Las Vegas ReVISION House™

Introduction

The ReVISION House™ Las Vegas house was conceived as a research and training platform intended to demonstrate cost-effective, market-ready methods for achieving net-zero energy consumption in the context of a typical 1960's southwestern ranch style home. The deep-energy retrofit project combines significant building envelope upgrades with efficient mechanical systems, and renewable energy systems without a complete gut rehab of the existing residence. To accomplish this, the thermal envelope improvements (walls, roof, windows, etc.) were made primarily from the exterior, (theoretically) leaving the interior building finishes largely intact. Added to the deep energy-efficiency measures are significant levels of renewable energy in the form of a solar PV system and a solar-thermal hot-water system. Using these strategies similar deep energy retrofit solutions could also be implemented under occupied conditions, making widespread application more viable.

Working with the projects' sponsors Green Builder® Media, and Building Media, Inc., Steven Winter Associates and the Department of Energy's Building America program set out to base-line the performance of the existing home, and to develop building retrofit strategies to meet the projects two performance goals: a 70% reduction in energy usage compared to the existing home; and overall net-zero energy performance.

The pre-retrofit home, located at 3546 Pueblo Way, in Las Vegas, NV was original constructed in the early 1960's. Designed by architect William Krisel, the prolific residential designer of more than 30,000 iconic mostly southern California "desert-modern" dwellings, the ReVISION House represents an archetypical building form allowing the strategies developed here to be disseminated across the entire US Southwest.

Fig. 1 photo: Julius Shulman

Fig. 2 photo: Julius Shulman

The above glamour-shot photos of a typical exterior and interior convey the architectural style associated with Krisel designed homes. Even beyond style, the homes emphasized simplicity of plan, build-ability, and comfort of living space. The light-filled, open interiors are fore-runners of the open-plans of today, making this prototype home an ideal platform to demonstrate the near-zero energy retrofit of this historic architectural form.

Fig. 3 Front elevation of ReVISION House™ Las Vegas

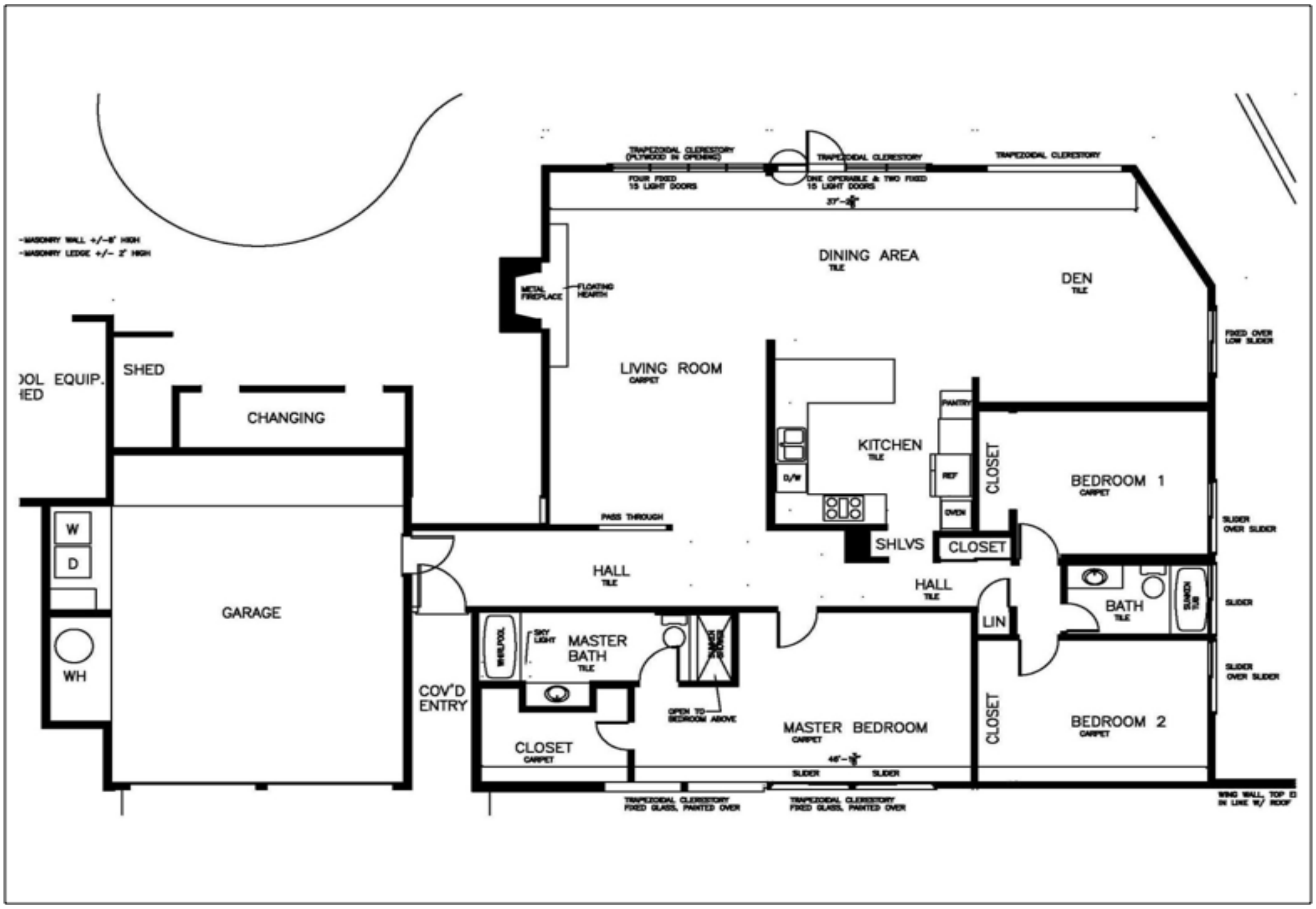


Fig. 4 ReVISION House™ Las Vegas Existing Plan

Existing Home Energy Analysis

To baseline the energy performance of the existing residence SWA initially performed testing on 3546 Pueblo Way in Las Vegas, Nevada on September 3rd, 2009. This audit was intended to investigate and document all the relevant performance related building specifications as they currently exist including building envelope, glazing, HVAC systems, hot-water, lighting, and appliances. Evaluation of this home included:

1. Air leakage test: Minneapolis Blower Door
2. Infrared Scan: Flir B50 IR camera
3. Duct leakage test: Minneapolis Duct Blaster
4. Visual inspection of components including insulation levels, equipment capacities and efficiencies, window types, etc.

Air leakage was analyzed using the blower door in conjunction with the infrared (IR) camera. By scanning the home before it is depressurized and then again while the blower door is running, the inspector can tell where air is entering an assembly. Air leakage often looks like tendrils of hair through the IR camera helping the auditor to differentiate between a simple conduction problem and an air leak. Also, cavities affected by air leakage will appear cooler or warmer with the blower door running than they did before the blower door was turned on. Using this diagnostic technique, air leakage can be detected in areas where it cannot be felt. More importantly, the point of origin of big air leaks can usually be detected.

