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Greening University Campus Buildings to Reduce Consumption and Emission While Fostering Hands-on Inquiry-Based Education

Nader Chalfoun*

University of Arizona, CAPLA, 1040 N Olive St. Tucson, Arizona 85721, USA

Abstract

This paper describes a method of greening university campus buildings that normally contribute to a large amount of energy and water consumption, air pollution, and resource depletions. The University of Arizona became engaged in the American College and University Presidents Climate Commitment emphasizing those university campuses must exercise leadership in their communities and throughout society by modeling ways to minimize global warming emissions, and by providing their graduates the knowledge and education to achieve climate neutrality.

The "House Energy Doctor" (HED) program is an education, research, and community outreach program at the University of Arizona's (UA) College of Architecture, planning and Landscape Architecture (CAPLA). During the last three years, and 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 important findings focused on inefficient windows, external insulation, shading of critical building elements, energy-saving light fixtures, and envelope 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 ft² consumed an annual average 75,970,411 KBtu (70.2 KBtu/ft²) at the cost of $2,186,264 per year. The 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. In addition, two of nine buildings "Arizona-Sonora" and "La Aldea" have been successfully certified for Energy Star Designation. The method can be replicated in different units around campus and as a model for implementation in other university campuses around the world.

* Corresponding author. Tel.: +520-621-6751; fax: +520-621-8700.
E-mail address: chalfoun@u.arizona.edu

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1. Introduction

University campus buildings contribute to a large amount of energy and water consumption, air pollution, and resource depletions due to their heavy use. In U.S.A., Arizonans spend over $9 Billion annually on primary energy consumption which is amazingly equivalent to the entire State budget. The building sector in Arizona consumes 45% of that energy. Realizing the fact that a major human security factor lies in sustainability, the University of Arizona has become engaged in the American College and University Presidents Climate Commitment. This agreement emphasizes that university campuses must exercise leadership in their communities and throughout society by modeling ways to minimize global warming emissions, and by providing their graduates the knowledge and education to achieve climate neutrality. The goal is that colleges and universities will provide students with the knowledge and skills needed to address the critical, systemic challenges faced by the world in this new century and enable them to benefit from the economic opportunities that will arise as a result of solutions they develop.

Since 1986, the “House Energy Doctor” (HED) program [1] is an education, research, and community outreach program at the University of Arizona's College of Architecture, planning and Landscape Architecture. The program promotes green architecture design through service learning of energy conservation and passive solar and using advanced field investigation methods of existing buildings and cutting edge energy audits. During the last three years, and through a multiyear agreement between the University's HED, Facilities Management, and Housing and Residence Life Directors, Level III energy audits have been conducted on nine major campus buildings to identify energy efficiency improvement opportunities and contribute to the greening of campus movement. The project was incorporated into the Arc 461K-561K, Sustainable Design and the LEED© Initiative taught by Chalfoun.

Nomenclature

HED	House Energy Doctor
CAPLA	College of Architecture, Planning, and Landscape Architecture
LEED	Leadership in Energy Efficient Design

2. Project Description

The University of Arizona (UA), is a land-grant public institution of higher education and research located in Tucson, Arizona, United States. It was founded in 1885 as the first university in the state of Arizona. Current total enrollment is approximately 40,000 students

Fig. 1 University of Arizona's main campus buildings.

The Main campus covers 380 acres (1.5 Km²) in central Tucson and is considered as a hub of community activities. There are 179 buildings on the main campus. Many of the early buildings, including the Arizona State Museum buildings and Centennial Hall, were designed by prominent Tucson architects and some were on the national Registry of Historic Buildings. Most of buildings were built prior to the sustainability and energy efficiency movement. Therefore, the opportunity to conduct energy audits and recommend energy retrofit strategies to these buildings is expected to yield a substantial amount of energy savings.

