Tucson regional strategies toward a more sustainable home

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Abstract

Individuals approach the implementation of sustainable strategies at home depend on many factors, which include personal values and economic status. Questions concerning the viability of sustainable home building persist, even within the industry. Utilizing current research, observations, and personal interviews with industry experts, this study attempted to define a prescriptive list of sustainability strategies to the average resident of the Tucson region interested in becoming more energy-efficient. A hierarchy of strategies emerged, ranging from low to no cost implementation strategies to high cost remodels. A consensus was reached concerning the importance of thermal envelope integrity as well as the often-overlooked benefit of shading strategies on the east and west side of a home. Limitations of this study include the scope of energy savings in the residential sector versus societal consumption as a whole, notably within the transportation or industrial sectors.

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SBE Capstone

Fall 2019

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FORWARD

How do I save money on my monthly electric bill? That was the question I asked myself in June of 2007 as I was entering the first summer in my first home. It was a modest 1,200 square foot ranch style home built in 1968 with a single carport and large back yard. I had bought this house from my cousin who had owned it for ten years prior. The front 5040 window was half plexiglass, repaired from the original pane's unfortunate meeting with a baseball, and half single pane glass original from 1968. The front door was solid wood but it stuck so bad I had to pull it open with both hands when it was humid out. There was no door seal, and I learned quickly that because of that fact I shared my "new" home with insects and the occasional mouse. The house had several tremendous upsides though, it was brick, had a nice mature Fruitless Mulberry tree in the front yard west of the carport, and the front door faced due north. I was not sure why that was a good thing, I just knew that my Grandma said it was and she was a real estate agent. I paid my first electric bill for that brick house in the middle of June. It was $95 and for only two weeks of service. I was on pace for $200 electric bills and summer had not yet arrived.

I knew that a remodel was in my near future, and was the reason I could afford the house in the first place, but I knew after that first electric bill what the priority would be: seal up this leaky house! My first project was to invest $1,200 and a weekend with my dad to replace every window and door in the house. There were only 7 windows a front door and a rear sliding patio door. We made sure to fit the doors and windows correctly and sealed them well with caulking. Next on my list was ceiling fans and full kitchen and bath remodel. I knew that I did not want that A/C on too much or else the monthly bill would exceed the budget, so I behaved accordingly. I opened windows when I could cool the house and did everything I could to avoid the mechanical system turning on. I ran fans and kept the thermostat at 80°F. I never had a bill exceeding $150. My yearly average was $88 per month.

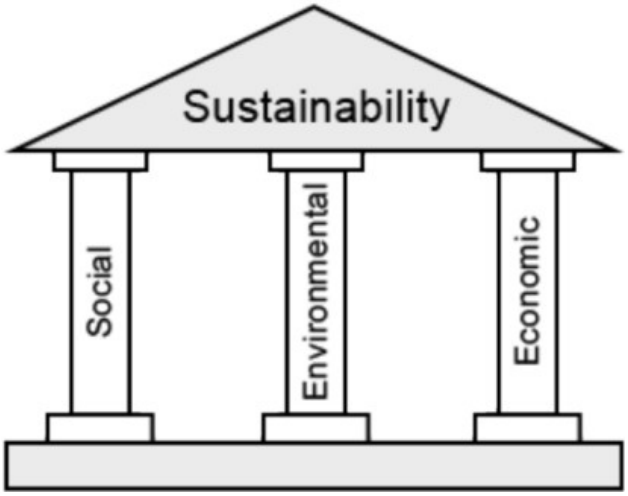
Those lessons began my exploration in to energy efficiency and passive cooling strategies. I was not alone in my efforts to conserve electricity. Conservation benefits the community at large, but I was after personal incentive. I was inspired to study these concepts further when my wife and I began designing our custom home build. A few years later I discovered the University of Arizona's Sustainable Buildings program, and here I am, compiling the lessons I have learned through experience as a homeowner, remodeler and manager of my custom home build.

INTRODUCTION

Sustainability is a buzzword concept that can be heard in many conversations related to anything from energy production to transportation and construction. In the residential sphere, it can manifest as homebuyer's questions about expected utility bills, or about solar panels. Indeed sustainability as a broad topic spans throughout our lives, as we use energy to heat and cool our

places of work and our homes, to light the night, and to move about our daily lives. A broad term like this needs context and definition in the scope of this project. With that in mind, we will look to the three pillars of sustainability to define the concept.

