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ZERO ENERGY HOUSE FOR THE SOUTHERN NEVADA AREA

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ABSTRACT

Las Vegas, Nevada, is one of the country's most rapidly growing cities. To accommodate this growth, a great deal of home building takes place in Clark County, where the city is located. Builders can sell virtually as many houses as they can construct. All of these houses require utility services that, in general, have to be developed. These, of course, include water, electrical power and natural gas. With the high cooling loads required in this environment, the summer demand peaks for electricity are particularly severe. The emphasis of this paper was placed on the energy conservation methods for a planned zero energy residential home for the Southern Nevada area, which would enable net zero electric energy consumption from the local utilities over a year period. Although also important, the cost outcome of the project was considered a secondary issue. The energy analysis was arranged in three principal parts:

- Reduction of heating and cooling loads through implementation of sound envelope construction
- Use of highly energy efficient A/C, gas furnace, and lights
- Solar control and utilization

The computer simulation package Energy 10 version 1.6 is employed during the envelope, A/C, furnace and energy-efficient light analysis. The software allows modeling and simulating of a buildings performance based on inputs such as geographical location, building type, orientation, construction materials used and others. The model selected for this study is reflective of the local construction practices, is a single-family one story, 1,610 ft^2 residential house with north facing façade and an attached two-car garage, which in this paper is called the "Base Case". As a result of the energy analysis performed in this paper, the low-energy house (Modified Case) was created. The Modified Case has the identical orientation and floor plan. Implementation of the full spectrum of energy conserving features yielded a dramatic 105% saving on the annual electrical energy consumption by the Modified Case house when compared to the house built according to the local practices. In addition, the space heating and space cooling energy consumptions were reduced by 96% and 72% respectively. Details of the simulations and the final design details are given in the paper.

INTRODUCTION

As rates for electricity and natural gas continue to climb, it is important to investigate and implement energy saving techniques. It is especially consequential for hot climates where a significant amount of energy is being spent on cooling.

UNLV has been awarded a project subcontract from the National Renewable Laboratory to develop a highly energy efficient home, and this research is a result of that effort. The design information support for this project was provided by ConSol - one of the largest independent energy consulting firms in the nation, which is also a partner of the DOE sponsored Zero Energy Home Research initiative.

In spite of the fact that a number of projects have been developed in the past few years aimed at energy conservation in the residential construction sector, it is important to recognize that the energy conservation results of each project are specific to the selected location, and to some degree reflective of the local construction practices. With this in mind, this research was conducted in close cooperation with a local builder and focused on modifying a typical home and allow it to register nearly zero energy use over a year's time.

MODEL DESCRIPTION

A 1610 ft^2 single story residential model with a 410 ft^2 attached garage, further in this paper called the Base Case, was selected for this study. The model is constructed by the local builder to the International Residential Code (IRC) and includes some Energy Star upgrades.

The energy conservation methods investigated and their significance was evaluated for the selected residential model located in the Las Vegas valley. The conducted research included the following phases:

1. The Energy-10 simulation code was employed to evaluate annual energy consumption of the selected residential model. This included estimates of the annual electric energy consumption, hot water use and total energy use.
2. Examination of the sound building envelope techniques and their effect on the energy conservation by the selected residential model house included:
   - Energy-10 simulations of exterior walls, roof and concrete slab insulation levels and air infiltration modeling.
   - Various glazing, framing and exterior window shading options and their effect on energy consumption.
3. Study of highly energy efficient components (A/C, gas furnace and water heater) and their effects on the annual energy conservation.
4. Solar control and utilization.

In order to accommodate the placement of the future PV and solar water heating systems, the original roof layout was altered; the predominantly East-West orientation of the original roof was modified to a South-North orientation. This design assured nearly 1,100 square feet of South oriented roof, sufficient for the implementation of the proposed features. The slope of the roof is 5:12. The house construction and materials are all as commonly practiced and selected by local builders. The total window area in the house is 14.65% of the living space floor area. Table 1 presents the construction details of the selected model house.

