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Economic Impact of the Reflectivity of Roofs

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Economic Impact of the Reflectivity of Roofs

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by

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This thesis is approved.

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Abstract

For years, dark roofs have been used on residential and commercial buildings in all areas of the United States, but these roofs absorb large amounts of solar radiation, which can result in high cooling costs for the building. In some parts of the country, using a cool roof on a building is more beneficial because it will lower the energy consumption (and therefore will reduce energy costs) of heating and cooling the building. This paper summarizes the results from using the program eQUEST to analyze three different types of buildings – an office, a high school, and a hospital – in each ASHRAE climate zone to determine the economic impact of using a cool roof as opposed to a dark roof on these buildings. Three different reflectivities of roofs are chosen: a light roof (reflectivity of 0.6), a medium roof (reflectivity of 0.4), and a dark roof (reflectivity of 0.1), and several types of simulation results (utility charges, roof conduction, max HVAC heating and cooling load, and max hourly heating and cooling load) are collected from the simulations.

According to the eQUEST simulations and assumed gas and electric rates, using a cool roof on a hospital anywhere in the United States increases the total energy consumption, and therefore is not advisable. In offices and schools in zones 4, 5, 6, and 7, and schools in zones 2 and 3, utilizing a cool roof may not be the most profitable investment; however, in many situations, it is economically viable. For schools in zone 1 and offices in zones 1, 2, and 3, utilizing cool roofs may be a good investment, depending on the company or school's minimum attractive rate of return (MARR). When constructing a roof where the cost of a cool roof and non-cool roof are the same, utilizing a cool roof is the better option in offices in all zones and schools in all zones except zones 5, 6, and 7

Introduction

Dark roofs absorb more energy from sunlight and therefore increase cooling costs of buildings during the summer months and reduce heating costs during the winter months. In warmer climates, cooling costs are higher in buildings with roofs with high absorptance coefficients. In cooler climates, heating costs are higher in buildings with roofs with low absorptance coefficients. Depending on the type of building, its uses, and where it is located, these costs can be significantly reduced if the right type of roof is chosen. According to a report from the U.S. Department of Energy (DOE) in 2010 (1), dark roofs can reach temperatures over 50° F higher than cool roofs in the same climate. According to the same report, using cool roofs can have a positive environmental impact by reducing the surrounding air temperatures, which increases air quality, reducing power plant emissions because of lower energy consumption of buildings, and reducing "heat trapped in the atmosphere by reflecting more sunlight back into space, which can slow climate change" (1). An article by the Consumer Energy Center states that using cool roofs can also reduce "roof maintenance and replacement expenses by extending roof life" (2). The Department of Energy report (1) states that annual cooling energy cost savings often substantially outweigh heating penalties as a result of installing a cool roof.

Background

The roof captures most of the heating load of a building, so changing it can have a drastic impact on the energy consumption of that building. Two factors, solar reflectance and thermal (sometimes called infrared) admittance, determine the temperature of a roof. Both values range from 0 to 1, with 1 being the highest emittance, leading to the coolest roof. The Lawrence Berkeley National Laboratory defines solar reflectance as "the fraction of the incident solar energy which is reflected by the surface in question" and thermal admittance as "the ability of a warm or hot material to shed some of its heat in the form of infrared radiation" (3). A surface that reflects 60% of sunlight has a solar reflectivity of 0.60. "Solar reflectance has the biggest effect on keeping [a] roof cool in the sun" (1). Most building materials have a thermal admittance of 0.9, the notable exception being clean, bare metallic surfaces, which have low to intermediate levels of emittance (3). The Solar Reflectance Index (SRI) is another standard for measuring a roof's ability to remain cool, as shown by a small temperature rise. "It is defined so that a standard black (reflectance 0.05, emittance 0.90) is 0 and a standard white (reflectance 0.80, emittance 0.90) is 100. For example, the standard black has a temperature rise of 90 deg. F (50 deg. C) in full sun, and 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 computed, the SRI can be computed by interpolating between the values for white and black. Materials with the highest SRI values are the coolest choices for roofing. Due to the way SRI is defined, particularly hot materials can even take slightly negative values, and particularly cool materials can even exceed 100" (3).

Roofs are often split into two categories: low-slope (typically found on commercial, industrial, and office buildings) and steep-slope (typically found on residence and retail buildings) (4), and they can be made out of many different kinds of materials. The most common types of roofs are built up, metal, modified bitumen, single-ply membrane, and spray polyurethane foam roofs. Built up roofs (BUR) are generally "made up of alternating bitumen layers and reinforcing fabric layers that, together, form finished roofing membranes. These membranes are laid out in cross sections across a building top's surface. For the most part, built-up roofing is fastened to roof decks and insulation for adherence" (5).

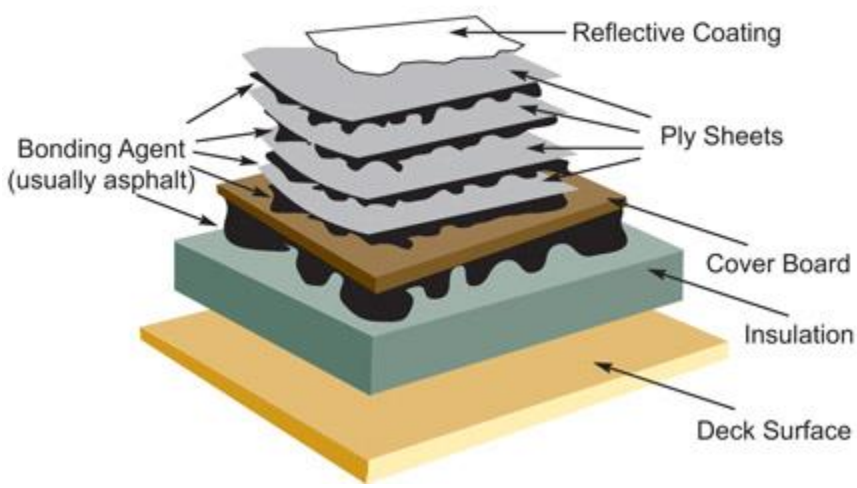


Figure 1: Built up roof (6).

"There are several metal materials which can be used for metal roofing: corrugated galvanized steel, aggregates of zinc, aluminum, and silicon-coated steel, metal tile sheets, stainless steel, copper, aluminum, stone-coated steel, lead, and tin. Because certain kinds of metal roofs, especially steel roofs, can become rusted from prolonged exposure to the sun, these roof types have surfacing layers applied that protect against or resist damaging influences such as sun exposure. These surfacing layers are typically coatings, which are applied for resistance against rust, waterproofing, or reflectivity of the sun's energy. They are typically made of materials such as epoxy, ceramic, or acrylic" (5).

Figure 2: Metal roof (7).

Modified bitumen roofs "are composed of reinforcing roof fabrics which function as 'carriers' for bitumen, when it is being manufactured into rolls. Similar to BUR membranes, bitumen roofing membranes are installed in layers. They are usually fastened to building tops as two-ply systems that are fully adhered to the roofing deck" (5).

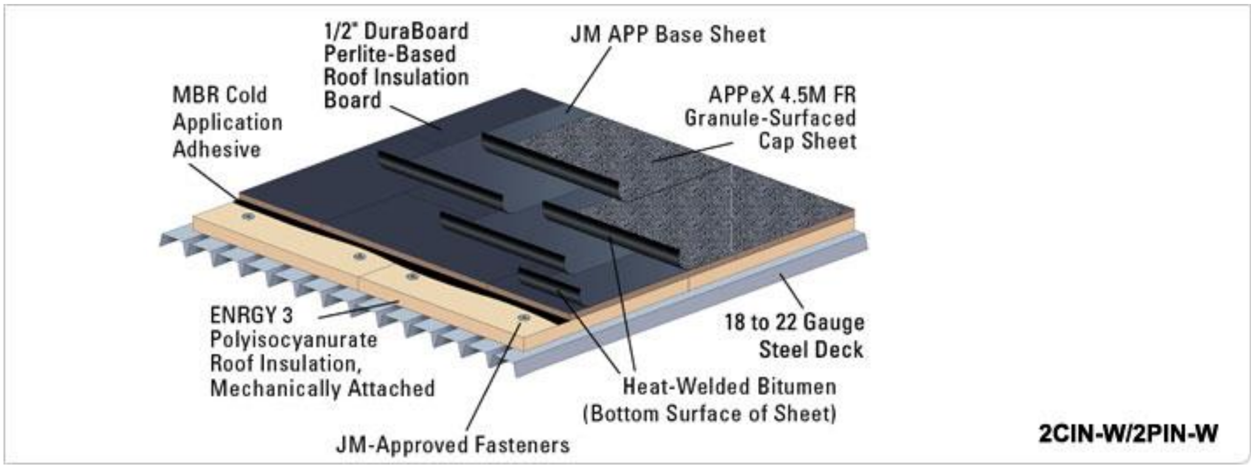


Figure 3: Modified bitumen roof (8).

Single-ply roofing membranes "are factory-made membranes. Generally speaking, there are two kinds of single-ply roofing membranes: thermoplastic membranes, which include PVC and TPO membranes, and thermoset membranes, which include EPDM membranes, a popular rubber roofing system" (5).

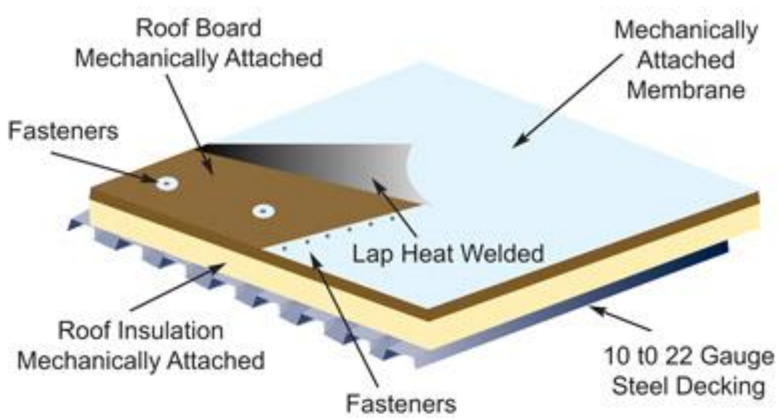


Figure 4: Single-ply roof (9).

Spray polyurethane foam (SPF) roofing is "foam-based and created by mixing and applying a two-part liquid that serves as this roofing system's base layer. It can easily be applied with different amounts of thickness for greater R-value, or insulation value, or sloping for drainage" (5).

Figure 5: SPF roof (10).

Methodology

The program eQUEST (11) was used to run simulations of building performance. Three different energy absorptance coefficients for the roof were used: dark (0.9), medium (0.6) and light (0.4). It is important to note that the solar reflectance of these roofs can be determined by subtracting their absorptance values from 1. For example, the light roof has a solar reflectance of 0.6 and the dark roof has a solar reflectance of 0.1. A city was chosen in each different zone of the ASHRAE climate zone map (shown in Figure 6), and a simulation for each different type of roof was run for an office, high school, and hospital in each of these zones (details of these buildings can be found in Appendix A).

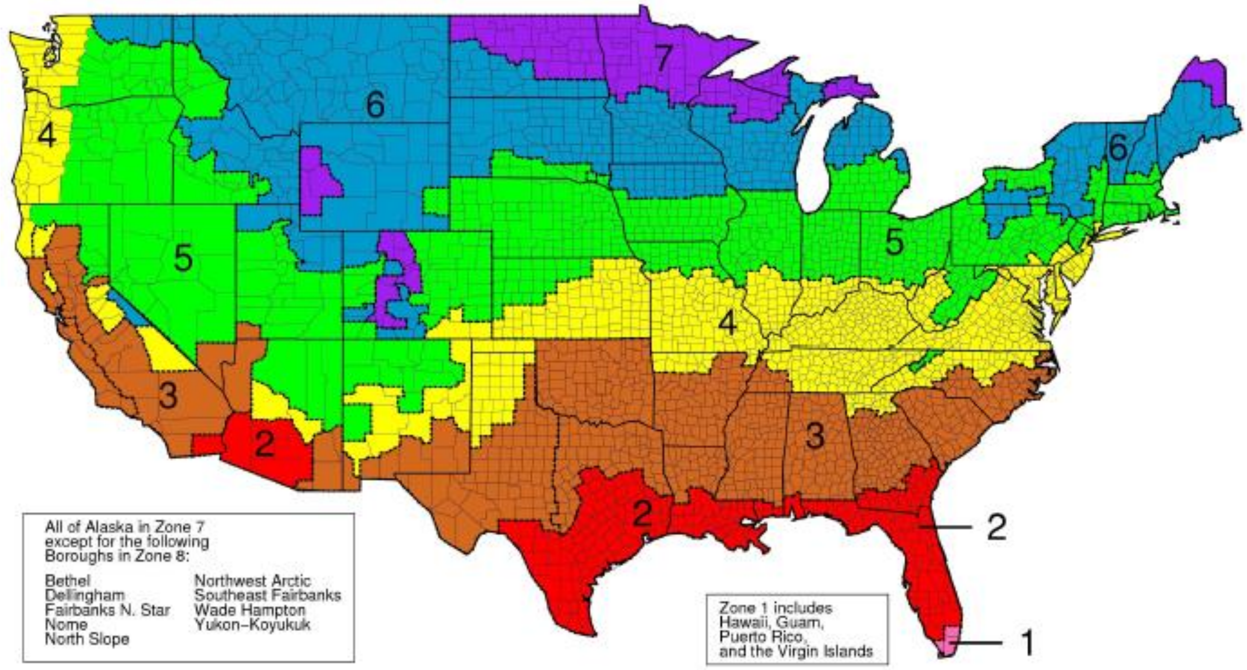


Figure 6: ASHRAE climate zone map (12).

