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Abstract

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Workshop on Fostering Smart Energy Applications through Advanced Visual Interfaces

Advanced Visual Interfaces for Smart Energy: Focusing Where it Matters Most

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ABSTRACT
Targeting reductions of electricity usage among consumers in their homes has been very popular among researchers, industry, and research funding organizations. Here we look behind the application surface to examine where visual energy-savings applications might have their greatest impact. We analyze residential, commercial, and industrial sectors in the US and observe differences regarding energy use, economic incentives, and leverage per establishment. We then give examples of industrial and commercial energy-savings applications being developed at Mitsubishi Electric and supported by its North American Research Laboratory, MERL.

Categories and Subject Descriptors

General Terms
Algorithms, Measurement, Performance, Design, Economics, Human Factors.

Keywords
Energy use, Reducing Greenhouse gases, visual interfaces

1. INTRODUCTION
Reducing greenhouse gas emissions through influencing humans to reduce and control consumption of energy is a goal for many in the visual interface and visualization research communities. Aside from the design and evaluation issues, we believe our research community should also consider the targets of the applications in light of the end goal to reduce emissions. The target that has figured largest to date appears to be electricity usage in the residential sector. In a 2010 survey, 41% of eco-feedback HCI papers were found to be about residential electricity usage as were 92% of the environmental psychology papers included in the survey [10]. But are these the application targets that will move us the furthest and the most quickly towards the end goal? In this paper we will examine data on energy consumption across consumer, commercial, and industrial sectors and also consider factors related to economic incentives and leverage. We argue that of the three sectors, achieving greenhouse gas emissions through energy savings in the residential sector (and particularly through influencing individual end-users) is in fact the most challenging. Commercial and industrial applications would appear to offer better chances for high impact.

Our investigation is grounded in an analysis of data available on energy usage in the US. While not necessarily representative of energy use worldwide, the US is the second largest emitter of CO_2 emissions [21], so it is instructive to consider the US case. We will look at total energy consumed and then break down the residential, commercial, and industrial sectors where visual interfaces for energy-savings are widely applicable for reducing energy consumption. It is important to understand not only energy consumption totals within sectors as a whole but also a factor we call leverage. We consider leverage to be related to the consumption of energy per establishment since, generally speaking, decision-makers operate on an establishment level. We will compare and contrast the average leverage factor afforded to residences, commercial buildings, and industrial facilities. We'll also look at economic incentives and other factors that might influence the likelihood of success for energy reduction applications. Then we will comment briefly on electric utilities as a special case for visual analytics applications. Finally, we will give brief examples of energy-savings applications being developed at Mitsubishi Electric supported by its North American Research Laboratory, MERL.

2. ENERGY USE ACROSS SECTORS
The well-known flowchart of US energy use by Lawrence Livermore National Laboratory and the US Department of Energy [7] shows that in 2012, total energy use was estimated to be 95.1 quadrillion BTUs (quads). The residential, commercial, and industrial end-user sectors collectively consumed approximately 43 quads (45%) of this total, the remainder consumed by transportation (26.7 quads, 28%) and rejected energy from electricity generation (25.7 quads, 27%). In order to break down these figures further, we'll be looking at other data sources between 2003 and 2009. Even though the total energy use in the US has fluctuated somewhat over this period, the fluctuations are not significant enough to be material for our arguments here.

2.1 Residential
For the residential sector, the U.S. Energy Information Administration reports that in 2009 there were 113.6M housing units using 10.18 quads [2], roughly 10% of the total energy used nationwide. This results in 89.6M BTU/household, 34.9M BTU/household member, and 45,500 BTU/ft2.

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As far as electricity usage goes, 4.388 quads (1286 billion kWh) of electricity were used in the sector for the year, with 38.6M BTU (11320 kWh) /household consumed. But an even bigger source of fuel than electricity was natural gas at 4.694 quads. Space heating was the dominant use of natural gas (63%) while electricity was more evenly spread across a number of uses including space heating, water heating, air-conditioning, refrigeration, cooking, clothes washing and drying, dishwashers, electronic appliances, and lighting. Targeting electricity usage alone in the residential sector would address 5% of the total energy consumed nationally. Since its uses are diverse, however, multiple behaviors may have to change to make a difference (not, for instance, simply turning up or down a thermostat).

