Potential Problem to Maximizing Energy Efficiency Savings in Arizona

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1. Introduction

Across nearly all of Arizona in the summer months it can be above 100 degrees Fahrenheit *outside* and a "comfortable" 70-85 *inside*. Air-conditioning is a wonderful thing. ICF International (2007) report that a large percentage of customers in Arizona Public Service's (APS) service territory have night-time summer thermostat settings in the "low country"[1] of approximately 74-81 degrees Fahrenheit. The largest percentage (approximately 20 percent) reporting they set their thermostat at 78-79 degrees Fahrenheit.[2] During the day customers tend to set their thermostat a little higher, especially if they are not home, with a greater percentage reporting settings of approximately 78-83.[3] [4]

Because the majority of Arizona residents live in locations that can be characterized as a desert climate it should come as no surprise that the major component of residential electricity usage is tied to air-conditioner usage.[5] ICF international (2007) estimated that for APS's service territory approximately 35.5 percent of all residential energy usage was due to central air conditioning.[6] Central air conditioning usage is nearly triple the next highest single cause of usage which was heating at 10.5 percent.[7] [8] [9]

For commercial and industrial consumers, the highest single component of usage was estimated to be interior lighting which accounted for 30 percent of all usage, whilst cooling accounts for 22 percent and ventilation accounts for 12 percent.[10]

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[1] Basically the hotter regions of Arizona.
[2] ICF International (2007) Table 3-7.
[3] ICF International (2007) Table 3-6.
[4] This result may be driven by some customers on Time-of-Use (TOU) plans, which encourages people to alter their behavior by charging different prices at different times of the day.
[5] Air-conditioner usage ranks high for commercial and industrial customers.
[6] ICF International (2007) Table 5-3.
[7] We say single cause because "other" which accounts for 14.3 percent includes *"all "not elsewhere classified" consumption, including items such as plug load and computer equipment, etc"*.
[8] Heating is relatively high because APS service territory includes some "high country" which is areas of the state that is not desert climate.
[9] Informal discussions with representatives with other utility companies in Arizona also suggest that usage is tied to air-conditioning.
[10] ICF International (2007) Figure 5-5

Thus, a lot of electricity is currently being used to ensure that homes and places of business remain cool - especially when occupied.

Recently the Arizona Corporation Commission (ACC) introduced an energy efficiency standard for all regulated electricity providers that requires a cumulative annual energy savings of at least 22 percent[11] by 2020.

Thus it appears likely that one area that could reap some potential efficiency gains is air-conditioning usage. Typically, there are two general energy efficiency measures that can be utilized to reduce air-conditioning usage. First, more efficient air-conditioning (AC) units could be installed, such that it takes less electricity to cool a given floor space to a particular temperature.[12]

Secondly, "weatherization" program can be implemented. Weatherization may include, improved roof and wall insulation, repairing of any leaking air-ducts, sealing of doors and window frames and screens on windows. Weatherization assists with ensuring that it takes less air-conditioning to cool a given space to a particular temperature due to a reduction in cool-air leakages as well as a reduction in hot-air injections into a particular space. Simply put, weatherization assists with reducing (increasing) how hot (cold) a home or place of work would get for a given amount of air-conditioning output – and thus less AC output is needed to maintain a given temperature.[13]

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[11] of 2019 retail sales.

[12] The efficiency of air-conditioning units are described by their (Seasonal Energy Efficiency Rating) SEER rating. The higher the SEER rating the more efficient the air-conditioning unit (See the Department of Energy (DOE) for more details).

[13] For instance it is expected that if the air-conditioner was switched off (or the thermostat is increased significantly) it would take a lot longer for a "weatherized" home to achieve a particular increase in ambient temperature than a non-weatherized home – in some cases the weatherized home may never reach certain ambient temperatures. All of which would assist with reducing the amount of air-condition, and as a result electricity usage, needed within a home/business.

However, even after more efficient AC units are installed and/or homes and businesses are weatherized then the final energy savings may not be as high as hypothesized. The reason being what is known in economics as the rebound effect.

Section 2 defines and discusses the rebound effect and explains how this phenomenon may limit the ability of Arizona to actually realize sufficient electricity savings. Section 3 provides some thoughts on how the rebound effect may impact the areas targeted under energy efficiency programs as well discusses how other potential areas for energy efficiency gains. Section 4 provides conclusions.