During the last three years, a total of 9 campus buildings have been audited for energy efficiency by the HED program. These buildings were selected to represent different old and new constructions (see Table 1 and Fig.2).

Table 1. The nine selected university of Arizona Buildings

Building Name	Area (ft²)	Function
Arizona-Sonora	127,903	Residence Hall
La Aldea Apartments	123,201	Residence Hall
Maricopa	32,0705	Residence Hall
College of Law	111,288	Education + Library
Medical Research Building (MRB)	296,676	Research + Labs
Keating	204,262	Research + Labs
CAPLA West	36,765	Education + Shop
CAPLA East	43,737	Education
University Service Building (USB)	105,610	Office Building
	1,081,512 ft² Total	

Fig. 2 The nine selected campus buildings

3. Project Phases

Three buildings have been selected in each semester of spring 2011, 2012, and 2013. All three phases of performance have been conducted by students and HED faculty in collaboration with The University of Arizona Facilities Managements director and professionals and building's manager. Below is the description of work on each phase:

3.1. Phase 1: Pre-Audit Data Collection

In order to assure successful energy audits, important information on the three selected buildings was obtained and processed in advanced. The information was then made available, in a Pre-Audit report, to the House Energy Doctor students to follow during the actual audit and measurements. The report includes the following:

- Construction documents of each building.
- Equipment and mechanical system specifications and their function diagrams
- Utilities information (electric/gas/water)
- Users and occupants information.
- Pre-visit to each building
- Development of site forms which are specific to Residence Life building take-offs.

Documenting the buildings' mechanical system is vital to the process. Some buildings use District Heating and Cooling Plant (DHCP) for their supply of steam and chilled water. Specifications were documented with input from facilities management personal and each building director.

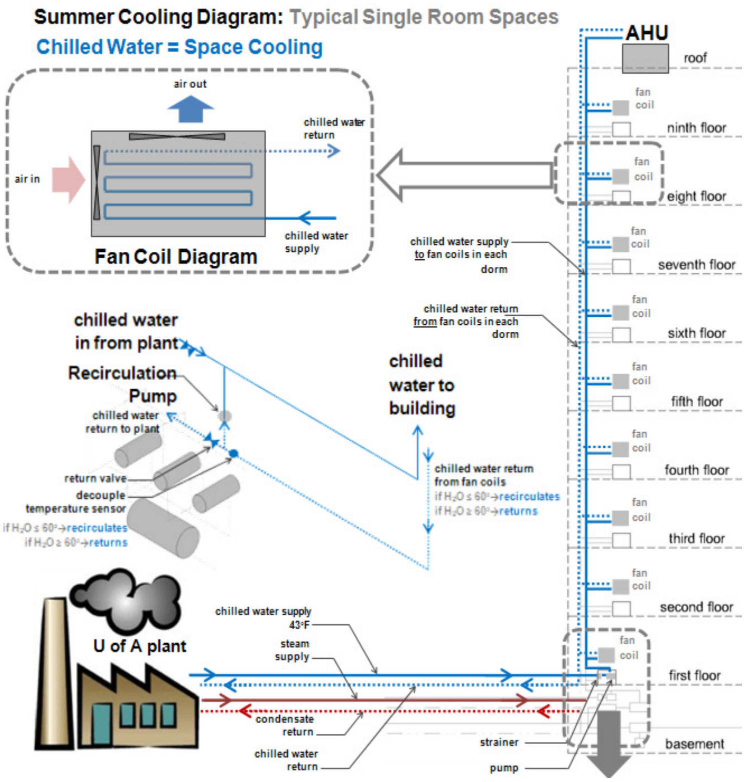


Fig. 3. District Heating and Cooling Plant [DHCP] diagram

Other buildings use traditional HVAC DX-split heat pump systems such as La-Aldea residence life building, while others use roof-top cooling towers for chilled water and traditional floor soffits for supplying heated air.