SIMULATIONS DESCRIPTION

This study employs the Energy-10 version 1.6 computer program, primarily chosen for its versatility and ease of use. This software program is a result of collaboration between the Sustainable Building Industry Council (SBIC), the National Renewable Energy Laboratory (NREL), the Lawrence Berkeley National Laboratory (LBNL), and the Berkeley Solar Group (BSG). Energy-10 aids architects and engineers in the design of low-energy buildings and is primarily oriented for the design of residential and small non-residential buildings generally less then 10,000 ft^2 that can be characterized by one or two thermal zones. It can also be used during early design stages of larger buildings. Simulation results are based on inputs such as geographical location, building type and size, roof and wall construction, HVAC system, etc. During simulations an updated Typical Meteorological Year (TMY2) data set is used for the particular location. The software program employs a thermal network method to account for the heat flow in walls and roofs. A pre-design wizard, a process called AutoBuild performs an energy analysis. During this time, Reference and Low Energy Cases are created. The Reference Case description is based on inputs specified by the user. The Low Energy Case building is derived from the Reference Case with a variety of energy saving strategies applied. Energy efficient strategies such as glazing, shading, insulation, energy efficient lights, duct leakage, high efficiency HVAC, etc. are among those offered by Energy-10 that can be applied to the Low-Energy Case. Both building performances can be evaluated and compared side by side. The evaluations are based on the hour-by-hour calculations through 8,760 hours of the year base on a typical reference year for a particular location using simulation analysis.

In order to implement the energy conservation analysis, the house was described into the Energy-10 simulation software to represent the typical residential Las Vegas valley construction and was named the “Base Case”. The roof, foundation, walls, and windows had been specified as described in Table 1. The HVAC system was set to run continuously at 70°F for the heating of the house and 78°F for cooling with no setback and setup points. To represent local construction practice, the ducts were placed outside of the conditioned envelope and the duct leakage was set to 21%, the default Energy-10 setting representative of regular construction.

TABLE 1: BASE CASE CONSTRUCTION DETAILS

Features	
Walls	2x4 wood frame with R-13 fiberglass in cavity, 1” polystyrene foam (R-4) covered with 3/8” one coat stucco on the outside. 1/2” gypsum wallboard and paint on the interior
Roof/Attic	R-30 blown cellulose in attic. 7/16” OSB and 1/2” concrete tile on outside. 1/2” gypsum wallboard on the inside.
Windows	Aluminum no thermal break frame. Double clear glass, U=0.49, SHGC=0.77, VT=0.81.
Heating/Cooling	Gas furnace, 78% efficiency. Direct expansion compressor, EER-9
Lighting	Incandescent
Photovoltaic	No
Slab	4” thick uninsulated concrete slab

While performing simulations, the Base Case house was assumed to be occupied by a family of four. Parameters such as hot water consumption, use of appliances, plug loads, lighting operation hours, etc. are Energy-10 defaults based on this occupant load. The results of the Base Case energy consumption simulations are presented in Figure 1. The analysis that followed was directed at selecting the most energy-efficient features to enhance the performance of the Base Case house. As the result of this effort, the building envelope construction components were considered and simulated first and then followed by the HVAC, gas furnace, and energy-efficient light simulations; all performed by employing Energy-10 software. During the analysis each mentioned component was examined one at a time. Based on the annual energy use, the most effective alternatives were selected for the low-energy (Modified) case design and simulations proceeded to the next component.

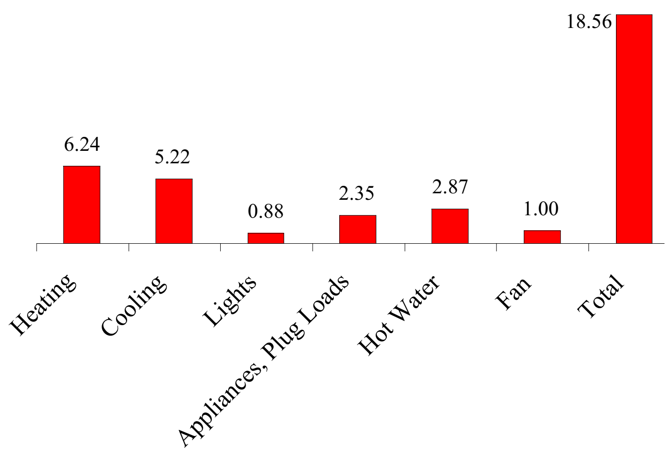

Fig. 1: Base Case annual energy consumption breakdown by component, kWhr/ft^2.

