Title
The U.S. on 10-15 kWh/day

Author
Coleman, Philip

Publication Date
2016-10-19

The U.S. on 10-15 kWh/day

Philip Coleman, Lawrence Berkeley National Laboratory, Swarthmore, PA
Yaw Agyeman, Lawrence Berkeley National Laboratory, Berkeley, CA

ABSTRACT

How much energy savings are possible from behavior change alone, absent significant retrofit investments? A testing of this question motivated this residential case study, with over a decade's worth of data. The test residence was the lead author's roughly 2,500 sf vintage 1980 house in southeastern Pennsylvania, which doubles as his office. During periods of single occupancy, energy usage averaged about 8 kWh and 2 ccf of gas per day, saving roughly $2,000 per year relative to typical residences of similar type and size. With fuller occupancy, the figures were 14 kWh and 2 ccf. This was achieved with old, low-efficiency HVAC equipment (12 SEER central air conditioner and 78% AFUE furnace) and minimal to non-existent comfort sacrifices.

How could consumption be this low? Behavior change was the key driver – specifically, aggressive use of the set-back thermostat, very conscientious deployment of windows, shades, a whole-house fan, etc., coupled with conventional low-cost energy conservation measures, such as CFL and LED lighting.

Is this model widely replicable? It may be, but it would require training of household members and may not be readily amenable to third-party profiteering. Could utility house call programs integrate behavioral training for residents, using tested behavioral change theories as part of conventional energy audits? In the age of climate change, deep savings are being sought from existing homes, but it may not be realistic to achieve them cost-effectively without considerable resident cooperation.

Introduction

As the impacts of climate change bear down increasingly on the planet, the urgency to counter it has escalated and will continue to. This will manifest itself in any number of ways, some unknown, but obvious effects in the energy management world are an increasing emphasis on energy conservation and renewable energy. Examples of this over the past decade have been the emergence of zero energy (or "net zero energy") buildings and, relatedly, passive houses (Passivhaus, in its coined German). This concept of designing (or retrofitting) buildings such that they have no or nearly no energy use is intuitively appealing in a world progressively heating due primarily to emissions from fossil fuel combustion, on which most buildings depend heavily.

However, especially with existing buildings, the investments needed to achieve these dramatic reductions are enormous and, almost always, not “cost-effective,” i.e., not financially alluring given any customary discount rates or prevailing costs of money. But short of nearly complete elimination of the carbon footprint of an existing building, there are often cost-effective strategies that can yield deep (at least 40%) savings beyond typical practice. The U.S. General Services Administration (GSA), for instance, has been able to reach this magnitude of savings using energy savings performance contracts (ESPCs) in numerous buildings, with an average of 38% savings achieved across a pilot portfolio of ten projects as part of its continuing “deep energy retrofit” initiative[1]. These projects are inherently cost-effective because federal ESPCs must demonstrate a net savings (i.e., savings must exceed payments) in each year of performance (which usually spans 15-25 years).

However, much of the focus of savings initiatives in existing residential buildings has been focused on the house itself. Houses would not use any energy if the people in them were not employing lighting, space conditioning, appliance use, etc. To draw from the gun lobby’s oft-cited slogan, “Houses don’t use energy, people do.” Consequently, perhaps a greater focus needs to be placed by the energy conservation community on the inhabitants of those houses. This might be especially appropriate where the uptake of expensive retrofit strategies is falling flat – e.g., where owners (especially of high usage homes) are not availing themselves of utility (or other) audit/retrofit initiatives.

This case study is focused on the residence of the lead author, who purchased the roughly 2,400 sq. foot two-story house in 2002 and continues to reside and work there. The house has achieved deep electricity savings – on the order of 70% relative to similar houses, according to Opower. Gas savings have also been fairly substantial. What is most interesting about this instance, though, is that the savings have been achieved with almost nothing in the way of infrastructure investment. CFL and LED lighting is used, the house has some beneficial architectural features (north-south orientation, wide eaves, and disproportionately south-facing glazing), and new appliances purchased are almost all ENERGY STAR®-compliant, but the bulk of the savings appear to be due to behavioral strategies, particularly aggressive control of windows, window shades, and the thermostat (the programmable model that came with the house). The house’s hot air furnace and split system air conditioner are not only roughly twenty years old, but have rated efficiencies (78% AFUE and 12 SEER) that would deem them illegal for current sale in the U.S.

How low is the house’s consumption?

