The Effect of High SRI Roofing Finishes Across Climate Zones in the U.S.

by

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ABSTRACT

The intent of this research is to determine if cool roofs lead to increased energy use in the U.S. and if so, in what climates. Directed by the LEED environmental building rating system, cool roofs are increasingly specified in an attempt to mitigate urban heat island effect. A typical single story retail building was simulated using eQUEST energy software across seven different climatic zones in the U.S.. Two roof types are varied, one with a low solar reflectance index of 30 (typical bituminous roof), and a roof with SRI of 90 (high performing membrane roof). The model also varied the perimeter / core fraction, internal loads, and schedule of operations.

The data suggests a certain point at which a high SRI roofing finish results in energy penalties over the course of the year in climate zones which are heating driven. Climate zones 5 and above appear to be the flipping point, beyond which the application of a high SRI roof creates sufficient heating penalties to outweigh the cooling energy benefits.

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CHAPTER 1

INTRODUCTION

The LEED criteria geared towards Urban Heat Island (UHI) mitigation does not stipulate best practices based on climate zone. Rather, it adopts a generalized points based approach rather than a being climatically responsive performance based. The intent of this research is to determine the potential negative effects on urban heat island mitigation and energy consumption in buildings as a result of specifying a cool roof. High albedo “cool roofs” are intended to reflect incident solar radiation as well as easily emit any stored heat either to ambient air or radiantly to the night sky. In climates with more heating days than cooling days, the specification of a high albedo roof may result in a requirement for added heating which otherwise would have been gathered passively through the roof. This implies that not only is cost of space heating increased, but greenhouse gas production from combustion is driven up as well, potentially exacerbating urban heat island effects.

Cool Roofs are measured for effectiveness by calculating its SRI, or Solar Reflectance Index.

Solar Reflectance Index (SRI)

SRI was developed recently as a metric for surface coating performance which accounts for both solar reflectance and thermal emissivity in a single numerical index. SRI indirectly indicates quantifies how hot an exterior building surface will become relative to the code standard black and standard white surfaces. SRI has gained attention in recent years in part due to the USGBC LEED SS credit 7.2 which requires high SRI roof surface finishes to help mitigate UHI. The LEED credit requires one of three options:

Requirements

-OPTION 1

Use roofing materials having a Solar Reflectance Index (SRI) equal to or greater than the values in the table below for a minimum of 75% of the roof surface.

OR

-OPTION 2

Install a vegetated roof for at least 50% of the roof area.

OR

-OPTION 3

Install high albedo and vegetated roof surfaces that, in combination, meet the following criteria:

(Area of SRI Roof / 0.75) + (Area of vegetated roof / 0.5) >= Total Roof Area

TABLE 1

LEED ROOF SLOPE AND SRI CRITERIA

Roof Type	Slope	SRI
Low-Sloped Roof	≤2:12	78
Steep-Sloped Roof	>2:12	29

Relevant Calculation Methods:

SRI is calculated in accordance with ASTM E1980 and is defined so that a standard black (reflectance 0.05, emittance 0.90) has an SRI value of 0 while a standard white surface (reflectance 0.80, emittance 0.90) has an SRI value of 100. SRI values can score above 100 and below 0 depending on the properties of the coating. For example, the standard black has a temperature rise of 90 deg. F (50 deg. C) when exposed to full sun, whereas the standard white has a temperature rise of 14.6 deg. F (8.1 deg. C). Once the maximum temperature rise of a given material has been determined, the SRI can be calculated by interpolating between the values for white and black. Materials with higher SRI values perform cooler while materials with low SRI values tend to get hotter and remain so for longer periods of time.

-Solar Reflectance: (ASTM E 908 Standard)

Solar reflectance is the fraction of incident solar radiation which is not absorbed or transmitted through the surface. In general it must be treated as a directional property that is a function of the reflected direction, the incident direction, and the incident wavelength. However it is also commonly averaged over the reflected hemisphere to give the hemispherical reflectivity.

-Infrared Emittance: (as defined by ASTM E408 standards)

Infrared emittance is a coefficient between 0 and 1 which measures a material’s ability to lose heat in the form of infrared radiation. A material with an emittance of 1 (“black body”), emits about 6.1 watts per square meter, for each degree C above ambient temperature.

CHAPTER 2

PREVIOUSLY CONDUCTED STUDY

A study conducted under the direction of Professor Harvey Bryan of Arizona State University entitled "*The Urban Heat Island Impact of a Vegetated Versus a High-Albedo roof in a Hot Arid Climate"* explored, through a side by side comparative analysis, the merit of vegetated roofs in the desert in terms of their ability to mitigate UHI for the sake of LEED credit. In the case studied by Dr. Bryan, it was found that due to the additional thermal mass required to maintain critical soil temperatures in desert green roofs, the ability to mitigate UHI effects was almost entirely compromised.

This study looks at another potentially misguiding aspect of UHI mitigation as set forth by the LEED rating system. The question which arose from this study is: 'In which climate zone(s) does a high albedo roof (intended for UHI mitigation) result in increased net energy use?

FIGURE 1
VEGETATED ROOF UHI STUDY

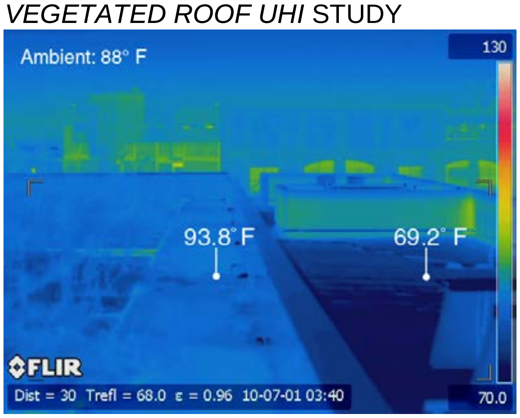
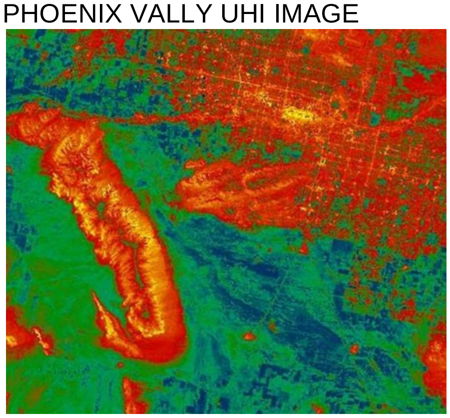


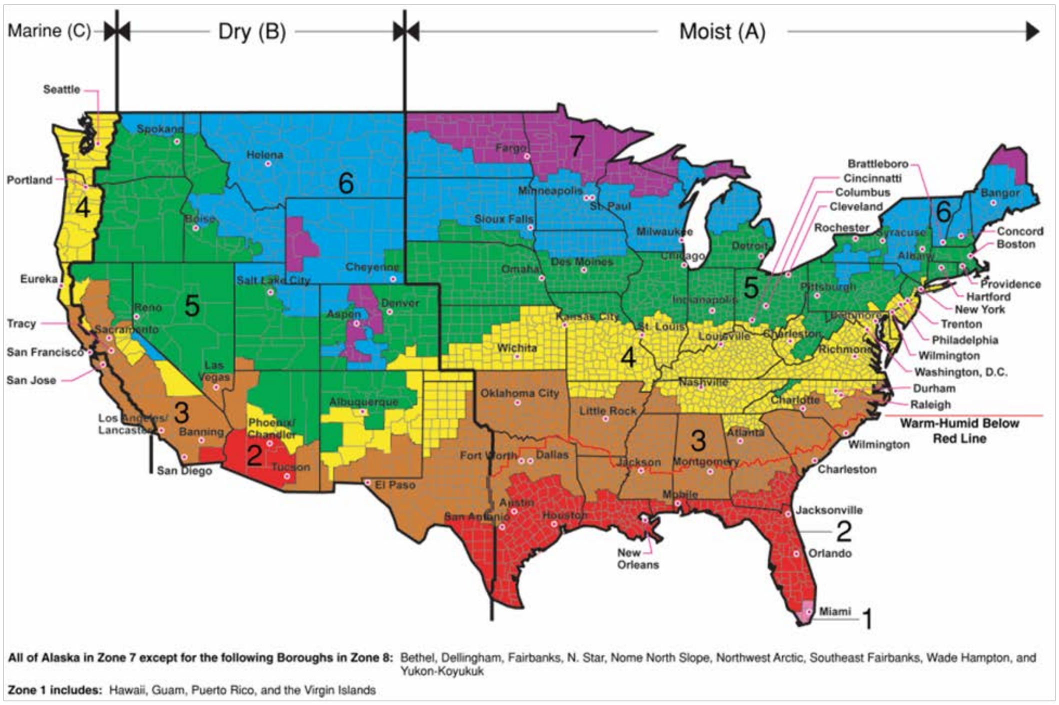
FIGURE 2
PHOENIX VALLY UHI IMAGE



CHAPTER 3

CLIMATE ZONES

FIGURE 3
US CLIMATE ZONE MAP



Climate zones in the United States vary dramatically, stretching across almost the full range as defined by ASHRAE. ASHRAE 90.1 establishes minimum design standards which reflect the climate zone in which the building is located. The ASHRAE 189 exempts all Climate Zones 5 and above from its SRI roof requirements, whereas LEED does not consider climate zone in its Cool Roof requirements.

TABLE 2

CLIMATE ZONE DESCRIPTION TABLE

International Climate Zone Definitions

Zone Number	Zone Name	Thermal Criteria (I-P Units)	Thermal Criteria (SI Units)
1A and 1B	Very Hot –Humid (1A) Dry (1B)	9000 < CDD50°F	5000 < CDD10°C
2A and 2B	Hot-Humid (2A) Dry (2B)	6300 < CDD50°F ≤ 9000	3500 < CDD10°C ≤ 5000
3A and 3B	Warm – Humid (3A) Dry (3B)	4500 < CDD50°F ≤ 6300	2500 < CDD10°C < 3500
3C	Warm – Marine (3C)	CDD50°F ≤ 4500 AND HDD65°F ≤ 3600	CDD10°C ≤ 2500 AND HDD18°C ≤ 2000
4A and 4B	Mixed-Humid (4A) Dry (4B)	CDD50°F ≤ 4500 AND 3600 < HDD65°F ≤ 5400	CDD10°C ≤ 2500 AND HDD18°C ≤ 3000
4C	Mixed – Marine (4C)	3600 < HDD65°F ≤ 5400	2000 < HDD18°C ≤ 3000
5A, 5B, and 5C	Cool-Humid (5A) Dry (5B) Marine (5C)	5400 < HDD65°F ≤ 7200	3000 < HDD18°C ≤ 4000
6A and 6B	Cold – Humid (6A) Dry (6B)	7200 < HDD65°F ≤ 9000	4000 < HDD18°C ≤ 5000
7	Very Cold	9000 < HDD65°F ≤ 12600	5000 < HDD18°C ≤ 7000
8	Subarctic	12600 < HDD65°F	7000 < HDD18°C

CHAPTER 4
COOL ROOFS

Hashem Akbari, a researcher with the Lawrence Berkeley National Laboratory, describes cool roofs as "...having high solar reflectance (high ability to reflect sunlight: spectrum 0.3–2.5μm) and high thermal emittance (high ability to emit thermal radiation: spectrum 4–80μm) stay cool in the sun. The same is true of roofs with lower thermal emittance but exceptionally high solar reflectance. Roofs that stay cool in the sun by minimizing solar absorption and maximizing thermal emission are hereafter denoted 'cool roofs' ". The metric used for cool roof technology is known as SRI, or Solar Reflectance Index. SRI is a calculation which takes a materials performance on both its solar reflectance properties as well as its infrared emmitance characteristics. According to LEED standards, to qualify for the Site Sustainability Credit 7.2 Heat Island, under "potential technologies and strategies", a "cool roof" must meet the following SRI rating standards:

-Minimum 75% of roof coverage

-Low slope cool roof: minimum SRI-78

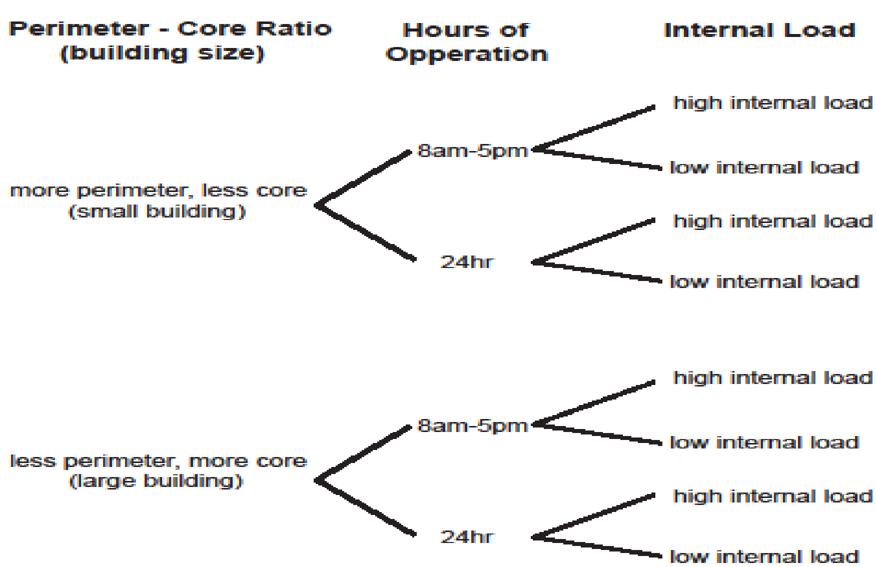
-Steep slope cool roof: minimum SRI-29

CHAPTER 5

METHODOLOGY

Simulation research is conducted using eQUEST energy analysis software. A single story retail building was selected as the standard typology to which a number of variations were made. Two roofing types (low SRI and High SRI) are studied across each of the seven different climate zones in the United States to determine at which point the High SRI roof incurs energy penalties due to excessive heat rejection.

