16 Years of

U.S. Green and Energy Efficient

Home Building

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Executive Summary

The purpose of this paper is to estimate the energy and CO_2 savings from U.S. energy efficient and green building programs for residences over the last 16 years (2000-2015). The energy savings and CO_2 reductions of rating systems such as Energy Star (EPA), LEED for Homes (USGBS), National Green Building Standard (NGBS), and Building America (BA) are calculated and compared to the total number of conventional homes built. Using this data, the weighted averages of each program's energy savings are determined. The result gives a perspective of how much energy these programs saved compared to conventional homes built in this period. The same calculation method is applied to the nation's total housing stock.

A brief analysis of super-insulated buildings, such as Passivhaus and Net Zero Energy Homes, is included. These are small in number but indicate the future of very low emissions buildings. The effect of PV is briefly covered and the trend toward power plant PV over individual house PV is noted. [1] Finally, the installed base of the 118 million occupied housing units is examined. [2] Changes in home characteristics over time are analyzed, particularly size of house, energy intensity, and per capita square footage.

After almost two decades of energy efficiency efforts home energy savings and CO_2 reductions are small. Table 1 shows that the energy and CO_2 savings obtained from several programs are less than one third of 1% for the total housing stock (bottom row, rightmost column). Energy savings objectives have been conservative (in the range of 10-20% overall). In addition such programs are voluntary, affecting only a small percent of residences built. At the same time, houses have been increasing in size; per capita square footage has grown by a factor of three since 1950. More ambitious standards, including Zero Energy Home, the German Passivhaus, and Zero Ready Energy homes are appearing but they number in the low thousands.

	Housing Units (in Thousands)			Percent of Housing Units			Energy/CO2 Reductions (%)		
	2015	2000-2015	Total Stock	2015	2000-2015	Total Stock	2015	2000-2015	Total Stock
US Total Housing Stock	118,000	118,000	118,000	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Housing Units Completed	966	20,140	118,000	0.8%	17.1%	100.0%	0.8%	17.1%	100.0%
Conventional Category									
Conventional Total	835	18,122	18,122	86.4%	90.0%	15.4%			
Green Category									
Local/Regional	6	117	117	0.6%	0.6%	0.1%	0.1%	0.09%	0.01%
LEED for Homes	16	78	78	1.7%	0.4%	0.1%	0.5%	0.1%	0.02%
NatlGrnBldStnd	15	57	57	1.6%	0.3%	0.05%	0.4%	0.1%	0.01%
Green Total	37	252	252	3.8%	1.2%	0.2%	1.0%	0.3%	0.05%
Energy Efficient Category									
Energy Star	84	1,657	1,657	8.7%	8.2%	1.4%	1.3%	1.2%	0.2%
Building America	0	54	54	0.00%	0.3%	0.05%	0.00%	0.13%	0.02%
Builders Challenge	8	51	51	0.8%	0.3%	0.04%	0.2%	0.1%	0.01%
Zero Ready Energy	2	4	4	0.2%	0.02%	0.003%	0.1%	0.01%	0.001%
Energy Efficient Total	94	1,766	1,766	9.7%	8.8%	1.5%	1.6%	1.5%	0.2%
Green & Energy Efficient Total	131	2,018	2,018	13.6%	10.0%	1.7%	2.6%	1.7%	0.3%

Table 1: Summation of CO2 Reductions in Housing

The intention of this table is to provide a perspective on the success of the different categories based on market share. A more detailed breakdown is provided in a subsequent section that shows the number of homes built within these categories for each year from 2000-2015. Most relevant is the 0.3% CO_2 reductions for the total housing stock (bottom row, rightmost column), demonstrating how little effect the programs in the period 2000-2015 have had on total housing emissions.

Early History of Very High Performance Residential Building

Constructing and operating buildings is the nation's major source of CO_2, far more than the combination of cars, trucks and buses. 49% of U.S. energy goes into homes and commercial buildings with homes generating more than half of the total building related CO_2. (9% of the nation's energy budget represents the embodied energy used in making buildings. Commercial buildings and institutional buildings are not typically owned or controlled by homeowners. The average person typically leaves home in the morning to go to work or school, and then returns to their home in the evening. They have little control over energy use in their workplace. They do control the purchasing decisions in buying, maintaining and operating their home. This report focuses on homes.

Interest in reducing energy use in buildings began in the U.S. with work at the Massachusetts Institute of Technology (MIT) on solar heated structures in the late 1940s. [3] This led to the construction of four successive research structures ending with the MIT Solar House IV built in 1958 that had active solar collectors for space and water heating.

