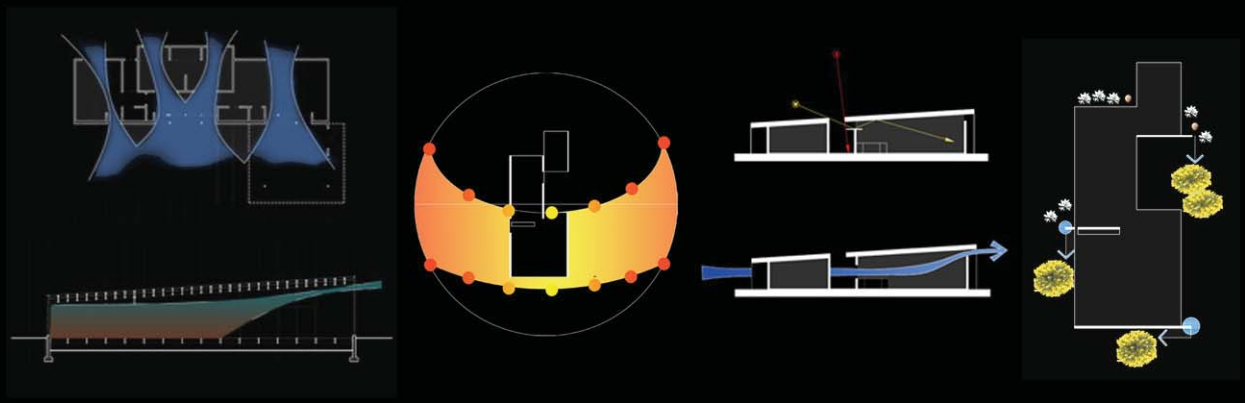
Conservation Technologies for Affordable Housing



ENERGY EFFICIENCY and WATER CONSERVATION DESIGN GUIDELINES 2007

FINAL DRAFT

Following a one-year monitoring phase and post-construction evaluations of the first two model homes built as part of this study, the enclosed guidelines are subject to minor modifications or changes.

Funded in part by
a grant from
The City of Tucson
Community Services Department

Submitted by
THE DRACHMAN INSTITUTE
COLLEGE OF ARCHITECTURE AND LANDSCAPE ARCHITECTURE
THE UNIVERSITY OF ARIZONA TUCSON, ARIZONA
and
Drachman Design Build Coalition, Inc.

Conservation Technologies for Affordable Housing

Energy Efficiency and Water Conservation Design Guidelines, 2007

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Additional Funding and Support
U.S. Dept. of Housing and Urban Development, Office of University Partnerships
The University of Arizona
College of Architecture and Landscape Architecture
and Drachman Institute

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The work that provided the basis for this publication was in part supported by funding under Grant Number COPCAZ-05-667 with the U.S. Department of Housing and Urban Development, Office of University Partnerships. The author and publisher are solely responsible for the accuracy of the statements and interpretations contained in this publication. Such interpretations do not necessarily reflect the views of the Government.

The Drachman Institute is a research and public service unit of the College of Architecture and Landscape Architecture at the University of Arizona dedicated to the environmentally sensitive and resource-conscious development of neighborhoods and communities. The Drachman Institute, in particular, focuses its research and outreach activities on the proposition that housing is the building block of neighborhoods and neighborhoods are the building blocks of communities. The work of the Drachman Institute therefore facilitates the development of demographically diverse neighborhoods, rich in environmental amenities and built from good-quality, well-designed, regionally-appropriate housing that conserves land, energy, and water.

The Drachman Institute, College of Architecture and Landscape Architecture
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ACKNOWLEDGEMENTS

The Drachman Institute would like to thank Emily Nottingham, Ron Koenig, Ron Whitman, and Joyce Alcantar of the City of Tucson Community Services Department for their encouragement and support.

We would also like to thank the students of the House Energy Doctor program who contributed their time towards research data collection for this work, and homeowners in Civano who contributed their residences and utility and water bills as subjects of this study.

The Drachman Institute would also like to acknowledge Carl Rald, Al Nichols, Doug Crocket, and Richard Michal for their efforts in the Community of Civano that have further informed the basis of this study.

TABLE OF CONTENTS

Executive Summary 1

Introduction 3

Faculty Affiliation with Civano 3
"Lessons from Civano" 4
Additional Resources 4
Collaboration and Partnerships 4
Approach 5
Outcome 5

Energy Efficiency and Water Conservation Design Guidelines 6

1 Building and Site Orientation 8
2 Site Work 10
3 Shading 12
4 Fenestration 13
5 Ventilation 17
6 Building Insulation 19
7 Building Materials 22
8 Reflectivity 25
9 Plant Materials 26
10 Landscape Water Systems 28
11 Plumbing Systems 30
12 Mechanical Systems 32
13 Appliances and Fixtures 34

Affordability Index 36

EXECUTIVE SUMMARY

The enclosed **Energy Efficiency and Water Conservation Design Guidelines** are the result of contracted research on and analysis of the technologies employed at the already-built Community of Civano (developed in Southeast Tucson beginning in 1996 to produce energy and water efficient housing) with the intent of using this data to facilitate the development of center city housing aimed at families of lower income.

Post-occupancy data obtained from selected households in Civano through occupant utility and water bills indicate lower energy and water use than average household energy and water consumption within the City of Tucson. This is in part due to the original standards and design requirements imposed upon development within Civano, including the Sustainable Energy Standard and additional landscaping and water use restrictions. In general, Civano houses were sold at well above the median new home sales price. The objective of this study was to determine what technologies employed at Civano reduced overall energy and water consumption, and to determine which of these technologies can be applied specifically to affordable housing development. Some of the overarching lessons learned from this study most applicable for affordable housing design include the following:

- Generally smaller lots (located at the original core of Civano) allow for self-shading of adjacent housing units resulting in reduced energy use for cooling needs, and allow for smaller yards requiring less water for landscaping;

- Solar orientation has a greater impact on thermal mass housing envelope designs than it does for highly insulated housing envelope designs (thermal mass homes that have improper solar orientation utilize 10-15 KBtu/SF per year more than thermal mass homes with proper orientation, compared to highly insulated homes with improper solar orientation resulting in a reduced performance of 2-7 KBtu/SF per year);

- Xeriscaping landscaping requirements, reclaimed water use for landscaping, and appropriate site grading for utilization of stormwater in Civano results in lower potable water use than in typical City of Tucson homes, providing a 34% -37% reduction (or 32,000 - 38,000 gallons) in annual potable water use per household;

- Solar Hot Water technologies result in significantly reduced energy loads providing energy savings up to 2,200 kWh per year (or 4.6 KBtu/SF per year);

- Highly insulated roofs (R-38 to R-42) and high reflectance roof materials (Reflectance 0.8-0.9) substantially contributed to the improved energy performance of households at Civano compared to code minimum roof insulation (R-25) and low reflectance roof materials (Reflectance 0.4-0.6) of typical City of Tucson homes;

- And, post-construction (or post-occupancy) whole-house pressurization allows for infiltration and air leakage testing of the home (problems found to cause up to 20% increased heating source consumption and 13% cooling source consumption) to ensure quality control and to optimize energy performance.

The guidelines that follow, as a result of these findings, include energy and water conservation technologies suitable for application in affordable housing design and retrofit in the Tucson area. Because some of the energy and water conservation strategies can tend to vary in cost with market fluctuation demands in

the housing construction industry and changes in related labor and materials' costs, the strategies are rated for affordability on a comparative scale, relative to current industry standards.

It is also important to note that there is a direct correlation between the number of occupants in a home and the amount of energy and water consumption for a household. The inhabitants' behaviors and interaction with the building systems also affects the amount of energy and water consumption. It is important to educate homeowners and renters about the use of their home and about their energy and water consumption behaviors in order to assist in the reduction of energy and water demand.

The strategies outlined within the following guidelines may also have varying effects on both energy and water consumption when multiple strategies are combined and implemented as integrated systems. Therefore, it is difficult to prescribe specific additive strategies for energy and water conservation without continuously reevaluating the overall design for optimization. For instance, evaporative cooling systems may conserve more energy on an annual basis compared to standard air conditioning or heat pump units, but they generally consume much higher amounts of water. In addition, increasing the amount of insulation in the building envelope and sealing the house from air leakage will allow for a smaller heating and cooling unit for the house because the demand loads will be reduced. An integrated systems approach to design is highly recommended.

INTRODUCTION

Faculty Affiliation with Civano

Civano is a 1,140 acre pre-planned community located at South Houghton and East Irvington roads in close proximity to the Rincon Mountains within the Tucson city limits. The original Civano development plan was based on New Urbanism design principles intended to foster community interaction and quality neighborhoods. The Civano housing design requirements were established with high environmental performance standards in order to maintain a position on the leading edge of sustainable development.

The College of Architecture and Landscape Architecture (CALA) at the University of Arizona has a significant history of involvement with Civano. Professors Larry Medlin and Nader Chalfoun, and the late adjunct research faculty Carl Rald contributed to the planning and analysis of Civano from the project's inception.

