Comparing Swiss and U.S. Homes in the Area of Energy Efficiency

Daphene C. Koch, PhD, Jason Kutch, William J. Hutzel, P.E., and Eric Holt
Purdue University
cyrd@purdue.edu

Abstract

The purpose of this project is to compare best construction practices that will improve energy efficiency in residential construction in both the United States (U.S.) and Switzerland. Comparisons were made using the Minergie Swiss system and the Energy Star ratings for a U.S. home. This research was conducted in collaboration with The University of Technology and Architecture (HTA) Lucerne in Switzerland and the College of Technology at Purdue University.

This project identifies and evaluates U.S. and Swiss technology used in low-energy residential buildings. The identification of Swiss technology has mostly been accomplished by visiting Switzerland during the summers of 2006 and 2007. First-hand knowledge of the systems was acquired from tours of Swiss homes and interviews with the students and faculty of HTA. The evaluation of annual residential energy consumption is found using building simulation software called REM/Rate. Based on these results, an economic decision is made as to which of the six homes being evaluated is most efficient.

The six homes being evaluated are as follows: 1. Baseline U.S. home, 2. Baseline Swiss home, 3. Energy Star U.S. home, 4. Minergie Swiss home, 5. U.S. combination of both of the Energy Star and Minergie home (hybrid), and 6. Swiss combination of both of the Energy Star and Minergie home (hybrid). Building simulation software determines a Home Energy Rating System (HERS) index for each home. The HERS index indicates the level of efficiency of each home in order to sufficiently compare them. This paper outlines the process, results, and conclusion for the home analysis.

Introduction

This project builds on existing international research collaboration between the Applied Energy Laboratory (AEL) in the Department of Mechanical Engineering Technology (MET) at Purdue University and an outstanding technical school in Lucerne, Switzerland. The University of Technology and Architecture (HTA) Lucerne has a curriculum that is comparable to the College of Technology at Purdue University. Their strongest major is Heating, Ventilation, and Air-Conditioning (HVAC) Engineering. The collaboration between Purdue University and HTA Lucerne has been occurring for three consecutive years and consists of alternating visits of students from both schools. The first visit of the year occurs in either May or June, with Purdue University students traveling to Switzerland. The duration of the visit is between two and three weeks. During the fall of the same year, HTA students travel to Purdue University. The duration of the visit is between three and four weeks.

The collaboration between Purdue University and HTA Lucerne has improved the research capabilities of both institutions. Past projects have involved students designing, specifying, and installing a heat recovery system, web-based controls, and an air-cooled chiller in the AEL at Purdue University. This year's collaboration with HTA will incorporate additional students from other departments at Purdue University. This increased collaboration will create a more diverse team with a higher degree of specialization. Students from the Building Construction Management (BCM) department will provide home design, cost estimating, and building analysis. Through these aids and leadership, a detailed report on energy efficient residential construction practices will be possible.

This study is needed to increase the awareness of energy conservation and to better the construction practices in both the United States and Switzerland in order to decrease energy consumption. In the United States, citizens use more than twice as much energy per person than an individual in Switzerland does. To address this problem, a collaborative effort between the school of HTA Lucerne in Switzerland and Purdue University will compare and analyze the energy use of residential construction in the United States and Switzerland.

Statement of the Problem

Present lifestyles in the United States use too much energy per person comparatively. As shown in Figure 1, the United States consumes nearly as much energy as Western Europe, Switzerland, Africa, and Bangladesh combined.