Uniform energy costs of $0.08/kWh, $12/kW, $0.80/therm, and $0.00/(therm/hr) were used, and the simulations were run for the year 2014. These specific types of buildings were chosen to measure the effects that building usage has on energy consumption. Offices are open during the day year-round (excluding holidays). Schools are open during the day, but are closed for summer break, which is the hottest part of the year. Hospitals are open all day every day, including holidays. All the default settings in eQUEST were used with the exception of the roof type and energy costs, and the zoning pattern was changed to "one per floor." A detailed summary report was produced after each building performance simulation, and the following types of simulation results that were collected and where in the report they were collected are as follows:

Metered Energy (kWh), Total Charge ($) – ES-E Summary of Utility Rate: Custom Elec Rate

Metered Energy (therm), Total Charge ($) – ES-E Summary of Utility Rate: Custom Gas Rate

Roof Conduction (Sensible, kBTU/H) – LS-B Space Peak Load Components: Plnm (T.--)

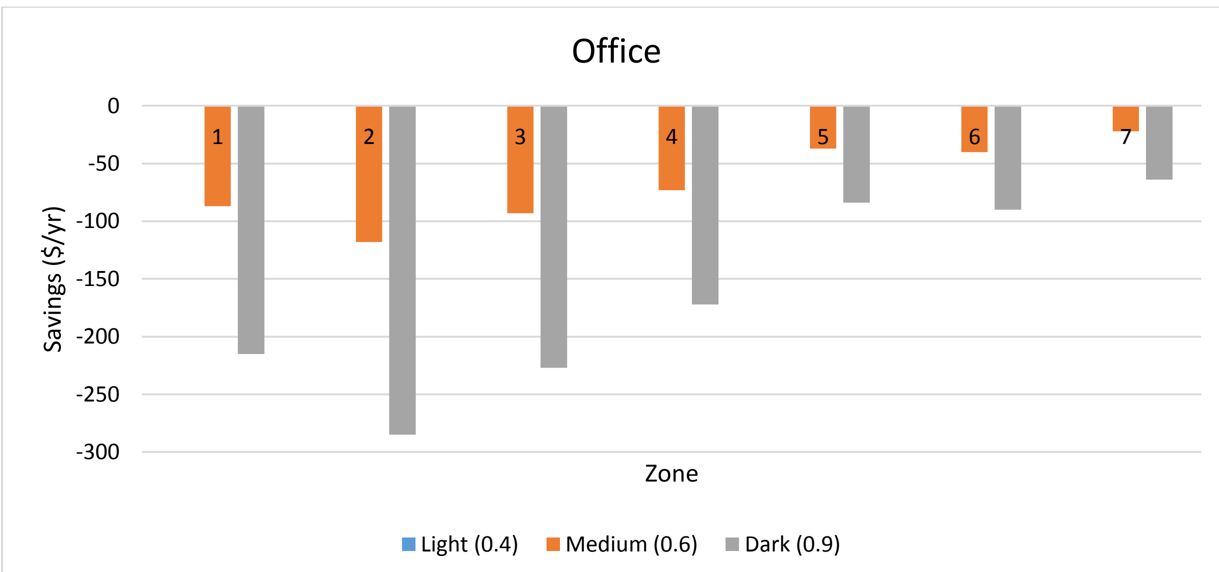
Max Cooling Load (kBTU/H), Max Heating Load (kBTU/H) – SS-D Building HVAC Load Summary

Max Hourly Cooling Load (kBTU), Max Hourly Heating Load (kBTU), and respective dates – SS-J Peak Heating and Cooling for: Sys1 (DDS) (T)

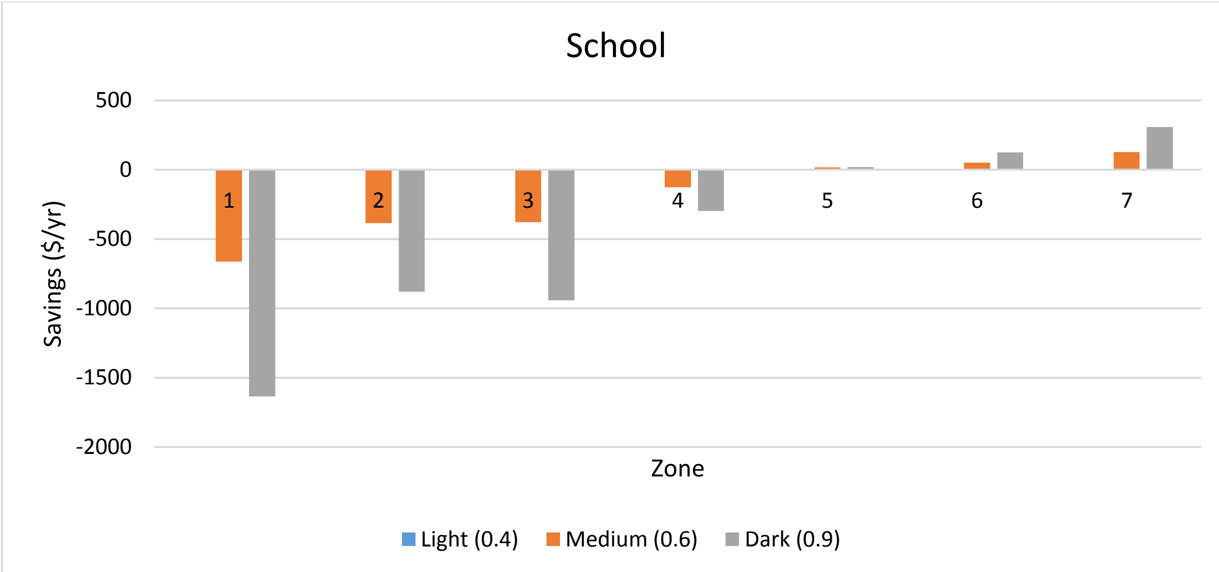
From the simulation results collected, graphs were made comparing the total cost, total cost per square foot, savings, savings per square foot, peak heating and cooling, and HVAC peak heating and cooling for each roof type and zone for each building. More details about how eQUEST was used can be found in Appendix A. Graphs and raw simulation results can be found in Appendices B and C, respectively.

Results

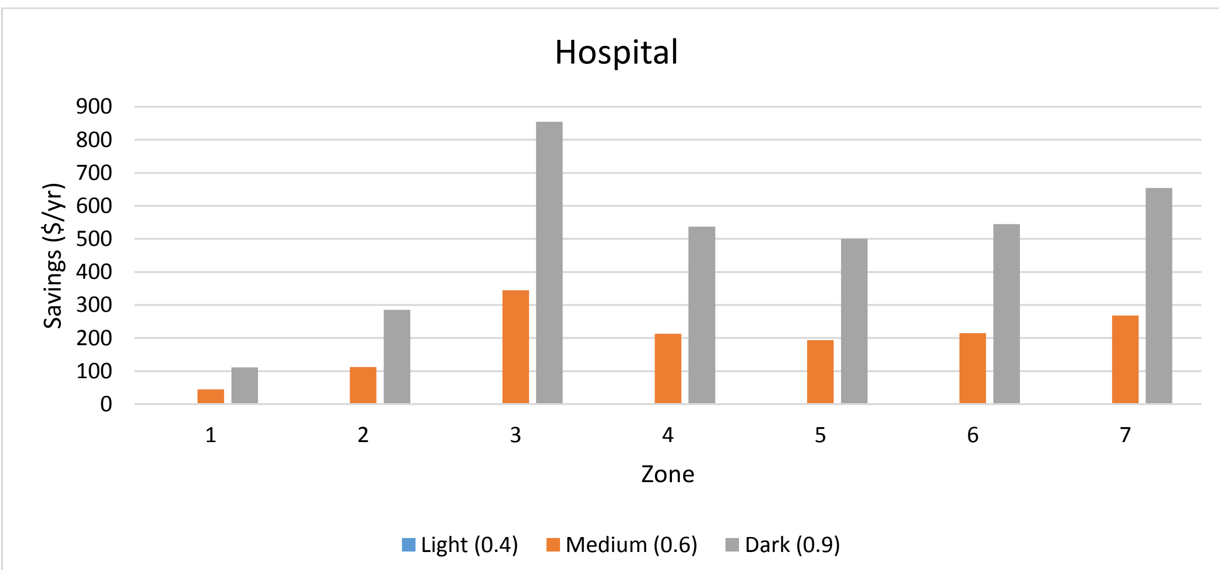
The largest savings resulting from using a cool roof (as opposed to a dark roof) on a school was in zone 1 at $1634 in a year. The largest savings resulting from using a cool roof on a small office building was in zone 2 at $285 in a year. Using a cool roof on a hospital in all zones resulted in an increase in energy costs, the greatest of which was in zone 3 at $854 in a year. The complete results are shown below [negative savings represent a cost, and the light roof (absorptance coefficient of 0.4) is the reference point]:



Graph 1: Office building utility cost savings per year for each ASHRAE climate zone. Note that negative savings represent a cost, and the light roof (absorptance coefficient of 0.4) is the reference/baseline point.

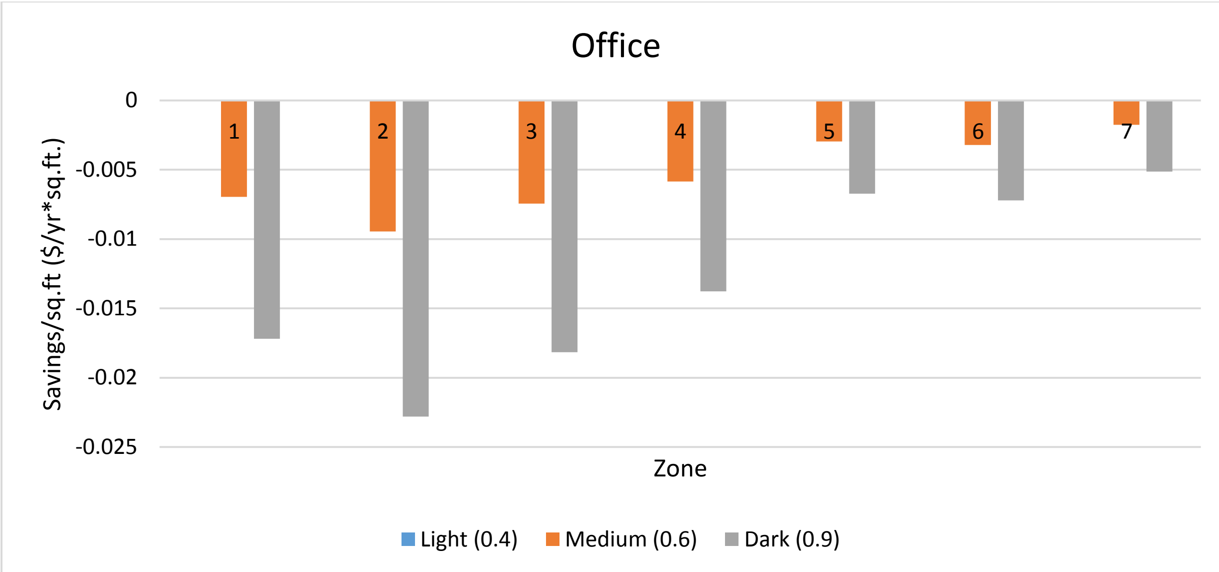


Graph 2: School utility cost savings per year for each ASHRAE climate zone. Note that negative savings represent a cost, and the light roof (absorptance coefficient of 0.4) is the reference/baseline point.

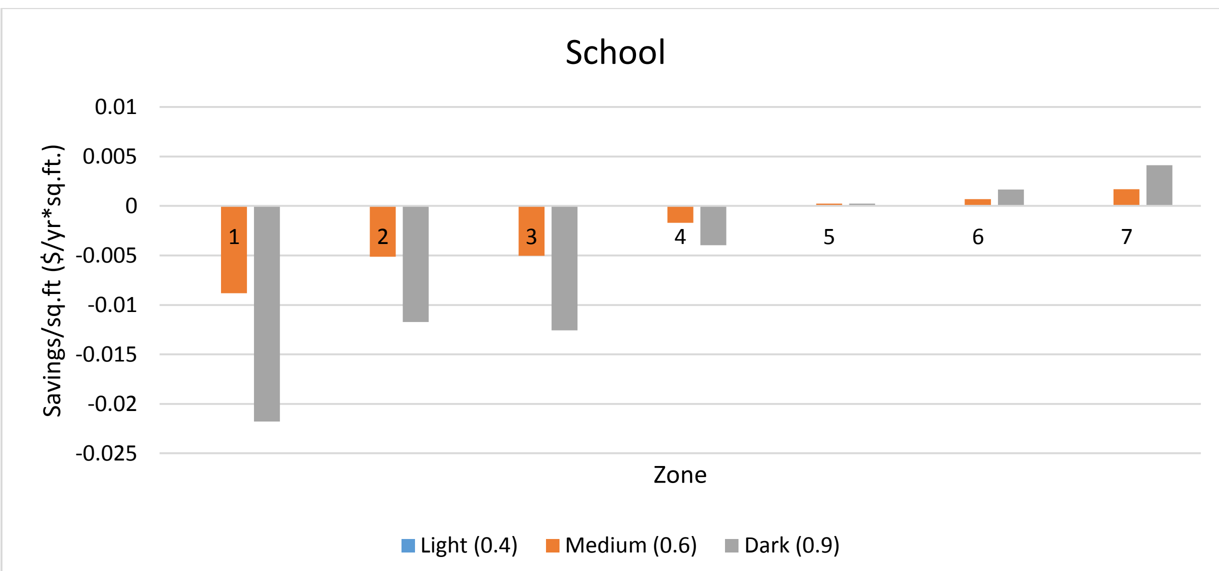


Graph 3: Hospital utility cost savings per year for each ASHRAE climate zone. The light roof (absorptance coefficient of 0.4) is the reference/baseline point.

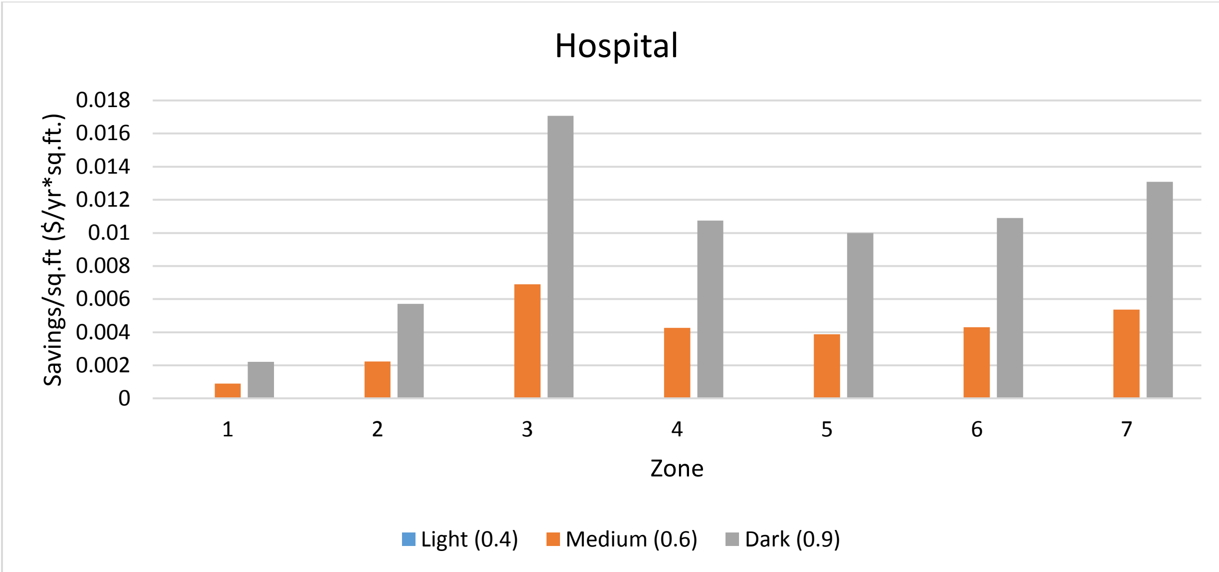
The largest savings per square foot was in an office building in zone 2 at $0.0228/ft^2, followed closely by a school in zone 1 at $0.0218/ft^2. A hospital in zone 3 had the largest cost per square foot at $0.0171/ft^2. The office has a roof area of 12,500 ft^2, the school has a roof area of 75,000 ft^2, and the hospital has a roof area of 50,000 ft^2. The complete results are shown below (negative savings represents a cost, and the light roof is the reference point):



Graph 4: Office utility savings per year per square foot for each ASHRAE climate zone. Note that negative savings represent a cost, and the light roof (absorptance coefficient of 0.4) is the reference/baseline point.



