AC 2010-178: ENERGY PRACTICES IN RESIDENTIAL BUILDINGS: A GLOBAL LOOK

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Energy in Residential Buildings: A Global Study

Abstract

The impact of energy use in U.S. residential construction is huge, this sector alone accounts for about 22% of the primary energy use. Within residential buildings, space heating, and water heating are the biggest opportunities for energy savings. The electricity used for lighting, cooling, and refrigeration should be targeted next. Despite the opportunities for energy and financial savings, many homeowners forgo necessary improvements due to initial cost concerns or a simple lack of information. This paper will explore global practices that exist to increase energy efficiency in residential construction and disseminate this information as a beginning of the best practice.

Background:

In today’s fast-pace technology-driven society the United States along with many other industrialized countries are producing enormous amount of energy to meet the demands of their rising populations. Figure 1 shows the trends over the past six decades. According to the U.S. Energy Information Administration (EIA), the United States consumed 101,554 trillion Btu (British Thermal Unit) of energy in 2007; an increase of 1.7 percent from 2006 and 6.7 percent from a decade prior.

In particular, the residential building sector accounted for 21,619 trillion Btu or 21.3 percent of the total energy consumed that year. But to gain a better understanding of the distribution of energy consumption within the residential sector, the EIA has broken down the primary energy consumption into three categories: fossil fuels, renewable energies, and electricity. Fossil fuels...
are comprised of coal, natural gas, and petroleum, whereas renewable energies consist of geothermal, solar/PV, and biomass energies. The total energy consumed by the residential sector in 2007, electricity accounted for a whopping 69.4 percent, slightly down from 70.2 percent the year before. Fossil fuels and renewable energies represented 28.2 percent and 2.4 percent of the total energy consumption respectively. Figure 2 shows the details of the primary use of energy in buildings in 2005. In this paper, we explore the ways we can minimize the energy consumption and hence reduce CO₂ emissions.

![Figure 2. DOE Primary energy Consumption 2005](image)

**Current Energy savings initiatives:**

The goal of the U.S. Department of Energy’s Building America program is to create commercially viable zero energy homes by 2020. In a day-in-age where the United States is striving to become a “greener” society it is surprising to learn the U.S. produced 6,006.710 million metric tons of CO₂ in 2007, illustrating the close correlation between the amount of energy consumed and the quantity of carbon dioxide produced. Since electricity was the leading source of energy consumed, it too was the principal producer of carbon dioxide within the residential sector. Furthermore, fossil fuels produced the second most carbon dioxide emissions and renewable energies do not generate any form of greenhouse gas emissions. Electricity was responsible for 72.3 percent of CO₂ emissions, whereas fossil fuels were only liable for 27.7 percent in 2007. Initiatives currently exist in the United States, Newfoundland, United Kingdom, Japan, and India to reduce carbon emissions.

**The United States:**

The Building America program provides resources to assist in obtaining the goals of:

- Produce homes that use 40% to 100% less energy,
- Integrate power systems leading to zero energy homes (ZEH), that produce as much energy as they use, by 2020,
- Improve indoor air quality and comfort,
- Reduce construction time and waste,
- Implement innovative energy- and material-saving technologies,
- Improve builder profitability,
- Provide new product opportunities to manufacturers and suppliers, and
- Increase the energy efficiency of existing homes.

Research is continuing to add to the body of knowledge for the testing and development of the continual push towards zero energy homes. Projects are testing the use of double stud wall framing, super insulated shell, and double glazed, low emissivity southern windows to provide more solar heating. Ground source heat pumps have been very effective, but can increase the initial cost of the home. Solar hot water heating systems with storage tanks are one of the ways in which energy is saved where appropriate due to regional weather differences in the U.S. One project in Denver, Colorado has applied these standards to build a habitat for humanity home in 2006, which was cost effective and energy efficient.