After the initial IR scan was conducted, the home was depressurized to 50 pascals with a Minneapolis Blower Door. The resulting flow reading was 2,725 cfm50 which equates to 7.5 air changes per hour @ 50 pascals (ACH50). Quantitatively this is a moderate amount of leakage, and less than originally anticipated. Leak locations and magnitudes were detected by feel and with the IR camera in the following locations:

- The gas fireplace: this lacked glass doors and, because a gas inlet was present, the damper was fixed in the open position (as required by code). A significant amount of air was pulled down the chimney.
- Ceiling mounted recessed can lights: there were several can lights in the ceiling of this home. The ceiling is a vented, closed cathedral configuration insulated with fiberglass batts in the rafter bays. Significant air leakage could be felt and imaged coming from these recesses light fixtures.

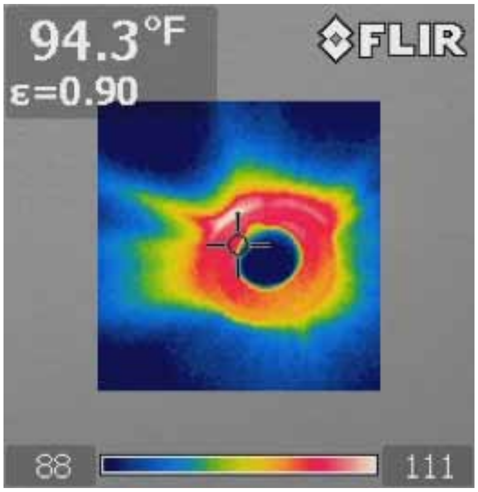


Fig. 5: Infrared Picture Showing Air Leakage from a recessed can light

- The duct chases/dropped ceiling: There were a few dropped ceilings to accommodate the duct work coming down from the roof mounted air handlers. These areas communicated freely with the vented rafter spaces. The below images show the affects of this air movement through the insulation in the kneewalls and rafters.

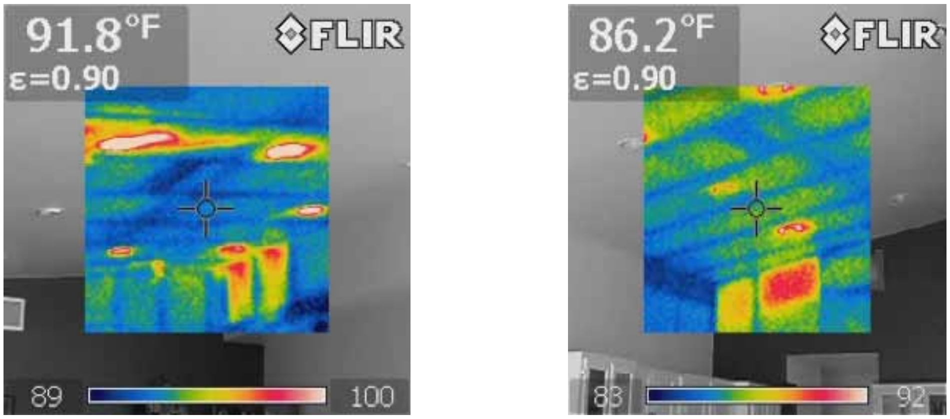


Fig. 6: Infrared Images Showing Air Leakage in Dropped Soffits and Rafter Bays

- Single pane, aluminum frame windows: Even when completely closed and locked, these windows leaked. Air was coming from the fixed windows as well as the operable ones.
- Outlets and switch plates: Air could be felt coming from these areas as well as seen with the IR camera. Interior wall penetrations leaked as much as exterior walls due to the connection with the vented roof.

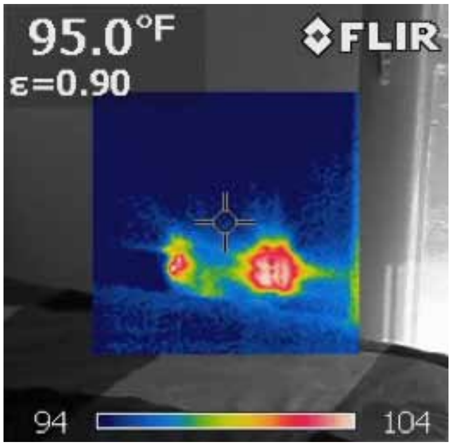


Fig. 7: Infrared Image Showing Leakage from Electrical Outlets

Even though the overall leakage is considered moderate, because this is a slab-on-grade home, most significant leaks occur through insulated assemblies, seriously degrading the ability of the insulation to perform as the intended thermal barrier. In addition to finding air leaks, the IR camera was used to detect thermal bypasses in the building shell. Besides the bypass in the kneewalls noted above, other problems areas included the corners, the wall/roof connection at the top plate around penetrations into the roof from lighting, smoke detectors, exhaust fans and heating/cooling registers. The following images of the ceiling were taken before noon on the southeast side of the house with the temperatures already over 100 degrees F outside.

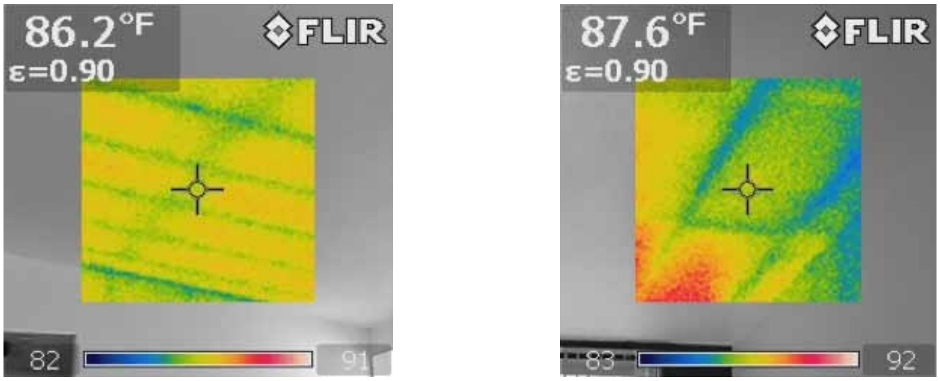


Fig. 8: Infrared Scan Showing Ineffectiveness of Insulation in Ceiling

Both of these IR images were taken prior to the blower door test. From these images it is clear that heat is getting around the insulation. In a well insulated cavity where it is much hotter outside than inside, the wood rafters should appear warmer than the cavity because they have a lower insulating value and the colors in the images would be reversed. The framing members should be yellow to red and the cavities green to blue in comparison. In the existing assembly the R-30 cavity insulation performed worse than the 2 x 10 rafters (approximately R-12).

HVAC Systems

There were two heating/cooling systems conditioning this home; both roof mounted Tempstar gas furnaces with central air conditioning units each with heating capacities of 80 kBTU/hr and 36 kBTU/hr of cooling for a total heating capacity of 160,000 BTU/h for heating and 72,000 BTH/h for cooling. Model and serial number nameplates were used to determine listed equipment efficiencies which were noted to the 0.80 AFUE and SEER 10 for heating and cooling respectively.

Both systems were tested for total duct leakage and leakage to the outside. Duct leakage tests were conducted per the Minneapolis Duct Blaster Operation Manual's pressurization protocol. The results are summarized in Table 1 1.

