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Zero energy house for the southern Nevada area

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ZERO ENERGY HOUSE FOR THE SOUTHERN NEVADA AREA

by

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ABSTRACT

Zero Energy House for the Southern Nevada Area

by

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Las Vegas, Nevada, is one of the country's most rapidly growing cities. With the high cooling loads required in this environment, the summer demand peaks for electricity are particularly severe. The main emphasis of this research was placed on the energy conservation methods for a planned zero energy residential home in the Southern Nevada area with the cost outcome being a secondary issue. The model selected for this study is reflective of the local construction practices, a single-family one story, 1610 ft^2 residential house with north facing façade and an attached two-car garage. The computer simulation package Energy 10 version 1.6 is employed during the energy analysis conservation. Implementation of the full spectrum of energy conserving features yielded a dramatic 105% saving on the annual electrical energy consumption. In addition, 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 this research.

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NOMENCLATURE

AFUE	Annual Fuel Utilization Efficiency
ARI	Air Conditioning and Refrigeration Institute
BLAST	Building Loads Analysis and Systems Thermodynamics
Btu	British thermal unit
cfm	cubic feet per minute
COMIS	Construction of Multizone Infiltration Specialists
DOE	Department of Energy
EER	Energy Efficiency Ratio
EL	External Lights
FRESA	Federal Renewable Energy Screening Assistant
FEDS	Facility Energy Decision System
HVAC	Heating Ventilating Air Conditioning
HW	Hot Water
IL	Internal Lights
MMBtu	Millions of British thermal units
MOOA	Minimum Occupied Outside Air
NAHB	National Association of Home Builders
PFD	Projected Frame Dimensions
PV	Photovoltaic
OT	Other in Energy-10 simulations
SEER	Seasonal Energy Efficiency Ratio
Scool	Sensible cooling
SHGC	Solar Heat Gain Coefficient
SPARK	Simulation Problem Analysis and Research Kernel
Tcool	Total cooling
TMY	Typical Meteorological Year
TRACE	Trane Air Conditioning Economics
TRNSYS	TRaNsient SYstem Simulation program
TXV	Thermostatic Expansion Valve
ZEH	Zero Energy Home

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The continuous encouragement and understanding of my family and especially my husband, Nigel has been indispensable while working on this study.

CHAPTER 1

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. Working in close cooperation with a local builder, the focus of this project was to modify a typical home and allow it to register nearly zero energy use over a year's time.

Review of Software Programs

The energy crisis of the1970's has influenced vigorous research in the field of energy conservation. Since energy consumption by buildings is tremendous, significant progress has been achieved in the field of energy conservation design to develop appropriate standards and guidelines. The energy consumption by a building is a complicated process of interactions between its different components (envelope construction, HVAC, appliances, etc.) and thus, computer-aided building simulation

programs are an essential part of the energy-efficient design. A great variety of the available software used for the design of energy-efficient buildings is employed during various stages of the design process. Though different software packages will deliver results with various degrees of accuracy, four distinct software groups can be recognized. The first group is screening tools such as FRESA (Federal Renewable Energy Screening Assistant) and FEDS (Facility Energy Decision System) that are essentially used for budgeting and programming of retrofits. The second group represents architectural design tools used for design development and schematics. These include Building Design Advisor and Energy-10. Load calculation and HVAC sizing software is the third group and includes DOE-2, BLAST (Building Loads Analysis and System Thermodynamic), TRACE (Trane Air Conditioning Economics), and EnergyPlus. Finally, the fourth group consists of economic assessment tools such as BLLC (Building Life cycle Cost) [1]. The following presents some further information relevant to the above mentioned software packages, also some additional information is provided on various software packages that are available for building design.

DOE-2 is a command line program for which a user creates input files. DOE-2 performs hourly building energy consumption simulations and costs based on the building architecture, materials used in the construction, location, HVAC equipment and other parameters. It is ideal for the analysis of new and existing buildings. This software was developed by the Simulation Research Group at Lawrence Berkeley Laboratory (LBL), and is supported by the Department of Energy (DOE). It is used in the U.S. as well as abroad to design low-energy buildings. Generally, it takes 6-12 months to learn this software and a training course is usually recommended for new users. This software

has evolved into more powerful and user friendly versions, namely DOE 2-2 and PowerDOE® [2].

TRNSYS (TraNsient SYstem Simulation Program) is a program with modular structure, and is commonly used by engineers, researchers, architects, and consulting firms for energy simulations, load calculations, and building performance analysis. Developed in 1975 by the Solar Energy Laboratory, University of Wisconsin, this software is very flexible and allows system modeling of variable complexity. This software uses FORTRAN subroutines to represent each physical component of a simulated system. The subroutines are combined into executable ASCII files. Input files describing how physical components are connected combine the subroutines. The output data includes life cycle costs, monthly summaries, annual results, and histograms (all in ASCII files format0 [3].

EnergyPlus – an energy analysis and thermal load simulation program, has incorporated the best features of DOE-2 and BLAST. This software allows performing simulation in steps of less than an hour and is based on the user's description of a building. The heat balance based solution method for building thermal loads allows simultaneous calculation of radiant and convective effects at the interior and exterior surfaces. Conduction transfer functions are used to account for the transient heat condition through the building walls, roofs, floors, etc. Most importantly, the program allows integration with other simulation programs (TRNSYS, COMIS, SPARK) to investigate many more building and HVAC design options since there is no single program that can handle every simulation situation [4].

Energy-10 Program Overview

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. There are 239 locations in the TMY2 set.

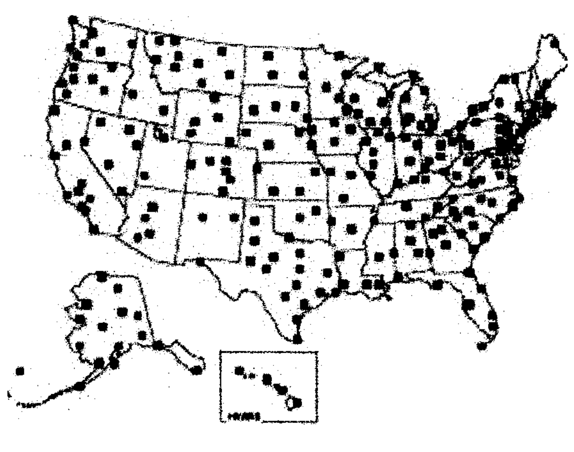


Figure 1. 239 Locations in the TMY2 Weather Stations Map [5].

This 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 8760 hours of the year based on a typical reference year for a particular location using simulation analysis [5], [6].

Review of Related Literature

According to the U.S. Department of Energy, the energy consumption by buildings is more than one third of all the energy and two thirds of all the electricity used in U.S. and is larger than any other sector of the U.S. economy. Modern residential houses are on average larger than ever before and employ more electrical devices. As the result of the increased awareness and concerns about energy conservation, a number of projects have been developed around the country aimed at improving the energy efficiency in the residential sector.

One of these projects is the Florida Zero Energy Home, which was constructed in the spring of 1998 and is the result of a joint collaboration between the Florida Solar Energy Center (FSEC) and the City of Lakeland municipal utility. In order to determine the effect of the energy efficient practices, two 2,425 square foot homes with identical

floor plans and orientation were constructed - one according to the local building practices and the other with energy-efficient features. The energy-efficient home construction incorporated a number of energy-efficient features such as a white tile reflective roof, thermal mass for exterior walls, solar control windows with wide overhangs, an interior duct system, a high efficiency air conditioning system, programmable thermostat, efficient lighting, solar water heater with propane back up to provide domestic hot water and a photovoltaic system. Data acquisition systems were installed in both houses to test them over the period of a year. After a year of performing tests, the conventional home had used 22,600 kWh (or 9.32 kWh/ft^2) of electricity. And the energy-efficient home used 6,960 kWh (or 2.87 kWh/ft^2) thus achieving annual energy savings due to the differences in the energy efficiency of 70%. Moreover, a 4 kW utility interactive PV system installed on the energy-efficient home had generated 5,180 kWh. With this energy generated by the PV system, the annual energy savings by the energy-efficient home had reached 92% when compared to the house built according to the local standards [8], [9]. Side-by side construction details for both of the houses are presented in the Table 1.

Table 1 Florida Zero Energy Home Experience [7]

Features	
Energy-Efficient Home	Standard Home
Reflective white-tile roof with R-30 fiberglass in the attic	Gray/brown asphalt shingle roof with R-30 fiberglass in the attic
3 foot overhangs	1.5 foot overhangs
Exterior insulation over concrete block system (R-10)	R-4 wall insulation on interior of concrete block walls
Solar control double-glazed windows	Single glazed windows with aluminum frames
Down-sized SEER 15, variable speed, 2-ton air conditioner with field-verified cooling coil air flow	Standard-efficiency, 4 ton, SEER-10 heat pump (a typical air conditioner on Florida)
Oversized, interior-mounted ducts	R-6 ducts located in attic
High efficiency refrigerator	Standard appliances
Compact fluorescent lighting	Standard incandescent lighting
Programmable thermostat 4 kW utility-interactive PV system 2 kW solar water heating	---

Figure 2 indicates the percentage of the energy savings on annual cooling contributed by each of the energy-efficient features implemented in the Florida Zero Energy Home.

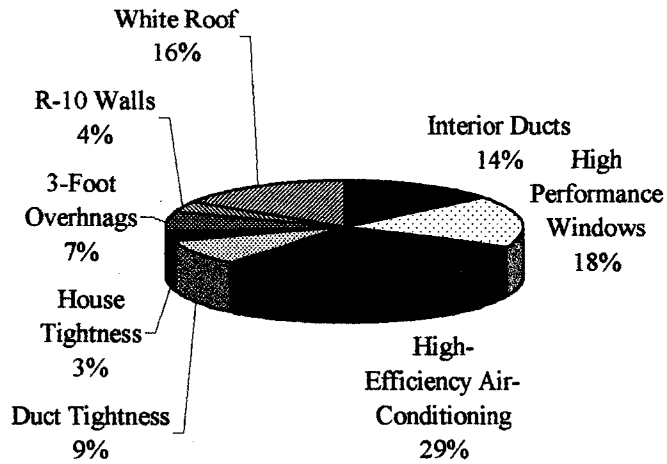


Figure 2. Florida home energy savings break down (annual cooling) [7].

The U.S. Department of Energy is a sponsor of the Zero Energy Homes (ZEH) initiative that is aimed to employ the accumulated experience in the field of residential construction, combined with the DOE expertise. The initiative directs its work towards accomplishing two goals; first, to construct houses that would use 50% less energy than those constructed according to the local standards, and second, to build more houses that can meet their own energy needs [10]. There are four partners in the initiative who work closely with the DOE – ConSol, Davis Energy Group, NAHB Research Center, and Steven Winter Associates.

The Ultimate Family Home built by Pardee is an example of the participation in the U.S. Department of Energy's Zero Energy Homes initiative. This house built to the highest standards is the product of a joint partnership with energy consultant ConSol, the National Renewable Energy Laboratory and teams of subcontractors and suppliers. This 5,300 square feet three level home features such energy efficient measures as R-21 walls,

radiant barrier roof sheathing, low air infiltration, spectrally selective windows, 16 SEER air conditioning, 0.95 AFUE furnace, sealed and insulated duck work, fluorescent lighting, energy star appliances, and an 8.6 kW PV system. The home is expected to consume about 90% less energy then a home built according to local practices. As the result of the above mentioned energy efficient features the house is expected to lower the annual energy used for cooling by 64% (from 31,565 kWh to 11,295 kWh) and by 53% energy used for space heating (from 979 therms to 457 therms). The overall electrical energy use is expected to be reduced by 62% (from 37,935 kWh to 14, 378 kWh) and natural gas use reduced by 46% (from 1,318 therms to 711 therms) [11]. Table 2 presents the detailed information.

Table 2 Pardee Ultimate Family Home Features and Standard House Features [11]

Features	Standard Home	Ultimate Family Home
Building Envelope	R-value	
Roof (attic)	30	38
Roof (cathedral)	19	30
Exterior Wall	13	21
Floor above garage	13	30
Attic radiant barrier	No	Yes
Low air infiltration	No	Yes
Fluorescent lighting	No	Yes
Glazing	U, SHGC	
Slider, Fixed, Patio	0.40, 0.40, 0.55	0.33, 0.33, 0.33
French Doors	0.65	0.33
Heating/Cooling		
Furnace AFUE	0.80	0.95
A/C	10 SEER	16 SEER with TXV
Duct insulation	4.2	R-6, buried in insulation
Water Heating		
Water heater size	50 gallon	Tankless
Energy Factor	0.53	0.82
Renewable Energy		
8.6 kW photovoltaic system	No	Yes
1.5 kW water heater	No	Yes

Note: In Table 2 the term "Energy Factor" represents the portion of the energy going into the heater that gets converted into usable hot water during the average conditions. It is also called "Energy Rating".

Other ZEH examples built under the U.S. Department of Energy's Zero Energy Homes initiative are the Morrison Homes at Lakeside in Sacramento, California. Houses ranging from 2,126 square feet to 3,672 square feet offer state-of-the-art energy-efficient construction and PV systems to meet energy demands. The houses are designed to reduce the annual energy bill by 60% [12]. Construction details of this project are listed in the Table 3.