Graph 5: School utility savings per year per square foot for each ASHRAE climate zone. Note that negative savings represent a cost, and the light roof (absorptance coefficient of 0.4) is the reference/baseline point.



Graph 6: Hospital utility savings per year per square foot for each ASHRAE climate zone. The light roof (absorptance coefficient of 0.4) is the reference/baseline point.

Economic Analysis

To determine the overall savings and maximum economic impact of using a cool roof, the largest savings from the three buildings was used (office in zone 2). Table 5 in the DOE report (shown in Table 1 below) lists the price premiums of several cool roof types over their dark roof counterparts.

Roof	Typical Non-Cool Surface	Cool Alternative	Price Premium ($/ft^2)
Built-Up Roof	Mineral aggregate embedded in flood coat	Light-colored aggregate, like marble chips, gray slag	0.00
	Asphaltic emulsion	Field applied coating on top of emulsion	0.80-1.50
	Mineral surfaced cap sheet	White mineral granules	0.50
Metal§	Unpainted metal	May already be cool	0.00
		Factory applied white paint	0.20
	Painted metal	Cool-colored paint	0.00-1.00+
Modified Bitumen	Mineral surfaced cap sheet	Factory applied coating, white mineral granules	0.50
	Gravel surface in bitumen	Light colored gravel	0.00
	Metallic foil	May already be cool	0.00
		Field applied coating	0.80-1.50
	Asphalt coating	Field applied coating on top of asphaltic coating	0.80-1.50
Shingles§	Mineral granules	White granules	0.00
		Cool-colored granules	0.35-0.75
Sprayed Polyurethane Foam	Liquid applied coating	Most coatings are already cool to protect the foam	0.00
	Aggregate	Light colored aggregate	0.00
Thermoplastic Membranes	White, colored, or dark surface	Choose a white or light colored surface	0.00
Thermoset Membranes	Dark membrane, not ballasted (adhered or mechanically attached)	Cool EPDM formulation	0.10-0.15
		Factory cool ply or coating on dark EPDM	0.50
Tiles§	Non-reflective colors	Clay, slate: naturally cool	0.00
		Cool colored coatings	0.00

*Premiums are the extra cost, per square foot of roof area, of installing the cool roof option as compared with the corresponding non-cool option. Premiums are based on achieving the minimum cool roof characteristics described in Table 1. Values are approximate, and are based on discussions with roofing contractors, manufacturers, wholesalers, and RSMeans cost data.
§These roofs may be used in steep slope applications where cool roof requirements are less stringent. Uncoated metal roofs normally meet requirements for steep slope, but not for low slope. Premiums for shingles & tiles are based on steep slope requirements. All other premiums are based on low slope requirements.

Table 1: Roof surfaces, cool alternatives, and approximate price premiums* (1).

Many types of cool roofs, such as shingles, modified bitumen, metal, thermoplastic and thermoset membranes, and tiles, cost the same as dark roofs, so there are no price premiums. Some types of cool roofs, however, do carry price premiums, such as the popular EPDM coating. Firestone Building Products, has created an EPDM coating with an initial reflectivity of 0.8, which corresponds to an absorbance of 0.2 (13). This reflectivity value will decrease over time (to 0.72 over three years, according to the Cool Roofs Rating Council), but an absorbance of 0.28 after 3 years leads to even lower energy costs than the generic roof absorbance rating of 0.4 used in the eQUEST simulations, which means actual savings from using a cool roof will be greater than the eQUEST simulation suggests. Using the simulation results with a cool roof absorptivity of 0.4 and dark roof absorptivity of 0.9, however, and assuming that a new roof is being constructed with a white EPDM coating that carries a price premium of $0.125/ft^2 over its dark roof counterpart, an internal rate of return can be calculated. According to a Progressive Materials article (14), EPDM roofs can last between 25 and 30 years. Using a modest increase in energy costs of

2% per year and a roof life of 30 years, an IRR of 20.1% was calculated using Microsoft Excel's IRR function. The IRR of other using other roof materials on different buildings in the various zones can similarly be calculated. With many of the suggested materials, building a cool roof carries no premium over building a dark roof, and so the annual savings in energy costs would come with no initial cost.

Using the building that benefits the most from a cool roof, the office in zone 2, the Excel "Solver" function, and the above assumptions of a 2% increase in energy costs per year and a roof life of 30 years, the break-even point (0% IRR) comes at spending $\$0.925/ft^2$ on a cool roof. All of the costs of making an existing non-cool roof a cool roof given in Table 6 of the DOE report (shown in Table 2 below) can far exceed this break-even price, so upgrading an existing roof is most likely economically unadvisable unless a significantly higher energy cost increase is experienced, the actual cost of the upgrade is on the low end of the approximate cost, or other incentives are offered from the government or energy suppliers.

Roof	Maintenance Option	Cool Alternative	Price Premium ($\$/ft^2$)
Smooth Dark Surface	Leave roof as-is	Apply cool coating	1.25-2.40
	Apply restorative dark coating (asphalt, bitumen, colored coating, etc.)	Apply cool coating instead	0.00-1.70
Rough Dark Surface	Leave roof as-is	Apply cool coating	1.45-2.75
	Apply restorative dark coating (asphalt, bitumen, colored coating, etc.)	Apply cool coating instead	0.00-1.90
Old Light or Cool Surface	Leave roof as-is	Apply maintenance coat (single coat)	0.80-2.00
	Apply restorative dark maintenance coating (asphalt, bitumen, colored coating, etc.)	Apply cool maintenance coating (single coat)	0.00-1.45
Any Roof	Replace roof	Replace with cool roof	See Table 5

***Premiums are the extra cost, per square foot of roof area, of installing the cool roof option as compared with the corresponding non-cool option. Premiums are based on achieving the minimum cool roof characteristics described in Table 1. Values are approximate, and are based on discussions with roofing contractors, manufacturers, wholesalers, and RSMeans cost data.**

Table 2: Making an existing roof cool, approximate price premiums* (1).

Using a cool roof significantly changed the roof load in all of the buildings in all of the zones, the smallest of which was a 43% decrease in the office in zone 2, and largest of which was a 52% decrease in the school in zone 7. The overall cost, cost per square foot, peak heating and cooling values, and HVAC heating and cooling values were not significantly affected. These graphs can be found in Appendix B.

According to the eQUEST simulations, using a cool roof on a hospital anywhere in the United States increases the total energy consumption, and therefore is not advisable. In offices and schools in zones 4, 5, 6, and 7, and schools in zones 2 and 3, the largest IRR obtained with assumptions of a 30 year roof life, energy increases of 4% per year, and a cool roof premium of $\$0.125/ft^2$ is 14.4%, so utilizing a cool roof may not be the most profitable investment; however, in many situations, it is economically viable. For schools in zone 1 and offices in zones 1, 2, and 3, utilizing cool roofs may be a good investment, depending on the company or school's minimum attractive rate of return (MARR). When constructing a roof where the cost of a cool roof and non-cool roof are the same, utilizing a cool roof is the better option in offices in all zones and schools in all zones except zones 5, 6, and 7.

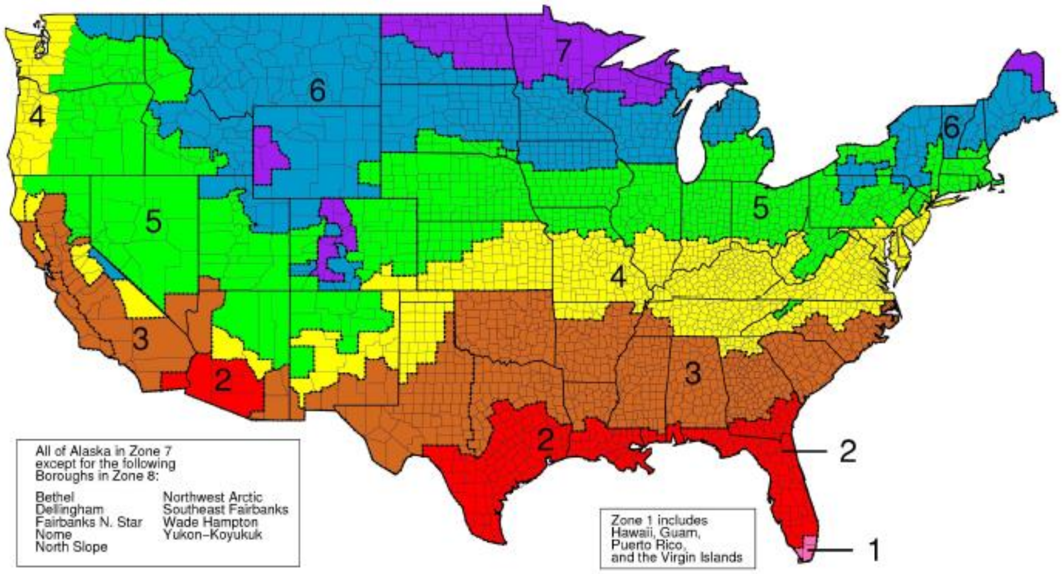
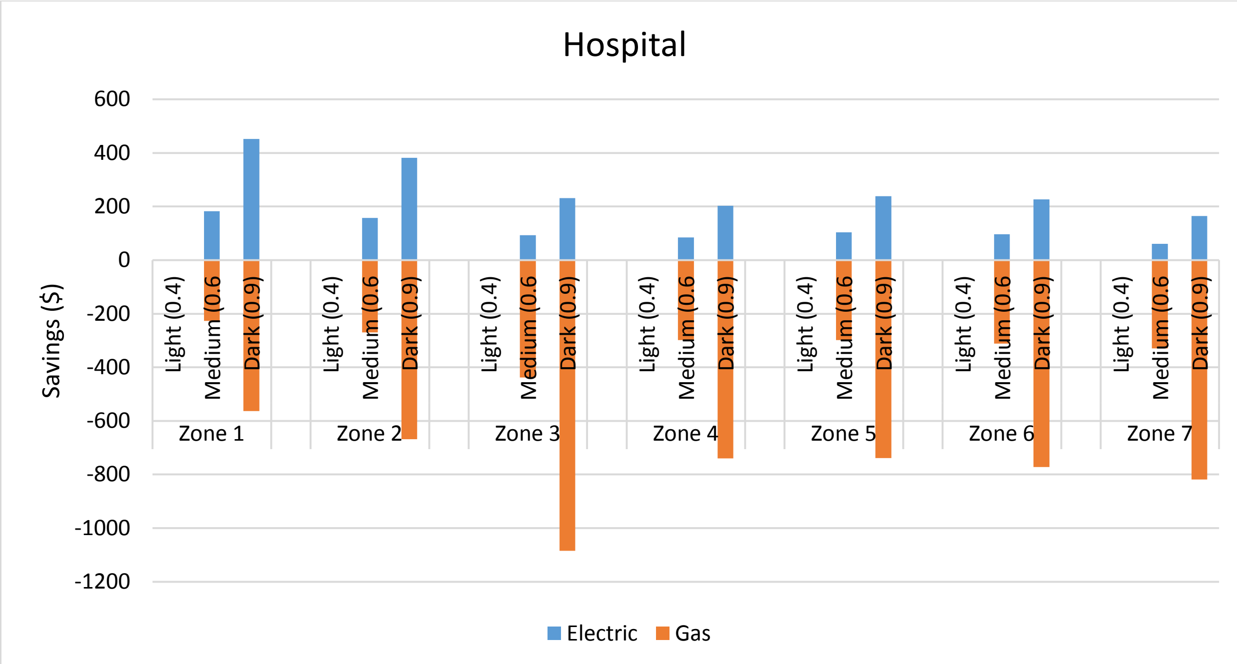


Figure 7: ASHRAE climate zone map (12).

Discussion

Using a cool roof is not advantageous when the building needs to be heated or cooled constantly, such as in a hospital, because the increase in heating costs outweigh the savings in cooling costs (as shown in Graph 7). In buildings that are open all year, but only during the day (offices, retailers, grocery stores, etc.), using cool roofs decreases energy consumption in all areas of the United States. Finally, in buildings that are only open part of the year, such as schools, using cool roofs reduces costs across most of the middle and southern parts of the United States. Graphs displaying the office and school savings in electric and gas costs for the different roof types of roofs can be found in Appendix B.



Graph 7: Hospital electric and gas savings per year for each ASHRAE climate zone. Note that a negative savings represents a cost, and the light roof (absorptance coefficient of 0.4) is the reference/baseline point.

Because many cool roof materials carry no premium over their non-cool roof counterparts, building a cool roof is economically beneficial in many commercial buildings and areas around the United States. Even with small price premiums, investing in a cool roof can have an internal return rate of over 20%. Upgrading a non-cool roof to a cool roof (when building a new roof is not necessary) is almost never advisable because it is not usually economically beneficial. In other words, the cost differential for replacement may be viable, but it is unlikely to be cost effective otherwise.

The economic benefit of a cool roof can be even greater than what was calculated, depending on actual solar reflectance and roof life; for example, cool Sprayed Polyurethane Foam (SPF) roofs can last upwards of 50+ years (14) and carry no price premium over non-cool SPF roofs. Local energy costs that are different than those used in the simulations will also impact a cool roof's IRR, which will impact its economic viability. An IRR threshold of 15% was used to determine whether or not using a cool roof is economically viable, so changing that threshold would impact in what regions a cool roof is desirable for a specific type of building. Actual savings will vary based on weather (snowfall, number of hot, cool days, etc.), building insulation, roof thermal admittance, and other factors, so the overall benefit is difficult to predict exactly. Sometimes, as in Los Angeles, incentives are offered for cool roofs, which increases their IRR. Los Angeles even passed an ordinance in 2013 that requires all new and refurbished homes to have cool roofs (15), and New York City has created an collaboration between NYC Service and the NYC Department of Buildings called "NYC °Cool Roofs" to "promote and facilitate the cooling of New York City's rooftops" (16). Large cities are beginning to understand the economic and environmental benefits of cool roofs and are encouraging business people and home owners alike to utilize them. Even in cases where building cool roofs are not very economically beneficial, they have positive environmental impacts, such as reducing local air temperature, which increases air quality, so contractors should still consider building cool roofs over non-cool roofs.

