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NewSolutions

The Community Solution℠

Community, a solution for saving the environment and conserving resources with equity for all.

The Energy Impact of Our Buildings

Peak Oil and climate change require a revolutionary approach to all aspects of our lives. To date much attention has been placed on the automobile's use of energy with secondary emphasis on food. But the energy used (and CO_2 generated) by the automobile or from food production is less than the energy used in our buildings. Furthermore, building energy consumption has been continually increasing in spite of improvements in building and appliance efficiency. Once more we are reminded that our problems are not solvable simply by improving technology.

It is important to determine the appropriate context when considering energy consumption relative to buildings. There must be a deep understanding of the current building infrastructure and the choices that have been made in the past decades that have resulted in this particular set of buildings. It is also important to grasp the concept of embodied and operating energy and the implications. Understanding a building as a container for a large number of appliances that use energy is vital. Perceiving the limitation of technical fixes is equally important.

This report delves deeply into energy consumption in the home component of the total building infrastructure.

Buildings, Energy and CO_2

The burning of fossil fuels generates the now life-threatening CO_2 that is changing the climate. It is useful to understand this direct correlation. Since they are closely related, both CO_2 emissions and fuel consumption figures are used as a measure of fossil fuels burned. This is reflected in the information contained in the *Buildings Energy Data Book*, an annual publication of the Oak Ridge National Laboratory.[1]

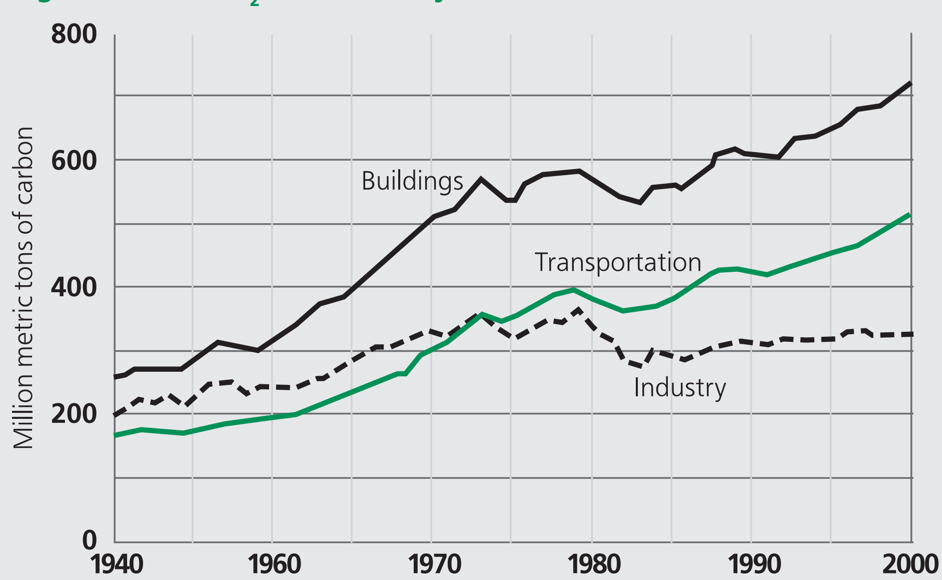
This report shows that the share of U.S. Primary Energy Consumption in 2004 for buildings was 39 quadrillion (a quadrillion = 1.0 x 10^{15}) British Thermal Units (Btus) or 39 "quads," which is about 39% of the total energy consumed in the country. (Note: The annual energy consumption in the U.S. is slightly more than 100 quads [each quad is one quadrillion British Thermal Units] so the numbers for energy used measured in quads and the numbers that are measured in percentages of total consumption are almost identical). The report also states that the carbon generated from building operation was 608.1 million metric tons or 38% of total carbon generated in the U.S. This shows the direct relationship between fuel consumed and greenhouse gases. The 39 quads for buildings is divided into 18 quads for commercial buildings and 21 quads for residential buildings.

Figure 1,[2] based on the work of Ed Mazria, compares the carbon generated by buildings, transportation and industry. It shows the high percentage of energy consumed for buildings, and that the rate of increase in energy consumption for buildings and for transportation is approximately the same.

Some analysts suggest that the 39% of energy used for buildings is low. Mazria uses 48% as the amount of energy devoted to buildings. He arrives at this number by including the energy consumed in construction and suggests that, over the lifetime of a building, 1/6 of the total energy consumed is used in construction (often referred to as embodied energy), and 5/6 of the total energy is consumed in operating the building. Using this ratio and applying it to the 39% previously noted gives a total number of 46.8% for both construction and operating energy of buildings.

Gil Masters at Stanford University[3] uses 40% rather than 39% as the amount of operating energy (22% for residential buildings, 18% for commercial buildings). He adds an additional 2% for a category of industrial buildings, giving a total of 42%, and then adds an additional 7% for the embodied energy in materials. If this 7% embodied energy is compared to his 42% operating energy, the result is a ratio of 1/7 to 6/7 between embodied energy and energy used to run the buildings. A Cana-

Figure 1: U.S. CO_2 Emissions by Sector



dian architectural organization[4] estimates 85.5 % for building operating energy and 14.5% for building embodied energy, the latter divided into initial embodied energy and recurring embodied energy (see Figure 2[4]**).** Over the life of the building, this gives the same ratio of 1/7 to 6/7 between the embodied energy and the operating energy as estimated by Masters and is close to the 1/6 and 5/6 suggested by Mazria.These ratios show that, as a rough rule of thumb, building energy is distributed 15% for embodied or construction energy and 85% for operating energy.

The total quantity of energy used in the U.S. for buildings for both operating energy and embodied energy can be estimated by taking the operating energy from the 2006 Buildings Energy Data Book (39%), adding the 2% for industrial buildings from Masters and applying the derived 1/7 ratio of embodied energy to operating energy, giving a good approximation of about 48% for the building energy portion of total yearly energy consumption. Thus almost half the energy consumed yearly in the country is in constructing and operating buildings, much more than either the energy for transportation or for food.