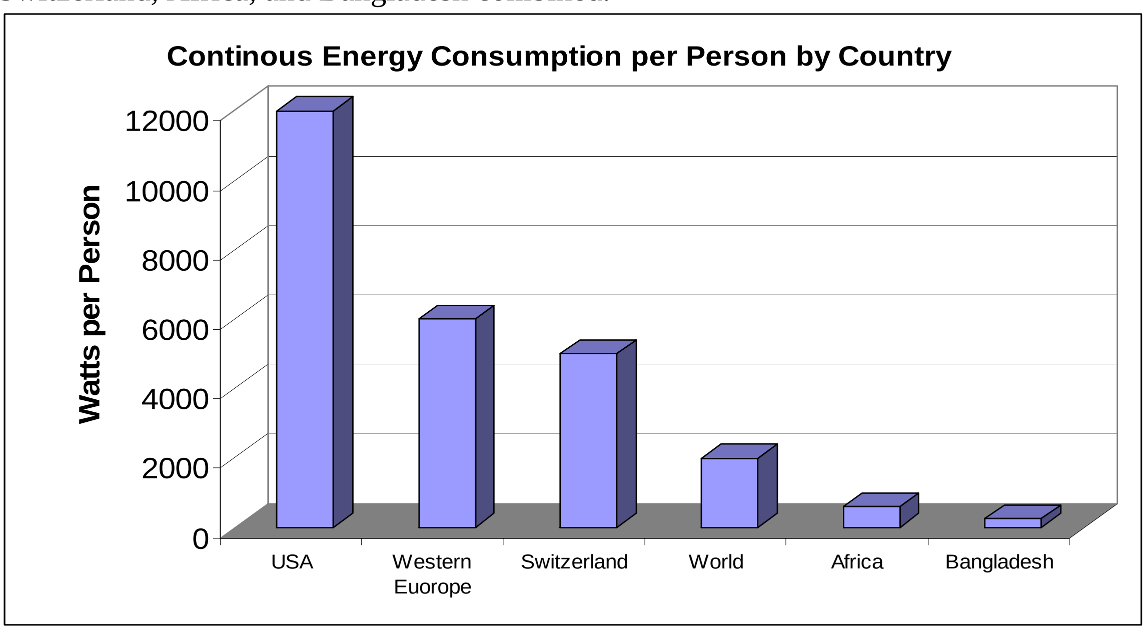

Figure 1. Continuous energy consumption per person by country [1]

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Narrowing the focus to energy consumption within the United States, research at the Energy Information Administration (EIA) has indicated a rise in energy consumption per sector [2]. Figure 2 indicates the utilization of energy between the years of 1949 and 2006 within industrial, transportation, residential, and commercial sectors. Although this research focuses on reducing the energy consumption of residential use, the graph indicates the rising energy consumption per capita as a whole for all sectors.

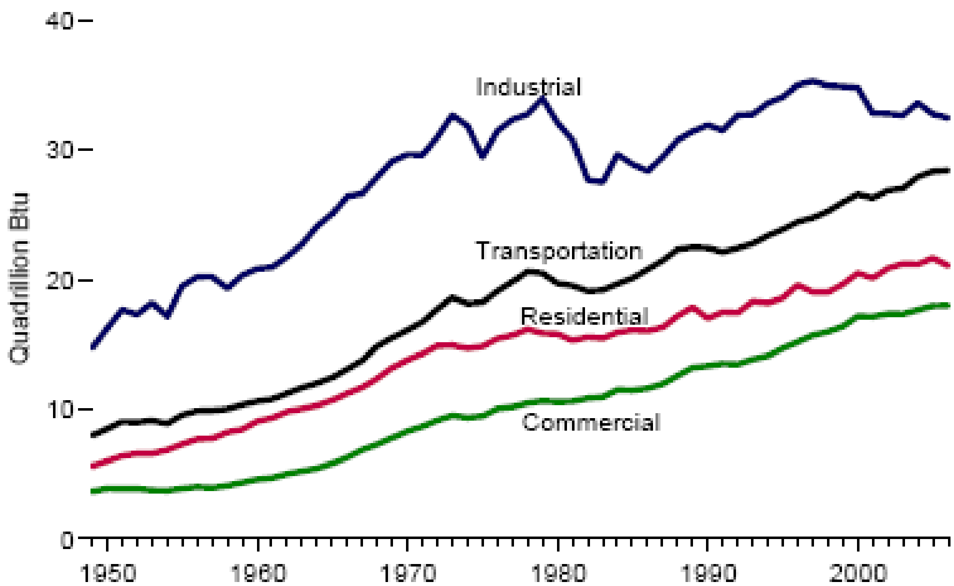


Figure 2. Total consumption by end-user sector, 1949–2006 [3]