**Canada**

Researchers in St. John’s, Newfoundland have developed a wind energy system that is able to support and sustain a two-storey single-family home. The wind energy system is dependent upon two main criteria: the average energy consumption based on two identical reference homes and the available wind energy in the region. Based upon data gathered from a local utility company, it was determined the two reference homes consumed an average of 58.1705 kWh per day. Maximum power was consumed in the mornings around 8 a.m., spiked again at 5 p.m., and lasted for 6 hours. Furthermore, the average daily wind speed was measured to be 5-6m/s, peaking from 9 a.m.-6 p.m. The challenge was not only to design the most efficient wind energy system but one that had enough storage capacity to maintain the house during peak energy consumption hours when no wind was available.

After obtaining all the necessary data HOMER, general-purpose hybrid system sizing and simulation software, was used to identify the best system to supply electricity to the home based on hourly performance simulations. It was determined a 10 kW Jacob 23-10 wind turbine was the most efficient renewable wind energy system for the house. According to HOMER, a Jacob 23-10 wind turbine would be able to support the energy needs of the home, and depending on the available wind energy, it could generate an excess of 7.8-21.1 percent of energy per year. Not to be mistaken, this home would still be connected to the power grid and on select on months would draw energy from the grid but would also supply enough power to the grid to offset its consumption. This investigation has lead to the development of a zero energy home (ZEH)—a home that does not consume any fossil fuels and relies solely on renewable energy sources to generate enough electricity where annual consumption equals annual production, thus giving the home owner essential energy security.

**The United Kingdom:**

Across the pond in Cardiff, UK, residential buildings are responsibly for 47 percent of their national energy consumption. With that in mind, homebuilders are determined to integrate renewable energy systems into their building designs enabling them to produce a zero energy
home for the consumer. In order to achieve this goal, builders have determined hot water systems, heating systems, and electricity for lighting and appliances must be converted to run on renewable resources. One of the most efficient ways to develop a ZEH is through the use of a solar hot water system. Researchers collected data on the annual total solar radiation, hours of direct sunlight, and orientation of the house—the direction in which the entrance façade is facing. Based on their findings researchers determined that solar panels facing the south with a 50° tilt equivalent to the latitude of Cardiff would be the optimal position to generate the greatest amount of solar energy. In order to achieve maximum efficiency, different solar collector areas with numerous mass flow rates were tested. Considering these key parameters, it was determined that a solar panel with a 5m² area along with a mass flow rate of 20 kg/h would produce a 35 percent collect efficiency rate. As a result, a solar hot water system could provide the necessary specific heat capacity while only using 21.5 percent of the standard domestic hot water load. In conjunction with the solar hot water system, builders deemed it necessary to implement an under floor heating system that will utilize the superfluous energy produced by the solar panel.

The under floor heating system is an active layer of the floor that is designed to disperse heating fluids throughout a pip grid underneath the entire house. The system is built in accordance with specific guidelines that will optimize the necessary heat output. The major advantage of an under floor heating system compared to traditional radiant heating systems, is an under floor heating system can reduce the water supply heating demand by 20 °C, thus saving considerable amounts of energy. In addition, due to the fact the heating system is in the floor, the air temperature steadily decreases at higher altitudes resulting in the same comfort levels (warm feet and cooler heads) while reducing the air temperature by 2° C. Finally, builders have realized the fact that renewable electric systems are the single most indispensable design that must be built into a zero energy home.

The grid connected renewable electric system will be composed of two wind turbine and a Photovoltaic array (PV) to generate the energy needed to sustain the home. Both components will have inverters to convert direct current to alternating current with an efficiency of 0.78. That electrical current will then be passed to a distribution board that will act as the gate keeper to the electrical outlets. According to the study, the annual energy consumption of the appliances and lighting figures to be 4672.0 kWh. TRNSYS, a software program designed to analyze electrical systems, predicted the annual power output produced by the renewable electric system to be 7305.9 kWh, 50 percent more then what is actually needed. Of the total electrical energy produced the two wind turbines account for 91 percent and the PV array accounts for the remaining 9 percent. Homebuilders in the UK have recognized the fact that renewable energy technologies must be incorporated into hot water systems, heating systems, and electrical systems in order to design a fully functioning zero energy home. But long before Newfoundland and the UK ever developed ZEHs, Japan has been at the forefront in the development of residential solar Photovoltaic array power systems.

