Conference Proceedings

ASES National Solar Conference 2016

San Francisco, CA, USA July 10-13, 2016

House Energy Doctor's Level III Building Energy Audits as Pedagogy and Outreach

Nader V. Chalfoun

University of Arizona, Tucson, Arizona (USA)

Abstract

Arizonans spend over $9 Billion annually on primary energy consumption which is equivalent to the entire state budget. The building sector in Arizona consumes 45% of that energy. Many older pre-energy code buildings have poor performance, and consume immense amount of energy. The House Energy Doctor© (HED) program has developed an in-house tool set that includes the operation of specific site instruments and "Site Survey Forms©" to be used in conducting Level III energy audits for existing residential and commercial buildings. The energy audit is a major part of the Masters of Science in "Design and Energy Conservation" and is used in providing outreach service to building owners while fostering students hand-on inquiry based learning. Since 1986, outcome of using the established HED Level III energy audit process has been successful in yielding pronounced education opportunity for students and for homeowners alike, while providing an average of 50% savings in the total energy used by existing buildings. These results also have a great impact on improving building's operation, reducing cost, and minimizing the carbon footprint a valuable resource in the emergence of America's new energy economy. This paper describes the HED Level III advanced energy audit process, provides details of the distinctive in-house developed Site Survey Forms, their contents and method of use, and demonstrate successful case studies applied to campus building and residential community single family houses.

Keywords: *Energy Efficiency, House Energy Doctor, Energy Audit, Site Tools, Existing Buildings, Education*

1. Introduction

The United States total primary energy consumption was 97.1 quadrillion Btu in 2013 (DOE/EIA-0383, 2015). Building operation consumes 75.7% of the total electricity and 43.1% of the total energy. The state of Arizona spends over $22 billion annually on primary energy consumption which is equivalent to the entire state budget, and this rate is increasing by 2-4% annualy. The building sector in Arizona consumes 45% of that energy. Buildings also account for carbon emmision, raw material use, waste output, and potable water consumption.

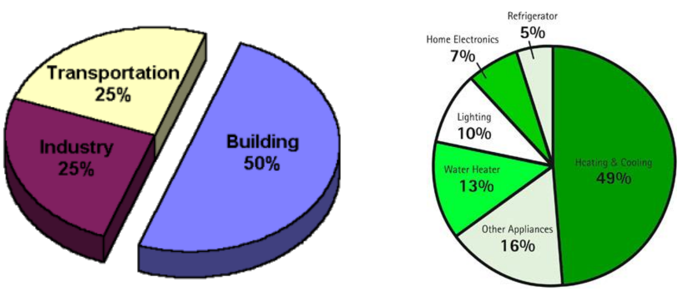


Fig. 1: World energy consumption (left) and energy consumption by type (right)
Source: Energy Information Administration (2008).

doi:10.18086/solar.2016.01.02 Available at http://proceedings.ises.org

In the residential sector, single-family homes account for over two-thirds of total delivered energy use. In the commercial sector, office, retail, and educational facilities use nearly half the delivered energy. With 90% of the housing units in Arizona are pre energy code, energy saving opportunity is great and can be achieved through energy audits and retrofit strategies. At the University of Arizona's CAPLA this opportunity was realized through the inception of the House Energy Doctor© (HED) program.

2. The House Energy Doctor© program

Since 1986, the "House Energy Doctor" (HED) program[1] is an education, research, and community outreach program developed by Dr. Chalfoun at the University of Arizona's College of Architecture, planning and Landscape Architecture (CAPLA). The program provides service while fostering hands-on inquiry based learning of high performance green architecture, energy conservation, and passive solar designs. It uses advanced field investigation methods of existing buildings and cutting edge energy audits. During the last 3 decades the program serviced over 140 residences, 32 commercial, 6 institutional, 4 medical buildings, and two National Parks, had over 120 publications, and conducted over 22 workshops worldwide. The program was developed into a full one-and-a-half year Masters of Science in Architecture curriculum and in 2012 was awarded the "Best Energy Education" in Pima County by the Department of Energy.