Table 1 1 Duct Leakage Test Results

	Total Leakage	Leakage to the Outside	Leakage to Outside
	(cfm@25)	(cfm@25)	(%)
System #1	258.0	154.0	11%
System #2	170.0	115.0	9%
Total:	428.0	269.0	10%

*Total system flow is estimated to be 1350 cfm/air handler based on air handler flow tests and flow measurements at registers.

Based on accepted practice, it is assumed that the air handlers were sized to deliver 450 cfm/ton of cooling for this climate resulting in a total flow of 1,350 cfm per air handler. At this flow rate, leakage to the outside is approximately 10% of the total flow to the conditioned space.

Walls and ceiling cavities were opened to verify cavity depths, insulation levels and quality of installation. The following existing energy related specifications were determined:

- Walls were found to be 3-1/2” in depth containing fiberglass batts, approximately R-11.
- The vaulted rafter cavities are 9” deep and also contain fiberglass batts which are the full depth of the cavity, approximately R-30 nominally.
- The dropped ceiling areas were insulated on the flat ceiling and the kneewalls with fiberglass batts, approximately R-38 & R-19 respectively.
- The ductwork, though insulated, was run in these cavities on top of the insulation leaving it in unconditioned space.
- No slab edge insulation was installed.
- Windows were single pane with metal frames in most cases. No storms were present.
- The water heater, located in the garage, was a 50 gallon, natural gas atmospheric unit in, pres ently leaking and beyond its useful life.

Even though the insulation levels appear to be reasonable, the infrared camera indicated that the cavity insulation is performing worse than the framing materials in each location. This means that the ceiling was performing worse than an R-11.25 and walls worse than an R-3.75 effective value (based on the thermal gradient generated by the IR imagery. The kneewall insulation appeared to be completely ineffective.

The performance goals for this project are to approach and potentially reach net-zero energy consumption on an annualized basis. To achieve this, the project team focused on getting the major building loads as low as practical; applied very high-efficiency equipment to the resultant loads; and sized renewable energy systems to match the annualized consumption of kilowatt-hours. Working within the structural confines of the existing building shell, and while leaving the majority of interior finishes intact, thermal envelope options were somewhat more limited than usual but none-the-less available.

Performance Optimization and ZEH Specifications

Using EnergyGauge USA 2.8.03, multiple parametric analyses were conducted to determine the optimal balance of wall and roof insulation values, glazing U-factors and solar heat gain coefficients (SHGC), and envelope tightness levels, again with the intent of minimizing, to the degree practical, space heating and cooling loads. Exterior walls are 2x4 framing, and with the interior finishes to remain, additional space for insulation cannot be obtained toward the interior, so an exterior foam sheathing solution was developed. Closed-cell spray polyurethane foam (ccSPF) and open-cell spray polyurethane (ocSPF) were looked at for the cavity fill while an EIFS solution was selected for the foam sheathing and exterior finish. Based on the optimization study and the required R-value in the R-21 range, ocSPF was selected as the fill insulation, with 2” EPS foam for the EIFS.

The roof is low pitch (2/12) 2 x 10 rafters with the pitched rafters forming the sloped ceiling plane for much of the house, thus most of the roof insulation must be within the rafter cavities, or above the roof decking. Given the extreme summer heat encountered in this location a heat-rejection strategy was developed for the roof covering. This consists of a “cool” standing seam metal roof over a 1-1/2” vented space. With this in place we reviewed options for the rafter cavity fill and selected a very aggressive R-55 and specified 8.5” of ccSPF to achieve it.

A small attic space exists above the entry hall and bedroom corridor. The cool-roof and rafter insulation strategy here is the same as the vaulted ceiling portions of the home, except that an ignition and thermal barrier needed to be added below the rafters to protect the foam insulation as no drywall ceiling existed at this location. As access from the bottom of the rafters is height restricted, support ledgers and horizontal furring were applied to the bottom of the rafters from above, and the gypsum board thermal barrier placed in the rafter cavities from above to rest on the furring and ledger supports. The extensive glazing in this home is integral to its iconic design, so the design team had three options in improving the performance of the glazing in this home to near-ZEH levels: select very high-performance southern glass; eliminate glass where incompatible to the interior space served; or do both. The third approach was selected with the existing single-glazed aluminum framed units replaced with triple low-e units (U-0.22, SHGC-0.19). The rear facing French doors (prior replacement units) were to be replaced with sliders in keeping with the original 1960's design.

Because the front of the home faces west and the major rooms occupying that elevation are two bedrooms, the extensive clerestory glazing in that elevation presents a huge solar-gain and cooling load, with little day-lighting or other benefit. Although modeling indicated substantial energy benefit in eliminating that glazing, the design team was concerned about altering the front appearance of this iconic home. Working with EIFS supplier and manufacturing partner Dryvit®, a design solution was arrived at where the front facing trapezoidal clerestory glass would be eliminated and replaced with a contrasting EIFS finish with a dark, reflective surface mimicking the glass.

Initial air-leakage envelope assumptions were borne out by envelope testing which resulted in 7.5 ACH50 results. As the entire thermal-boundary of the home will be made up of ccSPF and ocSPF, air leakage assumptions for the completed home were anticipated to be in the 2.0 ACH50 area. The majority of leak points remaining following completion were anticipated to be between the concrete slab and the wall framing, and the typical leak points around the sliding door and glazing components.

In hot-dry Las Vegas, cooling is a denominate cumulative energy load, as well as a dominate peak energy load. A key strategy when aiming for a net-zero energy outcome is therefore reducing the cooling load as much as practical. One component of this is rejecting heat energy before it has the chance to penetrate the thermal envelope. Because this one story home has a large roof-to-floor area ratio, and the roof is impacted with very significant solar loading, a "cool-roof" strategy was adopted. A cool-roof is defined as a roof covering which maintains a level of solar reflectance at 0.65 (for a low sloped roof, which is 2/12 or less as defined by ASTM Standard E 1918-97). With these criteria in mind, the design team selected a standing seam metal roof with a solar reflectance (SR) and thermal emittance (TE) above the minimum thresholds as define by the Cool Roof Ratings Council (CRRC).

To further improve the solar heat rejection performance, the standing seam roof was installed over a 1-1/2" vented space with continuous vents at the eaves and at the ridge. Earlier studies by Oakridge National Lab (Miller, W., et al, 2007) found up to 30% heat rejection capability using the "above-sheathing-ventilation" (ASV) approach alone. SWA also isolated two sets of three contiguous vented bays for side-by-side temperature monitoring of a roof deck radiant barrier strategy versus a standard roofing underlayment. Given the aggressive solar heat rejection strategy adopted, the question of how much more heat-rejection performance beyond the vented cool-roof can be obtained is one the design team desired to answer. Data collection was initiated in July 2010 and early results show an approximate 15 degree reduction in peak temperature in the radiant barrier rafter bay versus the standard rafter bay. This result is encouraging based on research team expectations.