Further research within the industrial, transportation, residential, and commercial sectors at the EIA has revealed the total consumed energy for 2006 by respective sectors [2]. Figure 3 illustrates that the residential sector consumed 21 percent of the total consumed energy in the United States in 2006.

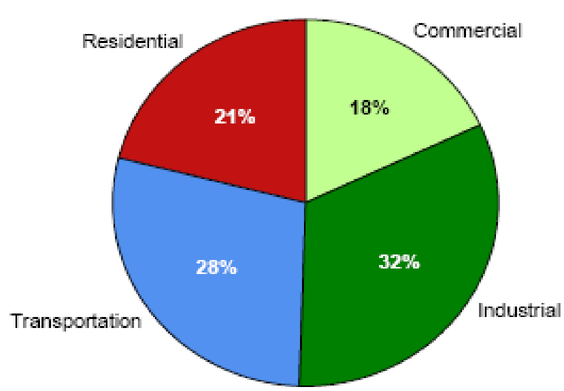


Figure 3. End-user sector shares of total consumption [3]

This research focuses on the residential sector and attempts to provide motion towards reducing energy consumption within that sector.

Statement of the Purpose

The purpose of this project is to compare the best construction practices of energy consumption efficiency in residential construction in both the United States and Switzerland. The comparison of a Minergie Swiss home to an Energy Star U.S. home is the basis for this research. Minergie is a sustainability brand for new and refurbished buildings. It is mutually supported by the Swiss Confederation and the Swiss Cantons along with trade and industry, is registered in Switzerland and around the world, and is defended firmly against unlicensed use [4]. Energy Star is a national, voluntary program sponsored and developed by the U.S. Environmental Protection Agency (EPA) that promotes energy-efficient products, including homes. Homes that have earned the Energy Star rating have met the EPA's performance guidelines for energy efficiency and received third-party verification from an accredited organization [5]

The Home Energy Rating System (HERS) Index is a scoring system established by the Residential Energy Services Network (RESNET) in which a home built to the specifications of the HERS Reference Home (based on the 2006 International Energy Conservation Code) scores a HERS Index of 100, while a net-zero-energy home scores a HERS Index of 0. The lower a home's HERS Index, the more energy efficient it is in comparison to the HERS Reference Home [2]. REM/Rate calculates heating, cooling, hot water, lighting, and appliance energy loads, consumption, and costs for new and existing homes. Climate data are available for cities and towns throughout North America. The home energy rating is calculated based on the proposed Department of Energy (DOE) HERS guidelines (10 CFR 437) as modified by the RESNET/NASEO HERS Technical Committee [6].

The REM/Rate is used to evaluate the following six homes on their annual costs to operate and their HERS index score: 1. Baseline U.S. home, 2. Baseline Swiss home, 3. Energy Star U.S. home, 4. Minergie Swiss home, 5. U.S. combination of both of the Energy Star and Minergie home (hybrid), and 6. Swiss combination of both of the Energy Star and Minergie home (hybrid). A second part of the evaluation, which is separate from REM/Rate, calculates an initial cost of materials required to save energy in the homes as outlined in the Energy Star and Minergie standards. This expense consists of the total cost of materials and labor. The initial cost does not include the cost of the home and land because too many other variables affect the overall cost of the home.