Fig. 4 (left) La Aldea split heat pump HVAC system, (Middle) CAPLA chilled water units, and roof-top cooling towers at the USB Building.

3.2. Phase 2: Level III Energy Audits

Prior to the energy audits, students in the Arc561e; Sustainable Design and the LEED© Initiative are taught principles of computer energy simulation using programs such as COMcheck, Autodesk Revit, Google Sketchup, and eQUEST. Students also are trained in the House Energy Laboratory on using specially developed site survey forms (Fig. 6) as well as different site instruments such as light meters, pyronometers, inclinometers, blower door, duct blasters, azimuth protractor, air-balancer, etc. (Fig. 7)

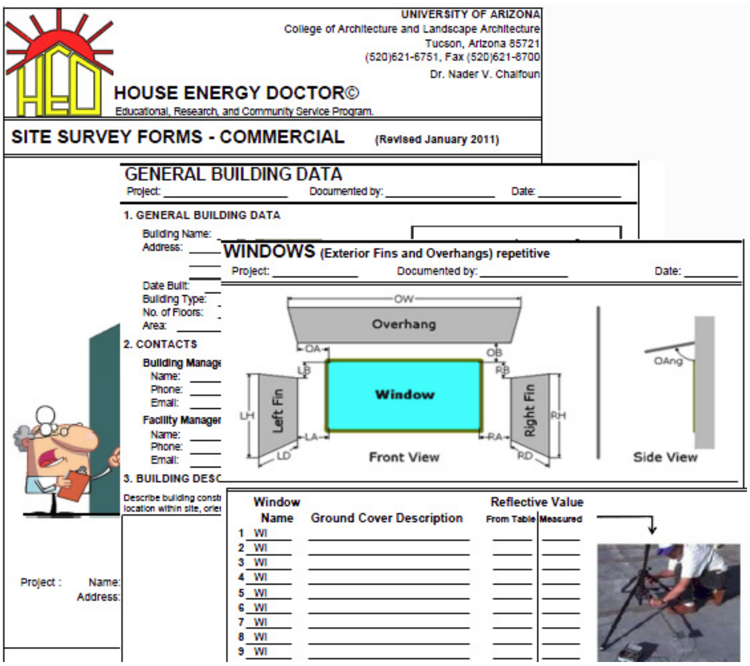


Fig. 5 (left) La Aldea split heat pump HVAC system, (right) roof-top cooling towers at the USB Building.

COMcheck is a code compliance tool that uses the envelope average area-weighted $UA_{average}$ value to compare with the pre-defined code values based on the climate location and the heating and cooling degree of that location. Calculation of the area weighted $UA_{average}$ value is as follows:

$$UA_{average} = \frac{U_1A_1 + U_2A_2 + \ldots U_nA_n}{A_1 + A_2 + \ldots A_n} \quad (1)$$

Since most of buildings were built prior to the sustainability and energy efficiency movement, none of them complied with COMcheck for Pima County.

