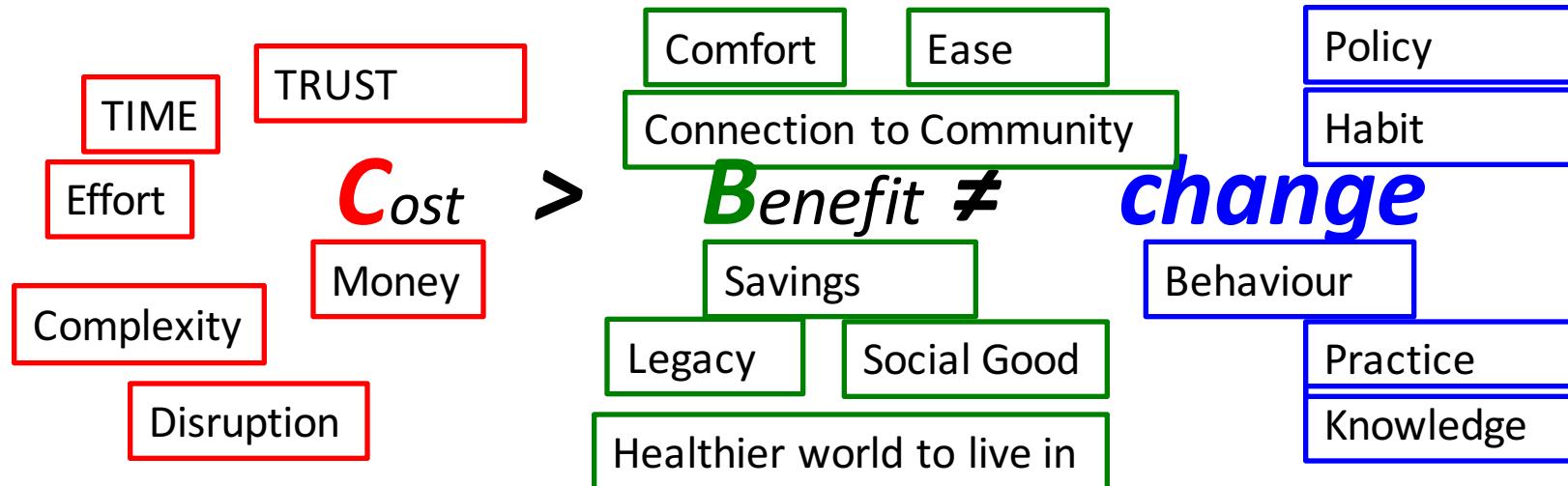
- supporting living practices



*There's an
app for
that !*

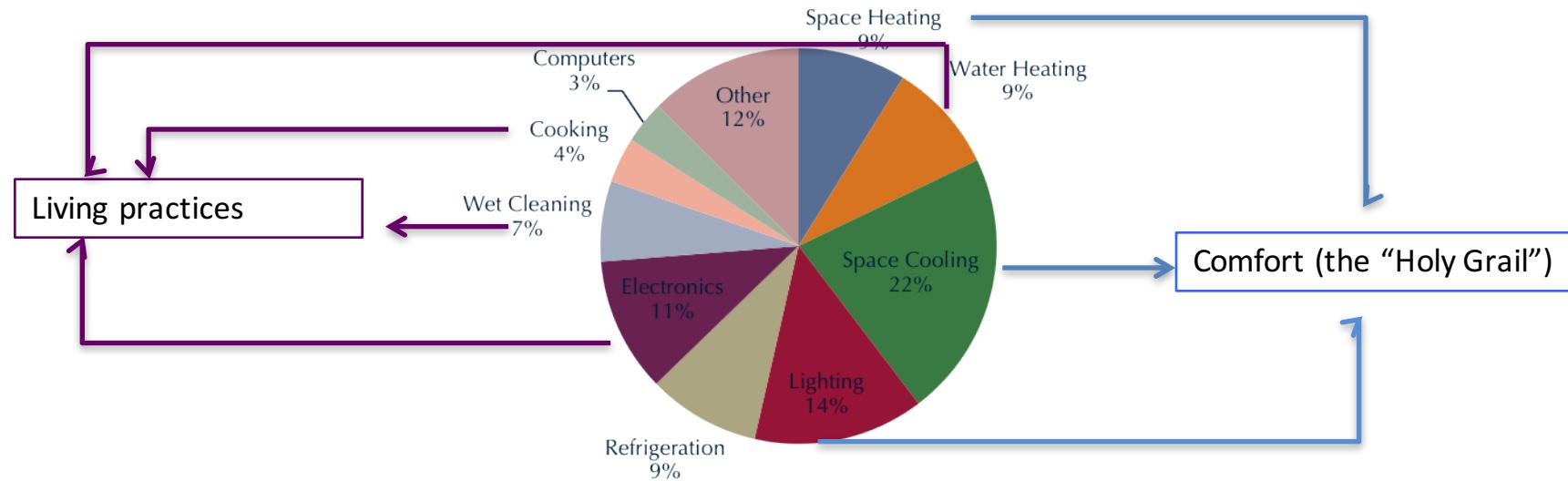


A simplistic model



Quick context: why we use energy

Residential Consumption by End Use, USA 2010.