In this simplistic model three general sustainability categories together hold up the overall concept of sustainability. These are social, environmental and economic sustainability. The model can best be thought of as a metaphorical description that a strategy must achieve all three pillars to sustain. For example, running a home air conditioner at 65°F in the middle of summer uses a lot of peak electricity. That electricity is generated primarily by burning coal; a recognized and excepted harm to the environment. That strategy cannot be sustainable. If the home is cooled using passive strategies and only supplement with forced air on the hottest days it is a lesser burden on the environment. Passive cooling strategies are supremely inexpensive(Economic), reduces carbon emissions and resource consumption (Environmental) and everyone can do it (Social); therefore a passive strategy can be considered "sustainable."



***Source**: Researchgate.net*

Southern Arizona has a unique climate and related challenges to solve in our built environment. Tucson and surrounding areas are set in the Arizona Upland biome subdivision of the Sonoran Desert, where temperatures in the summer can soar well over 100°F, and winters can fall below freezing. This climate poses a problem for the built environment that many other

regions do not have. We must build to keep occupied spaces cool in the harsh summer yet warm in the potentially freezing winter. Also, the harsh sun and violent monsoon season in this region wreak havoc on unsheltered structures. There are positives in our region as well. Seasons outside of the Foresummer Drought and Monsoon Seasons, which represent seven months out of the year are mild, with an average high temperature of around 74°F,and fairly easy to adapt to. Average night time lows during the same seven month period are around 49°F, and the annual average low temperature is about 58°F("Climate Tucson - Arizona," n.d.).

According to the U.S. Energy Information Administration, 55 percent of energy usage occurs in the home. With that figure in mind, we must mitigate unnecessary usage for multiple reasons. First, the goals related to renewable energy production are much more attainable with a smaller demand for energy. Next, lower consumption leads to a lesser burden on finite natural resources and minimizes humanity's tread on the planet. Lastly, the individual has a solid economic incentive to conserve in the form of a smaller utility bill. We can see that occupant comfort is a major driver for home energy use accounting for 32 percent of energy consumption for space heating and air conditioning purposes (Figure 1). Strategies that can reduce this expenditure without too high a cost would have a significant impact on local power consumption which can then filter into better feasibility of on-site renewable power sourcing. Although much research is available on this topic, a simple prescriptive guide seems to be lacking. The end goal of this project is to provide a list of actions for the homeowner or occupant to implement. Whether they are building a new residence, trying to save energy in an old one or lowering the bills in a rental home, these strategies can be completed easily and with a high degree of success. It is implied that effort on the part of the occupant is crucial to the success of any energy conservation or sustainability strategy.

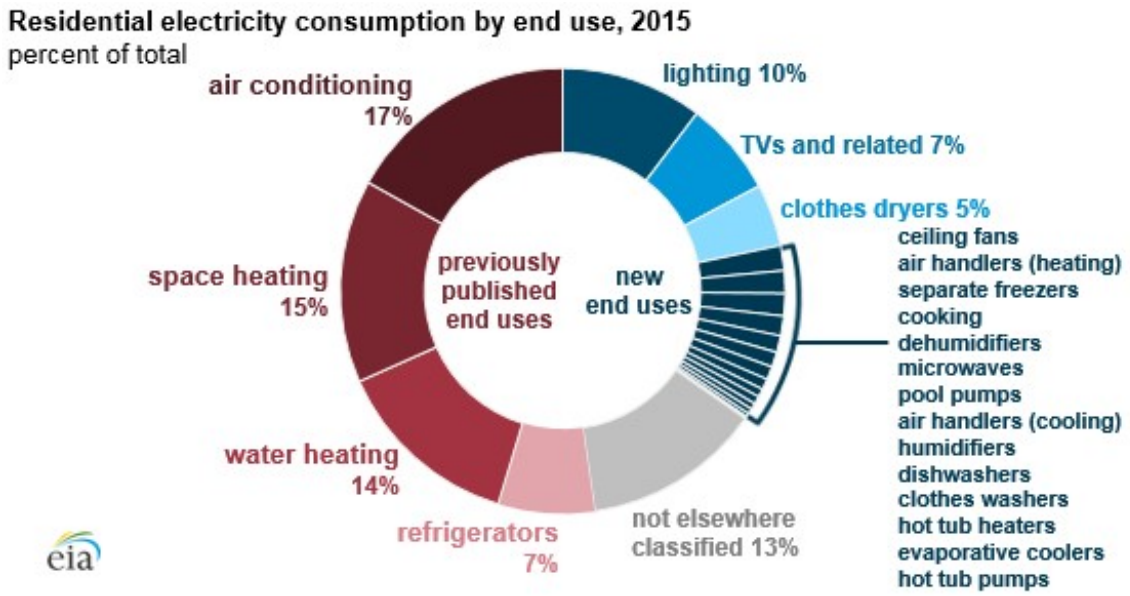


Figure 1. ***Source:*** *U.S. Energy Information Administration, 2015 Residential Energy Consumption Survey*