Once the building enclosure specifications were finalized, alternate mechanical systems were investigated beginning with HVAC equipment. Initially the design team was intrigued with a very high performance ductless mini-split heat-pump system. The high efficiency ratings and the ductless configuration would allow for a relatively non-obtrusive retrofit, which the design team felt fit well with the occupied retrofit message. Other considerations, including first-cost, forced an alternate, more conventional ducted heat-pump system to be selected. The existing design of the home, with the centrally located ceiling drops (which contained the existing ducts) provided an ideal location for the redesigned compact duct layout to be placed inside-the-conditioned-space. To replace the two roof mounted air-handlers, a single, interior floor mounted vertical air handler was chosen. A single return, central to the floor plan was placed at the base of the AHU, with a sound baffle to mitigate blower fan noise.

Manual J sizing determined a 3-ton capacity with the peak heating and cooling being closely matched. The dry Las Vegas climate permitted a higher than typical sensible-heat-ratio of 0.85 for improved sensible performance and better comfort. The Trane® equipment combination provides a SEER of 18 for cooling, and a HSPF of 8.5. Along with the single-zone variable-speed system, programmable user controls and automated air filtration sections were selected for improved indoor-air-quality.

The design team initially investigated a separately ducted energy-recovery-ventilator (ERV) for the (ASHRAE 62.2-2010) required fresh air ventilation. Energy modeling found that even with an 80% efficient ERV, the net BTU energy savings would be less than the operational energy cost, and the decision was made to go with an exhaust-only strategy. SWA has excellent experience and performance test data with this type system, and given that this home does not have an attached garage or radon concerns, exhaust only ventilation Panasonic WhisperGreen fans (model number FV08VKSI) were selected. Local regulations require an exhaust fan for the laundry closet, which, being centrally located in the plan, was the fan selected to be programmed for constant flow to meet ASHRAE 62.2 ventilation standards.

As a net-zero-energy home in a hot-dry climate, the inclusion of solar hot water was very desirable. The selected system consists of an EagleSun DBS (drain back system). The DBS drain back is unique in that it contains an integrated 10 gallon drain back tank with integrated pump on top of the 60 gallon storage tank for quicker and easier installation. Modeling estimated a 75% solar contribution. When the solar contribution does not meet the full hot water demand, a Rinnai natural-gas tankless water heater will make up the difference. Plumbed in series with the solar, the tankless water heater uses the solar hot water as a pre-heat tank. If the water supplied from the tank is 130 degrees F, the Rinnai won't activate; is less than 130 F it will. The very compact nature of the tankless unit allows installation central to the hot water use in the house reducing losses.

The home had been largely renovated in the 1990's including replacing all the kitchen appliances. Even so the existing refrigerator, dishwasher, range and laundry appliances were not near as efficient as newer EnergyStar® devices. With EnergyStar qualified appliances, a range of performances is available with only the minimum performance levels being indicated. All appliances will be replaced with new, higher than minimally performing EnergyStar qualified devices.

The existing permanently installed lighting fixtures were fully documented and placed into the energy model along with the default operation and use schedule. Because the fixtures were so numerous, and inefficient (100% incandescent), the resulting energy use is significant, even as a percentage of the energy in the existing home (1971 kWh) a year. To control costs and to obtain the performance levels desired, a hybrid strategy was selected to reuse many of the existing fixtures, and re-lamp them with high efficacy devices, both compact fluorescent and LED. To accommodate the existing recessed fixtures in the sloped ceiling, metal enclosures were fabricated and fitted over the fixtures prior to the foam insulation application. The new metal jacket allows the foam to be sprayed against the device while providing a small air space between the insulation and the heat generating lamp.

An integrated lighting control system was also planned since most of the existing lighting and switch wiring could be made compatible with that application. Time-of-day controls, dimmers, group "activity settings" controls and options further allow the occupant to fine-tune and adjust the artificial lighting to specific needs, activities and time-of-day to reduce energy use even further. These efforts provided for a nearly 75% reduction in predicted lighting energy down to 551 annual kWh.

The cumulative improvement to the homes' energy performance was predicted to bring the energy use down to about 9000 kWh from 30,000 kWh a year. To get to the net-zero energy goals, the design team matched the remaining power needs with on-site renewables, in this case a 6 kilowatt SunPower PV system. Even though the roof surface faces a non-ideal southeast (versus true south), the low roof slope limits the performance de-rate more than a steeper slope would, and excellent production can still be obtained. The 500 square foot 6kW system is predicted to produce 9621 kWh annually, resulting in net-zero performance.

Construction Process:

Initial demolition and removals commenced late November 2009. Because the finished project was intended to be a completed "show home" to be displayed at the International Builders Show (IBS) in early February a very compressed timeframe added logistical difficulty. As a result, building processes and crews overlapped throughout the project.

Building Envelope Upgrades

Exterior stucco and board-and-batten finishes were stripped exposing the original stud cavities. The ill-fitting fiberglass batts (nominally R-11) were also removed leaving the frame cavities void. The interior drywall (much of which had been previously replaced due to a fire in the 1990's) was left in place, keeping the interior wall finishes largely intact. The carport, which had been previously changed to a garage, was gutted, bringing it back to the original carport function. Having exposed the wall framing cavities, minor electrical work could be accommodated from the exterior, and additional hose-bibs could be added. Once accomplished, the open-cell spray foam was added to the frame cavities, and raked flush.


Fig. 9: Exposed wall framing


Fig. 10: Open-cell foam insulation


Fig. 11: Exterior EIFS

Structural sheathing in the form of CDX plywood was added as Las Vegas in is a high-risk seismic zone and the home previously lacked much in the way of lateral bracing. Two Simpson Strong-Tie "Strong-Wall®" panels were also added at the rear elevation which is predominately glass.

Following the sheathing application an EIFS (exterior-insulation-finish-system) was added over 2" of EPS foam insulation. Cumulative R-value of the upgraded wall is 21.25. The EIFS has multiple benefits for this project: it mimics the stucco removed from the existing walls; it is a complete system including the exterior foam, thus providing R-value and thermal breaks; and it comes with complete water management details for around windows, door, penetrations and base terminations. Most other thick foam applications require fussy and expensive alternate detailing.

With the extensive glazing and the low-performance capabilities of the existing windows, the fenestration represented a real weak-link in the buildings envelope performance. The replacement units, a combination of double and triple glazed low-e fiberglass units were custom fabricated to fit the existing openings and install easily. The flange-type frames married well with the EIFS creating a relatively simple operation. The large trapezoidal units above the rear sliders were too big to fabricate as triples, so rather than subdivide the glass, high performance double glazed windows were selected. These face north, so the increase in SHGC has little performance impact.

Work on the roof proceeded using a similar strategy, with all roof covering and the roof decking removed leaving the rafter framing and the ceiling gypsum board attached to the bottom of the sloped rafters. Where a sloped ceiling did not exist (but a small attic space did) ledgers were attached along the bottom edge of the rafters and gypsum board was laid onto the ledgers. All 2 x 10 rafter spaces were then filled with 8.5" of closed-cell foam leaving a small 1" void at the top. The result is an R-55.25 assembly with outstanding air-sealing.