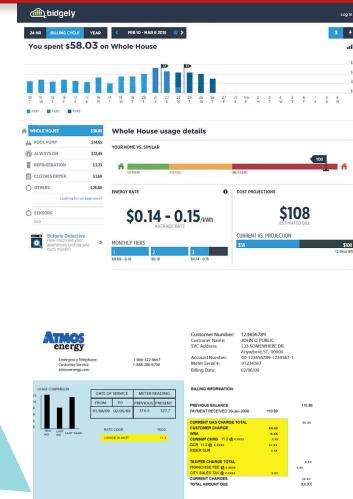
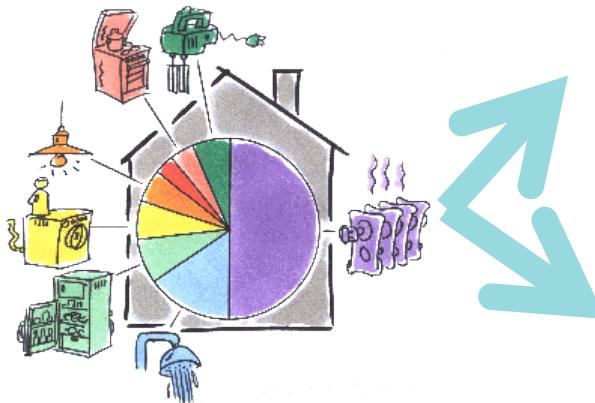


US DoE, Building Energy Data Book, Table 21.5, 2012.

Human Centered Systems for Sustainable Living



People have trouble understanding their use



1. USAGE IN MWH: This is the number thousands of units of electricity you used this month. Some bills may show usage in kWh (kilowatt hours) or units of kWh (kilo-watt hours). One kWh is equal to 1000.000 BTUs.

2. DISTRIBUTION CHARGE: This charge is levied by your local utility company to pay for the infrastructure that it needs to serve each customer. Some bills may read **PUBLIC UTILITY CHARGE**, **FACILITY CHARGE**, **TRANSMISSION CHARGE**, or **TRANSMISSION FACILITY CHARGE**.

3. ENERGY CHARGE: This charge is the cost of the electricity you used.

4. CONSUMPTION CHARGE: This charge covers any variable fuel costs and the company's variable costs incurred to produce the electricity you used.

5. GAS LIGHT RECOVERY CHARGE: This charge includes the actual gas cost paid to acquire and transport the charges to the utility company, plus a fixed charge for the cost of the equipment used to convert the natural gas into electricity.

6. SURCHARGE: This is a charge imposed by the regulatory authorities to recover special expenses, such as rate base depreciation, which are not included in the basic rates.

7. FRANCHISEE FEE: This is a fee that is levied by local municipalities. The company collects and passes the fee on to the franchisee. Some bills may read **FRANCHISEE FEE**, **FRANCHISEE TAX**, or **FRANCHISEE CHARGE**.

8. LOCAL UTILITY TAX: This requires any sales tax assessed by your city or state, and any contribution you have made to an energy assistance program.

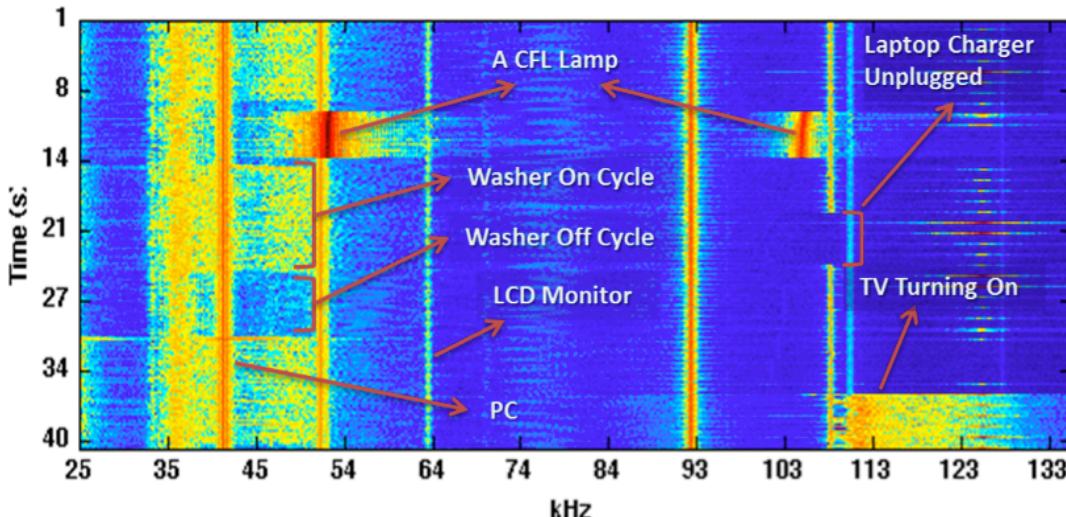
9. RETURNED BILL: If the word "Returned" appears next to your total or reading please take usage information from the previous month and add it to the new meter reading. Then subtract the previous month's usage and add the new meter reading to get the correct total.