Fig. 2: House Energy Doctor© program at the University of Arizona

The program offers energy education through 1) Studios, 2) courses, 3) empirical research laboratories, and 4) Thesis development. One of the most important achievement of HED is the establishment of the Tucson's first residential annual heating and cooling baseline consumption of 55.6 kBtu/ft². This index was then used to develop the first energy code that was implemented in Pima County[2]. The research findings demonstrated methods to save over 60% of existing buildings' heating and cooling consumption using different levels of advanced energy audits.

3. HED Advanced Level III Residential Energy Audits

Energy audits can be interpreted in many different ways by individuals depending on the scope, complexity, and required level of evaluation. Thus energy audits techniques must be defined in advance. The HED program developed three major energy audit levels increasing in complexity and based on project goals and time spent on site. Level I: Basic walk-through observation, Level II: Walk through with instrumentations and measuring tools, and finally Level III: consists of the Level II and conducting energy simulation, optimization and recommendation for improvement that includes return on investment analysis.

Fig. 3: House Energy Doctor© Levels of Energy Auditing

3.1. Energy Audit Level I

This is the simplest and shortest energy audit process that requires few hours spent on the facility. HED students walk through the buildings guided by building owner or homeowner. They conduct visual inspection of the building envelope and the mechanical and lighting systems taking notes and photographs. Typically, utility bills are collected and compared with industry standard benchmarks to identify potential savings. A short report is sent to the building owner shortly after inspection.

Fig. 4: House Energy Doctor© Level I energy audits

3.2. Energy Audit Level II

This level is considered a standard audit but with instruments. It often requires more than one day tour of the facility to quantify energy usage through more detailed review of the building envelope, equipment, HVAC systems, and operational characteristics (efficiency). On-site measurements and testing of performance is conducted using site tools and instruments. Example of these tools are roof inclinometer, solar reflectance pyronometer, thermometers measuring supply and return temperatures, clocking the electric meters using stopwatch, air-balancers to measure and balance volume of air supplied by the duct system, etc. An interview with the building owner is also conducted that reveals time of use, thermostat settings, appliances schedule, and more.

Fig. 5: House Energy Doctor© instruments used in Level II energy audits

Standard energy engineering calculations are used to analyze efficiencies and calculate energy and cost savings based on improvements and recommended changes. This Level II audit often include economic analysis of recommended conservation measures.

3.3. Energy Audit Level III

This is considered HED's most comprehensive evaluation of energy use patterns of buildings achieved through the use of advanced data collection methods combined with industry standard computer simulation techniques. The simulations account for weather and other variables to predict typical year-round energy use profile. This level requires site visits activities and data collection beyond those conducted in Level II. For example a blower door test is required and all appliances and electric lighting systems must be documented in details. Students use an in-house developed instrument called Azimuth Protractor© (developed by Dr. Chalfoun) to accurately measures building orientation. The mechanical system efficiency is measured on site and a special set of site forms are used to accurately collect all the needed data.

