Exploring the Potential for Natural Gas Savings from Passive Design Strategies

A Study Conducted by:

California Sustainability Alliance

A Navigant Consulting Program,
Sponsored by Southern California Gas Company,
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The California Sustainability Alliance (the Alliance) is an innovative market transformation program funded by California utility customers under the auspices of the California Public Utilities Commission. The Alliance leverages action on environmental initiatives such as climate, smart land use and growth, renewable energy, waste management, water use efficiency and transportation planning to help the State of California achieve its aggressive energy efficiency goals more effectively and economically. In partnership with public and private organizations throughout California, the Alliance precipitates widespread market transformation by tackling major barriers to sustainability.

For information about the California Sustainability Alliance, go to:

www.sustainca.org

The project team gives special thanks to the following subject matter experts whose input and assistance were critical to the development of this report:

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GLOSSARY

Air Barrier – construction materials that control airflow between a conditioned space and an unconditioned space.

Climate Zone – A city or region associated with specific annual weather characteristics.

Energy Efficiency Ratio (EER) – the measure of performance of building air conditioning systems. EER = rated cooling out in kBtuh / rated electric input in kW.

R-Value - the measure of the thermal resistance of insulation or any material or building component expressed in ft^2-hr-°F/Btu.

Seasonal Energy Efficiency Ratio – the measure of seasonal performance of an air conditioning system. SEER = seasonal output in kBtu / total electric output in kWh.

Site Energy - The energy directly consumed at a facility typically measured with utility meters.

Source Energy - The sum of the energy consumed at a facility and the energy required to extract, convert, and transmit that energy to the facility.

Source Energy Factor - The unit of source energy consumed per unit of energy or fuel delivered to the facility. The values used in this study were:

- Source electricity = Site electricity x 3.15 (kBtu)
- Source natural gas = Site natural gas x 1.09 (kBtu)

ABBREVIATIONS AND ACRONYMS

AC – Air conditioner
ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.
Btuh – British thermal unit per hour
CCZ – California climate zone
CFM – Cubic feet per minute
CMU – Concrete masonry unit
COP – Coefficient of performance
CZ – Climate zone
DOE – US Department of Energy
DX – Direct expansion
EER – Energy efficiency ratio
HVAC – Heating, ventilation, and air conditioning
IEAD – Insulation entirely above deck
IEER – Integrated energy efficiency ratio
IPLV – Integrated part load value (COP, EER, kW/ton)
kW – Kilowatt
LPD – Lighting power density
NREL – National Renewable Energy Laboratory
PCM – Phase change material
PSZ – Package unit single zone
PTAC – Packaged terminal air conditioner
RSHGC – Relative solar heat gain coefficient
SEER – Seasonal energy efficiency ratio
SF – Square feet
SHGC – Solar heat gain coefficient
SoCalGas – Southern California Gas Company
VAV – Variable air volume
W – Watt

EXECUTIVE SUMMARY

Background

The California Sustainability Alliance (the Alliance) sought to complete a technical feasibility study to quantify the potential for natural gas savings associated with passive design strategies in small commercial facilities located in Southern California.

Possible reasons that passive design strategies are often overlooked in commercial facilities may include the following:

- In renovation projects, the building orientation and systems have already been developed
- In new construction, gas savings are overlooked in favor of other building design concerns

This study investigates and quantifies potential natural gas savings from passive design strategies in the four most predominant Southern California climate zones (Beach Cities, Downtown Los Angeles, Mountains, and Desert). The four commercial building types studied are Small Office, Medium Office, Outpatient Healthcare, and Large Hotel.

The Alliance team used the United States Department of Energy (US DOE) prototype building EnergyPlus models as the baseline and then added passive design strategies to the models.

The passive design strategies modeled in this study are listed below.

Figure 1: Passive Design Strategies

Building Integrated Shading	Passive Solar Landscaping
Air Barrier (Seal Envelope)	Natural Ventilation
Additional Insulation	Night Time Flushing
Phase Change Insulation	Optimized Daylighting
Reduced Window Area	Evaporative Cooling

Source: Alliance team

Significant Findings

Overall, the following passive design strategies produced the most gas savings in all buildings and in all climate zones (CZs):

- Building Integrated Shading: Specifying windows with lower U-factors and higher solar heat gain coefficients (SHGCs) combined with overhangs. Note that Title – 24 requires overhangs in order to use windows with a higher SHGC
- Adding insulation to walls and roofs
- Reducing leaks and infiltration (air barrier)

Combining these three passive design strategies results in the largest amount of natural gas savings. The combined strategies produce slightly less energy savings than the individual strategies added together. This is due to interactive effects of the strategies when they are combined.