Poor energy literacy



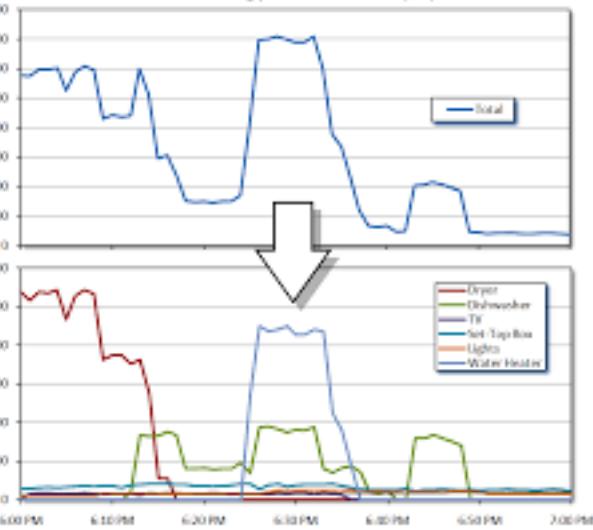
The magic of analytics

- Monitoring energy use



Carrie Armel, K., Gupta, A., Shrimali, G., and Albert, A. Is disaggregation the holy grail of energy efficiency? The case of electricity. *Energy Policy* 52, (2012), 213–234

Total Energy Use, Top (W)
Itemized Energy Use, Bottom (W)

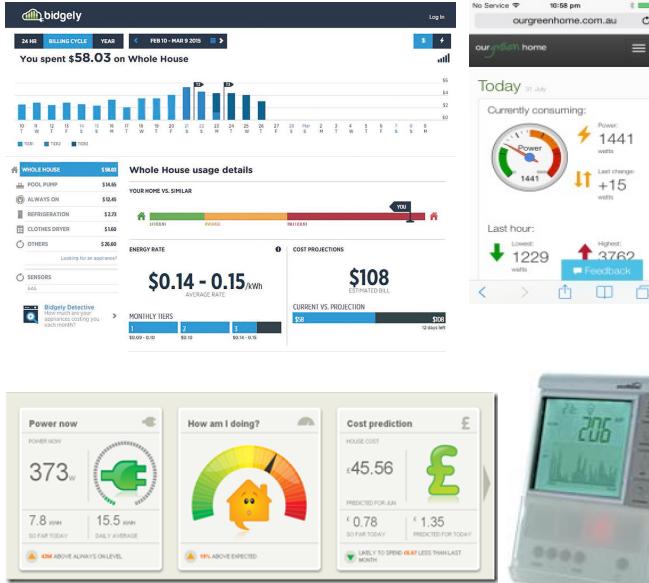


Christensen et al. NILM Applications for the Energy-Efficient Home. US DoE, 2012



Eco-feedback approaches

- Aggregate reporting



- Combined (HEMS)



- Detail POC



Human Centered Systems for Sustainable Living



Results from the field

- Aggregate reporting is insufficiently rich
- Retrospective reporting does not inform behaviour
- While initial response shows high change (15%), rates drop off quickly
- Social comparison is effective

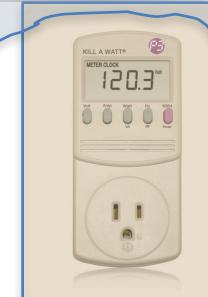


Eco-feedback approaches

- Dashboards/Portals



In-Home Displays



Ambient Displays

Mobile

Detail

Aggregate



Human Centered Systems for Sustainable Living

Standard feedback for the extra-informed resident



www.ge.com



Human Centered Systems for Sustainable Living

SFU

SCHOOL OF INTERACTIVE
ARTS + TECHNOLOGY

What is a user?

- Consumer of energy
- Decision maker about allocation of resources
- Consumer of information?
- Interacts with artifacts and technology
- *Resident/householder/inhabitant*



More data ≠ more efficiency

?



It's a program on conserving energy



| Systems for Sustainable Living

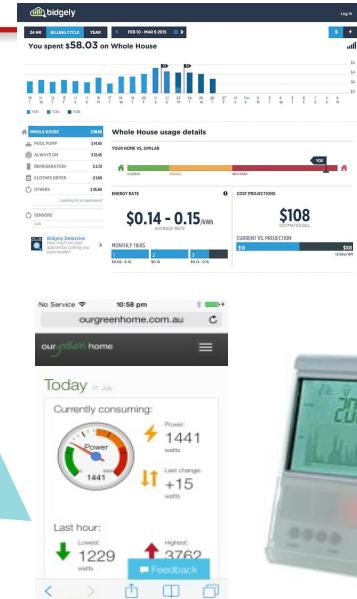
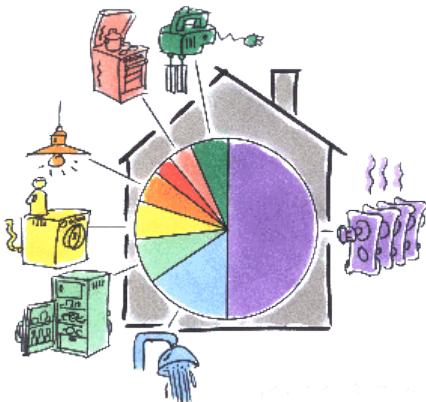
SFU