Eight parametric variations were run within each of the low or high SRI simulations to determine energy consumption sensitivities to variations in core to perimeter ratio, internal loads, and schedules of operation. In all, 56 permutations (8 parametric variations across 7 climate zones) were ran for each type of roofing finish, totalling 112 simulations. The following diagram illustrates the various permutations which were considered:



BASELINE SIMULATION ASSUMPTIONS:

Low SRI Roofing Finish: built up roof (absorptivity: 0.7)
High SRI Roofing Finish: built up roof (absorptivity: 0.1)

Zone 1 : Miami, FL
Zone 2 : Phoenix, AZ
Zone 3 : Oklahoma City, OK
Zone 4 : Nashville, TN
Zone 5 : Omaha, NE
Zone 6 : Minneapolis, MN
Zone 7 : Fargo, ND

Building Specifications :

FIGURE 4

LOWER FOOTPRINT / HIGHER CORE (LARGE FOOTPRINT)
Perimeter/Core Fraction: (11,880 sqft perim/ 24742 total) – 0.4801

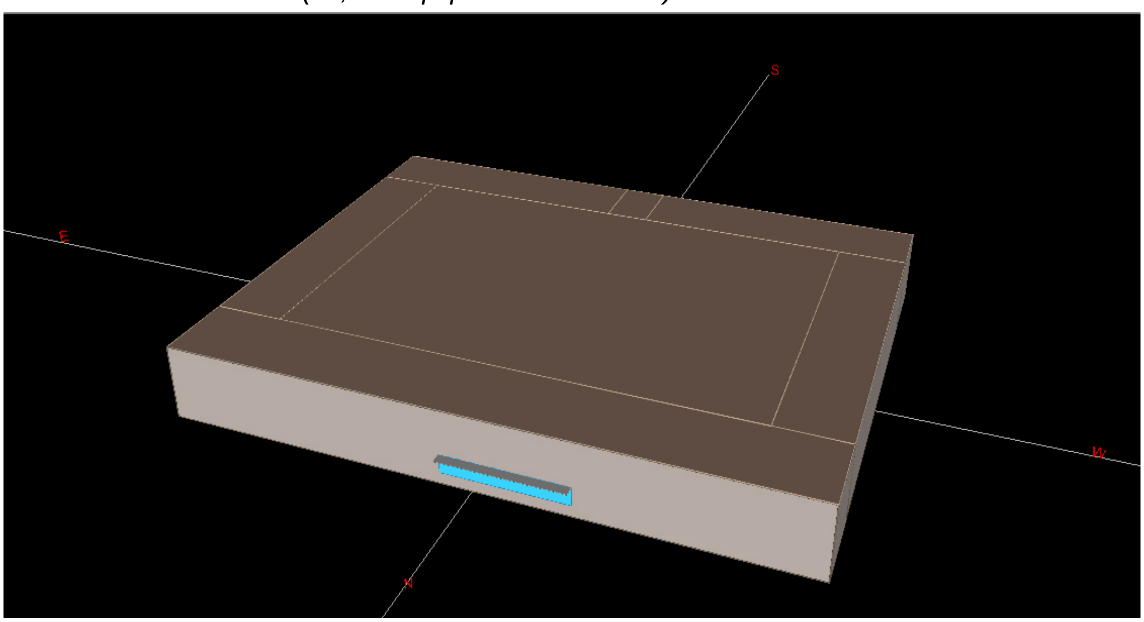


TABLE 3

SMALL BUILDING DESCRIPTION

Items	Description
Program	
Building type	RETAIL
Available fuel types	Electricity, Gas
Form	
Total floor area	24,742 sqft
Footprint dimensions	178' x 139'
Number of floors	1
Floor Area Multiplier	5.2745
Window fraction	5%
Window location	North and South only
Perimeter Zone Depth	20ft
Floor to ceiling height	20ft
Construction	
Exterior walls	
Construction	8" CMU block walls
Insulation	ASHRAE 90.1 2007 Standard per Climate Zone non-residential; Walls, above grade, mass
Roofs	
Construction	Built-up Roof: Roof membrane+Roof insulation+metal decking
Insulation	ASHRAE 90.1 2007 Standard per Climate Zone non-residential; Roofs, Insul. Above Deck
Windows	
Dimensions	based on window fraction and location
Type	Clear Glazing, double pane, 1/2"
Foundation	
Type	Slab on grade (unheated)

Construction Dimension	6" concrete slab Based on floor area
HVAC Heating type Cooling Type Distribution system Thermostat set point Thermostat setback Supply air temp Ventilation	 Gas furnace inside package unit DX package units per zone CAV 74F cooling/ 74F heating 86F cooling/ 62F heating Max 104F / Min 55F 1.0 CFM/sqft
Supply Fan Fan Sch	 See Schedules
Internal Loads Lighting Power Density Lighting Schedules Daylighting Controls Plug Loads Power Density Plug load Schedule Occupancy Occupancy Sch	 1.5W/sqft See Schedules Off 0.54w/sqft See Schedules See Schedules

FIGURE 5

LOWER PERIMETER / HIGHER CORE (LARGE FOOTPRINT)
Perimeter/Core Fraction: (28,100 sqft perim/ 130,502 total) – 0.2153

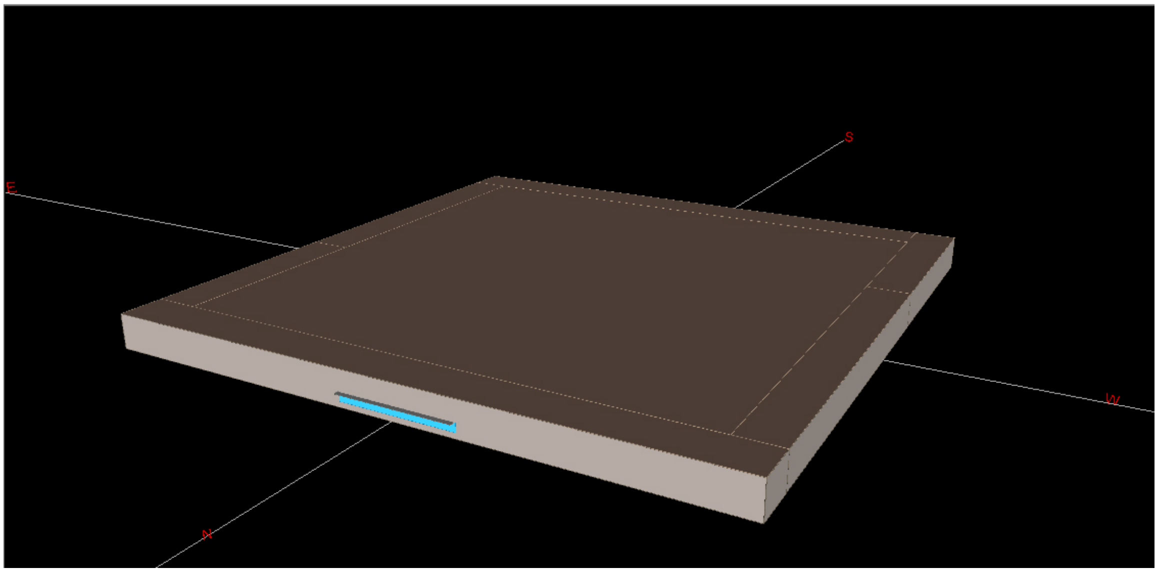


TABLE 4

LARGE BUILDING DESCRIPTION

Items	Description
Program	
Building type	RETAIL
Available fuel types	Electricity, Gas
Form	
Total floor area	130,502 sqft
Footprint dimensions	361' x 361'
Number of floors	1
Floor Area Multiplier	1
Window fraction	5%
Window location	North and South only
Perimeter Zone Depth	20ft
Floor to ceiling height	20ft

Construction	
Exterior walls	
Construction	8" CMU block walls
Insulation	ASHRAE 90.1 2007 Standard per Climate Zone non-residential; Walls, above grade, mass
Roofs	
Construction	Built-up Roof: Roof membrane+Roof insulation+metal decking
Insulation	ASHRAE 90.1 2007 Standard per Climate Zone non-residential; Roofs, Insul. Above Deck
Windows	
Dimensions	based on window fraction and location
Type	Clear Glazing, double pane, 1/2"
Foundation	
Type	Slab on grade (unheated)
Construction	6" concrete slab
Dimension	Based on floor area
HVAC	
Heating type	Gas furnace inside package unit
Cooling Type	DX package units per zone
Distribution system	CAV
Thermostat set point	74F cooling/ 74F heating
Thermostat setback	86F cooling/ 62F heating
Supply air temp	Max 104F / Min 55F
Ventilation	1.0 CFM/sqft
Supply Fan	
Fan Sch	See Schedules
Internal Loads	
Lighting	
Power Density	1.5W/sqft
Lighting Schedules	See Schedules
Daylighting Controls	Off
Plug Loads	
Power Density	0.54w/sqft
Plug load Schedule	See Schedules
Occupancy	
Occupancy Sch	See Schedules

TABLE 5

SCHEDULES:

Schedule	**Hours of Operation**	**Type**	**Days of Week**
Internal Loads			
Lighting	9am-6pm (Sunday Closed)	Fraction	Weekdays, Sunday
	24 Hour	Fraction	24hr - 7 days/wk
Plug Loads	9am-6pm (Sunday Closed)	Fraction	Weekdays, Sunday
	24 Hour	Fraction	24hr - 7 days/wk
Occupancy	9am-6pm (Sunday Closed)	Fraction	Weekdays, Sunday
	24 Hour	Fraction	24hr - 7 days/wk
Infiltration			
Perimeter	9am-6pm (Sunday Closed)	Fraction	Weekdays, Sunday
	24 Hour	Fraction	24hr - 7 days/wk
Core	9am-6pm (Sunday Closed)	Fraction	Weekdays, Sunday
	24 Hour	Fraction	24hr - 7 days/wk
HVAC			
Cooling T-stat	5am-6pm (Sunday Closed)	Temp F	Weekdays, Sunday
	24 Hour	Temp F	24hr - 7 days/wk
Heating T-stat	4am-6pm (Sunday Closed)	Temp F	Weekdays, Sunday
	24 Hour	Temp F	24hr - 7 days/wk
Fan	4am-6pm (Sunday Closed)	On / Off	Weekdays, Sunday
	24 Hour	On / Off	24hr - 7 days/wk

PARAMETRIC INPUT:

SRI values were simulated by creating varying the absorptance value of the roofing finish. Roofs with SRI values of 30 and 90 were modeled as having roof surface absorptance values of 0.70 and 0.10 respectively.