The results of the three passive design strategies combined are shown in the table below.

Table 1: Source Natural Gas Savings (kBtu)

Prototype	CCZ6	CCZ9	CCZ15	CCZ16
Small Office	2,893	2,159	1,508	11,292
Medium Office	1,209	1,457	930	30,239
Outpatient Healthcare	19,656	26,490	7,513	8,436
Large Hotel	268,591	272,300	107,486	441,050

Source: Alliance team analysis

The passive design strategies saved the most natural gas in the Large Hotel building prototype models. CCZ16 (mountains) produced the most natural gas savings for all of the building prototype models except Outpatient Healthcare.

The Medium Office and Outpatient Healthcare prototype models include some conditioned spaces that use electric reheat. The previous table is based on those two building prototype models having electric reheat. This type of space conditioning is common in these types of buildings.

The Alliance team converted the energy consumption of the electric reheat to natural gas energy for the Medium Office and Outpatient Healthcare models. The results of that analysis are shown in the table below.

Table 2: Source Natural Gas Savings with Natural Gas Reheat (kBtu)

Prototype	CCZ6	CCZ9	CCZ15	CCZ16
Small Office	2,893	2,159	1,508	11,292
Medium Office	13,710	16,230	13,327	140,641
Outpatient Healthcare	97,946	101,572	24,645	80,810
Large Hotel	268,591	272,300	107,486	441,050

Source: Alliance team analysis

Significantly more natural gas savings is achieved when the buildings use natural gas for reheat instead of electric resistance.

Both electric reheat and natural gas reheat are possible in buildings like the Medium Office prototype and the Outpatient Healthcare prototype. Focusing on buildings that use natural gas will provide opportunities for more natural gas savings.

The natural gas savings as a percentage of space heating natural gas energy consumption with natural gas reheat for the three combined passive design strategies are shown below.

Table 3: Source Gas Savings as a Percentage of Heating w/ Gas Reheat (kBtu)

Prototype	CCZ6	CCZ9	CCZ15	CCZ16
Small Office	54%	49%	47%	35%
Medium Office	71%	66%	69%	47%
Outpatient Healthcare	39%	42%	9%	19%
Large Hotel	40%	36%	19%	17%

Source: Alliance team analysis

The Alliance team optimized each passive design strategy in order to produce the most natural gas savings possible without increasing cooling energy consumption. Many of the passive design strategies also saved significant cooling energy. The total source energy saved for the three combined passive design strategies are shown in the table below.

Table 4: Total Source Energy Savings with Natural Gas Reheat (kBtu)

Prototype	CCZ6	CCZ9	CCZ15	CCZ16
Small Office	18,418	15,714	20,348	23,115
Medium Office	12,038	42,265	130,155	165,661
Outpatient Healthcare	111,086	131,103	77,633	89,839
Large Hotel	166,064	345,119	395,987	370,649

Source: Alliance team analysis

The results vary by building and CZ, and some passive design strategies work better in one building type versus another. Additionally, some passive design strategies work better in one climate versus another. The total source energy savings indicate that the passive design strategies are effective at savings natural gas and overall energy consumption.

SECTION 2: CALIFORNIA CLIMATE ZONES

The climate zones shown in Table 5 were selected for this study in order to cover a variety of weather conditions representative of Southern California.

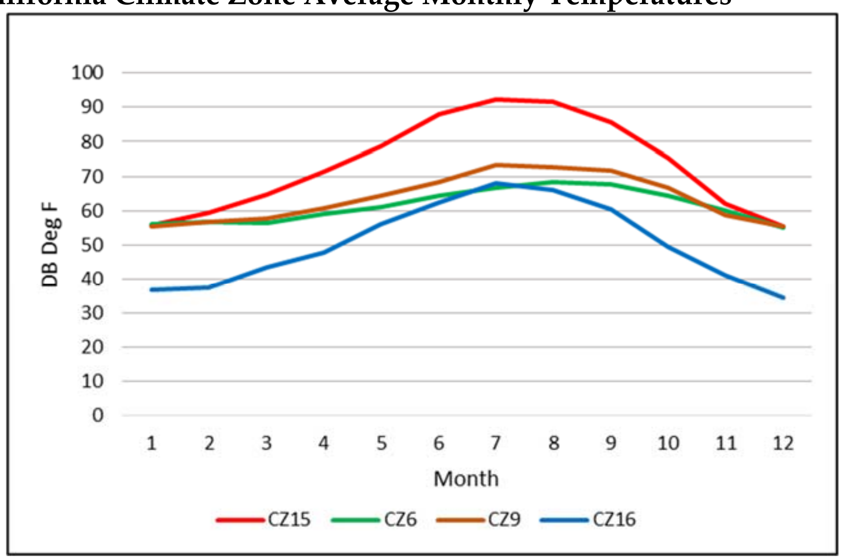
Table 5: Modeled California Climate Zones