Acknowledgements

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Appendix A
Using eQUEST

All of the default settings in eQUEST were used except for a few, shown below:

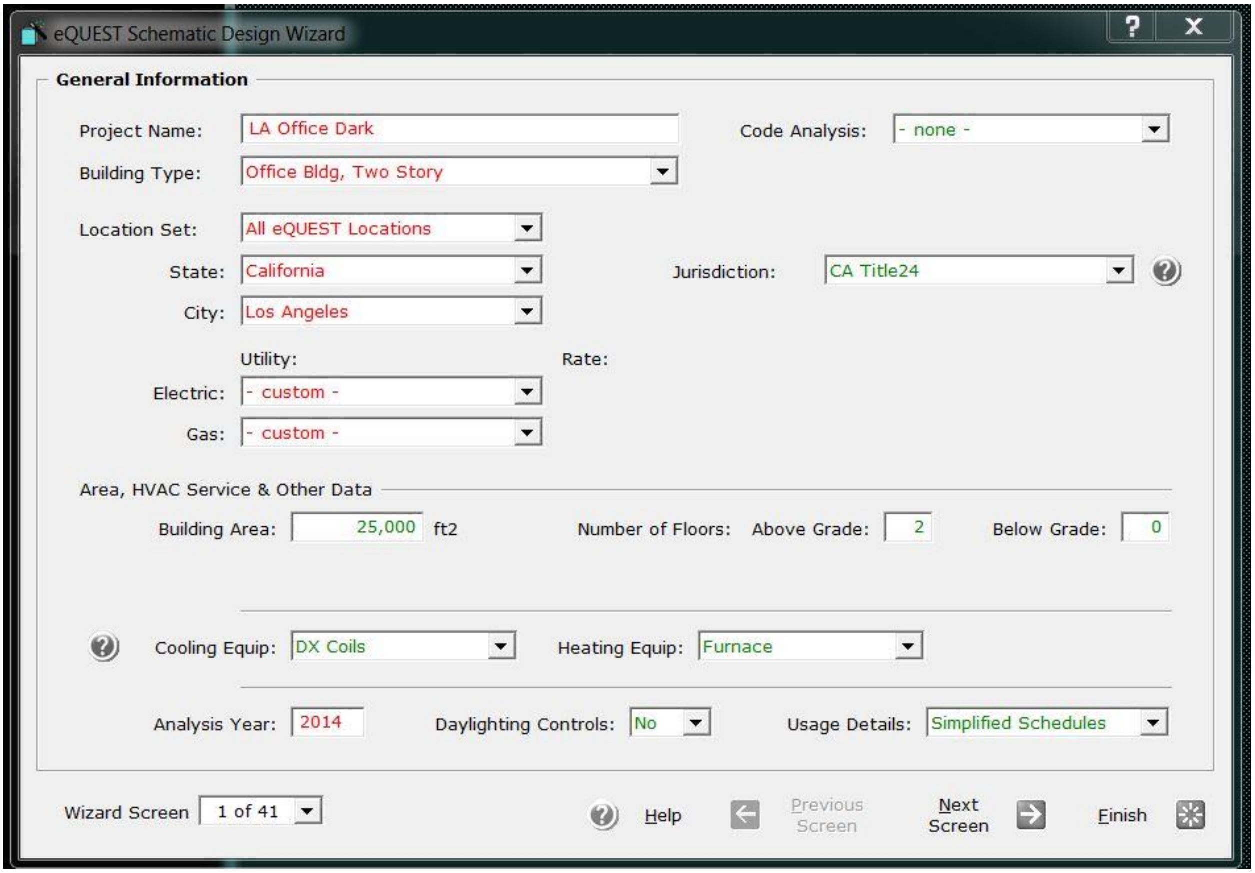

Figure 8: Main screen of the eQUEST Building Creation Wizard.

Figure 8 shows the first screen of the Building Creation Wizard, found on the left-hand side of the main screen. In this window, the type of building, its location, analysis year, and utility rates were all adjusted. The buildings used were Office Bldg, Two Story; Health, Hospital (inpatient); and School, Secondary (High School). The locations used for zones 1-7, in order, were Miami, FL; Houston, TX; Los Angeles, CA; Philadelphia, PA; Chicagosimul, IL; Minneapolis, MN; and Duluth, MN. Data files for these locations can be downloaded from the Internet through eQUEST.

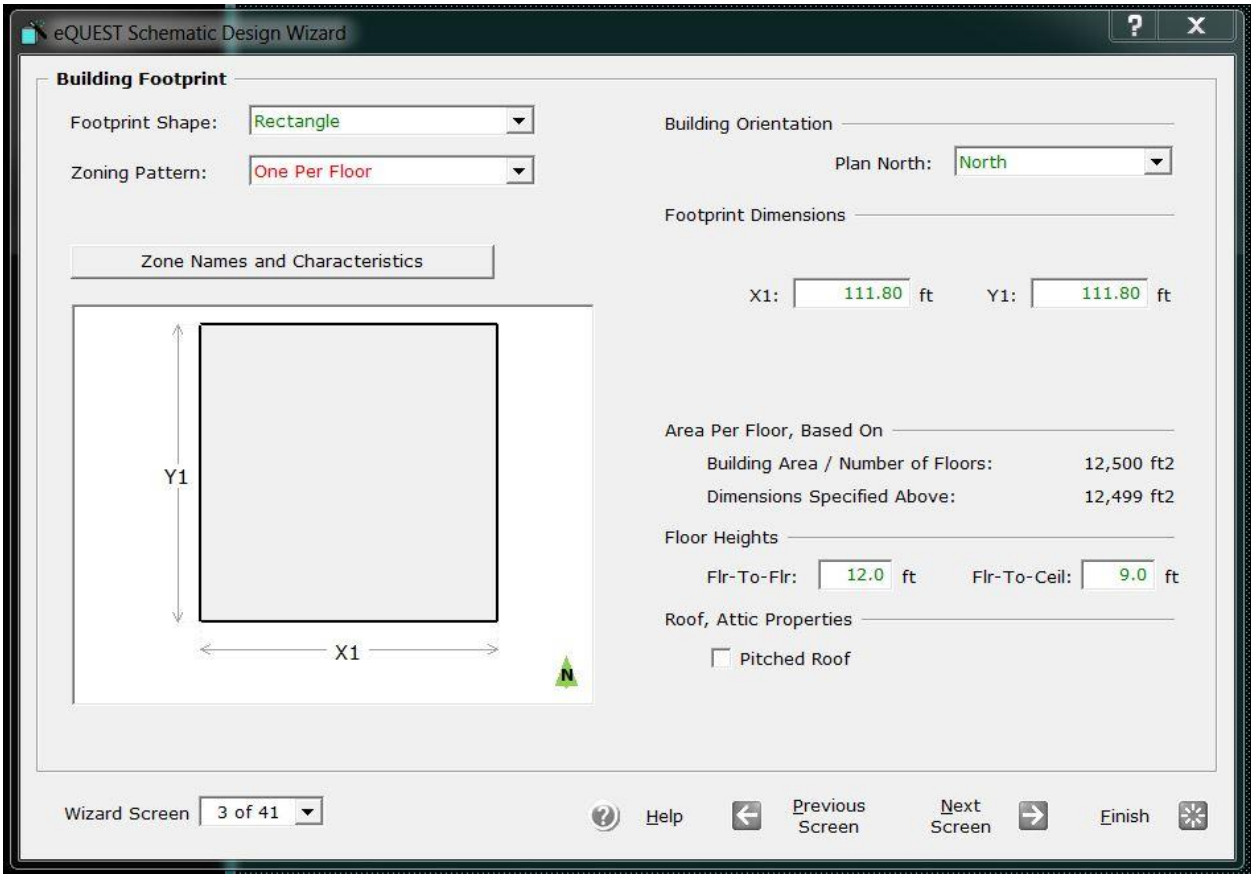

Figure 9: Zoning pattern in the eQUEST Building Simulation Wizard.

The zoning patter of all buildings was changed to "One Per Floor" because only one zone (roof) is being considered. Roof area can also be calculated by multiplying the X1 and Y1 footprint dimensions, or by dividing the building area by the total number of floors, which are both shown in Figure 8.

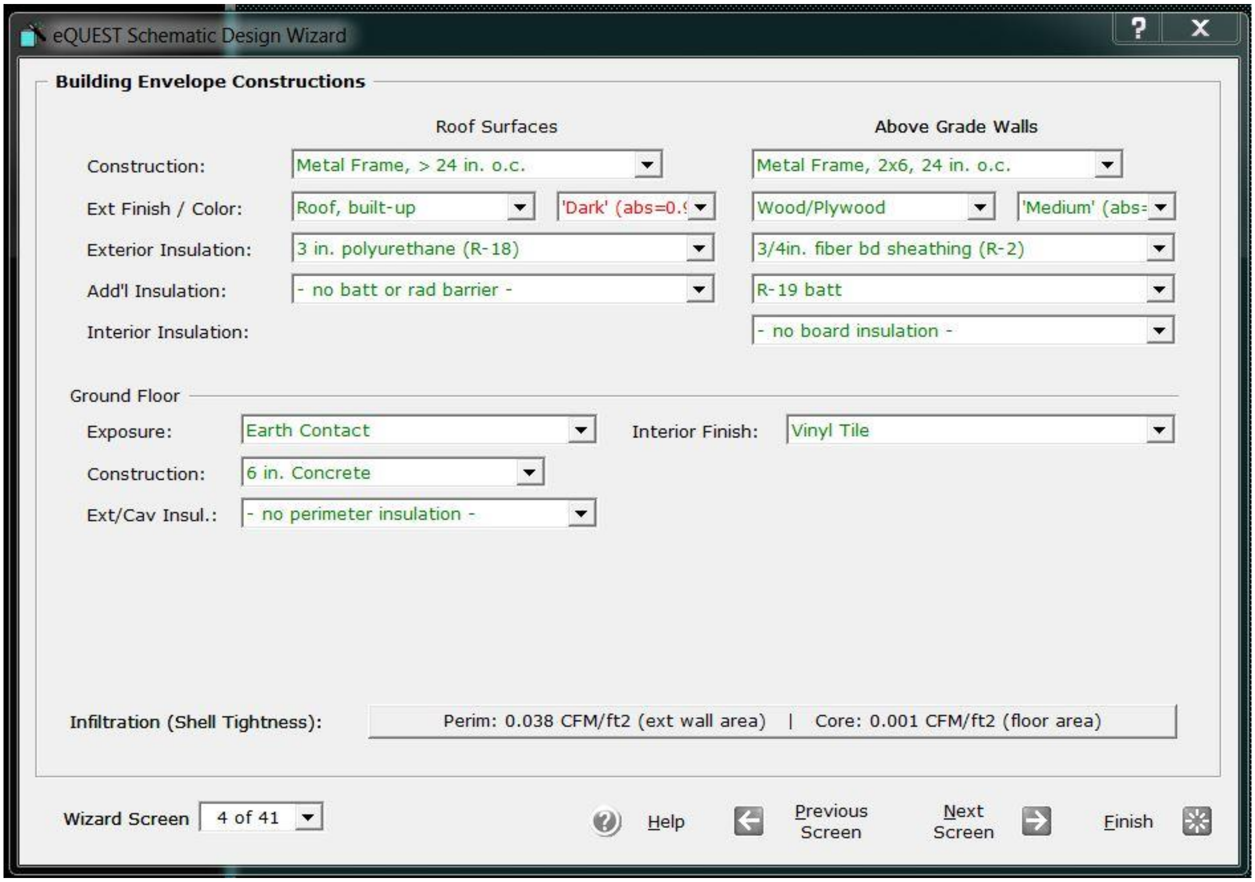

Figure 10: Roof color in the eQUEST Building Simulation Wizard.

Roof color can be changed in this window. Dark (abs=0.9), Medium (abs=0.6), and Light (abs=0.4) colors were used.

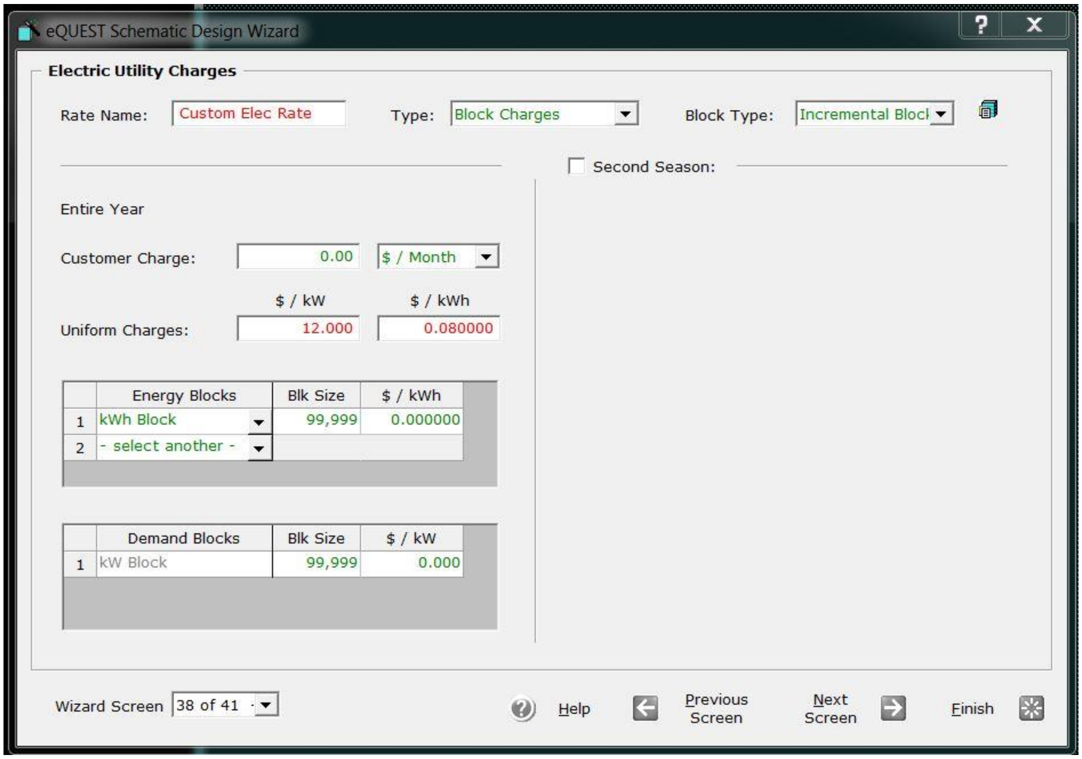

Figure 11: Custom electric rate in the eQUEST Building Simulation Wizard.