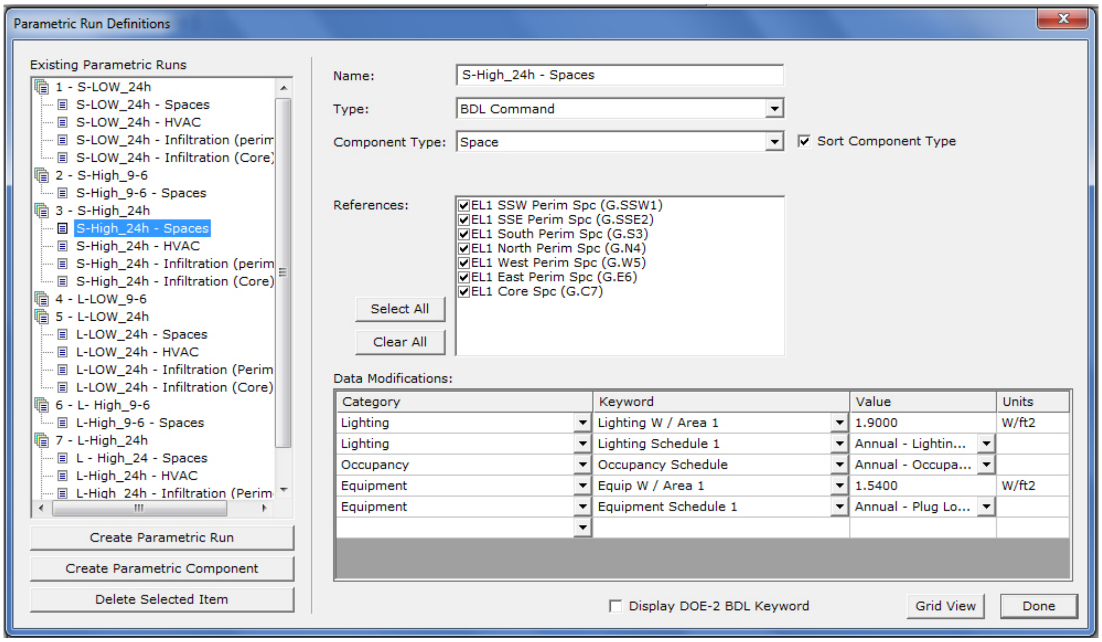
FIGURE 6

PARAMETRIC VARIATIONS

Roofing Type (SRI)	
High	abs= 0.1
Low	abs= 0.7
Perim - Core Ratio	
more perim, less core	24,742 sqft
less perim, more core	130,502 sqft
Internal Loads	
Lighting power density	
High	1.5 W/sqft
Low	1.9 W/sqft
Plug load Density	
High	1.54 W/sqft
Low	0.48 W/sqft
Schedules	
High	24 hour
Low	9am - 6pm

FIGURE 6

PARAMETRIC IMPUT EXAMPLE



Energy Conversion Methods:

Energy expenditure is considered in three different forms to capture a wider perspective for comparative analysis. Site energy, source energy and carbon emissions are calculated based on electricity and gas consumed annually by building operation. Site and source energy are converted from kWh and therms to MBTU's, whereas carbon emissions are expressed in lbs of CO_2e.

-Site Energy:

Site energy refers to the total energy consumed by the building on site. This metric essentially assumes that energy production and delivery is 100% efficient.

Conversion Method: $MBTU = \frac{(kWh\ x\ 3413)+(Therms\ x\ 100{,}000)}{1{,}000{,}000}$

-Source Energy

Source energy refers to the total energy input required to produce and deliver the energy to the site for use. This takes into account the transmission losses and power generation inefficiency.

Conversion Method:

$$MBTU = \frac{(kWh\ x\ 3413\ x\ 3) + (Therms\ x\ 100{,}000)}{1{,}000{,}000}$$

-Carbon Emissions

Carbon emissions are a measure of both energy consumption and environmental impact as a direct result of building operation.

Conversion Method:

$$LBS\ of\ C02 = (kWh\ x\ 1.67 lbs\ C02/kWh) + (Therms\ x\ 29.3 \frac{therms}{kWh} x\ 0.51 lbs\ C02/kWh\ )$$

-Cost

Energy costs are calculated using averaged annual price figures published U.S. Energy information Administration. This research takes into account an average rate per kWk and therm based on the average annual prices from the past two year.

TABLE 7

AVERAGE YEARLY ENERGY PRICES

		Electricity				Gas		
		Cost (dollars/kWh)				Cost (dollars/Therm)		
Climate Zone	**City**	2011	2010	Avg.		2011	2010	Avg.
1	Miami	0.1013	0.1022	0.102		1.109	1.059	1.08
2	Phoenix	0.0883	0.0865	0.087		0.709	0.319	0.51
3	Oaklahoma City	0.0686	0.0651	0.067		0.756	0.353	0.55
4	Nashville	0.1034	0.0912	0.097		0.885	0.383	0.63
5	Omaha	0.0757	0.073	0.074		0.622	0.297	0.46
6	Minneapolis	0.0845	0.0793	0.082		0.95	0.65	0.80
7	Fargo	0.0697	0.0658	0.068		0.855	0.374	0.61

Based on 2010 - 2011 commercial end-use yearly averages from the U.S. Energy Information Administration

TABLE 8

AVERAGE FUEL / ELECTRICITY COST COMPARISON PER EQUIVALANT UNIT

ENERGY SOURCE	$/UNIT FUEL	$/THERM EQUIVALENT
Natural gas	$0.80/Therm	$0.80/Therm
Electricity	$0.095/kWh	$2.80/Therm
Propane	$2.10/gallon	$2.29/Therm
Heating oil	$3.60/gallon	$2.59/Therm

Source: U.S. Department of Energy - Energy Information Administration, March 2011
*One Therm is equivalent to 100,000 Btu or 100 cubic feet CCF.

CHAPTER 6

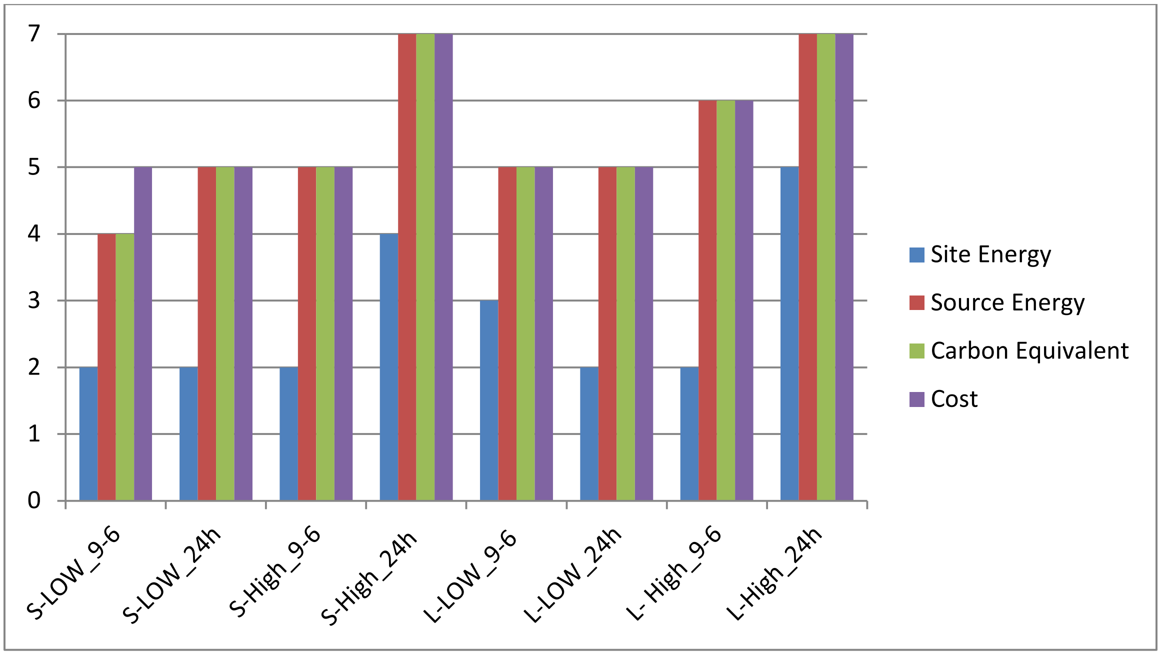
RESULTS

The results from the simulation show in many instances significant energy, carbon and cost penalties when using a high SRI roof in colder climate zones. The climatic point at which the flip occurs (penalties, as opposed to savings) depends largely on the internal load profile, schedule of operations and perimeter/core ratio. The building types which are most prone to penalties are the ones with the low internal loads in combination with short schedules of operation. The core to perimeter ratio had far less of an effect on changing the energy profiles of the buildings in the case of this study, due to the building being internally driven as opposed to skin driven in respects to load.

On the opposite side of the spectrum, buildings with high internal load profiles and 24 hour operation schedules incurred only minor penalties resulted in climate zones 5 for the smaller footprint building and zone 6 for the larger. I this case, the buildings were able to offset any potential penalties from changes in thermal envelope performance with increased internal gain, and 24 hour operations.

FIGURE 7

CUMULATIVE RESULTS ACROSS CLIMATE ZONES



The figure above is intended to illustrate the climatic zone where penalties are realized as a result of using the high SRI roof based on the building operation type and schedule. For every zone above each bar penalties are incurred, below the maximum savings are realized.

TABLE 9

SITE ENERGY COMBINED MBUT SAVINGS/PENALTIES ACROSS CLIMATE ZONES

	(Low SRI-HighSRI)							
	Savings Site Energy MBTU							
Zone	S-LOW_9-6	S-LOW_24h	S-High_9-6	S-High_24h	L-LOW_9-6	L-LOW_24h	L- High_9-6	L-High_24h
1	36.98	79.22	41.40	77.10	39.36	79.69	45.32	75.56
2	-5.93	44.60	17.15	76.86	26.43	48.13	43.11	63.04
3	-35.59	-12.90	-14.35	47.46	-22.77	31.41	3.75	61.95
4	-38.13	11.36	-13.45	21.03	-20.26	12.29	4.66	33.29
5	-51.33	-18.64	-29.23	-2.03	-38.61	-15.26	-10.75	16.38
6	-61.08	-44.20	-42.42	-19.51	-49.59	-33.70	-21.16	-5.84
7	-51.27	-43.39	-31.71	-22.05	-31.43	-29.31	-29.33	-5.97

The source energy saving/ penalty results are generally consistent with the site energy results in respects to the climate zones which experience penalties. The calculation though reflects the inefficiencies inherent in delivering electricity, which are in the form of transmission losses, and conversion losses (combusting fuel to produce electricity). This metric give a more accurate insight as to what the true level of energy consumption is.

TABLE 10

SOURCE ENERGY COMBINED MBTU SAVINGS/PENALTIES ACROSS CLIMATE ZONES

	(Low SRI-HighSRI)							
	Savings Source Energy MBTU							
Zone	S-LOW_9-6	S-LOW_24h	S-High_9-6	S-High_24h	L-LOW_9-6	L-LOW_24h	L- High_9-6	L-High_24h
1	119.16	237.65	126.52	231.30	121.34	239.08	136.59	226.69
2	54.35	139.34	89.71	230.58	120.97	145.19	148.43	189.11
3	4.14	30.51	31.93	166.51	22.90	139.26	58.36	193.96
4	8.83	114.84	43.34	97.21	36.26	95.91	67.87	113.77
5	-14.60	41.77	12.20	52.58	0.30	35.80	36.35	81.71
6	-36.78	-20.11	-16.69	17.22	-21.20	-7.29	16.73	38.25
7	-16.46	-25.71	5.63	5.53	-14.30	-2.42	-4.00	31.84
	5	6	6	0	6	6	7	0

Carbon emission penalties occur only in the more severe climates, which are the most heating intensive zones and passive heat is critical. The carbon emission conversion calculation reveals the reason for the upward climate zone shift for realizing penalties, which is due to the fact that electrical production emits far more carbon per unit of energy delivered for use on the site. Climate 6,7,& 7 resulted in increased carbon emission as the result of the use of a high SRI roofing finish.