Dr. Nader Chalfoun, with more than 25 years of experience in energy and solar design, helped developed the City's energy consumption baseline upon which the City and County based the first local energy compliance code. As a code committee member, he developed Chapter 4 of the Sustainable Energy Standard (SES) for Civano. As a Solar Energy Council member, he reviewed and approved funding for the Civano Neighborhood Center on its Solar Energy application. Dr. Chalfoun and his students have conducted numerous home energy audits in Civano as part of his House Energy Doctor program at the College of Architecture and landscape Architecture. He developed the Civano Builders Education Workshops and published many papers and journal articles on Civano buildings' and materials' energy performance. Currently, he is working with Pulte Homes on the development of Civano Neighborhoods II & III. He was also recently granted funding from TMC to help in the development of their new Rincon Community Hospital in CIVANO (RCHC) project.

Professor/Architect Larry Medlin was involved even before the formal Civano project as a nine-year member of the Tucson/Pima County Metropolitan Energy Commission and later the 'Solar Village' Steering Committee. He participated in initial discussions with then Governor Bruce Babbitt to set aside State Trust Land, served as the 'local architect' member of the first Community Solar Village Planning Charette, and as the then College of Architecture host for the second design workshop.

As faculty members at CALA, Medlin and Rald directed design studio projects focused on 'Solar Village' design and planning concepts with widespread community participation. Through Richard Larry Medlin Architect, Inc., they prepared the original Civano Design Guidelines in 1997. Rald planned energy workshops and, using infrared camera scans, conducted construction standards and energy performance audits of Civano residences in collaboration with local builders.

“Lessons from Civano”

Technologies that are used in this report, **Conservation Technologies for Affordable Housing,** have been defined by careful analysis of strategies that have been successful or unsuccessful in Civano, balanced against initial and long-term costs, and evaluated from the perspective of affordability. Advanced computer simulation and site investigations have assisted in identification of the most successful material assemblies, verified by post-occupancy studies of actual Civano residences, in order to compare the predicted performance of the assemblies and technologies with the actual performance of the inhabited dwellings.

These technologies include solar orientation, siting and landscape guidelines, passive solar gain strategies, passive ventilation and cooling strategies, daylighting, and mechanical systems including plumbing for water conservation, graywater capture and use, and rain-water harvesting.

Additional Resources

The College of Architecture and Landscape Architecture (CALA) brings numerous and valuable resources to this project beyond the funding provided by the City of Tucson grant. These resources include expert faculty, staff, and students who carry out the research, analysis, design, document preparation and publication, training, education, outreach, and comprehensive project direction, oversight, administration, and management. This knowledge will consequently be passed on through the College curriculum and by students as they move on to their own professional practices. In addition, CALA has its own media and public relations operations to insure, working with the City of Tucson, the garnering of the widespread and quality attention this Demonstration Project deserves.

As a partner of the Drachman Institute (DI), the 501c3 non-profit housing provider, Drachman Design Build Coalition, Inc. (DDBC), utilizes the professional services of registered architects and landscape architects who are members of the CALA faculty. Faculty work with a licensed contractor (qualifying party Corky Poster) and engineer (Richard Michal), who serve as board members, and students who provide labor for stipends or course credit. In this way, the DDBC brings together research, design, engineering and professional services that can accomplish innovative housing with an affordable price tag.

Collaboration and Partnerships

CALA and DI have established strong relationships (through projects including the three-year COPC “Community Futures Demonstration Project in Housing Design” and three-year COPC “Building Healthy Neighborhoods” grants from the U.S. Department of Housing and Urban Design) with the partners that will be critical for the broad success of the Lessons from Civano Demonstration Project. These partners include for-profit and non-profit builders/developers, government staff and elected officials at all levels, and community residents.

Over the past several years, DI has worked with a number of housing providers to develop new housing plans, including Habitat for Humanity, Chicanos Por La Causa, Primavera Foundation, and City of Tucson Community Services Department.

Approach

The complete report is comprised of the following *two components*:

A. **Analysis** of Civano design and performance strategies by faculty members and others intimately involved in the planning and evaluation of Civano to date. Review of data, strategies and efforts. The document for this component is ***Conservation Technologies for Affordable Housing: Research and Analysis Report.***

B. **Synthesis** of data; consolidation into guidelines for design. Review of performance criteria for energy/water use; review/evaluation of housing built, post-occupancy evaluations of material assemblies, passive and active design strategies and water conservation proposals and results. The document for this component is ***Conservation Technologies for Affordable Housing: Energy Efficiency and Water Conservation Design Guidelines***.

Outcome

The outcome of the efforts for this project include the following:

A. Analysis and synthesis of goals and outcomes of Civano energy and water conservation strategies to date, resulting in *Guidelines* for transfer of Civano-based technologies to the lowest cost strata of housing construction.

B. Application of energy efficiency and water conservation technologies outlined in the *Guidelines* to the design of four model home plans and construction of two of these homes for affordable homeownership in Barrio San Antonio in Tucson.

C. Monitoring of energy efficiency and water conservation data for one year for the first two homes built in Barrio San Antonio.

D. Dissemination of post construction evaluations of efficacy of strategies through public workshops and one-on-one consultation sessions with local builders/developers.

ENERGY EFFICIENCY and WATER CONSERVATION DESIGN GUIDELINES

After careful investigation of both the thermal performance and water use of existing residences in Civano, the following recommendations constitute a summary of the conservation technology strategies most applicable for affordable housing design and construction. The guidelines are defined through thirteen major categories, each of which contains various strategies that are applicable for different conservation methods.

1 **Building and Site Orientation**
2 **Site Work**
3 **Shading**
4 **Fenestration**
5 **Ventilation**
6 **Building Insulation**
7 **Building Materials**
8 **Reflectivity**
9 **Plant Materials**
10 **Landscape Water Systems**
11 **Plumbing Systems**
12 **Mechanical Systems**
13 **Appliances and Fixtures**

The strategies within the following guidelines will have varying effects on both energy and water consumption when multiple strategies are combined and implemented as integrated systems. The recommended approach to utilizing these guidelines is to consider an integrative set of strategies, with consideration of costs (initial and long-term) to achieve the greatest energy and water savings that is feasible. There can potentially be a diminishing means of return on the value for implementing too many strategies simultaneously. It is difficult to prescribe specific additive strategies for energy and water conservation without continuously reevaluating the overall design for both cost and conservation optimization.

The various costs to be considered include initial or first costs, operational costs, and maintenance costs. Analyzing all of these costs together provides life cycle costs. The evaluation of initial costs for the strategies within the guidelines is based on new construction; some strategies may incur higher initial costs for renovation applications. The payback period for each strategy is another factor to consider; the most feasible and financially effective strategies will typically have a payback period less than seven or eight years. The following list describes the various types of costs:

Initial Costs: Implementation costs of strategy including materials, construction, and labor.
Operational Costs: Ongoing energy and water use costs.
Maintenance Costs: Costs related to repairs and maintenance of materials, system, or equipment.
Payback Period: Amount of time it takes for a conservation strategy's cost savings to cover its purchase, installation, and operating costs.

The following icons represent various indicators for the performance of the design guideline strategies:

Affordability
This icon indicates strategies most applicable for affordable housing including first costs, operating costs, or life cycle costs. For more detail on affordability refer to cost performance indicators for each strategy.

Energy Conservation
This icon indicates energy conservation strategies.

Environmental Conservation
This icon indicates environmentally friendly strategies, including renewable resources, regional materials, or recycled content.

Water Conservation
This icon indicates water conservation strategies.

Air Quality
This icon indicates strategies that improve air quality (indoor or outdoor).

Renovation
This icon indicates strategies that are applicable to renovation and rehabilitation of existing housing.

The following icons represent various cost performance indicators for the design guideline strategies:

This icon indicates cost of strategy is higher than standard or comparable strategies, products or technologies, or that there is generally a high cost.

This icon indicates cost of strategy is equal to standard or comparable strategies, products or technologies, or that there is generally an average cost.

This icon indicates cost of strategy is less than standard or comparable strategies, products or technologies, or that there is generally a low cost.

This icon indicates NO costs to implement the strategy.

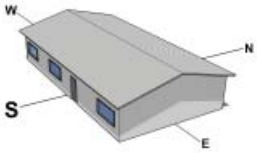
NA

This icon indicates cost comparison is not applicable or that there are no comparable strategies or technologies. (However, there may be direct or indirect costs associated with the strategy.)

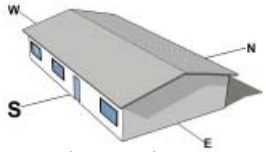
1 Building and Site Orientation

The solar orientation of a building is a primary design decision that informs the placement and area of fenestration and affects the optimization of both passive and active solar collection. Research on homes in Civano indicated that thermal mass houses were negatively effected by improper solar orientation (up to 10-15 KBtu/SF per year increased energy source consumption) to a greater degree than highly insulated houses (see **Building Insulation** and **Building Materials**).