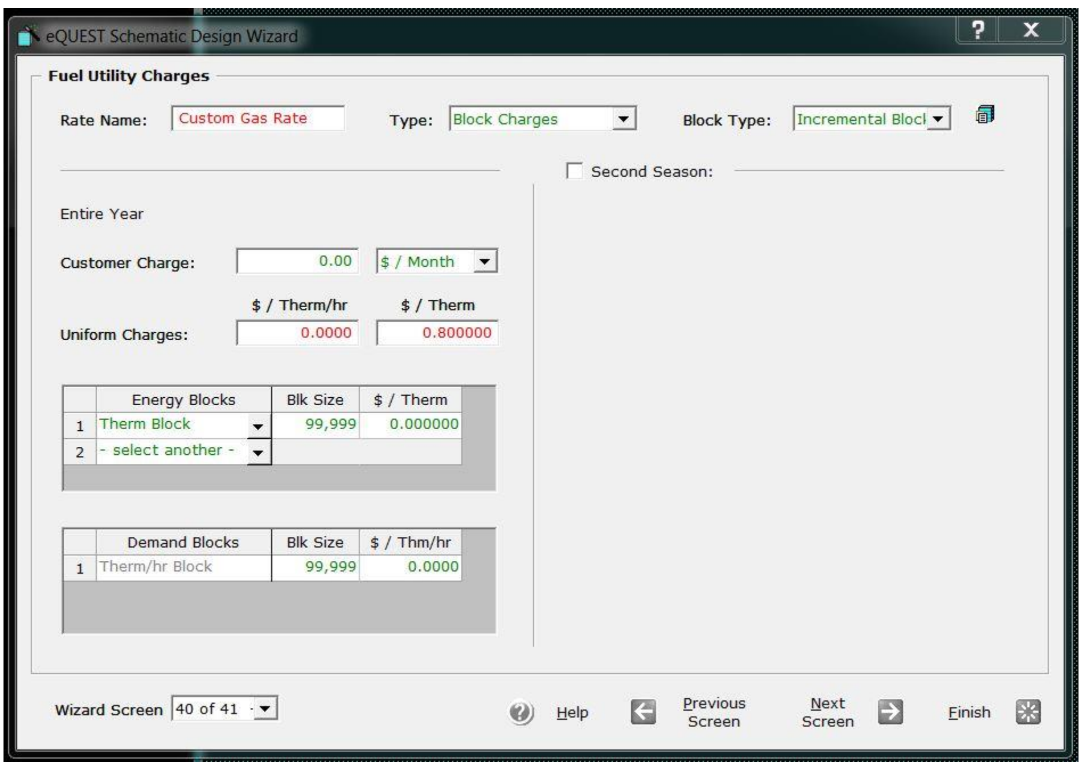

Figure 12: Custom gas rate in the eQUEST Building Simulation Wizard.

Custom gas and electric rates were used as shown.

After all inputs are finished, the simulation can be run. The “Simulate Building Performance” button on the left side of the screen can be clicked, which brings up a window that presents three options. When “View Detailed Simulation Output File…” is chosen, a long text document is created, and the following simulation results can be collected:

Metered Energy (kWh), Total Charge ($) – ES-E Summary of Utility Rate: Custom Elec Rate

Metered Energy (therm), Total Charge ($) – ES-E Summary of Utility Rate: Custom Gas Rate

Roof Conduction (Sensible, kBTU/H) – LS-B Space Peak Load Components: Plnm (T.--)

Max Cooling Load (kBTU/H), Max Heating Load (kBTU/H) – SS-D Building HVAC Load Summary

Max Hourly Cooling Load (kBTU), Max Hourly Heating Load (kBTU), and respective dates – SS-J Peak Heating and Cooling for: Sys1 (DDS) (T)

The locations of these values are shown below:

LA Office Dark - Baseline Design.SIM - D2SimViewer

File Edit View Window Help

Report: ES-E Summary of Utility-Rate: | Component: Custom Elec Rate

```
LA Office Dark                                                          DOE-2.2-48r    3/13/2015    10:18:37  BDL RUN  4

REPORT- ES-E Summary of Utility-Rate:       Custom Elec Rate                              WEATHER FILE- CZ06RV2 WYEC2
---------------------------------------------------------------------------------------------------------------------------

        RESOURCE:  ELECTRICITY          DEMAND-INTERVAL  15                    3413. BTU/KWH
     BILLING-DAY:  31                 RATE-LIMITATION:    0.0000
          METERS:  EM1
    POWER-FACTOR:  0.80              EXCESS-KVAR-FRAC:  0.75          EXCESS-KVAR-CHG:   0.0000

 RATE-QUALIFICATIONS           BLOCK-CHARGES                  DEMAND-RATCHETS                 MIN-MON-RATCHETS
 -------------------------   ------------------------------  ------------------------------  ------------------------------
   MIN-ENERGY:          0.0  Cust 1 Elec Uniform Blk1
   MAX-ENERGY:          0.0
   MIN-DEMAND:          0.0
   MAX-DEMAND:          0.0
 QUALIFY-RATE:     ALL YEAR
 USE-MIN-QUAL:           NO
```

MONTH	METERED ENERGY KWH	BILLING ENERGY KWH	METERED DEMAND KW	BILLING DEMAND KW	ENERGY CHARGE ($)	DEMAND CHARGE ($)	ENERGY CST ADJ ($)	TAXES ($)	SURCHRG ($)	FIXED CHARGE ($)	MINIMUM CHARGE ($)	VIRTUAL RATE ($/UNIT)	TOTAL CHARGE ($)
JAN	15360	15360	82.1	82.1	1229	986	0	0	0	0	0	0.1442	2214
FEB	14066	14066	83.8	83.8	1125	1006	0	0	0	0	0	0.1515	2131
MAR	15680	15680	91.8	91.8	1254	1102	0	0	0	0	0	0.1503	2356
APR	16696	16696	89.5	89.5	1336	1074	0	0	0	0	0	0.1443	2409
MAY	16766	16766	91.0	91.0	1341	1091	0	0	0	0	0	0.1451	2433
JUN	18355	18355	100.7	100.7	1468	1209	0	0	0	0	0	0.1459	2677
JUL	20920	20920	103.0	103.0	1674	1236	0	0	0	0	0	0.1391	2909
AUG	20453	20453	100.5	100.5	1636	1206	0	0	0	0	0	0.1390	2842
SEP	19915	19915	107.8	107.8	1593	1293	0	0	0	0	0	0.1449	2886
OCT	18866	18866	102.5	102.5	1509	1230	0	0	0	0	0	0.1452	2740
NOV	14418	14418	88.3	88.3	1153	1059	0	0	0	0	0	0.1535	2213
DEC	16037	16037	84.7	84.7	1283	1016	0	0	0	0	0	0.1434	2299
TOTAL	207531	207531	107.8		16603	13508	0	0	0	0		0.1451	30110

```
LA Office Dark                                                          DOE-2.2-48r    3/13/2015    10:18:37  BDL RUN  4

REPORT- ES-F Block-Charges and Ratchets for Custom Elec Rate                              WEATHER FILE- CZ06RV2 WYEC2
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```
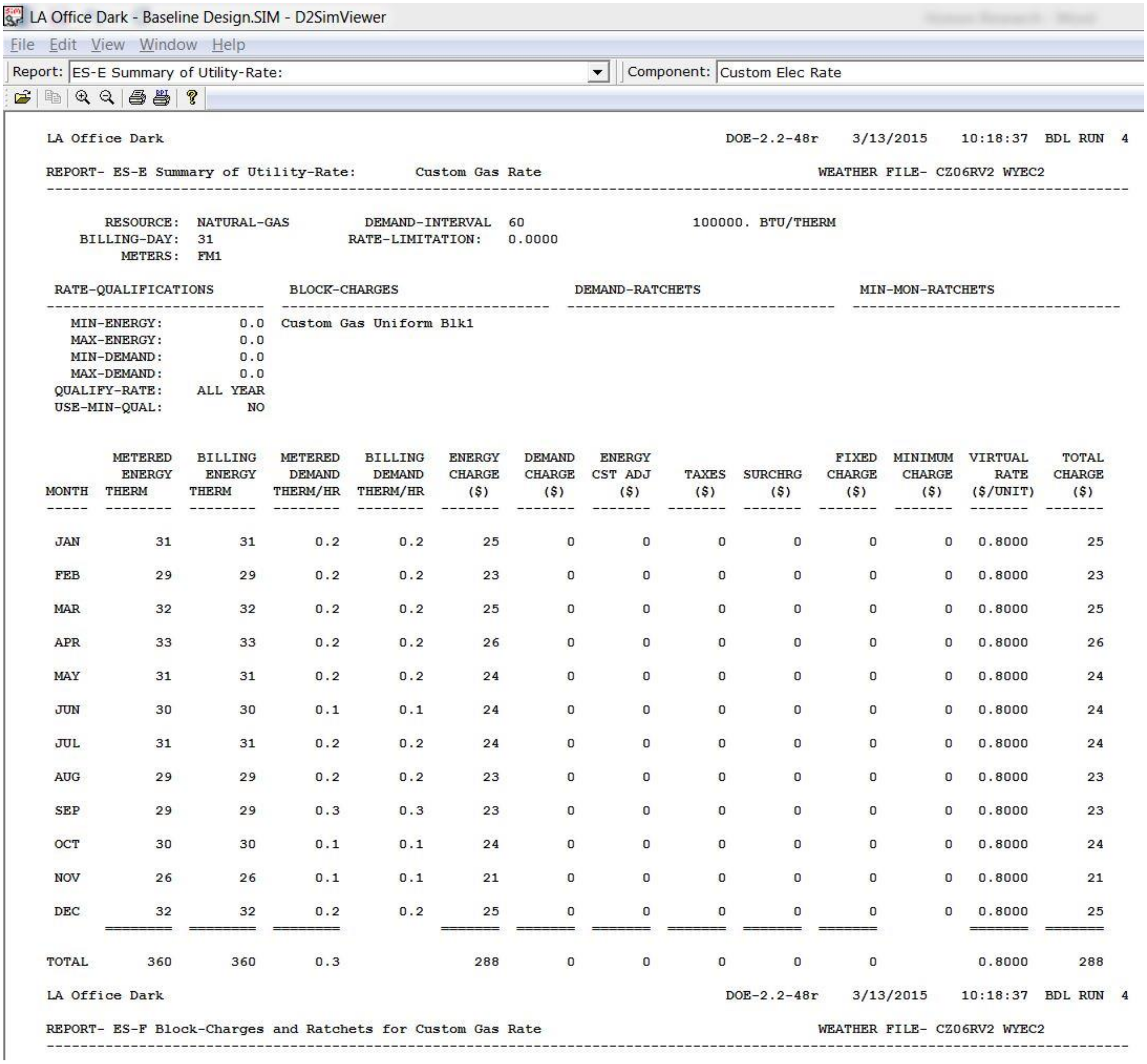

Figure 13: Electric cost in the eQUEST Detailed Simulation Output File.

Total Metered Energy (kWh) and Total Charge ($) were collected.



LA Office Dark - Baseline Design.SIM - D2SimViewer

File Edit View Window Help

Report: ES-E Summary of Utility-Rate: Component: Custom Elec Rate

LA Office Dark DOE-2.2-48r 3/13/2015 10:18:37 BDL RUN 4

REPORT- ES-E Summary of Utility-Rate: Custom Gas Rate WEATHER FILE- CZ06RV2 WYEC2

RESOURCE: NATURAL-GAS DEMAND-INTERVAL 60 100000. BTU/THERM
BILLING-DAY: 31 RATE-LIMITATION: 0.0000
METERS: FM1

RATE-QUALIFICATIONS		BLOCK-CHARGES	DEMAND-RATCHETS	MIN-MON-RATCHETS
MIN-ENERGY:	0.0	Custom Gas Uniform Blk1		
MAX-ENERGY:	0.0			
MIN-DEMAND:	0.0			
MAX-DEMAND:	0.0			
QUALIFY-RATE:	ALL YEAR			
USE-MIN-QUAL:	NO			

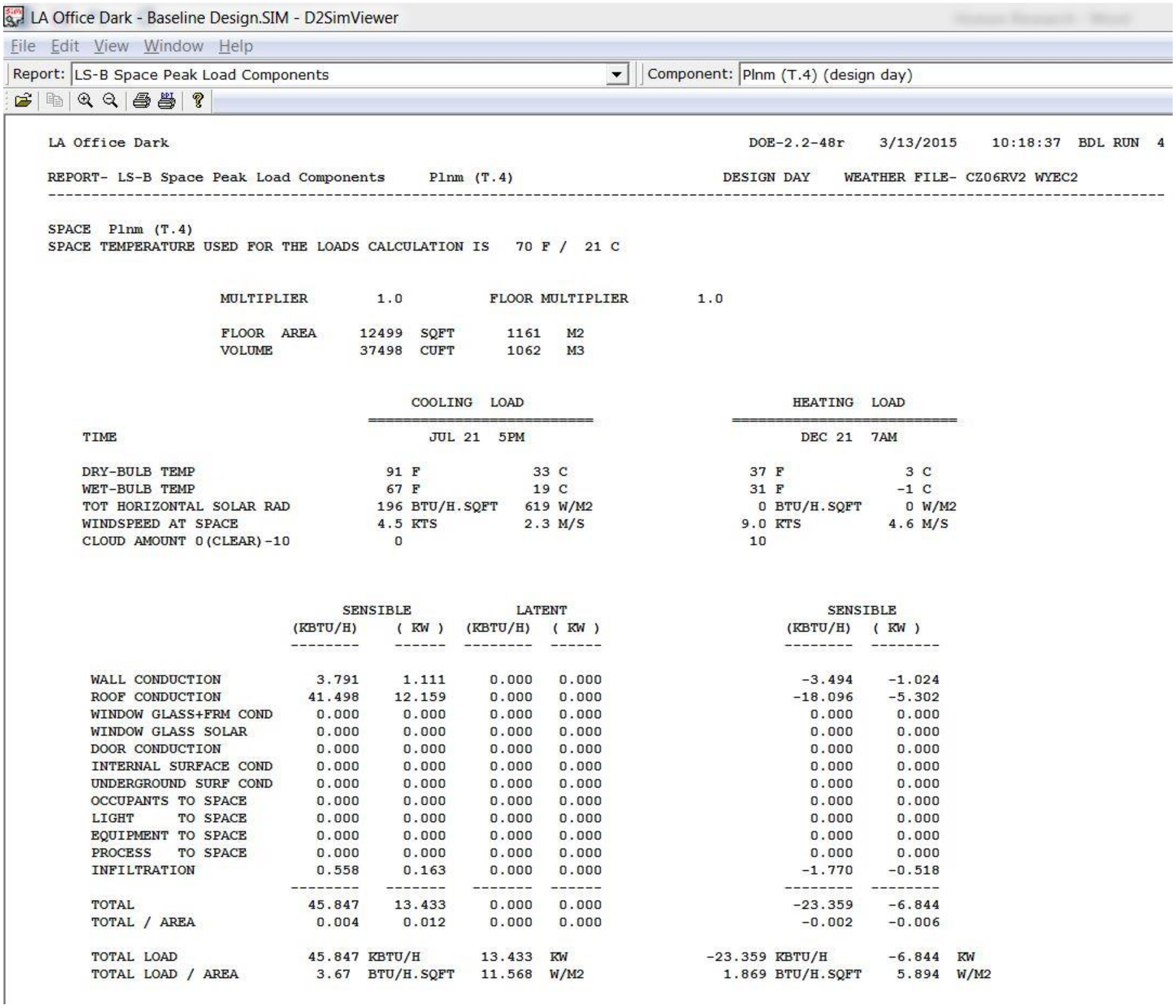
MONTH	METERED ENERGY THERM	BILLING ENERGY THERM	METERED DEMAND THERM/HR	BILLING DEMAND THERM/HR	ENERGY CHARGE ($)	DEMAND CHARGE ($)	ENERGY CST ADJ ($)	TAXES ($)	SURCHRG ($)	FIXED CHARGE ($)	MINIMUM CHARGE ($)	VIRTUAL RATE ($/UNIT)	TOTAL CHARGE ($)
JAN	31	31	0.2	0.2	25	0	0	0	0	0	0	0.8000	25
FEB	29	29	0.2	0.2	23	0	0	0	0	0	0	0.8000	23
MAR	32	32	0.2	0.2	25	0	0	0	0	0	0	0.8000	25
APR	33	33	0.2	0.2	26	0	0	0	0	0	0	0.8000	26
MAY	31	31	0.2	0.2	24	0	0	0	0	0	0	0.8000	24
JUN	30	30	0.1	0.1	24	0	0	0	0	0	0	0.8000	24
JUL	31	31	0.2	0.2	24	0	0	0	0	0	0	0.8000	24
AUG	29	29	0.2	0.2	23	0	0	0	0	0	0	0.8000	23
SEP	29	29	0.3	0.3	23	0	0	0	0	0	0	0.8000	23
OCT	30	30	0.1	0.1	24	0	0	0	0	0	0	0.8000	24
NOV	26	26	0.1	0.1	21	0	0	0	0	0	0	0.8000	21
DEC	32	32	0.2	0.2	25	0	0	0	0	0	0	0.8000	25
TOTAL	360	360	0.3		288	0	0	0	0	0		0.8000	288

LA Office Dark DOE-2.2-48r 3/13/2015 10:18:37 BDL RUN 4

REPORT- ES-F Block-Charges and Ratchets for Custom Gas Rate WEATHER FILE- CZ06RV2 WYEC2

Figure 14: Gas cost in the eQUEST Detailed Simulation Output File.

Total Metered Energy (therm) and Total Charge ($) were collected.



LA Office Dark - Baseline Design.SIM - D2SimViewer

File Edit View Window Help

Report: LS-B Space Peak Load Components | Component: Plnm (T.4) (design day)