TABLE 11

CARBON EMISSION (LBS C02e ANNUAL) BENEFIT / PENALTY ACROSS CLIMATE ZONES

	(Low SRI-HighSRI)							
	Savings Carbon Emissions LBS C02e							
Zone	S-LOW_9-6	S-LOW_24h	S-High_9-6	S-High_24h	L-LOW_9-6	L-LOW_24h	L- High_9-6	L-High_24h
1	19492.04	38760.69	20651.92	37725.30	19813.82	38994.49	22281.98	36973.80
2	9357.21	22765.08	14893.50	37608.33	20015.53	23686.85	24340.00	30844.83
3	1433.51	5449.43	5720.47	27322.52	4358.29	23021.58	9840.77	31691.41
4	2283.22	19283.22	7640.75	16087.77	6577.26	16046.63	11437.96	18650.46
5	-1429.18	7479.84	2672.87	8977.22	843.09	6396.35	6397.55	13549.18
6	-4997.56	-2510.34	-1966.08	3325.69	-2584.94	-546.86	3276.36	6620.60
7	-1745.85	-3479.43	1606.62	1391.23	-1785.50	190.17	-78.87	5533.98
	5	6	6	0	6	6	7	0

FIGURE 8

CARBON EMISSION (LBS C02e ANNUAL) BENEFIT / PENALTY ACROSS CLIMATE ZONES

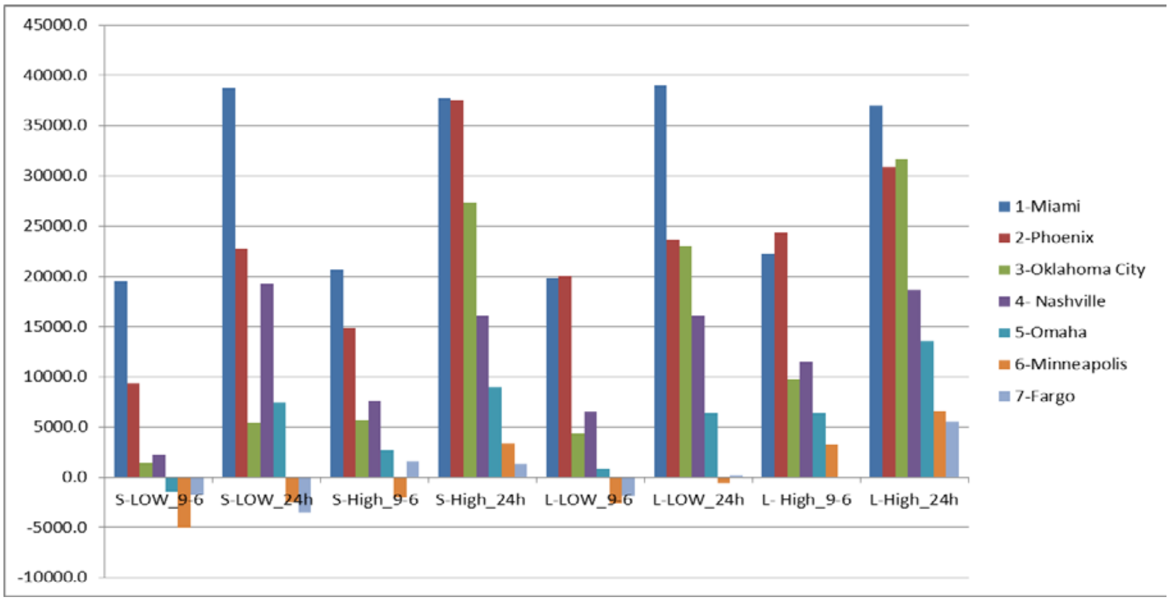


TABLE 13

COST OF OPERATION BENEFIT / PENALTY ACROSS CLIMATE ZONES

	(Low SRI-HighSRI)							
	Savings Cost of Operation $							
Zone	S-LOW_9-6	S-LOW_24h	S-High_9-6	S-High_24h	L-LOW_9-6	L-LOW_24h	L- High_9-6	L-High_24h
1	1180.47	2361.62	1256.27	2298.53	1204.40	2375.86	1357.07	2252.75
2	586.38	1198.85	830.73	1968.25	1103.38	1240.75	1299.46	1614.28
3	81.60	233.25	245.36	1098.99	194.37	931.38	404.21	1270.38
4	278.82	1219.06	544.21	977.70	498.03	1004.78	730.17	1103.09
5	79.78	433.53	221.78	460.03	157.01	368.71	355.41	636.72
6	-294.28	-160.89	-133.56	137.66	-169.62	-58.33	133.75	305.95
7	-76.51	-145.48	61.01	53.47	-75.75	4.17	-6.68	222.45
	6	6	6	0	6	6	7	0

The cost analysis was done using averaged annual energy costs by the state in which the city was based in. As seen in the table above, penalties are rare and only occur in the most heating intensive climate zones. Looking at the cost comparison table for the two energy types, it is obvious why this is the case, natural gas is far cheaper (about half the price when converted to equivalent terms) than electricity is. Since cooling energy(electrically driven) realized a great deal of savings during the summers in all climate zones, it is no wonder why in general cost savings are seen across the board. It is only in the upper climate zones that we see a cost penalty incurred due to heavy heating demand.

Gas consumption, in terms of therms, was penalized in all climate zones except for zone 1, while electrical consumption saw benefits in all climate zones. This indicates that the high SRI roof is performing as expected in the summer by rejecting unnecessary heat from entering the building. It is during the winter months when this high performing roof continues to reject passive heat which would be useful in offsetting the need for heat within the space.

TABLE 14

SITE ENERGY ELECTRICAL SAVINGS/PENALTIES ACROSS CLIMATE ZONES

	(Low SRI-HighSRI)							
	Savings kWh							
Zone	S-LOW_9-6	S-LOW_24h	S-High_9-6	S-High_24h	L-LOW_9-6	L-LOW_24h	L- High_9-6	L-High_24h
1	12040	23210	12470	22590	12010	23350	13370	22140
2	8830	13880	10630	22520	13850	14220	15430	18470
3	5820	6360	6780	17440	6690	15800	8000	19340
4	6880	15160	8320	11160	8280	12250	9260	11790
5	5380	8850	6070	8000	5700	7480	6900	9570
6	3560	3530	3770	5380	4160	3870	5550	6460
7	5100	2590	5470	4040	2510	3940	3710	5540

TABLE 15

SITE ENERGY GAS SAVINGS/PENALTIES ACROSS CLIMATE ZONES

	(Low SRI-HighSRI)							
	Savings Therms							
Zone	S-LOW_9-6	S-LOW_24h	S-High_9-6	S-High_24h	L-LOW_9-6	L-LOW_24h	L- High_9-6	L-High_24h
1	-41	0	-12	0	-16	0	-3	0
2	-361	-28	-191	0	-208	-4	-96	0
3	-555	-346	-375	-121	-456	-225	-236	-41
4	-616	-404	-419	-171	-485	-295	-269	-70
5	-697	-489	-500	-293	-581	-408	-343	-163
6	-732	-563	-553	-379	-638	-469	-401	-279
7	-687	-522	-504	-358	-400	-428	-420	-249

CHAPTER 7

CONCLUSION

Cool roof technology has great potential when it comes to mitigating urban heat island effect in certain climates, as well reducing space conditioning demands. Though this may be, cool roofs have their limitations in certain climates; therefore one must address cool roof feasibility based on climate, with the issue of heating demands primarily in mind, as the benefits to cooling are nearly universal. In no instance in this analysis did cooling consumption ever result in a penalty in energy, carbon emission, or cost. As the data would suggest for large commercial buildings with low internal load profiles and short hours of operation, a high SRI roofing finish can result in annual net site energy penalties in climate zones 3 and above due to excessive heat rejection. For the same building type, annual net penalties in source energy and carbon emission are realized in climate zone 5 and above.

Suggestions for best practice are unfortunately very limited to a specific set of conditions within the scope of this research, as it is acknowledged that not all buildings are single story big box retail with a limited set of variable characteristics. As a general rule, it can be concluded that there is no clear benefit is offered by cool roofs in the upper extreme climates such as 7, 6 and even 5, as the colder regions experienced penalties across the board in cost, C02 equivalency, site and source energy. Heating driven zones must be rigorously studied for feasibility to avoid penalties brought on by the misapplication of what is generally thought to be a universally beneficial product.

The warmer climates, such as 1 and 2, cool roofs performs dual duty as a means of mitigating urban heat island effect while preventing excessive heat gain, ultimately reducing contribution to UHI as well as the overall energy demand for space cooling. These regions are almost entirely cooling driven, so much so that in certain permutations of the building operation, no heat is ever required throughout the year. An added benefit to this is that no fuel is ever combusted and exhausted directly into the urban environment, as it would be in heating driven climate.

The ultimate suggestion arrived upon by this research would be to develop a more comprehensive criteria for sustainable building based on performance rather than a primitive points based system. The USGBC LEED SS credit 7.2 criteria regarding urban heat island mitigation is set up in such a way that would reward designers for deciding to use a cool roof on a building regardless of climate, be it Miami, FL or Fargo, ND. The points based system is quite prone to allowing gross generalizations to work their way into building designs.

Future Research:

The path to determining the true impact of a high SRI roof towards urban heat island effect is quite complex and would require more research than what is presented here. To make a more sound conclusion as to what the true impact of UHI has on society, a greater understanding is required as to what the major causes and effects of UHI are, and under which circumstances it makes sense to attenuate. The metrics used in this study (site and source energy, carbon equivalency, and cost) are intended as a means of reaching a more meaningful conclusion as to how the SRI rating of a roof could potentially have effects on UHI. The issue taken here is that current energy rating criteria are not accounting for the energy penalties towards heating in cold climates which the specifications of a high SRI roof can cause.

The question is whether winter heating penalties incurred are outweighed by the summer cooling benefits in terms of a metric which captures energy consumption as well as environmental impact. Site vs. source energy and C02 equivalency become important measures to be able to make these comparisons. The source energy conversion calculation is taking into account the reality of electrical consumption, being that it is far less efficient than what site energy calculations would lead one to believe. This is critical to understanding if heating penalties outweigh cooling benefits because heating in much of the U.S. is delivered via on-site fuel combustion and cooling through electrically driven mechanical systems. These two types of energy sources have vastly differing environmental impacts, as well as the potential for affecting urban heat island impacts. A deeper understanding of what causes UHI would greatly expand the potential reach of this research.

The traditional though as to what causes UHI is the thermal storage capacity of the built environment (i.e. pavement, mass of construction, etc.), but what are the potential effects of decreased radiative night-sky coupling caused by increased urban pollution? The Solar energy absorbed during daytime hours is shed to the night sky more effectively when sky conditions are clearer. This begs the question that if high SRI roof finishes result in net decreases in energy consumption, and thereby allowing for clearer sky conditions from decreasing greenhouse gas emissions, would urban pollution reduction be a significant measure towards UHI mitigation? Or is it more effective as a combination of both thermal mass reduction and reducing GHG emissions?

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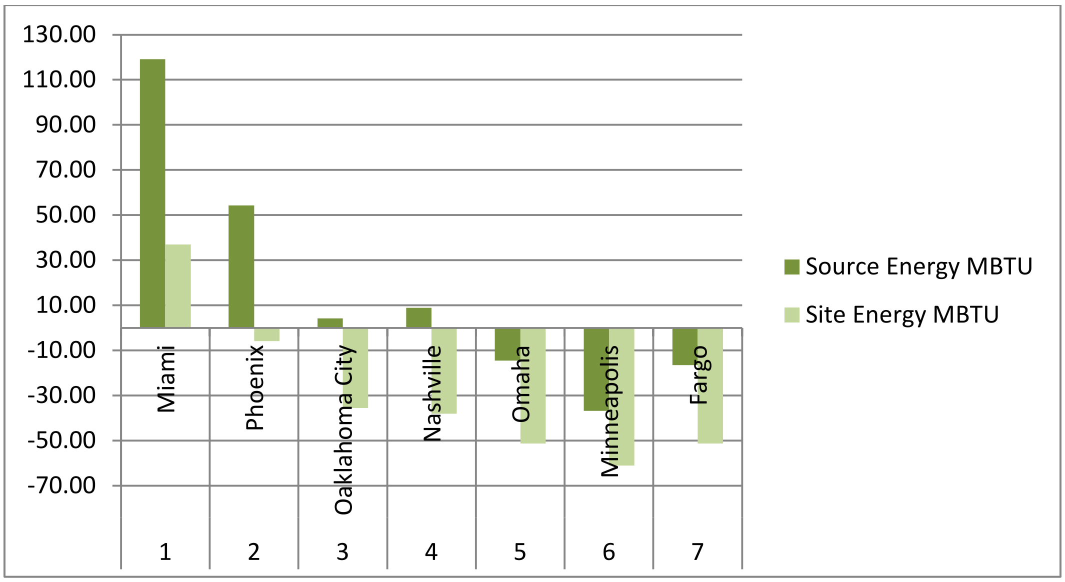
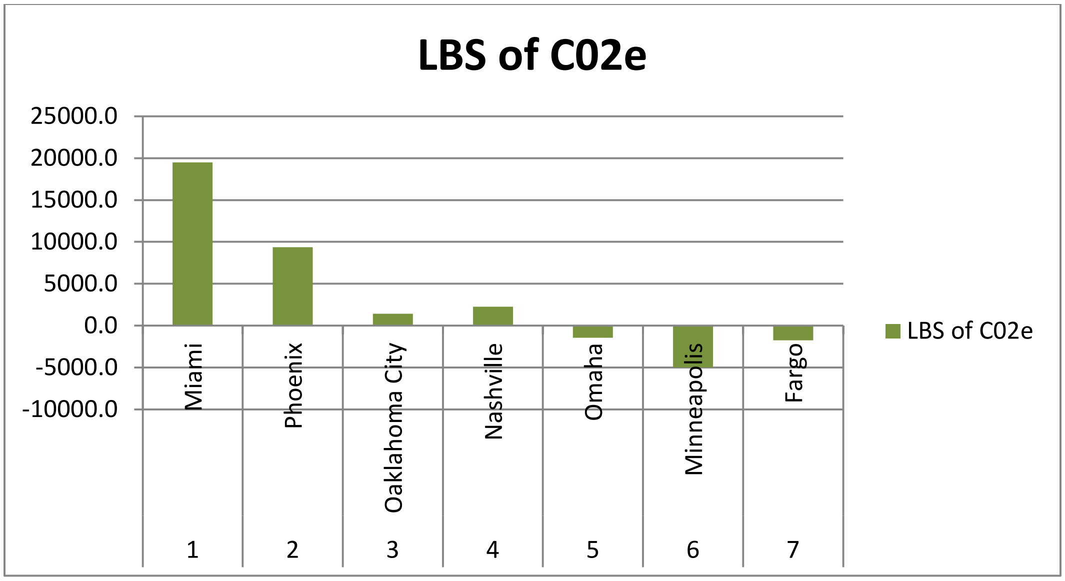
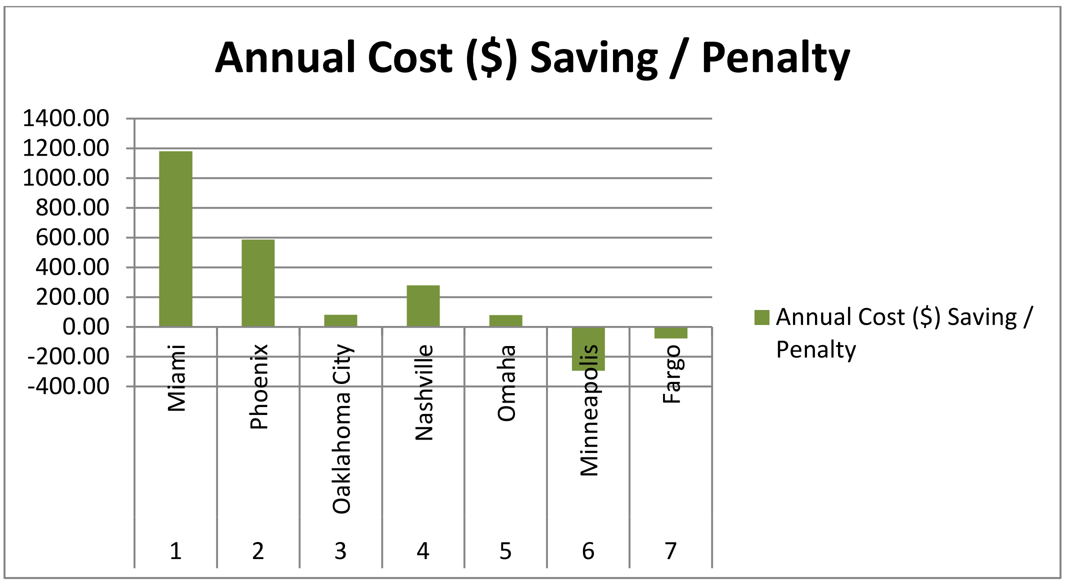
APPENDIX A