Looking at the economic factors, total residential energy expenditures come to $230B annually, $2024/household/year, or $1.03/ft2/yr. [2]. Energy management in the residential sector has often focused on electricity usage with applications offered through electricity providers. OPower, considered a highly successful program to reduce electricity consumption in residences, includes comparisons to neighbors in their reporting. They reported saving an average of 2.8% in electricity usage [8], or an average of $.03 a kWh [19] in electricity costs. However, given that the price of electricity in the US averages around $.10 per kWh [6], the savings in dollars for the end consumer is not all that significant. Even an optimistic projection of total energy savings (20%) in utility bills on average would result in a savings of $265/year for all primary energy, or $190/year for only electrical loads. Given that the installed cost of many available Home Energy Management Systems (HEMS) systems can range from a few hundred to over a thousand dollars, the economics of this situation are daunting when left up to individual households. It has been found in studies of demand-response programs that cost savings is often not a sufficient motivator at any rate; improving the environment and averting risk of blackouts may be equally important [11]. In fact, a debate has been raging in the literature regarding whether consumers act rationally or not when it comes to energy consumption behaviors [21].

In sum, reducing energy consumption in the residential sector is a complex enterprise where economics and leverage offer particular challenges. Government and utility policy will likely be the determining factor to achieve wide deployment, necessary for success. Focusing only on electricity usage alone narrows the area of opportunity further. At best, such a target addresses only 5% of total energy consumed in the US.

2.2 Commercial

The picture for commercial buildings that emerges is quite different from residential even though the total energy consumption is within striking distance—in 2012, 10.6 quads for residential; 8.3 for commercial. In 2003, the most recent year for which the Commercial Buildings Energy Consumption Survey (CPECS) is available [1], there were 4.859 million buildings, including malls, included in the survey consuming 6.5 quads. An average building thus consumed 1.3 billion BTUs. Compared to an average residence, an average commercial building consumed 15X the energy, as shown in Table 1. Considering that there can be one individual responsible for energy management for an entire building (or even sometimes a campus or a set of commonly owned buildings), there is a striking difference in the potential of a single decision maker to affect energy savings. Of course this depends on whether there are steps than can effectively be taken at a building or campus level.

The energy cost per square foot of commercial buildings is almost a third again as much as residential ($1.51/ft2 commercial vs. 1.03/ft2 residential). Further, the annual energy costs on average per commercial establishment are $22,200 compared to $2024 for residential. 20% savings on energy bills would yield $4440 in annual savings on average, although these savings would be magnified with larger buildings or campuses. These potential dollar savings for commercial buildings are likely to be significant enough to get the attention of building managers and owners, and it can be safely assumed that rational decision making would be driving these behaviors.

Building Energy Management Systems (BEMS) are a growing business in the US and elsewhere. They typically employ multiple types of data analytics: predictive, decision, and visual, requiring a human in the loop. The objective of a BEMS is to actively and constantly re-adjust the operation of a building's systems in order to maintain the comfort of occupants while simultaneously minimizing energy expenditure. A BEMS would typically control heating, ventilation, and air conditioning (HVAC) systems, but might also have access to other equipment such as motorized shades, variable transparency windows, or lighting. An informal sampling of BEMS vendors suggests that most are advertising payback periods of 1-2 years.

Installation costs for BEMS are non-trivial. An active BEMS includes multiple sensors, a computational platform, and remotely controlled actuators. However, a factor working in favor of BEMS costs is that BEMS can easily be deployed as a remote service, leading to significant economies of scale: a single human operator can serve as the building energy manager for many commercial buildings. In contrast, deploying home energy management as a remote service is problematic from an occupant privacy point of view.