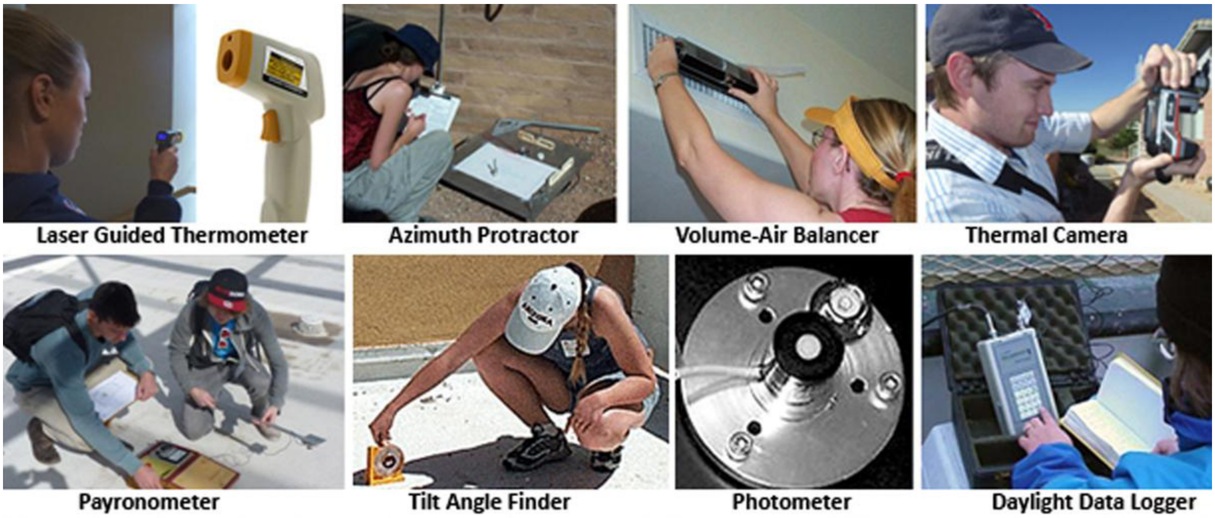


Fig. 6 House Energy Doctor set of site instruments and tools used by the students to conduct level III energy audits

During the audit day, students were divided into teams and for each building they collected the following information:

1. Building orientation and geometry in relation to sun angles (an important variable in desert architecture)
2. Size and placement of openings throughout the building facades.
3. Envelope materials information such as R-value, heat capacity, and compositions [2]
4. Exterior and interior materials shortwave reflectance, textures, absorbtance, and translucencies
5. Light intensities and distribution in all indoor spaces and daylight use potential
6. Shading devices and their locations and geometry.
7. Building uses and occupancy schedules
8. Mechanical heating and cooling systems and air-handlers capacities and efficiencies
9. Building thermostat settings and scheduling, including setbacks if applicable
10. Location of ducts and duct insulation
11. Water heating equipment
12. Building's internal plug-loads and equipments.

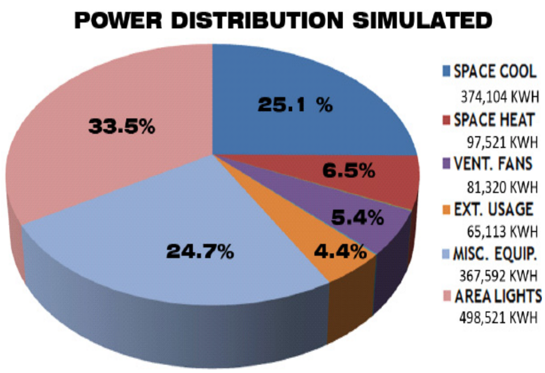
Figure 7 illustrates some of the problems associated directly and indirectly with high energy consumption in campus buildings. It includes lack of shading, thermal bridging and old and inefficient mechanical system components.

Fig. 7 Some of the major energy consumption were associated with lack of shading devices at La Aldea Building (Left), Heat dissipation related to the Single Glazed Facade at CAPLA West Building (Middle), and Aged and inefficient roof-top cooling towers at the USB Building (Right).

3.3. Phase III: Post Audit

After information was gathered during the Audit Phase, envelop schedules must be developed for each building that include all the basic information required to run an as-is simulation - we call it the "Basecase". Each basecase was first simulated using the DOE COMcheck software to verify its compliance with the minimum energy code mandated by the ASHRAE 90.1, 2007 for Pima County and City of Tucson.

After compliance was checked, a breakdown of each of the buildings' energy consumption by type was presented and compared with the actual utility bills provided by the Facilities Management. Each result must demonstrate a minimum of ± 20% in heating and cooling consumption compared to the actual onsite meters.