Fig. 12: Applying Closed-cell foam at rafters

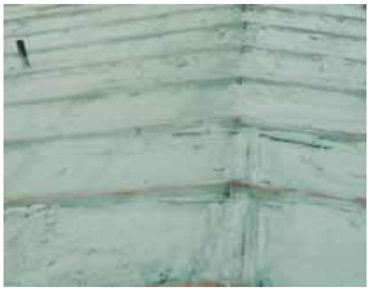


Fig. 13: 8.5" of foam in 2 x 10 rafters

Rafter foam insulation was followed by plywood roof decking; a drainage underlayment membrane, cross-lapped furring strips; and a fully vented "cool" metal roof.

Fig. 13: Decked roof with vent space

Fig. 14: Metal roof installation

Mechanical System Upgrades

The first step in reaching the ultimate performance goal is getting the building envelope loads down as low as practical. The next step is to meet those loads with the most efficient mechanical systems practical. For the ReVISION House this included complete replacement of the HVAC systems using the specifications described above. Since the plan was altered slightly for the inclusion of the air-handler in conditioned space (in a small centrally located closet) and the redesigned ducts are accommodated in the now-in-conditioned-space attic loft, integrating the new SEER 18 heatpump, went smoothly. The zero-leak objective for the ducts was emphasized, as was the testing requirement, so the installer had additional motivation to see that the install was virtually leak-free. The installer did make minor adjustments to the register locations (although CARB felt them to be unnecessary). Operation or comfort was not affected by the changes.

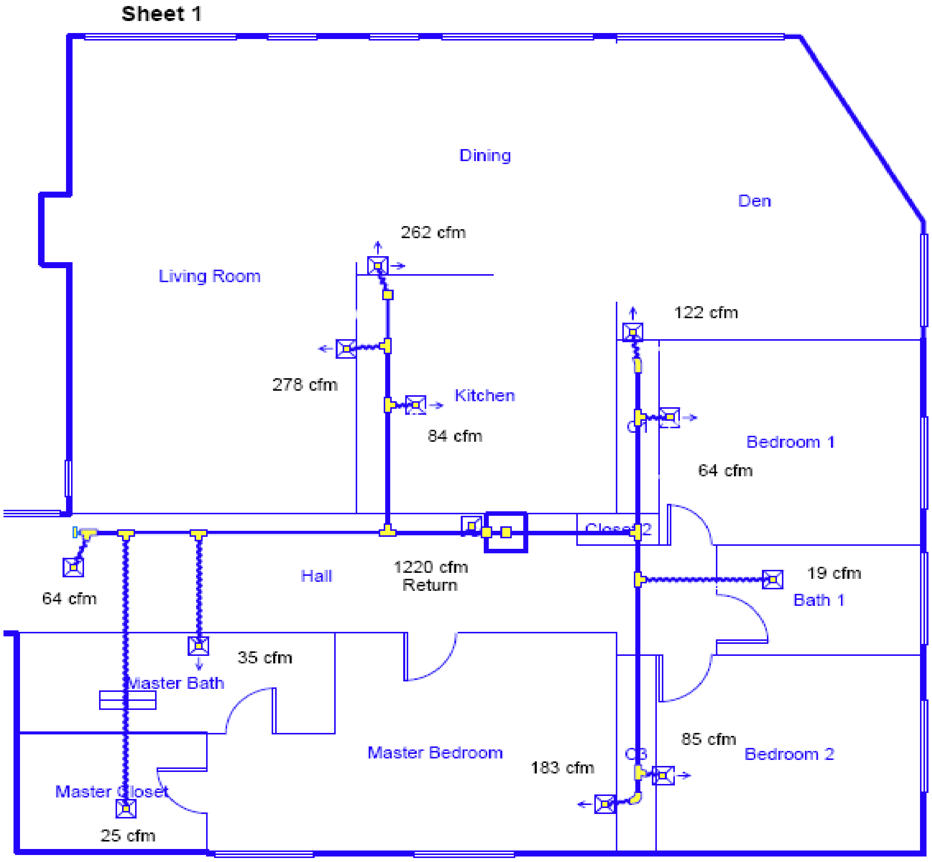


Fig. 15: Revised HVAC design

In efficient homes, domestic hot water can be the largest load, so as described in the specifications above, the design team was aggressive in attacking it. Using the drainback solar thermal system as a direct pre-heat, and the tankless gas unit as a backup raised questions by both the solar manufacturer and the tankless water heater manufacturer. CARB has had good experience with this arrangement in the past, and convinced both manufacturers of its viability. Two changes occurred during installation due to non-availability of a 60 gallon storage tank: an eighty gallon tank was substituted; and because of the additional tank height, the drainback reservoir tank needed to be relocated and not directly mounted on top of the tank.

ASHRAE 62.2 ventilation remained as specified using an exhaust only approach and a Panasonic Whisper-Green fan, but since the municipality insisted on an exhaust fan for the laundry “room” (really a closet), CARB decided to use that centrally-located device as the prime whole-house ventilation fan, with the two other bath fans as spot exhaust.

Prior to the foaming of the roof rafters, a strategy allowing the existing recessed can light housings was developed. Small sheet metal cylindrical spacers were fabricated and placed over the devices creating a 1/2” air space between the devices and the insulation. A minimum of 3” of closed cell foam covered the tops of the spacers. During this phase the lighting wiring circuits were traced and labeled, allowing the later installation of the Lutron® control system. Only minimal rewiring was required.

Final Testing and Inspection Results:

Following completion of construction Steven Winter Associates conducted final testing on 3546 Pueblo Way in Las Vegas, Nevada on February 28, 2010. Evaluation of this home included:

1. Air leakage test: Minneapolis Blower Door
2. Infrared Scan: Flir B50 IR camera
3. Duct leakage test: Minneapolis Duct Blaster
4. Visual inspection of components.

Blower Door Results

Air leakage was analyzed using the blower door in conjunction with the infrared (IR) camera. By scanning the home before it is depressurized and then again while the blower door is running, the inspector can tell where air is entering an assembly. Air leakage often looks like tendrils of hair through the IR camera helping the auditor to differentiate between a simple conduction problem and an air leak. Also, cavities affected by air leakage will appear cooler or warmer with the blower door running than they did before the blower door was turned on. Using this diagnostic technique, air leakage can be detected in areas where it cannot be felt. More importantly, the point of origin of big air leaks can usually be detected.

After the initial IR scan was conducted, the home was depressurized to 50 pascals with a Minneapolis Blower Door. The resulting flow reading was 800 cfm50 which equates to 2.2 air changes per hour @ 50 pascals (ACH50). Prior to the retrofits, the air leakage rate was approximately 7.5 ACH50. This is a 71% reduction in air leakage due to air sealing and insulating the walls and ceiling with spray foam insulation.

The majority of the remaining air leaks appeared to be coming from the following locations:

- The fireplace: Originally supplied with a natural gas option, the fireplace lacks glass doors and, by code, the flue damper was sealed in the open position. Sealed glass doors were recommended after initial testing, but designers chose to leave the fireplace as built, with the exception of removing the gas-line and altering the damper to be operational. Further sealing of the fireplace during

Fig. 16: Living room

the blower door test showed that an additional 120 CFM@50 could be eliminated if the fireplace had been better sealed. This amounts to 15% of the air leakage detected during the final testing.