South-facing building orientation



summer - shaded



winter - solar access

Orient the building with the longer facade facing south or at maximum 15° from south. Complement this strategy with proper horizontal shading to alleviate summer solar gain (see **Shading**). Complement this strategy with proper fenestration (size and location) and thermal mass (i.e. exposed slab) to allow for winter solar gain (see **Fenestration** and **Building Materials**). If building orientation is restricted due to lot configuration, additional measures should be implemented (see **Shading**).

Initial Costs: NA **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** 0 years

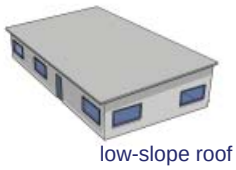
Locate houses on smaller lots with narrow widths

Smaller, narrower lot sizes allow for self-shading of adjacent housing units, improving energy conservation especially during summer months (special consideration to be given for passive solar gain heating strategies). Smaller lots also reduce amount of landscape required, improving water conservation.

Initial Costs: NA **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** 0 years

Minimize surface area to volume ratio and minimize volume to floor area ratio


flat roof


low-slope roof

Minimize the amount of surface area relative to conditioned house volume. Reduce surface area through use of flat or low slope roof; or reduce occupied house volume with an insulated ceiling and vented attic space. If surface to volume ratio is not optimized, additional measures should be implemented (see **Shading**). Some exceptions include courtyard housing designs, as courtyards between exterior walls of the home create self-shaded microclimates and alleviate exposure of exterior walls to solar radiation as well as induce natural cross ventilation. Conditioned house volume should be minimized in relation to occupiable square footage. The volumetric air space requires heating and cooling, and energy use can be reduced with low volume to floor area ratios.

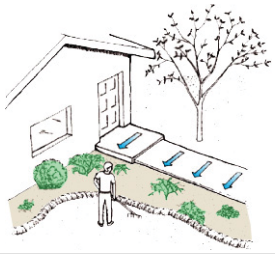
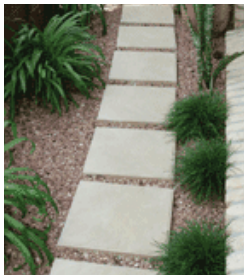
Initial Costs: NA **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** 0 years

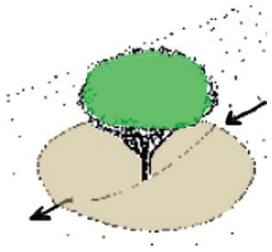
Program storage and utility spaces to the west 	Place garage, utility room, storage, etc. to the west to buffer the occupied rooms of the house from intensive afternoon and evening solar radiation. If lot configuration does not allow for protection of occupied rooms from the west, additional measures should be implemented (see **Shading**). **Initial Costs:** = **Maintenance Costs:** NA **Operational Costs:** ▼ **Payback Period:** 0 years	

Locate houses on site to minimize disturbance of existing vegetation 	Locate structures on the site to minimize impact on native and existing vegetation to minimize the need for additional or new landscaping materials. New plant materials typically require more water than existing plants for the first two years until establishment at a site. **Initial Costs:** NA **Maintenance Costs:** ▼ **Operational Costs:** ▼ **Payback Period:** 0 years	

2 Site Work

Thorough and thoughtful integration of site grading, hydrology, and landscape structural systems will allow for maximum utilization of stormwater runoff for supplemental on-site irrigation purposes. A goal of zero stormwater runoff from any given lot is ideal. Utilization of the natural topography to control and redirect storm and water runoff can minimize site work grading costs for affordable construction. Research on homes in Civano indicated that utilization of collected stormwater for landscape irrigation purposes contributed to the significant reduction in potable water use (totalling up to 38,000 gallons potable water use reduction per year).

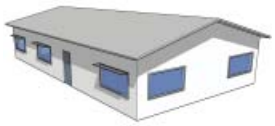
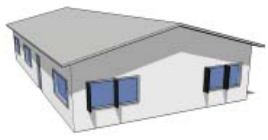
Grade site to make use of stormwater runoff	Direct and utilize site stormwater runoff for supplemental on-site irrigation through appropriate grading. Minimize the length and steepness of slopes to alleviate erosion and loss of stormwater. If steep slopes* cannot be avoided, provide planted materials on slope to reduce runoff and alleviate erosion. (*Steep slope lots are typically less feasible for affordable housing development.) **Initial Costs:** = **Operational Costs:** ▼ **Maintenance Costs:** ▼ **Payback Period:** 0 years	
Slope paved areas towards planted areas 	Slope all paved areas towards planted areas to make maximum use of stormwater for trees and plants. **Initial Costs:** = **Operational Costs:** ▼ **Maintenance Costs:** ▼ **Payback Period:** 0 years	
Use pervious hardscape materials  	Select pervious materials for paving, patios, walkways and driveways (such as decomposed granite or pervious paving blocks). If pervious materials are deemed infeasible, provide for on-site detention and use of rainwater runoff from impervious surfaces. **Initial Costs:** = **Operational Costs:** ▼ **Maintenance Costs:** = **Payback Period:** 0 years	

Provide concave landscape basins for shade trees 	Through proper planning and design, contour the site into a series of concave landscape basins where essential shade trees are to be located. Providing water retention at shade tree plantings allows for fuller growth of trees to assist in shading the house for energy conservation. **Initial Costs:** = **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** 1 year	
Size stormwater catchment for peak monsoon rainfall collection	Size surface water basin detention system to capture all site rainwater during peak monsoon storms. Ensure that finish floor slab elevation is higher than full surface water basins. Locate surface water basins away from on-grade slabs and foundations. **Initial Costs:** = **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** varies	
Augment stormwater collection area with rainwater cisterns 	Augment surface water basin systems with water collection cisterns that capture roof runoff to optimize stormwater collection. Size cisterns according to roof collection area (see **Appendix 12** for cistern installation). Locate catchment cisterns near planted areas to allow for gravity flow irrigation directly to plants. Rainfall is typically a higher quality water source compared to graywater, so it should be considered for irrigating food/herb gardens and sensitive, household potted plants. More complex, large volume, underground cisterns requiring pumps are probably not feasible for single-family affordable housing projects. (Also see **Landscape Water Systems**) **Initial Costs:** NA **Maintenance Costs:** NA **Operational Costs:** ▼ **Payback Period:** 2-7 years	
Preserve natural plant vegetation 	Preserve natural existing plant vegetation to reduce landscape water use and maximize natural drainage. Retaining native plants on the site as part of the landscape will assist in erosion control and is an affordable means of landscaping. Refer to the City of Tucson Land Use Code for native plant preservation requirements: *http://www.tucsonaz.gov/planning/codes/luc/lucweb/1Art3div8.html* **Initial Costs:** = **Maintenance Costs:** ▼ **Operational Costs:** ▼ **Payback Period:** 0 years	

3 Shading

Shading is perhaps one of the most effective strategies in hot climates for reducing energy load demand. Effective shading strategies provide solar protection in summer as well as solar access in winter. Shading devices must be sized for specific geographical locations and according to window sizes, configuration, and orientation. Shading strategies include integrated overhangs, attached exterior screens, trees, and other features that assist in mitigating solar radiation to minimize cooling loads for the home.

Shading devices and landscape trees are often viewed as additional costs for new construction that make housing less affordable. It is important to consider ways to design these features for dual-purpose or dual-use in order to optimize the feasibility. For instance, self-shading of the house through courtyard designs allows for additional outdoor rooms and reduces energy loads, and horizontal overhangs can be integrated as extended roof eaves to minimize added costs for shading features.

Extend roof eaves 	Extend roof eaves to provide horizontal shading of walls and windows. This is most effective on the south facade where sun angles tend to be higher in the sky, or at greater altitude. (South eaves should extend a minimum of 0.15 x Wall Height) **Initial Costs:** ▼ **Operational Costs:** ▼ **Maintenance Costs:** NA **Payback Period:** 1 year	
Provide horizontal overhangs above south-facing windows 	Provide horizontal shading overhangs above south-facing windows to protect glazing from solar radiation during mid-day in the summer. Extend these overhangs on both sides of the windows to protect from late morning and early afternoon sun. (South overhangs should extend outwards a minimum of 0.15 x Window Height and 0.5 x Window Width on either side) **Initial Costs:** ▼ **Operational Costs:** ▼ **Maintenance Costs:** NA **Payback Period:** 1 year	
Provide vertical fins at east, west, and north-facing windows 	Provide vertical fin shading devices at east, west, and north-facing windows to protect glazing from solar radiation during morning and afternoon summer sun. (East + West fins should project a minimum of 0.25 x Window Width) **Initial Costs:** ▼ **Operational Costs:** ▼ **Maintenance Costs:** NA **Payback Period:** 1 year	

Locate trees strategically to assist in shading the house

Locate trees (evergreen or deciduous) on east and west sides of house, near windows, to assist in shading. Locate deciduous trees on south side of house, near windows, to assist in summer shading and allow for winter heat gain. (See **Plant Materials**) An expansive tree canopy can also assist in shading the roof of the house and direct air for ventilation to further reduce energy consumption.