ELECTRIC AND GAS UTILITY BILLS

	Electricity (KWH)			Gas (Therms)		
Month	Actual	Adjusted	Simulated	Actual	Adjusted	Simulated
Janurary	105,786.50	100,729.50	124,112.56	1,790.00	1,975.00	2,131.98
February	100,952.00	101,728.00	101,810.78	2,089.00	2,289.00	2,015.28
March	72,598.00	77,287.00	110,878.12	1,862.00	2,033.00	2,225.37
April	86,755.00	90,749.00	107,863.14	1,693.00	1,849.00	2,104.22
May	125,748.00	137,806.00	128,231.70	1,271.00	1,388.00	1,961.16
June	72,651.00	167,344.00	139,332.79	891.00	2,679.00	1,681.55
July	123,579.00	231,873.00	152,047.45	868.00	2,299.00	1,567.45
August	111,237.00	234,531.00	152,039.14	934.00	2,342.00	1,439.24
Septembe	124,043.00	129,436.00	128,445.66	1,260.00	1,009.00	1,392.56
October	120,383.00	125,838.00	113,995.64	1,375.00	1,375.00	1,545.50
Novembe	90,499.00	88,532.00	108,065.57	1,787.00	1,906.00	1,674.25
Decembe	90,234.00	90,612.00	120,275.35	2,082.00	2,206.00	1,937.62
TOTAL	1,224,465.50	1,576,465.50	1,487,098.87	17,902.00	23,350.00	21,676.17
		5.6% DIFF.			7.2% DIFF.	

Fig. 8 Total consumption breakdown by type (top) and utility bills (bottom) to compare actual consumption with computer simulation results. Simulation is accurate if the difference between the two falls within ± 20%.

4. Building Performance Optimization

For building performance optimization, the research team used the advanced DOE eQUEST 3.4 energy simulation program [3] to investigate different energy efficient design options of the envelope, building scheduling and seasonal and diurnal operations, and the mechanical system that contribute the most to energy waste. To accomplish that, building geometry and thermal zones must be identified in the input file.

Parametric analysis then follows to prescribe means to improve the base case. Some of these common major design deficiencies that were revealed by the energy analysis are:

- Inefficient windows and glazing systems
- Lack of insulation in roof and exterior walls

- Increased air leaks and infiltration due to penetration for wall fan-coil units fresh-air intakes
- Lack of daylight use which caused high electric load
- Lack of insulation in exterior walls and roof
- All windows are single pane
- Lack of windows shading
- Thermostat has no setbacks
- Exposed roof top package units efficiency
- Lack of shading devices on exterior windows
- Envelope surface to volume area ratio
- Exterior lighting running throughout the day
- Dark heat absorbing exterior colors