Table 3 Features of the Morrison Homes at Lakeside, Sacramento [12]

Features	
Insulation	R-19 wall R-30 second-story floor insulation (for two-story plans) R-38 attic R-6 duct insulation
Windows	Spectrally selective glass high performance windows Sliders U=0.36, SHGC=0.33 Fixed U=0.33, SHGC=0.36 Patio door U=0.35, SHGC=0.35
Heating	0.92 AFUE furnace
Cooling	14 SEER A/C
Lighting	All fluorescent
Water heating	Tankless water heater with 0.82 energy rating. Hot water pipe insulation
Appliances	Energy Star®
Photovoltaic	2 kW roof-integrated photovoltaic tile system

The largest yet Zero Energy Home community project was initiated in 2003 in California. Built by Clarum Homes, these homes are designed to use almost zero energy over the year period. The project is expected to be completed in 2005 and will consist of 257 solar-powered single-family homes and townhouses. The annual energy reduction is anticipated to be at least 50% [13].

Table 4 Features at the Clarum Homes [13]

Features	
Walls/Roof	Foam wrapped Radiant roof barrier sheathing
Windows	Low-E, U=0.4, SHGC=0.4 French doors: U=0.85, SHGC=0.7
Cooling/Heating	90% AFUE furnace, programmable thermostat Ceiling fan outlets reduce the need for A/C Tightly sealed ducts
Water heating	Tankless water heater with 0.82 energy factor Low-flow showers
Lighting	Fluorescent light bulbs
Appliances	Energy Star®
Photovoltaic	1.2- to 2.4 kW photovoltaic system

Yet another close collaboration between the U.S. Department of Energy's Zero Energy Homes initiative and residential builders, is Tucson's Armory Park Del Sol development. Built by the John Wesley Miller Companies, the development combines

traditional architecture and energy-efficient features. While every house in the development is designed to use approximately 50% less electricity than an average home, one of the homes in this subdivision is particularly designed as a ZEH. The 1,718 square foot home features the following energy-conservation measures: solid-filled masonry block exterior walls, a reflective roof coating, R-41 fiberglass ceiling insulation, SEER-18 A/C unit, and utility connected 4.2 PV array. More detailed information can be found in Table 5. The home is anticipated to use 7,000 kWh of energy annually compared to 18,000 kWh used by a similar conventional home. The home is now occupied, and is being monitored by NAHB research center engineers to determine if it does meet the net zero energy goal [14].

Table 5 Tucson's Armory Park Del Sol Home Features [14]

Features	
Walls	Solid-filled masonry block R-14, 2" polyisocyanurate exterior insulation
Ceiling/Roof/Attic	Three-ply built-up roofing with reflective coating Radiant barrier roof decking R-41 fiberglass batt ceiling insulation
Windows	Low-E, argon-filled, U=0.32, SHGC=0.35
Heating/Cooling	Tankless water heater to boost water temperature from solar for space heating 18 SEER A/C unit with variable speed blower, Puron refrigerant Efficient ceiling fans
Lights	Fluorescent
Appliances	Energy Star® horizontal axis washer, dryer, refrigerator, dishwasher
Photovoltaic	4.2 kW PV array, roof mounted
Solar domestic water and space heating	Four, 4' by 8' solar water collectors, unpressurized, drainback system 210-gallon hot water tank with heat exchanger supplies hydronic space heating Short hot water plumbing runs in conditioned space

Significance of this Study

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 to some degree specific to the selected location, and reflective of the local construction practices. With this in mind, this research was based on a close partnership with a local residential contractor. The prototype selected for this research is an actual residential tract house representative of the Las Vegas area. Previous ZEH studies were studied for the purpose of obtaining a general direction for this research. The energy conservation methods investigated and their significance on energy conservation was evaluated for the selected residential model located in the Las Vegas valley. The 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) on the annual energy conservation.
4. Solar control and utilization.

CHAPTER 2

ENERGY CONSERVATION METHODOLOGY

Base Case Description

Energy consumption is the main concern when designing a low-energy building, and thus a whole building design approach has to be adopted. In general practice, however, design decisions are made without considerations regarding the future house orientation, site planning and land development, or energy and water consumption. The design of a low-energy building calls for a whole new design approach where all energy-conserving measures work in conjunction, complementing each other and as the result improving the overall building energy consumption and increasing the indoor comfort. Considering the above-mentioned aspects, the site selection for the future ZEH has taken some time to complete. The site of the house had to allow for a PV and solar water heater systems to be installed on the roof, and so the adjacent houses could not shade the ZEH. In addition, since the contractor is planning to show the house, it was desirable to build the house fairly early during the subdivision construction, to allow access to the house by the general public. After the above mentioned aspects had been considered, and the future subdivision planned out, lot number 99, was selected for the future ZEH construction. Figures 33, 34 and 35 in the Appendix show the future lot plan, subdivision location and subdivision layout respectively.

The prototype used for this study which in this paper was called the Base Case, is a single story 1,610 ft^2 residential house with 410 ft^2 of attached garage. Figures 36 and 37 in the Appendix provide elevations and floor plan details. 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. Figure 38 in the Appendix presents a modified roof layout plan. This design assured nearly 1,100 square feet of South oriented roof, sufficient for the implementation of the proposed features. The house construction and materials are all as commonly practiced and selected by local builders. A 2 by 4-inch wood stud frame is used for the exterior wall construction with R-13 fiberglass insulation placed in the wall cavity. Each exterior wall is covered with 1" polystyrene foam and finished with one coat stucco over it on the outside, and with drywall and paint on the inside. Table 6 presents the construction details of the selected prototype house.

Table 6 Base Case Construction Description

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. ½" gypsum wallboard and paint on the interior
Roof/Attic	R-30 blown cellulose in attic. 7/16" OSB and ½" concrete tile on outside. ½" 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, SEER-10 (EER=9)
Lighting	Incandescent
Photovoltaic	No
Slab	4" thick uninsulated concrete slab

The roof has a slope of 5:12 and is constructed from 7/16" Oriented Strand Board (OSB) with concrete roof tiles over it. R-30 blown cellulose insulation is placed in the attic. The house is erected on a 4" thick uninsulated concrete slab and a dominant portion of the interior floor is carpeted. The total window area in the house is 14.65% of the living space floor area. The windows in the Base Case house are double clear glass with aluminum with no thermal break frame. The percentage of the window area of the Base Case house is common for the given geographical location and is prevailing for a tract house of this size. Table 7 provides detailed window placement information.

Table 7 Base Case Window Placement

Window Orientation	Window Area, ft^2	Percent of Total Window Area
North	43.17	18.31
East	15.00	6.36
South	120.50	51.13
West	57.00	24.18

Energy-10 Simulations Description

In order to start implementing the energy conservation analysis, the house was described into the Energy-10 simulation software to represent the typical construction and was named the "Base Case". The roof, foundation, walls, and windows had been specified as described previously (Tables 6 and 7 present the details). Direct Expansion (DX) compression cooling with a gas furnace was used as an HVAC system for this model. The efficiency of the gas furnace is 78% and EER of the DX compressor is 9. 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. Utility rates for these simulations are $0.09/kWh for electricity and $0.77/Therm for natural gas [15,16]. Table 8 provides the detailed information of Energy-10 simulations for the Base Case.

Table 8 Energy-10 Base Case Simulation Results

Description:	
Weather file	Las Vegas (TMY2)
Floor Area, ft^2	1610.0
Surface Area, ft^2	5043.9
Volume, ft^3	14490.0
Total Conduction UA, Btu/h-F	507.5
Average U-value, Btu/hr- ft^2-F	0.101
Wall Construction	R-13
Roof Construction	R-30
Floor type, insulation	Reff=9.4
Window Construction	6068, U=0.64, etc.
Window Shading	12-17, etc.
Wall total gross area, ft^2	1656
Roof total gross area, ft^2	1778
Ground total gross area, ft^2	1610
Window total gross area, ft^2	236
Windows (N/E/S/W:Roof)	4/1/4/5:0
Glazing name	double, U=0.49
Operating parameters	
HVAC system	DX Cooling with Gas Furnace
Rated Output (Heat/ SCool/TCool), kBtu/h	49/45/60
Rated Air Flow/MOOA, cfm	2230/0
Heating thermostat	70.0 °F, no setback
Cooling thermostat	78.0 °F, no setup
Heat/Cool performance	Eff=78, EER=9
Duct leaks/conduction, total %	11/10
Peak Gains: IL, EL, HW, OT; W/ ft^2	0.20/0.04/0.66/0.36
Infiltration, in^2	ELA=227.8
Results	
Simulation dates	01-Jan to 31-Dec
Energy use, kBtu	101920
Energy cost, $	1910
Total electric, kWh	15215
Internal/External lights, kWh	1279/138
Heating/Cooling/Fan, kWh	0/8404/1610
Hot water/Other, kWh	0/3784
Peak electric, kW	9.5
Fuel, hw/heat/total, kBtu	15770/34290/50060
Emissions, CO2/SO2/Nox, lbs	26362/126/69

In Figure 3 the results of the Energy-10 simulations are presented for the Base Case loads distribution. These load estimates indicate the heating, cooling and other requirements for the selected house and are based on the size of the house, window area, levels of insulation and the local weather conditions. Simulations show the dominating cooling load, which is followed by the combined fan, hot water, plug and appliances loads and heating load.

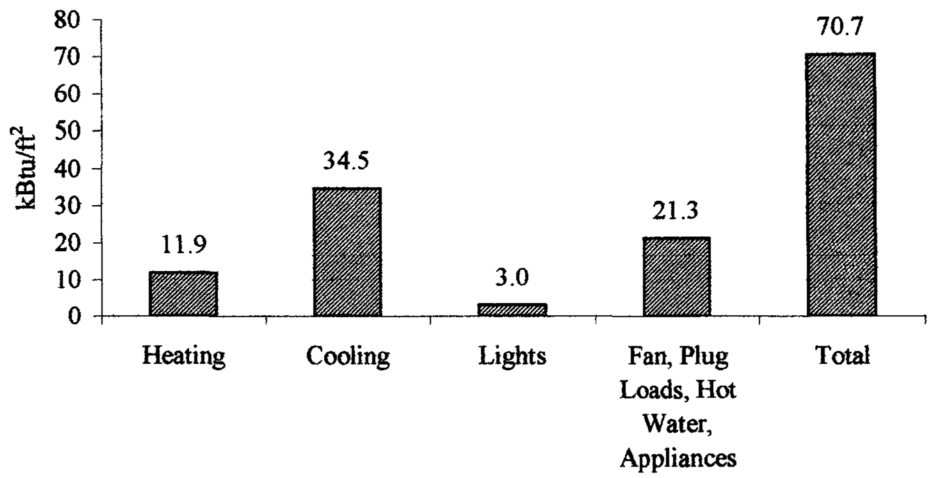


Figure 3. Base Case annual loads distribution breakdown.

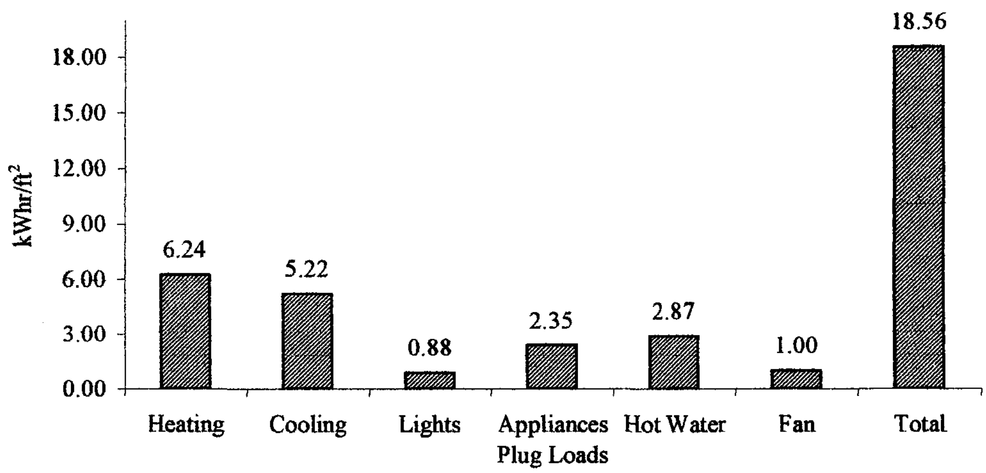


Figure 4. Base Case annual energy consumption breakdown by component.

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 component indicated below in Figure 5 was examined one at a time. For example, when considering various wall constructions, alternative R-values were simulated thus allowing the investigation of the effect of that particular component on the energy-consumption by the Base Case house. 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.