Initial Costs: = **Operational Costs:** ▼
Maintenance Costs: = **Payback Period:** 0-2 years

Utilize plant materials to assist in shading

Use deciduous vines to shade east and south walls. Use evergreen vines to shade west walls. Locate shrubs around house perimeter to assist in shading walls and in creating a cooler microclimate through evapotranspiration. (See **Plant Materials**)

Initial Costs: = **Operational Costs:** ▼
Maintenance Costs: = **Payback Period:** 0-2 years

Provide operable exterior shade screens for glazing

Shade glazing units (windows and doors) with exterior operable shade screens to prevent solar radiation from reaching the inside of the house, and to allow for light to enter at desired times. Shade screens and blinds are often located on the inside of windows and doors, after solar radiation has entered the house. Exterior shade screens can be substituted for, or supplement, interior blinds.

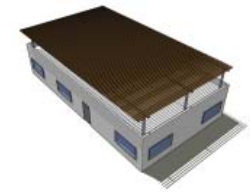
Initial Costs: ▲ **Operational Costs:** ▼
Maintenance Costs: = **Payback Period:** 3-5 years

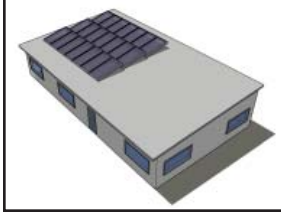
Shade outdoor spaces

Shade outdoor spaces with attached ramadas or shade cloths or other lightweight structures to provide extended usable living space. Attached shade structures also shade the surfaces of adjacent house walls. Many shade structures can be constructed with affordable materials and minimal footings or structural requirements. Outdoor spaces can be self-shaded with courtyard designs as well.

Initial Costs: ▲ **Operational Costs:** ▼
Maintenance Costs: = **Payback Period:** 2-7 years

Shade the roof





Shade the roof entirely - with secondary roof shade structure providing a 6” minimum air space above the roof. Shade the roof partially - with solar water heater panels or photovoltaic panels mounted on secondary framing structure over roof.

Initial Costs: ▲ **Operational Costs:** ▼
Maintenance Costs: = **Payback Period:** 8+ years

4 Fenestration

Windows are the elements of the house that typically contribute most significantly to heat gains and losses. The location and size of windows affects solar collection and the glazing material affects passage of solar radiation and daylight. Improved glazing and window frame options have become more affordable over time. In addition, improved construction detailing around windows and doors - such as inclusion of insulated headers and tight flashing and seals around window frames - is feasible for affordable housing design and improves the energy efficiency of the house.

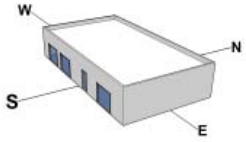
When houses at Civano were pressurized in order to test for air leakage, a selection of infiltration levels were found to be up to 1.0 air change per hour (ACH), which is twice the acceptable level for residential construction (0.5 ACH). Conducting blower-door tests on the homes allowed for further improvements to the construction, especially at window and door frame seals, and improved the overall energy performance of the houses through air leak remediation at identified locations. This is not a major cost and is a reasonable method to improve energy efficiency and ensure that the building, as a system, is optimized.

Limit amount of fenestration to floor area

Limit the ratio of fenestration (window and door glazing area) to the habitable floor area of the house (20% or less is recommended). Minimizing glazing will reduce both heat gain and conditioned indoor air loss to provide lower energy load demands in the summer. Placement and sizing of fenestration should be balanced to optimize daylighting and views to create a healthy indoor environment.

Initial Costs: ▼ **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** 0 years

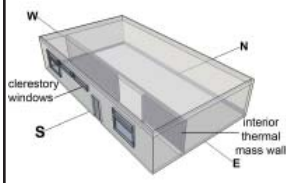
Locate windows to optimize solar control



Locate windows on the south-facing facade for winter solar gain (40% to 60% of the total window area is recommended to be located on the south). Minimize, or even omit, east and west-facing glazing area to prevent summer solar gain, or incorporate shading strategies (see **Shading**).

Initial Costs: ● **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** 0 years

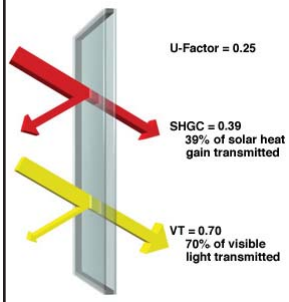
Provide south-facing clerestory windows when combined with thermal mass design



South-facing clerestory windows will allow for direct solar gain by interior thermal mass walls, providing passive means for heating and cooling interior living spaces (see **Building Materials** for thermal mass strategies). These clerestory windows should be operable for ventilating spaces during summer nights (see **Ventilation**) and should be equipped with night insulation during winter to retain heat (see **Building Insulation**).

Initial Costs: = **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** varies

Specify energy efficient window glazing technologies



Specify double-glazed window units (minimum per current code). Specify spectrally selective (low-solar-gain) low-e glazing and locate low-e coating on the inside face of the outer pane*. Argon or krypton gas filled in the air gap between glazing layers can assist in slowing the conduction of heat within the gap from one pane of glass to the other. (*Note: if window manufacturer is located in a region other than the southwest, the low-e coating is typically on the outside face of the inside pane to retain heat in the house, contrary to desired effect of low-e coating for southwest climate.)

Initial Costs: = **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** 2-4 years

Specify energy efficient window frame technologies

aluminum frame with break

aluminum-clad wood

Specify insulating thermal breaks for aluminum or other metal window frames to prevent conduction of heat or cold into or out of house. Specify the lowest U-value window systems as feasible for construction. Composite frame technologies (such as vinyl-clad aluminum, or aluminum-clad wood) allow for improved U-values but are more expensive than standard metal or vinyl frames. Vinyl frames are not as durable over time when compared with metal frames, and can be considered an increase to life-cycle costs. Studies on Civano homes with vinyl window frames indicated signs of warping due to overexposure to solar radiation, which resulted in major air leaks at frames.

Initial Costs: ▲ **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** varies

Provide blower-door test for whole house

blower-door contraption

smokestick infiltration test

Photos: House Energy Doctor

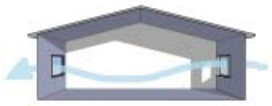
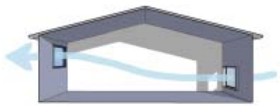
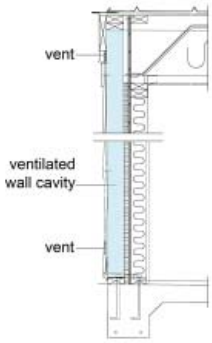
Pressurization of the house allows for infiltration and exfiltration testing around window and door frames to determine where air leaks may be occurring. This testing method, called the blower-door test, is conducted with a blower-door contraption (located at one of the doors to the house) that first depresurizes the house interior to 50 pascal to get an Air Change per Hour (ACH) reading, then fully pressurizes the house interior and is combined with smokesticks that are held near fenestration to allow for visibility of potential air leak locations. Remediation of leak areas typically includes application of proper weather-stripping and exterior sealant around frame, but may require replacement of faulty window component manufacture or installation.

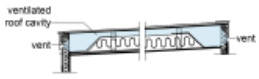
Initial Costs: NA
Operational Costs: NA
Maintenance Costs: NA
Payback Period: 0 years

5 Ventilation

The potential of a building envelope to gain or lose heat by convection is significant (160 times more per square foot than conduction). Convective heat gain or loss is a result of the introduction of outside air at a temperature different from that maintained in the indoor space. This process is commonly called ventilation. Uncontrolled ventilation can occur through poor building construction by means of infiltration and exfiltration or air leakage. Controlled ventilation can occur by passive means or mechanical means.

Passive ventilation strategies include orchestrated air movement directly through an indoor or outdoor habitable space to create cooling effects for thermal comfort, or air movement within cavaties of the building envelope to assist in cooling material surfaces and removing static heat. Mechanical ventilation is achieved with air handling units and ductwork or mechanical fans. Passive strategies are very affordable and can improve the energy conservation and air quality of a home.