2. The Rebound Effect

Jevons (1866) was the first to postulate that an increase in technical efficiency of a product or process may in fact cause an increase (rather than a decrease) in the amount of the resource consumed.[14]

Jevons cites evidence that when the technical efficiency of coal-fired steam engines increased, so that less coal was needed to produce a given amount of output/power, in fact the aggregate amount of coal consumed in the United Kingdom actually increased rather than decreasing as potentially expected.

The reason being that more technologically advanced steam engine become extremely popular not only in the transportation sector, more coal-fired steam trains, but in a gamut of other industries. Also an improvement in technological efficiency may increase the productivity of the economy and thus economic growth occurs which also may cause more natural resources such as coal to be consumed.

[14] To a degree, the outcome with respect to coal consumption is an extreme case of the rebound or "take-back" effect. However this effect is often discussed when looking at improving the fuel efficiency of cars. Once the efficiency of cars increases there is a potential incentive (lower cost per mile) to drive more miles. Therefore the full hypothesized fuel savings are not actually realized.

Recently within the literature there has been a return to re-defining and empirically estimating the rebound effect for energy services.[15] Generally speaking, there are three main potential components to the rebound effect:[16]

Direct rebound effects: An improvement in energy efficiency, via technological advancement, for a particular device (AC units) that requires electricity as an input will decrease the *marginal* price[17] [18] of using the device. Thus, due to the law of demand, this reduction in price could potentially lead to an *increase* in consumption/usage of that device.

As a result this potential increase in overall consumption may offset some, if not all,[19] of the hypothesized reduction in electricity consumption provided by the original energy efficiency improvement. Such that the actual realized savings may be lower than the expected savings.

Indirect effects: The lower marginal price of the usage of a particular device may potentially lead to overall changes (increases) in the demand for other goods, services as well as factors of production that also require electricity for their provision.

For example, some of the potential cost savings obtained from a more efficient AC unit may be allocated to consumption goods elsewhere in the economy.[20]

Economy-wide effects: A fall in the real price of electricity (thus we are looking more at a technological advancement that occurs at the source of electricity generation rather than within an electricity consuming device) may reduce the price of intermediate and final goods and services throughout the economy. This in turn may lead to a gamut of price and quantity

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[15] See Khazzoom (1980), Greening et al., (2000), Sorrell & Dimitropoulos (2007) Sorrell et al. (2009) for a good review of the literature. Some of these results are briefly discussed later.
[16] The focus below is generally on electricity usage for a particular device. But can be generalized to other energy sources.
[17] We are using marginal price rather than marginal cost to distinguish that the impact measured is at the consumer level rather than the producer level.
[18] The technological advancement may cause the up-front (fixed) costs to increase or decrease.
[19] And Jevons suggested that more than 100 percent of any potential savings may be offset.
[20] The actual amount of savings that are "generated" are of course a function of the size of the direct effect.

adjustments occurring throughout the economy such that relatively energy-intensive goods and sectors are most likely to gain at the expense of less energy-intensive ones.

If we focus on Arizona and higher-rated energy efficient AC units for the moment it is clear that an energy efficiency program that attempts to incentivize building owners (residential as well as commercial and industrial) to adopt more efficient AC units are going to potentially face direct and indirect rebound effects.

The largest worry, to some degree is the direct effect, that is after the installation of more efficient AC units the building owners alter their behavior from before the new unit was installed and instead decide (due to the marginal price being lower) to simply have a thermostat setting *below* what it was set before the energy-efficiency intervention.

In economics terms, the question that remains is, "are current building owners satiated in terms of their thermostat settings?" That is too say, what percentage of current building owners have their thermostat set at the *lowest* setting (coolest) that the owner would desire.

Whilst ICF international (2007) reports the thermostat setting that residents actually set their AC units at,[21] this does not necessarily imply that the setting they choose/report is the lowest the resident would desire.

Of course, at first glance, one could argue that if the building owner has not set their AC to the lowest setting that they would desire then the owner is acting irrational and should change his/her behavior.