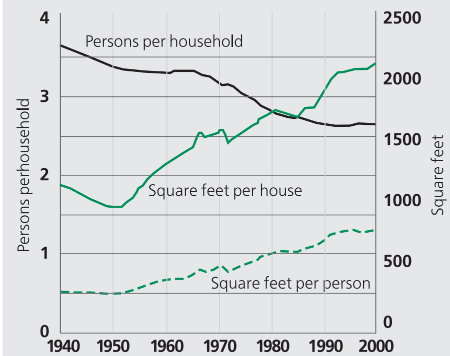
Per Capita Square Footage

The 2006 Buildings Energy Data Book[1] estimates that the U.S. has a total of 5 million commercial buildings totaling 75 billion square feet. It also shows there are about 114 million households living in about 90 million residential buildings in the U.S. totaling about 175 billion square feet (extrapolated from the year 2000).[1] The total square footage for commercial and residential buildings is about 250 billion square feet.

The approximate distribution of types of residences is 83% single family, 13% multifamily and 4% manufactured housing. The average household size is 2.6 persons (see Figure 3[1]). This gives an average residential square foot per person for existing residential units of approximately 600 square feet. The average commercial square foot per person is about 250 square feet.

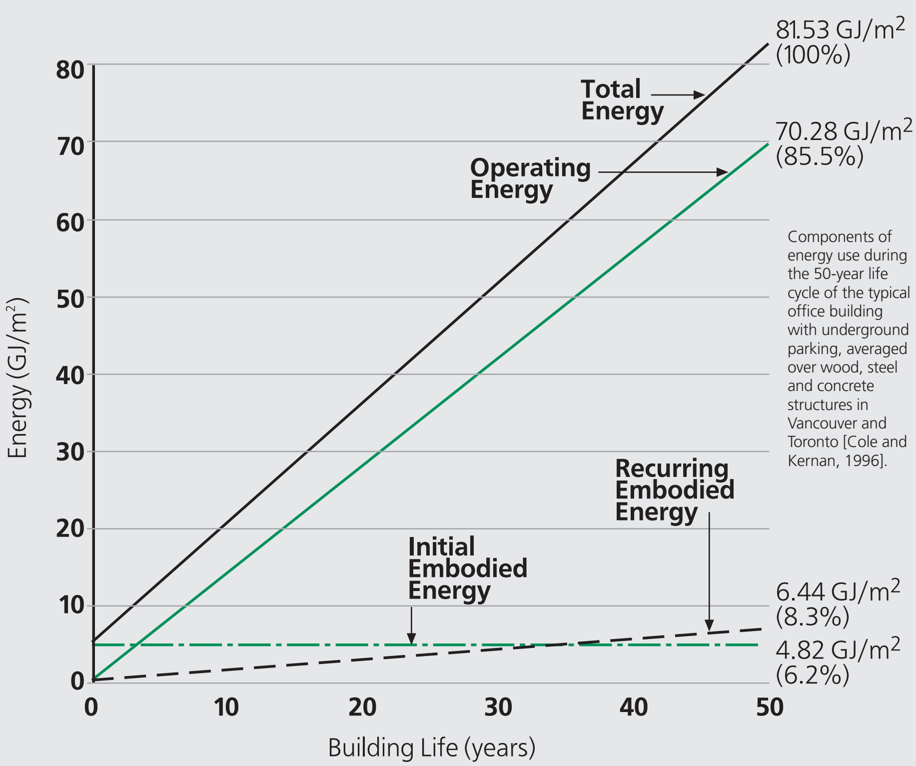
The average size of a new single family home built in 2005 was 2,227 square feet while the average size of a multi-family home built that year was 1,149 square feet. 1.6 million single family homes and 296,000 multifamily homes were built in 2005.[1] At 2.6 residents per household,[1] new construction was about 800 square feet per capita, an increase of 200 square feet in just 15 years..

Figure 3: Changes in House Size and Density



In 1990, per capita square footage was approximately 600. In 2005, per capita square footage for new construction increased to 800.

Figure 2: Relationship of Operating Energy to Embodied Energy



Other new housing statistics verify an increasing amount of square footage per person. In 1950, America's average square footage for new residential buildings was about 300 square feet per person versus the approximately 800 square feet per person for today's new construction.[5] A more detailed study in *The Journal of Industrial Ecology* shows that for houses the average per capita square foot in 1950 was 293 sq.ft. compared to 893 sq.ft. per capita in 2003, an increase of three times.[6]

Robert Putnam in his book *Bowling Alone* describes the deterioration of the conviviality of community and its replacement with isolation.[7] The increased square footage per person may be partially due to American's increasing time spent at home as social relations degrade and people become more separate. Americans now spend about 90% of their time within a building, much of it in solitary watching of TV or surfing the Internet.[8]

Per Capita Building Energy Consumption

It is important to know buildings' operating energy requirements per person using the 39 quads of operating energy previously noted.[1] One quad is about equivalent to the energy in 45 million short tons of coal or 172 million barrels of crude oil.[1] The 39 quads used in operating buildings each year is the equivalent of approximately 6,708 million barrels of oil yearly. Residential buildings use 21 of the 39 quads or the equivalent of 3,612 million barrels of oil yearly, and commercial buildings use 18 of the 39 quads or the equivalent of 3,096 barrels of oil yearly. On a per capita basis (using a population figure of 295 million which was the population at the time this data was produced) building operating energy consumption was 22.7 Barrels of Oil Equivalent (BOE) per person, composed of 12.2 BOE for residential buildings and 10.5 BOE for commercial buildings.

This calculation only applies to operating energy. As noted in a preceding section, construction embodied energy is estimated at about 7% of all energy, the equivalent of 1,204 million barrels of oil. On a per capita basis total building embodied energy consumption is 3.9 BOE per person, composed of 2.1 BOE per person for residential and 1.8 BOE per person for commercial. The total yearly per capita home energy used is 14.3 BOE – 12.2 of operating energy plus 2.1 of embodied energy.

Embodied (or construction) energy is not as obvious as the operating energy measured in utility bills. However, it is apparent when one moves from a small house to a larger one. The higher cost of the larger house is not just from inflation but represents the energy embodied in the new house, both the energy used at the time of initial construction and also the energy used for remodeling or repairs over the life of the home. Per person, Americans consume far less energy for their cars or food than for their homes. The per person energy consumption for food is ten barrels per year, for automobiles nine barrels per year, and 12.2 for homes.

Besides using more energy than cars, buildings use a wider variety of fuels including petroleum, natural gas, coal, uranium and electricity from dams and other renewables. It is clear that fossil fuels are being used when the gas tank of a car is filled. The smell of the gasoline is obvious. The efficiency of driving can be measured in terms of miles per gallon. The use of energy in buildings is not as obvious. The natural gas that warms the house or the coal that generates the electricity to run its machines is not visible. But nonetheless energy is being consumed constantly in homes – much more energy than in cars. Buildings are also generating CO_2 just as cars are, but at a higher rate.