PARAMETRIC RUN 1

Lower Perimeter, Higher Core							
Low Internal Load							
9am-6pm Operation		**High SRI Savings / Penalties**					
							Cost savings /penalty
limate Zon	**City**	kWh Annual	Therms Annual	Site MBTU's	Source MBTU's	LBS of CO2	due to high SRI
1	Miami	12040	-41	36.98	119.16	19492.0	1180.47
2	Phoenix	8830	-361	-5.93	54.35	9357.2	586.38
3	Oaklahoma City	5820	-555	-35.59	4.14	1433.5	81.60
4	Nashville	6880	-616	-38.13	8.83	2283.2	278.82
5	Omaha	5380	-697	-51.33	-14.60	-1429.2	79.78
6	Minneapolis	3560	-732	-61.08	-36.78	-4997.6	-294.28
7	Fargo	5100	-687	-51.27	-16.46	-1745.9	-76.51

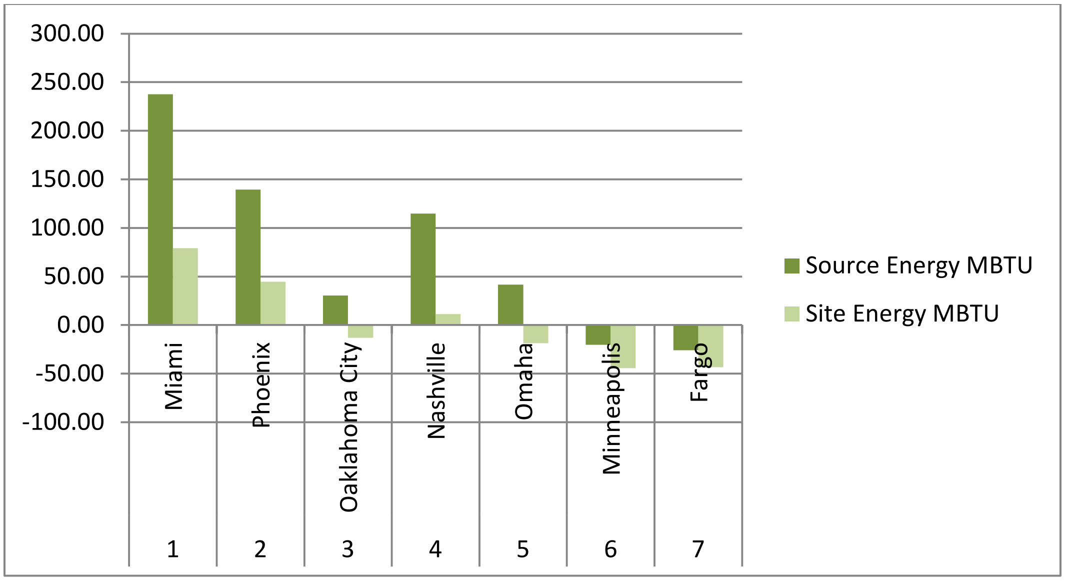






PARAMETRIC RUN 2

Lower Perimeter, Higher Core							
Low Internal Load							
24 Hour Operation		**High SRI Savings / Penalties**					
							Cost savings /penalty
Climate Zone	**City**	kWh Annual	Therms Annual	Site MBTU's	Source MBTU's	LBS of CO2	due to high SRI
1	Miami	23210	0	79.22	237.65	38760.7	2361.62
2	Phoenix	13880	-28	44.60	139.34	22765.1	1198.85
3	Oaklahoma City	6360	-346	-12.90	30.51	5449.4	233.25
4	Nashville	15160	-404	11.36	114.84	19283.2	1219.06
5	Omaha	8850	-489	-18.64	41.77	7479.8	433.53
6	Minneapolis	3530	-563	-44.20	-20.11	-2510.3	-160.89
7	Fargo	2590	-522	-43.39	-25.71	-3479.4	-145.48



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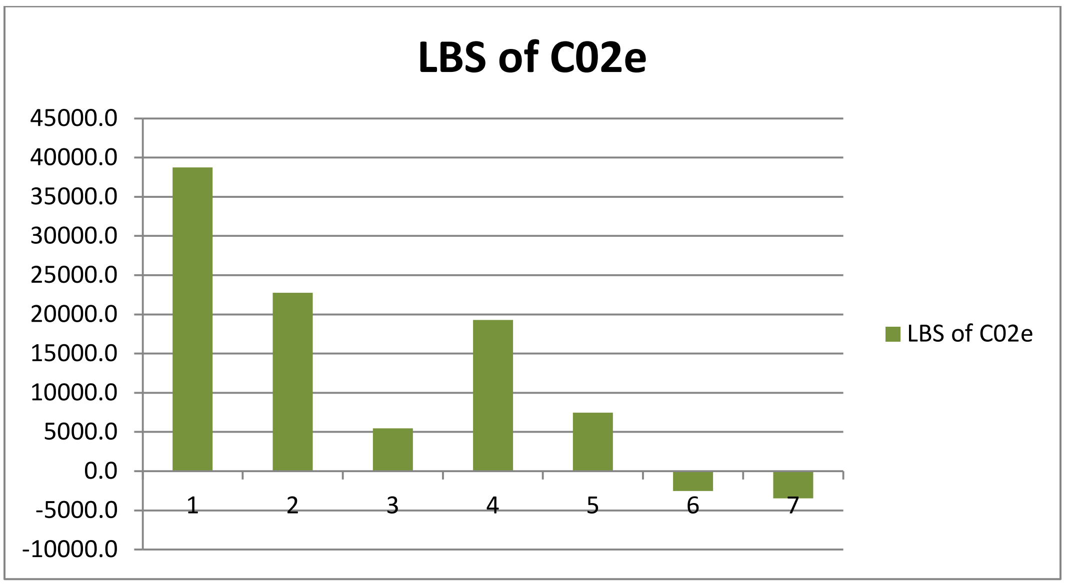

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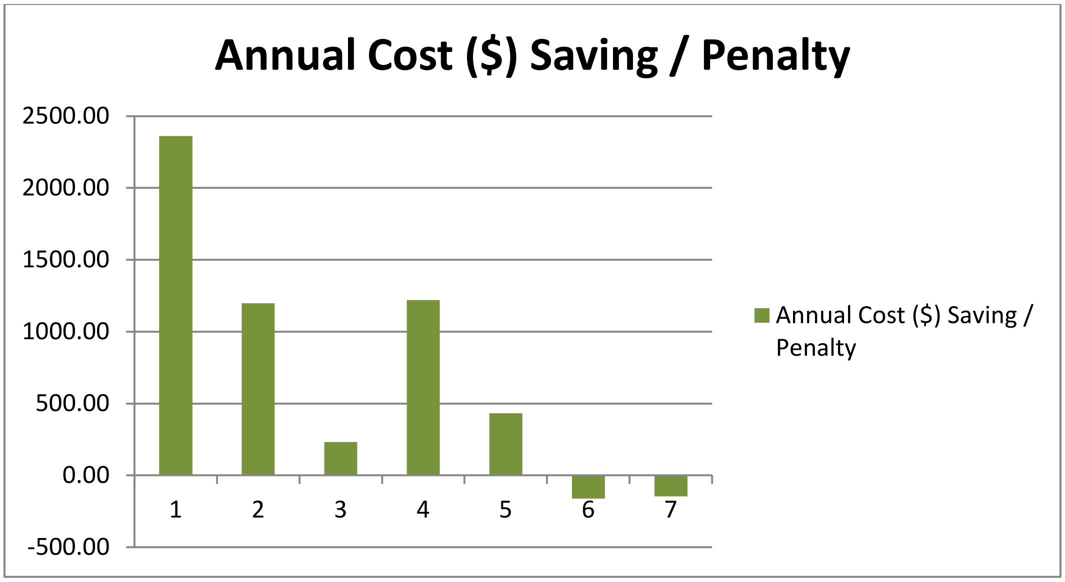
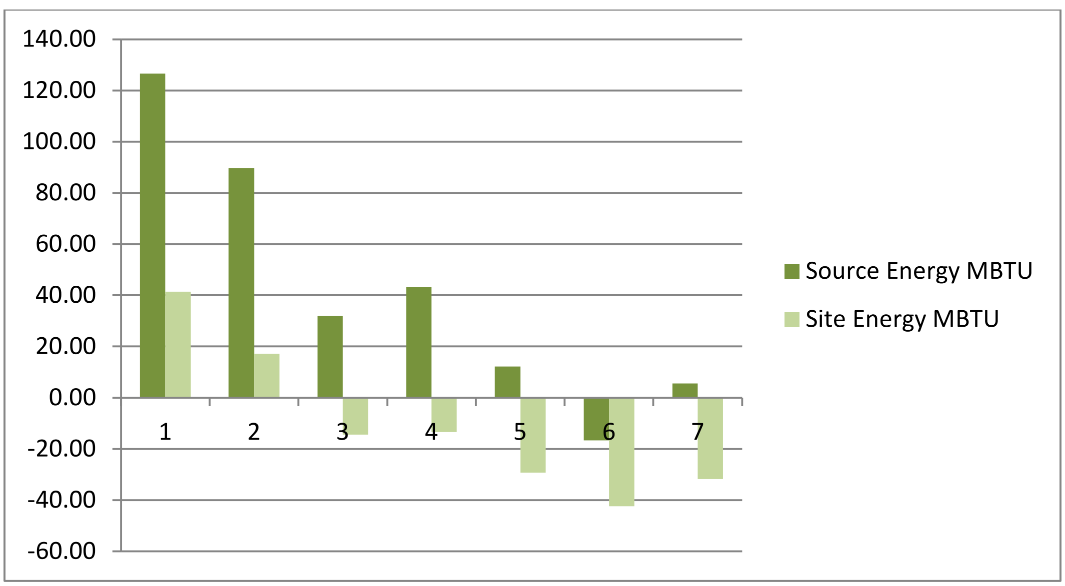