Southern California Area	California Climate Zone	Examples of cities in Climate Zone
Northern Mountains	16	Lake Arrowhead, Running Springs
Arid Desert	15	Palm Springs, Palm Desert
Beach Cities	6	Huntington Beach, Newport Beach
Downtown Los Angeles	9	Burbank-Glendale, Los Angeles

Sources: The Alliance team and California Energy Commission climate zone descriptions

A comparison of the average monthly temperatures for each of the CCZs is shown in Figure 2. The Northern Mountains (CZ16) have the coldest average temperatures, while the Arid Desert (CZ15) has the highest average temperatures. The Beach Cities (CZ6) and Downtown Los Angeles (CZ9) are similar climates, with Downtown having slightly higher average temperatures between May and September.

Figure 2: California Climate Zone Average Monthly Temperatures



Sources: Alliance team analysis and EnergyPlus weather data

SECTION 3: BUILDING PROTOTYPES

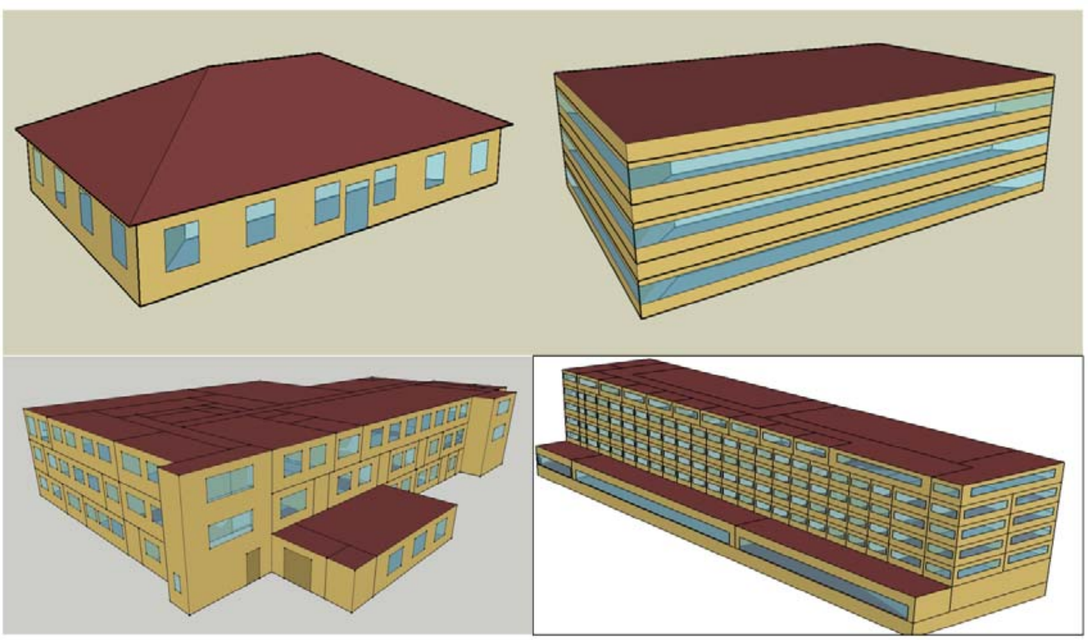
The four building types modeled are Small Office, Medium Office, Outpatient Healthcare, and Large Hotel. A general description of the building prototypes is shown in Table 6.