This project will examine the appropriate sustainable construction techniques and strategies for southern Arizona low rise residential buildings. It will analyze several popular strategies for residential sustainability in this region utilizing case studies, local building experts and relevant product suppliers. The study's goals are twofold in this endeavor: first, to determine how efficient homes in the Tucson area are in general, and second, provide a list of strategies that could easily be adapted to fulfill energy conservation goals that would generally not be cost-prohibitive. The study will illuminate reasons why some strategies should be employed before others, especially for economic reasons. To that end, the study will explore the following question: what regional strategies should be employed to achieve a more sustainable home, and can they be easily retrofit to existing homes?

Energy efficiency in home design has been a topic of study since the 1970s. Presumably the energy crisis shed light on the possibility of shortages of fossil fuels and therefore the need to conserve energy in the housing sector. With historical data and personal experience, I hypothesize that the most appropriate energy conservation techniques in the Tucson region will be shading strategies, air infiltration/exfiltration mitigation and passive solar design for new projects.

LITERATURE REVIEW

Much research has been conducted in the field of sustainability and energy efficiency; however a great deal of it focuses on heating the indoors. The Tucson region typically focuses on the opposite: keeping heat out. Intense solar radiation is part of the local climate and must be mitigated to achieve human comfort levels in the built environment. Building design and strategies to mitigate heat gain are also relevant to this study.

Research to quantify the energy savings of tree plantings around residences have been ongoing for over twenty years. An experiment in Sacramento, California, concluded that between two test sites an average cooling energy savings of 30% was achieved (Akbari, Kurn, Bretz, & Hanford, 1997). The authors strategically placed boxed trees around two residences and compared cooling energy usage of the properties with and without tree shade. Moving to the desert region it was found by studies that tree xeriscaped landscapes are effective in urban heat island (UHI) mitigation (Chow & Brazel, 2012). The "radiative shading" concept was further studied and supported the conclusions (Wang, Zhao, Yang, & Song, 2016). This study also explored the use of evapotranspiration from grass lawns and other vegetation as a UHI mitigation strategy, but irrigation requirements were a concern in the desert. Shading from trees proved

more effective in cooling the surrounding area. Optimized planting locations provide shade on strategic areas of a residence, mainly windows and doors, and maximize the benefits of tree shade on the home cooling load, while preserving the south-facing roof for solar PVs if desired (Zhao, Wentz, & Murray, 2017).

Design and construction contribute greatly to the comfort and sustainability of a residence as it interacts with the climatic forces of the locale. Building shape, orientation, and a purposeful yard design create comfortable outdoor spaces in addition to indoor spaces that require less energy to maintain (Chalfoun, 2003). Thermal mass materials have been proven to blunt indoor temperature variations in climates hat experience high diurnal temperature variation (Kalogirou, Florides, & Tassou, 2002). High thermal mass materials were used in unison with passive strategies in a study of Mexican low-income residences with positive results (Marincic, Ochoa, & Alpuche, 2014). In mild seasons, cool night air extracts stored heat in the thermal mass, known as passive cooling. Solar orientation and trees provide summer shading of the structure as previously described, mitigating unwanted heat gain. The low winter sun is allowed into the structure to help passively heat the thermal mass in the winter. Thermal mass is not as valuable everywhere, as a Nordic study concluded that the energy savings of building with thermal mass materials is small and is effectively canceled out due to a higher production primary energy use (Dodoo, Gustavsson, & Sathre, 2012). This study, however, does concede that the heating load of a concrete structure in the Nordic climate is lower than that of its wood-framed counterpart.

The primary objective of this study is to determine viability of retrofitting existing homes with sustainable features. A 2005 study from Belgium completed that task utilizing building

energy modeling. The authors provide a hierarchy of economical retrofits to save energy in Belgian homes based on optimal value for performance. Ranked from best to worst are roof insulation, floor insulation, energy-efficient windows/glazing, efficient heating system, and finally renewable energy sources, PV panels in this study (Dodoo et al., 2012). Although helpful, Belgian sustainable strategies will differ significantly from the American desert southwest for many reasons including vernacular architecture and local climate differences.