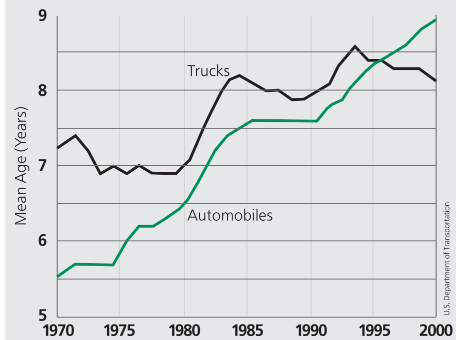
Like our cars, U.S. buildings – commercial, industrial, and residential – consume far more energy than the equivalent buildings in the rest of the world. Also, like our cars, our buildings are bigger than they need to be and are often inefficient and wasteful. Our architects have for years designed energy-consuming buildings under the mantra of “bringing the outdoors inside” and “blurring the difference between out and in.” This stylistic fixation with size and many large windows makes our buildings very energy consumptive.

In the U.S. 38% of CO_2 emissions are from buildings while on a world wide basis 10% of emissions are from buildings.[1] Comparing the two numbers shows that the buildings in the U.S. (with 5% of the world’s population) generate 42% of the world’s CO_2 emissions from buildings. This is an example of extremely excessive consumption.

Longevity of Buildings

Compared to cars and food, buildings have a much longer life. The average age of a car or light truck (see Figure 4)[8] is around nine years old. Few passenger vehicles last more than 12-16 years.

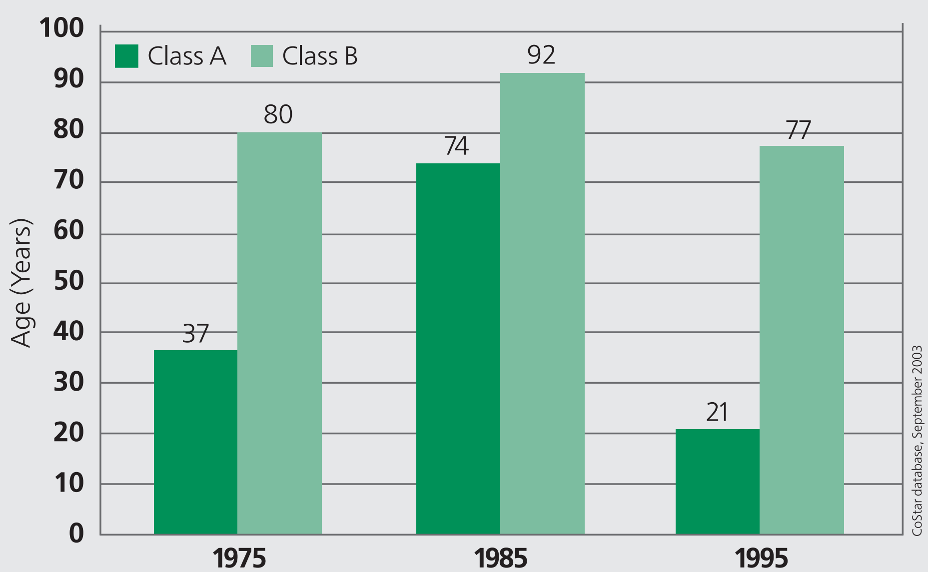
Figure 4: Median Age of U.S. Cars and Trucks



But the average life of a house is more than 75 years.[9] The Empire State Building is 75 years old and it shows little signs of aging.[10] Commercial and other large buildings can last for centuries. Many existing New York buildings are even older than the Empire State building (see Figure 5).[8]

The life span of existing buildings is an important consideration when estimating future energy needs for buildings. It shows

Figure 5: Median Age of NYC Office Buildings



*Median age incorporates building renovation dates as beginning dates of buildings.
Note: Class A and B indicate general quality of the buildings, including location, management, construction and tenant standards.

that there is a limit to the benefits of new energy conserving building techniques that are applied only to new homes. There are 114 million households in the U.S. and the country builds approximately 1.6-2.0 million new household units annually.[1] It will take many decades to replace the existing homes at that rate. By that time it is questionable if there will be any fossil fuels remaining.

Building Energy Consumption Trends

Houses built prior to 1970 use 51,600 Btus per square foot and use[1] 56% of the total energy consumed by residential buildings (see Table 1). Houses built from 2000 to 2001 consume 36,600 Btus per square foot but consume only 1% of the total residential energy.

It is important to realize that the efficiency of America's new buildings is not much improved in terms of energy, having only decreased consumption from 51,600 Btus per sq.ft. to 36,600 Btus per sq.ft., not too impressive in 35 years. And even less improvement has been made when measured on a per capita basis. Prior to 1970 each household member used 40.3 million Btus annually for housing while in 2001 each used 32.9 million. The improvement in efficiency has been limited because each person now uses more square footage and more energy-consuming appliances than ever before. Also, efficiency gains are less effective because of the law of diminishing returns. For example, furnaces have improved from 50% to 94% efficient. There is little more gain possible since the furnaces cannot be more than 100 percent efficient.

Building Operating Fuels

Primary house fuels are natural gas and electricity although there are still some homes that burn fuel oil for heat. Electricity is mostly derived from coal, since coal is the most popular fuel for power plants. The small amounts of fuel oil and coal that are burned directly are trucked to the houses. Natural gas and electricity are carried to the house in buried pipes and overhead wires.

The use of electricity generated by coal plants to heat a home rather than burning the coal in the home does not eliminate pollutants but simply moves them from the place of consumption to the place of generation. (Much more coal is used in heating with electricity generated from coal than would be used if the coal were burned directly for its heat at the house). The percentage distribution for fuel consumed in buildings is shown in Table 2.[1]

Note that coal and nuclear combined provide 52% of the country's energy used in buildings. The U.S. government plans to increase the percentage of energy from these extremely toxic fuels to replace declining supplies of oil and natural gas. Most of the energy designated "other renewables" comes from wood, so there is little hope for growth in the use of that fuel unless the country is deforested. Only a fraction of 1% of the energy consumed comes from photovoltaics and wind turbines, reminding us that renewable sources are important but limited.

