Title:

“PASSIVE AND ACTIVE;”
A SUSTAINABLE SINGLE FAMILY RESIDENCE IN TUBAC, ARIZONA

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ABSTRACT
Situated in the heart of the Tumacacori valley in Tubac Arizona, the Isaacson residence is a climate responsive, passive and active solar, and energy efficient single family dwelling. Although its indoor living space is only 2,478 ft², the dwelling is designed to have a series of outdoor living terraces, almost the same size as the house itself. These terraces positively integrate the building with its pristine surroundings. The design concept of these outdoor living spaces was informed by the fact that the climate in Tubac is characterized by a hot and dry summer season with a large temperature swing (av. 26 °F) due to clear sky conditions. Therefore summer outdoors are pleasant at night. Winters are mild (av. 58.1°F) but the large diurnal temperature swing can cause only few harsh cold winter nights. As a result, with careful design, occupants can spend more than half of the year outdoors. Therefore activities such as cooking, dining and even shower facilities were provided in the design. To predict the complex interplay between the energy efficient, passive and active solar and green technologies the thermal performance of the envelope was optimized using the Energy-10 computer simulation software. While the operating cost of average homes in this region is $0.75/ft², the house operates on $0.28/ft². The residence is considered a showcase for future energy efficient and green development in the Tubac and the Santa Cruz County in Arizona.

INTRODUCTION
In the spring of 2005 Mr. and Mrs. Issacson, a couple artists from Florida, purchased a property in Tubac, Arizona for the purpose of joining the artists community situated near the wonderful Tumacacori valley. Mrs. Isaacson is a producer/photographer/painter and Mr. Isaacson is a producer/videographer/writer. They requested a small 2400ft² single story contemporary house that can expand. “We need a great room with living and dining spaces, open to a real kitchen for serious cooking, a master bedroom, office/den, guest room, and workroom/studio space. We are very “visual” people, and bought this property because of its expansive views and we need high ceilings and lots of windows to work and live well. Reconciling this with energy efficiency concerns may be the toughest job” Mrs. Isaacson said.

This paper emphasizes a synthesis between “logic” and “intuition” to develop sustainable and green strategies for the Isaacson residence. The author collaborated closely with the homeowners to optimize the design and the thermal performance of the envelope. The well informed and knowledgeable owners combined with the gorgeous site views provided the necessary ingredient for the success of the design as a showcase for energy efficiency.
GREEN DESIGN FEATURES AND PROCESS

Minimizing Impact on Site: Locating a coordinate on the 4.64 acres north/west sloping site that would yield minimum grade interruption to the existing landscape while provide proper cut-and-fill was the first major decision.

![Coordinate Image]

Figure 2: Site coordinate selected to optimize cut-and-fill and to provide minimum interruption to the mountainous skyline as the house is sighted from the south road.

Views: In compliant with the owner’s desire, a tripartite floor plan with three interlocking quarters and a common entrance were envisioned. The orientation of spaces was dictated by the spectacular views which provoked an urgent desire for large panoramic windows that increases the house potential for heat loss and gain. This was mitigated by the use thermal mass as explained later in the thermal performance section.

![Floor Plan Image]

Figure 3: The tripartite floor plan with living quarters oriented to the site spectacular views while the two major sleeping and guest quarters oriented for passive and active solar collection respectively.

![Floor Plan Image]

Figure 4: Floor plan showing surrounding outdoor spaces and the south sunken entryway/garden.
**Outdoor Spaces:** Although the size of the house indoor spaces is only 2,478 ft², a series of outdoor living terraces, almost the size as the house itself, were developed. These terraces positively integrate the building with its pristine surroundings. The concept was informed by the fact that the climate in Tubac is characterized by a hot and dry summer season with a large temperature swing that averages 26 °F. This is mainly due to clear sky conditions. Therefore summer outdoors are pleasant at night. Winters temperatures are also mild with an average of 58 °F, however the large diurnal temperature swing can cause only few harsh cold winter nights. As a result, and with the careful design of these outdoor spaces, homeowners can now spend more than half of the year outdoors engaged in activities such as living, cooking, dining and swimming. Even a shower facility was provided in the design.