METHODOLOGY

Prescribing anything to a group of people, much less energy efficient measures, is a subjective task. Opinions, individual goals, expectations, and budget can all factor in to the final recommendation. It is due to this subjectivity that this study is carried out utilizing a qualitative research method. There is no right and wrong strategy toward sustainability and efficiency, specifically when dealing with existing homes that may have less desirable traits such as improper solar orientation, single-pane windows, insufficient insulation, etcetera.

This study will research real estate data for the Tucson metropolitan area to determine the number of existing homes in the area, materials of which they are constructed, and energy performance data of a sample of homes throughout. Sources will include personal interviews with building professionals, market research of energy-efficient retrofit components such as windows and doors, and case studies of residential properties. This study intends to interview experts and observe case studies to understand the most appropriate energy-efficiency strategies to be implemented by Tucsonans. It is expected that a hierarchy of value will emerge after discovery of return on investments (ROIs) of specific energy-efficient options.

DATA, RESULTS & DISCUSSION

Many factors that affect the energy efficiency of a building. Correcting some of these factors in an existing home can be cost-prohibitive. By consulting with local professionals and experts, this study pins down the most important components of the energy-efficient home, and prescribe corrective actions homeowners can take to lower their energy usage and utility bills.

I want to take a moment to acknowledge and thank the experts that accepted interview requests for this endeavor. First is John Ward, Professional Engineer and Project Manager for Urban Moment, LLC, a local real estate investment group, also 1st Vice-Chair of the Southern Arizona Home Builders Association. Next is Michael Ginsburg, Energy Efficiency Expert with over forty years of home building experience, and designer/builder of the S.E.E.D. Home (Super Energy Efficient Designed). Mr. Ginsburg's point of view is of particular interest to me as his S.E.E.D. home design is one that I hold in particularly high regard. His custom and semi-custom building experience lend credibility to his opinions. John Ward is extremely knowledgeable in the design and construction of large subdivisions. He served as Director of Land Acquisition and Development for Pulte/Del Webb before becoming KB Homes Tucson Division Vice President of Land Acquisition. He has served many years on the SAHBA Board of Directors and currently oversees a diverse portfolio of real estate projects.

The inspiration for my sustainable home design and pursuit of a degree in Sustainable Built Environments came from a Sustainable Home Tour in 2013. My dad and I toured the crown jewel of Michael Ginsburg's career: The S.E.E.D. Home. The attractive midtown residence incorporated a highly insulated thermal building envelope constructed of structural insulated panels, or SIPs. The concrete slab was also insulated from underneath and featured a

hydronic radiant floor heating and cooling system. The home maintained consistent comfortable temperatures without the need for a forced-air system! I was already impressed. Rounding out the total design was a solar photovoltaic system, gray water plumbing, rainwater harvesting, and an ERV (Energy Recovery Ventilator) that provided fresh air for the super-tight house without sacrificing indoor air temperature. Benefits associated with the near net-zero home are a comfortable quiet home, a healthy environment with filtered fresh air, and almost no utility expense (The S.E.E.D. Home). This home represents the gold standard in residential home design.

I asked the experts a series of questions related to energy-efficient design measures in the form of a questionnaire. The following is the questionnaire with their answers.

ENERGY EFFICIENCY QUESTIONNAIRE

1) What component of the building is most critical to energy efficiency?

According to John Ward, "proper insulation installation, especially attic insulation. Improper installation, even in isolated areas can negate the benefits of increasing R values." Michael Ginsburg added, "First and foremost is the integrity of the thermal envelope meaning as air tight as possible and properly installed insulation (whatever kind)." The point here is both the thermal envelope and the integrity of the insulation are key for energy efficiency.

2) What is your opinion on the effectiveness of solar fabric shades or solar window screens or shade strategies such as strategic tree plantings?

According to Ward, "house orientation/window placement/shade fabrics and/or tree placement opportunities are the least often considered EE function that offers the biggest impact for a

nominal investment." Ward provides an answer that looks holistically at solar gain concerning windows and orientation. Ginsburg expands on shade strategies, including fabric window coverings and tree plantings, "they are cost-effective ways to shield windows from direct solar gain especially for east and west-facing windows. For South facing windows it depends on how much solar gain is wanted during the winter months and the quality of the windows. North facing windows are a non-issue for window shields." Both experts agree that one of the least expensive and helpful strategies to prevent heat gain and reduce cooling load in the southern Arizona region are shading devices and strategically placed trees.