The energy crises in the 1970s led to other developments to reduce energy use in U.S. homes, particularly passive solar homes. This effort was exemplified in a popular book *The Passive Solar Energy Book: A Complete Guide to Passive Solar Home, Greenhouse and Building Design* by Edward Mazria, published in 1979. (Mazria is the founder of Architecture 2030). Passive solar design was an option to the complication and expense of active solar heating approaches. Passive solar design uses south oriented glazing systems with direct and indirect gain (e.g. Trombe walls) from the sun. Such designs include interior thermal mass to maintain interior thermal comfort while reducing the requirement for active heating and cooling systems. Many heavily glazed passive solar homes suffered summertime overheating. They also often required nighttime insulation for windows in cold climates. About 250,000 passive solar homes were built in the country in the last four decades. [4] [5]

Over time researchers recognized that reducing building cooling and heating needs and balancing this with solar gain would achieve the lowest energy use for the least expense. In cold and cloudy climates better-insulated buildings could achieve much lower energy use than conventionally insulated structures. This led to the advent of "super-insulated" homes. Super-insulation was a term first coined by Wayne Schick at the University of Illinois in Champaign-Urbana. In 1976 he and his group developed a computer simulation at the Small Homes Council at the University of Illinois for what they called a Lo-Cal House, designed for the climate of Madison, WI. The house was never built; the effort was a computer modelling exercise. But its design features were important, particularly very high insulation levels for ceiling, walls and floors. The design called for a "tightly" built house to reduce air leakage. Ventilation was provided by an air-to-air heat exchanger.

In 1977, the National Research Council of Canada sponsored what was called the Saskatchewan House built in Regina, Saskatchewan. It included an air-to-air heat exchanger for ventilation. It had no furnace and was the first house to publicly demonstrate the value of super-insulation. Harold Orr was a key person in this effort and became well known to low energy home aficionados throughout North America. (Orr received recent awards from International Passivhaus organizations). In 1979, the Leger Super-insulated House was built in East Pepperell, Massachusetts reducing the amount of natural gas used to heat the building significantly. In 1984, three super-insulated homes were built in Great Falls, Montana with excellent results. A number of super-insulated houses were built over the next few years. Unfortunately, interest subsided as energy prices dropped in the 1980s.

Net Zero Energy Homes (NZEH)

In recent decades, the cost and price of electricity producing photovoltaics (PVs) declined to such an extent that using them for house-level distributed electrical generation became more feasible. Some of the terms people use to describe this include the following: zero net site energy use, zero net source energy use, net zero energy emissions, net zero cost, and net zero-energy building. The common feature of all such homes is the presence of photovoltaic panels. (PV)

In the early 1990s the Florida Solar Energy Center analyzed the possibility of reducing all home energy end-uses (cooling, heating, water heating, refrigerators, lighting and appliances) such that with photovoltaic electricity it might be possible to realize an annual zero net energy load. Called the "Minimum Electricity Building," the exercise estimated that it might be possible to reduce total electrical load in a hot climate by two-thirds and heating and cooling by up to 80%.

To evaluate the concept, two highly instrumented homes were built in Lakeland, Florida in 1998 – both with the same floor plan and constructed by the same builder. One of these was of conventional construction and served as the project control. The experimental building, called "PVRES" (for Photovoltaic Residence) included an interior duct system (i.e. inside the conditioned space) with a high efficiency heat pump, better wall insulation, a white reflective roof system, solar water heating and efficient interior appliances and lighting. Over one year, the experimental building used about a quarter of the electricity of the control building. The success of this project provided impetus for a new program at the U.S. Department of Energy labeled "Zero Energy Homes." This concept included a set of active and passive solar features with super-insulation and high efficiency appliances which, when combined with solar power generation, could effectively lower annual net energy (electricity) requirements to zero – thus the name.

Since the original zero energy home projects, there have been many noteworthy zero energy homes constructed. Such homes featured better-insulated walls and foundations with low-e windows and much higher efficiency appliances and lighting. The detailed monitoring of the earlier homes produced useful information about the technologies and methods needed to achieve zero electrical energy use. It has been argued that greater investments in efficiency were likely warranted to further reduce space heating needs.

Another example of how this research paid off was a development in Lenoir City, Tennessee by Oak Ridge National Laboratories. Oak Ridge constructed five successively more advanced small near zero energy homes from 2002 - 2005 within a Habitat for Humanity development. The project was most impressive in that it was applied to small, affordable homes. A variety of efficient building methods and technologies were used including:

Heat Pump Water heater linked to the refrigerator for heat recovery
Unvented crawl space controlled by the thermostat for supplemental summer cooling
Ground Source Heat Pumps using foundation heat recovery
Structural Insulated Panels throughout
Heating and cooling duct system within the insulated envelope
High performance windows, efficient appliances
Grey water waste heat recovery system

An impressive Zero Energy Home (ZEH) project was conceived by the National Renewable Energy Laboratory (NREL). It was a small 1,280 square foot Habitat for Humanity home located in Wheat Ridge, Colorado. The small home was super-insulated with R-60 ceiling, R-40 double stud walls and R-30 floor insulation. A small heat recovery ventilator provided ventilation. Very high performance low-e solar glass with argon fill and a U-factor of 0.2 was used for the east, west and north faces with a higher transmission U-factor 0.3 glass used for the south exposure. The home used solar water heating backed up by a tank-less gas water heater and included a 4 kW rooftop PV system.

ZEH homes were proven early in the history but the high cost of PV panels limited their growth. Because of the cost, net zero home sales are still only a fraction of the overall market. In 2014, the U.S. Department of Energy (DOE) certified 370 homes as being "net-zero energy ready." Before that, it had deemed an additional 14,500 as being close to zero-energy specifications. [6] Recent reductions in the cost of solar panels, make Zero Energy Homes or Net Zero Energy homes much more feasible.