Table 2: Distribution of Fuel Used in Buildings

Fuel	All Buildings	Residential	Commercial
Coal	37%	35%	41%
Natural Gas	31%	33%	29%
Nuclear	15%	14%	16%
Petroleum	8%	9%	7%
Hydro	5%	5%	5%
Other Renewables	3%	4%	2%

Table 1: 2001 Residential Energy Consumption

Year	Per Square Foot (10^3 Btu)	Per Household (10^6 Btu)	Per Household Member (10^6 Btu)	Percent of Total Consumption
Prior to 1970	51.6	100.7	40.3	56%
1970-1979	45.5	79.0	31.6	15%
1980-1989	41.4	79.7	31.9	15%
1990-1999	38.5	91.3	31.2	13%
2000-2001	36.6	111.1	32.9	1%
Average	**46.7**	**92.2**	**36.0**	**100.0**

Per household consumption has increased more than 10% since 1970 .

Indirect Building Energy Uses

There are two underground pipes that run to buildings that also consume energy which are not covered in the *2006 Buildings Energy Data Book*. One is the water pipe that brings water to the building and the second is the sewer pipe that removes the effluent from the house. The basic formula is water in, mixed with urine and feces (along with the so called grey water from bathing and laundry), and sewage out.

There is an energy cost for lifting the water from wells, rivers or reservoirs with electric pumps, pumping the water from source to purification plant and from purification plant to building. The purification process is also energy intensive. The sewage must be pumped with electric pumps, purified and pumped or transported to some dumping site. This analysis does not include the energy to provide purified water and process waste but it should be kept in mind that there are other energy costs associated with buildings not included here.

Energy-Consuming Machines in Buildings

In addition to the energy consumed in construction and maintenace of buildings, we should also consider the large number of energy-using machines contained in the buildings. Table 3 shows the distribution of energy consumption for both residential and commercial buildings – the differences are notable.

The major use of energy in commercial buildings is for lighting (25%). Since the vast majority of commercial lighting uses fluorescent bulbs, major energy savings by changing light bulb types does not apply to this kind of building. Larger buildings, and most commercial buildings are larger than

Table 3: U.S. Buildings Primary Energy and Expenditure End-Use Splits, 2004

Energy consumed is shown in quads and % of totals

End Use	Residential		Commercial		All Buildings	
Space Heating	6.6	32%	2.3	13%	8.9	23%
Lighting	2.5	12%	4.3	25%	6.8	18%
Space Cooling	2.3	11%	1.9	11%	4.2	11%
Water Heating	2.7	13%	1.1	6%	3.7	10%
Refrigeration	1.7	8%	1.1	6%	2.8	7%
Electronics	1.1	5%	1.0	6%	2.0	5%
Cooking	1.0	5%	0.4	2%	1.3	3%
Wet Clean	1.0	5%			1.0	3%
Ventilation			1.0	6%	1.0	3%
Computers	0.2	1%	0.4	3%	0.7	2%
Other	0.9	4%	1.8	10%	2.6	7%
Adjusted to SEDS*	1.1	5%	2.2	13%	3.3	9%
Total	**21.1**	**100%**	**17.4**	**100%**	**38.5**	**100%**

* State Energy Data System

residences, have less square exterior surface for each square foot of floor area. Thus the heating loads decline with size.

The major use of residential building energy is for space heating – 32% of the total. The machine that consumes the most energy is the furnace or other device for space heating. A furnace may burn natural gas, oil, coal or wood. An electric furnace will use electricity to heat water or air for heating the house. A more recent invention that uses electricity is the heat pump, which operates on the same principle of compression as a refrigerator. Electricity may also heat the house by resistance electric heaters in different rooms, but these are very wasteful of energy. Major energy savings could be achieved if buildings were designed to be smaller, more compact and better insulated. However, even if a building used no energy for heat, it will still use energy for everything else.

"Green" Building – Hype or Help?

Americans use the rationale of new technologies that are "on the horizon" or "just around the corner" to continue their prodigious use of energy. The fuel cell dream has sustained the continuous manufacturing of low-mileage, energy-wasteful

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cars for decades. In a similar manner, the building industry has continued to build low performance buildings under the mantra of "green building," which includes a wide variety of building technologies and philosophies using such terminology as "eco-friendly," and proffering ideas or programs such as Energy Star, LEED, Zero Energy and "Building America." These are typically portrayed as exciting new developments that are "ready now," "almost here" or "at a breakthrough point." This gives the impression of significant and rapid progress – an impression that only lasts until the numbers are analyzed.

Like the fuel cell dream, such ideas are used to make the population feel that businesses and government are on top of the problem. And like the fuel cell, they have had little impact on reducing the consumption of energy. A very small number of buildings have been built under these designations. One source estimates that 2,600 "green" buildings were constructed in 2002 and 14,600 in 2004, only a fraction of 1 percent of all homes built.[11] Though some of these represent viable advances, it may take many decades to see their impacts. The various "green" options are discussed in more detail below.

Energy Star

Building energy use is controlled by laws enacted in building codes. Building codes are set by the International Code Council (ICC), whose mission is to provide the codes, standards, products, and services concerned with the safety and performance of the built environment. The ICC was established in 1994 as a nonprofit organization to develop a single national set of model construction codes, combining codes from three groups – Building Officials and Code Administrators International, Inc. (BOCA), International Conference of Building Officials (ICBO), and Southern Building Code Congress International, Inc. (SBCCI). The ICC has developed an inventory of International Codes, including the International Building Code, Energy Conservation Code, Electrical Code and several others.[12]

Energy Star is a set of guidelines that emphasizes energy-efficient products and practices that conform to the codes. In 1992 the Environmental Protection Agency (EPA) introduced Energy Star as a voluntary labeling program to promote energy-efficient products to reduce greenhouse gas emissions including CO_2. To qualify for Energy Star rating, new homes must meet the EPA guidelines for energy efficiency. Such homes must be at least 15% more energy efficient than homes built to the standard ICC requirements.[13]

In 1996, EPA partnered with the U.S. Department of Energy to focus on particular product categories. Energy Star labels are now found on major appliances, office equipment, lighting, and home electronics as well as new homes, commercial and industrial buildings.[14] Of appliances shipped during the period 2000 to 2004, only 26% of room air conditioners, 25% of refrigerators, 17% of clothes dryers, and 33% of dishwashers carried the Energy Star label.