3) Being that the median income in Tucson is less than $40,000 per year, what is the best way for an average Tucsonan to reduce their household energy use and monthly utility bills?

Ward clarifies that the Tucson metropolitan area including Oro Valley, Marana and Pima County has a median household income closer to $46,000. He states, "answering this with the assumption that we are talking about an existing home and wanting to achieve the biggest bang for the buck: Programmable thermostats and education on the maintaining steady temperature values rather than letting a house heat up or cool down and then having to re-condition the environment. " Ginsburg adds, " There is no ‘one best way’. There are multiple things that can be done and the cost factor varies from small dollar to large dollar outlay. A few easy ones are : 1. Change air filters regularly meaning once a month, if need be. Use a MERV 8 minimum and preferably MERV 11 (MERV=minimum energy rating value). Caulking around perimeter of the house at windows and door entrances. If old steel or aluminum sash windows and you can afford it, replace windows with life-time warranty vinyl framed windows with high-performance

LowE3 coatings. If possible and there is an attic, ‘fix’ and improve attic insulation." As expected, we see a couple different answers to the existing home question. Ward believes occupant behavior has much to do with the reduction in energy usage, and Ginsburg starts at a comprehensive maintenance plan that addresses any obvious deficiencies in the building envelope and climate control systems.

4) Is the investment in solar PV panels worthwhile? Why or why not?

Ward answers, "solar PV investment is worthwhile – if viewed from a 7-10 year time period for return on investment. When connected to an electric provider that will buy back (or credit) for excess solar power, the return function is faster." Ginsburg notes, "generally speaking, yes, especially if you are going to live in the home longer-term as opposed to near term selling the home. It also depends on the existing energy efficiency of the existing house because if the house is poorly insulated then a larger PV system will be required thus increasing the upfront cost." Interestingly, Ward continues, "but homebuyers will NOT pay a premium for Solar on a production home build basis…it's just a good marketing tool. Buyer decision making is different on the custom build platform." In his experience, PV systems are not highly in demand within the production home market.

5) Do you recommend other energy conservation strategies before taking the plunge into household renewable energy generation? (If you recommend PVs at all).

Ward believes there is a list of items that should be completed "regardless of plunging into renewable energy generation or not," these include:

a. Ensure a tight building envelope (balanced air pressure) – no air leaks.

b. Orientation/shade opportunities

c. HVAC operational efficiency

d. Light-colored roofing material and exterior wall

Ginsburg reaffirms the importance of maintenance, and, "additionally, water heating is a large portion of a home's energy bill, whether gas or electric. New water heaters are much more energy-efficient than older models, and replacing one that is, say 7 years old or has become problematic, is a good idea. Almost all new units have 2" of polyurethane foam in their jacket. If purchasing a new water heater ALWAYS have the installer replace the existing drain valve with a STRAIGHT FULL PORT BALL VALVE with hose connection fitting for easy flushing of sediment buildup every 6months for about one minute. Contrary to so-called conventional wisdom you do NOT need or want to fully drain a water heater. It is completely unnecessary if, from the beginning (new installation with full port ball valve), you merely flush it for up to one minute." The prescription for improving energy-efficiency begins to clear up. It also appears that a hierarchy is emerging with respect to cost and ease of implementation of improvements. First, repair anything that could leak air or cause inefficiency of HVAC equipment. Next, consider shading the east, west and south of the home. Then proceed to new equipment such as water heatersand possibly new millworks.

6) Finally, if you are designing a new construction energy-efficient home, what are your mandatory features?

Ward lists, "proper sizing of the HVAC system, quality multi-pane windows, proper insulation installation, HE appliances, and most importantly building envelop testing (air pressure test) from a certified EE tester." Ginsburg exclaims, "big question! One, full surround air tight thermal envelope. Two, superior insulation of the thermal envelope. Three, lowE3 high-

performance energy-efficient windows. Four, proper solar orientation – long face of the house facing north and south. Five, installation of an ERV (Energy Recovery Ventilator) for proper filtered fresh air injection into the house while simultaneously exhausting stale indoor air. Six, use of high-efficiency air source heat pump for air conditioning and heating, not gas heating. Seventh, if all of the above (not #6) seriously consider an in-floor hydronic radiant heating AND cooling system." These answers encompass the best case scenario for the experts. We observe the trend of maximum importance placed on integrity of the thermal envelope with high-quality insulation, windows and doors that are properly installed. Air blower testing confirms the integrity, and high-end features that Ginsburg suggests push the home toward near net-zero status when coupled with renewable energy generation.