Fig. 6: House Energy Doctor© level III energy audits

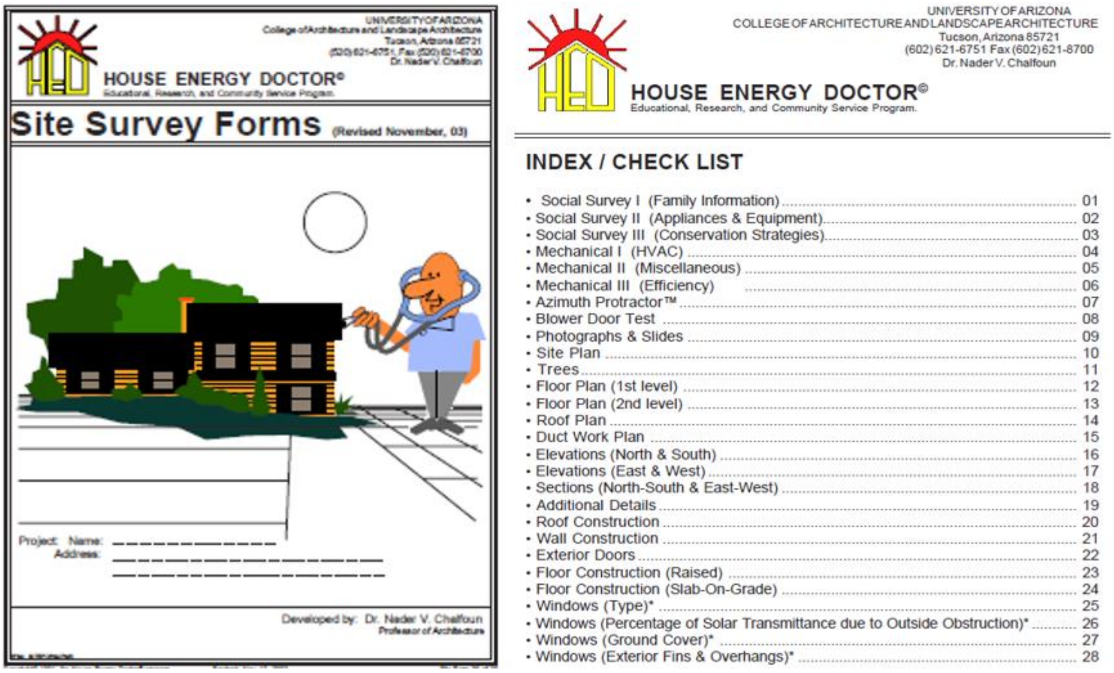
After the elaborate site visit, students auditors energy simulation software to develop a baseline energy usages of the as-is building. The baseline performance must be validated by comparing it with the actual utility bills and make sure the predicted consumption falls between ±20%. Auditors then conduct parametric analysis by making one-at-a-time changes to improve the efficiency of various building and mechanical systems as compared to the baseline performance. An optimized case is then developed and reported to the building owner after a thorough economic analysis that proof the best return on investment to the client.

Fig. 7: Validation of the Basecase simulation results

Because of the time involvement in this level, considering the detailed data collection and accurate computer energy and economic modeling, this is considered the most time consuming and most expensive level of energy auditing conducted by HED.

4. HED Site Survey Forms

In 1996, the House Energy Doctor program received a grant from the Department of Energy to develop a special set of site survey forms to be used during the different levels of energy audits. The forms are developed to help students collect comprehensive and complete data during their visit to the building avoiding revisits due to any missing information. This important if sites are in remote locations and require traveling time and expenses. The forms also provides valuable information on building material and systems performance such that it could be used as a teaching tool to students and building owners alike. There are 28 site survey forms and some are repetitive for larger buildings where for example the number of openings exceeds the maximum numbers on the forms. Duplicate forms could then be used. All forms are available for download on the House Energy Doctor website: http://hed.arizona.edu/hed/. They have been used by many students and clients not just for conducting Level III energy audits but also for research purposes.



INDEX / CHECK LIST

- Social Survey I (Family Information) 01
- Social Survey II (Appliances & Equipment) 02
- Social Survey III (Conservation Strategies) 03
- Mechanical I (HVAC) 04
- Mechanical II (Miscellaneous) 05
- Mechanical III (Efficiency) 06
- Azimuth Protractor™ 07
- Blower Door Test 08
- Photographs & Slides 09
- Site Plan 10
- Trees 11
- Floor Plan (1st level) 12
- Floor Plan (2nd level) 13
- Roof Plan 14
- Duct Work Plan 15
- Elevations (North & South) 16
- Elevations (East & West) 17
- Sections (North-South & East-West) 18
- Additional Details 19
- Roof Construction 20
- Wall Construction 21
- Exterior Doors 22
- Floor Construction (Raised) 23
- Floor Construction (Slab-On-Grade) 24
- Windows (Type)* 25
- Windows (Percentage of Solar Transmittance due to Outside Obstruction)* 26
- Windows (Ground Cover)* 27
- Windows (Exterior Fins & Overhangs)* 28

Fig. 8: HED Site Survey Forms

The forms basically represents three major aspects of take-off data from site; 1) Social survey forms, 2) Envelope forms, and 3) Mechanical systems.

4.1. Social Survey Forms

These forms are used by the students during the audit. They interview the building owners to get information on the building use profile and internal loads, etc. The forms cover 10 main topics, these are:

1. Family Size	2. Family Daily Pattern
3. Guests and Visitors	4. Vacations
5. Thermostat Settings	6. Demand Charge Account
7. Inventory of Household Appliances	8. Usage Patterns of Common Household Appliances
9. Proposed Conservation Strategies	10. Proposed Budget upgrade/retrofit Budget

Fig. 9: HED students conducting the social survey

An important function of one of the forms is to question the building owner about favorable energy conservation strategies that he/she would like investigated. It also ask building owners whether they have an allocated budget for upgrade/retrofit and the approximate dollar amount.