Energy Star is heavily promoted as a success story for energy conservation in homes and appliances. Its benefits in 2005 (avoiding 35 million metric tons of greenhouse gas emissions) are said to be twice those of the year 2000. This is a 15% per year improvement rate, and even though the avoided emissions number is large, it is only 5% of current building emissions.

Each American household spends on average $1,680 per year on energy.[1] Total energy expenses for 114 million households were $191 billion. Energy Star savings were $12 billion, only about 6% of energy expenses. The Energy Star organization projects a doubling of benefits in the next 10 years which would translate to only an 8% improvement rate.[15]

After 13 years, the Energy Star program has made relatively small progress toward reducing CO_2 emissions by the 70-90% needed to avoid climate calamity. Like the government Corporate Average Fuel Economy (CAFE) standards for automobiles, the effort is too little too late. Other nations, such as Germany, have advanced to the point where new houses are *required* to limit energy consumption to 32,000 Btus per square foot per year. Energy Star offers a small and welcome improvement but does not approach the scale of change that needs to be made.

LEED

The U.S. Green Building Council (founded in 1993) established the Leadership in Energy and Environmental Design (LEED) Green Building rating for commercial buildings. This is a nationally accepted benchmark for the design, construction, and operation of high performance "green buildings." The designation does not mean the building is actually a green color, nor is high performance defined. Like the Energy Star program, LEED does offer improvement over existing commercial buildings, but the improvements are relatively minor and the impact of the program has been limited.

Some so called "green buildings" are little more energy-efficient than traditional structures.[16] Builders may seek the LEED certification more as a marketing tool than anything else. (A LEED designation allows a plaque to be installed on the building).

Since the year 2000, only 430 buildings have been LEED certified,[17] with 3,655 registered to be certified upon completion. Comparing these miniscule numbers to the approximately 5 million commercial buildings in place shows the negligible effect of the program to date.

Many of the LEED "green" features are not particularly relevant to the building's energy use. For example, placing a bike rack near the building earns one point, which is the same value earned if 5% of the building's energy comes from renewable sources. Likewise, installing a metal grate at the entrance to reduce particle count earns one point while increasing energy efficiency, which might cost tens of thousands of dollars, only earns two points. The certification is also expensive.

The LEED program is an example of a "green" effort which serves mostly as a public relations tool – it will not help to obtain a significant reduction of energy consumption and CO_2 emissions.

Zero Energy

The Zero Energy program was established by the Department of Energy in 2002.[18] The title gives the impression that the home is so efficient it uses little energy and that it creates all the energy it uses. One of its frequently used slogans is "buildings that generate more energy than they use." But a building that generates more energy than it uses is simply a building with an array of solar panels on its roof. It does not mean that the building is particularly efficient.

Buildings use energy; they do not generate it, and suggestions to the contrary are misleading. A Zero Energy home's excess energy, created by solar panels, is fed into the power grid during daylight hours. But when the sun goes down, the house draws power *from* the grid. It is still dependent on this external power source for an uninterrupted supply of electricity.

Since Zero Energy buildings employ Photovoltaic panels (PVs) to generate electricity from sunlight, it is important to understand the history of this technology. PVs have been in existence for many decades and are not a new technology.[19]

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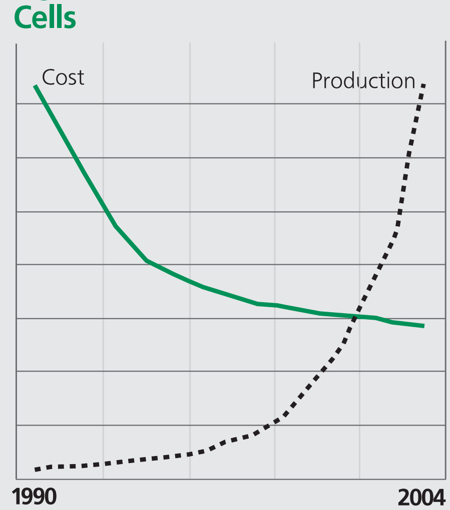
The photovoltaic effect was first discovered in 1839. In 1923 Albert Einstein received the Nobel Prize for his theory explaining the photovoltaic effect. In 1954 Bell Labs produced the first cells with 4.5% efficiency. In 1959 Hoffman Electronics produced a 14% efficient PV cell. [20] In October 2006 Kyocera, a Japanese solar company, announced that it had achieved a new world record of 18.5% energy conversion efficiency for a 15cm x 15cm multicrystalline silicon solar cell.[21] From 14% in 1959 to 18.5% in 2006 – this can hardly be considered a substantial improvement. Such numbers instead indicate a somewhat mature technology.

Photovoltaics also require energy-expensive materials such as glass, aluminum and silicon wafers. In spite of the massive amount of research that has been expended in PVs, the devices still remain expensive. Costs will decrease with volume but not by the amount popularly thought (see Figure 6).[22]

As stated earlier, creating the "zero energy house" effect requires solar energy, both photovoltaic and thermal. But improvements in performance of these devices have been extremely slow. Only a miniscule amount of the energy used in the U.S. comes from PV components, about one thousandth of one percent in 2004.

Figure 6: Costs of Photovoltaic Cells



Furthermore, a zero energy house will be one that reflects the high cost of PV panels.[1,23]

Building America

Another Department of Energy program is "Building America." It focuses on research and development for residential energy systems that could reduce home energy use by 40%-70%. The program also intends to increase the use of onsite residential power and renewable energy systems by up to 30%. The Building America methods have been used in about 35,000 residences, less than 1/10 of 1 percent of new homes built yearly.

Research goals are to realize 20%-30% energy savings in existing homes.[24] In a major Public Relations exhibit in March, 2005, a Building America team of volunteers increased a 1,200-square-foot tract house to a custom-built, 4,200-square-foot, nine-bedroom, six-bathroom, super energy-efficient home, complete with pond, waterfall, and Jacuzzi.[25] This is all too symptomatic of the majority of efforts to build showcase energy-efficient homes. Most of this kind of development takes place at the top end of the market, where owners may pay for innovation or where builders want to show their commitment to "greening" building. The result may be a building that uses less energy per square foot but more total energy than the original tract house.

Green Building Summary

Unfortunately, in general, the category of 'green' building has served more as a public relations ploy for government and industry than a serious cultural transition to low energy housing. These activities have been marginal at best, accounting for fractions of a percent of annual residences constructed.