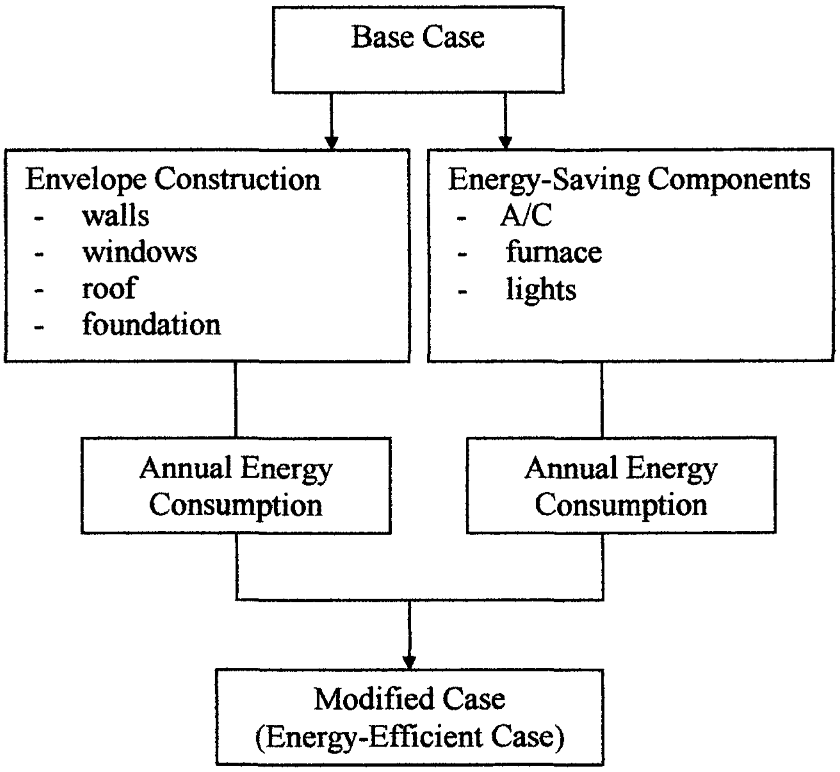


Figure 5. Schematic representation of Energy-10 simulations.

Chapter Summary

The foregoing chapter presented a complete description of a singe-family residential house model representative for the Las Vegas valley. Annual energy consumption analysis was carried out for the selected prototype residential construction employing the Energy-10 simulation package. This analysis helped to identify the energy loads distribution; with cooling loads being by far the most significant, followed by heating, hot water appliances, plug loads and the fan. Based on this analysis, the direction for the following study was selected as follows:

- Implementation of sound building envelope construction techniques
- Use of the highly energy-efficient A/C, gas furnace and lights
- Solar control and utilization

CHAPTER 3

ENERGY CONSERVATION ANALYSIS

Windows Characteristics

Windows, due to their low insulating properties, have a great impact on the overall energy use by a building. It was estimated that about five percent of national energy use in the U.S. is attributed to windows [17]. Solar radiation enters through windows primarily in two different wavelengths – visible light and invisible long-wave infrared radiation. This radiation is then absorbed by the objects in the building or bounced back out. The absorbed radiation creates a green house effect – objects that absorb the radiation will emit it at longer wavelength, or simply, emit heat into the building space. Thus, controlling the solar heat gain entering through the windows will be reflected in the energy consumption of the building.

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.

Glazing

Materials such as glass or plastic are usually used for window glazing. Five different 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 9 presents glazing system types and descriptive names. Glazing properties can be found in Table 10.

Table 9 Glazing System Types and Their Associated Descriptive Names [5]

Glazing Type	Descriptive Name
Single	Single Clear Glass
Double	Double Clear Glass
Double Low-E	Double Glass with Low-Emittance Coating
Triple	Triple Clear Glass
Triple Low-E	Heat Mirror 88 Film with Clear Glass

Table 10 Glazing System Properties [5]

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 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).

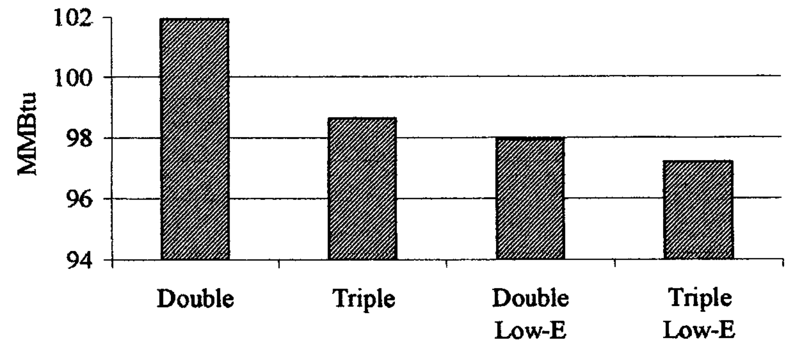


Figure 6. Base Case annual energy consumption for the window glazing systems.

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. The overall results of the performed set of simulations presented in Figure 6 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.

Framing

The choice of framing material has a great impact on a window's thermal performance. From aluminum to vinyl and fiberglass, each framing material possesses a variety of advantages and disadvantages. Thus, window-framing material should be carefully evaluated to determine its effectiveness for the specific design and climate. Four different window-framing materials were simulated with the Base Case house model. Framing material properties employed by Energy-10 are presented in Table 11.

Table 11 Framing Material's Properties [5]

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. Wood and vinyl generally offer better insulating benefits than metal frames. An aluminum frame with thermal break is designed with non-metal components separating the glass panes that helps to reduce the heat flow through the frame quite substantially compared to the all metal frame.

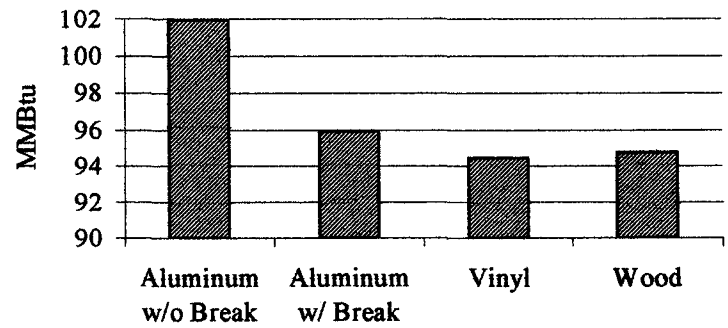


Figure 7. Base Case annual energy consumption for the window framing materials.

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

Shading

Two different types of external horizontal shading have been considered in this paper. 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. 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.

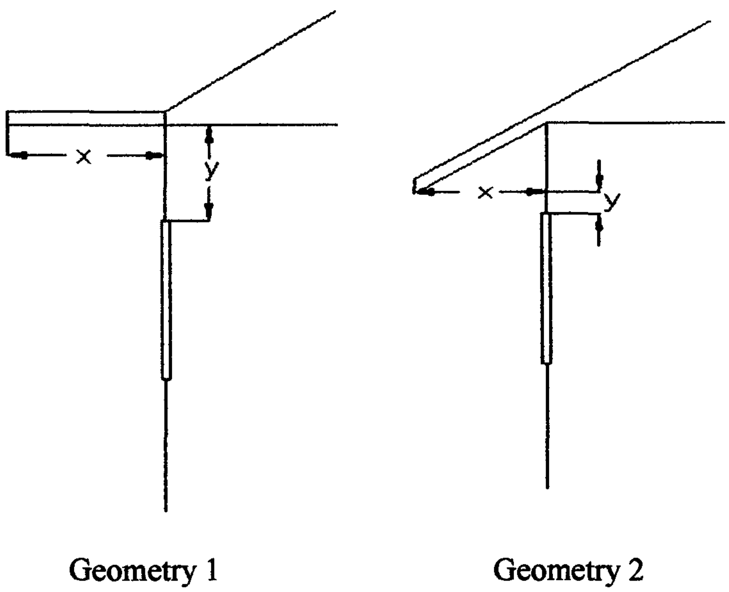


Figure 8. Shading geometries.

For Geometry 1, a horizontal shading structure was placed at a distance of 12 inches above the top edge of a window. Initial simulation was performed for a window with no shading geometry (x was set to 0 inches) and was 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.

Similarly, Geometry 2 was simulated with no shading (x was set to 0 inches) and followed by a set of simulations with variable roof overhang lengths. A roof overhang is a fixed building feature that when carefully designed can help to reduce unwanted solar gain. During this set of simulations each window on the East, West and South walls of

the building was set at two different distances (12" and 24") above the top edge of a window. The following figures present the results of these simulations.

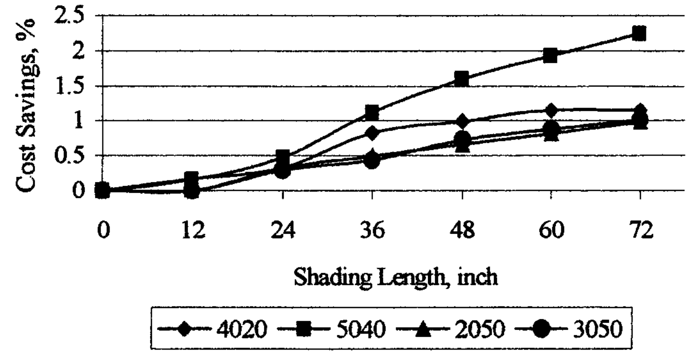


Figure 9. Heating and cooling energy cost savings for Geometry 1 for windows located on the East and West sides of the Base Case house.

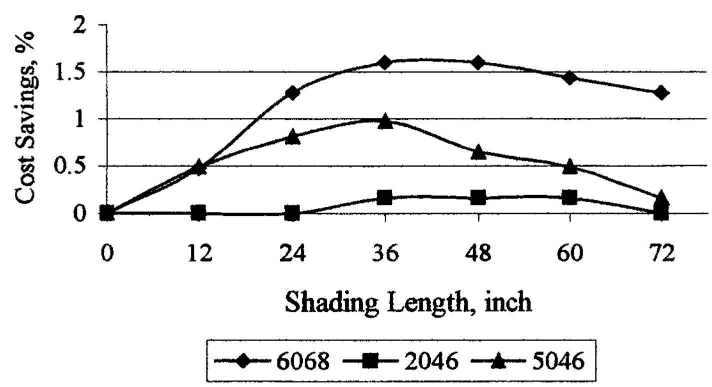


Figure 10. Heating and cooling energy cost savings for Geometry 1 for windows located on the South side of the Base Case house.

Note: Window abbreviations such as 2046, 5046, etc. represent a window nominal size. For instance, 4020 is a window 4' wide by 2' high, 5046 is a window 5'wide and 4'-6" high.

The results of the simulations performed for Geometry 1 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 considered to take advantage of the solar gain during the winter time and shield undesirable heat gain during the summer. Energy-10 simulations indicate that by increasing shading of the south facing windows, both the heating and the cooling loads were affected; increasing the shading length led to the increased heating load while at the same time the cooling load decreased. Based on these simulations, the optimum shading length for the windows with southern orientation was found to be 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.

Geometry 2 represents a roof overhang. The roof overhang is a fixed building structure with a slope the same as that of the roof. The effect of shading of the house windows was simulated with roof overhangs of various lengths by placing one window at a time on each wall. The following figures provide simulations results for Geometry 2 set at 12" and 24" above the top edge of each window.

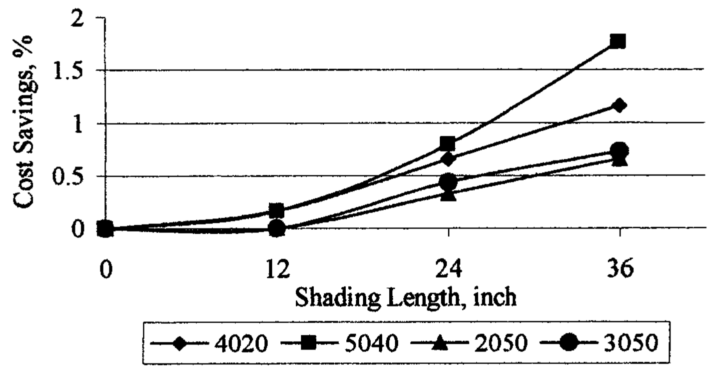


Figure 11. Heating and cooling energy cost savings for Geometry 2 set at 12" above the top edge of a window located on the East and West sides of the Base Case house.

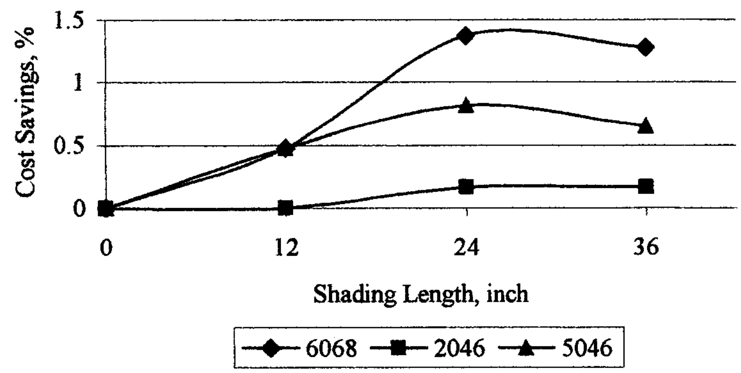


Figure 12. Heating and cooling energy cost savings for Geometry 2 set at 12" above the top edge of a window located on the South side of the Base Case house.

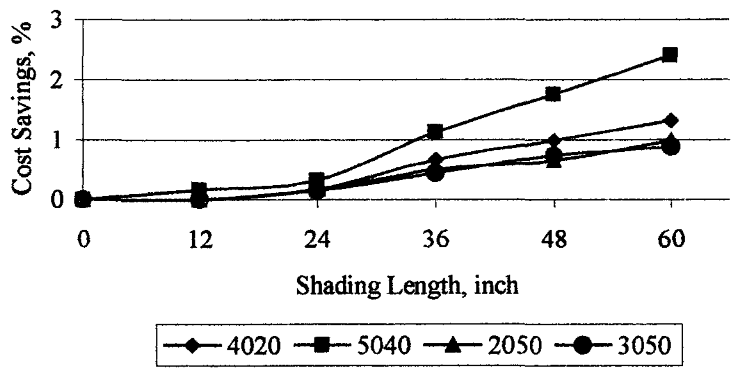


Figure 13. Heating and cooling energy cost savings for Geometry 2 set at 24" above the top edge of a window located on the East and West sides of the Base Case house.