ENERGY-10 SIMULATIONS RESULTS

Window Characteristics

The window orientation, percentage of window area, type of glazing, window frame material and external shading all affect the amount of the solar gain entering a house and play an important role in the energy conservation. While the importance of the above mentioned parameters is thoroughly understood, only the last three energy conservation options, namely the window glazing type, the windows frame details and external shading are addressed in this analysis. During the simulations it was assumed that the Base Case did not have any internal shading such as draperies or blinds.

Five dif ferent glazing systems were simulated in this study for the Base Case. Aluminum with no thermal break window frame was used during each simulation. The glazing system properties presented in the Energy-10 library were developed by using the WINDOW-4 program at Lawrence Berkeley National Laboratory. Table 2 presents glazing systems properties. The obtained simulation results for the annual energy consumptions were then compared to the Base Case (double clear glass glazing with aluminum no thermal break frame). Completed simulations indicate that a triple glass window provides the most annual heating energy savings for the considered Base Case house. On the other hand, a double glass glazing with a low-e coating saves the most energy on annual cooling for the Base Case.

TABLE 2: GLAZING SYSTEM PROPERTIES

Glazing Type	U-factor, BTU/hr-ft^2-°F	Solar Heat Gain Coefficient (SHGC)	Visible Transmittance (VT)
Single	1.11	0.86	0.90
Double	0.49	0.77	0.81
Double Low-E	0.26	0.56	0.75
Triple	0.32	0.68	0.74
Triple Low-E	0.23	0.58	0.71

The overall results of the performed set of simulations indicate that a triple glass window with a low-e coating offers the most annual energy savings. Replacing a double clear glass (Base Case) with a triple glass low-e window the annual energy consumption reached 4.67%. On the other hand, the annual energy consumption for a double low-e glazing was very marginal when compared to a triple low-e with the annual energy savings of 3.91% and from a practical point of view represents a more realistic choice.

Four different window-framing materials were simulated with the Base Case house model. Framing material properties employed by Energy-10 are presented in Table 3.

TABLE 3: FRAMING MATERIAL'S PROPERTIES

Frame Material	PFD Width, inches	PFD U-value, Btu/hr-ft^2-°F	Opaque Width, inches
Aluminum no Break	2.25	1.90	1.50
Aluminum with Break	2.25	0.60	1.50
Vinyl	2.75	0.30	1.50
Wood	2.75	0.40	2.00

Projected frame dimensions (PFD) width is the width of the window frame and the part of the glass thermally affected by the frame. In Energy-10 the PFD width is 0.75 inches greater than the opaque width of a window frame. PFD U-value represents the heat loss through the frame per square foot of the PFD area per °F of temperature difference. Opaque width is the actual width of the window frame.

The performed Energy-10 simulations indicate that a vinyl window frame provides the most energy efficient performance for the given model and climate with 7.33% savings on the annual energy consumption when compared to the aluminum no thermal break frame (Base Case).

Two different types of external horizontal shading have been considered in this research. Since external shading devices alter both, the cooling and heating loads of a building at different rates, the effectiveness of horizontal shading is investigated based on the annual heating and cooling energy cost savings it provides.

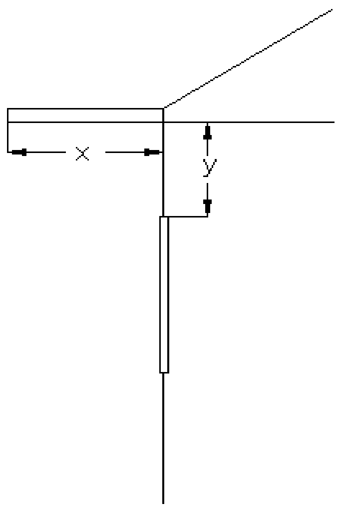

Fig. 2: Shading geometry 1.

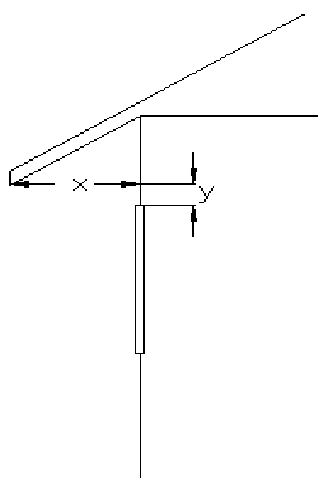

Fig. 3: Shading geometry 2.