However, that type of thinking would be false. The reason is due to another major economic concept known as opportunity cost. Every time an individual turns their thermostat down one degree Fahrenheit it will generally mean that the AC unit will be running more often, thus more electricity is consumed which in turn will mean a higher electricity bill. In paying the higher

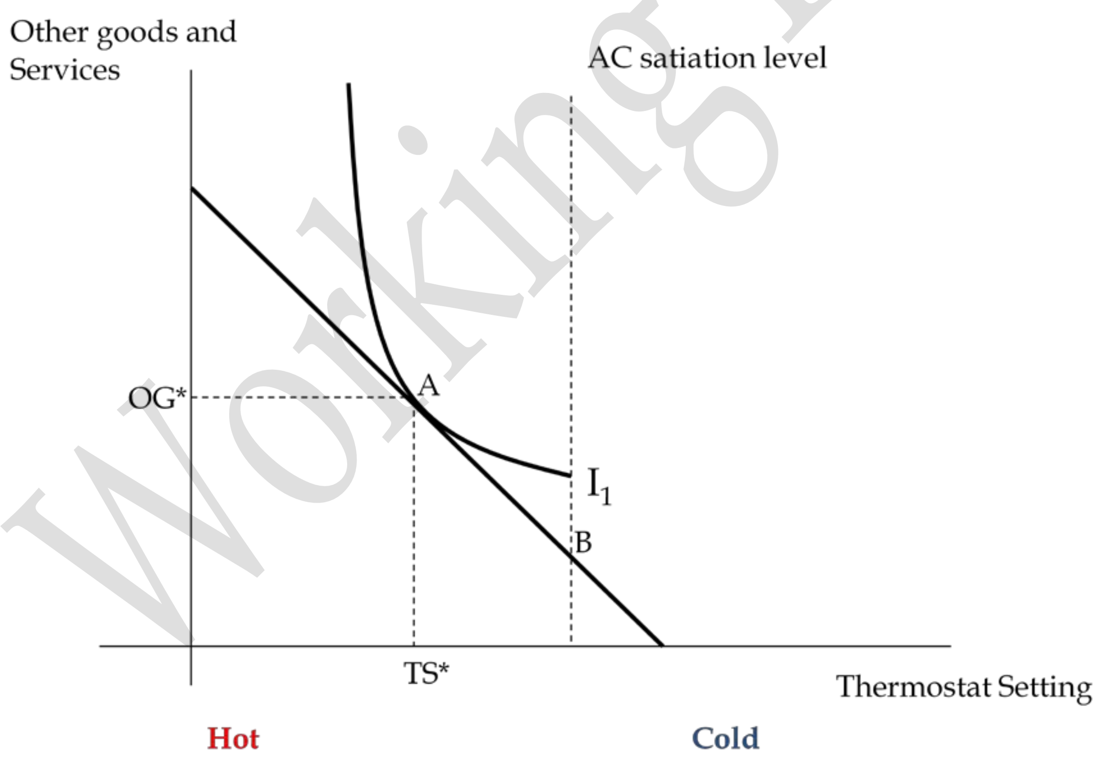
[21] See Section 1.

electricity bill this would leave the building owner with less available income to spend on other goods and services.

Thus, the opportunity cost of having the AC unit at a lower thermostat setting is the goods and services that the individual could have otherwise purchased with the income that now must be allocated to paying for the increased electricity bill.

Therefore it is entirely possible that building owners when allocating out their expenditures decide to trade-off between AC thermostat settings and the consumption of other goods and services such that in equilibrium the individual chooses an AC thermostat setting that is not at their AC satiation point. See Figure one for an illustration.[22]

Figure One: Individual in Equilibrium



[22] We are assuming some familiarity with indifference curve analysis.

In figure one (focusing on static results)[23] [24] the individual gets to allocate their income in two ways, either lowering their thermostat setting to a cooler setting and/or spend their income on other goods and services. Given the individual's preferences, denoted by I_1, the individual's optimal choice is point A. Such that they consume OG* units of other services and TS* is their thermostat setting.

By design we have assumed an AC satiation level that is to the *right* of A.[25] Such that if the individual chose to set their thermostat at their most preferred temperature, the individual would be at point B on their budget constraint.[26] It clear that being at point B would mean that the individual is on a lower indifference curve than the individual curve at point A. Thus B gives an overall lower level of satisfaction than point A.

Therefore, if a significant percentage of building owners have their AC thermostat setting at a higher level than their satiation level then the direct rebound impact may be relatively significant. That is to say that when newer, more efficient, AC units are installed building owners react by lowering their thermostat setting – thus offsetting some of the predicted energy savings.[27] [28] See Figure two for an illustration.

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[23] If we looked at the problem throughout the year it may be true that for some months (cooler months) individuals can easily obtain their most preferred AC setting. Also if included varying weather impacts the budget constraint may shift for a given weather condition (July versus December in Phoenix etc).