Follow up conversations with the experts brought a clearer idea of what the energy efficiency road mad could look like. I asked John Ward why we do not see production homes being built with high thermal mass materials. Research by Marincic, et. al. (2014) indicates that in the desert region where diurnal temperature variation is large, high thermal mass structures perform well at buffering the outdoor temperature extremes. His answer was a short "Too Expensive." Much like his experience with solar photovoltaics, subdivision home buyers are not willing to pay for premium materials. "Decision making is different on the custom build platform," he states. We went on to discuss the value of high thermal mass adobe blocks, with both of us agreeing in the dream vision of a low maintenance house built from adobe block, strategically placed fenestrations, and a steel roof. The take-home message is that while that style works best in our climate, it is likely too expensive to sell many units in our market, and therefore does not satisfy the economic leg of the sustainability model. However, some production builders are beginning to explore constructing homes with sustainability in

mind. Time will tell if this is adopted by other builders.

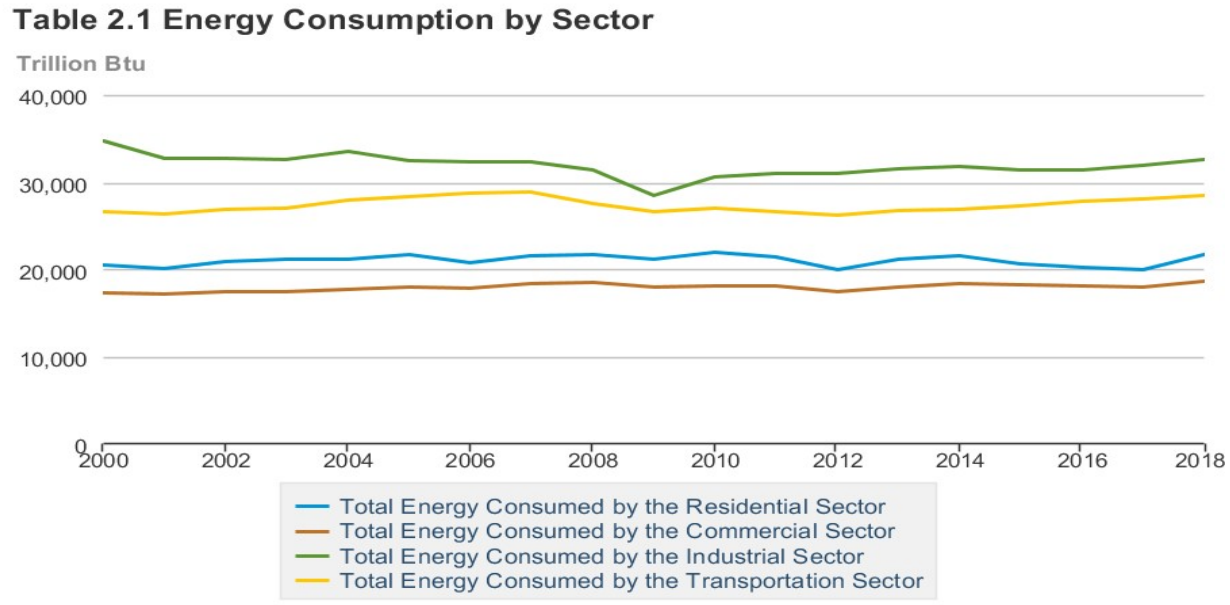
The City of Tucson has a population of 545,975 in the city, and 994,000 in the metro area. The median income within city limits is $39,617 and $48,676 for the metropolitan statistical area (mapazdashboard 2018). Many of the nearly 210,000 households will remain in existing residential buildings. Of those households, 49.3% own the home, according to the Tucson population page at worldpopulationreview.com. So only half of the city's population has a reasonable chance to upgrade the sustainability of the building that they live in. This statistic alone represents the importance of this study. We must provide implementable options for all residents, regardless of economic status or income. Armed with knowledge, all citizens can live more sustainably. Through conversations with building and sustainability experts, a tiered strategy organization surfaced. It is not expected that all people will have the same sustainability goals, have the same habits, and the construction and condition of their homes will vary greatly. Thus, tier 1 energy efficiency strategies would include any low to no cost to implement. These strategies can include passive cooling, the opening of windows when temperatures are cooler outside, inexpensive shading, proper maintenance to seal the homes thermal envelope, education and behavior modification. A thorough understanding of what decision making, such as lowering the thermostat temperature, has on the energy use of the dwelling (and the utility bill to follow) can be very helpful in curtailing unsustainable behaviors and habits. The use of ceiling fans for occupant comfort for example, and the discipline to shut them off when exiting a room go far in saving energy. Tier 2 strategies would include minor upgrades that have some up-front cost, but a quick return on investment. Some of these strategies can be implemented by renters and home owners alike. They can include light occupancy sensors, timers, detached shade structures, and window & door replacement. Tier 3 would include major remodels that would be expensive and