Geometry 1 represents a horizontal shading structure that is independent of a building roof structure. This makes it possible to introduce a shading feature after a building's roof was designed. On the other hand, Geometry 2 is a roof overhang that is incorporated into a house roof structure and thus should be considered and designed before a building is constructed. During Energy-10 simulations, shading is an attribute of a window (i.e. the effect of solar shading of walls is not calculated) and is assumed to be three times the window width. Simulations were performed for both shading geometries described above for East, West, and South oriented windows in two distinct sets. Simulations were performed for a variety of window sizes by placing one window at a time on each wall of the model house. Initial simulations were performed for each window with no shading geometry (x was set to 0 inches) and were followed by simulations with an overhang 12 inches of length up to 72 inches in 12-inch increments.

Annual heating and cooling energy use was then determined for each simulated overhang length and the annual cooling and heating costs calculated. The results of the simulations performed for both geometries considered indicate that the length of horizontal shading had a major influence on the annual cooling and heating energy costs. The length of a horizontal shading for a window with a southern orientation should be carefully evaluated to take advantage of the solar gain during the winter time and shield undesirable heat gain during the summer. Based on Energy-10 simulations, the optimum shading length for the windows with southern orientation was found to be between 24 and 36 inches for the given location of the Base Case house model. The effect of a horizontal shading on the energy preservation was not so obvious since the annual energy savings increased at the same time as the length of the shading was increased for windows facing East and West. This is due to the fact that the sun is very low in the sky in the East and West in both winter and summer and is able to penetrate even beneath very low external shading.

<u>Slab Insulation</u>

Three different types of slab insulation were investigated in this study, namely, horizontal, vertical, and fully insulated slab. For each type the R-values were varied from R-0 (R-0 being no slab insulation, the Base Case) to R-10. Nine different slab insulation simulations were performed using the Energy-10 simulation engine. The performed analysis indicates that a R-10 fully insulated slab proves to be the most energy beneficial when compared to the uninsulated slab (the Base Case), with the annual energy savings reaching 12.31%. This type of slab insulation permits 32.40% heating energy consumption savings and reduction in cooling energy consumption of 3.37%.

<u>Exterior Wall Construction</u>

Three different exterior wall construction types were investigated in this study; a 2x6 wood stud frame construction with two different levels of cavity insulation (R-19 and R-23) and a third, Insulated Concrete Form

(ICF). The results of each simulation were then compared to the Base Case, 2x4 wood stud frame with R-13 in cavity insulation to determine the annual energy conservation benefits.

The ICF used in this study is an insulated concrete sandwich wall constructed with Dow's Styrofoam extruded polystyrene (R-5 per inch at 75 °F). Named Styrofoam Thermal-Mass Technology, this precast concrete panel constructed from 2 inches of concrete (R-0.08 per inch) on the exterior side, followed by 2 inches of Styrofoam, and 4 inches of concrete on the interior side. The entire wall steady-state R-value that includes R-values of concrete layers, polystyrene insulation, interior air film coefficient (R-0.68) and exterior air film coefficient (R-0.17) is 11.33. While the wall mass performance R-value (also called dynamic R-value) varies for different climates, occupancy type and the building design it is estimated to be equivalent to a wood stud wall construction with R-36 for the Las Vegas area.

Energy-10 simulations performed for various exterior wall insulation levels indicate that 6.40 % could be saved on the annual energy consumption if the original 2x4 R-13 exterior wall construction is substituted with the ICF, thus offering the best energy-conservation benefit among the considered options. It is important to note, however, that the software employed for this study uses steady-state R-values during simulations. Being unable to evaluate the benefits of the dynamic R-value, an ICF wall was described into Energy-10 and simulated as an equivalent R-36 wood stud wall. This did not reflect the whole complexity of the assembly or provided a precise estimate of the dynamic thermal performance benefits offered by an ICF type wall that are believed to have a great effect on the energy conservation.