SCHOOL OF INTERACTIVE
ARTS + TECHNOLOGY

People have trouble changing their use

Daily activities



Poor energy literacy



Human Centered Systems for Sustainable Living

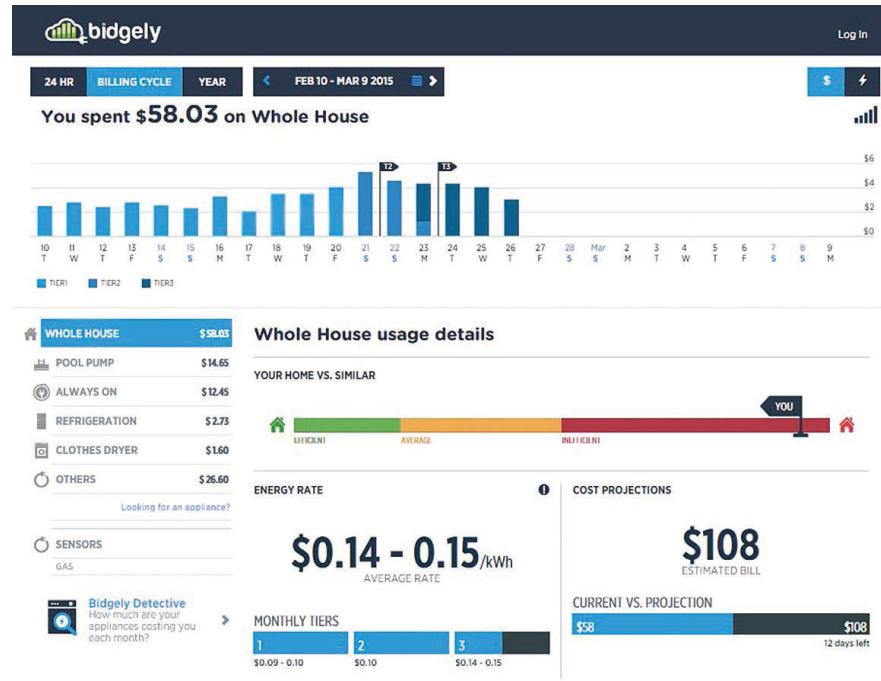


SFU



SCHOOL OF INTERACTIVE
ARTS + TECHNOLOGY

What's the issue?



Human Centered Systems for Sustainable Living

SCHOOL OF INTERACTIVE
ARTS + TECHNOLOGY

What are we missing?

- Engineering approaches are task- or data-driven
- Misaligned design
 - People don't use energy as a goal [Strengers]
 - Making which invisible visible ?
- Traditional infovis principles support only a small portion of the space
 - new ways of thinking about the problem
 - Expanding dimensions of personal visualization [Huang et al 2015]



Factors : Cognitive

- Knowledge (What does “understand” mean?)
 - Conceptual models and analytical reasoning (👍)
 - When do I spend more energy?
 - How much energy do my appliances take?
 - **Situational awareness**
 - What is using energy right now, and why?
 - **Operational knowledge (actionable) ****
 - What can I do about it [now]?



Factors : Behavioural

- Engagement and Motivation (What makes people behave differently?)
 - Extrinsic
 - Financial incentives (rebates) or disincentives (rate hikes tied to usage)
 - Intrinsic
 - Internal satisfaction in meeting goals
 - contributing to common good
 - Normative
 - social comparisons
 - shared goals
- Humans are not rational actors



Factors : effort

- Information access (How accessible is the feedback?)
 - Effort to find information
 - Ease of interpretation
 - What does that red light mean?
 - Appropriate context
 - Type of knowledge to support



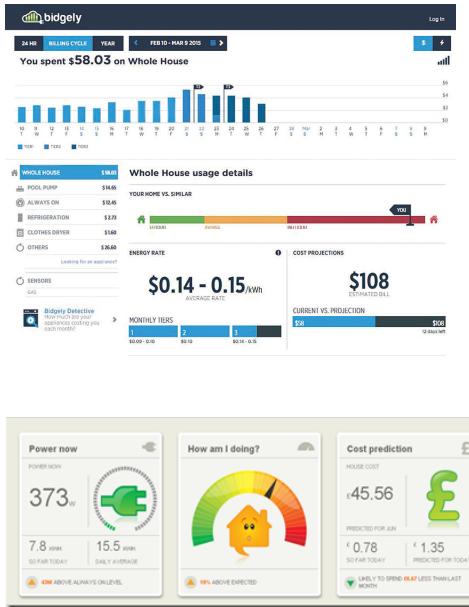
Design dimensions for eco-feedback

- Data
 - Mental model and scope (what's a kWh?)
 - Additional: derived, personal, actions and consequence
- Reasoning and behaviour
 - Knowledge type, motivation
- Context
 - Temporal, spatial and binding
- Effort
 - Attentional demand, interaction cost
- Communicative scope
 - Affect, ecological fit