Provide operable windows for cross ventilation 	Provide opposing windows for natural cross ventilation. Summer nighttime ventilation is a useful interior house cooling method, especially when combined with thermal mass design (see **Building Materials**). Windows located on south and north-facing walls, not separated by interior partitions, will allow for optimal cross ventilation cooling. **Initial Costs:** NA **Operational Costs:** ▼ **Maintenance Costs:** NA **Payback Period:** 2 years	
Maximize height difference between opposing operable windows 	Maximize the height difference between operable inlet and outlet windows on opposite sides of a space or room in order to promote stack ventilation air movement throughout the volume of the space and increase the cooling effects. **Initial Costs:** ● **Operational Costs:** ▼ **Maintenance Costs:** NA **Payback Period:** 0 years	
Incorporate vented exterior walls 	Incorporate vented exterior wall cavities in the building envelope design to allow for passage of air through stratification to assist cooling functions. Exterior wall construction includes a space or gap (of 4" or more) between outer sheathing layer and underlying structure for air flow. **Initial Costs:** = **Operational Costs:** ▼ **Maintenance Costs:** NA **Payback Period:** 1-3 years	

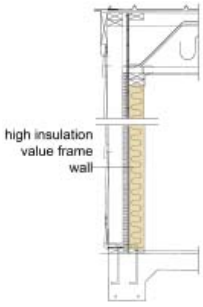
Incorporate vented roofs 	Incorporate vented roof cavities in the building envelope design to allow for passage of air to assist cooling functions. Roof construction includes a space or gap (of 6” or more) between outer sheathing layer and underlying structure, or attic space, for air flow. **Initial Costs:** = **Maintenance Costs:** NA **Operational Costs:** ▼ **Payback Period:** 1-3 years	
Specify weather-stripping at windows and doors 	Detail windows and doors for maximum air tightness when closed (0.50 ACH is the minimum air changes per hour IEC 2006 code requirement for residential construction in Tucson). Specify weather-stripping at all windows and doors to limit air leakage (see **Fenestration**). **Initial Costs:** = **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** 1 year	
Specify insulating gaskets at electrical penetrations 	Electric conduits can be a large source of heat escape through the building envelope. Specify insulating gaskets at all outlets and switches to limit air leakage at wall penetrations. **Initial Costs:** = **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** 1 year	
Locate landscape trees to channel air flow 	Utilize local wind roses to determine summer and winter month prevailing wind directions. Place landscape trees in appropriate location and distance from house to assist in channeling air-flow during cooling season (summer), and to assist in blocking cold winds (winter). **Initial Costs:** NA **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** varies	

6 Building Insulation

Insulation is a highly recommended material that resists heat by reducing or by delaying its passage to or from building's skin. The two basic types of insulation are:

1) **Resistance**: measured by the R-value and used to minimiz the passage of heat, and
2) **Capacity**: measured by volumetric heat and used to maximize thermal storage capacity (or time lag) of the material

Civano homes that were studied are primarily thermal mass designs utilizing capacity of wall materials to slow and store the solar radiation to assist in indoor thermal comfort (thermal mass materials are discussed in the **Building Materials** section). However, every roof studied on the Civano houses was designed above minimum code insulation requirements, ranging in R-value from R-30 to as high as R-42. The improved energy performance of the homes at Civano can be partially attributed to the highly insulated roofs. Highly insulative unitized building systems, such as Structural Insulated Panels (SIPs) or straw

Design a highly insulative roof 	Design for a high insulation roof exceeding the R-25 code minimum (R-38 recommended). Roofs receive the greatest amount of direct solar radiation compared to any other building envelope surface (in the Tucson region), and should be designed with the most resistive insulation values. Additional roof insulation can be added to attic spaces during retrofit of housing using blown-in insulation technologies. **Initial Costs:** ▲ **Operational Costs:** ▼ **Maintenance Costs:** = **Payback Period:** 1 year	
Provide high insulation value walls for frame construction 	Design for high insulation value walls exceeding the R-13 code minimum (R-19 or higher recommended). Frame wall cavaties can be optimized for higher insulation values through wider stud sizes (2x6 spaced 24" o.c. in lieu of 2x4 spaced 16" o.c.) and framing can be value engineered to allow for reduced lumber costs with fewer studs (see **Building Materials**). Additional insulation can be added to wall spaces during retrofit of housing using blown-in insulation technologies. **Initial Costs:** ▲ **Operational Costs:** ▼ **Maintenance Costs:** = **Payback Period:** 1-2 years	
Specify appropriate insulation technology 	Specify insulation materials that have the highest performance and remain feasible. There are a variety of insulation technologies, including blown-in insulation which fills cavities more thoroughly than batt insulation and can be added to existing wall and roof cavaties, and spray-foam insulation which thoroughly seals the building envelope prevent air leaks. There are also insulation materials that consist of recycled content and are eco-friendly, such as cotton fiber insulation. **Initial Costs:** NA **Operational Costs:** ▼ **Maintenance Costs:** NA **Payback Period:** varies	

Use insulated structural headers at windows and doors with frame wall construction

Use structural insulated headers above window and door frame openings to improve consistency in frame wall insulation value. Headers above openings in typical frame wall construction leave a gap in the insulation continuum. Insulated headers (stress-rated wood flanges with foam insulation sandwiched between the webs) provide a more consistent thermal resistance value for the building envelope construction and help conserve energy.

Initial Costs: ▲ **Operational Costs:** ▼
Maintenance Costs: = **Payback Period:** 1-2 years

Specify thermal isolators with metal frame construction

Unlike wood studs, metal studs have hig heat conduction causing serious thermal bridging. Specify thermal isolators (i.e. neoprene blocks) with metal frame construction to prevent energy loss through thermal conductivity.

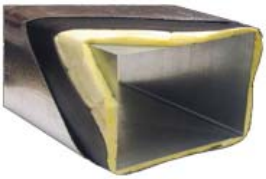
Initial Costs: NA **Operational Costs:** ▼
Maintenance Costs: = **Payback Period:** 1 year

Insulate hot and cold water pipes

Insulate hot and cold water pipes with flexible, thermal polyethylene pipe wrap. Insulating water pipes conserves energy for heating and cooling water, and also conserves water through reduced tempering times.

Initial Costs: = **Operational Costs:** ▼
Maintenance Costs: = **Payback Period:** 1 year

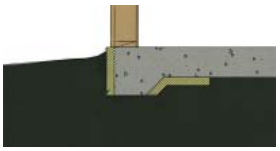
Insulate mechanical ductwork



Insulate mechanical ductwork in unconditioned spaces. Specify duct wrap with insulation value exceeding the R-5 code minimum for ductwork that is located in unconditioned space or outdoors (R-8 minimum recommended). Use mastic seals between ductwork sections for its durability and cracking resistance.

Initial Costs: = **Operational Costs:** ▼
Maintenance Costs: = **Payback Period:** 1 year

Insulate slab edge perimeter



Provide R-9 minimum rigid board slab-edge insulation at two-feet (2'-0") deep or two-feet (2'-0") horizontally. Perimeter slab edge insulation improves the energy conservation of the home, especially in the heating months, and is almost necessary if radiant floor heating or cooling systems are installed. There is greater complexity and expense when detailing slab edge insulation with frame wall homes due to termination of insulation, location and configuration of edge flashing, and incorporation of termite protection measures.

Initial Costs: ▲ **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** 6-8 years

Incorporate earth berms

Incorporate earth berms around portions of walls that do not have on grade doors. Earth has an R-19 value per three-foot (3'-0") width. If there is in situ excavation required (i.e. for foundation footings, etc.), then re-using the excavated earth as berm fill is an affordable means to provide added insulation value to the house.

Initial Costs: = **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** varies

Provide night insulation for windows

night insulated sun-space with thermal mass wall + floor

Provide R-7 night insulation materials for windows during heating months, especially when combined with thermal mass designs, to retain heat inside the house at night. This passive strategy can assist in energy savings and is not very costly to implement, but requires occupant interaction.

Initial Costs: = **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** 2 years

7 Building Materials

The selection of building materials is an early design decision that will permanently affect the thermal performance of buildings. Each material is unique in its construction cost and technique, but also in its thermal storage and thermal resistance capabilities. Construction costs of the various building materials can vary over time, due to multiple factors such as inflation, material availability, and labor expertise availability. The building envelope and its material composition plays a significant role in energy conservation, and material selection and costs should be carefully balanced for optimized performance.

Civano homes that were studied included thermal mass, high insulation materials, and composite building technologies. Although the performance of these construction methods result in improved energy performance, the current costs for such materials can be more costly than traditional frame designs. Research data on the Civano thermal mass homes indicates that solar orientation has a significant impact on the performance of thermal mass housing envelope designs (thermal mass homes are adversely effected by improper solar orientation in terms of energy consumption). When selecting thermal mass materials for design, proper solar orientation and fenestration configuration must complement the building envelope composition for optimized performance (see **Building and Site Orientation** and **Fenestration**).

Use frame wall construction with high R-value insulation

wood frame

metal frame

Use frame wall construction with high R-value insulation. Frame wall construction remains the most affordable building method on the current construction market. Frame wall cavaties can be optimized for higher insulation values through wider stud sizes (2x6 spaced 24” o.c. in lieu of 2x4 spaced 16” o.c.) and framing can be value engineered to allow for reduced lumber costs with fewer studs. Provide high insulation value in the walls exceeding the R-13 code minimum (R-19 or higher recommended) (see **Building Insulation**). Metal stud frame walls are slightly more expensive in material costs than wood frame, but alleviate potential waste of inadequate framing members often incurred in lumber today. Both framing materials are relatively eco-friendly as metal studs are about 50% recycled and can be re-recycled, and if specified lumber is harvested from sustainable forestry practices.

Initial Costs: ▼ **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** varies

Use exposed concrete floor slabs

Exposing concrete floor slabs on the interior of the house provides thermal storage because of concrete’s thermal capacity. Combine this strategy with fenestration that allows for direct solar radiation to be received by the floor slab. This strategy helps to moderate indoor temperature fluctuations (especially in climates with large diurnal temperature swings) and conserves energy. Indoor air quality is also improved due to omission of carpets or floor materials and adhesives that tend to off-gas fumes.