4.2. Envelope Data Forms

These forms are used to document all the envelope information needed for computer simulation. For example, one form is used to identify the exact building orientation in relation to south. Homeowners usually do not have this information and underestimate its importance. When they are asked about the orientation of their building they usually eye ball pointing to the south.

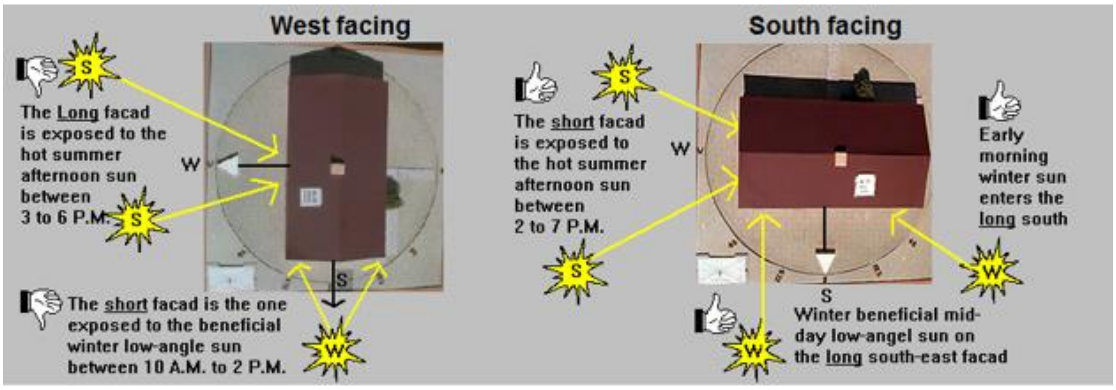


Fig. 10: Importance of building orientation

Professor Chalfoun has developed a patented instrument called "Azimuth Protractor©". It is a device for determining accurately the exact angel of orientation (or azimuth) of any given surface wall or site boundaries relative to the true south orientation. The device takes into consideration longitude correction, equation of time correction, and true verses magnetic north. Associated with the device is a software AP© written in ACAD Lisp language, which generates AP Charts for the specific day of the site visit. The charts are mounted on the device platform before going to site. The sun shadow of the 2", 3", or 4" pin is observed and alligned with the chart a protractor arm is swang out to allign with the wall, and the azimuth angel could be read on the engraved protractor.

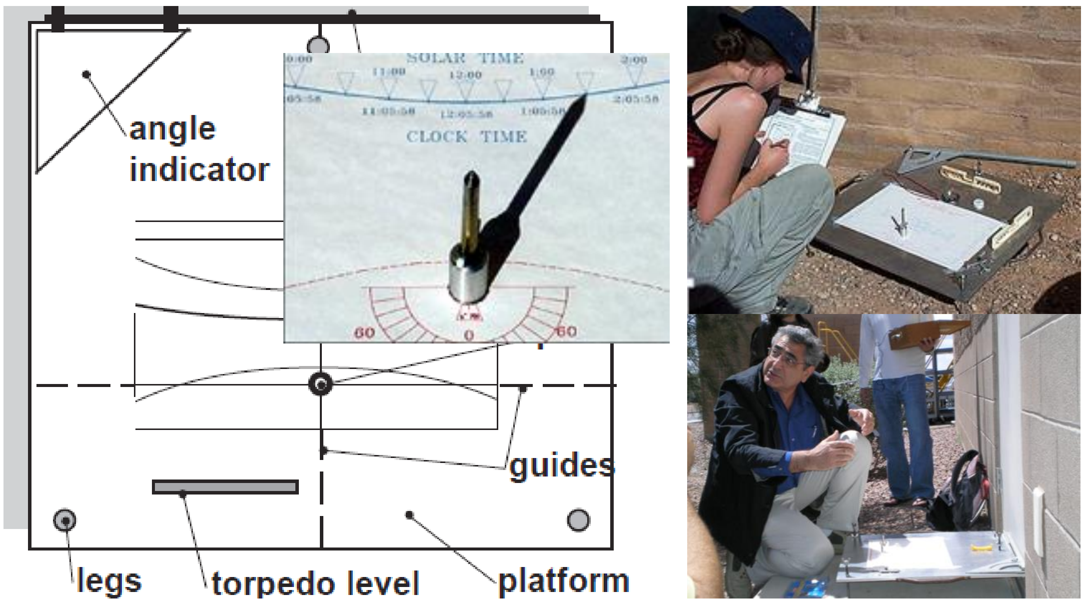


Fig. 11: The "Azimuth Protractor©".