And, lamentably, when an opportunity arises to make major improvements for new construction, government and business seem committed to the status quo. In September, 2005 the Department of Energy refused to support a bill to increase R-values in walls from R-13 to R-15.[26] The National Association of Home Builders had lobbied against the change. This shows the true position of the government and construction industry. In countries where energy is taken seriously, required wall R-values of 40 are common.

A Return of Passive Solar?

Passive solar began as a grass roots movement during the first energy crisis in the 1970s. Most passive solar homes were built by individuals and custom builders. Author Douglas Balcomb notes that passive solar design was the rage in energy-efficient architecture in the early 1980s.[27] He estimates that 180,000 passive solar houses were built in that period and further estimates that such homes used about 20 percent of the heat required by conventional homes.

Balcomb acknowledges that such efforts have declined and now most architects have "only vague memories of passive solar." Estimating another 70,000 were built during the ensuing years, gives approximately 250,000 passive homes. This is only about one third of one percent of the total of 90 million residential buildings (including single family and multiple-family). Few, if any, large passive solar developments of multiple homes exist. This may explain Balcomb's comment concerning "vague memories." Passive solar has not moved to mainstream building. It is possible that the Peak Oil crisis may resurrect interest.

Designing and operating a passive solar home is not as easy as using a conventional heating system. The designer must find the right balance between the amount of south facing glass and the thermal storage required. It is difficult to deal with the heat loss through long winter nights compared to the heat gain during short winter days. If not well-planned and managed, the house can easily overheat in warmer weather. And in cloudy colder weather (and nights) the heat loss through the windows can be very high unless some kinds of window covers are utilized.

In addition, a passive solar home costs more than a conventional home since passive features must be added while a heating system is still required for backup. It may be worth it for the projected 80% heat savings – detailed cost differences are not available. But the energy for heating a house is only 32% of the total energy used in the building.[1] Thus an 80% savings in heat translates into a total household energy savings of about 25%. The other 75% must also be reduced.

More Recent Efforts

As our review of green building has shown, efforts in this country to significantly impact construction methodologies have, to date, produced little in the way of results. Several current projects, however, show more promise:

High Performance Building

A recent effort with a new approach to construction methods is high performance building, developed by the Building Technology Center (BTC) at Oak Ridge National Labs in Tennessee. The BTC, in conjunction with Habitat for Humanity, has built five small high performance homes in Tennessee[28] which are constructed with thick Structural Insulated Panels (SIPS) with high R-values – R-40 instead of the more common R-11 – and with a very tight envelope.

One of the most significant features in these smaller-than-average houses is the inclusion of the heating system and ductwork within the conditioned space so that the estimated 37% loss of heat through ductworks in unconditioned space is eliminated.

BTC has now begun evaluating ways to retrofit existing homes.[29]

The Passive House

Another new concept in building, "passivhaus" or passive house, has arisen in Northern Europe. The concept began with the traditional passive solar house as a starting point. This was combined, however, with a very well insulated and air-tight building envelope. The passive houses built in Germany and the Scandinavian countries have no space heating or cooling systems.

The total energy consumption of one group of multi-unit terrace houses near Goteborg, Sweden is close to 1/3 of non-passive houses – 5,400 kWh per year compared with approximately 15,000 kWh per year for a standard multi-unit terraced house[30] or the 78,000 Btus of a Energy Star house in the U.S. The building has 19-inch-thick walls compared to the standard U.S. 3 ½-inch-thick wall. Solar panels for electricity are part of the building. Germany has built 4,000 such passive houses in the last several years.[31]

Since 1990 another 6,000 have been built in other areas of Europe using the same principles.[32] These houses are addressing all energy used in a house.

A Question of Choice

While these last two examples offer some hope for future buildings, even they don't represent technical housing breakthroughs. Nor are there any on the horizon or even being considered relative to building. Rather, there are only a large number of possible small iterative improvements. The major factors in energy-consuming homes are size and style. Our homes, like our cars, are basically too big with wasteful features such as high ceilings, excessive lighting, and large expanses of glass. For decades consumers and builders have rejected energy-conserving features as simply a cost neither will pay. Very few have been willing to trade off floor space for efficiency of operation.

It could have been different. The average house size grew from about 1,000 square feet in 1950 to 1,520 square feet by 1971, two years before the first Mideast crisis.[1] (see Figure 3 on page 2) During this first oil crisis, a cultural choice could have been made to increase expenditures on efficiency rather than on size. If this had been done, possibly the average size of a house today might be the same 1,520 square feet rather than 2,227 square feet – the average size of houses built in 2005. A high performance 1,520 sq.ft house might have been built that used 45 million Btus annually instead of the current 185 million Btus.[1] The money for the extra space could have been put into building a very high performance building envelope, purchasing high quality triple-paned windows and incorporating high performance appliances.

Unfortunately the nation chose differently and now has an enormous investment in inefficient large buildings. Our residences are now at least twice the size of typical homes in Europe and Japan and consume 2.4 times the energy.[33] Those countries made different choices in the 1970s, choices focused on reducing energy consumption.

A Question of Values

The American Council for an Energy-Efficient Economy (ACEEE) monitors many high-energy-consuming industries, including housing.[34] The organization has published three reports within a decade that list 198 energy-saving technologies and practices. Each one has the potential to save at least ¼ of 1% of the energy consumed when the specific technology or practice has matured (which typically takes decades!).

