Energy Savings and Cost Effectiveness of Energy Efficient Housing

Steven M. Lehigh

Abstract This paper analyzes the performance and cost effectiveness of energy-efficient single family detached housing. A housing development known as Civano, located in Southeast Tucson, Arizona, was used as the study site because the community has established energy performance guidelines to which a developer must conform in order to build in the community. The guidelines stipulate that houses must use 50% less energy than is required by the Tucson Metropolitan Energy Code. A survey was conducted to obtain energy usage data and general information about the population's concern for energy and their usage habits. A total of 54 households were surveyed out of 80 total inhabited residences, and for 15 houses at least eight months of data was collected. The data shows that the houses are using about 50% less energy than the average Tucson house, but this does not lead to a 50% monetary savings on energy bills. The monetary savings leads to a payback period of between five and ten years for the increased purchase price due to the energy saving modifications.

Introduction

In 1990, the Intergovernmental Panel on Climate Change (IPCC) published the first of several reports by several hundred leading atmospheric scientists, in an attempt to create a consensus about the state of global warming and its future implications, if any. The reports concluded that atmospheric concentrations of greenhouse gases were increasing, and that human activities were the cause. The reports failed to link increased concentrations to an increase in Earth's mean surface temperature, but they stated that an increase or decrease in global temperature of more than 2°C would drastically effect Earth's ecosystems (Miller, 1995). There have since been two more reports published in 1995 and 2000, that go beyond the initial 1990 report to strengthen the position stated in the initial 1990 report. These reports have spawned initiatives such as the Kyoto Protocol, which attempt to get international compliance for reducing greenhouse gas emissions. The goal set for the US is to limit emissions to 93% of its 1990 emission levels by 2012.

Although there are many sources of greenhouse gas emissions, most reduction measures provide no direct economic benefit to the user. For instance enhancing a car's catalytic converter would cost the driver more, but he/she would not *directly* receive any of the benefits from the change. If instead the solutions utilized energy efficiency, e.g. better gas mileage in cars, the benefits of less pollution may be the same, but the owner is also compensated by having to spend less to travel the same distance.

In this vein, it can be seen how increasing energy efficiency in building design can produce the same benefits. Since the invention of the air conditioner, and the idea of central heating and cooling, the face of development has been drastically changed. The idea that any building could be built anywhere, without consideration for solar and internal heat gain, became the popular paradigm, and still is common practice. But there are also new trends moving away from being this climate-independent approach, toward using more thoughtful designs and new technologies to create buildings and houses that use less resources (Gottfried, 1996). The problem is that most energy-efficient developments are designed for customers who specifically want a building of this nature either for public appeal, to emphasize the ideology of the company, or personal preferences (in the case of housing), but not for economic reasons. As a result, these buildings are developed on an individual basis (Hawken, 1999).

The obvious hope for energy efficient practices is that they will pay for themselves over time through reduced operating costs, and provide the same services to residents while requiring less energy. One problem is that developers have to invest a larger amount in the construction process and then pass on the difference to home buyers, which burdens the developer with the task of convincing home buyers that their more expensive houses are either going to pay them back eventually, assuming that this is even true, or that such a house is simply a better house. The most crucial factor for creating a market for mass construction of energy-efficient housing will based on the payback period for the investment in energy efficiency. For the most part all attempts at energy efficient buildings have been done one by one, usually in cases where the image and ideal were more important than economics. In this examination, a housing project has been designed from a developer's perspective and the results could influence future developments.

In southeast Tucson, Arizona is the Community of Civano, a planned community expected to include 800 houses. The overall theme of Civano is "a new vision of community balancing human needs and natural resources."(McDonough, 1998) One of the many foci of the development is energy conservation and efficiency. Houses incorporate both passive and active solar principles, solar water heaters, thermal mass, low-e windows, and increased insulation in both the walls and the ceiling. Using advanced technology does increase energy efficiency but it also increases price. Houses are expected to be 50% more efficient than is outlined by the Model Energy Code (SES, 1998). Each of the five developers involved in the project must run the specifications of their models through MEC Check Software, which calculates the building's performance against the standard. Due to the complexities and differences in residents' energy using habits, the community standards are set up to only regulate the aspects that the builder can address; the heating and cooling loads.