The term Net Zero Homes sometimes only refers to the building's electricity use. A home with this designation could also be consuming natural gas. The definition is somewhat complex and different ways of measurement are used including Net Zero Site Energy, Net Zero Source Energy, Net Zero Energy Costs, and Net Zero Energy Emissions. [7] [8]

Passivhaus

The Passivhaus (or Passive House) building method is a German design strategy for achieving buildings with very low energy use including an 80% heating and cooling reduction. It was developed in the late-1980s by Dr. Bo Adamson and Dr. Wolfgang Feist in Europe. Dr. Feist, founder of Passivhaus Institute (PHI) in Germany, has acknowledged the contribution of Harold Orr and William Shurcliff, a physicist from MIT, who made important contributions to home energy reductions.[9] Harold Orr was one of the principals on the team that designed the Saskatchewan Conservation House (noted earlier). That house was the basis for Canada's R-2000 housing program and the Passivhaus (Passive House) program in Europe and the USA. Another key contributor in the U.S. in recent times is Katrin Klingenberg, who founded Passive House Institute US.

Passivhaus differs from ZEH in that it emphasizes the economic advantage of improving the building envelope to a point where a furnace is no longer necessary. It requires airtight construction to the extent possible. The specific targets are annual space heating energy use of no more than 15 kWh/m^2 and a total primary energy consumption of 120 kWh/m^2.

Tens of thousands of passive houses (both new and retrofitted) have been constructed in Europe. The first one built in the U.S. was constructed in Urbana, IL in 2003, called the Smith House, by Katrin Klingenberg. The second was the Waldsee BioHaus Environmental Living Center at the German Language Village in Bemidji, Minnesota, built in 2006. It was the first officially certified Passivhaus on this continent representing modern German architecture and very efficient building design. About 200-300 passive houses have been built through 2015 in North America. [10]

ZEH and Passivhaus Commonality

Both the Zero Energy Home and Passivhaus concepts require extremely energy efficient building envelopes to reach their goals. [11] There is a risk that builders of ZEH homes might under invest in envelope energy efficiency and over emphasize solar PV panels. On the other hand Passivhaus builders might over invest, in terms of adding more insulation to the building envelope, to the extent that adding PV panels is cheaper then adding more insulation. Which is better is an ongoing argument which will continually shift as both approaches evolve. The latest versions of the Passivhaus standard from PHI include solar PV as an alternate option to adding more insulation. An American version of the Passivhaus standard has recently been developed based on the theory that the number of U.S. climate zones require a unique approach to super-insulation. [12]

Almost forty years of research effort has shown that new home heating and cooling energy can be reduced by 80% with incremental additional costs in the range of 5-15%. However, to date there has been resistance in the U.S. to setting such a high standard for new buildings. There are many examples of homes with energy reductions of 50-80%, but the number of such homes built is very low. This might be surprising due the expressed public interest in reducing greenhouse gas emissions significantly. But without building codes that require this new method of building, we will likely continue to build conventional buildings for many years.

<u>Arguments Against Very Energy Efficient Homes</u>

There are several reasons for the limited production of very efficient homes. Often people are encouraged to take small steps in terms of making better homes. Or they are told the payback is too low. The main arguments are summarized below.

It's Easy to Be Green: This idea is often marketed under the phrase "it doesn't have to cost more to be green!" Or "begin with small steps and take bigger ones later". This viewpoint, that it's not hard to save energy, is popular in the mass media, encourages small steps and leads to ineffective actions. People want to make it seem easy and fun, but the actual savings from such an approach are quite small.

Payback Time: Even though there may be huge societal consequences if home CO_2 emissions are not lowered, there is an economic theory that is partly to blame for the slow progress. This theory utilizes an arbitrary time horizon (payback period) for personal decisions. Most people in the U.S. only live in a house for an average of seven years. Under the current economic thinking, a technology or innovation such as super-insulation must pay for itself in about half that time, about three to four years. Based on this perspective most people tend to reject the idea, assuming they will lose money on energy improvements. But when someone does a kitchen remodel or buys a new car, they don't ask, "what's the payback period?" "Payback period" does not take into account the future costs of climate change. To limit home CO_2 emissions requires a different way of thinking, one that is considering the future of the human race as a whole rather than one's own financial situation.

Getting back the efficiency investment: It costs more to build an energy efficient home than a conventional home. A builder might never recover the additional cost incurred of building an energy efficient home because the market for such homes is small. The benefits of reduced energy use will go to the person who buys the house. But it may be that most people will not pay for the additional building cost to obtain that efficiency. For a spec builder, this would mean it might be harder to sell the house and recover the additional cost. This highlights an economic limitation, which is the perceived lack of valuation of energy efficiency features in resale. Some information about this valuation gap has been provided by California studies, where some energy efficient homes have sold for a premium. But under today's views, there is a significant risk.[13] [14]

Resistance to Change: The home construction industry is conservative. It is unique with a very large number of contractors building a relatively few homes at a time. There are few large corporations. Profit margins are small and the owners avoid risk, particularly risk of new technology because of the uncertainty of estimating labor costs. Builders prefer to repeat the same patterns from home to home. The building industry suffered enormously in the 2008 recession. Many companies went out of business in the recession. Many laborers and carpenters in the construction industry were forced to find new careers. Until building codes are enacted that require energy efficiency, few builders will take the risks.