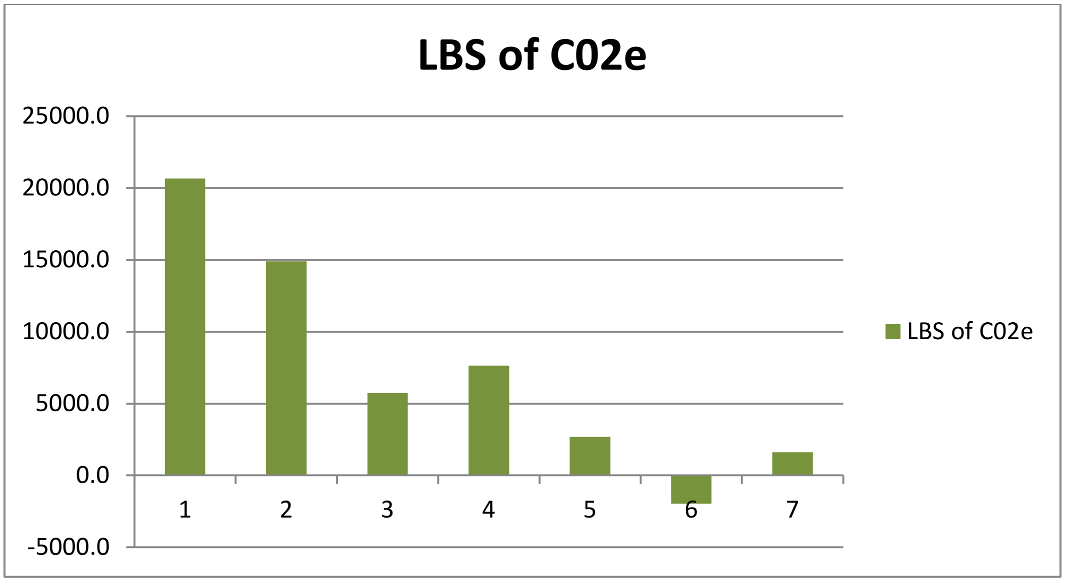
PARAMETRIC RUN 3

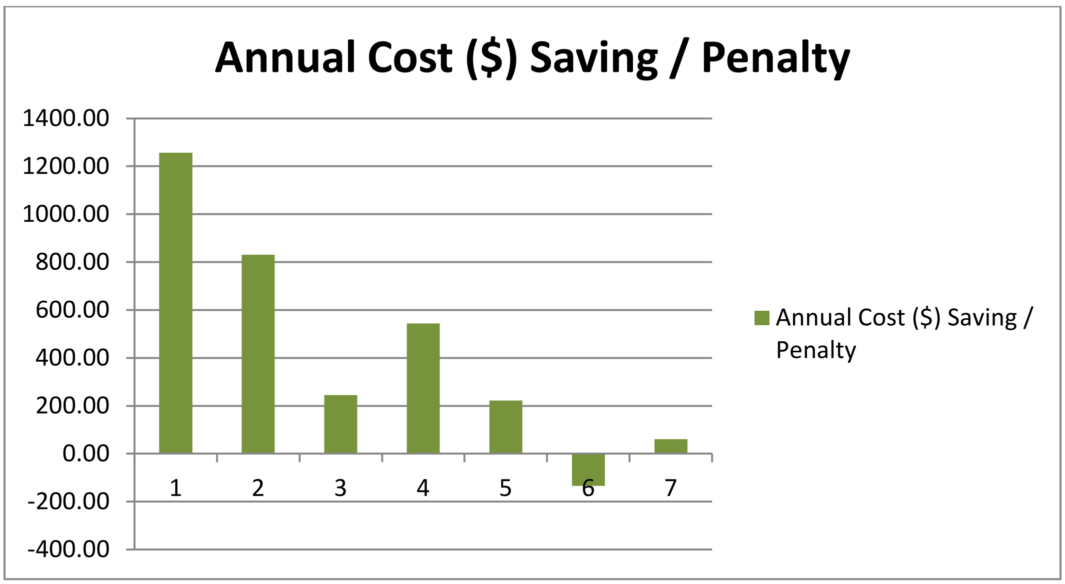
Lower Perimeter, Higher Core
High Internal Load
9am-6pm Operation

High SRI Savings / Penalties

limate Zon	City	kWh Annual	Therms Annual	Site MBTU's	Source MBTU's	LBS of CO2	Cost savings /penalty due to high SRI
1	Miami	12470	-12	41.40	126.52	20651.9	1256.27
2	Phoenix	10630	-191	17.15	89.71	14893.5	830.73
3	Oaklahoma City	6780	-375	-14.35	31.93	5720.5	245.36
4	Nashville	8320	-419	-13.45	43.34	7640.8	544.21
5	Omaha	6070	-500	-29.23	12.20	2672.9	221.78
6	Minneapolis	3770	-553	-42.42	-16.69	-1966.1	-133.56
7	Fargo	5470	-504	-31.71	5.63	1606.6	61.01

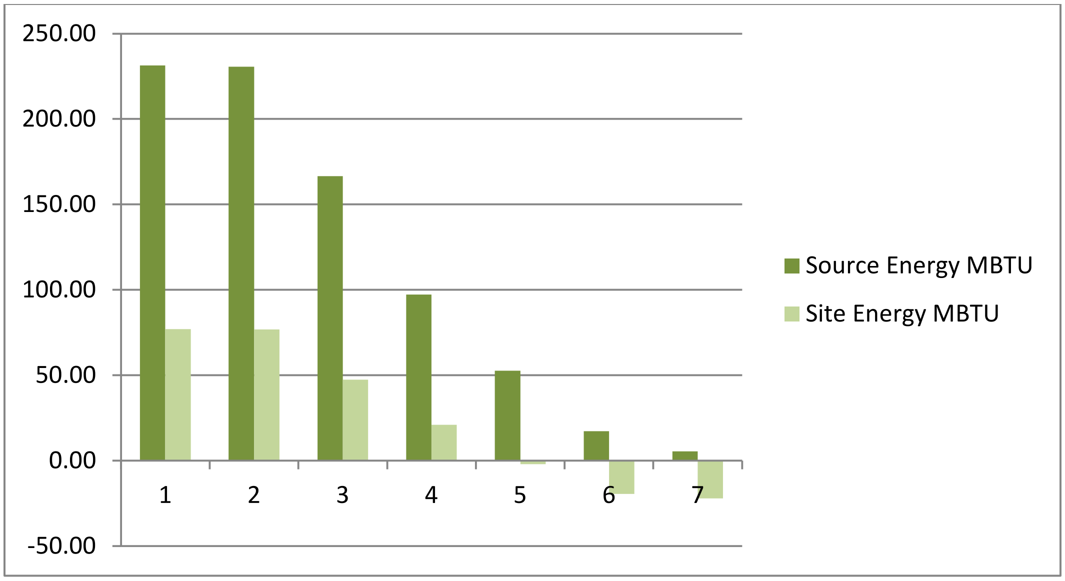






PARAMETRIC RUN 4

Lower Perimeter, Higher Core								
High Internal Load								
24 Hour Operation			**High SRI Savings / Penalties**					
								Cost savings /penalty
Climate Zone	**City**		kWh Annual	Therms Annual	Site MBTU's	Source MBTU's	LBS of CO2	due to high SRI
1	Miami		22590	0	77.10	231.30	37725.3	2298.53
2	Phoenix		22520	0	76.86	230.58	37608.3	1968.25
3	Oaklahoma City		17440	-121	47.46	166.51	27322.5	1098.99
4	Nashville		11160	-171	21.03	97.21	16087.8	977.70
5	Omaha		8000	-293	-2.03	52.58	8977.2	460.03
6	Minneapolis		5380	-379	-19.51	17.22	3325.7	137.66
7	Fargo		4040	-358	-22.05	5.53	1391.2	53.47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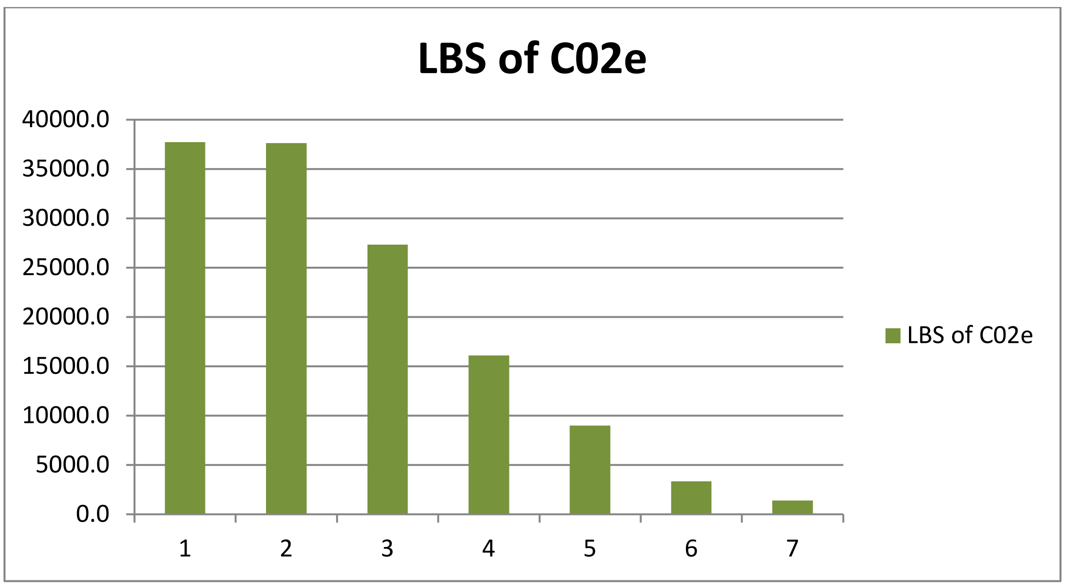
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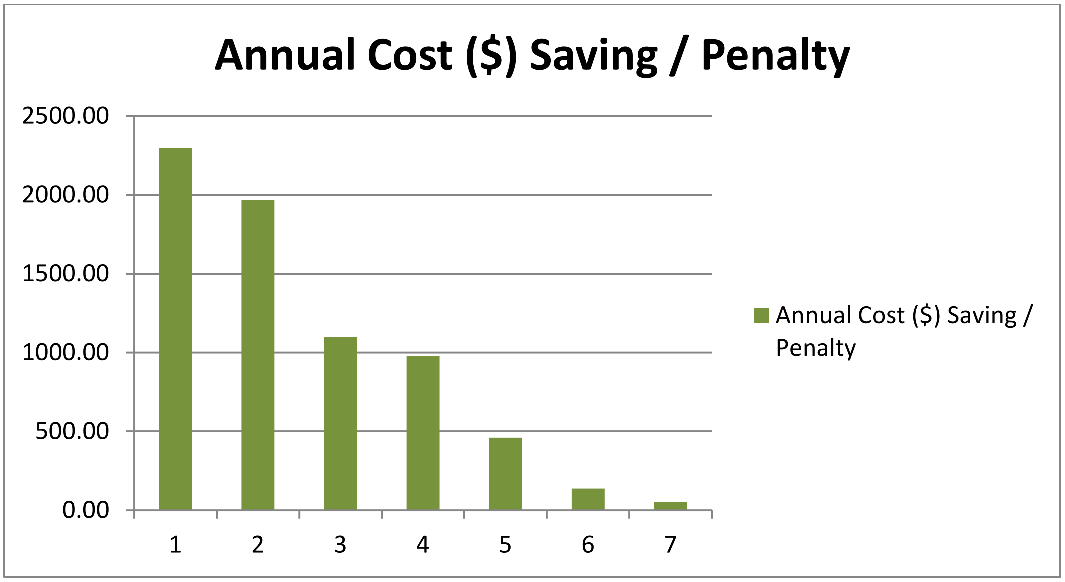
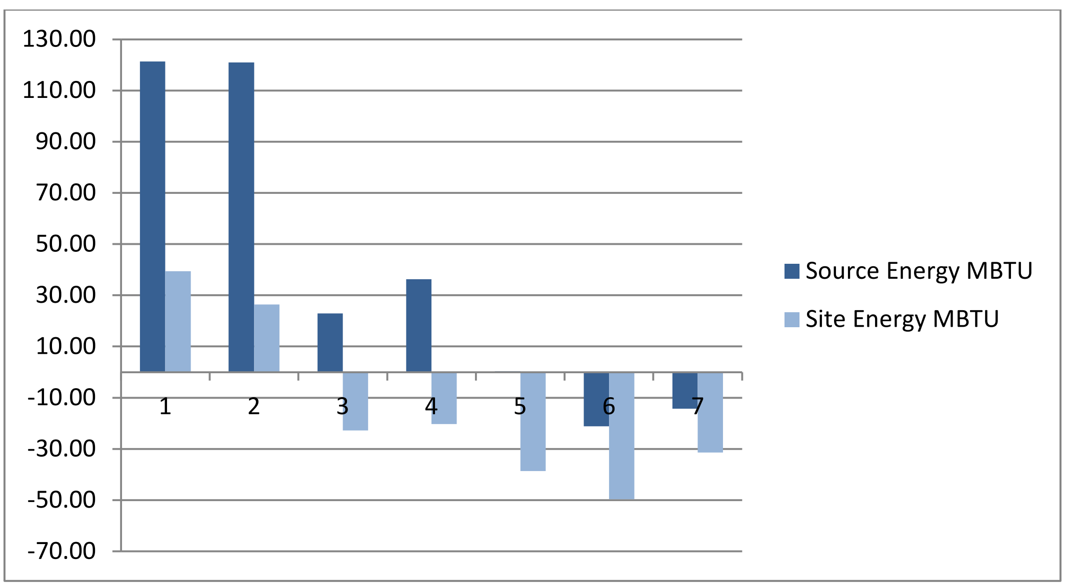
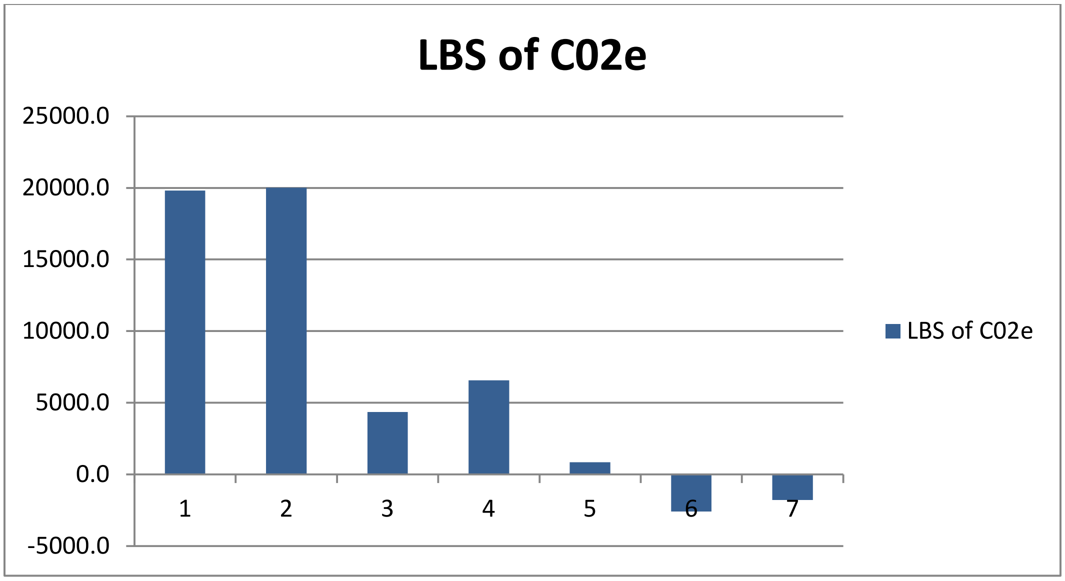
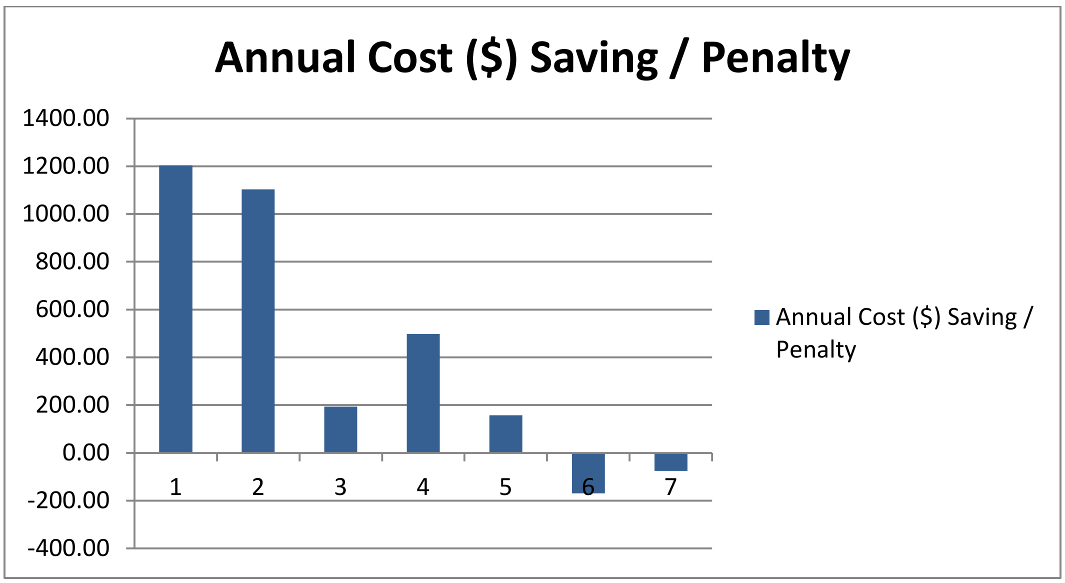