Review of Literature

The U.S. Department of Energy (DOE) has initiated a program called Building America [7]. This program is reengineering new and existing American homes for energy efficiency, energy security, and affordability. The goals are to reduce whole-house energy use by 40–70 percent, reduce construction time and waste, and improve indoor air quality and comfort. This study will investigate the opportunity to incorporate Switzerland construction practices into the United States with the goal of minimizing annual energy usage. This investigation shares DOE's goals of improving energy efficiency. The following review of literature focuses on U.S. and Swiss residential construction practices that minimize energy consumption.

Current Energy-Saving Methods

The main topics researched were conducting energy analysis for residential buildings, estimating life cycle costs, and evaluating cultural differences. According to the Energy Star Web site, a home in the United States is considered to be qualified for an Energy Star rating if that home has been rated to be at least 15 percent more efficient than homes built in accordance to the 2004 International Residential Code (IRC) [8]. They state that homebuyers are increasingly interested in green buildings, and as a result, an Energy Star rating is a system that can make buyers aware of inspected energy saving.

Minergie is a standard by which new and refurbished buildings can be designed and built, and it is mutually supported by the Swiss Confederation and the Swiss Cantons [4]. The main objective measured by the standard is specific energy, which is used to measure the building quality. From experience abroad and discussions with homeowners, professors, and students, the Minergie home is stated to be approximately 20 percent more efficient than a standard Switzerland home. Swiss homes are constructed of thick masonry, and typical R-values in the walls are approximately R-20. An R-value is a measure of a material's resistance to heat flow. The higher the R-value, the more the material insulates [9]. In contrast, according to ASHRAE, an Energy Star home uses a variety of exterior wall combinations [10]. Options in the wall construction category may include 2x4 R-11, 2x4 R-13, 2x6 R-19, 2x6 R-19 with one inch of foam board insulation or 2x6 R-19 with two inches of foam board insulation.

Evaluation of U.S. & Swiss Residences

Similar research has been done at Oak Ridge National Laboratories (ORNL) and the National Renewable Energy Laboratory (NREL) to investigate zero-energy homes (ZEH). The ORNL is the largest science and energy lab run by the Department of Energy (DOE). Energy conservation is one of their major missions. With ORNL, The Energy Efficiency and Renewable Energy (EERE) Program develops sustainable energy technologies to create a cleaner environment, a stronger economy, and a more secure future for our nation. The program is committed to expanding energy resource options and to improving efficiency in every element of energy production and use [11]. At ORNL, five homes were investigated. One was a baseline home, and the other four were incremental attempts towards zero-energy homes. Christian states:

> "Affordable energy efficient ZEHs is the grand challenge set forth by the Department of Energy Building Technologies Program. For the goal to have sustaining national focus the concept requires promise in a variety of different U.S. climates and all price ranges [12]."

ORNL's research specifically addresses affordable housing in a mixed, humid climate. At the NREL, the evaluation of ZEH's is being conducted through the use of thermal imaging to detect heat loss. The study focused on analyzing the power consumption of a control home and a ZEH. NREL indicates that during peak times of solar heating loads, a ZEH generates more power than it uses, which reduces power demand on the utility provider [13]. Christian states that "The United States Department of Energy's (DOE) long-term goal is to create technologies that enable net-zero energy residences at low incremental cost by the year 2020 [12].” The parameters measured in this research were indoor air quality and energy usage.

According to the U.S. Department of Energy and Jansen, the program REM/Rate is a user-friendly yet highly sophisticated residential energy analysis, code compliance, and rating software utility developed specifically for the needs of HERS providers [6, 14]. Jansen, a professional home rater, has stated REM/Rate to be the best program for rating residential homes [17].