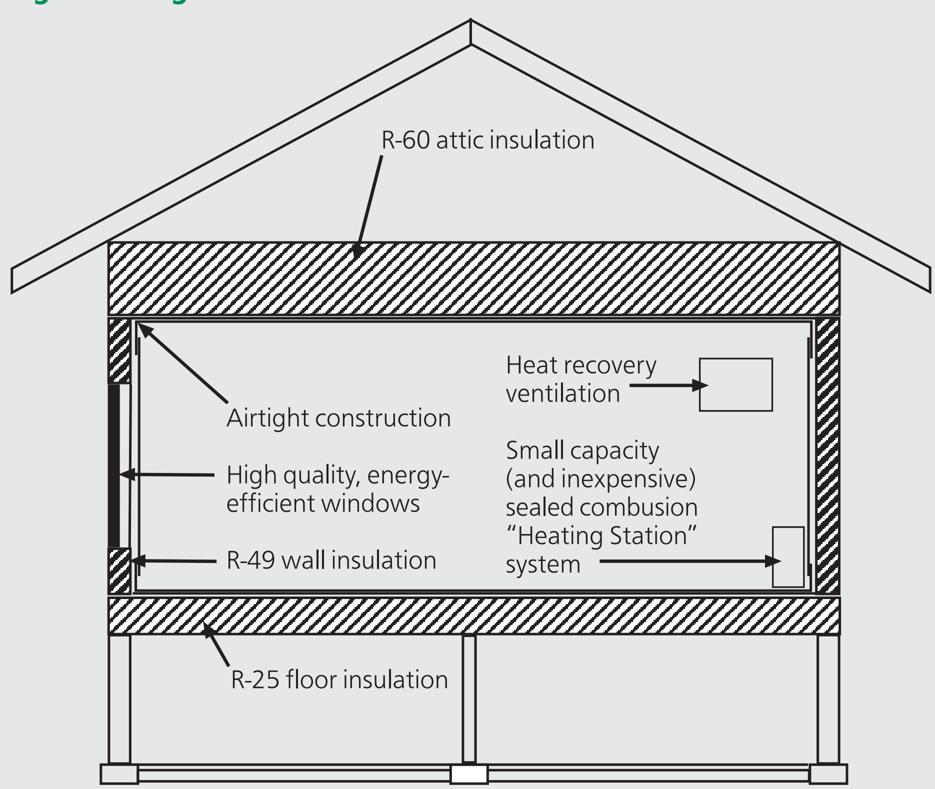
Perusing these reports is a valuable experience in that it shows both the depth and breath of possible reductions in energy use in buildings. However, one also sees the difficulties of making substantial changes. These difficulties are not merely technical, they are also cultural: resistance to changing standard construction practices as well as our consumer cultural values of convenience, comfort, style, and guaranteed economic payoffs. Unfortunately, these cultural values do not consider the needs of future generations or the planet.

While we might reasonably expect consistent improvement in building efficiency of about 1.5-2.0 % per year as has been the case in the auto industry,[35] Jevin's Paradox (the argument that as machines become more efficient, consumption increases so no net gain is made) seems to be in effect in building. That is, the more the improvement relative to efficiency, the more the improvements are cancelled out by larger buildings, more lights, more machines, and other accoutrements of a consumption orientation.

Without a significant change in our values, no technological advances will solve our energy problems.

In principle, retrofitting should adopt as much as possible the characteristics of high performance home construction.

Figure 7: High Performance Home Construction



What Now? The Retrofit Option

Now that we have all these large, inefficient buildings, what can we do? Size is one of the two major problems. One alternative to resolve the size issue is to double up households which, if energy prices increase dramatically, will be done in some cases. Also, practices can be put in place that use only part of a house during the times of the year when heating or cooling is required. This practice is common in poorer parts of the world where some parts of the building are only used when the weather is less extreme. Such practices could become part of the American culture.

Another less likely alternative will be to actually dismantle buildings and use the components to build more energy efficient replacements. This is extreme but very rapid changes caused by Peak Oil and climate change could lead to shifts in the perspectives and needs of people. In that case, deconstructing houses carefully for their materials will be common.

The more likely scenario will be for people to retrofit their homes. The principles are simple – make the building as small as possible, as "thick" as possible, and as airtight as possible, with all furnaces and heating ductwork placed within the conditioned space (see Figure 7[36]). But increasing the efficiency of the building envelope or changing appliances will be expensive, so before undertaking this effort, we need to reconsider how energy is consumed in the home.

Considering Total Home Energy Consumption

To determine the most effective use of our monetary resources for retrofitting, we need first to connect the energy consumption measurements for a variety of machines with the energy expenditures for different parts of the house envelope. The energy in buildings for heating and cooling is allocated to the walls, ceilings/roofs, and windows along with estimates of infiltration. This allocation must take into account the different forms of energy consumption for the building in winter and summer.

> Analyzing your home for greater energy efficiency should take into account not just the energy use, but the life span of the appliance or building component.

Table 4[1] shows the allocation for the distribution of all housing energy. Windows are listed separately from walls and the values show the high percentage of energy that passes through window glass. (There are typically 16 windows with a total area of 235 square feet in the average 2,047 square foot house.)[1]

This table provides an outline of the large number of options for reducing energy consumption in a home. These national averages can serve as a guideline for home owners planning major or minor retrofits. They also show that energy savings must be done in many steps – there are not just one or two major opportunities.

When making decisions about saving energy, the life span of appliances is an important consideration. It may be better in some cases to replace appliances rather than make changes in the building envelope. In other cases, envelope changes should take priority. Machines and appliances have a much shorter life than windows and walls. On average, an appliance's life span is 11 years.[1] Some examples of average lifetime (in years) are: refrigerator-13, freezer-11, room air conditioner-10, range-14, clothes washer-11, clothes dryer-13, water heater-10. Furnaces, heat pumps and central air conditioners typically have a life span of 16-18 years.[1]

Table 4: Total Home Energy Use[1]

End Use	%	Heat%	Cool%
Space Heating/Cooling	43		
Roof		12	14
Walls		19	11
Foundation		15	
Infiltration		28	16
Windows (conduction)		26	1
Windows (solar gain			32
Internal Gains			27
Lighting	12		
Water Heating	13		
Refrigeration	8		
Electronics	5		
Cooking	5		
Wet Clean	5		
Computers	5		
Other	4		
Adjustment SEDS	5		

General Retrofit Guidelines

While each home is different, the following provide some general guidelines for retrofitting:

Lighting

The top five residential energy consuming machines – space heating, lighting, space cooling, water heating and refrigeration – use 76% of the total energy.[1] One of the five, lighting, could immediately be reduced substantially (by a factor of three) by replacing incandescent light bulbs with compact fluorescents. Improving house lighting by a factor of three would save 8% of total home energy use and should be done without delay. Improving the other four will be more difficult and more expensive.

Infiltration

Leaks account for 8-10% of a house's energy loss in the winter, so the second priority should be to find and seal those leaks with caulk or weather-stripping to make it as air-tight as possible. For fresh air, a heat exchanger is much more effective than uncontrolled leaks. Tightening the envelope is not an expensive process, but does require some skill and care.