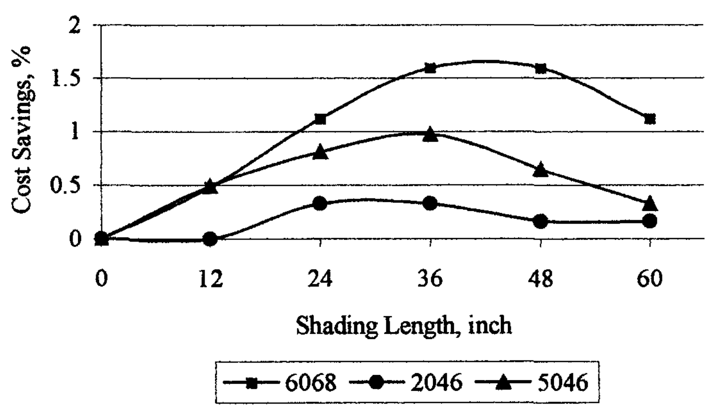


Figure 14. Heating and cooling energy cost savings for Geometry 2 set at 24" above the top edge of a window located on the South side of the Base Case house.

The simulation results of Geometry 2 indicate a correlation between external shading set at 12" above the top edge and energy savings for South facing windows. Here, 24 inches of external shading proves to be the most efficient for windows 5046 and 6068. There is no distinct savings benefit between 24 inches and 36 inches of shading for

the 2046 window. Similar to the results of the Geometry 1, the cut off length for the most energy efficient horizontal shading length for windows facing east and west could not be determined. In addition, after placing shading higher, at 24 inches above the top edge of a window, the best performance was observed for external shading being 36 inches long for south facing windows 6058 and 5046 and 24 inches for window 2046. No cut off length could be estimated for the east and west facing windows. Thus, it can be concluded that whether Geometry 1 or Geometry 2 is selected as a means to provide external shading for a south oriented window, the best annual energy savings are achieved with shading lengths being between 24 and 36 inches. Horizontal shading does not work well for windows located in the east and west walls of the building. Increasing the length of the horizontal shading does not prove to be an economical solution to the problem. A very long horizontal shading on these walls will obstruct views and reduce the overall esthetics of the building. External, movable shading is perhaps the best option here.

Slab Insulation

Proper floor insulation can affect energy requirements by reducing the heat loss and increasing comfort inside the building. Three different types of slab insulation were investigated in this study, namely, horizontal, vertical, and fully insulated slab. Horizontal insulation is applied from the top edge of the slab and extends horizontally to the interior or the exterior from the perimeter for the specified distance. This type of insulation may also be placed directly to the underside of the slab and extend inwardly horizontal from the perimeter for the specified distance. Vertical slab insulation is usually applied to the exterior of the slab and extends downward from the top edge of the slab for a specified distance. In the case of a fully insulated slab, the insulation extends downward

from the top edge of the slab, along the entire perimeter and covers the whole area under the slab. Energy-10 models the heat flow for the slab-on-grade floor construction as the sum of two parallel-path heat flows. First is the heat flow through the perimeter, calculations of the steady state are based on the difference between the inside and outside temperatures and do not take into the account the thermal lag of the surrounding earth. Second is the heat flow to the floor. This calculation is dynamic and accounts for the thermal mass of the floor construction, but results in no net heat flow because the boundary condition on the bottom of the floor is adiabatic [5].

While investigating the effect of these types of insulation on energy conservation, 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 impact on annual energy consumption was determined for each simulation and presented in the Figure 15.

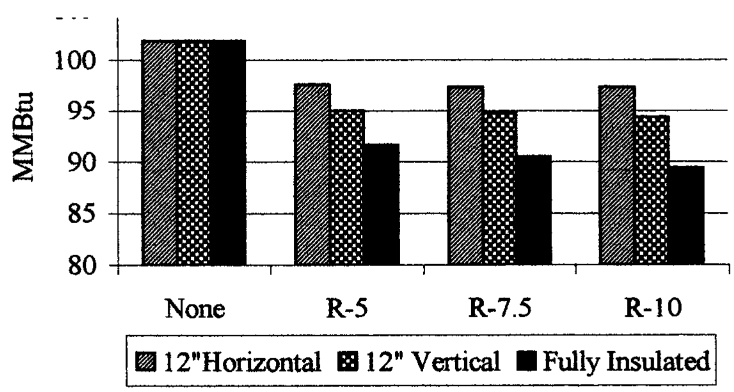


Figure 15. Annual energy consumption by the Base Case house with various levels of slab insulation.

Figure 15 illustrates the effect of various types and levels of insulation investigated and their effect on the annual energy consumption for the Base Case house. The performed analysis allows the conclusion 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%. As a word of caution, the software authors state that the model used for the slab-on-grade floor simulation used in Energy-10 does not represent a true situation very well, thus permitting some degree of inaccuracy.

Exterior Wall Construction

Proper use of insulation leads to the increase in energy efficiency of the house while providing a more comfortable environment and is considered to be one of the most cost-effective ways to save energy and reduce the heating and cooling demands of a house.

Three different exterior wall construction types were investigated in this study; a 2x6 wood stud frame construction with two different levels of cavity insulation 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. A 2x6 wood stud frame was simulated with R-19 fiberglass insulation, and with high performance R-23 fiberglass. The last one is not intended for an open blow application, however, it is designed to be applied in a Blow-In-Blanket System, and it is used in a closed cavity application that should be installed behind OPTIMA Fabric or the equivalent. Lastly, an ICF exterior wall construction was

simulated. ICF's construction was found to be very effective in reducing building heating and cooling loads.

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 exterior concrete side can be finished in a variety of ways such as stucco or siding; the interior surface of the wall can be textured and painted which makes this type of wall construction very appealing to builders. Strong, noncorrosive fiber reinforced epoxy resin connectors help to bind the insulation layer to the concrete. This type of construction provides superior energy conservation due to the thermal mass effect achieved by incorporating concrete layers that are able to store significant amount of thermal energy and delay heat transfer through the walls resulting in three important benefits:

1. Lower response time moderates indoor temperature fluctuation caused by both solar gain and from heat produced by internal energy sources (computers, appliances, etc)
2. Reduced energy consumption
3. Building energy demand is moved off-peak

Other benefits offered by this type of exterior wall construction include significantly reduced air infiltration due to elimination of the wood frame construction and simplicity and speed of construction [18].

The manufacturer states that the steady-state R-value of the composite wall construction is 11.33. This is the entire wall 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) [19]. 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. This high resistance allows the heat to be absorbed during the daytime by the concrete, stored and released at nighttime to the exterior. A large thermal mass wall was found to very effective in climates with large interior-exterior temperature differences occurring within 24-hour periods. Figure 16 presents the results of Energy-10 exterior wall construction simulations.

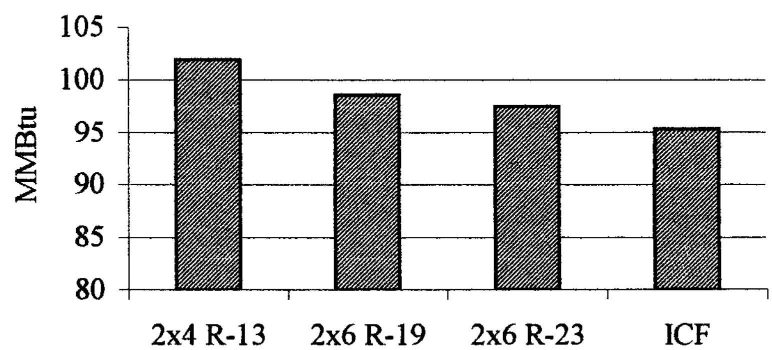


Figure 16. Annual energy consumption by the Base Case house for various exterior wall construction types.

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 and as the result, the ICF wall was described into Energy-10 and was 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

Proper roof insulation is another of the crucial aspects in reducing building energy consumption. In hot climates the temperature of the roof can reach as high as 140 °F. This heat then radiates across the attic increasing the temperature of the insulation which in turn conducts the heat into the conditioned space increasing the load on the cooling system.

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). The cellulose insulation provides relatively high insulating characteristics and can be installed to any depth (R-value) desired. It also provides good resistance to air leakage. The following figure presents the effect of the variable levels of attic insulation on the annual energy consumption by the Base Case house as obtained form Energy-10 simulations.

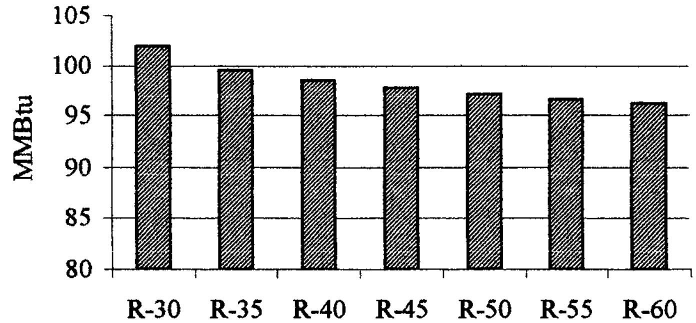


Figure 17. Annual energy consumption by the Base Case for various levels of attic insulation.

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. A radiant barrier is an aluminum foil material that helps to block as much as 95% of the radiant heat flow, thus keeping the attic cooler. 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, its effect 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 building air infiltration can have a great effect on the energy consumption. The U.S. Department of Energy Office of Energy Efficiency and Renewable Energy estimates that over 30% of air infiltration is caused by cracks in the walls, floor and ceilings [20]. With this in mind, 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 (LBNL). 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. In practice the ELA parameter is measured by a blower-door test. 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 [5]. The results of both simulations are displayed in Figure 18.

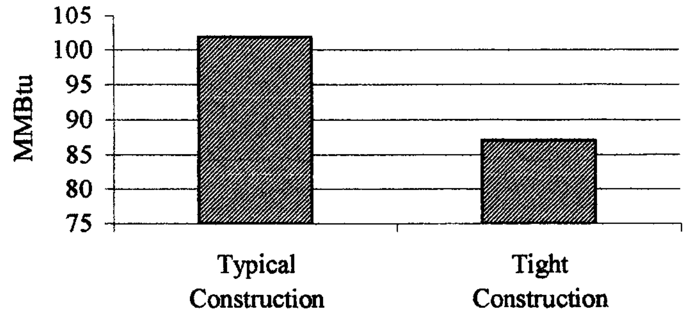
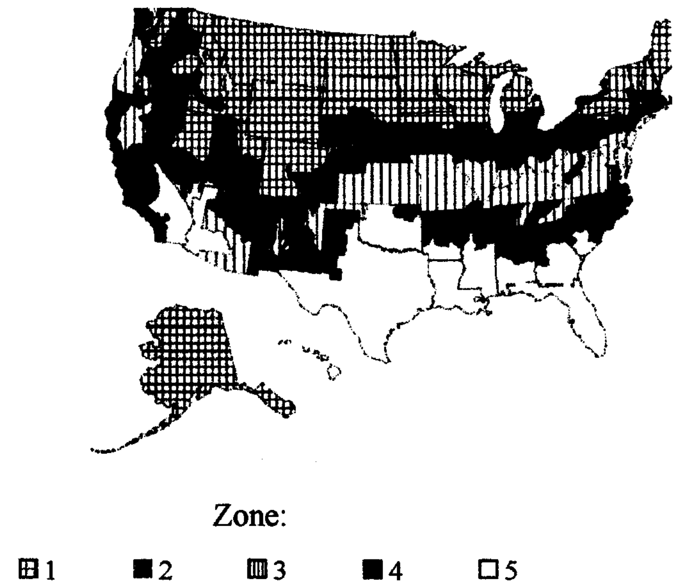


Figure 18. The effect of an envelope construction quality on the annual energy consumption by the Base Case house.

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 offers 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.

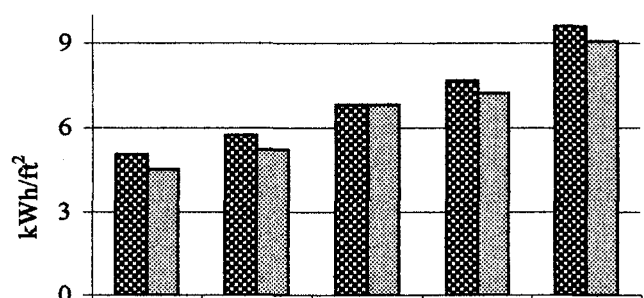
Air Conditioning System

With extremely high summer temperatures in the Las Vegas valley, the electrical energy consumption is quite substantial. Research conducted by the NAHB Research Center has evaluated electric energy consumption in the residential sector and indicates that a residential construction in Las Vegas on average consumes the most electric energy annually that accounts for 9.06 kWh per square foot [20]. The normalized data collected for the 5,900 households sampled and summarized in Figure 19 represents an average consumption of electric energy per square foot of heated space.



Zone 1 is less than 2,000 CDD and greater than 7,000 HDD
Zone 2 is less than 2,000 CDD and 5,500-7,000 HDD
Zone 3 is less than 2,000 CDD and 4,000-5,499 HDD
Zone 4 is less than 2,000 CDD and less than 4,000 HDD
Zone 5 is 2,000 CDD or more and less than 4,000 HDD

Figure 19. Climate zones in the United States (EIA climate zone map) [20].