[24] Also as a simplifying reason we have assumed that the marginal cost of lowering the temperature remains constant. That is to say that the additional cost of lowering the temperature from 100 to 99 is the same as it is when going from 70-69. If there were increasing marginal costs of lowering the temperature the budget line would get steeper as you move down it. This could further enforce the outcome we are illustrating.

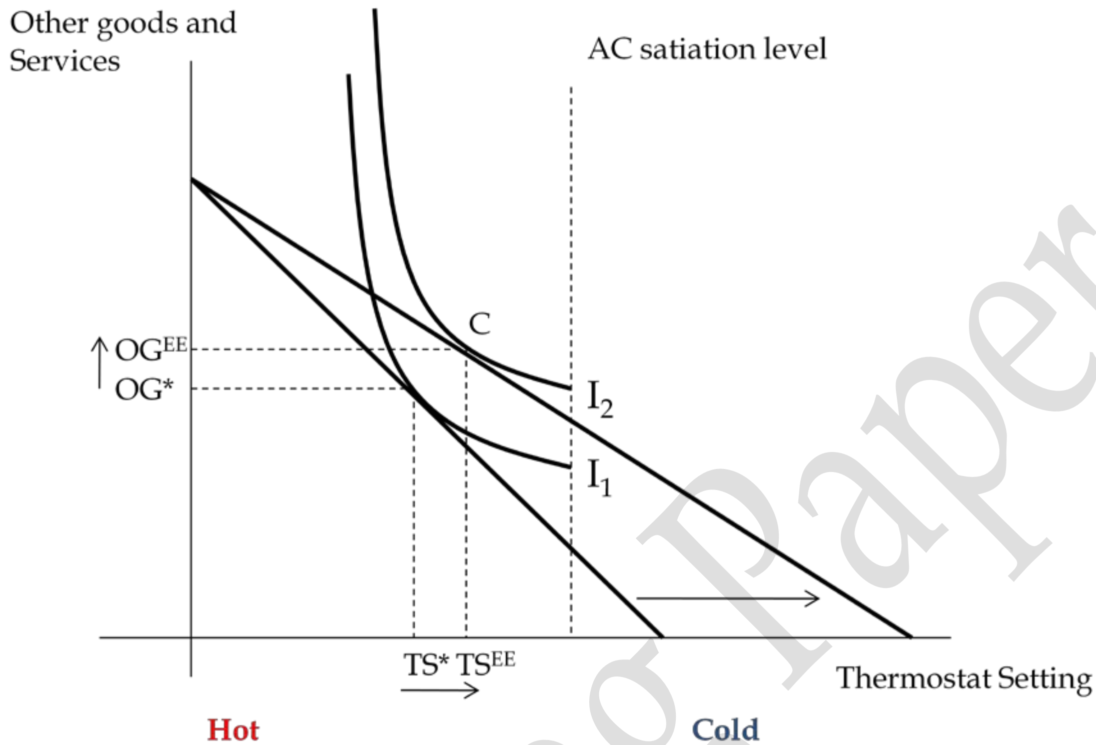
[25] If it was to the left of "A" then the individual would not be maximizing their satisfaction. Because they would be spending money, which they could otherwise be spending on other goods and services, on lowering their thermostat to a temperature below the most preferred level which at a minimum would be adding no additional satisfaction (it could well be lowering satisfaction).

[26] Note, we have assumed that the individual has the income to choose to set their AC at their satiation point if they wanted too. It is entirely possible that the satiation point lies to the right of the budget constraint.

[27] Importantly the size of the reaction may vary across different population characteristics – for instance income, home type, attitudes to the environment, and age/efficiency of original AC unit.

[28] Many predictions on energy savings are based upon comparing AC units via technology standards and computing the savings for a *given amount* of AC output.

Figure Two: Individual in Equilibrium after More Efficient AC unit is installed



The impact that a more efficient AC unit would have at the individual level would be to cause the budget constraint to pivot outwards. That is to say that the cost of lowering the thermostat setting would fall due to a more efficient AC unit.[29] [30]

To understand this outcome is relatively simple. The (absolute) slope of the budget constraint is (P_t / P_o) where P_t can be defined as the price paid to reduce building temperature by 1 degree Fahrenheit and P_o is the price of all other goods and services.