Windows

Table 4 shows the high energy cost of windows. If possible, replace single-glazed windows with double-glazed ones. In houses with excessive amounts of glass, some of the window area could be replaced with framed and insulated wall sections. Window covers should be part of the house and used extensively in cold weather, since so much energy loss is through window glass. In the summer, shades or awnings can be added to reduce the sunlight heating the building through the windows.

The "Envelope"

Retrofitting the envelope – the floor, walls, and roofs – is a complex process. Ceilings can usually be insulated if the attics are accessible, building the insulation up to R-50–R-60. Similarly, floors may be insulated to a greater depth if there is sufficient joist depth. Whereas in ceilings insulation can be laid on top of the existing joists, floors may have to be "thickened" by attaching additional framing material to deepen the joist spaces so they can contain more insulation. If the floor is on a slab, it may be possible to dig around the foundation and insulate what is accessible.

Walls may be furred out (made thicker) for more insulation. These new furred-out walls will either rest inside the house on the floor adjacent to the existing exterior walls or rest on ledgers which are bolted to the rim joists on the outside of the house. Inside furred-out walls will take some of the floor space but will be much cheaper to build than outside furred walls. Thick, well-insulated walls offer space at windows for various movable insulation like "window quilts." Pockets for sliding window covers could also be incorporated.

Furnaces

Moving the ductwork and furnace into the conditioned space can save up to a third of the energy consumed for heating, according to calculations done at Oak Ridge National Labs.[28] This would be a fairly complex retrofit, involving tearing the old ductwork out of the walls and replacing it with insulation, repositioning the furnace and building new ducts.

Attached Solar Spaces

Retrofitting by attaching solar spaces (greenhouses or sunrooms) can provide a source of heat. Properly configured, small fans move heated air from the solar space into the living space in cold weather and ventilate the solar space in warm weather. They typically incorporate heat storage mass, such as masonry or water. In cooler weather it is necessary to use insulated shutters or to close the solar space off from the living area to limit nighttime heat loss. In warm weather, reflecting panels may be used to reject heat.

Appliances

Clothes dryers use ten times the energy of the clothes washer. So hanging one's laundry out on sunny days, or on an inside rack when it rains, as they do in Europe, makes abundant sense.

Hot water heaters could be set on pilot light until hot water is required and hot water use could take place in a relatively small time period. After the period of heavy use, the hot water setting could be returned to pilot. Electric hot water heaters can be modified with switches that turn the unit on and off at scheduled times. Moving the hot water heater closer to the points of use would reduce energy use, or installing instant, so-called "flash" water heaters can replace the wasteful standby units that keep water hot day and night.

Replacing all 12- to 15-year-old furnaces, air conditioners, refrigerators and freezers with new energy-efficient, high-end units would result in a major energy reduction. Another option would be to replace electric stoves, dryers and refrigerators with natural gas units, as this will reduce total consumption since the conversion of coal to electricity essentially wastes energy.

Finally, consider eliminating appliances when you can do the same task by hand.

Changing Practices

Changing our habits is as important as changing the infrastructure. Setting our thermostats to 55 degrees instead of 70 degrees will be uncomfortable but not dangerous. The world functioned without air conditioning for thousands of years and it may be necessary to abandon it. Keeping water hot day and night to be able to bathe at any time will probably not be viable in the future. Washing clothes in cold water will become the norm and the clothes dryer may fade into history along with the SUV, replaced by outside clotheslines or drying racks inside the house.

Cooking with pressure cookers saves more than half the cooking energy. Canning and drying of food will replace freezing. There are many other personal measures that can be taken to reduce energy use, which may be uncomfortable and inconvenient but which are necessary to reduce our energy consumption to a sustainable level and stop global warming.

Retraining an Industry – Providers and Consumers

The construction industry requires a high degree of skill both for professionals, such as architects and general contractors, and trades people such as carpenters, electricians and plumbers. Most trades are licensed and require passing a comprehensive test and showing some years of experience in the relevant trade. Thus, the industry provides a pool of talented and experienced people who are capable of implementing changes rapidly.

It would matter little to framers and insulators if walls were made from 2x6s, 2x8s, 2x10s or 2x12s rather than today's standard of 2x4s. With a little practice they could become equally adept at building double exterior walls with sandwiched insulation, which are much more insulating compared to single walls. The techniques for energy efficiency are well developed and few tradespeople would be baffled.

There will be a major shift in the future from new building to remodeling which will open up new employment opportunities. Retrofitting will be labor-intensive and in the future someone who understands how to modify a house to use less energy will be in demand and paid a good salary. Also, there is a large "do it yourself" movement in the country and as people see the need, they will begin to do retrofit tasks themselves.

The problem, as always, will be attitude. Architects and builders have historically focused on providing the maximum amount of floor space for the least amount of money. Thicker walls will reduce the livable area and increase the cost. To shift the emphasis from the largest possible size to an energy frugal view is contrary to our core belief that "Bigger is Better." However, with a change in attitude and perspective from the general population, professional and trades people will adjust. The nature of those in the building business is practical, and if consumer priorities shift, so will those of builders and designers.

It is said that necessity is the mother of invention, and, as energy shortages appear and prices rise, more and more people will take responsibility for dealing with their homes in a personal and local manner. Maybe Web surfing and TV viewing will be replaced with calking parties, window covering "sewing" bees and similar activities.

Summary

The largest consumer of energy in the U.S. is the buildings in which we live and work. Ninety percent of our time is spent inside buildings, and they increase in size each year. American homes are twice the size of European and Japanese homes. They are excessively large and waste massive amounts of energy.

Since buildings have a long life span – most buildings currently in existence will still remain after the depletion of oil – it will not be possible to replace them with new energy-efficient buildings because of the cost and use of resources, including fossil fuels. The only sensible option is to begin a major retrofit of all buildings to reduce their energy consumption.

Government and the building industry tend to oppose legislation to alter building codes towards efficiency, so it will be up to individuals to make choices for an energy-constrained world. Individuals would be well advised to develop the understanding of building energy consumption along with the skills to upgrade their homes. The process will not be cheap in time or money.

Finally, we must also change our short-sighted habits and realize that our personal choices will make a difference. Continuing to live and consume energy in a modern home is like continuing to drive a low-MPG car. Our children and grand children will not thank us for it. We must change from a world view of consumption to one of conservation, choosing to share resources across the world and with those yet to be born.

– *Pat Murphy*

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