- Slab/bottom plate connection: consistently, the coldest spot in any room in the home was the slab to wall connection. Because this is a retrofit application, sealing this connection was difficult. An attempt was made to seal the edge of the bottom plate to the slab from the exterior, but an air tight sill-to-slab seal was not accomplished.

- Plumbing penetrations: there were new penetrations through the roof from the solar thermal panels and the HVAC refrigerant lines which were not present during the initial testing. These lines were installed after the spray foam insulation and were consequently not well sealed after the fact.

- Bath fans: although Panasonic WhisperGreen bath fans with dampers were installed, there is still a small amount of air that was pulled through these penetrations during the blower door test. This is consistent with what we see in most homes.

Infrared Scan

In addition to finding air leaks, the IR camera was used to detect thermal bypasses in the building shell. As noted above, the largest thermal bypass in this home was located along the edge where the wall meets the slab. Most other bypasses detected in the pre-retrofit audit were corrected when the walls and roof were sprayed with foam insulation. The following IR images show good alignment of the insulation, even coverage and few thermal bypasses.

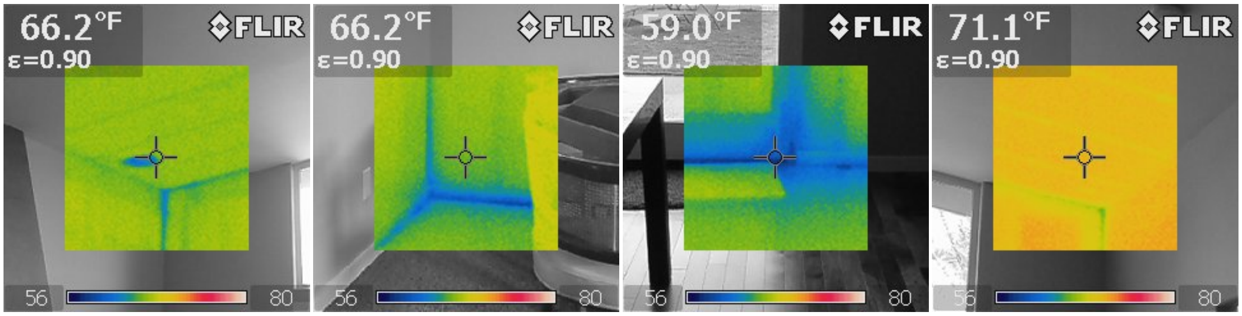


Fig. 17: Post-construction IR Images

Duct Leakage Testing and CFM Flows

Originally, there were two roof top heating/cooling systems conditioning this home with a combined capacity of 160 kBtuh for heating and 6 tons of cooling. Duct leakage to the outside was approximately 10% of total system flow and total leakage was 16% of total flow.

With the building envelope improvements and the resulting drastic load reductions, a single one-zone HVAC system was specified and designed into the plan. The air-source heat pump was configured with the air-handler located in conditioned space, and all ductwork redesigned and moved to within conditioned space. Testing revealed total duct leakage was reduced to 5% and leakage to the outside was so low it was not detectable with the duct blaster gauges, therefore essentially zero.

An Alnor Low-Flow flow-hood was used to confirm the actual HVAC air-flows at each of the supply registers. Although the final design varied slightly from the final HVAC design (the installer added a supply register at the entry foyer, and relocated a register in the master bedroom) all spatial flows were within 10% of the design intent and the total flows were within 5%.

Mechanical Ventilation

Initially, there was no mechanical ventilation installed in the home. The final design called for continuous exhaust-only ventilation to be provided by two Panasonic WhisperGreen exhaust fans. When tested with an Alnor Low-Flow, Flow Hood these fans were exhausting at a rate of 78 and 75 cfm continuously at the same time. This total exhaust rate was higher than the ASHRAE 62.2 recommended levels, so adjustments were made to the fans to reduce the flows to approximately 25 cfm each on a continuous basis with a boost upon occupancy. With one fan located in the centrally located laundry closet, and one in the master bath, good ventilation distribution is also achieved.

Final Performance Results and HERS Index

Incorporating the final test results into the energy model along with the final (and confirmed) performance related building specifications yielded a HERS Index of minus 1, and a corresponding small surplus of energy generation on an annualized basis. These results match to a high degree of accuracy the design team's predictions result in a true net-zero energy home.

Figs. 18, 19: Completed ReVISION House™ Las Vegas

Project: LAS VEGAS ZERO ENERGY HOME

1. SPECIFICATIONS

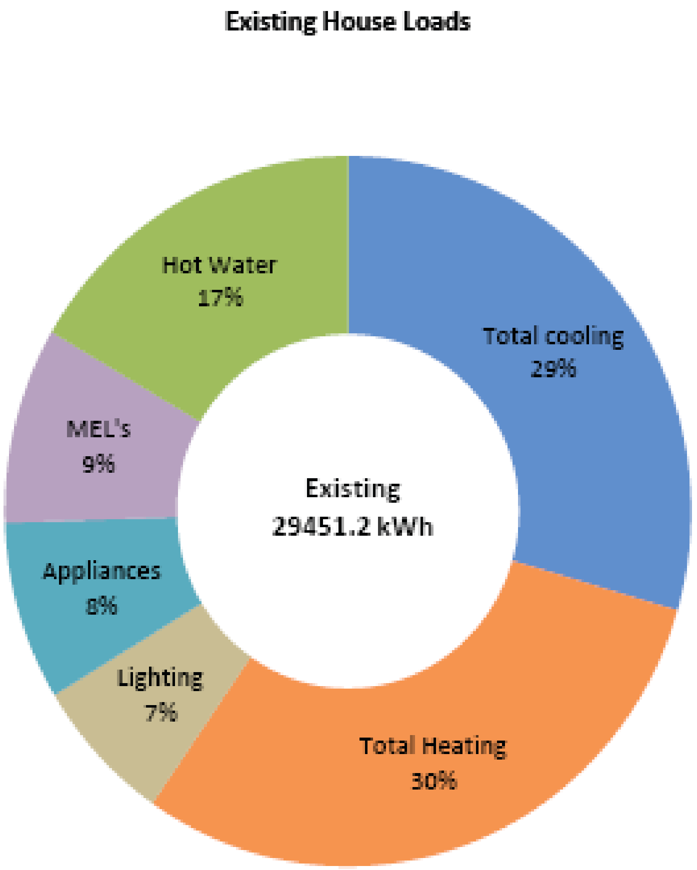
SPECIFICATIONS	EXISTING SPECS	PROPOSED SPECS
Architectural/Civil		South gable windows (bedroom) removed; East windows raised to sill height 18"; One North facing French door removed; Added new North facing french doors at entrance lobby; Door to garage removed
Foundation Assembly	Uninsulated slab on grade	Uninsulated slab on grade
Above Grade Wall Assembly	Compressed fiberglass batts cavity insulation R-10	R-21.65 with 3.5" BASF open cell foam R-3.9/inch (R-13.65)+ 2" continuous EPS R-4.0/inch (R-8)
Ceiling Assembly	Ceiling R-30, Knee Walls R-19 with 10% voids respectively	R-55.25 with 8.5" closed cell spray foam R-6.5/inch
Window Glazing	Single, metal glazing with U val=1.11 and SHGC=0.86	Triple Low E, U val =0.22; SHGC= 0.19; Double Low E, U val = 0.34; SHGC = 0.19 (rear windows & doors)
Building Infiltration	ACH @ 50 = 7.5	ACH @ 50 = 2.2
Whole House Ventilation	None	Continuous 50 CFM exhaust, 6 watt E-Star fan
Cooling System	Rooftop 72,000 BTUh PTAC SEER 10,	Trane 36,000 BTUh system w/ SEER 18
Heating System	Rooftop 120,000 BTUh PTAC, AFUE .80	Trane 36,000 BTUh system w/ HSPF 9.0 & COP 3.41
Ductwork	R-6, 11.2% leakage to outside	R-6, min. leakage to outside, ducts in cond. space
Water Heating	40 gal gas waterheater with 0.56 EF	Tank less gas waterheater with 0.84 EF
Solar Hot water	None	60 gallon storage tank, 80 sft array
Lighting	14% CFL	90% High Efficacy Lighting Package
Appliances	Varies	All Energy star appliances
Photovoltaics	None	SunPower SPR Solar PV Power System, 5.67 kW DC