Roof Insulation

To investigate the effect of the resistance to the conductive heat flow on energy savings, six simulations were performed for the Base Case with variable levels of roof insulation. In all six simulations the attic R-value was varied by changing the thickness of loose cellulose insulation (R-3.63 per inch).

Energy-10 simulations indicate the reduction in annual energy consumption is directly proportional to the increase in the levels of attic insulation. Doubling the R-value in the attic from R-30 to R-60 leads to 5.65% in the annual energy savings. Installing a radiant barrier in addition to the conventional roof insulation is another way to further reduce the heating and cooling energy use. Since a radiant barrier helps to stop radiant heat energy, its performance can not be expressed in R-values. The version of the Energy-10 used in the simulations does not allow for the simulations with a radiant barrier. Due to this limitation, a radiant barrier impact on the annual energy savings could not be evaluated.

As it was previously indicated, R-60 attic insulation provides the best annual energy savings benefits, however, this high insulation level most likely will not be implemented in practice. On the other hand, the potential benefits of a radiant barrier on the energy savings are very appealing but could not be quantified using the selected software package. Therefore, taking into consideration the two foregoing reasons, it was determined to choose R-50 as the attic insulation level for the Modified Case house. The use of R-50 attic insulation provides 4.72% savings on the annual energy consumption.

Building Envelope Infiltration Modeling

The "Sherman-Grimsrud" model offered by Energy-10 was employed to estimate hourly infiltration based on current wind velocity and the difference between the inside and outside temperature. This infiltration model was developed by Max Sherman and David Grimsrud of the Lawrence Berkeley National Laboratory. The primary parameter employed in Energy-10 to calculate air infiltration is the Effective Leakage Area (ELA) that represents the total crack area in a building. Energy-10 software package offers two default ELA settings: the first setting represents a typical construction (ELA= 0.0009* total gross wall area in inches) and the second one is for a tight envelope construction. The latter is 27% of the former.

Though the precise effect of the air infiltration on the energy consumption should be determined from the on-site blower door test the Energy-10 software simulations offer a good estimate. Simulation results indicate that significant energy savings can be achieved by improving the quality of the building envelope construction resulting in a substantial 14.67% reduction in the annual energy use by the Base Case house.

Air Conditioning System

With extremely high summer temperatures in the Las Vegas valley, the electrical energy consumption is quite substantial. With this in mind, to achieve superior energy conservation the highly efficient water-cooled evaporative air conditioning system manufactured by Freus Inc. was selected. The Freus was simulated as air conditioning unit with Energy Efficiency Ratio (EER) 16. Energy-10 simulations performed for the Freus A/C unit indicate highly favorable results. Replacing the conventional cooling unit (EER-9) with the Freus unit (EER-16) resulted in a savings on the annual cooling energy consumption reaching 47.2% and 13.14% on the overall annual energy consumption.

HVAC Duct System Leakage

During Energy-10 simulations, the Base Case duct leakages were set to represent an average value of 21% for ducts located outside the conditioned space (this is the default Energy-10 setting for locating the ducts outside the conditioned space). To simulate an energy-efficient case (i.e. running ducts inside the conditioned space) duct leakages were reduced to 3% (Energy-10 default setting for interior located ducts).

Installing ducts inside a heated envelope resulted in quite a notable saving on the annual energy consumed by the Base Case house and constituted 13.78%. Heating and cooling energy consumption were reduced by 25.35% and 16.85% respectively. It is worth mentioning that these savings translated into a substantial 19% annual heating and cooling energy cost reduction.

Gas Furnace Efficiency

Furnace heating effectiveness is expressed in Annual Fuel Utilization Efficiency (AFUE). It measures the amount of the fuel supplied to the amount of the heat delivered to the house. In this research the performance of the Base Case house with 78% gas furnace efficiency was compared to the 92% furnace efficiency. Increasing the gas furnace efficiency resulted in 5.11% savings on the annual energy use. In addition, the heating energy consumption was reduced by 15.50%.

Energy Efficient Lights

To see the effect of use of the energy-efficient lighting, the Base Case was simulated with all of it's incandescent fixtures, (interior and exterior) being replaced by fluorescent lights. In the simulations the energy efficient fluorescent lights were set to consume 1/4 of the electrical energy of regular incandescent lights. The results of these simulations indicate that by replacing the regular incandescent lights with energy-efficient fluorescent ones the annual energy consumption was reduced by 3.30%.