Methods

The total number of residences inhabited at the time of the study was 80 households. Data regarding the energy use of the currently occupied houses was collected by conducting a door-to-door survey in February of 2001. Residents who had their most recent energy bill, referred to as the "February" bill (read by the utility on 2/6/01), were surveyed and then were given a postcard to provide the information from the March bill upon arrival. Past monthly energy use data was estimated from the bar graph printed with the bill, along with the current reading. The total sample of this type was 23, with past readings ranging from two months to a full year. There were also 31 residents who were surveyed but did not have their bill available, so they were solely given the post card, limiting their data to the month of March. Of the remaining 26 households, six opted to not participate, and the other 20 could not be contacted. Every house was visited the first time on a weekday during the day, a second time on an alternate weekday during the night, and a third time on Saturday during the day. The survey also addressed some other issues, such as how much of a factor energy was in their decision to move to Civano, and whether or not residents have added anything that might affect their energy bills in any way.

With the data being so fragmented, the residence times being so scattered, only the samples that had at least eight months of data were used. For one, it means that the data went back at least through July, which covers most of the summer season. With both dominant energy using seasons covered, extrapolating through the milder months lowers the chance for misrepresentations. Separating the residences by type, into all-electric (total sample of five) and gas/electric groups(total sample of ten), yearly averages were estimated from the existing data by extrapolating the known months into full years using a multiplier. The multiplier was established using the residences for which a full years' worth of data was collected; for gas/electric houses there were three, and for all-electric there was only one, by using the formula X=(March 2000 through Feb 2001)/(July 2000 through Feb 2001), where the dates represent the total energy use for those periods. If for example, energy use was the same for every month of the year the multiplier would be 12/8=1.5.

The energy data from the survey were compared to a baseline energy consumption standard that was established when the goals for Civano were created. The Metropolitan Baseline Analysis for 1990 set the precedent for the energy use per square foot of a traditional residence, which they determined to be 55,563 British Thermal Units (Btu) per square foot per year (Chalfoun, 1990). From this the total energy and monetary savings for the average Civano house were calculated. Although the standard is not the one the community is actually comparing itself to currently, it provides a good reference for this study. The new standard for Civano sets goals for the heating and cooling costs of the residences since they are the only factors that can be realistically controlled by the builder, but they are not easy to calculate without doing a complex analysis. There is currently a study being funded by the Department of Energy (DOE) that will do just this, but it requires constant temperature monitoring and load monitoring of the heating and cooling systems. Since the data collected was taken straight from the residents' energy bills, it is more applicable to compare their performance to the results found in the original study, and just take into account the differences in this analysis and the goals of the community. A total use analyses of energy use is also useful because it can detect whether or not residents are displacing their heating/cooling savings with other energy intensive items, such as spas or extra refrigerators.

Results

Housing Type Since most of the residents had moved into their homes within the past year, very few had enough data to give a yearly average for their energy use. In an attempt to better estimate the yearly average with the limited data, summer and winter use were compared by averaging energy use for June, July and August and testing it for a difference in the average amount of energy used for the months of December, January and February. A one sample t-test was done, using the difference between the seasons for each residence. It showed that winter use was significantly greater than summer use (P=.0395). Most importantly though, the distribution showed two distinct groups, one that had greater use in the summer, and a larger group that had greater use in the winter. Splitting the total sample into two groups, all-electric houses and