The impact of energy-inefficient and faulty operation is another factor that is magnified in commercial buildings and campuses. Commercial buildings often have a diversity of types and sizes of HVAC equipment, which often interact in unforeseen and problematic ways. In addition, scheduling maintenance is often quite challenging, and dashboards that provide information about energy performance can be very helpful in these applications. As an example, a fault detection and diagnostic method was implemented on a number of buildings on a corporate campus in Washington state to classify and rank the importance of the tens of thousands of alarms coming from the HVAC systems installed in the buildings [5]. As a result of these analytics, a number of faults were identified which, when repaired, were estimated to save thousands of dollars (the largest of which, when repaired, resulted in an annual savings of $11,291 by itself). As a result of installing analytics software, it is estimated that this corporate campus was able to reduce the total energy consumption by 6-10%, representing tens of thousands of dollars in reduced energy bills. Examples such as this can provide sufficient justification of the system installation cost.

We have focused here on BEMS, but efforts also exist in providing feedback to human occupants in commercial buildings to change their behavior to increase savings further [4].

2.3 Industrial

On its face, the industrial sector shows even greater leverage for potential energy savings than the other two sectors discussed above. The percentage of total US energy consumption in the industrial sector is greater than the residential and commercial sectors combined, and the number of establishments is far fewer. The US Energy Information Administration estimated that total energy consumption in 2006 by the US industrial sector as just over 21 quads. At the time, they reported 170,166 non-duplicative establishments contributed to this total. An average establishment thus used approximately 123.5 trillion BTUs. As shown in Table 1, the leverage of an individual establishment in the manufacturing sector is 1400 times that of an average residence and 93 times that of an average commercial building.

Factory operators are highly motivated to reduce costs, energy use among them. As pointed out in [12], analyzing electricity consumption in conjunction with product line data can not only save energy costs but also increase the productivity of a product line as a whole. Factory Energy Management Systems (FEMS) have emerged to use readings from dedicated modules for energy measurement within a factory automation network to estimate the specific energy consumption and completion time per production unit, average breakdown rates, etc., detect anomalous cases, and alert an operator or an analyst, so that countermeasures can be taken. Visualization plays a critical role.

Table 1: Comparative Leverage per US Establishment

Sector	*Total energy used (quads)*	*# establishments (M)*	*Energy use per estab. (M BTUs)*	*Leverage factor*
Residential	10.6	113	90	1X
Commercial	6.5	4.9	1326	15X
Industrial	21	.17	123529	1400X

Table 1 shows a summary of the three sectors we have been discussing with data in each row coming from the most recent studies available from the US Energy Information Administration in that sector. Our main point should be clear. By large factors, individual residences have the least leverage to reduce overall energy consumption, followed by buildings in the commercial sector and facilities in the industrial sector. Other economic and social factors compound these differences. Nevertheless, it is quite true that other factors not discussed here may influence the potential for energy savings success. Examples would include current efficiency of energy usage and necessity of energy usage. For instance, factories have no choice but to use power to produce goods but homeowners could potentially go without power for certain periods if they were so motivated.

3. Electric Utilities

Electric utilities consume a large amount of primary energy resources to generate electricity--38 quads in the US in 2012 [7]—most of which uses carbon-based fuel. Obviously, a goal is to increase the use of environmentally friendly energy resources (wind and solar) relative to carbon-based resources. However, energy production from these sources is intermittent, depending on the vagaries of wind and sunlight. Several already difficult planning problems are made significantly more complex by increasing penetration of renewable power sources with intermittent output. Deciding which generators are to be turned on or off (unit commitment) is difficult due to its high combinatorial complexity even when power demand is known with complete certainty. The same is true for economic dispatch, which takes into account the operations to produce energy at the lowest cost subject to operational limits of generation and transmission facilities. In practice, as with most planning problems, human planners take a significant part in determining the final output. Uncertain power availability as a result of intermittent output forces the planner to consider multiple possible scenarios for future power demand. Human planners in the planning loop must be able to see and reason with such uncertain information, a great opportunity for visual analytics methods to contribute towards planning applications.