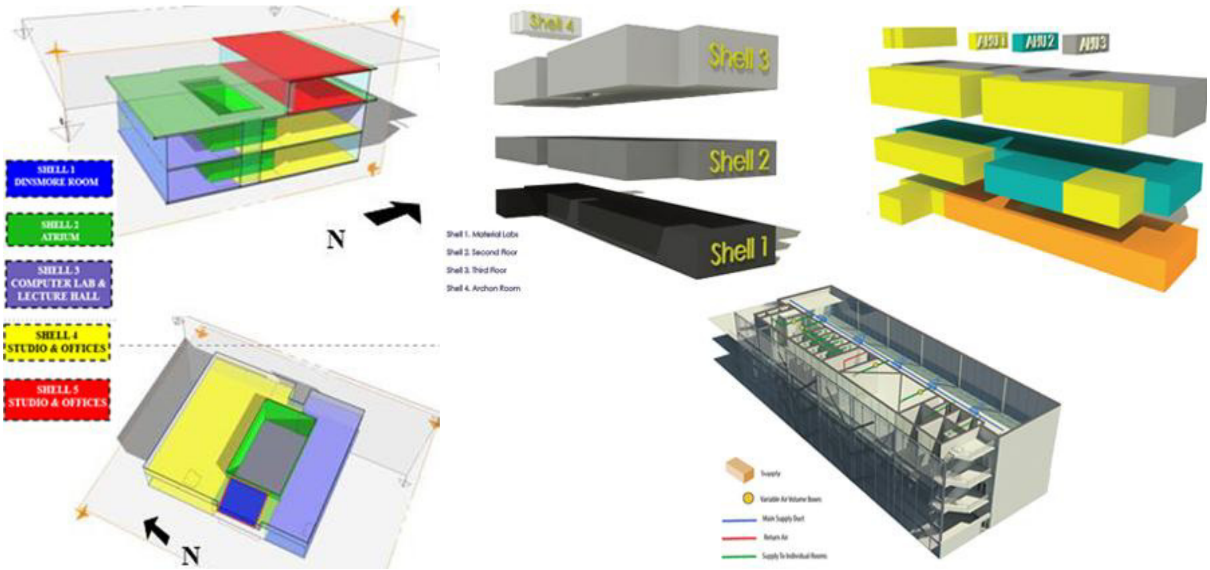


Fig. 9 Thermal zones and 3-D geometry of CAPLA East and West Buildings. It also showing is the different geometrical shapes (called shells by eQUEST) for the buildings

These design deficiencies were then optimized each separately before making final recommendation. Results for each strategy were examined by the eQUEST software in terms of its contribution to the major heating and cooling energy consumption.

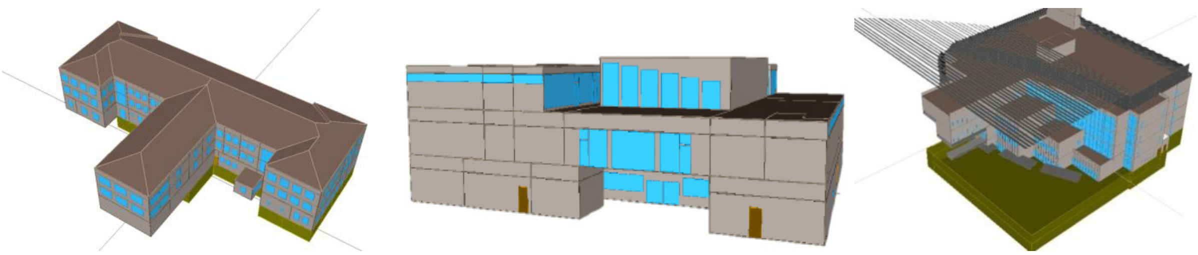


Fig.10 3-D Model of Maricopa Residence (Left), CAPLA West (Middle) and Keating Medical Building (Right)

To demonstrate the optimization process, one of the strategies was to replace some of the old HVAC DX split heat pump systems at La Aldea with higher efficiency units. This strategy resulted in a annual 206,899 KWh electric savings and $15,724 cost saving

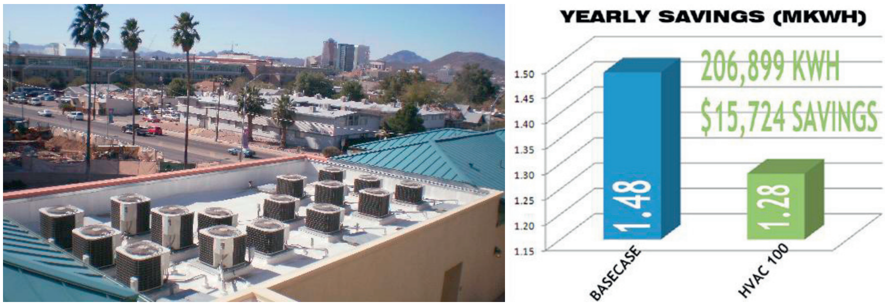


Fig. 11 Energy and Cost Savings from Replacing Some Inefficient DX Split Units at La Aldea

Another important strategy was to promote the use of daylight by upgrading all the light fixtures with high efficiency light bulbs and installing photo sensors so that light will not turn on during the day as shown in Fig. 14 below. This strategy resulted in an annual 43,417 KWh electric savings and $3,299 cost saving.