Japan:

In 1994, Japan launched a 70,000 PV-roof market in response to rising energy consumption rates, propelling them to become the world leader of PV cell manufacturing. As of 2003, Japan has manufactured 60 percent of the world’s PV systems, allocating 55 percent of all
manufactured products to stay in the country\textsuperscript{10}. As it stands, the Japanese residential sector has the greatest share of total PV systems within the local market, accounting for 85 percent. Astonishingly, the residential sector purchased 204 MW of the 400 MW of PV systems produced for Japanese markets in 2003. In 1994, the Japanese grid-connected PV systems produced only 3.5 kW per application, but due to an overwhelming popularity, homeowners have pushed for increased system capabilities in order to handle 5-7 kW as consumers are striving to meet a net zero energy target\textsuperscript{10}.

Sekisui Chemical Co., a leading home manufacture in Japan, only offered PV systems as upgrades to existing outdated electrical systems, but after realizing how high the demand for these renewable energy systems have become, they have started to incorporate PV systems into the construction of new homes. The fact of the matter is average non-PV homes in Japan consumes 10,750 kWh; whereas a house with a PV system consumes only 7,167 kWh form the grid\textsuperscript{10}. Furthermore, depending on the maximum output of the system, many of Sekisui’s customers have been able to obtain zero utility costs even before reaching a net zero energy goals, in thanks to time-of-day pricing. Since these homes are still connected to the grid, the average home with a PV system installed can sell energy back to the power company during peak demand at peak rates and purchase energy at inexpensive rates, a very attractive incentive for home buyers\textsuperscript{9}. As the demand for larger more efficient PV panels increase, Japan is on its way to viably producing a ZEH market. These details illustrate as how industrialized countries are improving home building techniques to consume less energy and in turn produce less CO\textsubscript{2} emission, but the World Business Council for Sustainable Development has emphasized the fact developing countries play a vital role in saving energy worldwide\textsuperscript{11}.

\textbf{India:}

According to the EIA, in 2007 India emitted 1400.709 million metric tons of carbon dioxide, representing 4.7 percent of the world’s total emissions\textsuperscript{5}. At present, the share of direct energy use of households in India is about 40\% of the total direct commercial and noncommercial indigenous energy use\textsuperscript{12, 13}. Although India has virtually no solar power now, the plan envisages the country generating 20GW from sunlight by 2020. Global solar capacity is predicted to be 27GW by then, according to the International Energy Agency, meaning India expects to be producing 74\% of this within just 10 years. India is considered a developing country. Once citizens, who are mostly agricultural workers, want to become more advanced socially and economically, the energy saving techniques they have implemented within their residential building sector might not seem as ground breaking in a sense of advanced technologies but is still important and needs to be considered in the bigger picture of reducing global CO\textsubscript{2} emissions.

Residential energy consumption consists of wood fuels, coal/charcoal, kerosene, and electricity. Non-commercial fuels such as wood fuel, coal/charcoal, and kerosene are typically used in rural areas and electricity is normally only supplied to urban communities. Even though electricity is hard to come by, many people in rural areas are switching from non-commercial fuels to electricity for cooking, water heating, and lighting purposes\textsuperscript{13}. This changeover might not be viewed as energy efficient, but since Indian households inadequately consume most biofuels the switch actually reduces environmental pollutants. For instance, households switching from wood fuels to electricity for water heating purposes are producing 2184 kg of CO\textsubscript{2} less per year. More
commonly, families transitioning from a wood stove with a 30 percent efficiency rating to kerosene stove with a 30 percent efficiency rating for cooking purposes and are reducing CO₂ emissions by 2061.5 kg per year\(^\text{13}\). A shift is truly taking place within the residential sector towards more efficient technologies; yes, these types of energy are not as efficient as renewable resources but for the time being they do produce less Carbon Dioxide emissions. On the other hand, as the demand for electricity grows, India must become a developed country and start to integrate renewable resources into their home building techniques.