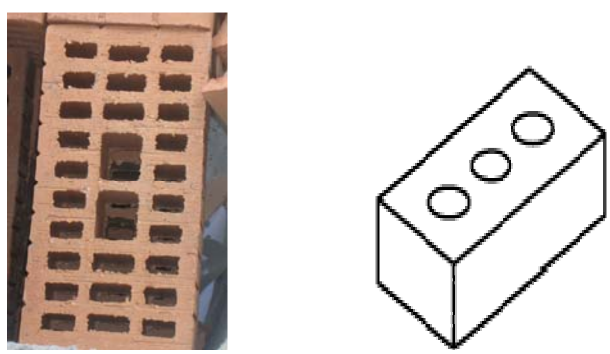
Comparison of U.S. and Swiss Residential Construction

The comparison of a Minergie Swiss home to an Energy Star U.S. home is the basis for this research. These two types of homes are evaluated to generate a hybrid model of best practices from each of the homes. This model is then identified as the most efficient home evaluated between Switzerland and the United States.

Six features are addressed in an Energy Star home. They include effective insulation, high-performance windows, tight construction and ducts, efficient heating and cooling equipment, efficient products, and third-party verification. In a Minergie home, all of the same features are addressed, but they are approached in different ways. This difference is the reason for our comparison of the buildings’ envelope materials, insulation R-Values, wall thicknesses, and the cost of each material.

Building Shell Info

The Swiss home is built almost completely without wood, while U.S. homes are typically wood frame. Swiss residential construction uses masonry bricks that are larger and have more holes, as shown in Figure 4. Aside from brick, Swiss homes use an abundance of concrete for the walls and floors, and U.S. homes usually only use concrete for foundation walls. The masonry provides additional thermal mass compared to the brick or wood-stud walls of the United States.



Standard Swiss Brick Standard American Brick

Figure 4. Swiss vs. American brick

In the United States, walls are usually made of 2" x 4" studs that are 12 or 16 inches apart. Wall sections vary in the products used on the exterior and the amount of insulation provided. Figure 5 shows a typical wall section for the average U.S. home.

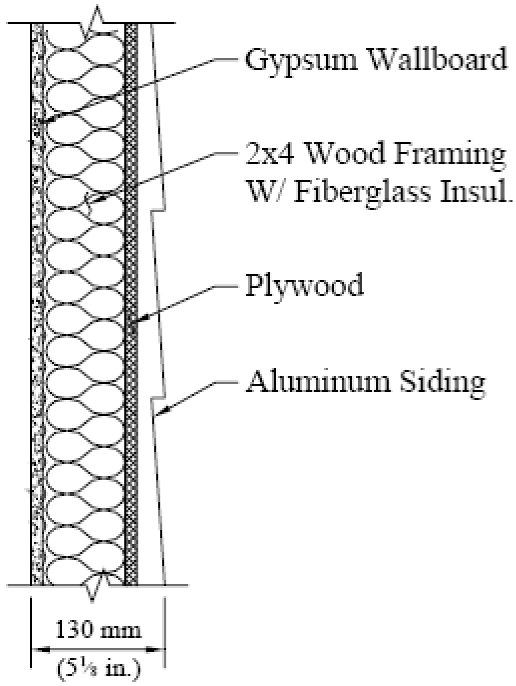


Figure 5. Typical residential exterior wall section for the United States

Figure 6 shows examples of typical Swiss and U.S. home construction. The Swiss homes are built with masonry and are built airtight so as not to allow infiltration of air through the walls or attic.

Swiss Home U.S. Home Example

Figure 6. Swiss vs. American building exterior walls

The U.S. home construction methods allow the home to breathe through the attic. This is required to keep them healthful and comfortable. The building envelope provides the thermal barrier between the indoor and outdoor environment, and its elements are the key determinants of a building's energy requirements, which result from the climate where it is located [10]. There is a trade-off between the tightness and thermal resistance of a home—the less tight a home is, the less thermal resistance it has. The correction to allow for the necessary airflow through a home is to add additional mechanical systems for ventilation. In Switzerland, the mechanical system is the factor that allows the high thermal barrier.

The Swiss normally use masonry walls to add additional thermal mass. This means that the house has more mass to retain heat and cooling or reject heat or cooling for longer periods. This method is used to reduce the amount of supplemental heating needed.