Also, P_t is a function of electricity prices (P_e) and the amount of electricity required to reduce building temperature by 1 degree Fahrenheit (Q_t) – which would be a function of a whole range

[29] We are assuming that the new AC unit requires less electricity to reduce the temperature to a given setting.
[30] Note, we have ignored including the cost to purchase the system to simplify the analysis. Also once installed the AC unit represents, to a degree, a sunk cost and thus that cost should not be considered when making decisions at the margin.

of factors including efficiency of AC unit, size of building, insulation of building – including number of windows, outside ambient temperature etc. Mathematically then:[31]

Thus the installation of a more efficient AC unit[32] would cause Q_t to fall which then would cause P_t to fall *assuming no change in electricity prices.*[33] Therefore the slope of the budget constraint falls and thus pivots outwards.

In the case described in figure two the new optimum is point C. Thus the individual reacts to the lower marginal cost/price of adjusting their thermostat setting by *lowering* their setting from TS^* to TS^{EE} (direct rebound effect). In the example above the individual also consumes more other goods and services, OG^* to OG^{EE} (known as the indirect rebound effect).

The result being that the amount of electricity savings that will actually occur will be less than the amount predicted.[34] The size of the divergence between predicted and actual savings may vary. For instance, in the example described in figure two the individual lowers their temperature setting but they still would use *less* electricity than before the new efficient AC unit was installed.

This is true because some of the "efficiency savings" are spent on other goods and services. Therefore the total amount of income spent on other goods and services increases. Conversely then, the *total expenditure* allocated to cooling must fall as a result (because incomes have not changed) which implies that the *total amount of electricity consumed* must have fallen – because

[31] As noted previously (footnote 24) we are assuming P_t is linear in Q_t . So we are assuming that the amount of electricity needed to reduce the temperature one degree Fahrenheit remains constant. It may be true that Q_t increases as we attempt to lower the temperature below a certain point. That is to say it becomes increasing difficult to lower temperatures. If we assumed this it would cause or budget constraint to become bowed out to the origin.

[32] As well as improved weatherization of the building.

[33] Changes in this assumption are discussed in Croucher, M. (2010) *"Decoupling: The Mechanism to Maximize Energy Efficiency Savings in Arizona?"* For now to justify this assumption we can assume that the actions by the individual do not cause any aggregate changes.

[34] The amount predicted typically assumes that individuals do not change their behavior. Which would mean in figure two that the individual continues to choose TS^* rather than TS^{EE}.

the price of electricity (P_e) has been assumed constant. It is entirely possible that they could use more electricity.[35]

The only case where the individual would not change their temperature setting occurs if the individual was already at their most preferred AC thermostat setting. In this case all gains from the installation of a more efficient AC unit would be converted into consumption of other goods and services. This is effectively the case that is assumed when technical specifications alone are used to predict actual savings.

However, the individual, through their purchase of other goods and services may cause electricity usage to increase elsewhere in the economy. If consumers tend to be purchase state-produced electricity -intensive goods and services then while their home electricity footprint may fall their overall electricity footprint may increase.[36]

Now, of course that is not to say that lowering of the thermostat, and or consuming of more general goods and services, is a bad thing from society's point of view. On the contrary, it is a good thing. Individuals who do lower their AC settings after the installation of a more efficient unit are doing so because it maximizes their overall level of satisfaction. This is illustrated in figure two by I_2 being a higher indifference curve than I_2. In a sense, the new AC unit allows individuals to move closer (obtain) to their AC satiation point or most preferred thermostat setting.

The size an impact of the rebound effect is an empirical question. Below is a discussion on limited empirical findings that look at the rebound effect for space cooling cases (cases where the major motivation is to cool the air) rather than say heating the air (space heating).

[35] The optimal point would have to occur such that in the end the amount of "other goods and services" actually falls.
[36] For example the individual may decide to consume a lot more tanning sessions which are electricity intensive.

Hausman (1979) found that an improvement in efficiency for AC units did indeed lead to an increase in their capacity utilization rate. That is, more efficient units when installed were used more often – however the overall electricity consumption did fall.[37]

Dubin et al (1983) found that the direct rebound effects from energy efficiency measures being introduced in Florida would be approximately 13 percent in non-summer months and only 1-2 percent in summer months.[38]

Using this results as inputs Greening et al. (2000) estimated a total rebound (or take-back) effect of between 0 – 50 percent when space-cooling energy efficiency measures are introduced.[39] [40] This relatively large range is primarily explained by initial capacity utilization rates.