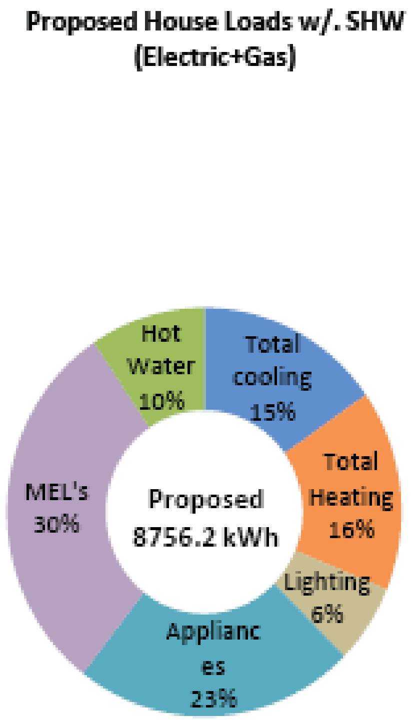
Table 1: Existing and Proposed Specifications

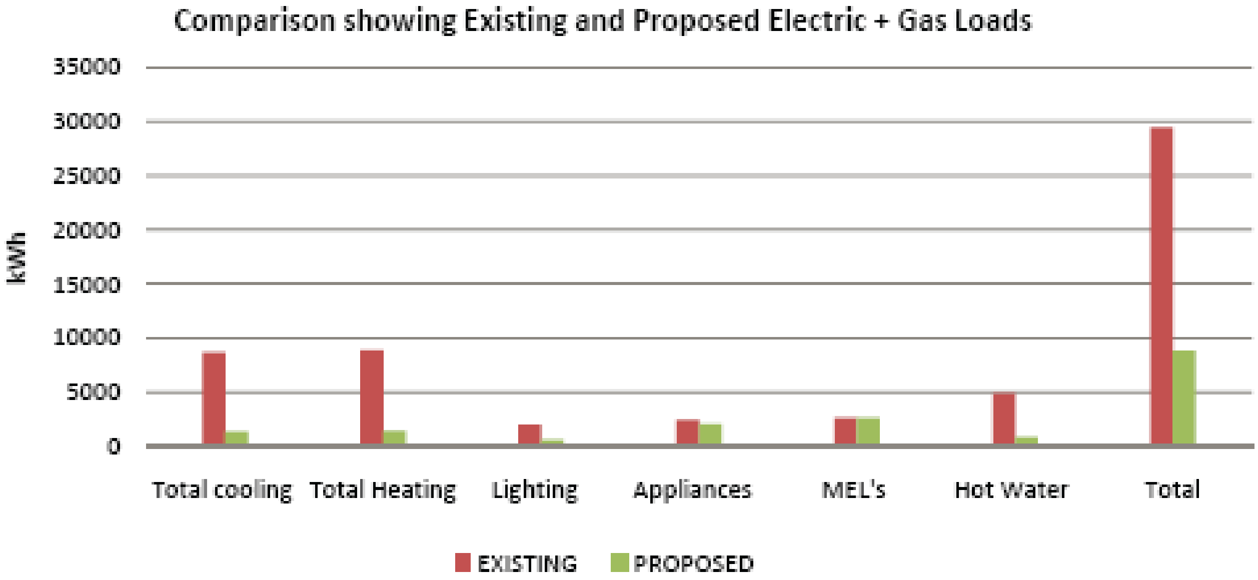
2. ENERGY MODELING RESULTS

ELECTRIC LOADS	BENCHMARK	PROPOSED w/ Solar hot-water
Total cooling (kWh)	8691	1386
Total Heating(kWh)	n/a	1520
Lighting (kWh)	1971	551
Appliances (kWh)	2399	2018
MEL's (kWh)	2631	2631
Pool pump	n/a	591.3
TOTAL ELECTRIC (kWh)	15692	8697.3
GAS LOADS	**EXISTING**	**PROPOSED w/ Solar hot-water**
Total Heating	302 Therms/ 8878.8 kWh	n/a
Hot Water	166 Therms/ 4880.4 kWh	28 Therms/823.2 kWh
TOTAL GAS	478 Therms/14053.2 kWh	28 Therms/823.2 kWh
TOTAL LOADS (GAS+ELECTRIC) (kWh)	**29451.2**	**9520.5**
PV Production (kWh)	n/a	10716
Net Energy	n/a	**1195.5**
HERS Index	123	-1

1. Appendices



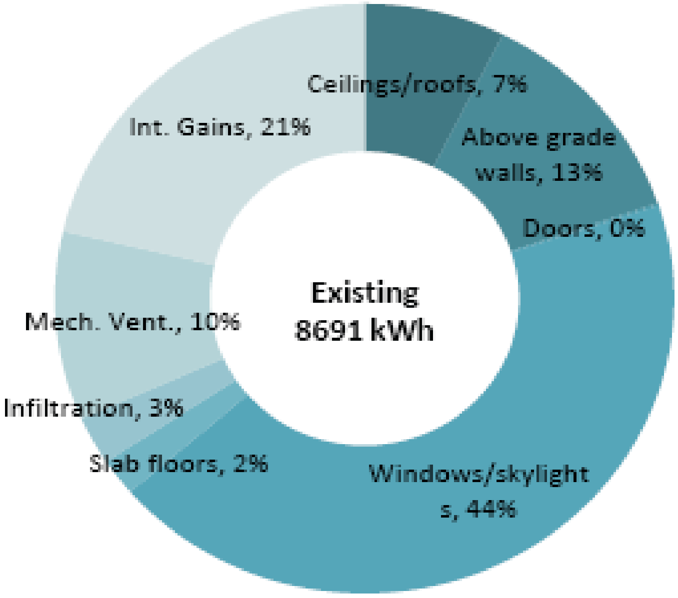


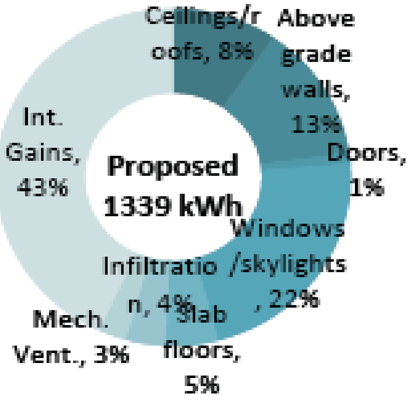


3. COMPONENT LOADS

Following tables give a breakdown of heating and cooling load of the building on a component basis.