In the five years ending with the March, 2016 utility meter readings, the house’s average daily consumption was 8.61 kWh and 1.71 ccf of gas. This translates to annualized averages of 3,146 kWh and 626 ccf. These numbers are somewhat difficult to interpret in isolation for those not familiar with residential energy consumption norms. Conveniently, Opower recently began partnering with PECO, the house's distribution utility, to benchmark electricity usage against similar homes in the area. The house has ranked either number 1, 2, or 3 out of 100 similar houses (i.e., houses of similar size with gas heating) in the area for each of the nine months of the Opower comparisons, ending in September, 2016. Opower also reports that the house has used 72% less electricity and saved $1,694 in electricity costs over the past year (ending with the August, 2016 meter reading) relative to an average performing house in that cohort (similar size and with gas heat). This is in line with EIA's Residential Energy Consumption Survey[2] (RECS), which reports that the average Pennsylvania home (2240 sq. feet in size, close to the main author's) used about 10,400 kWh annually; Opower's estimated 72% reduction would imply that the average for the house's cohort is roughly 11,300 kWh.

The house's gas consumption is more difficult to benchmark. However, the American Gas Association publishes annual average gas consumption for houses by state in most years[3]. For the years AGA covers that were also part of the subject house's data set, gas usage was 15% lower during multiple occupancy years (2008-2010) and 21% lower during the single occupancy years covered (2012-2014). While not as dramatic as the electric savings, the figures probably somewhat understate the normalized savings somewhat, given that the house is slightly bigger than the average Pennyslvanian one (by 5-7%, depending on which of two measurements is used).

Can the low consumption be explained away?

How can we explain the house's low consumption? Is it technology? The owner has long employed compact fluorescent lamps (CFLs), and more recently light-emitting diodes (LEDs) in most of the house's light fixtures. And new appliances (dishwasher, refrigerator, clothes washer, and dehumidifier) and office equipment are all ENERGY STAR-labeled models; a recently purchased 40-gallon tank style gas water heater, with an energy factor of 0.62, is not (the ENERGY STAR threshold is 0.67), but is somewhat more efficient than required by U.S. appliance standards. However, the house's main energy-using equipment, a roughly 110,000 Btu/h input hot air furnace and 42,000 Btu/h (3.5 ton) central air conditioner, are both 20 years old and of low efficiency – the furnace's 78% AFUE (annual fuel utilization efficiency) and central air conditioner's 12 SEER (seasonal energy efficiency rating) both fall below what is legal for sale in the U.S. now. According to the EIA's RECS, these two uses account for over half of site energy use in Pennsylvania houses. With appliances, electronics, and lighting comprising not even a third of Pennsylvania homes' total energy consumption (per RECS), it is difficult to posit that the efficiency of this equipment in the house explains much of its low consumption.

The house's envelope and ducts might be another consideration regarding its overall efficiency. The insulation levels are unknown but not extraordinary, in line with 1980 residential construction in the northeast; accordingly, the author (a former home energy auditor) considers the house to be relatively "thermally light," in line with wood houses of its vintage. The house was deemed to have about average tightness from a March, 2012 energy audit's blower door test. Following this, $550 worth of air sealing was conducted (in September, 2012). However, no significant drop in either gas or electric consumption is evident beyond that point. The house's ductwork may be unusually tight, given that it was re-designed somewhat in 2003, shortly after purchase, in order to address a comfort problem in a couple of the house's upstairs bedrooms. As part of this work, the seams of the upgraded portions were sealed with silver (aka "metallic") tape. Following this work, in 2004, the owner spent $1,100 to have the ducts sealed with a blow-in aerosol technology that purported to achieve a 41% reduction in their leakage.

Another potential explanation of the low usage relates to the nearly single occupancy (a second occupant has been present for roughly one of the past five years, in total). This is a compelling argument, especially regarding non-space conditioning usage, which tends to correlate with occupancy. Indeed, consumption was higher (by 68% for electricity and 15% for gas) in the five years preceding the single occupancy (2006-2011), when there were generally three to five residents in the house. But the electric usage over those years, which varied little and averaged 5,300 kWh per year, still lies roughly 50% beneath the expected figures, per RECS and Opower. And the gas consumption's 15% exceedance was minimal, and still fell 15% below AGA's average figures for Pennyslvania residences.

One additional note regarding occupancy is that, at the same time single occupancy commenced in 2011, the owner also moved his office from a remote location into the house. This meant that, among other things, space conditioning during weekday days was not able to be set back using the thermostat, as it had often been before. In other words, in one sense, occupancy (in terms of hours with at least one resident at home) may have actually *increased* starting in 2011.

Another hypothesis is that the owner enforces a "shiver in the dark" set of conditions in the house. Instead of making a qualitative argument regarding this, it is probably most useful to relay a set of facts regarding the conditions maintained in the house.