Selected Features Summary

Based on the above-mentioned analysis a number of energy-efficient features were selected and applied to the Modified Case. These preferred features are summarized and presented in Figure 4. Implementation of the selected superior envelope construction materials and incorporation of energy saving components into the Modified Case house design allowed a 59.80% reduction of the total annual energy consumption (from 18.56 kWhr/ft^2 to 7.46 kWhr/ft^2). Electrical energy use was reduced by over 52.6% (from 9.45 kWhr/ft^2 to 4.48 kWhr/ft^2). Though the energy costs were not the principal objective in this research, it worth noting that the annual energy cost was reduced by 57% from $1,910 to $822 (or from $159/month average to $68.5/month).

WATER HEATER

In this research a "batch" type solar domestic water heater was combined with on demand tankless water heater. The estimated energy savings believed to reach 80% thus potentially reducing the energy consumption from 9.78 kBtu/ft^2 to 1.96 kBtu/ft^2 (from 2.87 kWhr/ft^2 to 0.571 kWhr/ft^2). The estimated energy savings should be considered preliminary due to factors affecting the hot water consumption such as the time of day and the lengths of time hot water being consumed.

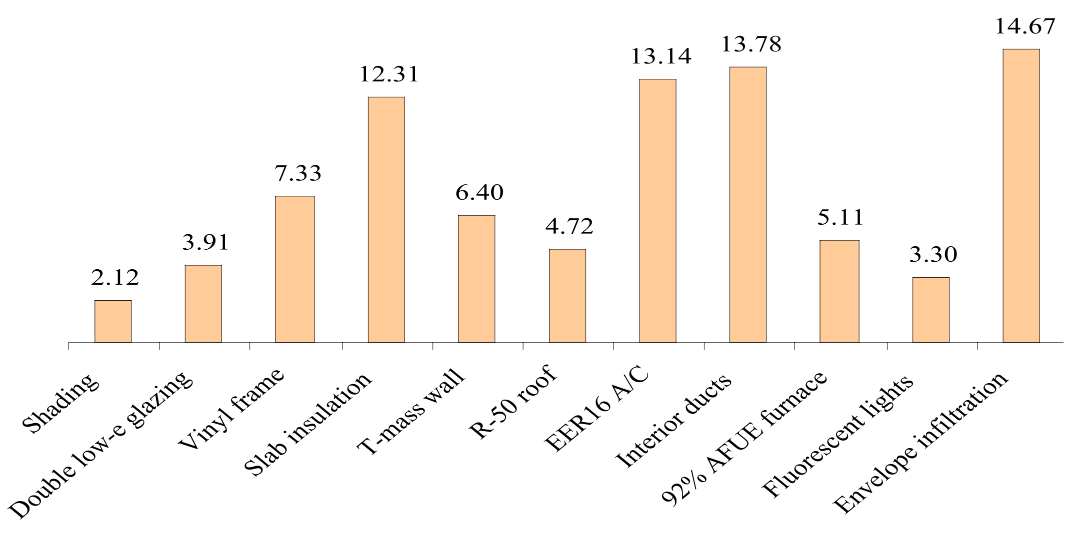

Fig. 4: Percentage of annual energy savings offered by each feature selected for the Modified Case house.

PHOTOVOLTAIC SYSTEM

Through the implementation of the energy conservation measures based on the Energy-10 simulations, the annual electric energy consumption by the Base Case house was reduced by 52.6% from the original 15,215 kWh to 7,213 kWh (from 9.45 kWh/ft^2 to 4.48 kWh/ft^2 on square foot bases). The Photovoltaic model selected to supplement the Modified Case house with electric energy is the GEPV-055-G Integrated Module for Roof Tiles manufactured by General Electric. The size of the PV module was estimated to be 4.8kW with the annual electric power output 8,100 kWh. These estimates indicate that with this supplemental energy generated by the PV system the Modified Case house annual electric energy consumption was reduced by 105% when compared to the Base Case.