Initial Costs: ▼ **Operational Costs:** ▼
Maintenance Costs: NA **Payback Period:** 1 year

Use alternative highly insulative building materials

straw bale

SIPs

Use alternative highly insulative building materials, such as straw bale (R-28), Heydon panels (R-25 for 6.5" thick), or SIPs (R-23 for 4" thick). Each of these building systems allows for continuous R-value for the exterior walls without the typical thermal breaks at stud locations found in frame wall construction. These alternative building materials can have higher initial costs and can require experienced labor for efficient and decent construction. Heydon wall panel systems are manufactured locally in Tucson and straw bale is a readily renewable resource. Space constraints in affordable housing design should also be a consideration as straw bale construction requires considerable wall thickness. The benefit of these building materials is the high thermal performance and long-term energy consumption savings.

Initial Costs: ▲ **Operational Costs:** ▼
Maintenance Costs: varies **Payback Period:** varies

Use alternative high thermal mass building materials

adobe block

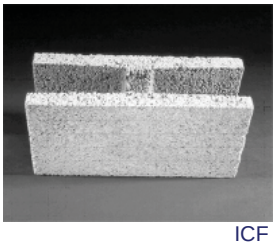
rammed earth

Use alternative high thermal mass building materials, such as adobe blocks, concrete masonry units, precast concrete panels, or rammed earth (12" minimum thickness for all thermal mass materials is recommended to allow for a full 8-hour thermal lag potential). Combine these building materials with passive-solar design strategies (proper solar orientation, south-facing windows, shading, night ventilation and night insulation) to optimize energy efficiency. These alternative building materials can have higher initial costs and can require experienced labor for efficient and decent construction. Some of these materials are regionally available (adobe block) and site specific (rammed earth).

Thermal mass materials are most effective when they can receive direct solar radiation and when the absorbing mass surface is located on the inside of the house. These materials help moderate indoor temperature fluctuations (especially in climates with large diurnal temperature swings), and tend to shift energy demand to off-peak periods due to thermal lag.

Initial Costs: ▲ **Operational Costs:** ▼
Maintenance Costs: varies **Payback Period:** varies

Use alternative composite insulated mass building materials



ICF

Rastra block

Use alternative insulated mass building materials, such as insulated concrete forms (ICF) such as Rastra block, or concrete insulated forms such as Integra block. These composite building material systems typically provide about an R-20 for 6”-8” wall thickness. ICF blocks are composed of expanded polystyrene foam forms, and are filled on site with concrete and reinforcing bar in the cells. Integra blocks are composed of concrete masonry unit forms with open cells, and are filled on site with sprayed polyurethane insulation and steel tension bars. Each of these building systems allows for continuous R-value for the exterior walls, while the Integra blocks allow for both continuous R-value in combination with thermal mass capacity. These alternative building materials are higher in initial costs and require experienced labor for efficient and decent construction. The benefit of these building materials is the high thermal performance combined with indoor temperature moderation resulting in energy consumption savings.

Initial Costs: ▲ **Operational Costs:** ▼

Maintenance Costs: varies **Payback Period:** varies

Use recycled materials for landscape features

Use recycled materials for landscape fences, benches, shade structures, arbors, etc. such as reclaimed lumber, or recycled corrugated metal or pipe. Material re-use reduces the embodied energy of construction and saves money.

Initial Costs: ▼ **Operational Costs:** ▼

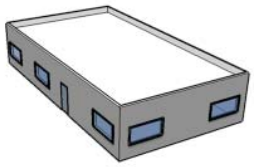
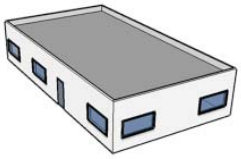
Maintenance Costs: = **Payback Period:** -

8 Reflectivity

Building energy performance is directly affected by the amount of direct (shortwave) solar radiation absorbed and reflected from the building envelope surfaces due to colors and textures. The quality (color and texture) of nearby ground cover and adjacent building surfaces also affect building energy performance through indirect (longwave) radiant reflection. In addition, the radiant absorption allowance, or emissivity, of material surfaces is also a factor in solar radiation control. The quality of surface materials impacts the larger urban scale of neighborhoods and communities due to its role in causing Urban Heat Island (UHI) effects. Specifying appropriate materials for landscaping and building structures can promote a better thermal quality environment.

Reflectivity is a very affordable design factor to control, as it strictly relates to material color and surface texture selection, both of which are minimally varied in cost. Maintaining reflectivity of surfaces can require some long-term care to optimize performance (re-painting or re-surfacing and cleaning). Applying high reflectance coatings to building surfaces is also a great strategy for upgrading the energy performance of existing homes.

The majority of houses studied at Civano used corrugated or standing seam metal roofing materials (0.60 - 0.80 typical reflectance values) or high reflective coating on flat roof designs (0.90 typical reflectance values). The improved energy performance of these homes can be partially attributed to these highly reflective roof materials.

Use light color roof materials 	Specify light color roof materials for high reflectance performance (Ref=0.75 minimum recommended). Roofs receive the greatest amount of direct solar radiation compared to any other building envelope surface (in the Tucson region) and high reflectance roof materials or coatings improve the energy performance. Apply light color roof coatings or appropriate paints to existing roof surfaces. **Initial Costs:** ● **Operational Costs:** ▼ **Maintenance Costs:** = **Payback Period:** 0 years	$ 💡 T
Use light color wall materials 	Specify light color wall materials for high reflectance performance. Do *not* use light color surfaces for passive solar collection walls. Apply light color coatings or appropriate paints to existing wall surfaces to improve the energy performance. **Initial Costs:** ● **Operational Costs:** ▼ **Maintenance Costs:** = **Payback Period:** 0 years	$ 💡 T
Use low-reflectance ground cover materials	Specify low-reflectance (and permeable) ground cover materials to reduce reflected radiation and to reduce UHI effects. **Initial Costs:** = **Operational Costs:** ▼ **Maintenance Costs:** = **Payback Period:** varies	$ 💡 💧 T

9 Plant Materials

Plant material selection and landscape should be designed to maximize water conservation and to assist in improved energy performance of nearby buildings and to improve outdoor thermal comfort. It is good practice to select native and drought tolerant species. Xeriscaping requirements at Civano provided for significantly less water use during peak summer months compared to City of Tucson households.

Specify appropriate trees to assist in shading the house and outdoor space 	Specify evergreen and deciduous trees on east and west sides of house, near windows, to assist in shading. Specify deciduous trees on south side of house, near windows, to assist in summer shading and allow for winter heat gain. Specify trees near habitable outdoor spaces to enhance thermal comfort through evapotranspiration cooling. (See **Shading**) **Initial Costs:** = **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** 0-2 years	
Specify appropriate plant materials to assist in shading the house and outdoor space 	Specify deciduous vines to shade south walls. Specify evergreen vines to shade east and west walls. Locate shrubs around house perimeter to assist in shading walls and in creating a cooler microclimate through evapotranspiration. Vine screen-walls and canopies can also provide shade for habitable outdoor spaces. (See **Shading**) **Initial Costs:** = **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** 0-2 years	
Create hydrozones with appropriate plant specification and location	Specify and group plants with similar water needs into distinct hydro-zones (planting zones with similar soil, light, and water conditions). **Initial Costs:** = **Maintenance Costs:** ▼ **Operational Costs:** ▼ **Payback Period:** 0-2 years	
Specify native plants 	Select native and desert-adapted plant material from the Department of Water Resources Low Water Use/Drought Tolerant Plant List available at: *http://www.water.az.gov/dwr/Content/Find_by_Program/Drought_and_Conservation/LowWaterPlantLists/TucsonAMA/2007_Plant_List_apha_botanical.pdf* Select appropriate native seeding from the City of Tucson Seed List Requirements (*Native Seed List, DSD 2-16.6.0*). **Initial Costs:** ● **Maintenance Costs:** ▼ **Operational Costs:** ▼ **Payback Period:** 0 years	

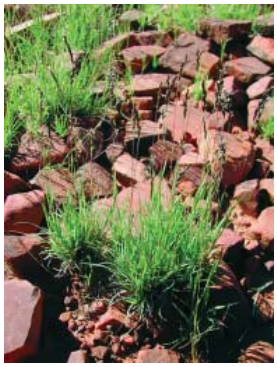
Utilize Xeriscaping principles as a basis for landscape design and plant selection

Incorporate xeriscaping principles into the entire landscape design, including drought tolerant or native plants, and conservation of water with surface mulches that provide improved and self-shaded soil conditions. Comply with revised City of Tucson 'Xeriscaping' Regulations as they apply to multi-family residential development (*http://www.tucsonaz.gov/water/ordinances.htm*).