![Outdoor Spaces](image)

**Passive and Active:** The roof of the house was designed with “passive” and “active” solar collection in mind. The roof atop the true south facing quarters is sloped towards the north to 1) facilitate solar collection on the south Trombe wall and windows in the winter months, 2) provide daylight access deep into the space through a continuous clerestory window equipped with a light shelf, and 3) provide shade on the south façade throughout the summer month. In contrast, the roof of the 25° east of south oriented guest quarters is sloped towards the south to provide solar collection on its surface when photovoltaic panels and solar water heater are mounted.

![Passive and Active](image)

**Thermal Storage:** The spectacular views provoked the homeowner’s urgent desire for large panoramic windows. Combined with the effect of a high mountain elevation and relatively cold winter nights caused by the large temperature swing, necessitated the use of high-mass thermal storage materials. Therefore the “Integra” block wall system was chosen for its interior high thermal storage that mitigates temperature swing and the R-28 exterior insulation that minimizes heat gain and loss. For this, the house geometry, proper orientation, and roof slopes provided the solar, light, and ventilation access necessary to accommodate such a thermal storage system.
Natural Ventilation: As thermal mass store heat during summer days to temper the house interior temperature swing, it must be vented (or discharged) during the night. The narrow single space house design and the location of operable windows on opposite sides and at different height allowed proper cross and stack natural ventilation to be regulated by the homeowners.

Fig.7: Integra blocks walls provides thermal mass storage to damp temperature swing of the interior while insure proper R-28 insulation value on the envelop exterior.

Fig.8: Cross and stack natural ventilation through the house interior discharging the heat stored in the thermal mass walls and slab.
**Rain Water Harvesting:** Water is scarce in the Sonoran Desert. In the last 30 years, ground water depth increased by 50 feet reaching over 350 feet on average. The Isaacson residence is designed to celebrate water on site, collect it for re-use in landscape and planting in the sunken garden and around the residence. Three cisterns are strategically located to receive rain water collected on the three roofs. On the south main entrance, a 1900 gallon 6’ diameter and 8’ high concrete cistern is placed and charged by the middle roof through an overhead gutter to always remind visitors of rain water harvesting. On the east and the west, two additional 500 gallon are placed and charged by the East wind roof and the west wing roof respectively.

![Fig. 9: Perspective view of the Isaacson residence showing the three rain water harvesting cistern](image)

**Graywater Recycling:** In 2001, the Arizona Department of Environmental Quality (ADEQ) regulated the use of residential graywater. This ruling made it possible to use graywater at the Isaacson residence for landscape irrigation. Graywater from cloth washer, bathtubs, showers, bath sinks, and condensate water from the two heat pumps was collected in a dedicated 4” gray water pvc pipe towards a mixing/switching valve on the east side of the house that diverts the water to the 2000 gallon septic tank with 4 50’ long leach fields.

![Fig. 10: Graywater collected and diverted to landscape irrigation on the north.](image)
**Trombe wall:** In a typical high diurnal temperature swing regions (about 28-36 °F on average), like in Tubac, where often cold winter nights and relatively cool summer nights can occur, the use of thermal heat storage systems is well recommended. The Isaacson house is equipped with a 48' long and 8' high Trombe wall made of the previously explained *Integra* blocks. The wall has 192 ft\(^3\) of mass and the slab has 96 ft\(^3\) of mass for a combined volumetric heat capacity of 34,496 Btu/°F. The Trombe wall is charged from the south by a series of 4’ high and 30’ long double-glazed windows. The windows are carefully shaded with a 3’ 2” horizontal overhang that only allow low-angle winter sun access while effectively block high-angle summer sun. During winter nights, all the heat stored in the masonry wall and concrete slab is slowly released into the 4’ wide and 8’ high corridor. A temperature differential operating fan, located at the ceiling of the corridor, running at a speed of 2 cfm/ft\(^3\) is then tuned on transforming the heat through under-slab ducts to the north relatively cooler side of the residence. Since the collector windows are operable, during summer night, the collected heat is ventilated to the outside discharging the thermal mass wall and slab and prepare them for next day storage.