```
LA Office Dark                                                            DOE-2.2-48r    3/13/2015    10:18:37  BDL RUN  4

REPORT- LS-B Space Peak Load Components      Plnm (T.4)                 DESIGN DAY     WEATHER FILE- CZ06RV2 WYEC2
---------------------------------------------------------------------------------------------------------------------------

SPACE  Plnm (T.4)
SPACE TEMPERATURE USED FOR THE LOADS CALCULATION IS   70 F /  21 C

                   MULTIPLIER        1.0         FLOOR MULTIPLIER        1.0

                   FLOOR  AREA     12499  SQFT      1161   M2
                   VOLUME          37498  CUFT      1062   M3

                                        COOLING  LOAD                        HEATING  LOAD
                                    ==========================          ==========================
    TIME                                   JUL 21  5PM                         DEC 21  7AM

    DRY-BULB TEMP                     91 F              33 C              37 F              3 C
    WET-BULB TEMP                     67 F              19 C              31 F             -1 C
    TOT HORIZONTAL SOLAR RAD         196 BTU/H.SQFT    619 W/M2            0 BTU/H.SQFT     0 W/M2
    WINDSPEED AT SPACE               4.5 KTS           2.3 M/S           9.0 KTS           4.6 M/S
    CLOUD AMOUNT 0(CLEAR)-10          0                                   10


                                  SENSIBLE           LATENT                         SENSIBLE
                             (KBTU/H)    ( KW )  (KBTU/H)  ( KW )              (KBTU/H)  ( KW )
                             --------    ------  --------  ------              --------  --------

     WALL CONDUCTION            3.791     1.111     0.000   0.000                -3.494    -1.024
     ROOF CONDUCTION           41.498    12.159     0.000   0.000               -18.096    -5.302
     WINDOW GLASS+FRM COND      0.000     0.000     0.000   0.000                 0.000     0.000
     WINDOW GLASS SOLAR         0.000     0.000     0.000   0.000                 0.000     0.000
     DOOR CONDUCTION            0.000     0.000     0.000   0.000                 0.000     0.000
     INTERNAL SURFACE COND      0.000     0.000     0.000   0.000                 0.000     0.000
     UNDERGROUND SURF COND      0.000     0.000     0.000   0.000                 0.000     0.000
     OCCUPANTS TO SPACE         0.000     0.000     0.000   0.000                 0.000     0.000
     LIGHT     TO SPACE         0.000     0.000     0.000   0.000                 0.000     0.000
     EQUIPMENT TO SPACE         0.000     0.000     0.000   0.000                 0.000     0.000
     PROCESS   TO SPACE         0.000     0.000     0.000   0.000                 0.000     0.000
     INFILTRATION               0.558     0.163     0.000   0.000                -1.770    -0.518
                             --------   -------   -------  ------              --------  --------
     TOTAL                     45.847    13.433     0.000   0.000               -23.359    -6.844
     TOTAL / AREA               0.004     0.012     0.000   0.000                -0.002    -0.006