Initial Costs: =
Maintenance Costs: ▼

Operational Costs: ▼
Payback Period: 0-2 years

Minimize turf to greatest extent possible or eliminate all together



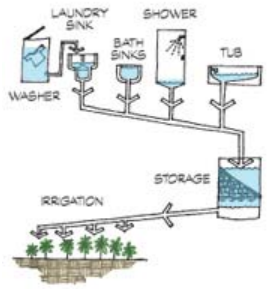
Exclude turf from the landscape installations for single-family housing. Use alternative ground cover materials such as rockscape, cactus, or native wildflowers.
If incorporating grasses into the landscape design for common areas, specify native and drought tolerant varieties such as buffalo grass or curly mesquite. (Encourage turf for children's play areas to be located at nearby parks, school playgrounds, or shared common outdoor spaces.)

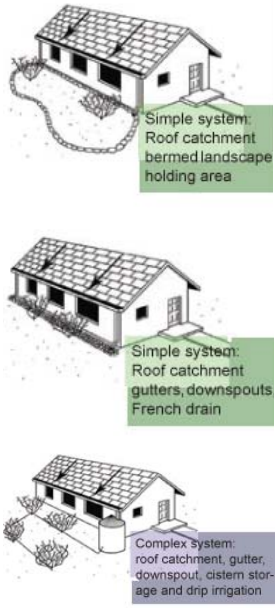
Initial Costs: ▼
Maintenance Costs: ▼

Operational Costs: ▼
Payback Period: 0 years

10 Landscape Water Systems

Sustainable landscape water systems include graywater distribution systems and water harvesting collection and distribution systems as well as utilization of natural watershed and runoff. The Civano water use data that was studied indicated significantly lower use, which can be partially attributed to reclaimed water use for landscaping.

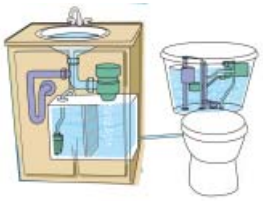
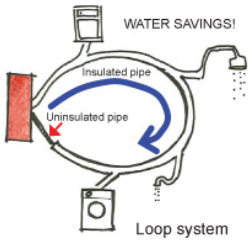
Utilize non-potable irrigation sources for landscape	Use only non-potable water, reclaimed water, harvested rainfall, and/or graywater for landscape irrigation. **Initial Costs:** = **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** varies	
Specify a graywater system 	Provide a separate graywater system for landscape irrigation. Develop a holding and distribution system utilizing graywater from the residence. Direct graywater toward planted areas. The recommended graywater irrigation is a branched drain system (see **Appendix 11**). Refer to Arizona Dept. of Environmental Quality 2001 Rules regarding use of Graywater for conforming uses: ADEQ, Title 18, Chapter 9, Article 7: R18-9-701, R18-9-711, R18-9-719 available at: *http://www.awpca.org/operator/Regulations/adeqr18-09.pdf.* For more information, refer to Water Casa Graywater Guidelines available at: *http://watercasa.org/publications/Graywater_Guidelines.pdf.* **Initial Costs:** NA **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** 2-7 years	
Incorporate rainwater harvesting collection and distribution 	Develop a distribution, holding, and storage system for rainwater harvesting (see **Site Work**). (See **Appendix 12** for culvert collection tank installation.) **Initial Costs:** NA **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** 2-7 years	
Design surface grading for natural water distribution to landscape	Provide basins surrounding planted areas to retain water. Contour site grading towards major planted areas (away from foundations). (See **Site Work**) **Initial Costs:** = **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** 1 year	

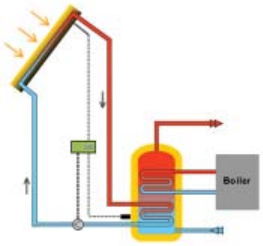
Hand-watering is recommended for landscape irrigation 	Hand-watering is best practice for conserving water when irrigating landscape, gardens, and plants. Although underground irrigation systems may be suitable for early growth establishment of plants and trees, these are generally more costly. If underground distribution is used for common areas, determine best method of underground distribution (perforated pipe generally recommended over drip system). Discontinue use of underground irrigation systems after 18 months or when plants mature. **Initial Costs:** ▼ **Operational Costs:** ▼ **Maintenance Costs:** ▼ **Payback Period:** 0 years	
Control roof runoff for landscape irrigation 	Direct roof water toward planted areas utilizing gutters, swales, and other diversion techniques. **Initial Costs:** NA **Operational Costs:** ▼ **Maintenance Costs:** NA **Payback Period:** varies	

11 Plumbing Systems

Plumbing systems are the primary network for transport and control of residential water to and from the home. Plumbing systems distribute potable water within the residence, and dispose of waste water (both graywater and blackwater) to sewage systems. Innovative methods for minimizing both water use and water waste are available in plumbing system designs and can be implemented affordably. These include selection of efficient plumbing fixtures, appropriate layout and locations of fixtures, and reclaiming graywater for use in landscaping irrigation.

Average monthly water use by single-family residential households in the City of Tucson is around 10,000 gallons (2004 data from Tucson Water). Residential water consumption encompasses many different uses including all faucets (kitchen, bathroom, utility, hose bibs), toilets, laundry facilities, and landscape irrigation. The Civano water use data that was studied indicated significantly lower use, which can partially be attributed to reclaimed water use for landscaping. In addition, solar water heating panels are installed on a majority of the Civano homes and have provided reduced electric or gas energy use for the residences (up to 4.6 KBtu/SF per year savings). Solar hot water panel installation is an additional up-front cost for affordable construction, but the energy cost savings for occupants typically pays back within 4-6 years.

Install a water saver system between lavatories and toilets 	Specify graywater capture of recycled lavatory water for use in toilets. Water saver technologies require that lavatories and toilets are plumbed within the same wall cavity (locate sink adjacent to toilet). **Initial Costs:** NA **Operational Costs:** ▼ **Maintenance Costs:** = **Payback Period:** 2-5 years	
Locate the water heater near hot water faucets 	Locate the water heater near hot water faucets to minimize length of hot water loop (also see **Appliances and Fixtures**). **Initial Costs:** ● **Operational Costs:** ▼ **Maintenance Costs:** ▼ **Payback Period:** 0 years	
Install a dual plumb graywater system	Install a dual plumb system for graywater system. The dual plumb system allows for branching of graywater distribution to maximize use of graywater. In 2001 Arizona changed the rules regarding use of residential graywater. It is now possible to make use of this source of water for landscape irrigation and composting. (See **Landscape Water Systems**.) For more information, refer to Water Casa Graywater Guidelines available at: *http://watercasa.org/publications/Graywater_Guidelines.pdf* **Initial Costs:** NA **Operational Costs:** ▼ **Maintenance Costs:** = **Payback Period:** 2-7 years	

Provide pressure regulation 	Provide pressure regulation (required by code). Pressure regulating valves can be installed at water inlet source to the house to reduce high incoming pressures and conserve water. **Initial Costs:** NA **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** 1 year	
Install a sub meter to monitor use patterns and minimize residential water use 	Install a sub meter to monitor the amount of outdoor water use relative to total household use and the changes in water use patterns. Aim for a total water use of 81 gpcd (*gallons per capita per day*) per year. **Initial Costs:** NA **Maintenance Costs:** = **Operational Costs:** NA **Payback Period:** -	
Install solar hot water panels  	Install solar hot water heating panels to reduce energy use for water heating. Batch heaters are the most affordable system and are appropriate for households of 2-4 people, but are not protected from freezing temperatures. Specify glycol or active system to protect from frequent freezing temperatures. First costs are offset within 4-6 years for the occupants of the house in electric or gas energy savings. **Initial Costs:** ▲ **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** 4-6 years	
Educate the occupants in operational efficiency of water use 	Educate the occupants in operational efficiency of water use. Provide an instructional manual to the occupants and make sure that the occupants are clear regarding the intention of these water conservation guidelines at the time the manual is presented. **Initial Costs:** NA **Maintenance Costs:** NA **Operational Costs:** ▼ **Payback Period:** -	

12 Mechanical Systems

Different types and combinations of mechanical equipment could be used for efficient heating and cooling of residential buildings. However, high efficiency mechanical systems will effectively reduce energy consumption but will not reduce heating or cooling loads. This is an important factor to convey to homeowners and occupants for the education on how energy demands are created.

The Civano homes that were studied included high efficiency (SEER 12) split heat pump systems that were sometimes complemented with other heating or cooling systems such as hydronic radiant floor heating and cool towers. Most of these complementary systems are not feasible for affordable housing design and construction as they increase first costs.

Specify high efficiency mechanical units

Specify high efficiency electric mechanical systems that provide both heating and cooling and exceed SEER 10 code minimum (such as SEER 12 split or packaged system heat pumps); or, specify high efficiency gas furnaces for heating needs exceeding AFUE 70% code minimum (AFUE 80% recommended) with high efficiency air cooling systems.

Initial Costs: ▲ **Operational Costs:** ▼
Maintenance Costs: = **Payback Period:** 1-2 years

Balance costs and conservation efficiency of mechanical cooling units

evaporative cooler

high efficiency A.C.