Eco-feedback approaches

- Dashboards/Portals



- Designed for analysis and reflection
- High effort
- Low engagement
- Resident as energy manager
- Financial and engineering models
- Partly actionable?
 - No context of use
 - Reduced learning



Eco-feedback approaches

In-Home Displays



- Persistent, lower effort (with caveats....)
- Situational awareness
- Data sparse
- Specific detail (POC)
- Actionable
 - (POCs) operational insights
 - misleading
- Poor ecological and aesthetic fit



Eco-feedback approaches

Ambient Displays



EnergyOrb, Ambient Inc, 2014



- BELOW YOUR AVERAGE
- YOUR AVERAGE
- ABOVE YOUR AVERAGE
- GENERATING MORE THAN YOU'RE USING

Wattson SolarMonitor, Smart Home Energy Inc, 2014

- Low detail (hazy)
- unintrusive
- Situational awareness
- Data sparse
- Reportedly engaging
- ambiguous
- Can be tuned to design sensibilities
 - People will use them ?
- Idiosyncratic, novelty item



Power-Aware Cord, Energy Design Studio, 2010

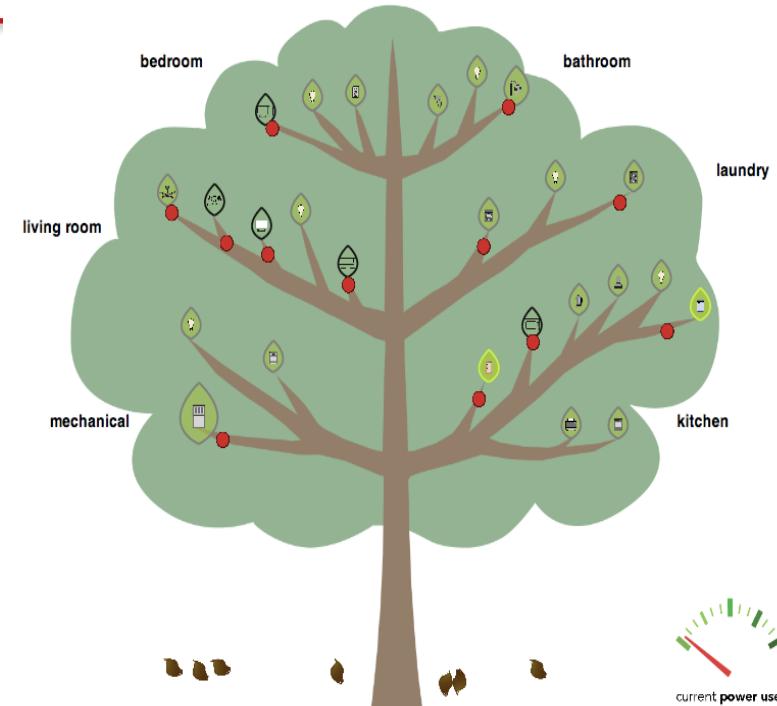
Human Centered Systems for Sustainable Living



SCHOOL OF INTERACTIVE
ARTS + TECHNOLOGY

Design Challenges for eco-feedback techniques

- Match the data model to what people are doing
 - New types of data
 - Data collection
- Provide multiple reference systems
 - *visaphors*
 - Cost
 - GHGs
 - Equivalences (“4 laundry cycles”)
- Meaningful norms
 - Personal goals and achievable thresholds
 - Social framing



Human Centered Systems for Sustainable Living



Right data

- Example:



- Point of choice vs point of consumption

- [Eves]

- Discretionary ??

- What/why is user doing?