	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
All Households	5.02	5.73	6.81	7.66	9.61
Single Family Detached	4.5	5.18	6.82	7.23	9.06

Figure 20. Annual electric energy consumption by climate zone (all households/single family detached) [20].

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 concept of evaporative air cooling has been used for hundreds of years all around the world and is especially effective in hot and dry climates. The magnitude of evaporative cooling depends on the relative humidity of the air, the lower the humidity the greater the evaporative cooling potential. The refined idea of evaporative cooling is employed for modern air conditioning technology and is very simple and straightforward: the process of water evaporation is combined with an air-moving system. The fresh outside air is drawn inside by a fan and filtered through a set of moist pads then cooled by evaporation and supplied inside a house. This type of air conditioning performs the best in hot and dry climates, it is known to increase humidity in the inside air and is sometimes called a "swamp cooler" [21].

The Freus water-cooled evaporative air conditioner uses a series of low-pressure water nozzles that sprays water mist over the copper condenser coils to remove heat after the R-22 refrigerant had been compressed. The copper condenser coils are cooled by continuously sprayed water allowing heat to be removed by conduction. About 3.5 inches of water is constantly maintained in the bottom of the condenser. The water is then pumped up to the center of the Freus unit which contains its own internal PVC cooling tower. A fan on top of the unit allows removing the heat. According to the manufacturer, with 95 °F outside air, a "dry" condenser needs to generate 250 psi while a "wet" Freus unit only needs 180 psi to generate the same cooling capacity. In addition, an air cooled unit loses about 20% of its rated efficiency when the outside temperature reaches 100 °F. The Freus water cooled evaporative air conditioner, on the other hand, has a minimal

efficiency drop in these conditions estimated to be only about 4% [22]. Table 12 below features detailed information about the Freus unit.

Table 12 Freus A/C Features [22]

Features	Water cooled condensing coil Standard rating at 95 db/75wb outdoor and 80db/67wb indoor conditions Superior Latent Control: High dehumidification with low CFM High sensible with high CFM Ultra quiet operation
Design /Application	Outdoor condensing unit for ground level or rooftop application Designed for use with evaporator blower and coils 15 Year limited warranty
Cabinet Construction	All Fiberglas cabinet with UV resistant gel coat Sound dampening construction materials Impact resistant UV inhibited ABS intake louver

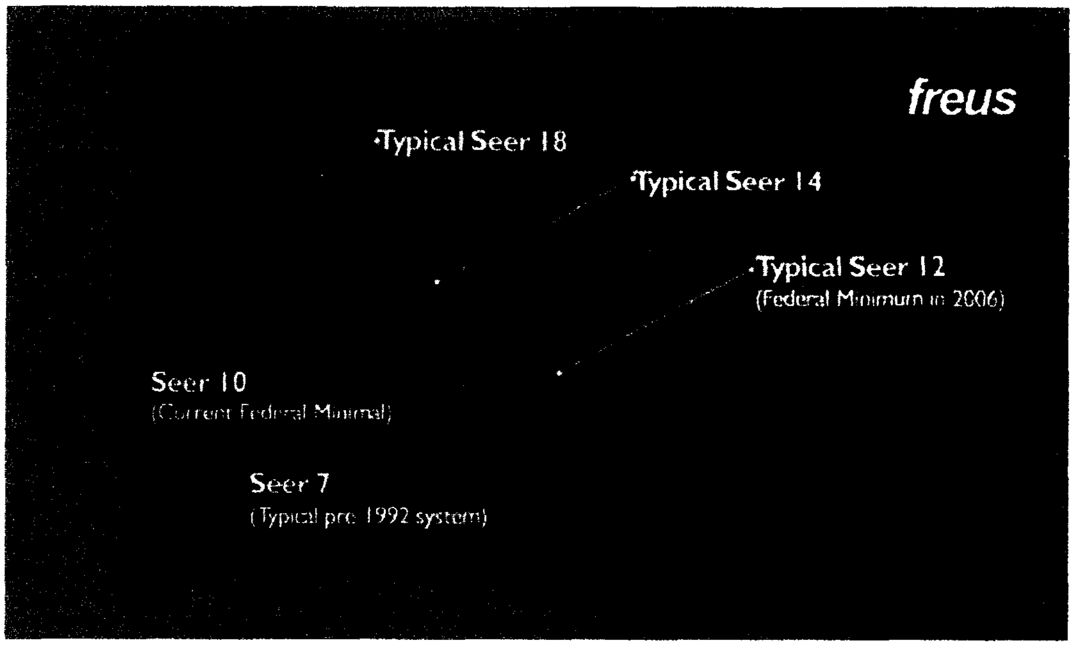


Figure 21. Air conditioning energy efficiency ratio. Freus water cooled vs. air cooled as given by the Freus unit manufacturer [22].

According to Eco-Smart [23], an organization operating under license from the nonprofit Florida House Institute for Sustainable Development, Freus water cooled condensing units have been estimated to save 50% to 60% on air conditioning energy consumption, when compared to a standard air-cooled unit with the Seasonal Energy Efficiency Ratio (SEER) of 10. The Air-Conditioning and Refrigeration Institute (ARI) states that the efficiency of a water-cooled unit can only be expressed in the Energy Efficiency Ratio (EER). Similar to SEER, EER has units Btu-hr of cooling per Watt-hr of energy used. However, EER testing is performed at 95 degrees drybulb and 75 degrees wetbulb, and is in contrast to the SEER testing at 82 degrees drybulb and 65 degrees wetbulb. ARI has stated that the Freus unit has a 16 EER.

Since an evaporative cooling A/C unit could not be simulated using the selected version of Energy-10, the Freus unit was simulated as a DX unit instead with EER 16. The outdoor design temperature used for the simulations is 106 °F and was determined from the weather data for the given location and is a 2.5 percentile value specified by the ASHRAE Handbook of Fundamentals (1993) along with the coincident wetbulb temperature. The cooling supply air temperature, the temperature of the air coming out of the unit, is 57 °F.

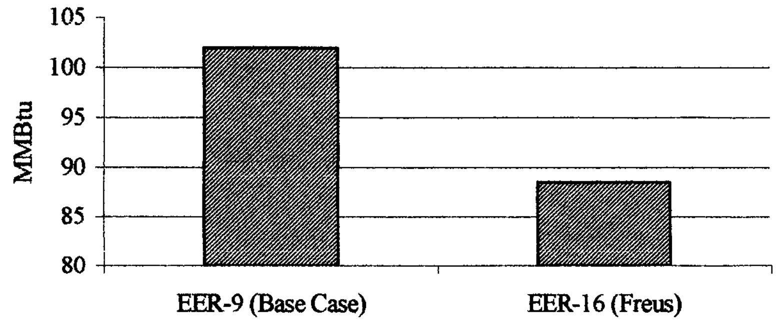


Figure 22. Annual energy consumption by the Base Case house with EER-9 and EER-16 (Freus) A/C units.

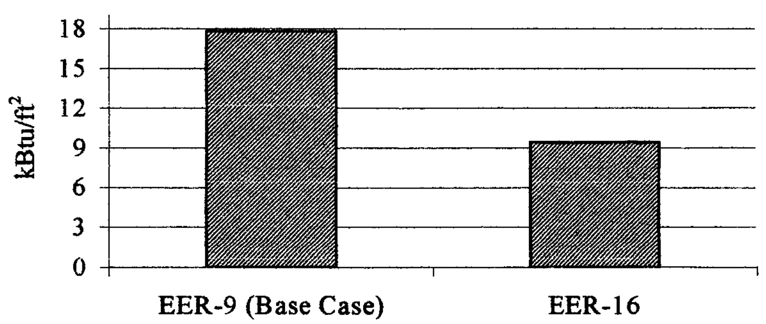


Figure 23. Annual cooling energy consumption by the Base Case house with EER-9 and EER-16 (Freus) A/C units.

Energy-10 simulations performed for the energy-efficient 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 annual energy consumption.

HVAC Duct System Leakage

HVAC duct tightness and location are two major factors influencing the living comfort inside a house and the energy consumption. Generally, ducts are installed outside the conditioned envelope in places such as the attic, crawlspace and basement. Unfortunately, installing the ducts in the attic is widely practiced among local builders and the least effective location for the ductwork that leads to the greatest energy loss. For instance, during the winter time the attic temperature is close to outside temperature and in the summer the attic temperature can reach above 140 °F. Locating the ducts in the attic will lead to heat losses and gains due to conduction and radiation. For ducts located outside the conditioned space the leakage results in 15-35% energy loss, increase in heating and cooling loads and substantially decrease air quality inside the house. Locating ductwork within a conditioned space helps to drastically reduce energy losses. Constructing a dropped ceiling is one of the ways to locate the ducts within the conditioned space. The typical temperature in this space ranges between 55 °F to 85 °F and allows minimal conduction and radiation losses. In the two-story construction, the ducts could be located between the first and the second floors. It is important to note that for ducts located in a conditioned space a minimum insulation is usually required. Typically, insulating ducts to R-2 to R-4 is quite sufficient [24].

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). The results of these simulations are presented in the Figure 24.

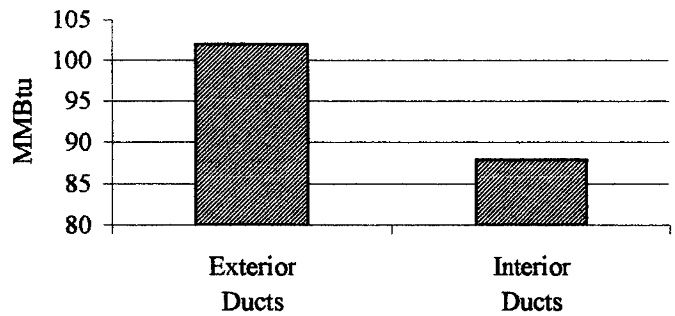


Figure 24. Annual energy consumption by the Base Case house with exterior and interior located ducts.

Installing ducts inside a heated envelope resulted in quite notable savings 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 on the annual heating and cooling energy consumption translated into a substantial 19% savings on the annual heating and cooling energy cost.

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 1992 the U.S. Department of Energy set a minimum efficiency standard for the furnaces sold in the U.S. to have an AFUE rating of 78%, [25]. The higher the AFUE the more efficient the furnace. New furnaces reach over 90% efficiency. In this research the performance of the Base Case house with 78% gas furnace efficiency was compared to the 92% furnace efficiency. The results of these simulations are presented below in the Figure 25.

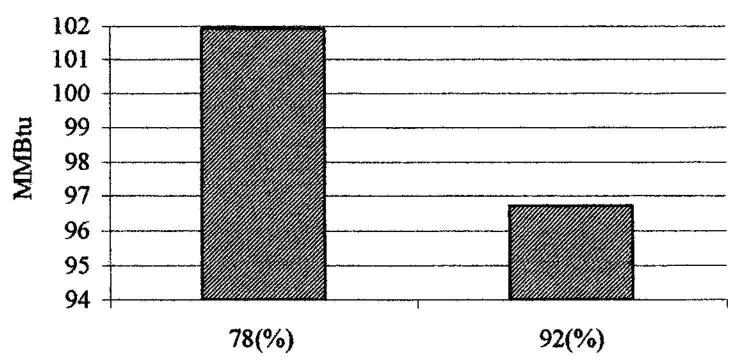


Figure 25. Base Case annual energy consumption with gas furnaces AFUE 78% and 92%.

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 Lighting

According to a DOE publication [26], 5% to 10% of energy costs are spent on lighting by an average household in the U.S. Typically, the least efficient and the cheapest, standard incandescent lamps, are used in the residential area. Fluorescent lamps present a great alternative to the typical incandescent. Although initially more expensive, they are found to be 4 times more efficient, last up to ten times longer and produce 90% less heat than the traditional incandescent lamps [27].

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 ¼ 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%.

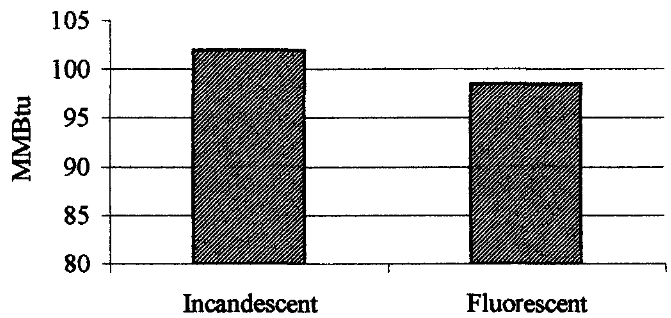


Figure 26. Base Case annual energy consumption with incandescent and fluorescent lamps.

Replacing incandescent lights with energy efficient fluorescent lights reduced electric annual energy consumption by lights from 3.0 $kBtu/ft^2$ to 0.7 $kBtu/ft^2$

Chapter Summary

Based on the Energy-10 simulation results, the following features were found to offer the best energy conserving benefits and selected to be incorporated into the Modified Case house design:

- Vinyl frame windows with double low-e glazing
- 3' Exterior shading for south, east and west façade of the house
- Styrofoam T-Mass exterior walls (R-36) construction
- Fully insulated concrete slab (R-10)
- R-50 attic insulation
- High quality construction of the house envelope
- Freus A/C unit (EER-16)
- Gas furnace (92% AFUE)
- Interior located ducts
- Fluorescent interior and exterior lights

CHAPTER 4

MODIFIED CASE

As the result of the Energy-10 simulations a number of energy-efficient features were selected and applied to the Modified Case. These preferred features are summarized and presented in Figure 27.