For instance, if an individual is running their current AC unit, 24 hours a day, in the summer months for example, then the introduction of a more efficient AC unit, even if used to lower thermostat settings, will generally lead to less than 24 hours a day usage once installed - thus the majority of energy efficiency savings will be realized. Even if the more efficient unit is ran 24 hours a day, because it is more efficient it will lead to less electricity being consumed.

Sorrell et al. (2009) notes that the majority of the empirical literature generally focuses on examining the rebound effect in the transport sector (do individuals drive more when the fuel efficiency of their vehicle increases?) and on space heating. In fact they only papers they are able to examine are the same ones Greening et al. (2000) examined.

Focusing only on short-run rebound impacts Sorrel estimates that the range for the rebound effect is 1-26 percent, whilst in the long-run it is potentially 26.5 percent.

[37] Within Hausman's dataset (homes all over the United States) the total annual electricity bill attributed to AC units was 11.6 percent. Far lower than the current estimate in Arizona of 35.5 percent.
[38] The results are a mixture of individuals receiving improved roof insulation as we all improved roof insulation and a more efficient AC unit (all free of charge).
[39] The previous papers only focused on the direct impact.
[40] This 50 percent upper bound is the highest rebound number across the different electricity-using scenarios examined by the authors. For instance, space heating (10-30 percent), water heating (<10-40 percent), and lighting (5-12 percent).

The authors also note a couple of important issues. First, the results discussed may not be applicable to other geographical areas, owing to differences in house types and weather conditions. Also the original empirical results are relatively dated.

Secondly, the authors argue that direct rebound effects may well be higher amongst low-income households, as they generally will be further away from their satiation point for cooling. Also, low-income households may have a lower capacity utilization rate for their AC unit than high-come households. That is to say, that because the electricity bill of low income households will represent a greater proportion of their income they will tend to not use their AC as much as potentially high income households.[41]

Costa & Kahn (2010) in a very recent paper found that the introduction of a new heating, ventilation and air-conditioning (HVAC) had an asymmetric impact on electricity usage depending upon weather conditions. The HVAC system alone, controlling for weather conditions,[42] caused electricity usage to decrease by approximately 17.5 percent.[43]

However, the mean temperature during the billing cycle is estimated to have an offsetting effect. Such that, if the mean monthly temperature was below 58.3°F (14.6°C) then the overall impact of the new HVAC system on that month's electricity usage would be negative.

If, for instance, the mean temperature is 75°F (23.9°C) within a given billing cycle a new HVAC is estimated to cause increases electricity purchases to *increase* by 5 percent – this implies that the rebound effect is greater than 100 percent in the hotter months.[44]

The results found by Costa & Kahn (2010) can be explained by adjusting our analysis above. Individuals may be installing new HVAC systems so that they can move closer to their AC satiation point in the summer (hotter) months in a more cost effective manner – the result being that electricity usage increases. As a result, during the winter (colder) months households may

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[41] This in turn re-enforces the concept that lower income households will be further away from their satiation point.
[42] As well as many other factors.
[43] Costa & Kahn (2010) Table: 8.
[44] This is the example provided by the authors themselves.

already have been able to obtain their satiation point with the older system, thus the new HVAC enables reaching the satiation point using less electricity.

Overall there remains a relatively limited amount of empirical evidence within the academic literature that examines the rebound effect for space cooling.[45] Also, none of the papers directly deal with an area such as Arizona which is potentially unique in terms of its overall electricity usage being so closely tied to air-conditioning usage.[46]

3. Rebound Effect and its Impact on Energy Efficiency Programs and Alternatives to Meeting Energy Efficiency Standards

As noted previously, the ACC recently introduced an energy efficiency standard (one of the most aggressive in the United States) for all regulated electricity utilities in Arizona. Section 2 points out that there is potentially a significant barrier to achieving the forecast level of energy efficiency gains (especially on the device – AC units - that tends to drive peak electricity demand in Arizona), namely the rebound effect.

Whilst the focus was on the empirical evidence of the rebound effect associated with space cooling, it was highlighted that the rebound effect is not simply specific to space cooling, but appears present when looking at energy efficiency measures for space heating as well as interior lighting – all be it that the rebound effect for these measures may be smaller.

To potentially minimize the rebound effect associated with more efficient AC units, and thus potentially maximize the total amount of electricity savings, it appears that individuals that are closest to their AC satiation point and/or have a relatively high AC capacity utilization rate should be targeted first.[47] [48] In general, it is conceivable that these characteristics would generally occur in the more affluent households of the Arizona populace.