The perceived economic downside of making our homes more efficient does not take into account the high probability of rising energy prices. Americans may end up living in houses that they cannot afford to heat and cool because they were inadequately designed and built. Four decades of research and application have shown that buildings can be built that use very little energy for heating and cooling. Installing insulation is much cheaper than installing replacement windows. The cost of insulating a new home is only 1.9% of the sales price.[15] It is also important to consider that the cost of retrofitting an existing home to a much higher performance level is relatively expensive.

Energy Savings of Key Energy Efficient and Green Building Programs

As noted above, interest in building efficiency intensified in the early 1990s. It took most of the decade to develop the rating systems along with the tools, products and techniques. The industry did not hit its stride until the beginning of the 2000s decade. Table 3 is a summation survey of housing built from 2000 through 2015. This table shows the total U.S. Housing Stock, and the units completed in the 16-year period of time. Below that is the conventional homes total.

It also includes most of the houses built to the codes, options, and standards discussed in a separate report. Note that the Green total (which includes the LEED for Homes program developed by the US Green Building Council and the National Green Building Standard (NGBS) developed by the National Home Building Association as well as state, local and regional efforts), number 37,000 units out of 996,000 units in 2015 or about 4% of the market. The energy efficient category, mostly Energy Star, Building America and Builders Challenge, have about 8 percent of the market. Combining the two categories shows about 12% of the homes built in 2015 were either green or energy efficient. Note that the percent savings is not easily determined for the 16-year period which provided most of the improvements since the 1990s. Energy efficiency and green together were about 10% of the home building completions for the period 2000-2015.

Housing Units (in Thousands)																	
Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Total**
US Total Housing Stock 2015																	118,000
Housing Units Completed	1,574	1,571	1,648	1,679	1,842	1,931	1,979	1,503	1,120	794	652	585	649	764	883	966	20,140
Conventional Category																	
Conventional Total	1,557	1,534	1,566	1,562	1,705	1,761	1,776	1,369	994	669	504	422	508	620	740	835	18,122
Green Category																	
Local/Regional Green (est)	7	7	7	7	7	7	7	7	8	9	9	8	7	7	7	6	117
LEED for Homes										2	3	7	15	17	18	16	78
NatlGrnBldStnd											1	4	8	14	15	15	57
Green Total	7	7	7	7	7	7	7	7	8	11	13	19	30	38	40	37	252
Energy Efficient Category																	
Energy Star	10	30	75	110	130	160	190	120	110	105	126	127	101	92	87	84	1,657
Building America						3	6	7	8	9	9	12	0	0	0	0	54
Builders Challenge												5	10	13	15	8	51
Zero Ready Energy														1	1	2	4
Energy Efficient Total	10	30	75	110	130	163	196	127	118	114	135	144	111	106	103	94	1,766
Green & Energy Efficient Total	17	37	82	117	137	170	203	134	126	125	148	163	141	144	143	131	2,018
% G and EE/All Housing Units	1%	2%	5%	7%	7%	9%	10%	9%	11%	16%	23%	28%	22%	19%	16%	14%	10%
% G/All Housing Units	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	2%	3%	5%	5%	5%	4%	1%
% EE/All Housing Units	1%	2%	5%	7%	7%	8%	10%	8%	11%	14%	21%	25%	17%	14%	12%	10%	9%
% Energy Star/All Housing Units	1%	2%	5%	7%	7%	8%	10%	8%	10%	13%	19%	22%	16%	12%	10%	9%	8%
% G & EE/All Hsng Units xcpt ES	0%	0%	0%	0%	0%	1%	1%	1%	1%	3%	3%	5%	5%	5%	5%	3%	1%
% ES	1%	2%	5%	7%	7%	8%	10%	8%	10%	13%	19%	22%	16%	12%	10%	9%	8%

Table 2 – Housing Unit History 2000-2015

This table shows the housing unit production for the years 2000-2015. It is divided into three categories – conventional, green and energy efficient. The bottom part of the table shows percentage relationships. The Housing Units Completed is the sum of the Conventional Category, the Green Category and the Energy Efficient Category. Note that the Green and Energy Efficient Category captured 1% of the market in 2000, increased to 28% of the market in 2011 and decreased to 14% of the market in 2015.

The Energy Star program is the largest of all the programs analyzed. Energy Star production reached a peak of 190,000 units completed in 2006 and declined to less than half of that number in 2015. Building America and its follow on related Builders Challenge program peaked at 17,000 units in 2011 and declined to 10,000 units in 2015. The total category of Energy Efficient homes peaked at 196,000 units in 2006 and declined to 94,000 units in 2015. This category's market share grew from 1% in 2000 to 25% in 2011 and declined to 10% in 2015.

The Green residential homes total for 2012-2015 was respectively 30,000, 38,000, 40,000 and 37,000 units, showing a small decline. Market share for this category increased from zero to 5% in 2012 and declined to 4% in 2015.

Note that the decline of both categories is occurring in a period of rapid housing growth, represented by the total units built for 2012-2015, which were respectively 649,000, 764,000, 883,000 and 966,000 units. In addition a disproportionate share of LEED for Homes and NGBS residences were in the multi-family category, which are smaller sized units than single family homes. So the energy savings is much less than if these programs were proportionally distributed between the single family home and multifamily categories.