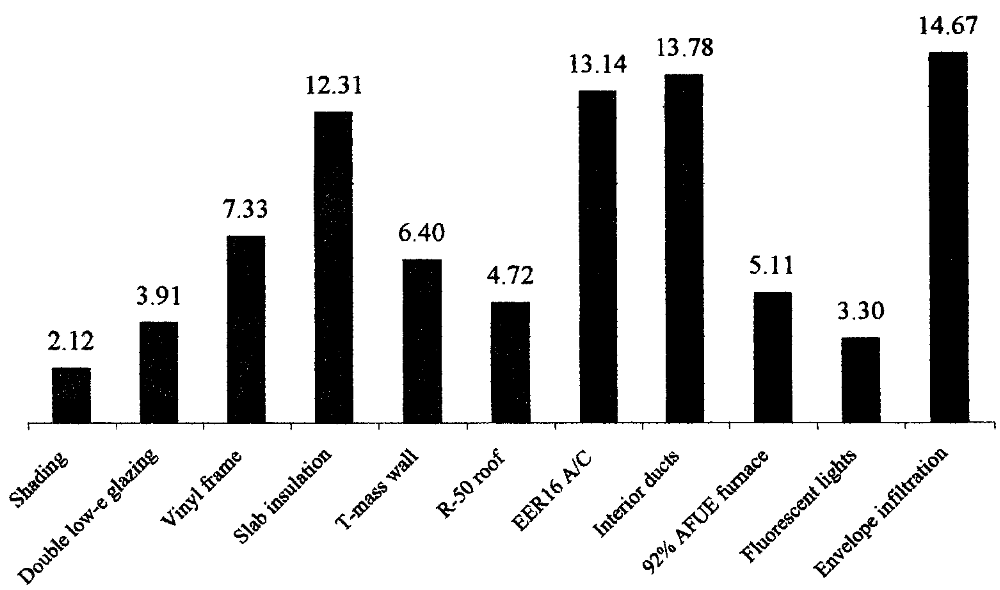
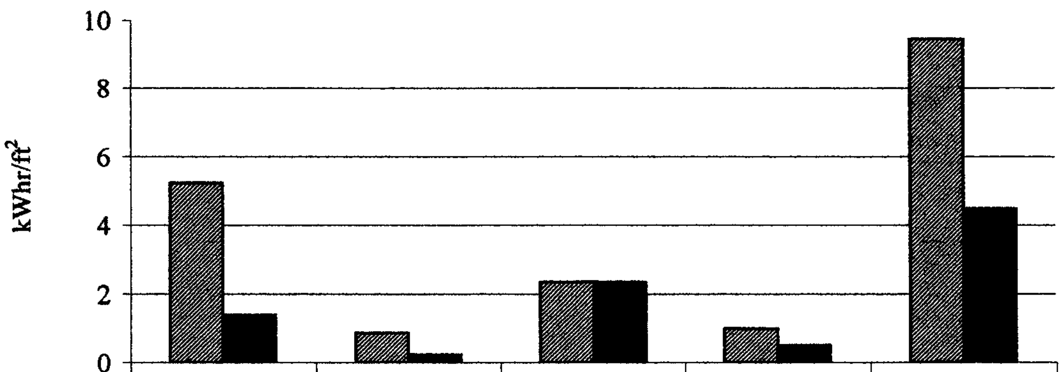


Figure 27. Percentage of annual energy savings offered by each feature selected for the Modified Case house.

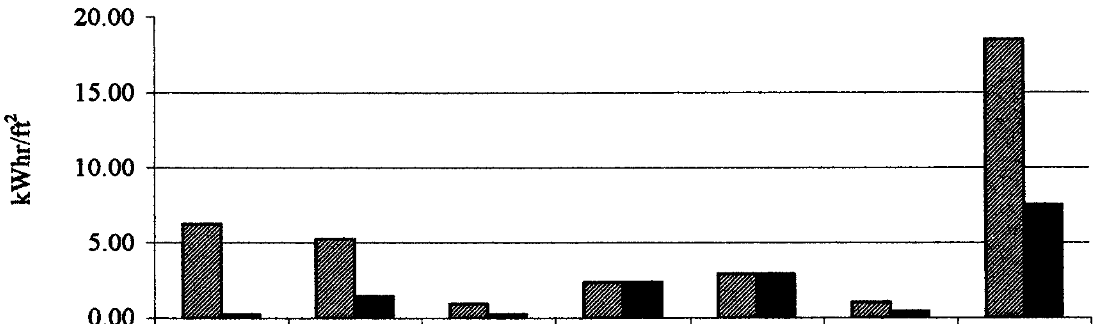
Implementation of the selected superior envelope construction materials and incorporation of energy saving components into the Modified Case house design allowed

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 is worth noting that the annual energy cost was reduced by 57% from $1910 to $822 (or from $159/month average to $68.5/month).



	Cooling	Lights	Appliances and Plug Loads	Fan	Total
Base Case	5.22	0.88	2.35	1.00	9.45
Modified Case	1.41	0.22	2.35	0.50	4.48

Figure 28. Annual electric energy consumption breakdown by component for the Base and Modified Cases.



	Heating	Cooling	Lights	Appliances Plug Loads	Hot Water	Fan	Total
Base Case	6.24	5.22	0.88	2.35	2.87	1.00	18.56
Modified Case	0.21	1.41	0.21	2.35	2.87	0.41	7.46

Figure 29. Annual total energy consumption breakdown by component for the Base and Modified Cases.

Table 13 Energy-10 Modified Case Simulations Results

Description:	
Weather file	Las Vegas (TMY2)
Floor area, ft^2	1610.0
Surface area, ft^2	5043.9
Volume, ft^3	14490.0
Total conduction UA, Btu/h-F	208.6
Average U-value, Btu/hr- ft^2-F	0.041
Wall construction	R-36
Roof construction	R-50
Floor type, insulation	Reff=23.5
Window construction	6068, U=0.27, etc.
Window shading	36-14, etc.
Wall total gross area, ft^2	1656
Roof total gross area, ft^2	1778
Ground total gross area, ft^2	1610
Window total gross area, ft^2	236
Windows (N/E/S/W:Roof)	4/1/4/5:0
Glazing name	double low-e, U=0.26
Operating parameters	
HVAC system	DX Cooling with Gas Furnace
Rated output (Heat/ SCool/TCool), kBtu/h	13/18/24
Rated air flow/MOOA, cfm	943/0
Heating thermostat	70.0 °F, no setback
Cooling thermostat	78.0 °F, no setup
Heat/Cool performance	Eff=92, EER=16
Duct leaks/conduction, total %	3/0
Peak Gains: IL, EL, HW, OT; W/ ft^2	0.05/0.01/0.66/0.36
Infiltration, in^2	ELA=59.6
Results	
Simulation dates	01-Jan to 31-Dec
Energy use, kBtu	40980
Energy cost, $	822
Total electric, kWh	7213
Internal/External lights, kWh	319/34
Heating/Cooling/Fan, kWh	0/2270/660
Hot water/Other, kWh	0/3784
Peak electric, kW	2.5
Fuel, hw/heat/total, kBtu	15770/1154/16924
Emissions, CO2/SO2/Nox, lbs	11619/59/32

Water Heater

Energy consumption can be dramatically reduced through the use of a tankless water heater, which can utilize propane, natural gas or electric energy. Used extensively around Europe and Japan, they were introduced to the U.S. market about 25 years ago. Tankless water heaters produce hot water on demand thus eliminating the standby heat loss that happens during water reheat cycles of conventional gas water heaters and usually account to 10%-20% of annual water heating costs. A gas-fired Rinnai Continuum tankless water heater unit with electronic ignition considered for this project was suggested by ConSol based on its energy savings and practicality. This model was successfully utilized during the prior ZEH project development of the WillowCreek at the Peppertree Park master planned community in California. According to the manufacturer, the Rinnai Continuum water-heating unit is 50% more energy efficient than a conventional natural gas water heater and is up to 70% more efficient than an electric water heater. The unit provides a great degree of flexibility allowing a user to program the water temperature for various needs around the house and enjoy never-ending supply of hot water 24 hours a day at the rate up to 8.5 gallons per minute [28].

The use of an integral collector storage ("batch") type solar water system to preheat domestic water can further reduce energy consumption. This type is the simplest of all solar water heaters and employs municipal waterline pressure to circulate the water through the large volume collector to the tankless water heater. Containing no mechanical moving parts, the integral collector solar water system is affordable, dependable and simple to install. This solar water system can be installed on a roof or on the ground and

consists of one or more collector/storage units located in an insulated box that has a glazed side facing the sun [29].

Although no simulations could be performed, an estimate of the potential benefit on the energy reduction by the implementation of the combination of tankless and solar water heater is presented here for consideration. Energy-10 simulations performed for the Base Case house with the conventional natural gas water heater estimate hot water energy consumption to be 9.78 kBtu/ft^2 (2.87 kWhr/ft^2). With up to 50% gas savings, the annual energy consumption by the tankless water heater alone can be reduced to 4.89 kBtu/ft^2 (1.43 kWhr/ft^2). Incorporating the solar technology to heat domestic water can further reduce the fuel demand. The estimated energy savings believed to reach 80% when a tankless water heater is integrated with a "batch" type solar water heating system 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 use such as the time of day and the lengths of time hot water being consumed.

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 15215 kWh to 7213 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 (GE). Table 13 presents detailed

information of the electrical performance for this model. Typical IV curves for this model are presented in Figure 30.

Table 14 GEPV-055-G Integrated Module for Roof Tiles [30]

Typical Performance Characteristics		
Peak power (Wp)	Watts	55
Maximum power voltage (Vmp)	Volts	8.4
Maximum power current (Imp)	Amps	6.6
Open circuit voltage (Voc)	Volts	10.4
Short circuit current (Isc)	Amps	7.5
Short circuit temperature coefficient	mA/°C	+3
Open circuit voltage coefficient	V/°C	-0.04
Maximum power temperature coefficient	%/°C	-0.5
Maximum series fuse	Amps	18

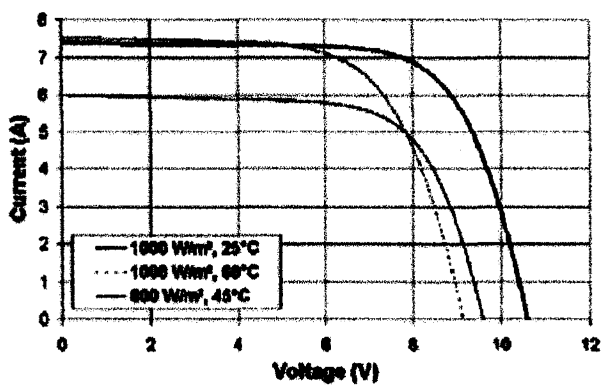


Figure 30. Typical IV curves for GEPV-055Module [30].

This module contains 18 single-crystal cells connected in series and is designed for use in residential constructions. It is designed to be compatible with such commonly used MonierLifetile™, Hanson® and Eagle® roof tiles. The details of the PV placement are shown in Figure 39 in the Appendix. This photovoltaic model was successfully put to use at the Clarum homes project built in El Palo Alto in California (a detailed description

of this project can be found in Chapter I). Since no simulations could be performed with the version of Energy-10 software employed in this research, GE estimates were used instead. These indicate that the annual electric power output by estimated 5kW system is 8100 kWh (based on the city location and the house size). 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. The results of the electric energy consumption are presented in Figure 31.

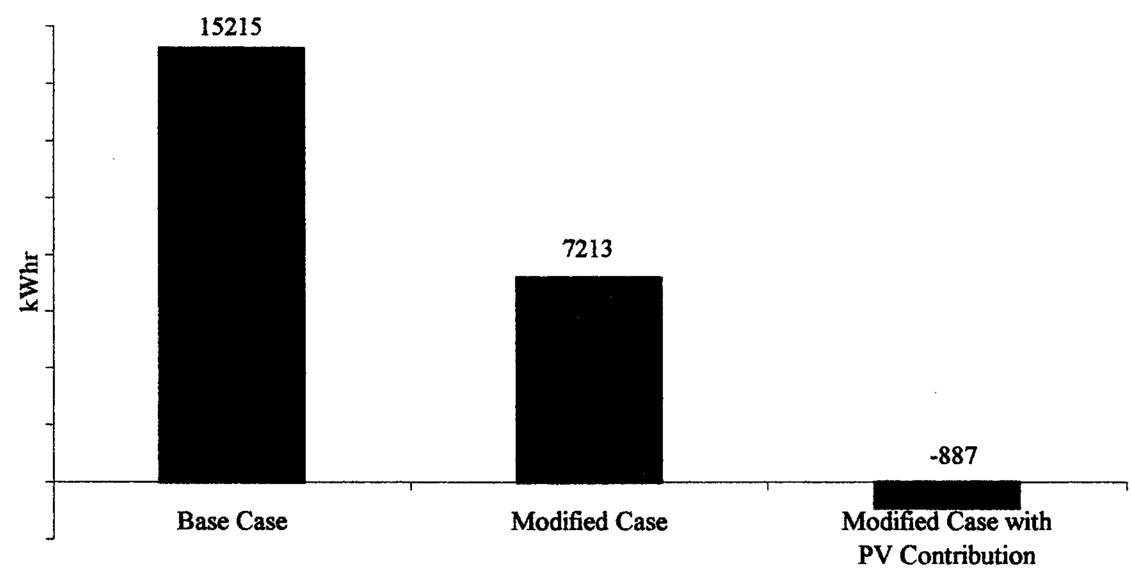


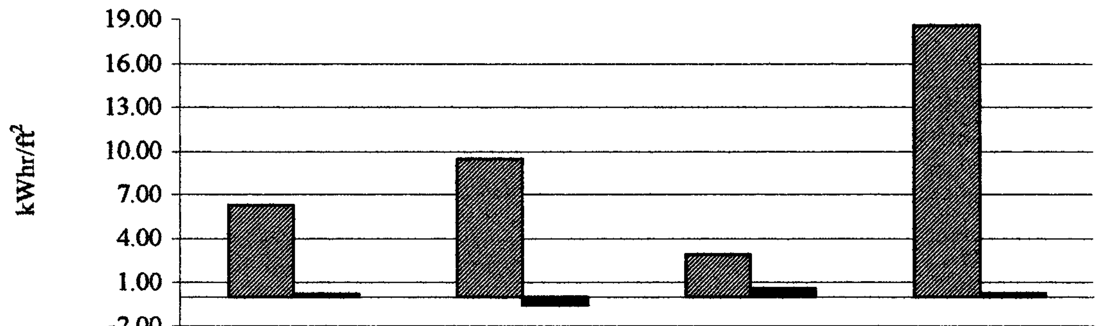
Figure 31. Annual electric energy consumption for the Base and Modified Cases with and without the PV contribution.