[45] Especially compared to other energy efficiency measures examined.
[46] The Costa & Kahn (2010) deals with California which is contiguous to Arizona, but still its weather conditions are still significantly different from Arizona weather conditions.
[47] To a degree there is potentially some correlation between characteristics.

Whereas, the greatest gains in terms of *satisfaction* (rather than recorded savings), may reside in targeting lower income residents for energy efficiency improvements.[49] In fact, the ACC requires, as part of the energy efficiency standard, that regulated utilities develop and propose a program that does target low-income households. Whilst this is admirable from an overall societal welfare point of view it may not be the most successful avenue for overall actual savings.

Another potential avenue for successful electricity savings is via changes in building codes. Allowances under the energy efficiency are allowed such that *"an affected utility may count toward meeting the standard up to one third of the energy savings, resulting from energy efficiency building codes, that are quantified and reported through a measurement and evaluation study undertaken by the affected utility"*.[50]

Advanced Energy (2005) looked at the actual energy usage for 7,141 homes in the phoenix metropolitan area. They found that homes that were energy efficient (Energy Star©) consumed 8.22 kilowatt hours per square foot whilst baseline homes consumed 8.36 kilowatt hours per square foot.[51] However, due to energy efficient homes (1,967 square foot) being larger than baseline homes (1,735 square foot) the overall electricity consumption for an energy efficient home(15,831 kWh annually) was *larger* than a baseline home (14,107 kWh annually).[52]

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[48] These are the individuals and/or businesses that are less likely to change their behavior with regards to AC settings, in terms of temperature set and time the unit is running (of course a more efficient unit should in itself cause the amount of time it is required to be run to fall).

[49] One can appeal to marginal analysis and marginal utility to show this may potentially be true.

[50] Arizona Corporation Commission Docket # 00000C-09-0427, Exhibit D.

[51] There most preferred comparison case is to compare energy efficiency homes versus baseline homes that do not have a swimming pool and use gas as the major source of heating. Advanced Energy (2005) Table 11.

[52] The authors note that many of the baseline homes may actually have an energy efficiency level that is comparable with the energy star homes but were not certified. Thus, the very presence of energy efficiency building standards may increase the energy efficiency of new homes that are built but not targeting/receiving certification. This raises another question which is, "should credit under the energy efficiency standard be received for this "spillover" effect?"

This effect could be explained by the idea that for larger homes, to make them desirable from a cooling perspective, the home builders need to make them energy efficient.[53] That is, if they did not make them energy efficient it may be extremely costly for the home-owner to set their thermostat to a minimum level of comfort let alone achieve their optimal thermostat setting.

This result does generate some questions with regards to how to *"measure electricity savings from building codes."* Should per square footage savings of an energy efficient home relative to a baseline home be used to determine the "savings"? Or due to the energy efficient homes being larger the end result is that the building code did not actually induce any savings but in fact caused electricity consumption to increase – and thus no credit can be claimed under the energy efficient standard?

New Building Institute (NBI) (2008) examined 121 Leadership in Energy and Environmental Design (LEED) new construction buildings. Overall, for all 121 LEED buildings examined, the median measured energy use intensity (EUI) was 69 kBtu/sf. This was approximately 24 percent *below* the national average for all commercial buildings.

Looking at a disaggregation by building activity type did not change the overall result of lower energy usage for LEED buildings on average. For instance, focusing just on offices, (the greatest percentage of buildings in the sample) LEED buildings had an EUI on average approximately 33 percent below national averages.

However, when examining actual EUIs versus design (predicted) EUIs it was found that actual EUIs for over half the projects deviated by more than 25 percent from predicted levels. Approximately 30 percent where significantly better than predicted but approximately 25 percent were significantly worse. At the extreme, several buildings use *more* energy than the predicted *baseline* modeling. That is, the LEED building had a higher EUI than a comparable non-LEED baseline building.

[53] Even just looking at baseline homes the authors find that larger baseline homes use less kWhs per square foot. Advanced Energy (2005) Figure 3.

The authors note that variation in overall results is likely to have come from a number of sources, including differences in operational practices and schedules,[54] equipment being used in the building, potential construction changes and other issues not anticipated in the energy modeling process.

Costa & Kahn (2010) examine the impact building codes have had on electricity consumption in California. They find that building codes, which were first introduced in 1978, did assist with reducing electricity consumption – however not instantaneously.