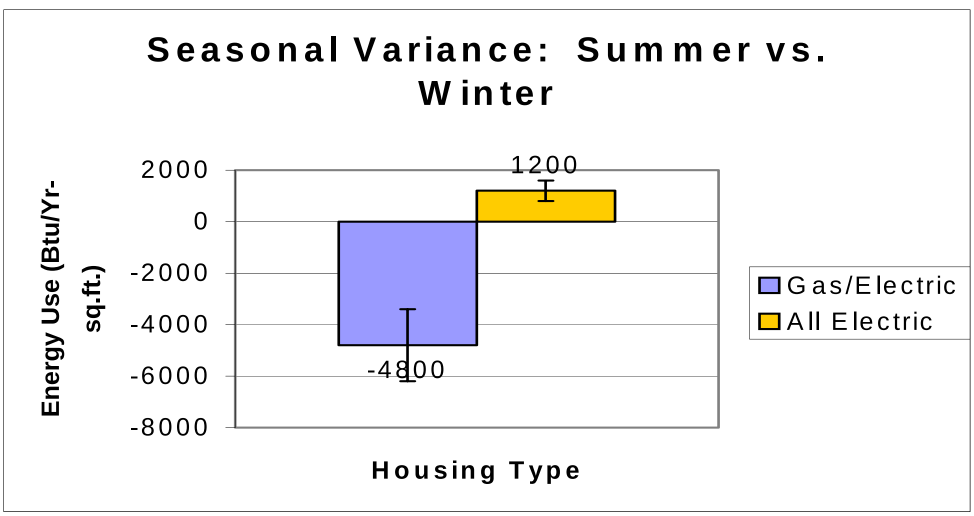

Figure 1 Summer use minus Winter use shows that all electric houses are using more energy in the summer months, while gas/electric houses use more in the winter months.

gas/electric houses, revealed the source of the discrepancy. Comparing the two types gave a P-value=.0077 (Figure 1), which means they have significantly different seasonal patterns. The reason for this is that houses hooked up with gas most likely have gas heaters that are used in the winter, and electric air conditioners for the summer, and due to the conversion factor when converting the different energy types to Btu's, gas use inflates the number of Btu's. Re-testing the comparison between summer and winter use, now factoring out the all-electric and gas/electric factor, still showed that the summer and winter months were effectively different for both housing types (P=.0053, P=.0526).

Yearly Average The results give average multipliers of 1.42 for the all-electric houses and 1.36 for the gas/electric houses. It is reasonable that both are lower than 1.5 because the months that are unaccounted for are March, April, May and June, which have relatively milder climates than the other months. Using these multipliers, yearly averages were calculated for every residence where at least eight months of data was available. The average for the five all-electric houses was 26,374 Btu/Yr-ft^2, and 30,714 Btu/ Yr-ft^{2}for the ten gas/electric houses. This translates into a 53% and 45% reduction in energy use respectively (Table 2).

Housing Type	Average Annual Use (Btu/ Yr-ft^2)	% Energy Savings	Average Annual Energy Cost (\$/Yr-ft^2)	Average Yearly Savings Compared to Standard
Standard	55,500	-	.84	-
All-Electric	26,400	53%	.65	$409 (25%)
Gas/Electric	30,700	45%	.56	$495 (30%)

Table 2 Comparison of the energy use and monetary savings between the two types of Civano houses and the standard Tucson house from the Chalfoun study.

The results were tested for any effect the builder might have on the performance of the house, and although the sample size for two of the developers is extremely small, there seems to be no statistically significant differences from builder to builder. Regression analyses also showed no statistical correlation between house size and performance, i.e. larger houses did not perform better or worse than smaller houses.

Economics The economic benefits that result from lower utility bills relative to the standard, add up to an average annual savings of $409 for all-electric houses and $495 for gas/electric houses (Table 2). All of these results are based on the average square-footage of the sampled houses, which for both types was about 1,780 ft^2 (Standard Deviation = 250 ft^2). Depending on the size of the house the amount of savings varies.

Besides just comparing the performance to the Chalfoun study (Chalfoun, 1990), a rough estimate can be made to get an idea of whether or not the houses are achieving the goals of the community. Using the Chalfoun study, a base consumption value can be estimated. If it is assumed that besides the shell of the house nothing else changes from the standard houses to the Civano houses, then the heating and cooling load from the standard house, estimated to be 66% of the total energy use, can be subtracted from the total energy consumption, to create a base value. With the above assumptions, this base value should not change from the standard to the Civano house, since this base energy use is for everything but heating and cooling. By this calculation, the base would be 18,800 Btu/Yr-ft^2 (one-third of 55,563, the total average consumption), meaning the standard house uses approximately 37,000 Btu/Yr-ft^2 for heating and cooling. Assuming that the Civano gas/electric houses are using the same base amount, then they are on average using 12,000 Btu/Yr-ft^2 for heating and cooling. This is a 66% reduction in energy use for heating and cooling, which for this approximation is essentially indistinguishable from the goal of a 75% reduction. Obviously this is a rough calculation, and it is suspect to assume that the houses would have the same base use; for one, the resident population of Civano is probably on average more energy conscious than the general population, introducing bias; but the calculation is a good first approximation until the DOE study is complete.