- Action hints



Design Challenges for eco-feedback techniques

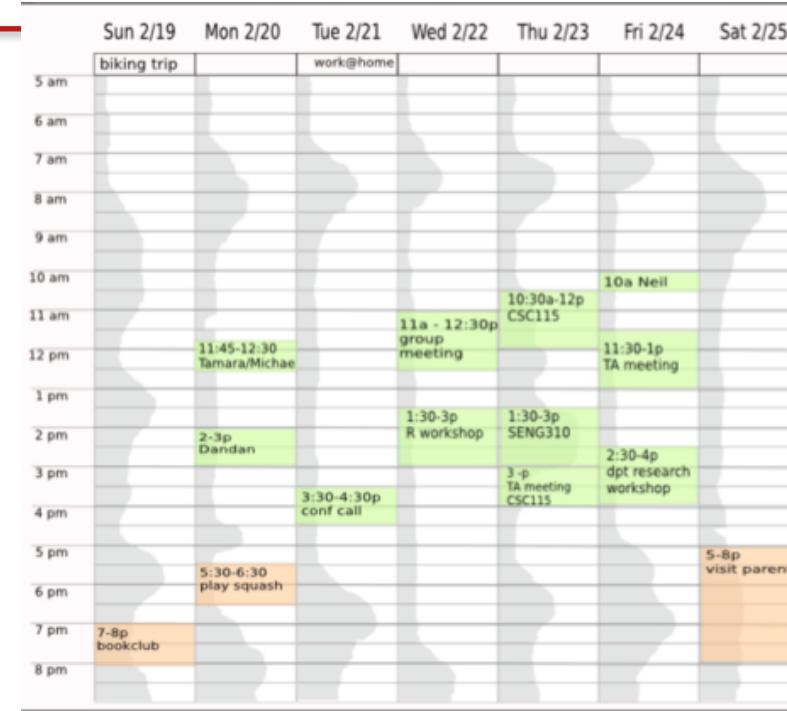
- Expand context
- Task/information models are incomplete
 - Analysis : **explicit** information task
 - Awareness: **implicit** relation (cooking dinner)
 - tighter mappings between activity and outcome
 - Reduced effort
- FRAMING and integration
 - Provide feedback in existing information landscape
 - Support sufficient external information



Context is not just extra information

Mashups and Framing

Reduce effort
Support "why" questions
Persistent awareness



Huang et al. Calvis, InfoVis 2014.

Human Centered Systems for Sustainable Living

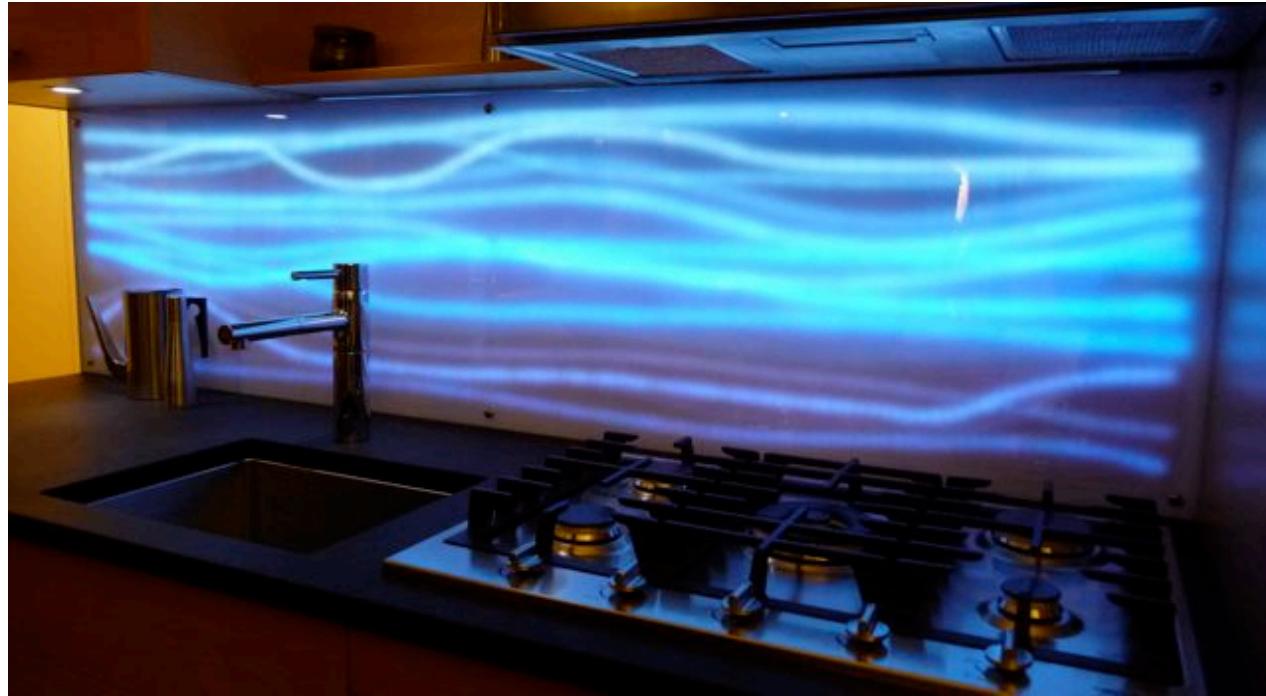


Design Challenges for eco-feedback techniques

- Enhance Communicative Scope
- Engagement, interest and motivation
- Aesthetics and **affect**
 - “Communicate a concern, rather than show data” [Kosara 2007]
 - Enhance experience, promote engagement
 - Amplify learning
- May (should) change data model!



Data themselves change the message: affect?