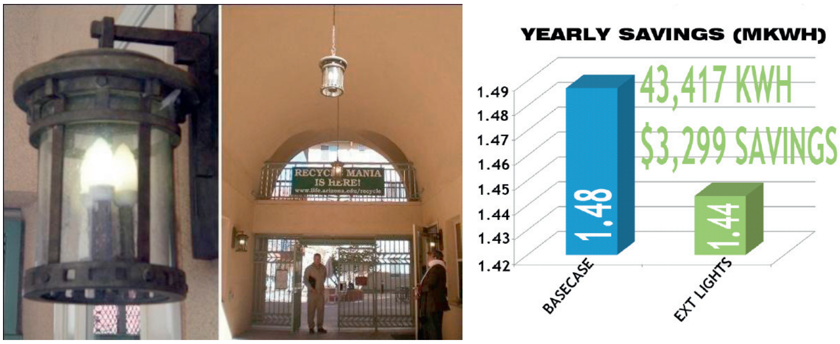


Fig. 12 Energy and Cost Savings Efficient Light Bulbs and the Use of Photo Sensors at La Aldea

Thus, the addition of a solar hot water heater acted as a water pre heater would reduce the energy needed by the boiler. This strategy would be an annual 2,000 MMBTU in Gas and $21,000 cost saving.

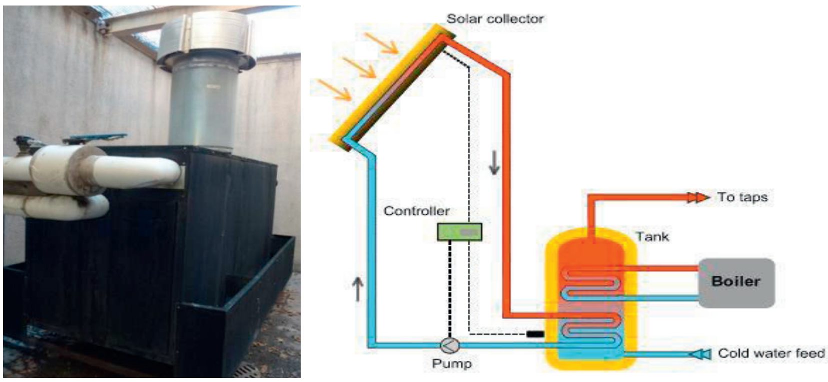


Fig. 13 Utilizing solar hot water heater will reduce the demand and consumption of the boiler at the Law Building

5. Results and Conclusion

The first three years of the "Greening of Campus" project demonstrated that the nine buildings total area of 1,081,512 ft² consumed an annual average 75,970,411 KBtu (70.2 KBtu/ft²) at the estimated cost of $2,186,264 per year. The implementation of the House Energy Doctor recommendations for all the nine buildings demonstrated that an approximate annual energy saving of 9,542,106 KBtu is achieved as well as an annual operating cost saving of $265,318 (12.1% savings). This energy savings will also benefit the environment. If the production of every 1 KWh of electricity releases 2.3 pound of carbon dioxide in the atmosphere, then one can estimate that the total 9,542,106 KBtu saved will reduce Carbon Dioxide emission by 2,915 Metric tons of CO2, calculated according to equation 2 below:

$$Total\ CO_2\ Emission = \frac{9{,}542{,}106}{3.415} X\, 2.3\ X 0.0004535924 \quad (2)$$

It has also been estimated that in Arizona for every university 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.

Another advantage to the energy simulation of campus buildings is the fact that we can now estimate the number of strategies and their savings that will allow us to compare with the LEED© performance and rank these buildings.

Fig. 14 The La Aldea Building can qualify for a LEED© Gold due to its potential accumulation of 119 points under the ranking process.

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