     TOTAL LOAD                45.847 KBTU/H     13.433  KW            -23.359 KBTU/H       -6.844  KW
     TOTAL LOAD / AREA          3.67  BTU/H.SQFT 11.568  W/M2            1.869 BTU/H.SQFT    5.894  W/M2
```

Figure 15: Roof load in the eQUEST Detailed Simulation Output File.

Roof Conduction – Sensible (kBTU/h) was collected.

LA Office Dark - Baseline Design.SIM - D2SimViewer

File Edit View Window Help

Report: SS-D Building HVAC Load Summary Component:

LA Office Dark DOE-2.2-48r 3/13/2015 10:18:37 BDL RUN 4

REPORT- SS-D Building HVAC Load Summary WEATHER FILE- CZ06RV2 WYEC2

	COOLING						HEATING						ELEC	
MONTH	COOLING ENERGY (MBTU)	TIME OF MAX DY	TIME OF MAX HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM COOLING LOAD (KBTU/HR)	HEATING ENERGY (MBTU)	TIME OF MAX DY	TIME OF MAX HR	DRY-BULB TEMP	WET-BULB TEMP	MAXIMUM HEATING LOAD (KBTU/HR)	ELEC-TRICAL ENERGY (KWH)	MAXIMUM ELEC LOAD (KW)
JAN	3.85042	10	12	79.F	55.F	292.519	0.000	31	24	50.F	49.F	0.000	15360.	81.005
FEB	6.13545	12	14	77.F	54.F	329.077	0.000	28	24	51.F	50.F	0.000	14066.	82.969
MAR	8.74949	18	14	79.F	67.F	429.707	0.000	31	1	52.F	51.F	0.000	15680.	90.681
APR	17.51652	22	12	80.F	63.F	405.649	0.000	30	1	55.F	55.F	0.000	16696.	89.400
MAY	24.22318	30	10	72.F	65.F	434.433	0.000	31	1	54.F	49.F	0.000	16766.	90.565
JUN	51.69802	23	17	77.F	70.F	572.477	0.000	30	1	61.F	58.F	0.000	18355.	100.176
JUL	78.94657	29	11	83.F	72.F	580.841	-0.004	14	8	61.F	57.F	-3.602	20920.	102.467
AUG	81.14722	18	10	76.F	66.F	577.943	-0.003	25	8	63.F	60.F	-3.333	20453.	99.232
SEP	74.18033	8	14	85.F	74.F	655.810	-0.005	15	8	61.F	58.F	-5.170	19915.	107.543
OCT	47.30396	1	14	85.F	73.F	557.905	0.000	31	1	55.F	47.F	0.000	18866.	101.882
NOV	15.71669	3	14	74.F	62.F	417.454	0.000	30	24	52.F	43.F	0.000	14418.	88.059
DEC	5.83104	19	14	79.F	53.F	336.456	0.000	31	24	48.F	47.F	0.000	16037.	84.050
TOTAL	415.299						-0.012						207539.	
MAX						655.810						-5.170		107.543

MAXIMUM DAILY INTEGRATED COOLING LOAD (DES DAY) 0.000 (KBTU)
MAXIMUM DAILY INTEGRATED COOLING LOAD (WTH FILE) 0.000 (KBTU)

LA Office Dark DOE-2.2-48r 3/13/2015 10:18:37 BDL RUN 4

REPORT- SS-E Building HVAC Load Hours WEATHER FILE- CZ06RV2 WYEC2

Figure 16: HVAC peak heating and cooling in the eQUEST Detailed Simulation Output File.

Max Cooling Load (kBTU/hr) and Max Heating Load (kBTU/hr) were collected (year maximum, not monthly maximum).

LA Office Dark - Baseline Design.SIM - D2SimViewer

File Edit View Window Help

Report: SS-J Peak Heating and Cooling for | Component: Sys1 (PSZ) (T.3) (design day)

LA Office Dark DOE-2.2-48r 3/13/2015 10:18:37 BDL RUN 4

REPORT- SS-J Peak Heating and Cooling for Sys1 (PSZ) (T.3) DESIGN DAY WEATHER FILE- CZ06RV2 WYEC2

	- - - - - C O O L I N G - - - - - NOV 2				- - - H E A T I N G - - - DEC 21			D A Y C O O L I N G P E A K JUL 24			
HOUR	HOURLY COOLING LOAD (KBTU)	SENSIBLE HEAT RATIO	DRY-BULB TEMP	WET-BULB TEMP	HOURLY HEATING LOAD (KBTU)	DRY-BULB TEMP	WET-BULB TEMP	HOURLY COOLING LOAD (KBTU)	SENSIBLE HEAT RATIO	DRY-BULB TEMP	WET-BULB TEMP
1	0.000	0.000	78.F	62.F	0.000	37.F	31.F	0.000	0.000	78.F	62.F
2	0.000	0.000	77.F	62.F	0.000	37.F	31.F	0.000	0.000	77.F	62.F
3	0.000	0.000	77.F	62.F	0.000	37.F	31.F	0.000	0.000	77.F	62.F
4	0.000	0.000	77.F	62.F	0.000	37.F	31.F	0.000	0.000	77.F	62.F
5	0.000	0.000	77.F	62.F	0.000	37.F	31.F	0.000	0.000	77.F	62.F
6	0.000	0.000	78.F	62.F	0.000	37.F	31.F	0.000	0.000	78.F	62.F
7	0.000	0.000	79.F	63.F	0.000	37.F	31.F	101.007	0.963	79.F	63.F
8	91.244	0.959	81.F	63.F	-84.337	37.F	31.F	305.576	0.941	81.F	63.F
9	301.303	0.942	83.F	64.F	-152.649	37.F	31.F	308.041	0.933	83.F	64.F
10	311.356	0.936	85.F	64.F	-134.806	37.F	31.F	292.896	0.925	85.F	64.F