Table 3 summaries the data from Table 2 in three categories. Category one is for the year 2015, category 2 is for the period 2000 – 2015 and category three is a number representative of the total housing stock. The left side of the chart shows the total number of units built in the three categories, while the right side of the chart shows the market share percentages for the three categories.

Housing Units (in Thousands)				Percent of Housing Units		
	2015	2000-2015	Total Stock	2015	2000-2015	Total Stock
US Total Housing Stock	118,000	118,000	118,000	100.0%	100.0%	100.0%
Housing Units Completed	966	20,140	118,000	0.8%	17.1%	100.0%
Conventional Category						
Conventional Total	835	18,122	18,122	86.4%	90.0%	15.4%
Green Category						
Local/Regional	6	117	117	0.6%	0.6%	0.1%
LEED for Homes	16	78	78	1.7%	0.4%	0.1%
NatlGrnBldStnd	15	57	57	1.6%	0.3%	0.05%
Green Total	37	252	252	3.8%	1.2%	0.2%
Energy Efficient Category						
Energy Star	84	1,657	1,657	8.7%	8.2%	1.4%
Building America	0	54	54	0.00%	0.3%	0.05%
Builders Challenge	8	51	51	0.8%	0.3%	0.04%
Zero Ready Energy	2	4	4	0.2%	0.02%	0.003%
Energy Efficient Total	94	1,766	1,766	9.7%	8.8%	1.5%
Green & Energy Efficient Total	131	2,018	2,018	13.6%	10.0%	1.7%

Table 3: Summation of the Units Built and Market Share for three periods

To determine the energy and CO_2 saved for the three categories, the percent of market is multiplied by the percent of energy saved for the various programs. Table 4 shows the energy saved for each category, ordered by the total number of homes built.

Category	Energy Reduction	Number of Units Built (thousands)
Conventional	0%	18,142
Energy Star	20%	1,657
Local/Regional	15%	117
LEED for Homes	30%	78
NatlGrnBldStnd	25%	57
Building America	50%	54
Builders Challenge	30%	51

Table 4: Percent of Energy Savings for Various Programs

Estimates of energy savings vary widely. The bulk of Energy Star homes built were targeted to provide a savings of 15%. Later versions set a target of 30%. The 20% used here is a weighted average. Local/Regional cover dozens of programs going back to 1990 when the first green building program was established in Austin, TX. Some sources say there were 70 local green building programs at one time with most of them no longer in operation as Energy Star, LEED for Homes and National Green Building Standard increased their share of the market.

LEED for Homes and National Green Building Standard each have four subcategories implying eight different possible energy reduction percentages. Obtaining the distribution for the eight categories and dividing the categories into single family and multifamily is difficult. Neither organization provides a good summary of its ratings.

Building America and Builders Challenge buildings are in decline. The Department of Energy is focused now on Zero Ready Energy Homes, a new program at a beginning stage. The number of such homes is too small to measure at this point.

Reviewing the following results will show that getting the Energy Reduction percentage very accurate is not necessary to get an overall perspective on the total energy savings for homes.

Table 5 shows the energy and CO_2 reductions of the three categories from table 3. The left side of Table 5 is a copy of the left side of Table 3. The right side of Table 5 shows the actual energy and CO_2 reductions, which are obtained by multiplying the percent in the left hand side of the table by the energy reduction percentages for each of the building types listed in Table 4. The savings for the entire period of 2000-2015 is only 1.7%. The most important number is in the bottom row and rightmost column. This shows the national effect on emissions, a reduction of 0.3%.

	Housing Units (in Thousands)			Energy/CO_2 Reductions (%)		
	2015	2000-2015	Total Stock	2015	2000-2015	Total Stock
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Conventional Category						
Conventional Total	835	18,122	18,122			
	0	0	0			
Green Category	0	0	0			
Local/Regional	6	117	117	0.1%	0.09%	0.01%
LEED for Homes	16	78	78	0.5%	0.1%	0.02%
NatlGrnBldStnd	15	57	57	0.4%	0.1%	0.01%
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Energy Efficient Total	94	1,766	1,766	1.6%	1.5%	0.2%
Green & Energy Efficient Total	131	2,018	2,018	2.6%	1.7%	0.3%

Table 5: Energy Savings – % Reduction: 2015 and 2000-2015

This table shows how little impact green and energy efficient building trends have had on lowering overall U.S. home energy use and CO_2 reductions. It is disappointing that these percentages are relatively small. Green and energy efficient offer some savings, in the range of 20 to 25%. When this rate of savings is applied to only 10% of the homes built during the period in question or to the 118 million homes that already exist, the reductions are miniscule.

However, it is important to realize that this 16-year period has been devoted to learning about energy savings in buildings and beginning to move an entire industry in a new direction. Climate change is not a simple environmental issue and the threat is growing exponentially. On the other hand, these efforts began long before the seriousness of climate change was understood, which entered the public consciousness with the Fourth International Panel on Climate Change Report in 2007 and the seminal film by Al Gore (2006) entitled *An Inconvenient Truth*. Should society and the government decide to make more rapid change, then the efforts that have been made in the last 16 years are invaluable. Without the work done to date, changing our buildings relative to energy consumption would be extremely difficult.