Table 6: Building Prototype Descriptions

Envelope / Equipment	Small Office	Medium Office	Outpatient Health	Large Hotel
Floor Area (Square Feet)	5,500	53,600	40,950	122,150
Number of Floors	1	3	3	6
Exterior Wall Type	Wood Frame	Steel frame	Steel frame	CMU
Roof Type	Attic	IEAD	IEAD	IEAD
Windows	Fixed	Fixed	Fixed	Fixed
Cooling Equipment	PSZ-AC / DX	Packaged VAV w Reheat	Packaged VAV w Reheat	Chiller
Heating Equipment	Gas furnace	Gas Boiler	Gas Boiler	Gas Boiler
Service Water Heating	Gas Water Heater	Gas Water Heater	Gas Water Heater	Gas Water Heater

Source: US Department of Energy (DOE) Scorecards

Figure 3: Small Office, Medium Office, Large Hotel, Outpatient Healthcare Models



Source: US DOE Commercial Building Model Scorecards

SECTION 4: PASSIVE DESIGN STRATEGIES

The Alliance team modeled the following passive design strategies for each of the four building types in each of the four CZs and documented the results of each measure. Solar water heating and radiant heating are discussed but were not modeled because the Alliance team deemed them to be well understood.

Building Integrated Shading

Allowing solar heat gain through windows in winter can reduce the amount of natural gas heating required. Shading in the summer when the sun is high in the sky can reduce the heat entering through windows. This strategy was modeled by using windows with a U-factor of 0.29 and a SHGC of 0.45 and adding overhangs to the design. The higher SHGC was used to increase winter solar heat gain and the shading was used to reduce summer heat gain.

California Title 24 – 2016 requires a U-factor of 0.36 or less and a SHGC of 0.25 or less for windows in all CZs. Overhangs are required in order to use a window with a greater SHGC.

Figure 4 shows an example of an overhang that could be used for these buildings. This example building has fins, which would only reduce the amount of natural gas savings. The use of fins was not modeled in the four prototype buildings.

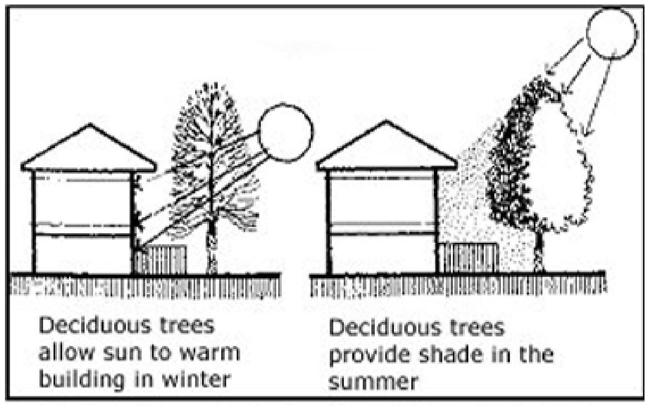
Figure 4: Overhang Example—NREL's Energy Systems Integration Facility

Source: Navigant

Passive Solar Landscaping

Passive solar landscaping can save energy by reducing heat gain to a building in the summer and allowing wanted solar heat gain in the winter. This can be accomplished by planting deciduous trees that are large enough to shade windows and walls in the summer but allow solar heat gain to windows and walls in the winter. One possibility for natural gas savings to existing buildings would be to make sure over-grown trees and vegetation are trimmed back and maintained as much as possible where seasonally appropriate.

Figure 5: Solar Landscaping Example



Examples of side landscape features that help to conserve energy
For more information see: greenglobes.com

Source: National Institute of Building Sciences, Whole Building Design Guide

Natural Ventilation

Natural ventilation can help reduce the need for mechanical cooling and mechanical ventilation. The natural flow of outside air can remove unwanted heat loads from the building. This will reduce the amount of time that mechanical cooling systems need to run, and it will also reduce the amount of time that mechanical fans need to run. Natural ventilation can be achieved through the use of operable windows and other architectural features.

Night Time Flushing

Night time flushing involves the use of whole-building fans to flush the building of heat that has been stored in the building's floors, walls, and furniture during the day from internal loads and the sun.

Optimized Daylighting

Optimizing the amount of natural daylight through vertical windows and skylights can reduce the amount of electrical lighting needed during certain times of the day. Natural light provides light covering the entire spectrum, whereas electric light only covers a small fraction of the light spectrum. Because natural light covers the entire spectrum, a human's eye does not need as much natural light as it does electric light.

Air Barrier

Tightening the building envelope reduces unwanted leakage and unwanted infiltration of unconditioned air. Heating and cooling energy can be saved by reducing leakage and infiltration.