In 2009, the Karnataka State Government (in which the City of Bangalore is situated) passed a new rule that all new houses must install solar water heating as part of the house to obtain electricity connection from the utility. This is to reduce the electricity consumption\(^\text{14}\).

**Summary:**

As the debate for stringent Carbon Dioxide emission standards continues to be at the forefront of domestic issues within the United States, one can only turn to the facts and determine that our present technology-driven lifestyles consume far too much energy if we are truly to become a “greener” more eco-friendly society. Americans have finally accepted the fact our intemperance in fossil fuels have contributed to global warming and consequently have had a negative effect on the environment. If evident change is to take place, one must realize the transition to renewable energy sources will be a tremendous undertaking that will require all industries to partake. Collaborations around the world must continue to develop cutting-edge energy-efficient technologies and, most importantly, learn how incorporate these systems into modern-day home building techniques at a reasonable financial price for a conservative consumer in today’s economy. As the United States spearheads the environmental revolution one can only be optimistic when considering the new innovations the future may hold that will harness natures’ spectacular powers and allow us to achieve goals that were once considered unattainable.

Figure 3 illustrates a comparison of the energy use by various countries\(^\text{18}\) illustrating that using reduced energy it is still possible to have a decent quality of life.
This paper begins a conversation to demonstrate the simple practices that can be applied to anyone. It is a starting point to share with all to begin best practices. Towards this end, ‘true green-100 everyday ways you can contribute to a healthier planet’ gives ways that everyone can practice easily everyday, such as using the compact fluorescent lamps, and switching off the lights and TV, and other appliances when not in use (8% energy savings)\textsuperscript{15,16}.

Thus, the goal is to work out a new balance between adequate energy use to sustain a decent quality of life and the imperative of not affecting the biosphere in ways inimical to human survival, as higher energy use does not guarantee anything except greater environmental burdens\textsuperscript{17}. The current US administration has pressed Congress to provide money to homeowners to improve energy efficiency -- and the economy -- by replacing doors, caulking windows and padding their attics with more insulation. Under one proposal being considered, $20 billion from February's economic stimulus package would be used to offer incentives of $1,000 to more than $3,000 for people to apply to projects that improve the energy efficiency of their homes. It is estimated that about 5 million homes could be retrofitted under the program, saving homeowners a total of $3.3 billion annually on energy bills\textsuperscript{19}. Similar plans will be useful in other countries to enhance the quality of life without burdening the environment.

The studies shown in this paper have been undertaken by master’s and undergraduate students. The master’s student compared the housing construction and their various attributes and rules and regulations at Switzerland and USA as part of his master’s thesis (results not included in this article). As part of the Purdue Discovery Park Undergraduate Research Internship (DURI), an undergraduate conducted part of the research presented here. As we see the vast amount of information related to research, we find that energy should be integrated into existing courses or a new course could be developed that exclusively addresses the global issues with respect to residential construction, energy, and environment. Until that happens, both undergraduate and graduate students can do independent studies, or do the undergraduate research, or as part of master’s theses. There are many avenues possible to integrate this research and education. In addition, these data/results could also be taken to middle and high schools, both to the teachers and students, and a solid effort could be made so many are aware of the required details regarding residential buildings. Work is ongoing in several of the above-mentioned areas. It is also already envisioned to extend/continue this study to other countries, such as Germany, Netherlands, Denmark, China and Brazil.
References:

18. Novaltantis, 2007