MODIFIED CASE FEATURES AND ENERGY CONSUMPTION SUMMARY

TABLE 4: MODIFID CASE CONSTRUCTION DETAILS

Walls	Styrofoam T-mass with R-36, 3/8" one coat stucco on the outside, 1/2" gypsum wallboard and paint on the interior
Ceiling/ Roof/Attic	R-50 blown cellulose in attic. Radiant barrier. 7/16" OSB and 1/2" concrete tile on outside. 1/2" gypsum wallboard on the inside.
Windows	Vinyl frame. Double Low-E glass, U=0.26, SHGC=0.65, VT=0.75.
Heating/Cooling	Gas furnace, 92% efficiency, EER=16 A/C
Lighting	Fluorescent
Photovoltaic	4.8 kW
Hot Water	Tankless/solar water heater
Slab insulation	4" thick fully insulated concrete slab

CONCLUSION

The full scope of energy conservation aspects in residential construction were considered and presented in this research. As a starting point, a model for this study, an actual single-family house typical for the Las Vegas valley and reflective of the local construction practices (the Base Case) was selected. The energy analysis was arranged in three principal parts:

1. Reduction of heating and cooling loads through implementation of sound envelope construction
2. Use of highly energy efficient A/C, gas furnace, and lights
3. Solar control and utilization

The combined effect of all the features selected for the envelope construction of the low energy Modified Case accounted for a 52.6% reduction on the annual electric energy use (from 15,215 kWh to 7,213 kWh). With the estimated additional energy supplied by the PV system the Modified Case house is expected to save 105% on the annual electric energy consumption. Furthermore, the overall annual energy consumption was reduced by 98.5%. This significant energy reduction allowed concluding that the Modified Case house model generated based on the Energy-10 simulations and subsequent analysis meets the zero energy goal.

It is important to remember that a building design is an elaborate process where architectural, structural and engineering parts of design must operate in agreement. Further analysis could provide additional information about interactions of the various house components and their effects on the energy consumption. However, the optimization problem was not considered in this project. A more accurate picture of energy savings could be achieved by employing software packages specifically designed to handle energy consumption, HVAC sizing, photovoltaic simulations and a solar water heater. Monitoring the performance of the designed ZEH model during normal occupied operation schedule for at least a year will allow conclusions of the acquired actual energy savings.

ACKNOWLEDGMENTS

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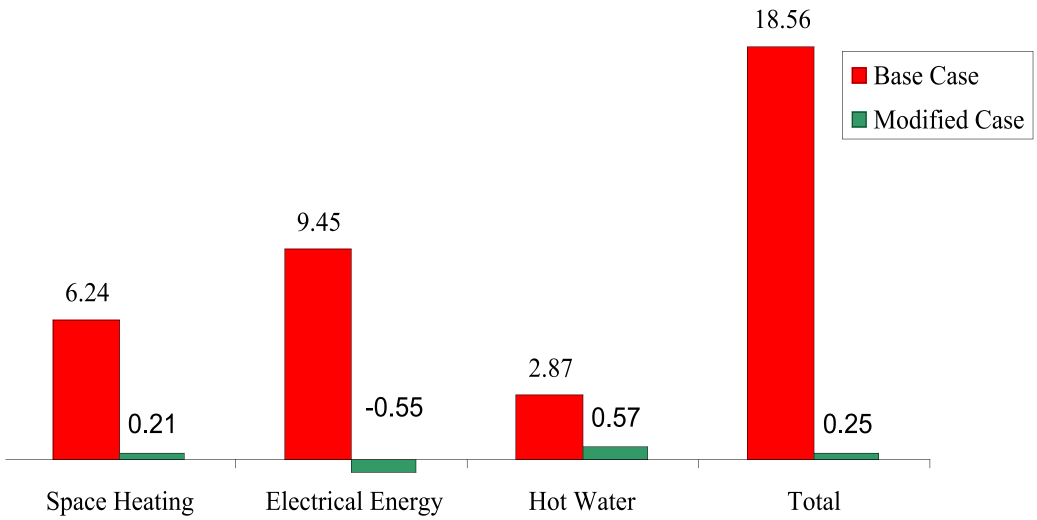

Fig. 5: Annual energy consumption breakdown for the Base and Modified Cases with PV and solar and tankless water heating energy accounted for, kWhr/ft^2.