What will the future bring? – hopefully the comfort and low energy use of passive house and ZEH. These two technologies verify that the industry can construct buildings that use 80% less heating and cooling energy with a small cost increase. The techniques of retrofitting existing buildings to use 50 to 80% less energy are also well known. As noted earlier, there is tremendous resistance to change. Other than in Europe, passive house standards are not being put into building codes, so change is still voluntary. There are no recent announcements from Building America on the success of the Zero Ready Energy Homes program. Passive Houses and Net Zero Energy homes are still being built in very small numbers.

The switch from coal to natural gas for electricity production may be relieving the pressure to reduce emissions in the U.S. by building better homes. The long-range trends from Table 2 do not show a lot of enthusiasm for energy efficiency or green building. To a great extent the government is trying to use persuasion to convince the industry of the advantages of Green and Energy Efficiency. But the industry is driven by preferences from the consumer and cannot be cavalier in its building practices. *Mandatory energy codes will be required for the building industry to move to a higher energy performance standard*.

This review illustrates the damage that can be done by having a multitude of competing housing energy programs, each touting its advantages and offerings, leaving the public confused. Every sale is hailed as a triumph but the longer range trends are not made available to people, fostering a misleading impression of rapid progress. Because the programs are voluntary, the market penetration is relatively small. So the general interest in the population remains low.

Another important consideration is that the average size of our homes has increased in this period which offsets energy efficiency. Usage of electronics in homes has also increased. These are obstacles to cutting energy use and CO_2 emissions.

Reviewing the Energy Intensity of the Existing Housing Stock

New construction is only a small part of the total housing energy and emissions problem. There are about 118 million occupied residences in the US. [16] The average rate of new construction is about 1.4 percent per year, and when demolition, condemnation, and conversion of residences are factored in, the net growth per year is about 1.2 percent. Once built, a residential building is likely to be usable for about one hundred years, if properly maintained. [17] It is necessary to understand the energy and emissions nature of the existing building stock to determine the optimum plan for CO_2 reductions.

Chapter 2 of the DOE's *Buildings Energy Data Book 2011* provides an excellent summary of the energy use patterns of existing residences. The important measure used is Energy Intensity (EI). Energy intensity, also referred to as Energy Use Intensity (EUI), is defined as the energy consumption per unit area of a building's floor plan, the unit area typically being square feet. The energy metric typically used is BTUs (British Thermal Units).

The two graphs on the left side of Figure 1 shows the change in energy intensity (in thousands of BTUs) per square foot as well as the energy intensity (in millions of BTUs) per household. The change in energy intensity per square foot declined from 75 thousand BTUs per square foot prior to 1950 (red) to 45 thousand BTUs per square foot (blue) in 2005 (a 55 year period). This is a 40% decline, less than one percent per year.

Household energy intensity declined from 115 million BTUs per household (red) to 95 million BTUs (blue) in the same period, a decline of 18%, less than half a percent per year. Note that the graph shows a decrease through 1989 and then an increase in household energy use for the next two periods. This is probably due to the increase in the average house size.

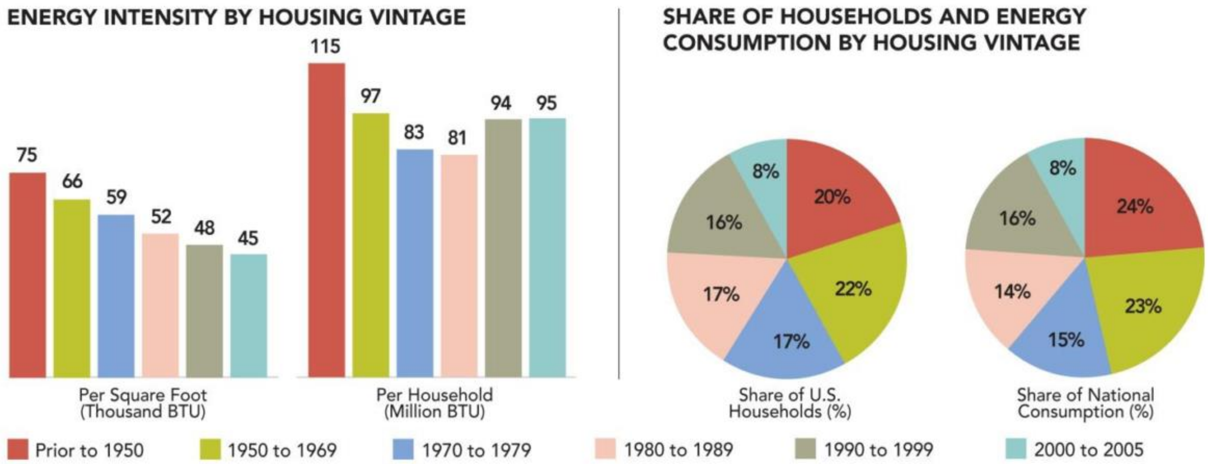

Figure 1 – Energy Intensity and Energy by Vintage [18]

The right side of Figure 1 shows the energy consumption allocated to housing by vintage, that is, the age of the building. Note that younger buildings, built after 2000, represent only 8% of the households and 8% of national energy consumption. This emphasizes the need for energy reducing solutions for the existing housing stock.