PARAMETRIC RUN 5

Higher Perimeter, Lower Core							
Low Internal Load							
9am-6pm Operation		High SRI Savings / Penalties					
							Cost savings /penalty
limate Zon	**City**	kWh Annual	Therms Annual	Site MBTU's	Source MBTU's	LBS of CO2	due to high SRI
1	Miami	12010	-16	39.36	121.34	19813.8	1204.40
2	Phoenix	13850	-208	26.43	120.97	20015.5	1103.38
3	Oaklahoma City	6690	-456	-22.77	22.90	4358.3	194.37
4	Nashville	8280	-485	-20.26	36.26	6577.3	498.03
5	Omaha	5700	-581	-38.61	0.30	843.1	157.01
6	Minneapolis	4160	-638	-49.59	-21.20	-2584.9	-169.62
7	Fargo	2510	-400	-31.43	-14.30	-1785.5	-75.75

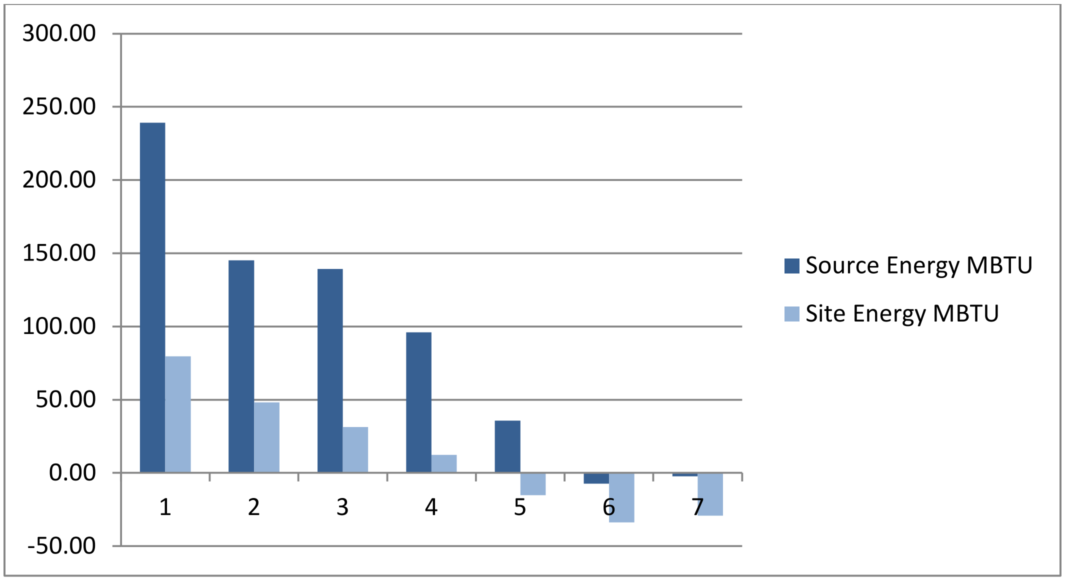






PARAMETRIC RUN 6

Higher Perimeter, Lower Core							
Low Internal Load							
24 Hour Operation		**High SRI Savings / Penalties**					
							Cost savings /penalty
Climate Zone	**City**	kWh Annual	Therms Annual	Site MBTU's	Source MBTU's	LBS of CO2	due to high SRI
1	Miami	23350	0	79.69	239.08	38994.5	2375.86
2	Phoenix	14220	-4	48.13	145.19	23686.9	1240.75
3	Oaklahoma City	15800	-225	31.41	139.26	23021.6	931.38
4	Nashville	12250	-295	12.29	95.91	16046.6	1004.78
5	Omaha	7480	-408	-15.26	35.80	6396.4	368.71
6	Minneapolis	3870	-469	-33.70	-7.29	-546.9	-58.33
7	Fargo	3940	-428	-29.31	-2.42	190.2	4.17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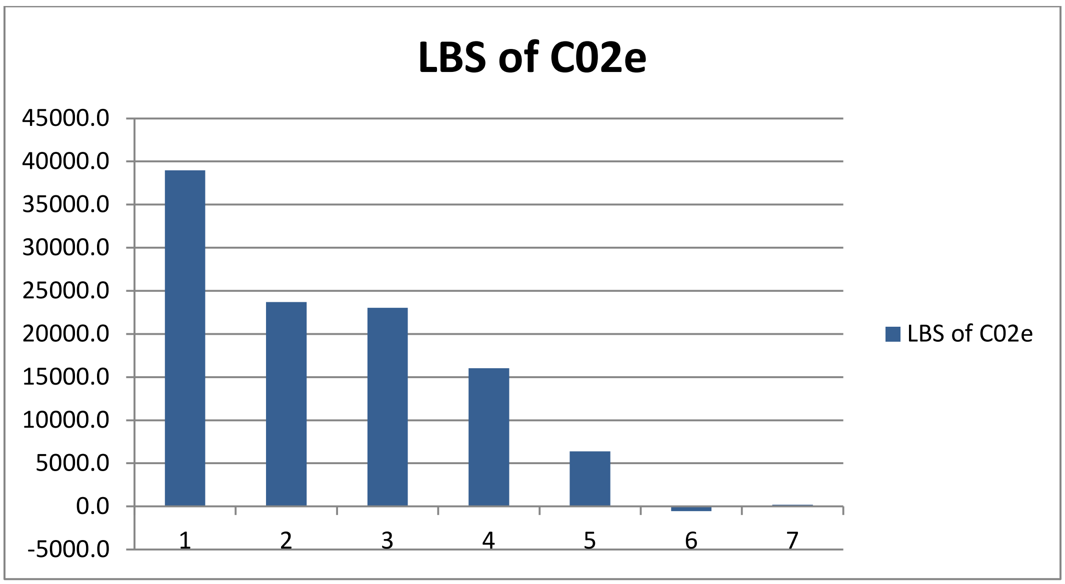
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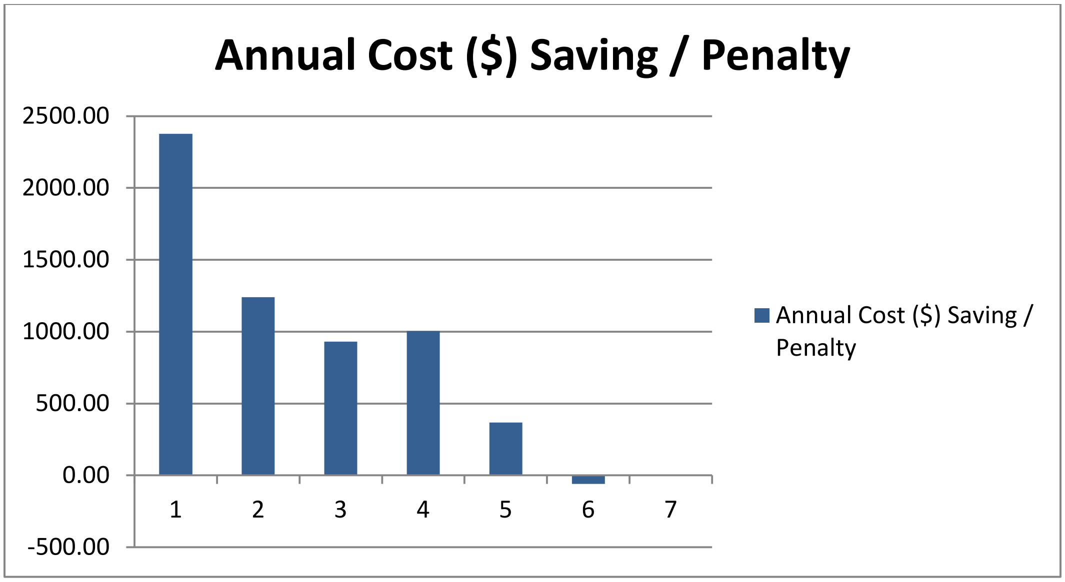
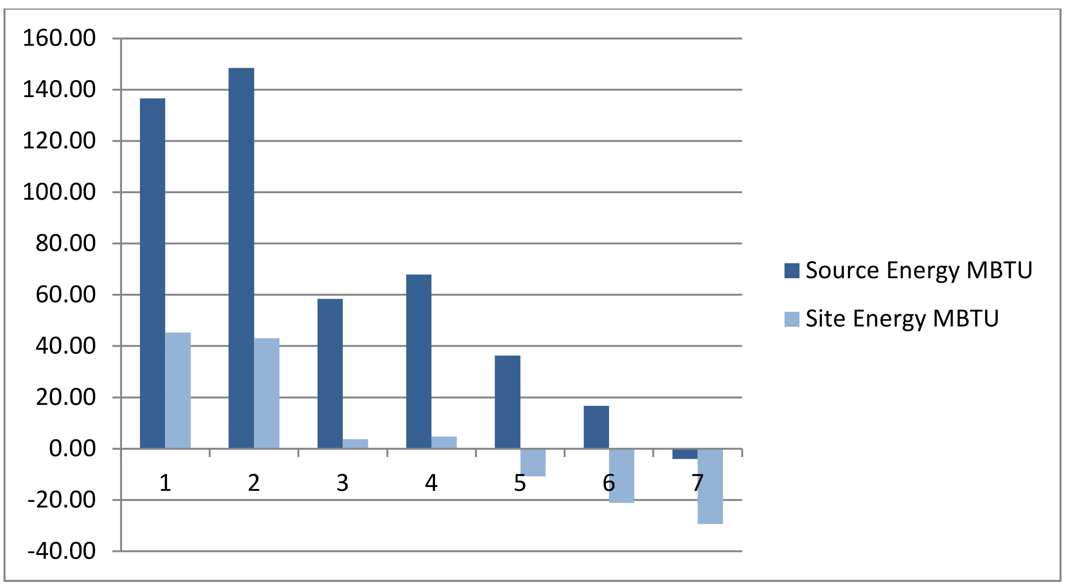
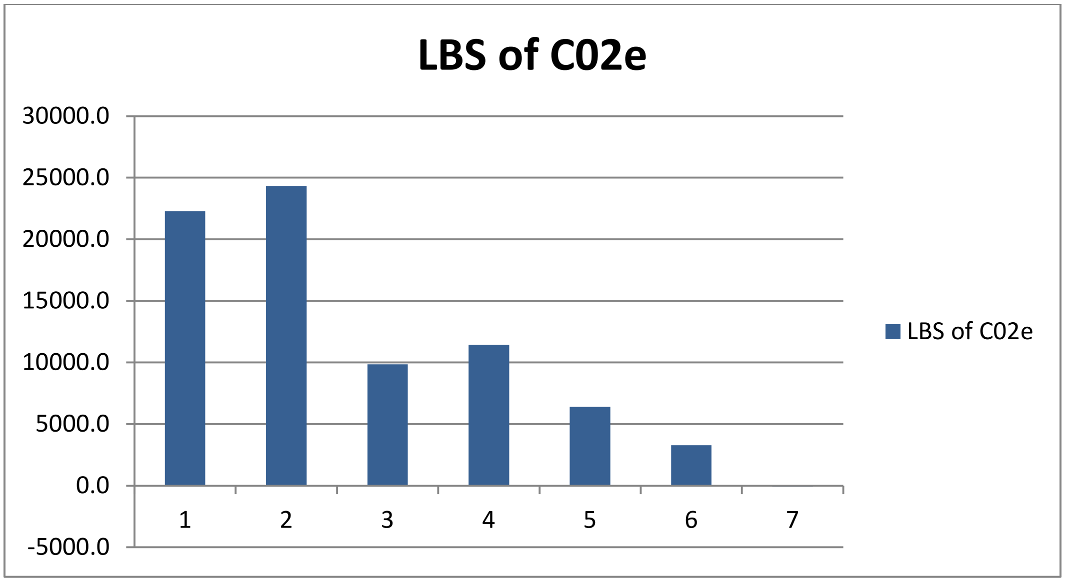