Information about the envelope leakage is measured on site using a blower door instrument. A blower door has a large calibrated fan that is temporarily mounted in a house door to measure the "leakiness" of the house and to assist in finding the location of the leaks. To measure the leakiness of the house, both the air flow through the fan and the differential pressure created across the house walls must be measured.

Fig. 12: The Blower Door experiment

When the envelope is depressurized and the 50 Pascal is acheived, the number of CFM and the volume are used to calculate the air leakage in a Air Change per House ACH format.

$$ACH\_50\ natural = \frac{60\ X\ Air\ Flow\ (cfm)\ X\ blower\ door\ factor}{17\ X\ House\ Volume(\text{cf})} \quad \text{(eq. 1)}$$

When the blower door fan is reversed, the envelope is then pressurized and the leaks could be detected through the use of smoke sticks. Additional envelope investigation techniques by the House Energy Doctor is measuring shortwave reflectance, using thermal camera to identify thermal bridges, locate trees and major landscape objects that might have effects on the interaction between the sun and the building, in addition to sketching and naming object for identification in the computer model.

Fig. 13: Above, auditors using thermal camera, measuring internal dimensions, roof tilt and sketching facades, Below: An infrared photo showing the CMU wall with thermal bridges through the grout

4.3. Mechanical System Forms

These forms are used to document data on the building's HVAC system that was either measured by the students or read of the equipment stickers. One important variable that has the greatest potential on simulated energy conservation number is equipment efficiencies. The HED auditor actually measures on site the actual running coefficient of performance (COP) of a heatpump or an AC unit through a three-step process; 1) use the airbalancer instrument to measure the CFM capacity of the ductwork, 2) use a stop watch to clock the meter and measure the power of the system, and 3) after measuring the supply and return temperatures of the system we use the following equation to obtain the COP:

$$COP = \frac{Capacity\ (\frac{Btu}{hr} or\ kW\ output)}{Power\ (\frac{Btu}{hr} or\ kW\ input)} \qquad \text{(eq. 2)}$$

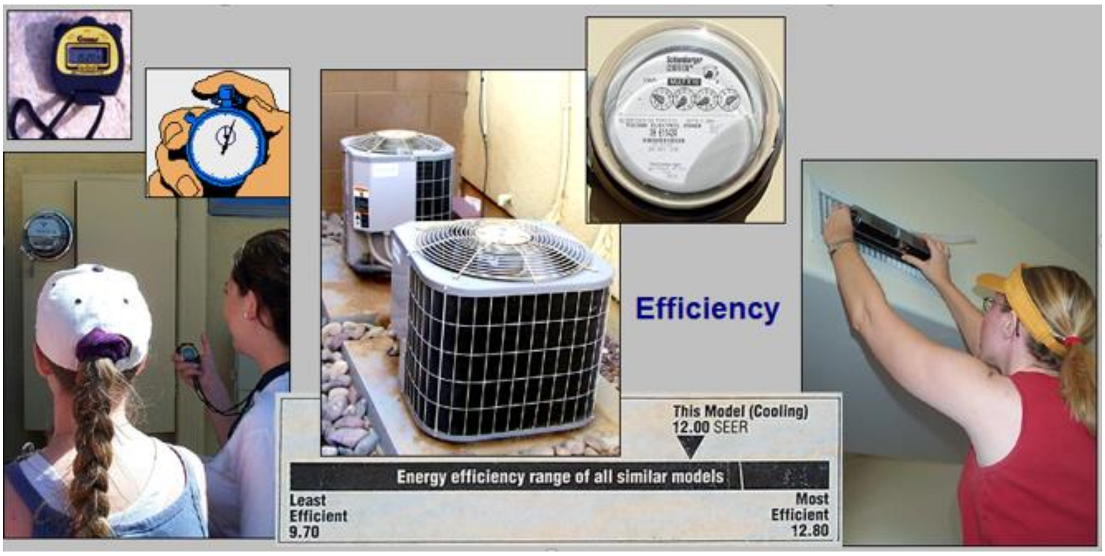


Fig. 13: Identifying system's COP by clocking the meter.