Discussion

Performance The performance levels are very respectable at about 50% greater efficiency than the standard, but the performance of the all-electric houses is a little misleading. Since the performance is based on the measured amount of energy use, all-electric houses are inherently lower than gas/electric houses because of the upstream inefficiencies of electricity production and distribution. Standard electricity production is only about 40% efficient by the time it is actually consumed (Harte, 1988), so although it is included in the price, it is not registered by the meter. Thus, houses are actually using more primary energy, when transmission losses and production inefficiencies are added in, which is one reason the annual energy costs for gas/electric houses were lower than the all-electric houses even though they use less metered energy. The second factor that may contribute to an inflated savings value for all-electric houses is that all of the houses in the study used to establish the standard were gas/electric houses. Because of the issues mentioned above, the standard houses are going to be using more *measured* energy in the same way that the gas/electric Civano houses are using more measured energy than the all-electric ones.

Economics Although the houses are using a lot less energy, the bulk of the savings comes from reduced gas consumption which has a smaller effect on economic savings. The reason percent energy savings does not translate directly into monetary savings, i.e. if all-electric houses are using 53% less energy they should also have 53% lower energy bills, is because the proportions of gas to electricity use change the costs of the energy. Of the total energy used by the "standard" house, 64% of it is gas, while gas only makes up 42% of the total energy used in the gas/electric houses studied in Civano. With electricity costing about 2.5 times more per Btu than gas, reductions in electricity have a far greater impact economically. This is evident in the savings analyses between the standard and the gas/electric Civano houses. With most of the energy saving practices in Civano concentrated on reducing heating and cooling loads, the share of gas in the total energy consumption is going to decrease since most uses outside of this realm use electricity. For instance, if the bulk of gas usage is for space heating, water heating, and clothes drying, and the Civano codes reduce the first two by the proposed 75%, it will greatly reduce the total amount of gas usage. But, if air conditioning is the only electricity-based energy user that is addressed by the codes, there are so many other electricity consumers within a household (lighting, refrigerators, extra freezers, etc.) that the reduction is proportionately less than in the case of gas. This becomes evident when the gas/electric houses are compared to the standard, but instead of comparing total consumption, the energy types are split up. The gas/electric houses are, on average, only using 11% less electricity than the standard houses, while they are using 64% less gas (Table 3).

Housing Type	Total Energy Use (Btu/Yr-ft^2)	Natural Gas Usage (Btu/Yr-ft^2; % Reduction)	Electricity Usage (Btu/Yr-ft^2; % Reduction)
Standard	55,500	20,000	35,500
Gas/Electric	30,700	17,800 (11%)	12,900 (64%)

Table 3 Comparison of percent share of energy type for the standard house v. the average Civano gas/electric house

Standards The discrepancy mentioned before in comparing all-electric and gas/electric houses, reveals the difficulty in establishing standards based on annual energy use. It appears as though all-electric houses out-perform gas/electric houses by the annual energy use measure, but gas/electric houses have a cheaper annual operating cost, which could be more important to the resident and/or developer. There is also no consideration for the number of residents in a household, and without reducing per-capita energy consumption, nothing is being accomplished. This could be an important issue in the case of Civano because the smaller residences attract adults who are no longer housing their children and do not want the burden of large energy bills from oversized houses. It would be interesting to compare per capita energy use for Civano houses versus standard houses.

The current computer modeling system that Civano is using to regulate performance appears to be successful from the small sample of data collected here. With four different housing types being examined, the sample size was split up and diminished quite a bit, but there appears to be no inherent difference in performance from builder to builder. With so many developers involved (eventually there will be two more building houses in Civano) it is encouraging to see that the modeling system is maintaining consistency with respect to energy use throughout the community.