possibly cost-prohibitive for many. However, in the event of a catastrophe, or a necessary repair, energy efficiency upgrades can be implemented at the time of reconstruction. These can include insulation upgrades, strategic locating of satellite structures like shops or garages, and attached shading patios, and high-efficiency HVAC systems.

Table 1 Summary of options

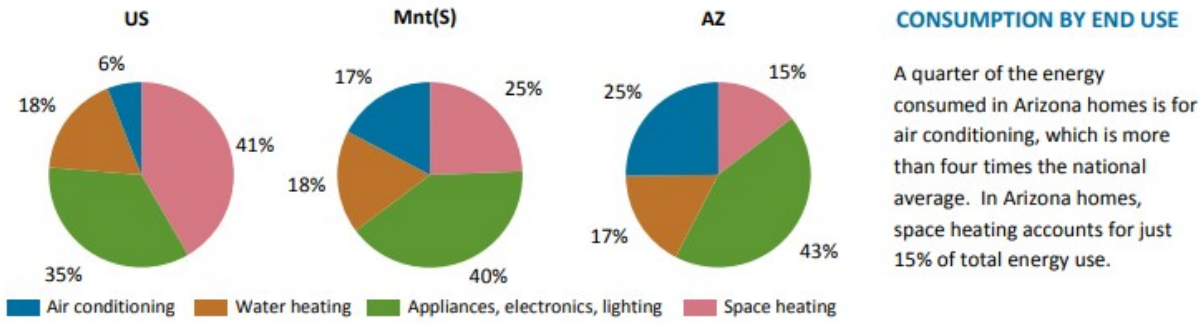
Tier 1 ($)	Tier 2 ($$)	Tier 3 ($$$)
Passive cooling	Occupancy sensors	Insulation upgrades
Opening windows to cool	Timers	Strategic locating of add-on
Shading	Detached shade	Attached shade
Seal thermal envelope	Window replacement	High-efficiency HVAC
Behavior modification	Door replacement	
Costs increases →		

Limitations of this research exist as residential energy use is a small part of societal consumption as a whole. The Energy Information Administration identifies the Residential Sector consuming considerably less energy than the Industrial and Transportation Sectors (see chart).