With 105% reduction on the electrical energy use, the Modified Case house is estimated to be totally independent from the current utility system. Although the net metering system rules currently in place at Nevada Power will not pay for the extra

power sent back by a utility integrated PV system to the grid, Nevada Power will offer rebates to their customers to complement the cost of a PV system purchase. The offered rebate will pay $5 per watt of a PV system to their residential consumers for a PV system up to 5 kW ($25, 000) The rebate is schedule to be available through June 2005 [31].

Chapter Summary

Based on the above described Energy-10 analysis and incorporating the passive solar features into the Modified Case house the design resulted in a dramatic 98.5% energy conservation. Energy consumption details are presented in Figure 32 below.



	Space Heating	Electrical Energy	Hot Water	Total
Base Case	6.24	9.45	2.87	18.56
Modified Case	0.21	-0.55	0.57	0.25

Figure 32. Annual energy consumption breakdown for the Base and Modified Cases with PV and solar water heating energy included.

Table 15 Low-Energy Case Features

Walls	Styrofoam T-mass with R-36, 1" polystyrene foam covered with 3/8" one coat stucco on the outside. ½" gypsum wallboard and paint on the interior
Ceiling/Roof/Attic	R-50 blown cellulose in attic. Radiant barrier. 7/16" OSB and ½" concrete tile on outside. ½" 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	5 kW
Hot Water	Tankless/solar water heater
Slab insulation	4" thick fully insulated concrete slab

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMENDATIONS

Summary and Conclusions

The full scope of energy conservation aspects in residential construction were considered and presented in this research. As a starting point for the research, 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

In regards to improving the energy efficiency of the envelope construction the following components were studied: the effect on the annual energy consumption for a variety of window framing and glazing, exterior shading options, exterior wall construction and insulation levels, attic and slab insulation levels, and the quality of the envelope construction. Likewise the consequences of the A/C efficiency and ducts location, uses of fluorescent lights, and efficiency a gas furnace on the energy conservation were among the parameters addressed in this research. Based on the

analysis described in this paper, the features offering a superior energy conservation advantage were chosen for the design of the low-energy (Modified Case) are as follows:

- Energy-10 simulations indicated that double low-e window glazing provided the most energy-efficiency amid the considered options and offered 3.91% on the annual energy savings
- Use of a vinyl window frame yielded the best energy conservation with 7.33% annual energy savings
- The ultimate length of the exterior window shading was found to be 36 inches for windows located on the south façade thus offering 2.12% annual energy savings for the Base Case model. Horizontal external shading was not found to be very effective for west and east facades of the Base Case building and therefore other options should be considered such as automated window shading and incorporation of appropriate landscape features
- An ICF exterior wall (R-36) that provides thermal mass benefit was estimated to have the most effect on the annual energy reduction (6.40%) among the considered options
- R-50 attic insulation level yielded 4.72% annual energy savings
- Among alternatives considered for the slab insulation, a fully insulated concrete slab was found to have the most impact on the space heating load and a minor effect on the cooling load offering 12.31% reduction on the annual energy consumption
- Reducing the uncontrolled air infiltration by monitoring the envelope construction quality had a dramatic effect on the energy conservation. Based

on the Energy-10 simulations, implementing tighter envelope construction allowed 14.67% savings on the annual energy

- Use of highly energy-efficient EER 16 A/C unit offered 13.14% reduction on the annual energy use
- 5.11% energy savings was attained when a conventional gas furnace (78% AFUE) is replaced with top of the line gas furnace (92% AFUE)
- Locating ducts within the conditioned envelope allowed a 13.78% reduction on the annual energy consumption

However, due to the simulation engine limitations there were a number of energy-conserving options that could not be simulated with a high degree of accuracy. These include:

- Simulation of energy-efficient appliances
- Roof radiant barrier
- Tankless water heater supplemented by the batch types solar water heater system
- Thermal mass effect of the ICF exterior walls on the annual energy consumption
- PV module

However, the combined effect of all the features generated and 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 was expected to save 105% on the annual electric energy consumption. Furthermore, the overall 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.

Recommendations for Further Study

Building design is an elaborate process where architectural, structural and engineering parts of design must operate in agreement. 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 actual acquired energy savings.

APPENDIX

BASE CASE HOME INFORMATION

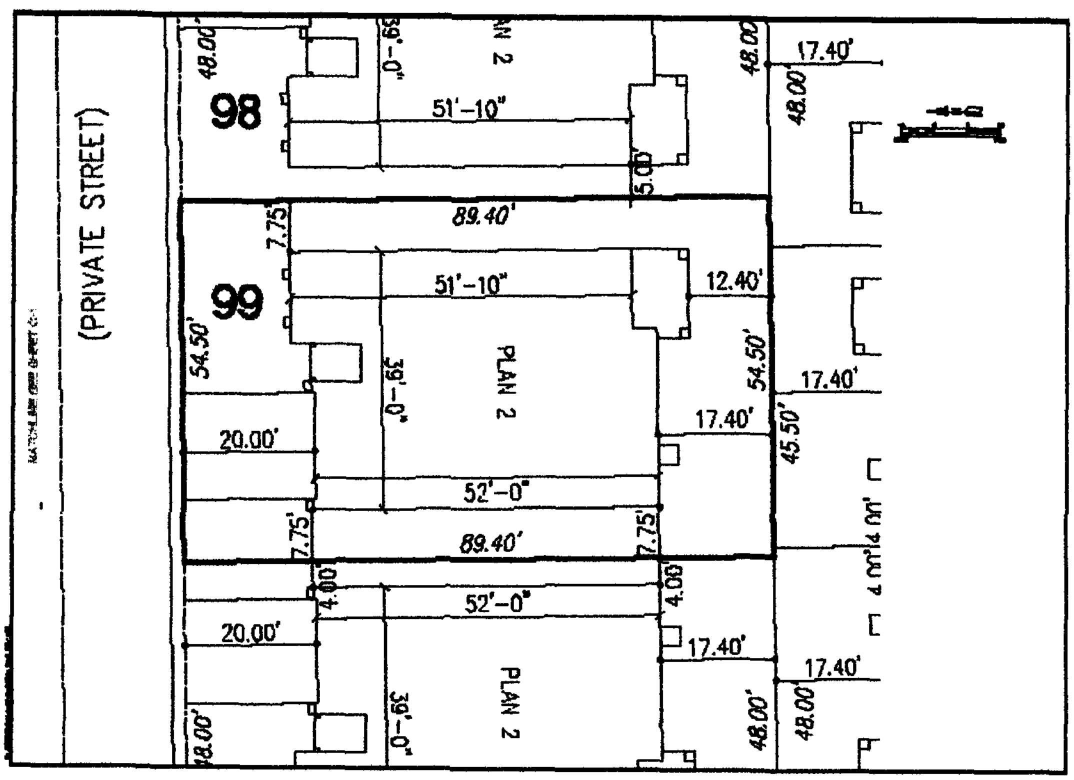


Figure 33. Lot 99, future location of ZEH.

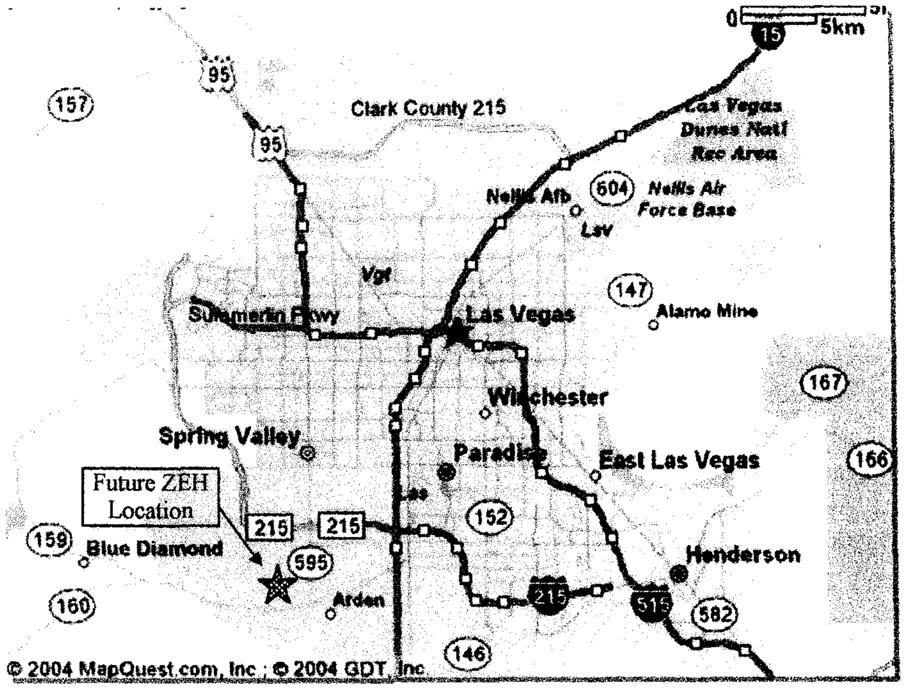


Figure 34. Future ZEH subdivision location.

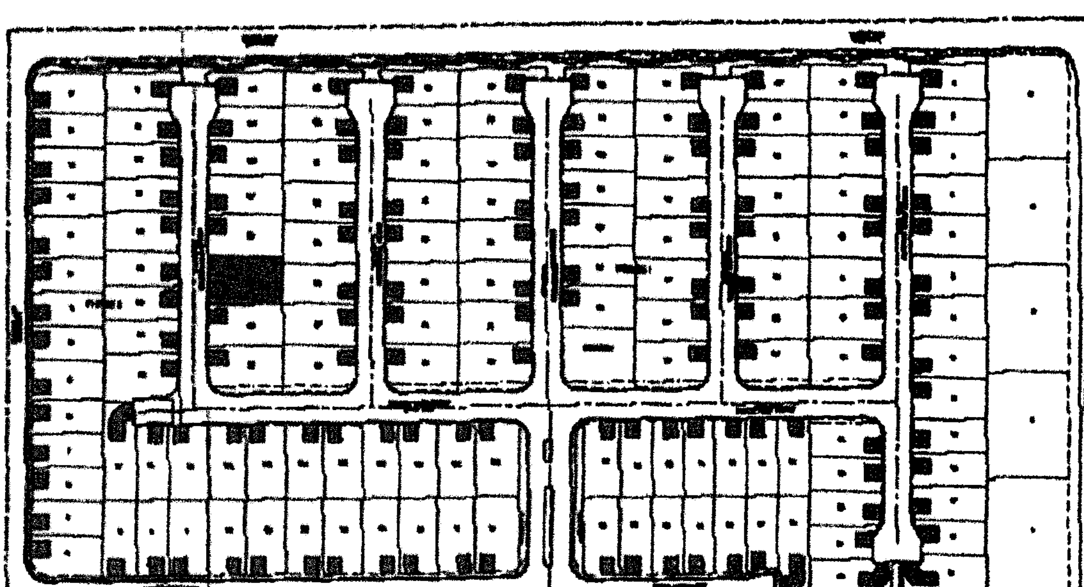


Figure 35. Future ZEH subdivision layout.