- The house is, on average, heated to 63° F in the winter – the default setting in the mornings is 62° F, but in the evenings the owner often overrides the thermostat from 63 to 64° F. The nighttime and unoccupied setback temperature ranges from 55-57° F.
- The house is cooled down to 77° F in the summer, with higher temperatures tolerated during "dry heat" conditions (i.e., with dew points below roughly 60° F).
- Lighting is generally turned off when not in use, albeit with a few conspicuous exceptions: the outdoor front steps are illuminated by exterior lights at night whenever anyone is home and awake; an "anchor" light just adjacent to the home's entrance hall is left on 24/7; and an upstairs lamp and a bank of two recessed can fixtures in the kitchen are often left on in the evenings when the house is occupied.

The owner lives comfortably and does not believe these conditions are tantamount to "shivering in the dark." His girlfriend, ex-wife, occasional tenants, and stepchildren have all largely concurred, but readers can draw their own conclusions as to whether these conditions constitute draconian circumstances.

Behavior as the key driver

So if technology and occupancy provide only partial explanations for the house's low usage, what is left? We argue that behavioral factors – specifically, aggressive energy management by the owner – are primarily responsible. In addition, a few architectural features of the house (e.g., orientation, design of the eaves, and the presence of a whole-house fan), have assisted the cause and may have deemed some of the behavioral strategies more fruitful in saving energy than they would be in most houses.

There are any number of energy-saving strategies employed in the house, from the obvious (setting back the thermostat at night) to the obscure (selectively making ice on cooler nights and avoiding warmer days). However, the great majority of them can be distilled into three categories:

- Shutdown policy: Everything from the heating and cooling equipment to the set top boxes that control the televisions are kept off whenever not expressly needed.
- Steadfast use of passive heating and cooling: The owner is very aggressive in employing windows, screened doors, and shades to alternately take advantage of, and repel, ambient outdoor conditions.
- Persistent mindfulness regarding the second law of thermodynamics. From a thermal standpoint, this translates to a constant recognition that minimizing temperature disparities (e.g., from outdoors to indoors or from the ambient basement and house temperature to that of the water heater) will also minimize energy usage. For instance, the water heater is set at the lowest temperature that will reliably accommodate the desire for the person with the hottest shower preference.

Heating, ventilating, and air conditioning (HVAC)

One of the key strategies for minimizing HVAC usage is the maintenance of a wide "dead zone" (the range between heating and cooling temperatures in which no active space conditioning is employed). As mentioned above, this is generally 63° F - 77° F. However, perhaps equally important is the owner's adamancy against letting the equipment run when the house is unoccupied. Consistent with the second law of thermodynamics principle that a temperature difference between adjacent spaces (in this case, ones with an imperfectly sealed and not highly insulated boundary) will not persist, he makes sure that heating and cooling are almost exclusively delivered during occupied periods (an exception is in very hot summer conditions, when the house's air conditioning occasionally runs in order to keep the house cooled to 81° F, primarily for the sake of the four house pets that reside there).

A third important strategy for minimizing HVAC operation is aggressive use of the reflective double cell shades that were installed (primarily as an aesthetic improvement, though the double-cell upgrade was driven by energy-efficiency concerns) in 2005. These are routinely lowered at night whenever the outdoor temperature is expected to fall below about 50° F, or whenever direct sunlight is shining in and the indoor temperature is expected to exceed roughly 75° F during the day. During heating season, most of the shades are not raised in the morning until direct sunlight is coming through (or the outdoor temperature warms up sufficiently). A key architectural design benefit of the house is that its preponderance of southern windows is well shaded by the wide eaves in the summer, but not in the winter, when the low sun penetrates the house's glazed southern exposure intensely (N.B.: the house's latitude is almost exactly 40° north).

Lastly, beyond optimizing radiative and conductive gains and losses, the owner also takes advantage of the ambient outdoor air for convective heating and cooling, whenever possible. This just takes the form of opening windows and screen doors whenever the outdoor air is thermally preferable to the indoor conditions. On summer nights and early mornings when conditions permit, this approach is fortified with the use of the home's whole-house fan.

Lighting

Lighting energy conservation comes primarily from an assiduous, though mostly habitual, turning off of almost all lights that are not in use. The exception to this, as aforementioned, are a few efficient lights that are sometimes left on in the evenings and early mornings as "anchors" to provide illumination in the house's ground and top floor. The other key to minimizing lighting energy comes from the almost exclusive use of CFL and LED (as opposed to incandescent) lighting in the house.