Table 1 shows the comparison of the U-values for the external walls of each of the homes studied. The American homes with wood and cavity insulation show higher U-values as expected, compared to the Swiss homes with masonry walls along with insulation covering the entire wall. The Swiss homes have much better thermal resistance, so they can hold heat in much longer than an American home, for instance.

Table 1. Wall thermal resistance

U-Values for Full External Wall of Studied Homes						
	United States		**Swiss**		**Hybrid**	
	Baseline	Energy Star	Baseline	Minergie	Energy Star	Minergie
U-Value (Btu/ft^2·°F·h)	0.067	0.053	0.053	0.033	0.053	0.033

Building Cost Information

Due to the large differences in the building of homes between the United States and Switzerland, the costs for those energy savings aspects that would change with each house were analyzed. The assumption is that the rest of the home would not change as a part of this study. Table 2 gives an outline of each home with the elements that would be changed according to the guidelines. The HVAC systems are the largest expense, drastically increasing the cost of the Swiss home.

Table 2. Cost comparison of energy components for each home

Costs for Energy Components						
	United States		**Swiss**		**Hybrid**	
	Baseline	Energy Star	Baseline	Minergie	Energy Star	Minergie
Insulation	$1,900	$3,040	$3,040	$5,225	$5,225	$3,040
HVAC	$2,400	$3,700	$12,000	$11,000	$3,700	$11,000
Appliances	$1,757	$1,973	$1,757	$1,973	$1,973	$1,973
Windows	$1,819	$2,465	$2,465	$3,145	$3,145	$2,465
Total Energy Costs	**$7,876**	**$11,178**	**$19,262**	**$21,343**	**$14,043**	**$18,478**

Mechanical Systems

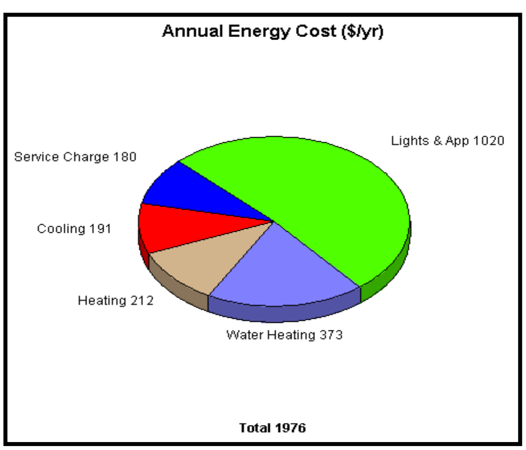
In Swiss homes, a whole house fan is used for ventilation that utilizes an energy recovery unit to reclaim heat. The fan is needed to supply fresh air to the home, since a Swiss home is built to be airtight, as opposed to a U.S. home that is dependent on infiltration through windows, doors, and cracks for fresh air. The whole house fan is used in combination with radiant heating. The radiant heater is similar to types used in the United States but is more typical for commercial use in the United States, not residential. The radiant heating loop is connected to one of many different options to heat the water and glycol mixture in the radiant heater. In Switzerland, the standard gas furnace has other options, such as a wood burning furnace that uses split wood or wood pellets. The heating can also be done using a ground source (geothermal) heat pump. This heat pump has pipes running down deep into the ground; the water and glycol mixture is sent down and back up through the pipes, gaining the heat energy from the ground and warming the home. The HVAC systems have high initial costs due to the installation of the ground loop underground. A process of excavation, installation, and backfill is used to bury the heat piping.