Additional Insulation

Adding insulation to the building envelope will save heating and cooling energy. Commercial buildings with high occupant and equipment loads will not benefit as much from this measure as buildings with lower internal loads. This strategy was modeled by adding an R-6 to the exterior walls and roofs of all the building prototypes. This would be the approximate equivalent to one inch of polystyrene building material.

Phase Change Insulation

Phase change materials (PCMs) such as paraffin (wax) store and release energy as they change from solids to liquids and vice versa. PCMs can be used as insulation in walls by enclosing them in sealed packaging and inserting them in wall materials. PCMs are most effective when combined with other strategies, such as night time flushing, to return the material back to the original phase (solid or liquid).

Evaporative Cooling

Taking advantage of the heat transferred through evaporation of water can save a tremendous amount of energy by reducing the need to run mechanical cooling equipment. Evaporative cooling can provide cooling using only 25% of the energy that mechanical cooling provides. This strategy is most appropriate for open-type commercial buildings like warehouses and manufacturing facilities. Evaporative cooling is less appropriate for larger internally loaded buildings. The main downside of evaporative cooling is the additional use of water resources.

Reduced Window Area

Reducing window area in some types of buildings can be effective at saving energy from heating and cooling. Windows allow significantly more heat gain through conduction and direct solar heat gain than insulated walls and roofs (consider an R-2 window versus an R-30 wall or roof).

Solar Hot Water

Heating domestic water with the sun can reduce the need for heating by natural gas. In addition, solar-heated water can be used for space heating in place of natural gas during certain times of the year.

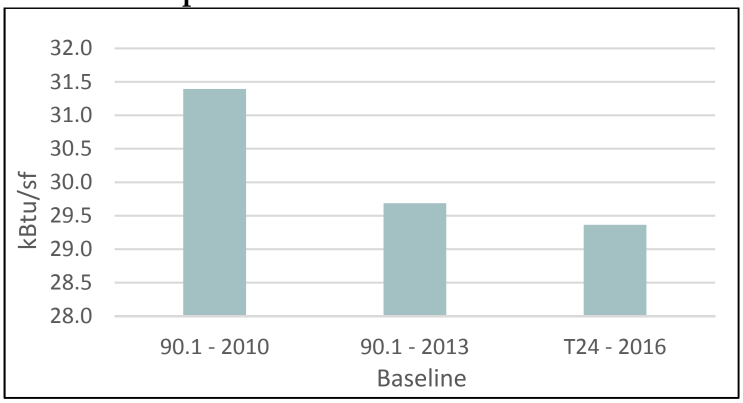
Radiant Heating

The use of radiant heating can reduce the amount of natural gas heating because radiant heat warms the occupant directly and makes the occupant feel warmer. Less heat is needed and less fan energy is required.

SECTION 5: RESULTS AND ANALYSIS

Figure 6 shows the relative differences of the baseline site energy consumption for the Medium Office building in CCZ9 (Downtown Los Angeles) using ASHRAE 90.1 standards and California Title 24 – 2016 building requirements.

Figure 6: Baseline Code Comparison Medium Office CCZ9 Site kBtu/SF



Sources: Alliance team analysis and EnergyPlus models

The ASHRAE 90.1 – 2013 Medium Office baseline model produces a significant reduction in energy use relative to the ASHRAE 90.1 – 2010 baseline model. The Title 24 – 2016 Medium Office baseline model produces additional reductions in total energy consumption relative to the ASHRAE 90.1 – 2013 baseline model.

The baseline site gas consumption for each building prototype for each climate zone is shown in the follow figure. Gas consumption for water heating and interior equipment is significantly more than for space heating. Heating gas consumption for the mountain climate zone 16 is significantly more than for the other three climate zones.

Table 7: Baseline Site Annual Natural Gas Consumption with Gas Reheat (Therms)

			Space Heating Gas			
Prototype	Hot Water	Equipment	CCZ6	CCZ9	CCZ15	CCZ16
Small Office	171		49	40	29	298
Medium Office	654		176	227	176	2,720
Outpatient Healthcare	1,072	1,785	2,290	2,205	2,476	3,909
Large Hotel	18,678	16,955	6,218	6,882	5,140	23,475

Sources: Alliance team analysis and EnergyPlus models

The natural gas consumption for the four prototype building models and four California climate zones for the baseline and each of the passive design strategies that save natural gas are shown in the figures below. The savings is expressed as source energy in kBtu/SF. The gas consumption values for the Medium Office and Outpatient Healthcare are based on gas reheat instead of electric reheat.