Appliances, electronics, and office equipment

When new appliances, electronics, or office equipment are obtained, they are almost always ENERGY STAR-labeled, and beyond that, generally models with low-energy configurations (e.g., the clothes dryer and oven/stove are gas-powered, the printer an inkjet). In addition, though, each machine is operated so as to minimize its energy use – the dish and clothes washers are always run with full loads and on low-energy settings, for example – and in some cases to help improve the house's thermal condition. For instance, in the summer, the dishwasher is run almost exclusively at night and when the windows are open to allow the dissipation of its waste heat.

Electricity use from electronics and office equipment is minimized by consistently turning them off, or at least having them go into sleep mode, when not in use. Power strips allow the two televisions and associated set top boxes to completely power down (which necessitates a roughly two-minute wait when they are turned back on). Except for the owner’s main work computer and a Dust Buster™, almost nothing in the house draws “vampire” energy. However, the owner tends to be less scrupulous about this during heating season, when the waste heat is at least contributing, rather than detracting from, a desired thermal condition.

Cooking

Cooking behavior is highly seasonal in the house. The gas oven is very rarely used during the summer and even the stove and electric toaster oven are employed sparingly; the relevant motto is “don’t pay twice,” i.e., avoid introducing heat with a kitchen appliance that then must be purged by the air conditioner. Cold or room temperature meals are disproportionately eaten in the summer. The owner tends to “batch-cook” and then re-heat meals using the microwave oven. Particularly in the summer, the oven, stove top, and toaster oven are turned off in advance of the food’s being finished and residual heat is relied upon to finish cooking.

In the winter, some of the strategy reverses: the oven and stove are used frequently, and much more hot food is consumed. When a pot of water is boiled for pasta or vegetables, the water is drained into a mixing bowl and left on the counter to help heat and humidify the house. Batch-cooked and leftover food are left on the counter or window sill to come to room temperature before refrigeration, adding to the house’s comfort while reducing the refrigerator’s electric-driven workload.

Conclusion

It is tempting to refer to the house as “efficient.” Its consumption, particularly of electricity, is unusually low. But the primary energy-using equipment (the furnace and air conditioner) in the house is decidedly inefficient. Consequently, some inside and outside the energy conservation community have posited (informally) that low occupancy or extreme thermal conditions explain the low usage. But the house, though more consumptive with higher occupancy, still used dramatically less energy – by roughly 50% electricity and 15% gas. And the thermal conditions maintained in the home, while not ideal for some, are hardly draconian.

Though it is virtually impossible to tease apart the contributions to the house’s energy performance, the only compelling explanation for most of the savings is the owner’s behavior (in combination with some basic, inexpensive conservation technology, such as the programmable thermostat, the double-cell shades, and efficient light bulbs). If this is true, as it appears – i.e., if the home’s deep energy savings are not technologically, but rather behaviorally driven – is it realistic to think that this set of behaviors could be transferred, for instance as part of utility companies’ energy conservation offerings? Are the principles too esoteric? Note that although the owner is an energy conservation professional, he has no academic background in physics or engineering. Minimizing the use of energy-consuming equipment use, maximizing passive heating and cooling, and being mindful of the principle that energy losses are higher where temperature disparities are greater do not seem like unduly unintuitive, hard-to-grasp concepts. All of these would seem to be amenable to being readily packaged into a short (5-10 hour, perhaps) course for willing homeowners. And while resident motivation may be questionable, the owner's estimated $2,000-2,500 in un-taxed annual utility savings (including water) would seem to provide significant incentive even beyond anything additional a program sponsor might offer.

The promise of technology has its limits, of course. Yet in the U.S. energy conservation world, savings initiatives, particularly those offered by utilities to homeowners, rely disproportionately on the replacement of lower-efficiency equipment with more efficient models. But if deep savings are the goal – and in a climate-changed world there is little question that it needs to be – behavioral approaches may be critical to substantial reductions. This is especially true given the costs involved in trying to achieve deep savings from solely technological/retrofit approaches.

1

Endnotes

Shonder, John. 2014. *Energy saving from the U.S. General Service Administration's National Deep Energy Retrofit program*. Oak Ridge National Lab report # ORNL/TM-2014/40.

2 Energy Information Administration (EIA). 2009. *Residential Energy Consumption Survey* (RECS). Washington, DC: U.S. Department of Energy.

3 American Gas Association. 2015. *Gas Facts, A Statistical Record of the Gas Industry (Based on 2014 Data)*. AGA F1012015.
https://www.aga.org/sites/default/files/table6-14.pdf