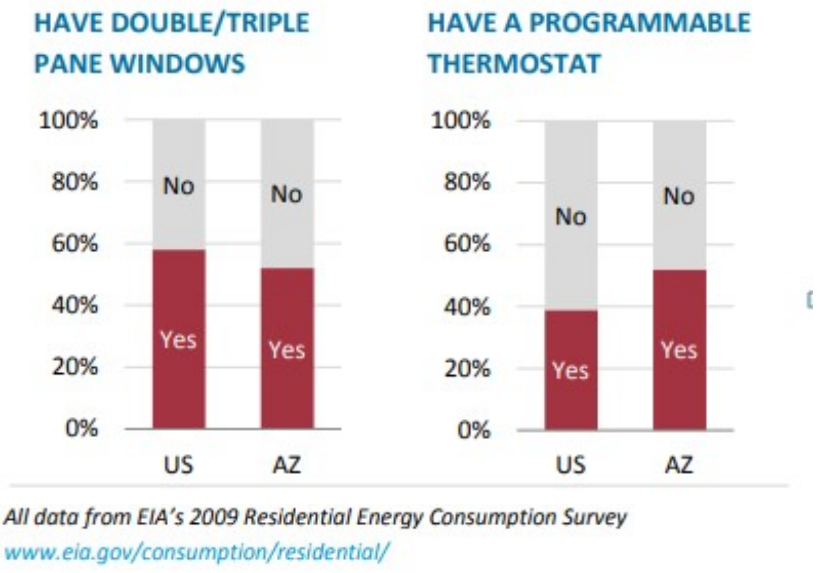


eia Source: U.S. Energy Information Administration

A more widespread savings of energy can be accomplished by focusing on lowering the energy demand of the most energy-hungry sectors. However, it is my opinion that the culture change begins at the local level, and that means at home; the residence. In addition, this study focuses on the Sonoran Desert region, specifically the Tucson metropolitan area. Energy use in Arizona differs from the rest of the United States, mostly due to our unique climate.



Figures by the Energy Information Administration show Arizona having more homes with a programmable thermostat than the national average, however fewer than the national average contain multi-pane windows.



All data from EIA's 2009 Residential Energy Consumption Survey
www.eia.gov/consumption/residential/

CONCLUSIONS

A September 2018 visit to a Green Building Council meeting of the Southern Arizona Home Builders Association was the catalyst to this research. I attended with my mentor, John Ward, and was surprised at my observations. The topic on the agenda was how to sell more "green" homes, and after a presentation from a representative from the National Home Builders Association a roundtable conversation ensued. I was astonished to learn that definitions of green building, sustainability and other concepts were not greatly understood by the people building these homes and trying to sell them. It seemed to me that better marketing needs to happen, built around educating the consumer of the return on investments and lifestyle benefits of sustainable construction. It became apparent to me that the lessons I have learned in the pursuit of my B.S. in

Sustainable Built Environments need to be broadcast to the community at large if there is to be market demand for such homes. Sustainable features also cost more to build and implement than conventional construction, and that fact seems to push lower-income folks away from sustainability. I intend to showcase the profound effect of low cost and behavioral modifications that can lower bills and inch our community toward a more sustainable residence.

After researching local climatic issues of which inhabitants of the Sonoran Desert must contend, along with real estate market demands and societal pressures, I have a good idea of how to respond to the question that I have received on many occasions concerning energy efficiency advice. "Where do I start?" and "What should I do?" are common. The short answer is "It depends." Numerous factors converge on the answer. Socioeconomic status can be a constraint in the pursuit of sustainable living measures, as well as home ownership, type of dwelling, and local regulatory limitations. These combined factors make establishing appropriate energy efficiency and sustainability strategies difficult. A tiered hierarchy of strategies emerged from interviews with local experts as well as identification of critical building components to address in the effort to achieve energy efficiency. It is important to note that individual sustainability goals will vary and similarly, economic situation will as well. This variability will inform an individual's sustainability strategy decision-making process.

The thermal envelope is recognized as the single most important component of the energy-efficient residence. Whether constructed of materials with high insulation or thermal mass, the integrity of the envelope is of utmost importance. Proper sealing of the envelope including correct installation of insulation is essential. Shading strategies are possibly the most overlooked energy efficiency measures, but can be the most effective as they prevent problem

solar heat gain at a low cost. Strategic tree plantings are a great way to both beautify an outdoor space while simultaneously providing strategic shade to a residential structure. There does not exist a 'best way' to achieve energy efficiency or sustainability due to variability in investment capital availability across classes, however the consensus opinion is to correct any air leakage problems first then implement no and low cost (Tier 1) strategies first, and progress to more expensive and sophisticated measures (Tiers 2 & 3) as budget and philosophy allow. The Tiered organization of strategies provides a road map to efficiency in retrofit situations as well as new home design.

One notable observation that came from this study, perhaps unsurprisingly, is the profound effect that human behavior has on sustainability. Even when high-performance materials are chosen, installer behavior can negate the investment. The condition can manifest as incorrectly installed insulation or ill-fitting windows and doors. This sentiment was shared by both construction experts I interviewed. Building envelope testing was recommended. Occupant behavior can also negate the highest technology home automation and smart home devices. Educational opportunities exist at a grass roots level that could aid in overall sustainable decision making. More research is needed on the rebound effect on energy usage after installing energy-efficient upgrades.

Finally, there was an epiphany during my conversation with Mr. Ward that perhaps budget billing from local utility companies could buffer the effect of poor energy use decision making by spreading the cost of that energy across all months of the year. A higher than can be afforded bill provides an excellent teachable moment in our opinions, and likewise an extremely

low bill can provide sufficient reward for positive decision making. Further research on the topic would be interesting.

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