Energy Savings

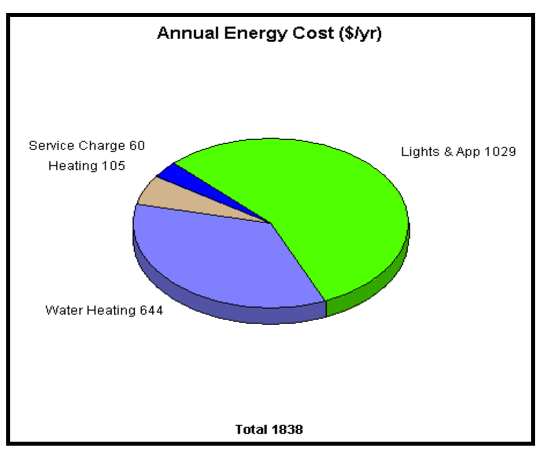
The REM/Rate program uses averages for winter and summer month data for a specific location to determine the total cost of operating a home with temperature set points of 70 degrees Fahrenheit for heating months and 76 degrees Fahrenheit for cooling months over the course of a year.

The homes were evaluated with the climate of Indianapolis, Indiana, and the same utility costs. The electric rate used was 0.10 $/kWh. The gas rate used was 0.26 $/CCF up to 45 CCF and 0.18 $/CCF over 45 CCF. Table 2 above shows the initial costs for each home if they were to be built in Indiana using the materials specified in REM/Rate and following standard build practices and building codes.

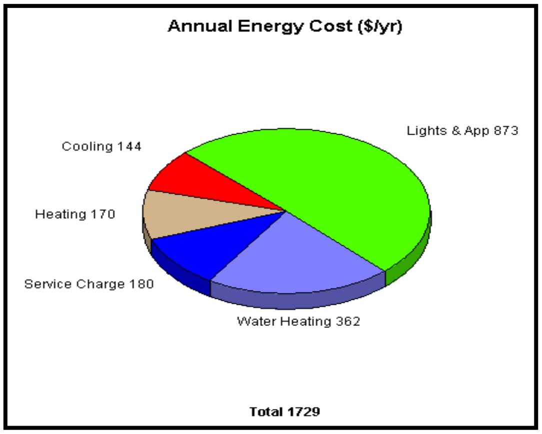
The yearly cost to operate the six homes listed below was found with REM/Rate, and they are illustrated in the charts below:



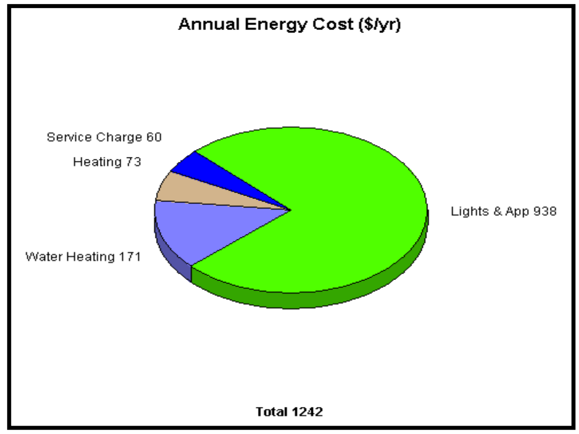
Baseline U.S. home



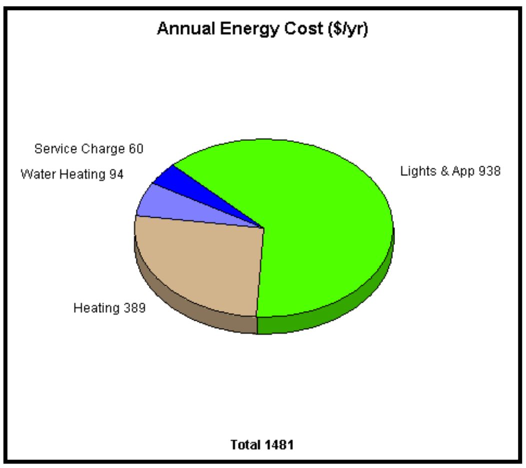
Baseline Swiss home



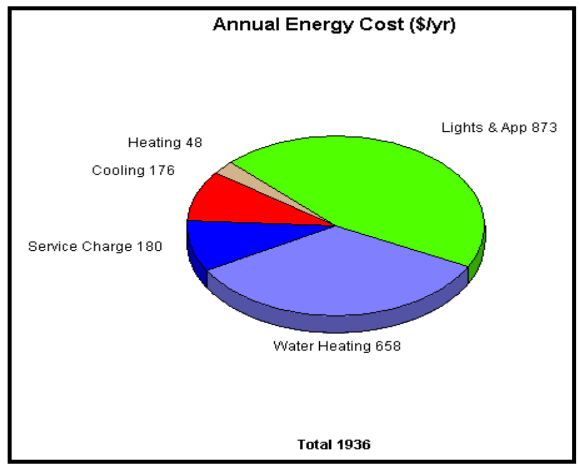
Energy Star U.S. home



Minergie Swiss home



Energy Star with Minergie Mechanical



Minergie with Energy Star Mechanical

Figure 7. REM/Rate analysis results for homes

Table 3 below displays the total cost per year per type of home in a table format taken from the same data shown in the pie charts. The table shows that the highest energy cost, and therefore consumption, was in the standard U.S. home at $1,976. This was followed by the hybrid Minergie home at $1,936, which utilized some U.S. concepts. The Standard Swiss home ($1,838/yr) was a little higher than the Energy Star home ($1,729). The most inexpensive home to operate was the Minergie hybrid home at $1,242 per year. The part of this analysis that is not covered is whether the Minergie system utilized wood heat; in that case, there would be no cost of heating.

Table 3. Energy costs

Energy Costs						
	United States		**Swiss**		**Hybrid**	
	Standard	Energy Star	Standard	Minergie	Energy Star	Minergie
Cost in U.S. Dollars per Year	$1,976	$1,729	$1,838	$1,242	$1,481	$1,936

A better analysis of these systems is to understand the savings comparison per year. Table 4 shows the savings of the energy-efficient homes and hybrid homes as compared to their standard counterparts. It seems that the Swiss Minergie standard that is being utilized is the best overall savings of any home. If U.S. standards are integrated with the Minergie, there is a negative impact that actually increases the cost of the home over the cost of the baseline home.

Table 4. Savings per year compared to standard baseline homes

Savings per Year from Stand to Energy Eff. Homes	
	Savings/yr ($)
U.S. Energy Star	$247.00
U.S. Hybrid Energy Star	$495.00
Swiss Minergie	$596.00
Swiss Hybrid Minergie	0 (-$98.00)

Conclusion

The final result of this research was an example of the best option between two different types of homes. The problem also is cultural, however, and this also needs to be examined. The rationality that home owners would give up summer cooling would be unlikely in areas of the southern United States. The Energy Star home did show a savings, but not as dramatic as the standards that are being utilized in Switzerland. The initial costs are also not going to increase the use of the Swiss standards in the United States. This research is an eye-opener to those who are searching for answers to the saving of energy in residential construction.

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Biography

Daphene Cyr Koch, PhD, is an Assistant Professor in Building Construction Management at Purdue University in West Lafayette, Indiana. She has more than 10 years of experience in mechanical construction and has been teaching for seven years. She has won numerous teaching awards locally and nationally.

Jason M. Kutch is a graduate student of Mechanical Engineering Technology at Purdue University in West Lafayette, Indiana. He has assisted the Technology department during his graduate school as a Technician in the Applied Energy Laboratory. His focus of study is sustainability in residential construction.

William J. Hutzel is an Associate Professor of Mechanical Engineering Technology at Purdue University in West Lafayette, Indiana. His areas of expertise include building controls, HVAC systems, and renewable energy. Professor Hutzel recently completed a fellowship in the U.S. Senate, where he worked on energy and global warming policy.

Eric A. Holt is a graduate student of Building Construction Management at Purdue University in West Lafayette, Indiana. He has worked the last 17 years in the Residential Construction Industry. His focus of study is Residential Construction and Building Information Modeling (BIM).