5. Commercial Energy Audit

Through a multiyear agreement between HED and the UA, Level III energy audits have been conducted on nine major campus buildings to identify energy efficiency opportunities that will contribute to the greening of campus. Some of the important findings are focused on replacement of inefficient windows, adding external insulation, shading for most of critical building elements, replacement of energy-saving light fixtures, and proposing change of envelope colors to increase solar reflectance in summer. Strategies for mechanical systems propose changes to current thermostat set points, run periods, replacement of old components with higher efficiency units, and water harvesting of condensates for landscape use.

The first three years of the "Greening of Campus" project demonstrated that the nine buildings total area of 1,081,512 ft^2 consumed an annual average 75,970,411 KBtu (70.2 KBtu/ft^2) at the cost of $2,186,264 per year. Implementation of the House Energy Doctor recommendations for the nine buildings will yield an annual energy savings of 9,542,106 KBtu and operating cost saving of $265,318 (12.1%). This energy saving will help the environment by a reduction of 2,915 Metric tons of CO_2 emission. The campus will also be saving 10.9 million gallons of water, an important environmental benefit for desert communities like the University of Arizona. In addition, two of nine buildings "Arizona-Sonora" and "La Aldea" have been successfully certified for Energy Star Designation.

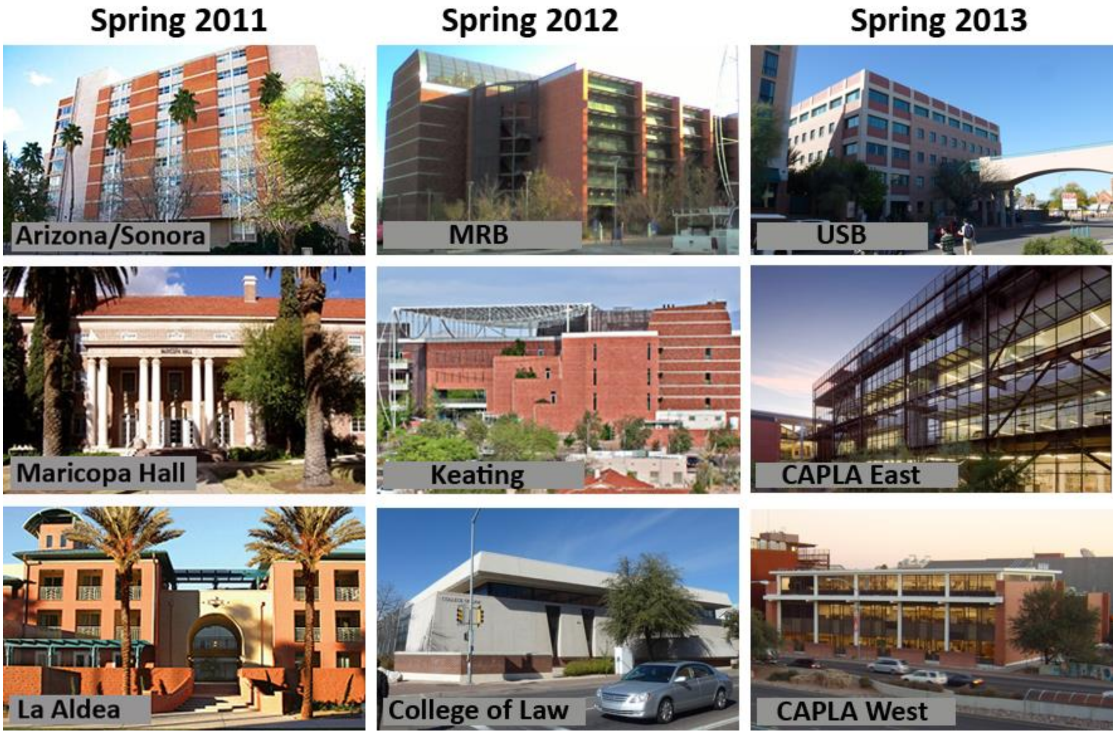


Fig. 14: University of Arizona Buildings.