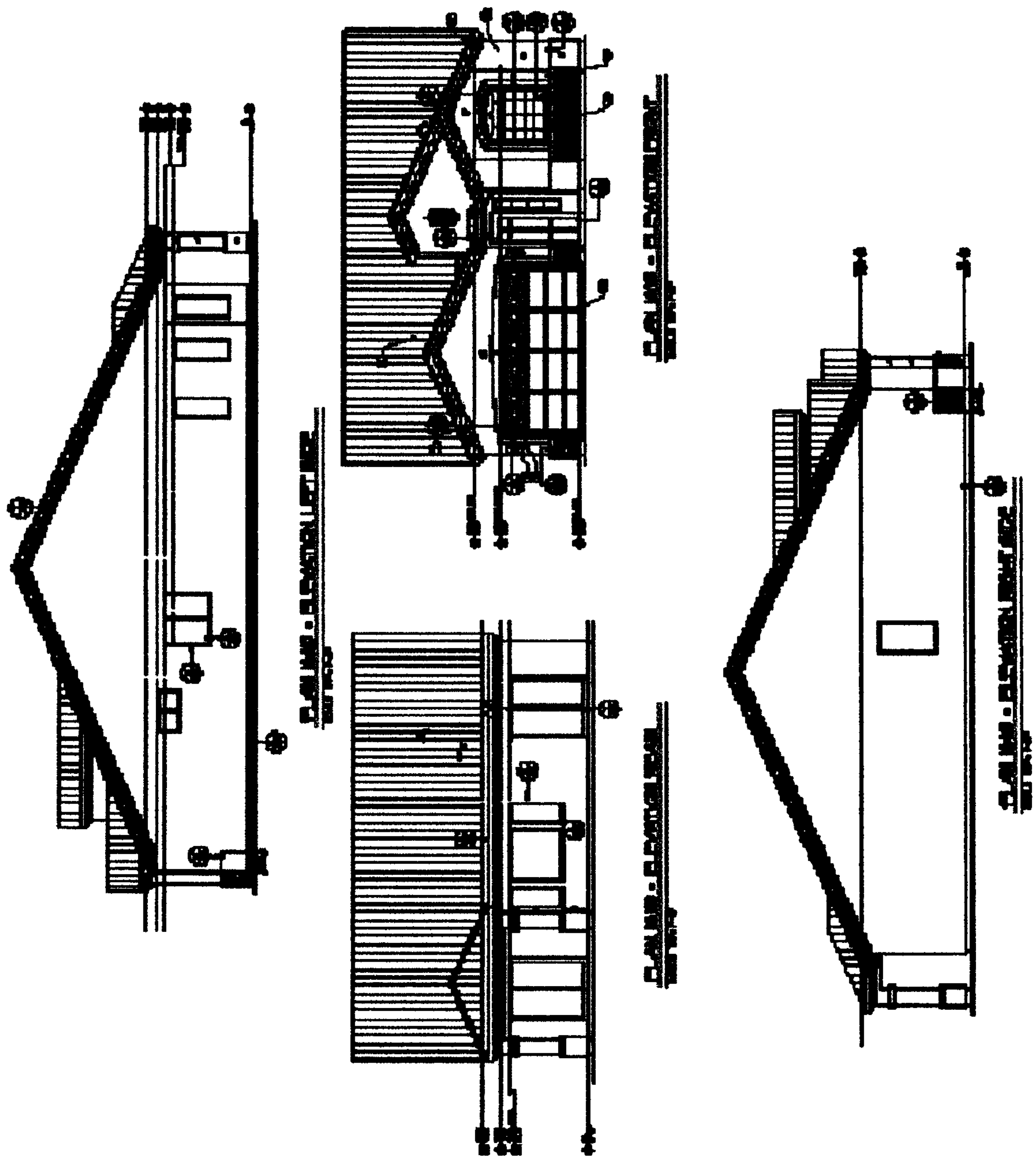


Figure 36. ZEH Elevations.

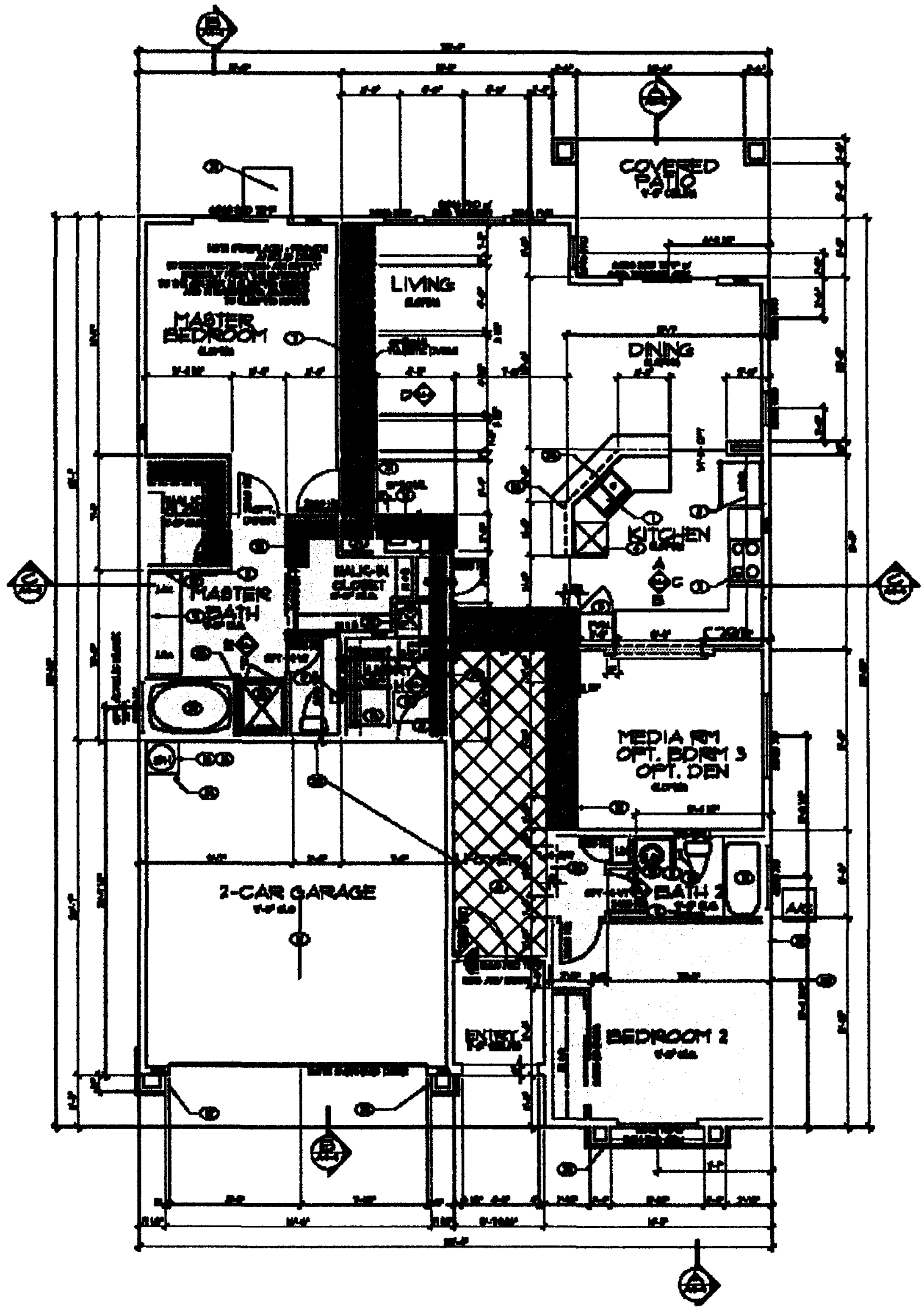


Figure 37. ZEH floor plan.

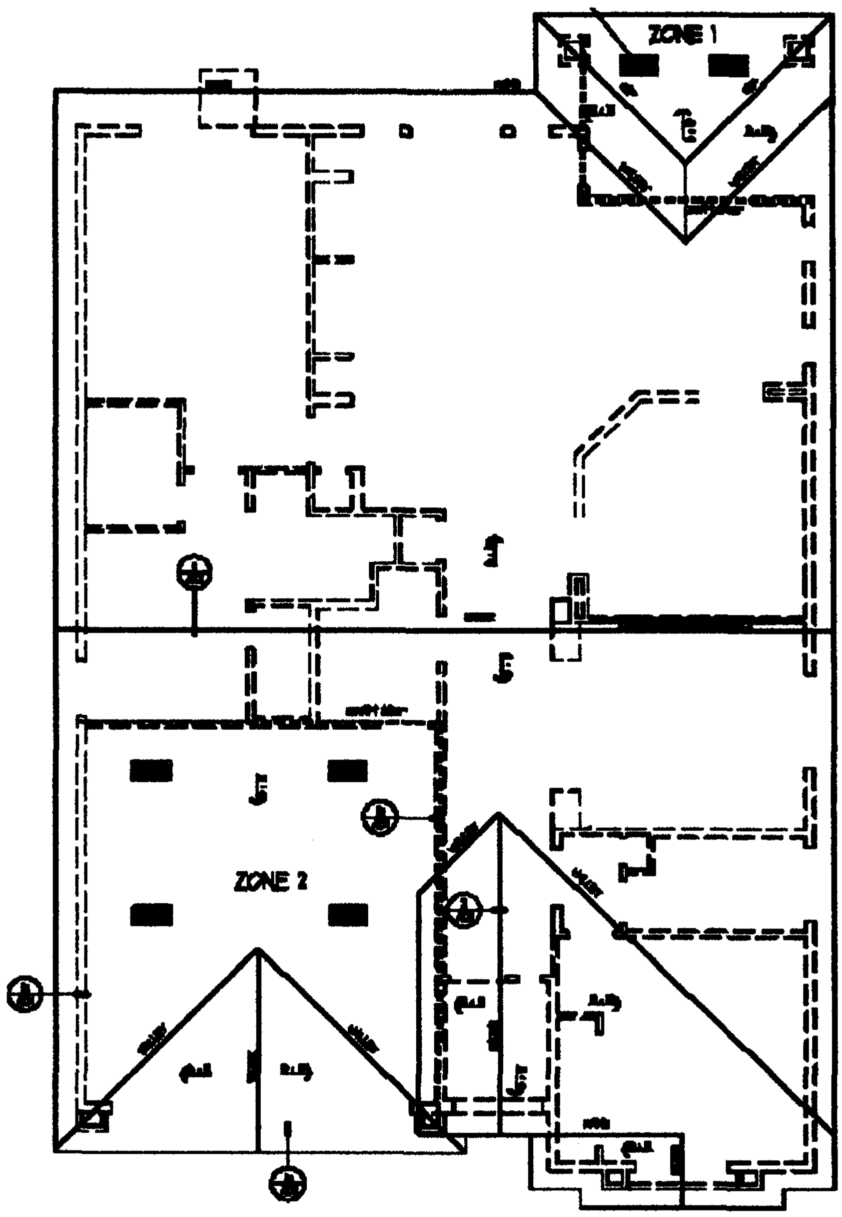


Figure 38. ZEH roof layout.

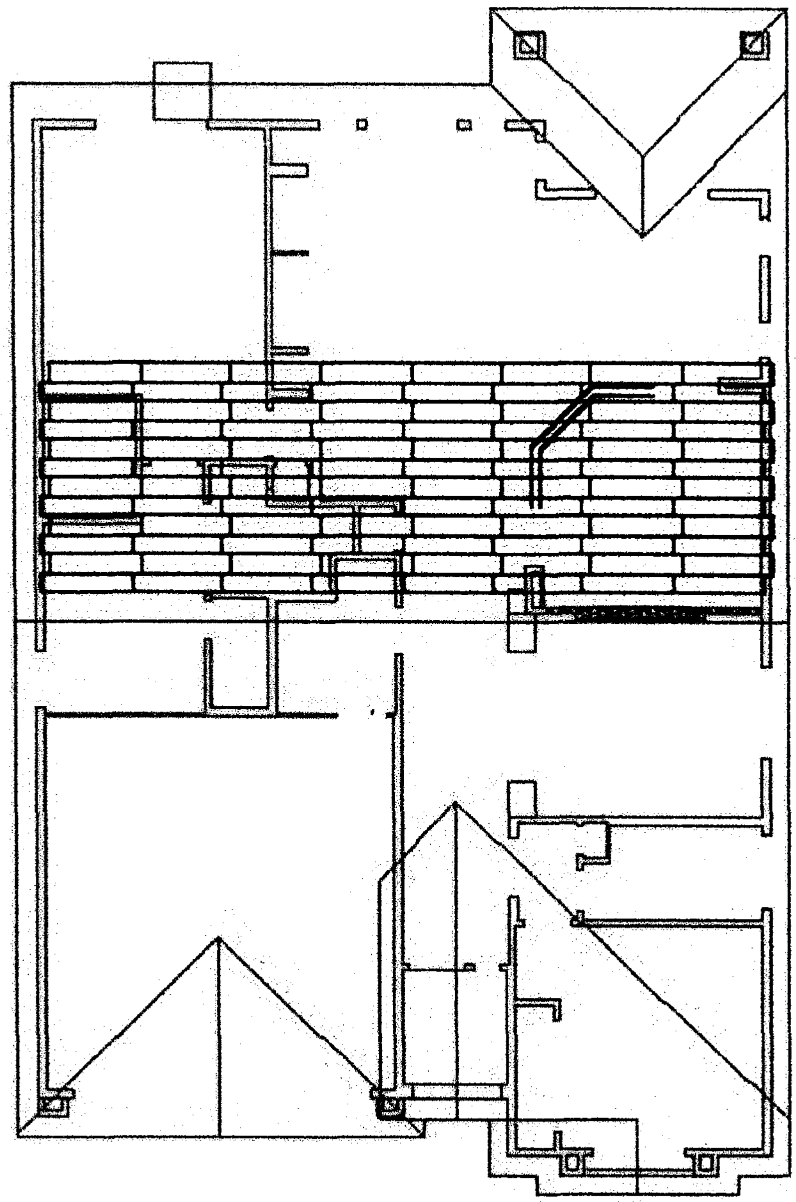


Figure 39. ZEH PV layout.

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