An even more general problem for electrical power utilities is that of wide-area situational awareness (WASA), that is, determining the general health of an electrical network from collected sensor data. Of particular interest for WASA purposes are the detection of anomalies that might signal an existing or future fault and loss of service. By some estimates, the average electrical utility collects about 80TB of operational data per year, with a trend to increase to 200TB/year when smart meter deployment is completed. Visual analytics are likely to be a key technology for deciding whether identified anomalous situations are associated with an actual fault, or not, in such a big data application.

4. R&D at Mitsubishi Electric

Mitsubishi Electric is developing applications to reduce energy consumption in all the sectors discussed in this paper [12] [14][15], but particularly in the commercial and industrial sectors. Its R&D organizations in Japan have developed advanced distribution management systems tested in an extensive Smart Grid demonstration project including fully functioning electrical distribution networks with a heavy concentration of solar energy generation [14]. They have also developed advanced technologies for office building energy savings [15]. MERL, its North American research laboratory, has developed technology to contribute to these efforts, particularly analytical methods. For example, MERL's algorithms for load-flow analysis have led to lower electrical losses and power generation costs for distribution management systems [13]. MERL has also developed predictive analytics methods for solving the unit commitment problem under uncertainty [17] as well as methods to save energy in buildings by pre-cooling or pre-heating the building thermal mass, using less expensive off-peak energy [17]. In the railway industrial sector, MERL collaborated on optimization methods to allow regenerative braking to increase energy savings by managing and distributing the recovered energy across a network of trains rather than within a single train [16] .

As for research in visual interfaces and visualization for energy savings, MERL has proposed methods for spatial-temporal information visualization applied to building energy management [9] and also collaborated on methods for visual querying and visualization for set-valued event data in electrical grid planning [20]. Figure 1 illustrates the spatial-temporal visualization method we called Wakame in visualizing a complex interaction across adjacent zones in a building caused by faulty equipment. The visualization concept is to use situated radar graphs that extrude upwards over time. Each of the radar graph's dimensions is a normalized sensor measurement, and the extrusions produce shapes that may take advantage of human shape recognition. In this example, periodicity of temperature fluctuations can be immediately recognized and also the spatial spread of the excess daytime temperatures that began in the zone second from bottom right.

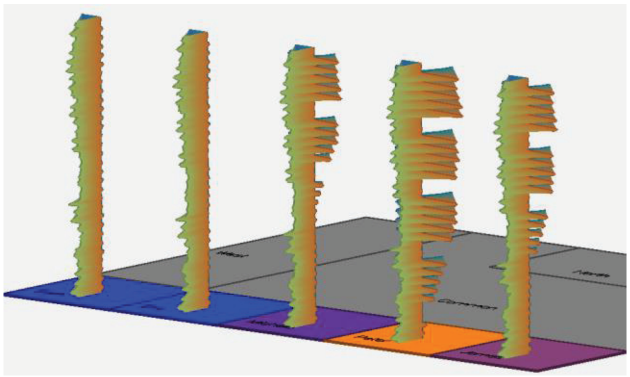

Figure 1: Visualization of cascading effects of an HVAC fault

5. CONCLUSION

Given the apparent skew of interest in the HCI and visualization research towards residential electricity savings, we have analyzed energy usage across three sectors in the US—residential, commercial, and industrial—in order to examine the question of where research in advanced visual interfaces and visual analytics might look for maximum effect. Looking at the factor of leverage (the amount of energy that an average establishment in each of these sectors consumes), we concluded that the residential sector was the most challenging target to reduce greenhouse gas emissions, followed by the commercial and industrial sectors. We also examined economic incentives and sociological factors that reinforced those conclusions. We then gave examples of research and development at Mitsubishi Electric and MERL that is addressing energy savings in the commercial and industrial sectors, including operations of electrical utilities. We hope to have at least raised questions that researchers might consider when searching for energy-savings application targets for their visualization and HCI research.

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