Table 8: Small Office Source Gas Consumption with Gas Reheat (kBtu/SF)

Passive Design Strategy	CCZ6	CCZ9	CCZ15	CCZ16
Baseline	4.36	4.18	3.97	9.28
(1) Add Insulation	4.12	4.09	3.91	8.69
(2) Air Barrier	4.18	4.01	3.85	8.53
(3) Phase Change Insulation	4.08	3.92	3.76	9.14
(4) Reduced Windows	4.32	4.12	3.92	8.89
(5) Windows & Overhang	4.21	4.04	3.86	8.51
Combined (1), (2) & (5)	3.83	3.79	3.69	7.23

Sources: Alliance team analysis and EnergyPlus models

Table 9: Medium Office Source Gas Consumption with Gas Reheat (kBtu/SF)

Passive Design Strategy	CCZ6	CCZ9	CCZ15	CCZ16
Baseline	1.66	1.76	1.67	6.62
(1) Add Insulation	1.61	1.70	1.61	6.10
(2) Air Barrier	1.58	1.68	1.61	6.13
(3) Phase Change Insulation	1.60	1.71	1.67	6.45
(5) Windows & Overhang	1.49	1.55	1.49	4.99
Combined (1), (2) & (5)	1.43	1.48	1.44	4.17

Sources: Alliance team analysis and EnergyPlus models

Table 10: Outpatient Healthcare Source Gas Consumption with Gas Reheat (kBtu/SF)

Passive Design Strategy	CCZ6	CCZ9	CCZ15	CCZ16
Baseline	13.27	13.05	13.72	17.57
(1) Add Insulation	11.97	11.89	13.53	17.68
(2) Air Barrier	13.20	13.00	13.65	17.46
(3) Phase Change Insulation	13.23	13.00	13.32	17.42
(5) Windows & Overhang	12.15	11.69	13.34	16.47
Combined (1), (2) & (5)	11.03	10.73	13.15	16.59

Sources: Alliance team analysis and EnergyPlus models

Table 11: Large Hotel Source Gas Consumption with Gas Reheat (kBtu/SF)

Passive Design Strategy	CCZ6	CCZ9	CCZ15	CCZ16
Baseline	37.35	37.94	36.39	52.75
(1) Add Insulation	36.23	36.82	36.09	51.27
(2) Air Barrier	37.02	37.62	36.19	51.96
(3) Phase Change Insulation	37.28	37.86	36.29	52.61
(5) Windows & Overhang	36.29	36.88	35.92	51.05
Combined (1), (2) & (5)	35.15	35.71	35.51	49.14

Sources: Alliance team analysis and EnergyPlus models

SECTION 6: CONCLUSIONS AND RECOMMENDATIONS

Overall, the three passive design strategies discussed in the Executive Summary produced the most gas savings in all buildings and in all climate zones.

PCM insulation modeling produced significant savings in most buildings and in most climate zones. Only one set of performance parameters were used for PCM insulation for all climate zones and better performance in the colder climates may be achieved with a different type of PCM and associated performance parameters.

Reducing windows in the Small Office building prototype model saves natural gas but does not allow for wanted solar heat gain on the east and west sides of the building for winter heating.

Passive solar landscaping involved modeling of deciduous trees that provided shading in the summer but allowed solar heat gain to windows and walls in the winter. This strategy actually increased natural gas consumption. One take-away from this strategy is that there may be an opportunity to save natural gas on existing buildings by trimming and maintaining overgrown trees and vegetation. In addition, building owners and operators should consider the type of trees they are planting and where they are planting them in new construction projects.

The other passive design strategies modeled in this study save cooling energy only. The passive design strategies modeled that saved gas were modeled to maximize gas savings without increasing cooling energy consumption. This can be seen in the comparison of total source energy savings to the source natural gas savings of the three passive design strategies combined.

The Alliance team recommends the following:

1. Encourage the use of windows with lower U-factors and higher SHGCs and install overhangs required by California Title 24 – 2016
2. Consider other gas saving strategies in combination with the passive design strategies. Some of the other strategies are heat recovery and active solar energy
3. Investigate additional opportunities to test PCM insulation in actual building installations
4. Investigate passive design strategies of future actual building construction relative to similar conventional building designs as opportunities become available
5. Investigate other passive design strategies such as Trombe walls and Transpired Solar Collectors for warehouses and small industrial type facilities.

SECTION 7: REFERENCES

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