6. Conclusion

The House Energy Doctor program at the University of Arizona is aiming at graduating new generations of informed energy conscious architects focused on green building design and reduced consumption. Since 50% of the nation's energy is consumed by buildings, the expected energy saving results are enormous. The savings also reduce greenhouse gas emission created by the generation of electricity that pollutes the air, causes climate change, and has adverse effects on human health, as well as negative biological impacts on plants and animals. Energy production is also depleting the water supply, a critical aspect of desert communities like Arizona. For example for every kWh of electricity generated, 2/3 gallon of water is consumed at the site of thermoelectric power plant. Arizona produces 17% of its energy from Hydroelectric, at the Hoover dam which actually consumes 65.85 Gallons per kWh (Torcellini et al. , 2003).

Since 1983, the House Energy Doctor program provides advanced level III energy audits and recommendations and has served over 140 residences, 30 commercial and 16 institutional buildings. With its hands-on inquiry based learning, the program has over 100 publications, and conducted numerous national; and international workshops. Through the years, the program has developed tool kits, instruments, and a set of special Site Forms that are used in the advanced energy audits. A Master's of Science in Design and Energy Conservation has been developed around the program that includes 14 graduate and upper division undergraduate courses, all centered around energy and water.

The average energy savings from the level III audits will have the greatest potential in reducing state energy consumption in buildings by at least 50%, significantly reduce green house gas emissions, mitigate climate change, and promote healthy living. On the University of Arizona campus, the HED process has now expanded to include all university buildings and in the last two years nine more buildings have been studied for retrofit by the House Energy Doctor program. The University of Arizona is the only university in the state with a diverse architecture, engineering, and environmental science expertise, and we witness now that more departments are joining the efforts with HED in Architecture.

7. Acknowledgment

The author would like to acknowledge all the national and international House Energy Doctor students who participated in the program and contributed to its success. They played the major role of conducting the energy audits and generated professional reports that contributed to savings in the state of Arizona and other communities. The author would like to also acknowledge the building owners who collaborated with the program faculty and students to facilitate the level III energy audits. I also would like to acknowledge Christopher Kopach, assistant Vice President, Facilities Management, Joseph Thomas Energy Conservation Manager at the University of Arizona, and James Van Arsdel, Assistant Vice President for Student Affairs. Special appreciation for all the buildings' Managers who facilitated the energy audits and provided faculty and students us access to the buildings.

8. References

DOE/EIA-0383, 2015. Annual Energy Outlook 2015, with projections to 2040. U.S. Energy Information Administration, Office of Integrated and International energy analysis. U.S. Department of Energy, Washington, DC 20585. [www.eia.gov/forecasts/aeo]

Chalfoun, N.V., 2013. “A Method for Greening University Campus Buildings While Fostering Hands-on Inquiry-Based Students' Learning", 6th International Multi-Conference on Engineering and Technological Innovation: IMETI 2013, July 9-12, 2013 ~ Orlando, Florida, U.S.A.

Chalfoun, N. V., 1991. The “House Energy Doctor©; an Educational, Research and Community Service Program at the College of Architecture, the University of Arizona. Proceedings of the Design for Desert Living Symposium, Jul. 21-26, Tucson, AZ, USA.

Chalfoun, N.V. et al, 1991. "Passive Solar and Energy Optimization for a Residential House Type in Tucson, Arizona: A Case Study for the Solar Village Project. International Solar Energy Society (ISES) Solar World Congress. Aug.17-24 1991, Denver, Colorado.

Chalfoun, N. V., and Michal, J. R., 2003. Thermal Performance Comparison of Alternative Building Envelope Systems: Analysis of five Residences in the Community of Civano, Architectural Research Centres Consortium (ARCC), College of Architecture and Environmental Design, ASU, Phoenix, Arizona, April 10-12, 2003.

Torcellini, P. et al., 2003. Consumptive Water Use for U.S. Power production: Technical Report, National Renewable Energy Laboratory (NREL), NREL/TP-550-33905, Golden, Colorado, U.S.A., pp. 5, Table 3.