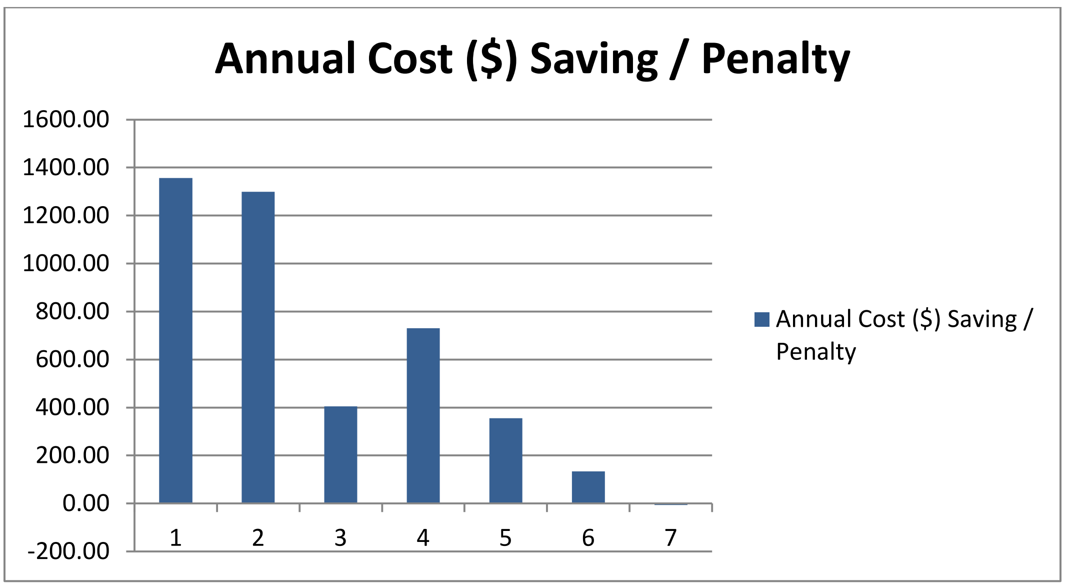


PARAMETRIC RUN 7

Higher Perimeter, Lower Core							
High Internal Load							
9am-6pm Operation		**High SRI Savings / Penalties**					
							Cost savings /penalty
limate Zon	**City**	kWh Annual	Therms Annual	Site MBTU's	Source MBTU's	LBS of CO2	due to high SRI
1	Miami	13370	-3	45.32	136.59	22282.0	1357.07
2	Phoenix	15430	-96	43.11	148.43	24340.0	1299.46
3	Oaklahoma City	8000	-236	3.75	58.36	9840.8	404.21
4	Nashville	9260	-269	4.66	67.87	11438.0	730.17
5	Omaha	6900	-343	-10.75	36.35	6397.6	355.41
6	Minneapolis	5550	-401	-21.16	16.73	3276.4	133.75
7	Fargo	3710	-420	-29.33	-4.00	-78.9	-6.68

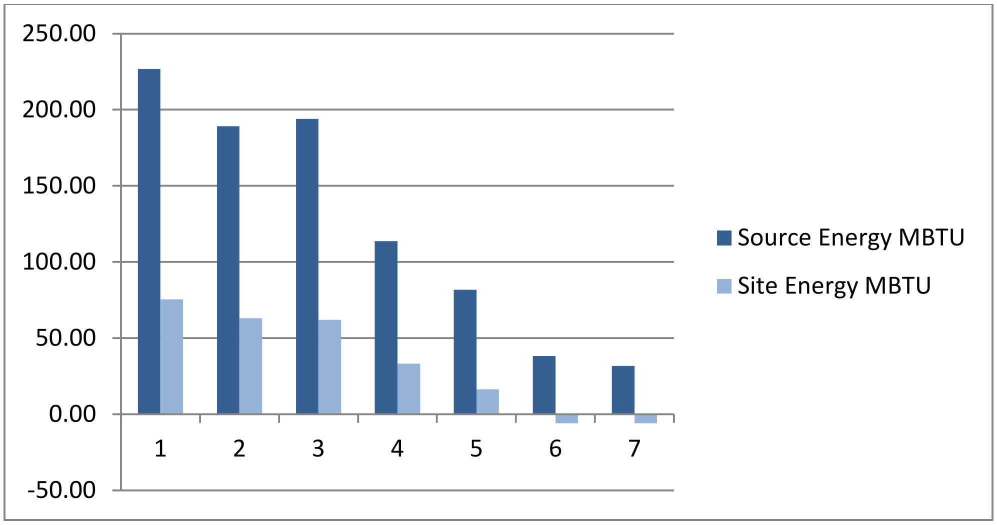






PARAMETRIC RUN 8

Higher Perimeter, Lower Core								
High Internal Load								
24 Hour Operation			**High SRI Savings / Penalties**					
								Cost savings /penalty
Climate Zone	**City**		kWh Annual	Therms Annual	Site MBTU's	Source MBTU's	LBS of CO2	due to high SRI
1	Miami		22140	0	75.56	226.69	36973.8	2252.75
2	Phoenix		18470	0	63.04	189.11	30844.8	1614.28
3	Oaklahoma City		19340	-41	61.95	193.96	31691.4	1270.38
4	Nashville		11790	-70	33.29	113.77	18650.5	1103.09
5	Omaha		9570	-163	16.38	81.71	13549.2	636.72
6	Minneapolis		6460	-279	-5.84	38.25	6620.6	305.95
7	Fargo		5540	-249	-5.97	31.84	5534.0	222.45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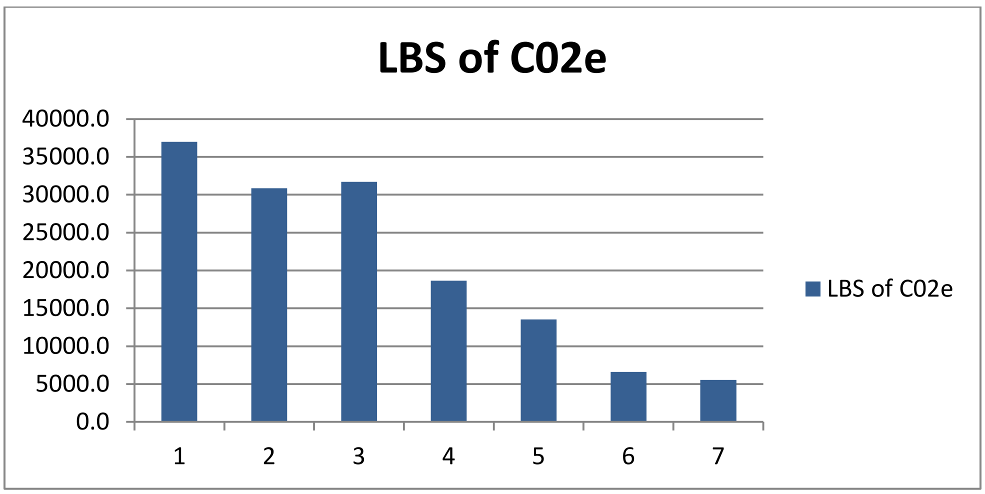
Site Energy MBTU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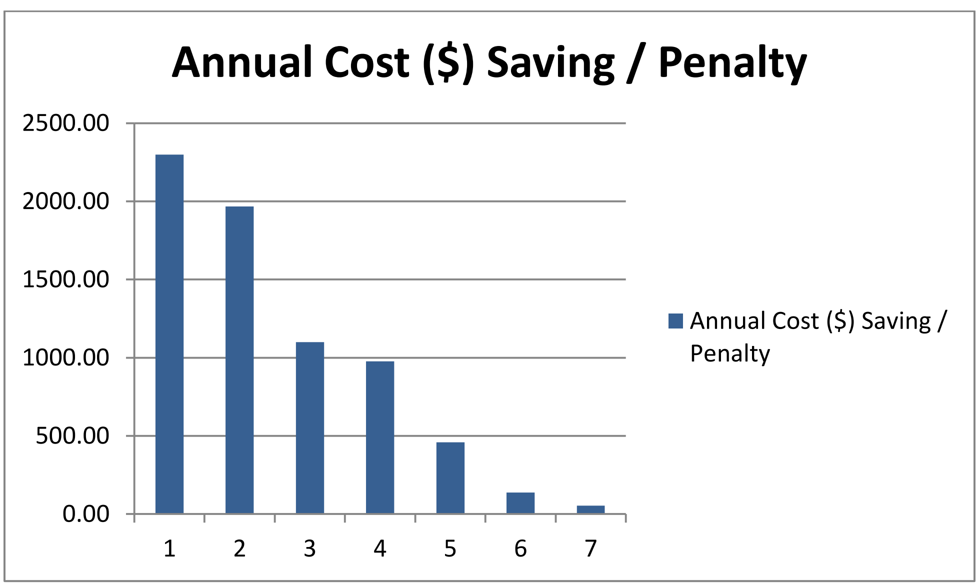
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