![Drawing by: Tim Kauffman](image)

**Fig. 11:** The Trombe Wall system showing the thermal mass storage walls and slab and the series of 32’ long 4’ high double glazed windows that charge the thermal mass. The ceiling temperature differential fan transport the heat to north side of the house in winter while the operable and carefully shaded windows vent the thermal mass to the outside in summer.
**Daylight:** Since the Isaacson residence is a live-work residence for the two artists, balancing daylight was an important design aspect especially for Mrs. Isaacson who is a photographer and painter. As explained above, the roof geometry was intentionally configured to provide a north slope—which we called “Passive.” This roof is opened to the south sky and provides direct gain, daylight and views to the Tumacacori Peak from the living quarters while simultaneously providing indirect daylight to the master bedroom, walk-in closet, master bath, and office all of which are located on the north side of the house. These clerestory windows provided adequate daylight distribution.

![South Clerestory windows](image)

Fig. 12: North Slope roof provides balanced daylight between north and south spaces.

**Vented Roof:** The potential of moving heat by convection is significant and much faster than by conduction. Building on the old Middle Eastern “ice-house” technology, the Isaacson residence roof was designed with a slope and a 5” air space between its standing-seem clad finish and the R-30 batt insulation with radiant barrier foil face up. The east wing roof with clerestory windows slopes 2” per foot and the west wing roof for photovoltaic collection slopes 3.5” per foot. When the sun strike the top of the steel roof it heats up the air inside the 5” space and by convection that air is forced to move upslope. The roof is then equipped with two ridge vents, one at the bottom and the other at the top of the slope, which help venting the stratified air and continuously replacing it with fresh relatively cooler air. This is one of most effective cooling strategies for hot desert regions. Although was not utilized in this design, that same hot air could be collected and used to heat the spaces during the winter season.

![Section through the south sloping Roof showing the 5” air-space and the proposed roof ridge vents.](image)

Fig. 13: Section through the south sloping Roof showing the 5” air-space and the proposed roof ridge vents.
THERMAL PERFORMANCE
Thermal performance of the Isaacson Residence was predicted using the Energy-10 computer simulation software. Simulation analysis of the original design yielded an annual 51.7 KBtu/ft² for cooling and 4.3 KBtu/ft² for heating with an average $0.6/ft² annual operating cost ($1189 cooling, $297 heating). The effect of thermal mass walls with exterior insulation saved almost one-third of the cost reducing it to $0.4/ft² per year. While the large cooling load is common to most residences in the Tubac area, the heating load, as estimated, was higher than the normal. This is mainly due to the large north facing window area that was designed to accommodate the magnificent views. To achieve the goal of minimizing the cooling load and to attempt to eliminate the need for auxiliary heat, additional strategies were proposed and implemented after consultation with the homeowners. These strategies are: a 6” space vented roof (was not executed during construction), south-facing clerestory windows for daylight, cross and stack ventilation, earth integration, high performance triple glazing systems, shading ramadas, trees, and overhangs, and two XL19i high efficiency heat pumps mechanical system with underground supply ducts. As a result, an additional 20% load saving was achieved, but most importantly the heating load is now been reduced to half and reached a level that can be attainable by indirect passive solar collection. Therefore, the carefully designed and sized thermal storage “Trombe” wall sub system was introduced on the south-facing side of the house. This innovative system did not block the main view to the Tumacacori peak on the south and provided most of the heating requirements in winter especially at night. Heat transport was through the temperature differential low-flow 2 cfm/ft³ fan as explained above.

CONCLUSION
The outstanding thermal performance of the Isaacson residence as predicted by computer simulation will be validated by comparing with the utility bills once the homeowners established a one year history. However, one should note that during construction, some of the energy conservation strategies that were originally intended in the designed and were simulated by the E-10 software, did not get executed. Among these are the 6” vented roof and the ridge vents, and some areas of the earth-bermed walls especially near the sunken garden. In addition, and after a recent visit to the residence, the author did a quick thermal imaging test and found that some areas of the Integra block walls may not have gotten enough of the injected polyurethane insulation as originally planned, leaving few less insulated areas of the wall. Nonetheless, the homeowners were completely satisfied with their innovative energy efficient home. They attested to the fact that their energy bills were the lowest that they have ever seen and that the house conforms to their lifestyle.

In conclusion, the Isaacson residence is an energy efficient passive and active solar house that demonstrates green technologies and sustainable design. Today, the residence is considered to be a showcase for future energy efficient and green development in the Tubac and the Santa Cruz County in Arizona.
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REFERENCES