Even though the energy efficiency of devices, like natural gas furnaces, has increased over the years, there is only a small reduction in energy use for heating. This is due to a long term increase in average house size over the decades. See Figure 2.

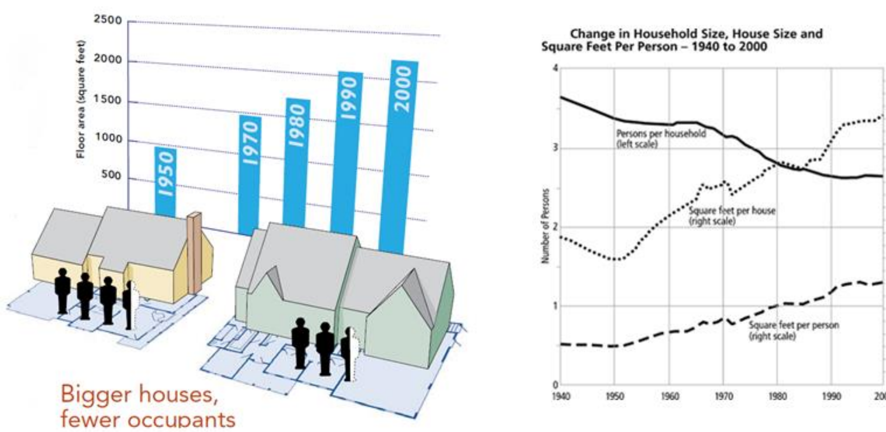

Figure 2: Change in House Size, House Size and Square Feet per Person [19]

Table 5 shows that not only have homes increased in size but also the number of occupants has decreased. This change, which began in the 1950s, is an example of Jevon's paradox, which says that as efficiency increases, consumption increases in parallel. This trend is continuing. Since 2010 the trend has continued with 2015 homes near 2,500 square feet in area.

Year	1950	1970	1990	2010
U.S. Home Size Square Feet-New	983	1,500	2,080	2,392
Residents per household	3.4	3.4	2.8	2.7
Square feet per person	292	478	760	900

Table 5: Change in home size, residents per household and square feet per person (New Construction) [20]

Figure 3 from the *Building Energy Data Book* provides the energy intensity for different housing types. The left hand side shows that single family detached homes are the most efficient on a square foot basis but least efficient on a household basis. The right hand side of this figure shows that single family homes use the lion's share of energy.

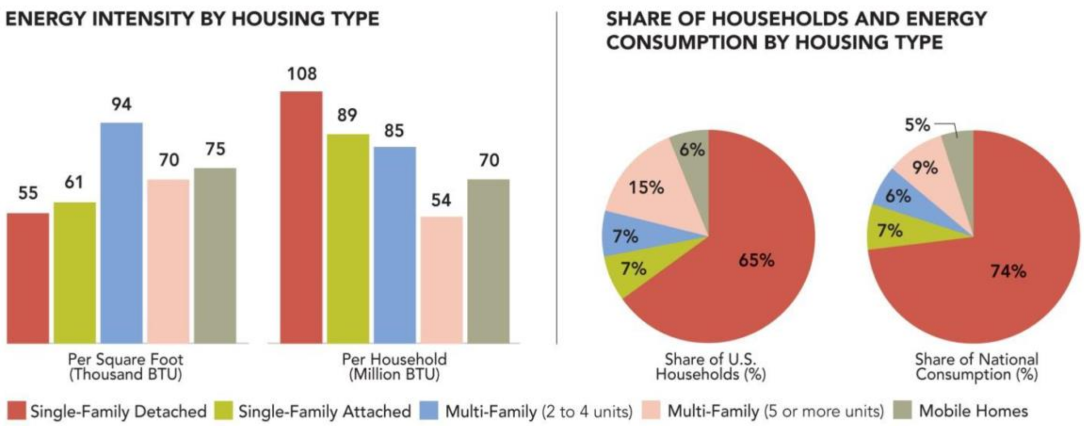

Figure 3: Energy Intensity by Type and Share of Households [21]

Should Energy Intensity be the Primary Metric?

Energy intensity applied to the total U.S. housing stock provides a much clearer perspective on energy use than the metrics used in the Home Energy Rating System (HERS) commonly applied to Green and Energy Efficient building. The HERS index is useful and provides better information than a myriad of certifications based on colors or precious metals, but at some point this index will have to adjust its "level 100" to later energy codes, making it difficult to understand earlier certifications. An "energy intensity" value would be the same for the life of the building although it may be changed by efficiency improvements or by homeowner behavior adjustments.

Scientists, researchers, and building engineers must use a practical physical measure to design more efficient buildings as well as to maintain and improve heating and cooling equipment in older buildings. Both the DOE and EPA do their calculations and projections on building energy use and CO_2 emissions. It would be useful to the public to understand the metrics so as to avoid being confused by colors or other irrelevant attributes.

It is not difficult to measure a home's energy directly without the need to map that energy use into an arbitrary rating scheme. The EPA maintains such an analysis that is frequently updated based on the most recent information available.[22] It includes the actual values for different kinds of energy including:

Electricity: 12,069 kWh per home × 1,232 lbs. CO_2 per megawatt-hour generated × (1/(1-0.072)) MWh generated/MWh delivered × 1 MWh/1,000 kWh × 1 metric ton/2,204.6 lb. = 7.270 metric tons CO_2/home.