Human Centered Systems for Sustainable Living



Design Challenges for eco-feedback techniques

- ecological fit and appropriate **data**



Human Centered Systems for Sustainable Living

Design Challenges for eco-feedback

- Functional aesthetics and ecological fit
 - Design sensibility of the home
- Encoding must be adaptive
 - Light
 - Viewing distance
 - Activity
 - Additional Function
- Proxemics [Greenberg]
- Opportunistic display



Social framing

- increasingly used by organisations
 - Issues of norming and activation
- Variations on a theme ?
 - budget rather than activities
 - Privacy , community and trust



- Common ground

OPPOWER

Friend Rank Groups Pages Comparison Ways to Save

Friend Rank

< March >

Rank	User	Electricity Use (kWh)
1	Top 20% of U.S. homes	283 kWh
2	Average home in the U.S.	774 kWh
3	Denis Du Bois	2112 kWh

Post to Facebook Post

Feeling competitive? Invite more friends

Privacy Policy Terms of Service

facebook

Search

Green on Facebook 

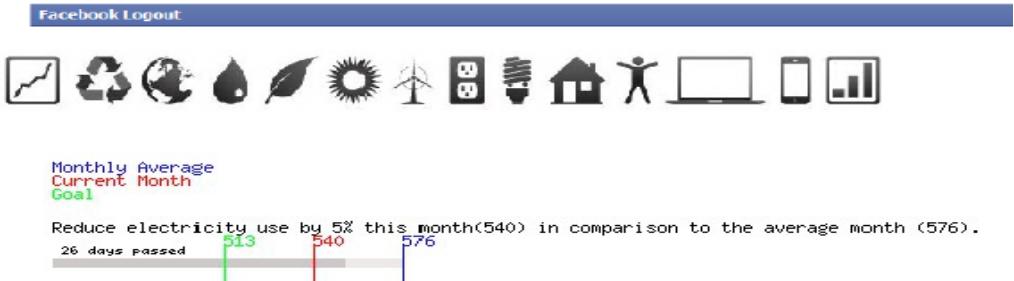
Internet/Software Wall

Green on Facebook 
Facebook, NRDC and Opower are partnering to use the power of social networking to help consumers make their homes more efficient, reduce their personal energy consumption, lower their utility bills and help protect the environment. Check out the Energy Efficiency tab to learn more!

Green on Facebook | Energy Efficiency With more than 600 million people around the world using Facebook, our greatest opportunity to affect environmental change is through the power and reach of our platform. We are working to develop products and initiatives that can engage the entire people on Facebook to get involved in environmental issues and solutions. By enabling millions of people from diverse backgrounds to easily connect and...

Wall Info Friend Activity Energy Efficiency Technical Infrastructure All posts

See More Page: 95,738 like this



Share and compare



Internet of Things → Awareness of Activity → Sharing → Better Health, Share This, 2014

Human Centered Systems for Sustainable Living



Social agency

- People like me?
- Comparison
- Joint goals
- Joint agency: documentation, tracking and enlisting
 - Walk to school program (BAST)
 - Localised decisions
- Social media, GPS
- District Energy management systems
 - Donate/share discretionary energy?



What is meaningful?

- What kinds of questions do people ask?
 - How am I doing wrt to “people like me”? My neighbourhood? My goal?
 - **What can I do about it?**
- Equivalences and experiential framing are key to engagement
(but **we don't know the right ones...**)
 - A distance of 14 Harry Potter CDs
 - 3 days where my child cannot play outside
- (How) could I live with “something like this” ?



How does NILM fit into this space?

- Extending the traditional scope of residential energy analytics
- Considering the entire information landscape of energy use
 - Recommender systems
 - Underpinning automation decisions
 - Informing building design applications and tools
- Expand richness of social schema