Balance costs and conservation performance of evaporative coolers and air conditioning systems. High efficiency a.c. units or heat pump systems are generally recommended.

a) **Evaporative Cooler:** low first cost, low operating cost, regular (monthly) maintenance required - neglect can result in high repair/ replacement costs. Can save 25%-50% energy use compared to a.c. or heat pump. Can use about 19,000 gallons more water a year than a standard a.c. unit.

Initial Costs: ▼ **Operational Costs:** ▼
Maintenance Costs: ▲ **Payback Period:** -

b) **Two-Stage Evaporative Cooler:** high first cost (comparable to a 3-ton a.c. unit), lower operating cost, average maintenance costs. Less energy use compared to standard a.c. or heat pump. Uses less water than standard evaporative cooler. *For homes with existing evaporative coolers, the heat-exchange first-stage unit can be added for easy retrofit and improved cooling efficiency.

Initial Costs: ▲ **Operational Costs:** ▼
Maintenance Costs: = **Payback Period:** -

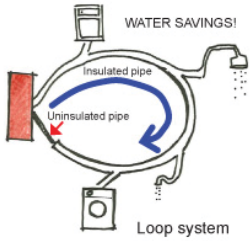
c) **High Efficiency A.C.:** higher first cost, average operating cost, low maintenance costs. High efficiency units are becoming more energy conserving with improved technology.

Initial Costs: ▲ **Operational Costs:** ▼
Maintenance Costs: = **Payback Period:** -

Size mechanical equipment appropriately	Specify appropriate size mechanical equipment without overdesigning system capacity. Appropriate mechanical unit size will minimize overall costs, save energy, and alleviate potential for high indoor humidity build-up. **Initial Costs:** NA ▼ **Operational Costs:** ▼ **Maintenance Costs:** ▼ **Payback Period:** -	
Specify zero-HCFC air conditioning units	If possible, install zero-HCFC (hydro chlorofluorocarbons) air conditioning units. Although first costs are high for these units, EPA regulations will prohibit the use of HCFCs by 2030. In addition, manufacturer's of residential air-conditioning units will not be allowed to produce R-22 refrigerants (HCFCs) as of 2010. Therefore, servicing costs on older a.c. units will rise due to limited availability of R-22, making standard units less affordable to maintain after 2010. **Initial Costs:** ▲ **Operational Costs:** = **Maintenance Costs:** ▼ **Payback Period:** -	
Provide mechanical system manuals and training for household occupants 	Provide occupants and homeowners with mechanical system training and education manuals for best appropriate use and function of the system for the users' needs. Ensure that homeowners understand how to use thermostat controls and functions for optimized energy efficiency (install programmable thermostats). **Initial Costs:** NA **Operational Costs:** ▼ **Maintenance Costs:** ▼ **Payback Period:** -	

13 Appliances and Fixtures

Appliances and fixtures contribute to both energy and water consumption in all modern households. Often the quantity, types, and frequency of use of appliances and fixtures relates to the number of members in a household and their socio-cultural behavior. Appliances and fixtures are continuously improved for both energy and water efficiency, many of which are also becoming more affordable. Appropriate selection, specification, and household occupant and consumer education all contribute to the effectiveness of energy and water conservation through available appliances and fixtures.

Install dual flush or high efficiency toilets 	Install HET (1.0g – high efficiency toilets) and/or dual flush toilets. For toilet performance testing refer to *http://www.cuwcc.org/MaPTesting.lasso.* (See **Appendix 9**) **Initial Costs:** = **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** 1-2 years	
Locate fixtures near hot water heater source 	Locate the water heater and fixtures nearby one another in order to minimize the lengths of the hot water loop (also see **Plumbing Systems**). **Initial Costs:** ● **Maintenance Costs:** ▼ **Operational Costs:** ▼ **Payback Period:** 0 years	
Install low-flow water fixtures  	Specify and install low-flow fixtures including toilets, sinks, and shower-heads. **Initial Costs:** = **Maintenance Costs:** = **Operational Costs:** ▼ **Payback Period:** 1 year	

Provide lists of acceptable energy and water conserving appliances and fixtures to homeowners

Provide a list of acceptable appliances and fixtures (along with their specifications) to homeowners for selection, including efficient light-bulbs, front-loading washers, water conserving dishwashers, energy efficient water heaters, instaheat water heaters, low energy demand pump with thermostat and timer at water heaters, and solar water heaters (weigh costs).

More information can be found on Energy Star qualified products at: *http://www.energystar.gov/index.cfm?fuseaction=find_a_product*. See also the CUWCC H2OUSE website for current recommendations pertaining to water saving appliances and devices: *http://www.cuwcc.org/home.html* and *http://www.h2ouse.org/action/index.cfm.*
(See **Appendix 8**)

Initial Costs: NA
Maintenance Costs: ▼
Operational Costs: ▼
Payback Period: varies

AFFORDABILITY INDEX

Energy Efficiency and Water Conservation

The following Affordability Index is provided as a general overview guide of comparative costs, long term costs, and energy or water use for various building systems in the Tucson region. It is important for developers and builders of affordable housing to consider the operating costs that will be incurred by residents in addition to the initial construction costs. Affordability encompasses a balance between home purchase price and long-term maintenance and operating costs. This matrix can be used for a quick reference to determine the relative scale of cost comparisons between systems, but should be combined with a more detailed review of the related guidelines, and an integrated systems approach to design for optimizing affordability with energy and water conservation.

CATEGORY	CHOICE	INITIAL COST	LONG TERM COSTS	ENERGY or WATER USE	NOTES
Planning (development costs)	infill	lowest	lowest	lowest	less infrastructure
	new land near core - clustered	lower	lower	lower	
	new land near core - spread out	average	average	average	
	new land far from core - clustered	higher	higher	higher	
	new land far from core - spread out	highest	highest	highest	more infrastructure
Building Orientation	diagonal			highest	difficult to control solar gain
	long axis East-West			lower	easy to control solar gain
	long axis North-South			higher	difficult to control solar gain
	courtyard			lowest	easiest to control solar gain
Site Work	paving	highest		high heat zone	watershed
	gravel	average		heat zone	pervious
	microbasins	low		uses rainfall	initial grading
	xeriscape	lowest		no extra water	native plants
	irrigation drip lines	average		uses water	can be limited to oasis plants
	sprinklers	high		uses most water	can be limited to oasis plants
Shading	trees	lowest			use water, deciduous on south
	roof overhang on south	low			
	window overhangs on south	low			
	operable vertical screens E, W, S	higher			depend on owner interaction
	shaded outdoor spaces	highest			
Fenestration	double pane, low E	lower		highest	
	double pane, low E thermal break	average		average	
	triple pane	high		low	
	triple pane, argon thermal break	highest		lowest	
Ventilation	natural	lowest	lowest	lowest	
	Ceiling Fans	low	low	low	
	HVAC	highest	highest	highest	
Building Insulation	fiberglass batts	lowest		lowest R-value	
	loose cellulose	lower			can compress
	blown-in cellulose	average			good coverage
	blown-in fiberglass	high			good coverage
	rigid	highest		highest R-value	joints should be taped
Thermal Mass	exposed slab	lowest			needs solar exposure
	slab with tile, brick	average			needs solar exposure
	slab with terrazzo	highest			needs solar exposure
	non-load bearing interior wall	lowest			needs solar exposure
	load bearing exterior wall	average			choose exposures
	interior + exterior load bearing wall	highest			choose exposures

AFFORDABILITY INDEX

CATEGORY	CHOICE	INITIAL COST	LONG TERM COSTS	ENERGY or WATER USE	NOTES
Building Materials (total wall assemblies)	wood frame w/ insulation	lowest	higher	high	can use low maintenance siding
	steel frame w/ insulation	low	average	high	can use low maintenance siding
	masonry w/ interior insulation	average	low	average	no maintenance
	masonry w/ exterior insulation	average	average	low	stucco maintenance
	insulated cavity masonry	high	low	low	no maintenance
	structural insulated panels	high	average	low	can use low maintenance siding
	insulated concrete forms	high	average	low	stucco maintenance
	rastra block	high	average	low	stucco maintenance
	straw bale	high	higher	lowest	stucco maintenance
	compressed earth blocks	higher	low	low	no maintenance
	adobe	higher	low	low	no maintenance
	rammed earth	highest	low	low	low maintenance
Reflectivity	light color roof			lowest	cost dependent on color availability for material specified
	light color walls			lower	cost dependent on color availability for material specified
	non-reflective groundcover (near windows)			low	cost dependent on color availability for material specified
Plumbing Systems	graywater plumbing initially	low			
	adding graywater plumbing later	average			
	graywater to irrigation lines	low			
	graywater to storage tanks w/ pumps	higher		saves more water	
	roof to irrigation swales	lowest			depends on weather
	roof to cistern above ground	low			independent of weather
	roof to cistern below ground	higher		saves more water	independent of weather
Mechanical Systems	evaporative cooler	low	average	lowest	rising water costs
	duct insulation	lowest	low	low	some added initial costs
	gas furnace	average	average	average	rising gas costs
	AC / heat pump	high	average	high	rising electricity costs; higher efficiency available