Natural gas: 52,372 cubic feet per home × 0.0544 kg CO_2/cubic foot × 1/1,000 kg/metric ton = 2.85 metric tons CO_2/home

Liquid petroleum gas: 70.4 gallons per home × 1/42 barrels/gallon × 219.3 kg CO_2/barrel × 1/1,000 kg/metric ton = 0.37 metric tons CO_2/home

Fuel oil: 47 gallons per home × 1/42 barrels/gallon × 429.61 kg CO_2/barrel × 1/1,000 kg/metric ton = 0.48 metric tons CO_2/home

Total CO_2 emissions for energy use per home are:
7.27 metric tons CO_2 for electricity +
2.85 metric tons CO_2 for natural gas +
0.37 metric tons CO_2 for liquid petroleum gas +
0.48 metric tons CO_2 for fuel oil =
10.97 metric tons CO_2 per home per year.

Note that most CO_2 comes from creating electricity from coal and natural gas, with very small amounts from liquid petroleum (LP) and fuel oil. The latter two are often trucked to rural residences. Essentially our electricity bill and natural gas bill provide all the information a homeowner needs to determine how much CO_2 they are generating from their home. When such a metric is applied, then understanding will grow. In some countries the utility bills must be shown when selling a home so the potential purchaser has a good sense of the efficiency of the home. Remember that each region will be different – the data above is for the nation as a whole.

Accurate measures, accurately applied will be vital in making the changes needed to address climate change.

Green/Energy Efficiency versus Emissions Intensity

CO_2 reduction needs to be ~~is~~ the common goal for buildings. However, as noted earlier, much of the popular rhetoric of green and energy efficient building covers up this significant metric by the use of colors or the names of metals to denote a building's energy performance. A few years ago the Oxford English Dictionary added the word greenwash, defined as "disinformation disseminated by an organization so as to present an environmentally responsible public image." The term creates many obstacles including wishful thinking, marketing hype, misleading statistics, and political naivety. Many new construction projects certified under a "green" methodology provide no substantiating information about their energy performance. Frequently, innovative "green" buildings are found to be underperforming after occupancy. In the worst case, greenwash is a deliberate attempt to hide potential failures, which could possibly aggravate global warming.

Some people argue that climate considerations require a balance between social, economic and environmental factors. In terms of a building many things could be considered. But the most urgent issue facing humanity is climate change and carbon dioxide (CO_2) emissions are responsible. As noted at the beginning of this paper, buildings account for roughly half of the total CO_2 emissions in the U.S. CO_2 emissions are measurable and understandable by environmentalists and skeptics alike.

CO_2 reduction will eventually be a fundamental part of design and construction. So it is surprising to find that buildings and homes are not routinely measured for energy and CO_2 performance after occupancy. This may be due to potential embarrassment as to the greenness of a structure. Today new homeowners typically are not interested in anything other than correcting defects after building completion. In the future they will need to become involved with understanding and reducing the CO_2 emissions of their homes.

There are two principle areas of concern. First even though a building may have been designed for relatively low CO_2 emissions, few are performing as well as the original calculations projected. This may be due to construction imperfections or malfunctioning equipment. Either could be corrected with post occupancy analysis and rework. Or it could be due to using untested methods of building to an efficiency standard. Secondly the performance of the home may be relatively good for heating and cooling but occupant use may drive up emissions through high usage of new equipment such as electronics and computers.

Building codes do not address limiting of CO_2 emissions from personal energy use habits. Many of the calculations for energy use deal mostly with analyzing the building envelope and HVAC equipment. So-called “dashboard” technology could be applied or personal reduction efforts can be made using devices like Kilowatt meters to bring more awareness of what are called “plug loads”.

The focus for out buildings should remain on CO_2 emissions. Often green rating systems tend to focus on a variety of products and activities, including comfort, productivity, ease of use, source of materials, and possibly a sense of wellbeing. These should be separated from energy codes to address the climate emergency. If not, they dilute our focus and effort to solving the critical problem of CO_2. There are many considerations of the built environment but attempting to address all issues has led to the current situation of multiple standards for meeting an arbitrary “green” standard as opposed to a simple measure of energy or emissions intensity.

Summary

There are six key points to conclude from this paper:

1. After decades of effort, home energy savings in new residences has been marginal because energy saving is voluntary. Strict universal energy codes need to be developed and applied as soon as possible.
2. Energy savings achieved were offset by new uses of energy such as central air conditioning and electronics. Better refrigerators in many cases led to multiple refrigerators in a single home.
3. The dominating factor for continued inefficiency has been an increase in the square feet per person from about 300 square feet in 1950 to more than 900 square feet today (single family homes).
4. New methods and technologies exist in the form of Zero Energy Houses (ZEH) and Passive House that are proven to cut heating and cooling energy use significantly.
5. There will be minimal climate reductions from better new buildings. The major changes must be in the existing building stock. The highly efficient new buildings provide technology and understanding for retrofitting older buildings.
6. New buildings, if not built to an efficiency improvement of 80% better than current buildings, may have to go through an expensive retrofit in the future.

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