They argue that there is a potential counter-veiling effect such that homes built in the 1970s and early 1980s were energy inefficient because the price of electricity was relatively low during that period. They find that the price of electricity at the time the house was built is *negatively* correlated with current electricity consumption.[55]

Overall, they find that relative to homes built prior to 1960, homes built between 1960 and 1983 consume roughly 5 percent more electricity – thus electricity prices at time of construction appear to have a lasting effect on overall electricity consumption.[56] Whilst homes built in the 1990s consume approximately 15 percent less electricity than homes built in the period 1978 - 1983 period. Finally, relative to homes built pre-1960, individuals living in homes built in 2006 or later consume approximately 16 percent fewer kilowatt hours per year.

Along with the impact of building codes (and indirectly electricity prices at the time of construction) Costa & Kahn examine the impact additional square footage has on electricity consumption. Not surprisingly they find that additions of square footage (so renovations on existing homes) on average increase electricity consumption by approximately 1.4 percent.

[54] Here we could include rebound effects.
[55] This could be explained by the fact that potentially when electricity prices are lower home builders tend to substitute devices that may use natural gas as an input and instead use electricity appliances. Thus later it becomes relatively expensive to switch feasible devices/activities to gas-based.
[56] This effect occurs even after controlling for demographic, structure and ideology variables.

Thus it appears that more stringent building codes, higher electricity prices at the time of construction, smaller homes[57] (they find a square footage elasticity of 0.42 – 0.47) all will assist with *new* Arizona households having relatively lower electricity foot-prints than current households.

Jacobsen & Kotchen (2010) examined the impact that overall more stringent changes in the state-wide energy code in Florida had on electricity consumption for homes build just before and just after the change in energy code in the town Gainesville, Florida. They estimate that the change in building code caused electricity consumption to decrease by 4 percent and natural gas consumption by 6 percent.[58]

Finally they note that approximately 22 percent of all U.S. residences are in the same national climate region as Gainesville (including western Arizona) which implies that there results may be somewhat representative of how energy codes affect more general regions of the county.

4. Conclusion

Creating "negawatts" (reduction in electricity consumption- negative megawatt hours) through energy efficiency measures is potentially a desirable outcome. It can assist with reducing the generation requirements that utilities face – especially if the "negawatts" are created at peak demand periods. With this in mind the Arizona Corporation Commission has introduced one of the most aggressive energy efficiency standards in the country.

When looking at electricity consumption in Arizona the running of AC units is a major component – especially at peak demand times. Unfortunately it appears that improving the efficiency of AC units may not necessarily generate the expected savings due to customers potentially changing their behavior - which is known as the rebound effect.

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[57] ICF International (2007) notes that the average home size in the APS service territory has increased, for homes built pre-1980 the average single story home was 1,884 square feet whilst for homes built after 2000 the average single story home was 2,125 square feet. A similar story is true for multi-story homes.
[58] The authors note that one potential alternative explanation is a shift from natural-gas to electric heating, caused for reasons independent of the code change. Although they argue that this is not consistent with anecdotal evidence about new construction in Florida.

This does not mean that improving underlying (technical) efficiency of homes and devices that consume electricity – and for that matter any resource – is not a desirable goal. Reducing the amount of inputs *per activity* is at the heart of most sustainability stories. It also allows many households to increase the amount of activities they undertaken- which ultimately leads to an increase in welfare.

It appears that to limit the rebound effect,[59] and comply with the energy efficiency standard the more affluent households with Arizona should be targeted first which may be in conflict with which households would see the greatest improvement in welfare from adopting energy efficient measures.

Whilst on the other hand, changes in building codes at the initial point of construction and overall smaller homes being built would potentially greatly assist with reducing energy consumption. Unfortunately the regulated utilities do not have direct control over these mechanisms.[60] Also, under the current standard the utility only receives partial credit for building code-induced efficiencies.

Simply put, focusing merely on reducing quantities of electricity consumption is potentially a very narrow way of thinking about improving the overall quality of life in Arizona.

[59] There are other potential market interventions available to limiting the rebound effect such as taxing away the financial benefits from having a more efficient AC unit, raising electricity prices as well as offering additional financial incentives to individuals who conserve electricity (other than the simple reduction in electricity bill due to using less electricity). All of which is left for future discuss.

[60] They could (and do) offer incentives to builders that build smaller more efficient homes. Or, if allowed, raise electricity prices such that builders are then "encouraged" to build electricity-efficient homes – something that Costa & Kahn (2010) found is potentially successful in preventing per capita increases in electricity consumption.

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