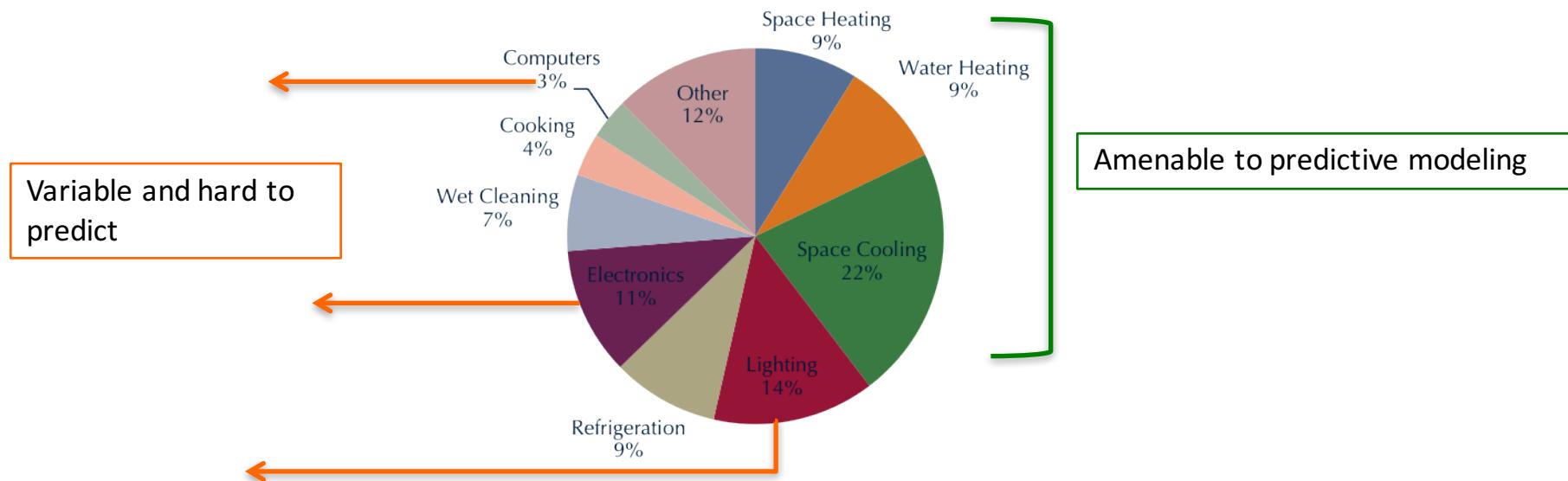
Non-intrusive Load Monitoring

- Load?
 - Simple consumption data insufficiently informative
 - Actions rather than appliances
 - **Discretionary load**
- Efficiency
 - Optimum deployment of resources
- Distributed implications
 - Generation as well as consumption
 - Local store vs. grid use



Track and characterise the critical data

Residential Consumption by End Use, USA 2010.

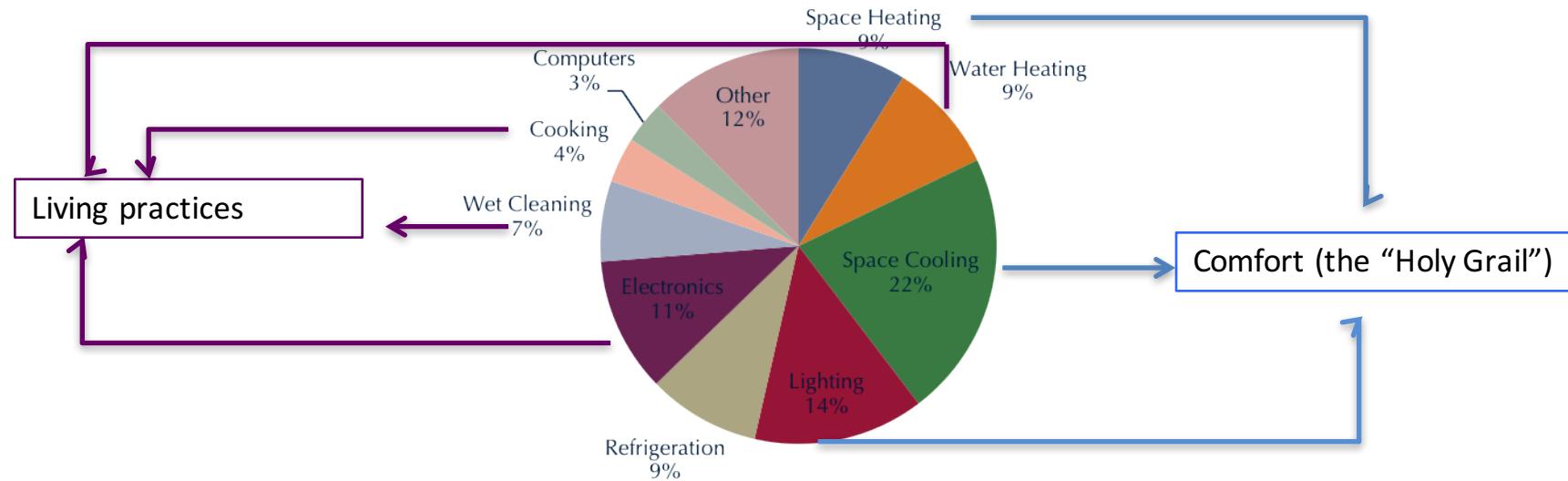


US DoE, Building Energy Data Book, Table 21.5, 2012.



Consider better models of user behaviour and *discretionary* use

Residential Consumption by End Use, USA 2010.



US DoE, Building Energy Data Book, Table 21.5, 2012.



Non-intrusive Load Monitoring

- Non-intrusive ?
 - Great privacy concerns
 - TRUST not simply privacy
- Agency, control and access
 - Where do the data sit?
 - Who owns them? Controls access? Gets to release interpretation?
 - Perceived benefit vs. perceived risk



Non-intrusive Load Monitoring

- Non-intrusive (Single Household)? Load Monitoring
 - More sophisticated comparison schema
 - Determinants of similarity
 - Normalized metrics
 - social media integration
- Measure “real” effect of social comparisons
 - Competition vs coordination vs collaboration
 - Social energy sharing?



Wrap it up

- NILM forms part of a larger initiative to use data to change behaviour
 - Insufficient understanding of the human factors
 - Sparse capture of relevant data
- Great potential to change/increase value to households
 - Influence policy and practice of energy utilities and building management
 - Requires richer data models, algorithms and application
- Engage with larger research community around dimensions



Thank you

- NSERC
 - City of Vancouver
 - Pacific Institute of Climate Solutions
 - BC Hydro
 - Government of Canada
 - MITACS
-
-and many creative students.



Human Centered Systems for Sustainable Living