Recommendations One of the major faults with the community is the lack of consideration for solar orientation in the placement of the houses. For the most part the houses are constructed with their longest outer walls facing East/West. This is the least optimal orientation in two respects. It is commonly understood that the East and West sides of a building are the hardest to shade, and thus designing them to have the smaller area decreases solar intake through their windows. It also decreases the opportunity for window area on the North/South facades, decreasing the amount of natural light entering the building that could decrease the need for artificial lighting. Apparently the reasoning behind the Civano orientation was that it significantly increased the number of developable lots. If energy and community are the two main goals of the development, a better solution might have been to eliminate the streets that run in front of the houses, in a similar manner to Village Homes in Davis, CA. In Civano, these streets are not supposed to be parked on and to not provide driveway access. Their elimination would not only create pedestrian only pathways, but by pushing the houses closer together more developable land becomes available.

In the Chalfoun study they cited evaporative coolers as an opportunity to avert quite a bit of energy use, by reducing the need for air conditioning. Unfortunately, none of the houses surveyed had one installed, and some people also felt that their air conditioners were oversized. It is unclear why evaporative coolers were avoided; whether it be tradition or effectiveness, as an alternative they could greatly reduce electricity demand.

Another concern is the location of the community with respect to the rest of Tucson. Understandably, there were many political issues involved in choosing the sight, but now that the commercial development is on hold, its isolated location is troubling. Much of the gains in energy efficiency will be offset by the pollution and transportation costs. Civano is not easily accessible by freeway and is at least a twenty-minute drive from downtown Tucson. Transit options were non-existent. There are also no shopping options along the pedestrian-friendly paths within the development. Walking to the nearest shopping center would effectively require the same initiative for a Civano resident as it would for any suburbanite willing to brave four lane roads with discontinuous sidewalks. As an environmentally conscious community, they could have done much better to address multiple issues.

Acknowledgements

I am greatly indebted to The Explorers Club, who provided the funding that made this study possible. I would also like to thank: Reuben Deumling for his endless hours of help, Dan Kammen, Wayne Sousa, Matt Orr, Peter Kennedy, Al Nichols, Brandy Lehigh, Chelsea Pailes, and especially the residents of Civano.

References

Chalfoun, N.V., M.R. Yoklic and K.J. Kent. Passive Solar and Energy Optimization for a Residential House Type in Tucson, Arizona: A Case Study for the Solar Village Project. ISES Solar World Congress, American Solar Energy Society, Denver Colorado. August 17-24, 1991.

FannieMae. 1999. Press Release, www.fanniemae.com/news/pressreleases/0256.html

Fickett, A.P., Gellings, C.W., Lovins, A.B., 1990. "Efficient Use of Electricity," *Scientific American* 263(3):64-74, September.

Frank, H.J.,1994. "Community Energy Assessment for the Tucson-Pima Metropolitan Area," Report prepared for the Tucson Metropolitan Energy Commission.

Gottfried, D., 1996. "The Economics of Green Buildings," *Sustainable Building Technical Manual: Green Building Design, Construction and Operation*, Public Technologies Inc., Annapolis Junction, MD.

Harte, J., 1988. *Consider a Spherical Cow*, University Science Books, Sausalito, CA. p.80.

Hawken, P., Lovins, A., Lovins, L.H., 1999. *Natural Capitalism*, Little, Brown and Company, Boston, MA.

Lovins, L.H., 1997. *Green Development: Integrating Ecology and Real Estate*, Wiley, New York.

McDonough, William. "Unsprawl Case Study: Community of Civano Arizona," Terrain: A Journal of the Built and Natural Environments. Issue 5 .www.terrain.org/Archives/Issue_5/Civano/

Miller, G.T., 1995. *Environmental Science: working with the Earth.* Belmont, CA: Wadsworth.

Nichols, A., 2001. Personal interview.

Rosenfeld, A.H., Hafemeister, D., 1998. "Energy-efficient buildings," *Scientific American* 258(4) 217-230, April.

"Sustainable Energy Standard," 1998. Modifications to the CABO Model Energy Code, 1995. www.tucsonmec.org/codes/suststd.html.

Zar, J.H. 1999. *Biostatiscal Analyses.* 4th ed. Prentice Hall. pp. 20-1