3.1. COOLING SEASON COMPONENT LOADS

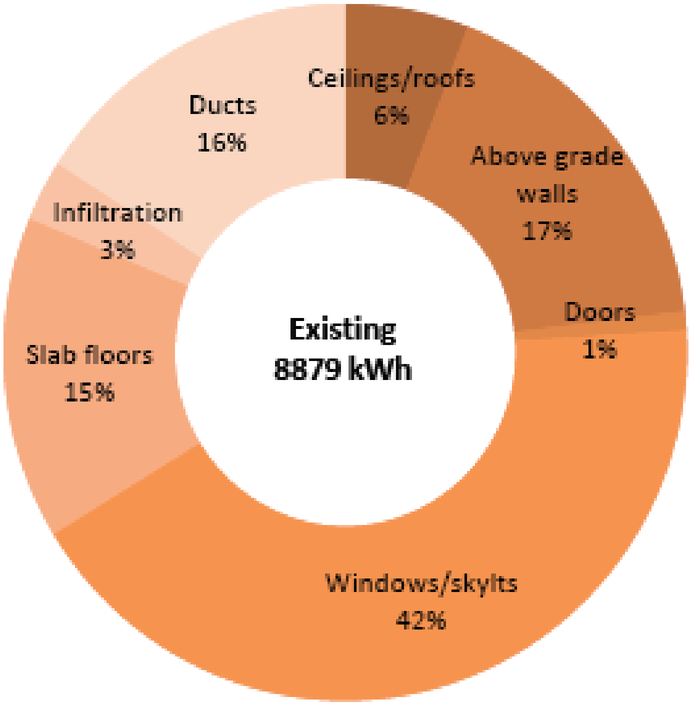


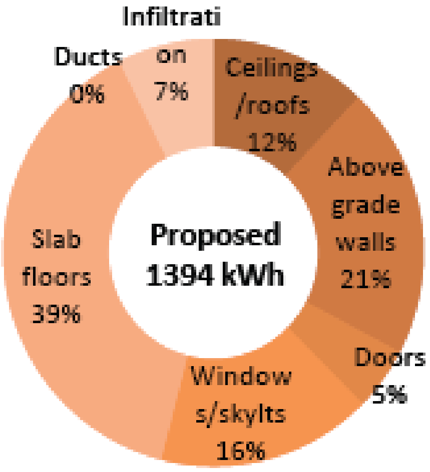


COOLING SEASON	EXISTING	PROPOSED
Ceilings/roofs	640.2	127.1
Above grade walls	1076.2	175.9
Doors	13.6	14.7
Windows/skylights	3800.6	298.1
Slab floors	177.1	63.5
Infiltration	231.6	48.9
Mech. Vent.	899.1	34.2
Int. Gains	1852.6	576.6

Table 3: Existing and Proposed Cooling Season Component Loads

3.2 HEATING SEASON COMPONENT LOADS





HEATING SEASON	EXISTING	PROPOSED
Ceilings/roofs	596.8	238.4
Above grade walls	1761.2	404.5
Doors	87.3	93.9
Windows/skylts	4308.4	325.0
Slab floors	1528.3	758.4
Infiltration	291.1	144.5
Ducts	1615.7	0.0
Int.Gains	-1310.0	-570.6

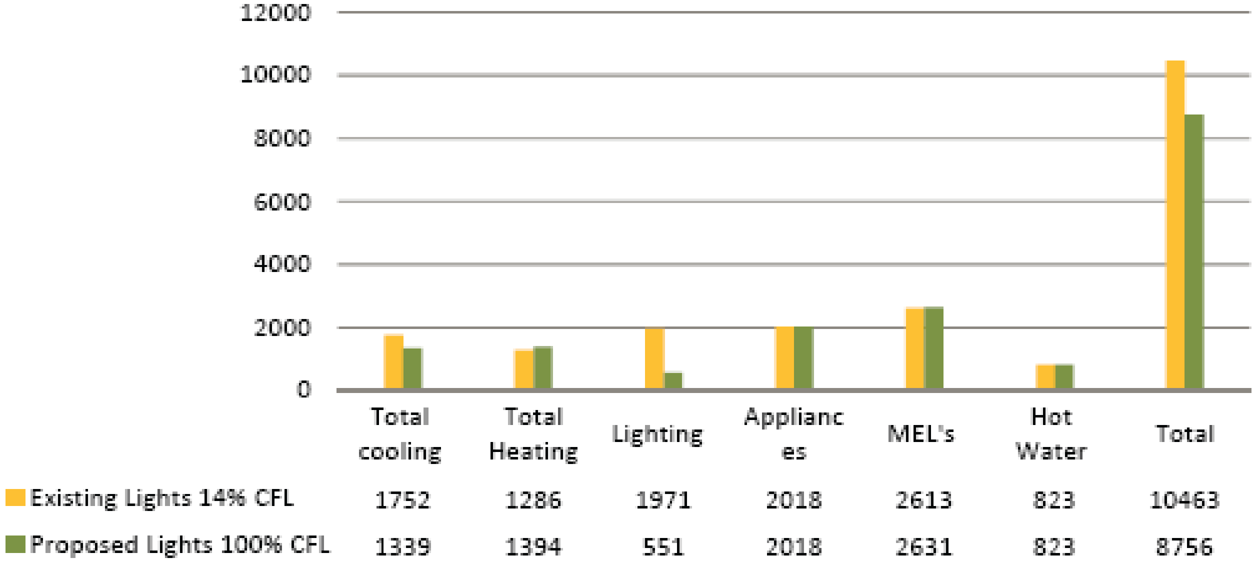
Table 4: Existing and Proposed Heating Season Component Loads

4. PARAMTERIC STUDY

Parametric Study 1: Lighting Loads

Following are the results of a parametric study to determine the impact of lighting fixture selection over the cooling and heating loads of the house. For this study, the energy model was run with proposed specifications as shown in Table 1 with existing lighting conditions of 14% CFL against a proposed lighting scenario of 100% CFL while keeping all other specifications the same.

Load Comparison
Proposed specs +Existing 14% CFL Vs. Proposed specs +Proposed 100% CFL



	Total cooling	Total Heating	Lighting	Appliances	MEL's	Hot Water	Total
🟨 Existing Lights 14% CFL	1752	1286	1971	2018	2613	823	10463
🟩 Proposed Lights 100% CFL	1339	1394	551	2018	2631	823	8756