11	296.811	0.929	87.F	65.F	-92.723	37.F	31.F	294.136	0.926	87.F	65.F
12	299.628	0.931	88.F	66.F	-79.372	37.F	31.F	292.925	0.929	88.F	66.F
13	307.143	0.934	89.F	66.F	-69.336	37.F	31.F	296.214	0.932	89.F	66.F
14	316.310	0.937	90.F	66.F	-62.098	37.F	31.F	304.005	0.935	90.F	66.F
15	320.812	0.939	91.F	66.F	-57.414	37.F	31.F	310.743	0.937	91.F	66.F
16	315.390	0.938	90.F	66.F	-55.151	37.F	31.F	316.076	0.938	90.F	66.F
17	292.395	0.934	90.F	66.F	-57.968	37.F	31.F	132.233	0.954	90.F	66.F
18	86.572	0.941	89.F	66.F	0.000	37.F	31.F	0.000	0.000	89.F	66.F
19	0.000	0.000	88.F	65.F	0.000	37.F	31.F	0.000	0.000	88.F	65.F
20	0.000	0.000	86.F	65.F	0.000	37.F	31.F	0.000	0.000	86.F	65.F
21	0.000	0.000	84.F	64.F	0.000	37.F	31.F	0.000	0.000	84.F	64.F
22	0.000	0.000	83.F	64.F	0.000	37.F	31.F	0.000	0.000	83.F	64.F
23	0.000	0.000	81.F	63.F	0.000	37.F	31.F	0.000	0.000	81.F	63.F
24	0.000	0.000	80.F	63.F	0.000	37.F	31.F	0.000	0.000	80.F	63.F
SUM								2953.852			
MAX	320.812				-152.649						

SYSTEM-TYPE	PSZ	SQFT/TON	935.1
COOLING PEAK	12.83 (BTU/HR- SQFT)	HEATING PEAK	-6.11 (BTU/HR- SQFT)
SUPPLY AIR PEAK FLOW	0.54 (CFM/SQFT)	MIN-OA/PERSON	24.25 (CFM)
OA FRAC AT CLG PEAK	0.164	OA FRAC AT HTG PEAK	0.164

* ASTERISKS INDICATE HOURS LOADS NOT MET

LA Office Dark DOE-2.2-48r 3/13/2015 10:18:37 BDL RUN 4

REPORT- SS-J Peak Heating and Cooling for Sys1 (PSZ) (T.3) WEATHER FILE- CZ06RV2 WYEC2

Figure 17: Peak heating and cooling in the eQUEST Detailed Simulation Output File.

Sum Max Cooling (kBTU), Sum Max Heating (kBTU) and respective dates were collected.

Building Descriptions

Office

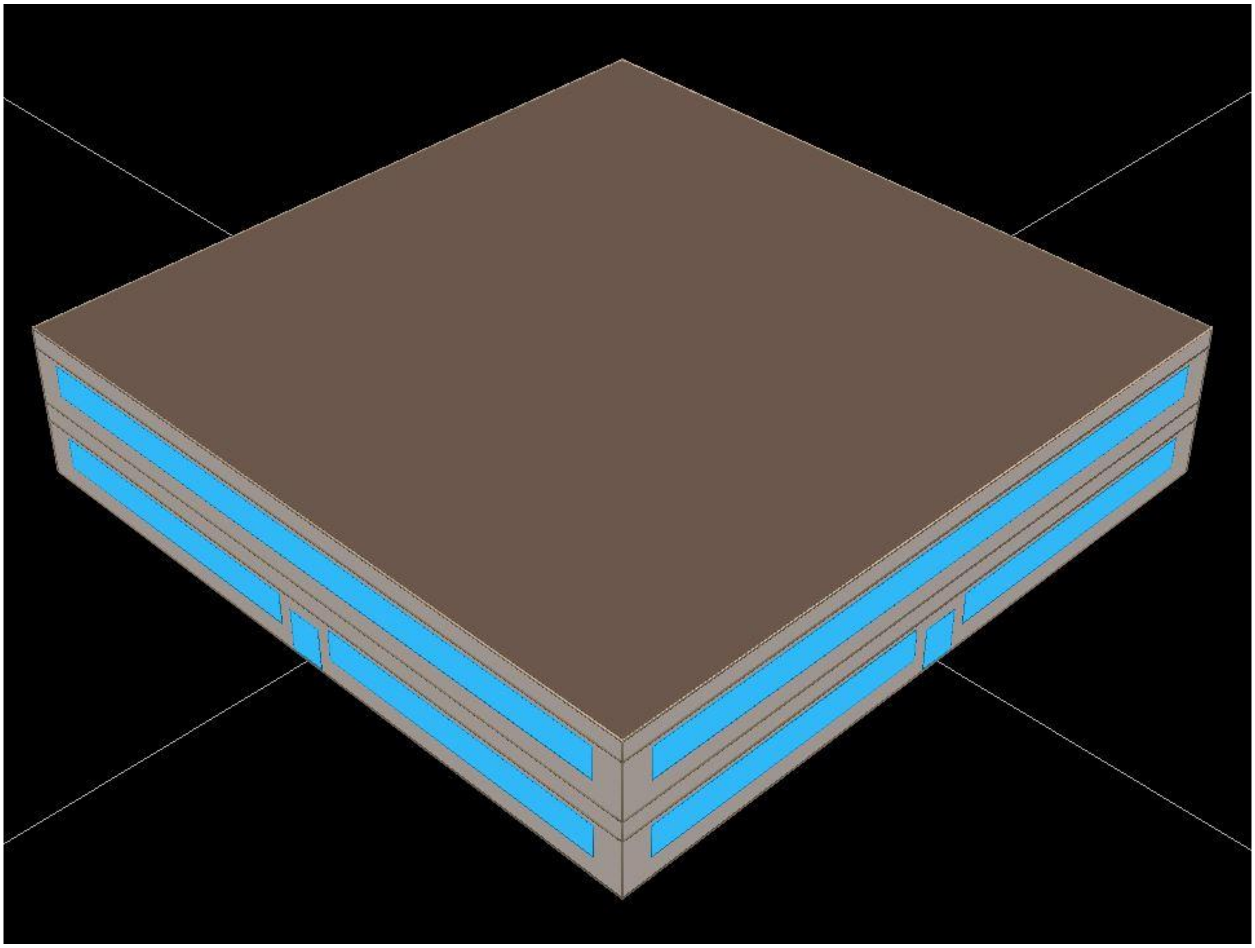


Figure 18: eQUEST office simulation.

- 2 stories (2 above grade, 0 below grade)
- 25,000 ft^2 total area
- 111.80 ft. x 111.80 ft. footprint
- Built-up roof, 3 in. polyurethane (R-18)
- Open 8am-5pm Mo-Fr, Closed Sa-Su and holidays

High School

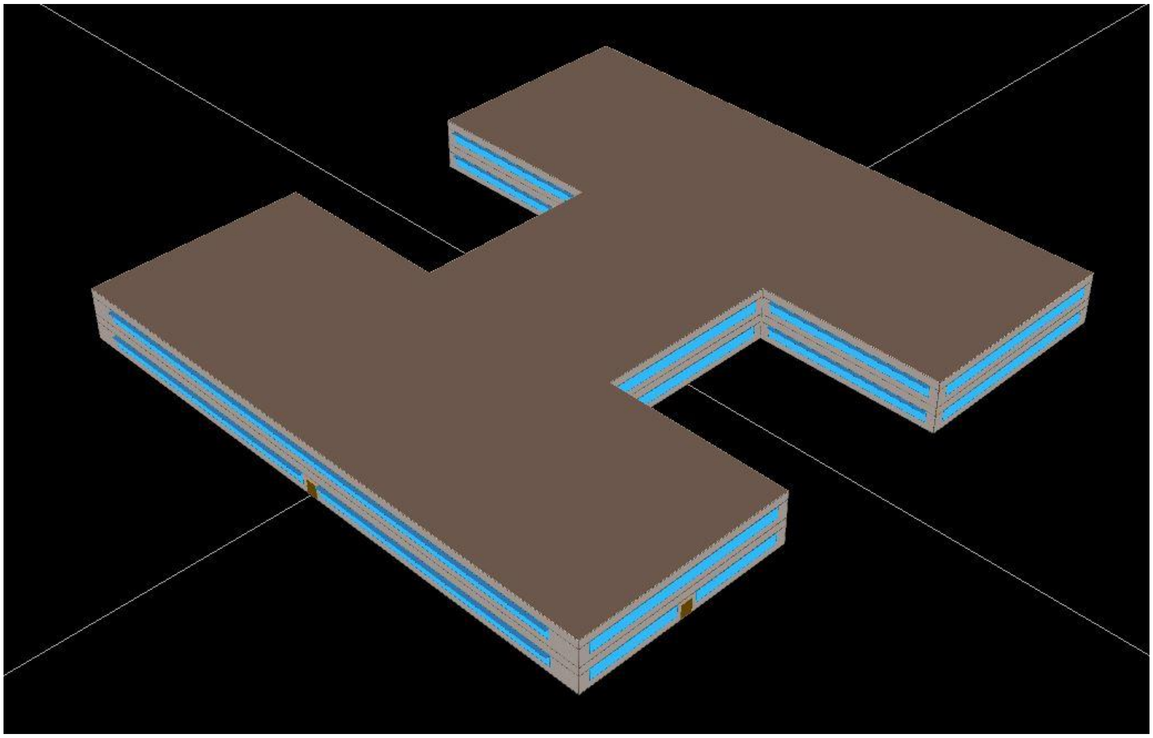


Figure 19: eQUEST school simulation.

- 2 floors (2 above grade, 0 below grade)
- 150,000 ft^2 total area
- X1: 312.20 ft. Y1: 295.75 ft.
  X2: 109.55 ft. Y2: 93.10 ft.
  X3: 93.10 ft. Y3. 109.55 ft.

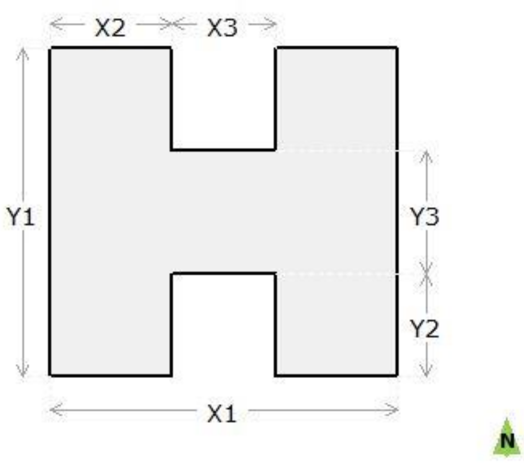


Figure 20: eQUEST school floorplan.

- Built-up roof, 3 in. polyurethane (R-18)
- Open 1/1/14 – 5/31/14 and 9/1//14 – 12/31/14 7am-5pm Mo-Fr, closed Sa-Su and holidays
  Closed 6/1/14 – 8/31/14

Hospital

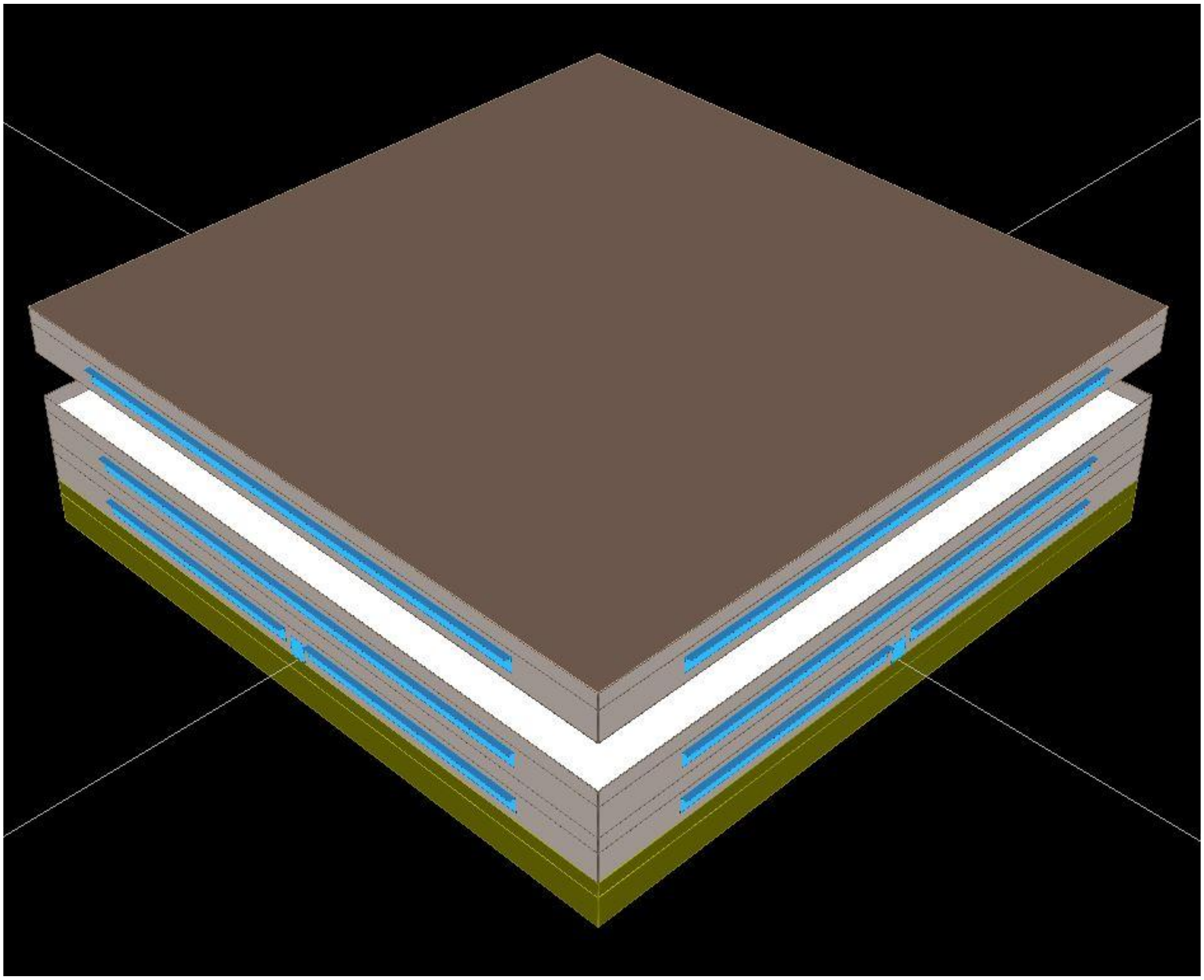
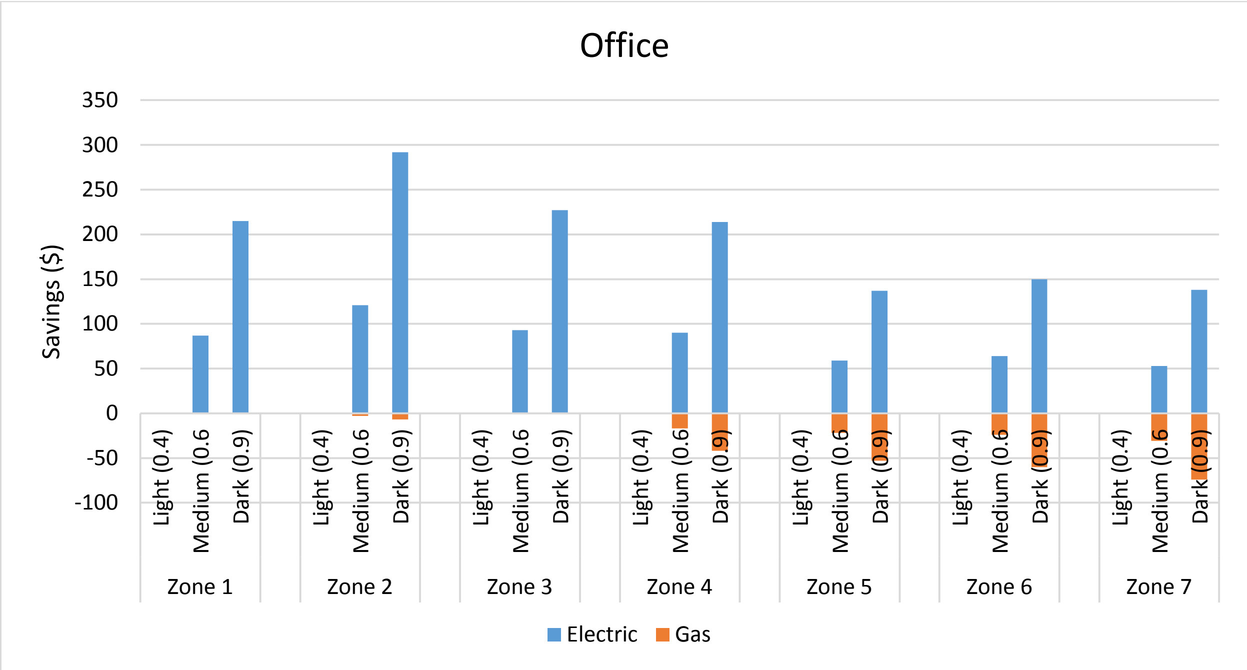


Figure 21: eQUEST hospital simulation.

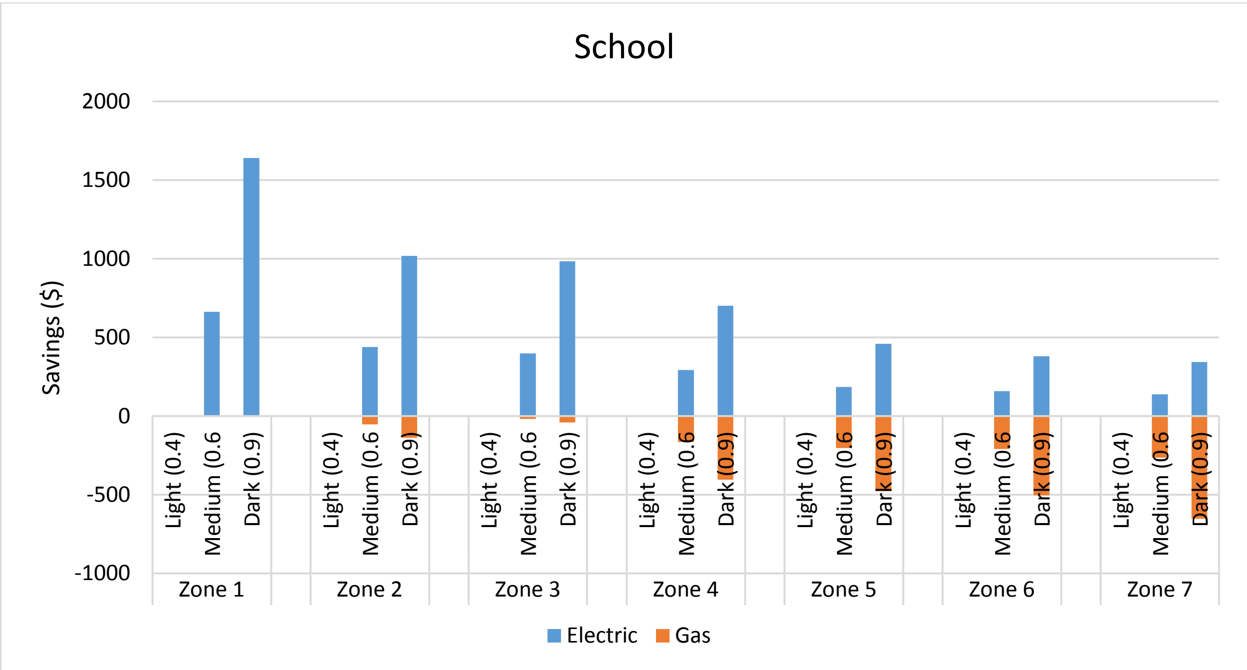
- 5 floors (4 above grade, 1 below grade)
- 250,000 ft^2 total area
- 223.6 ft. x 223.6 ft. footprint
- Built-up roof
- Open 12am-12am Su-Sa, never closed

Appendix B
Result Graphs

Gas and Electric Savings

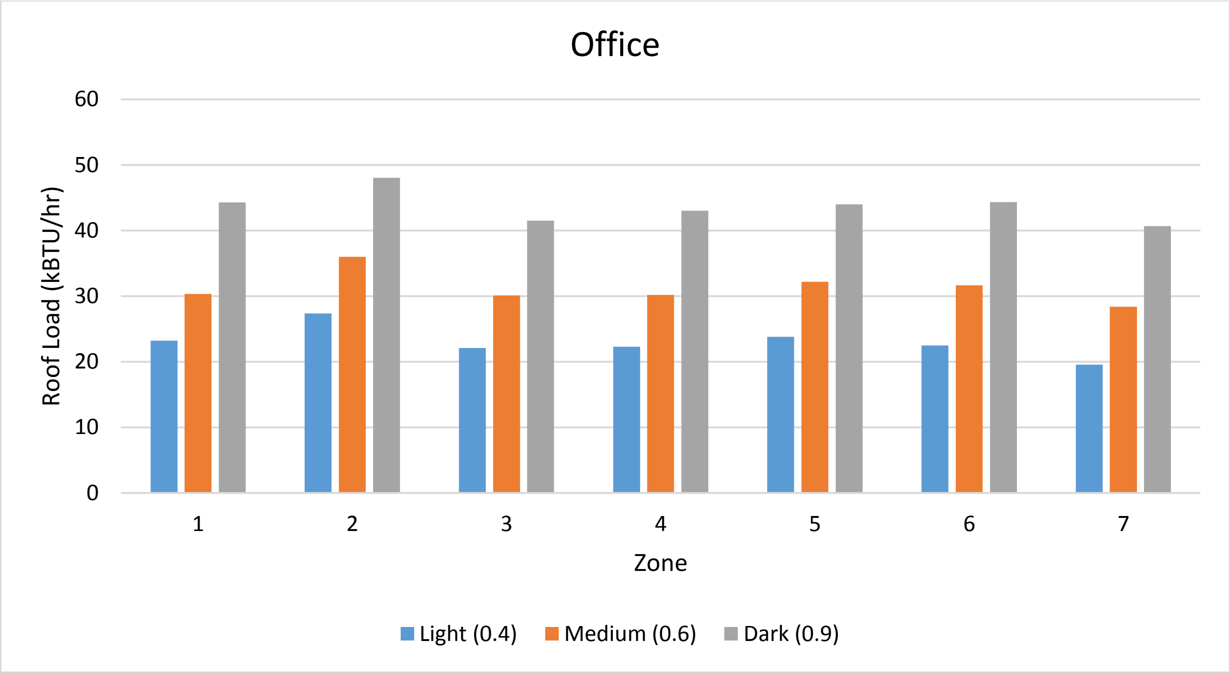


Graph 8: Hospital electric and gas savings per year for each ASHRAE climate zone. Note that a negative savings represents a cost, and the light roof (absorptance coefficient of 0.4) is the reference/baseline point.

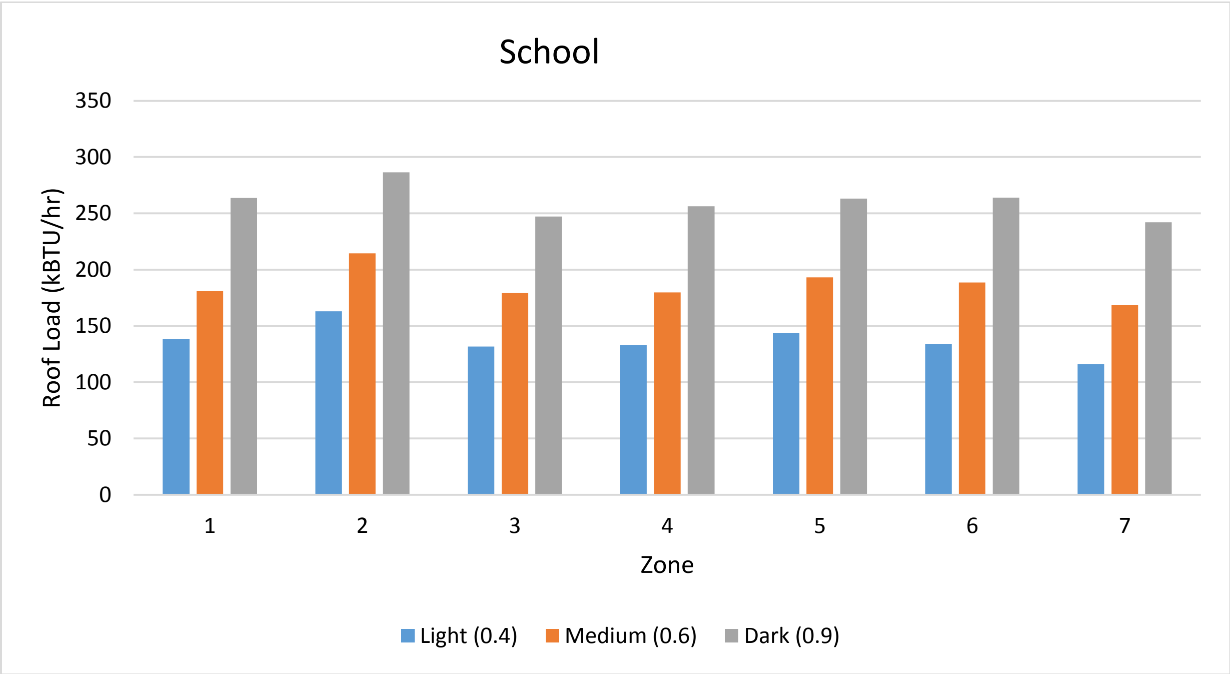


Graph 9: Hospital electric and gas savings per year for each ASHRAE climate zone. Note that a negative savings represents a cost, and the light roof (absorptance coefficient of 0.4) is the reference/baseline point.

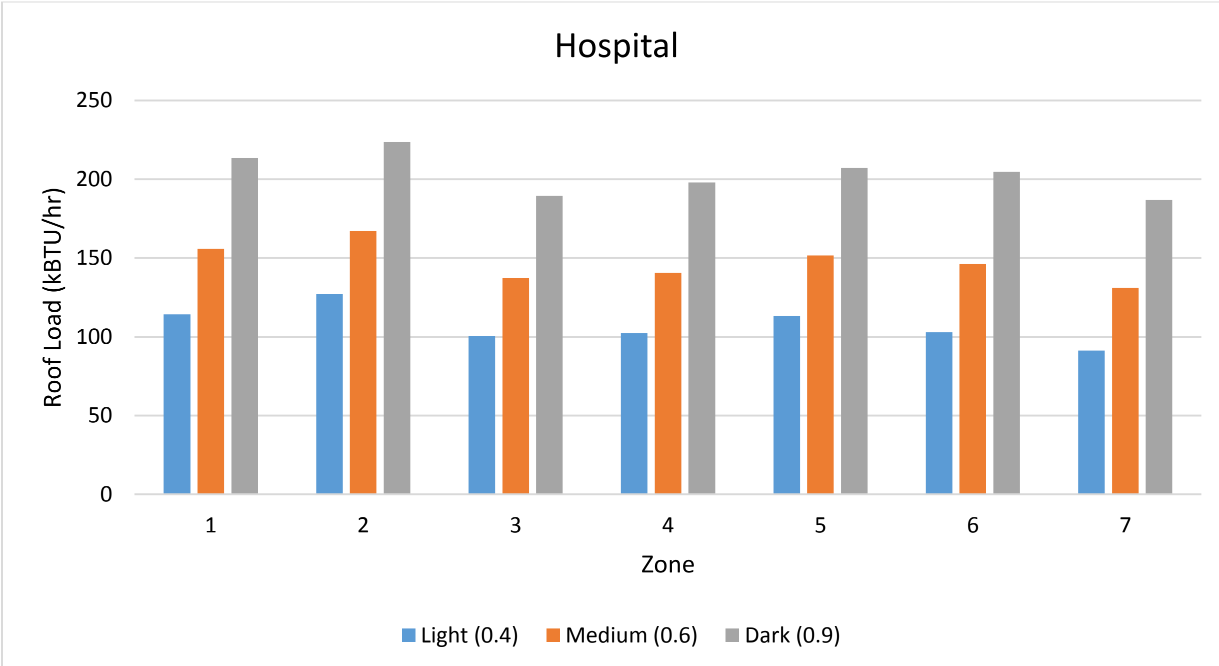
Roof Load



Graph 10: Office roof load for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

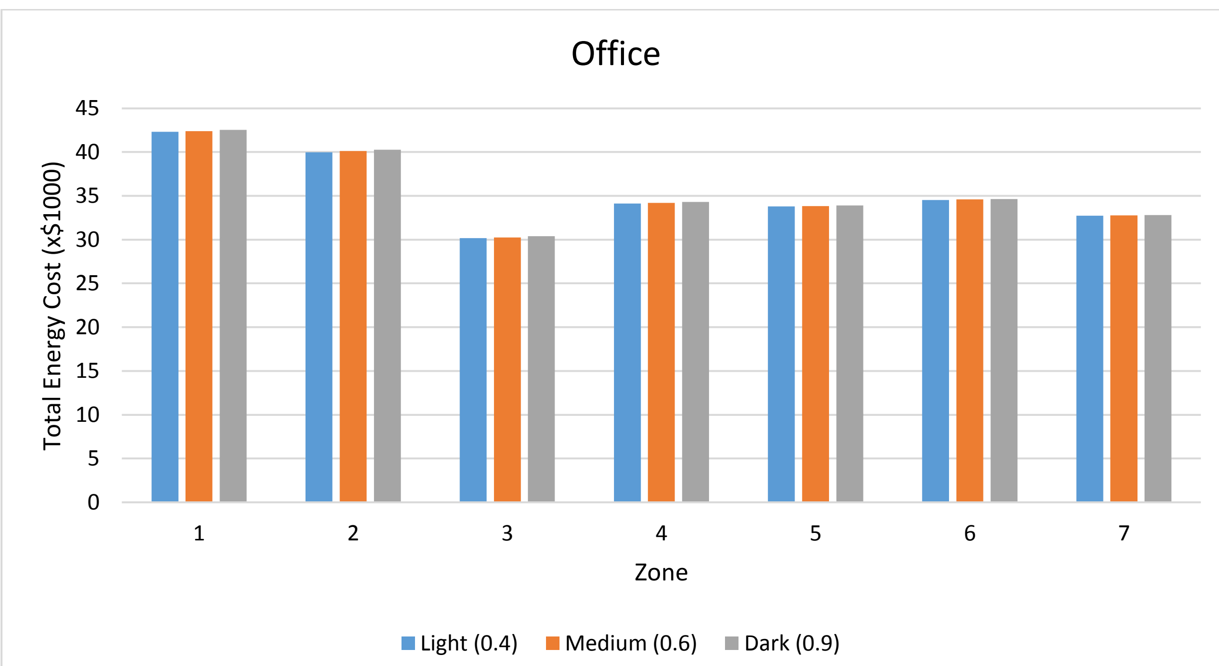


Graph 11: School roof load for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

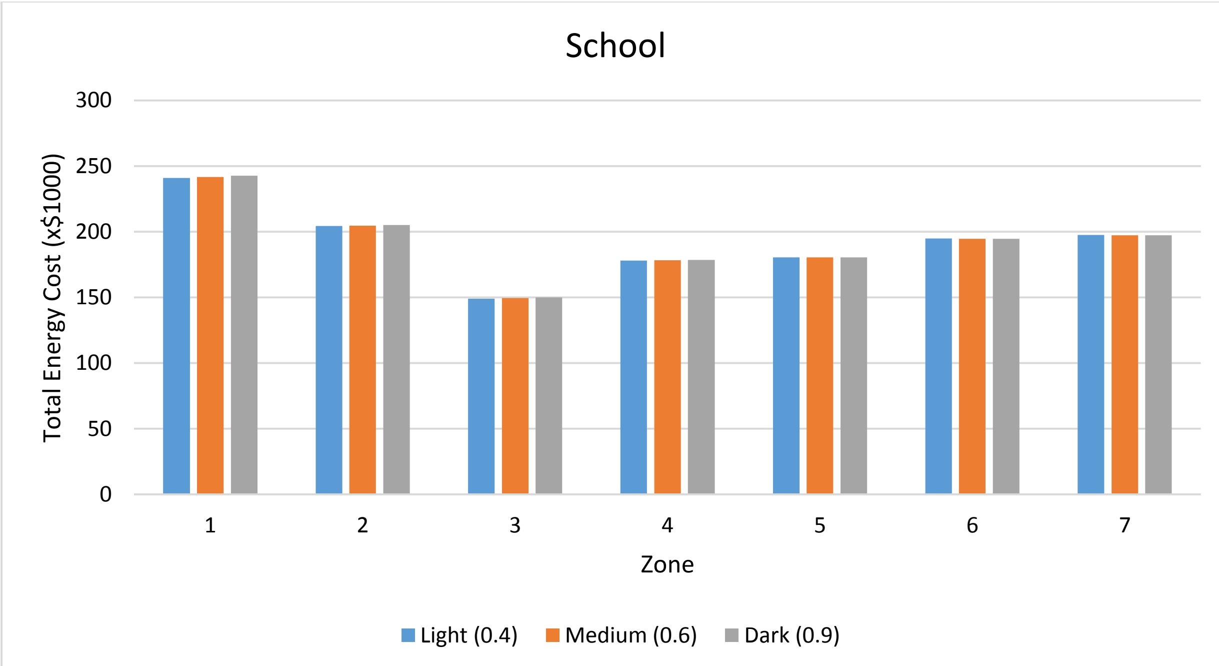


Graph 12: Hospital roof load for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

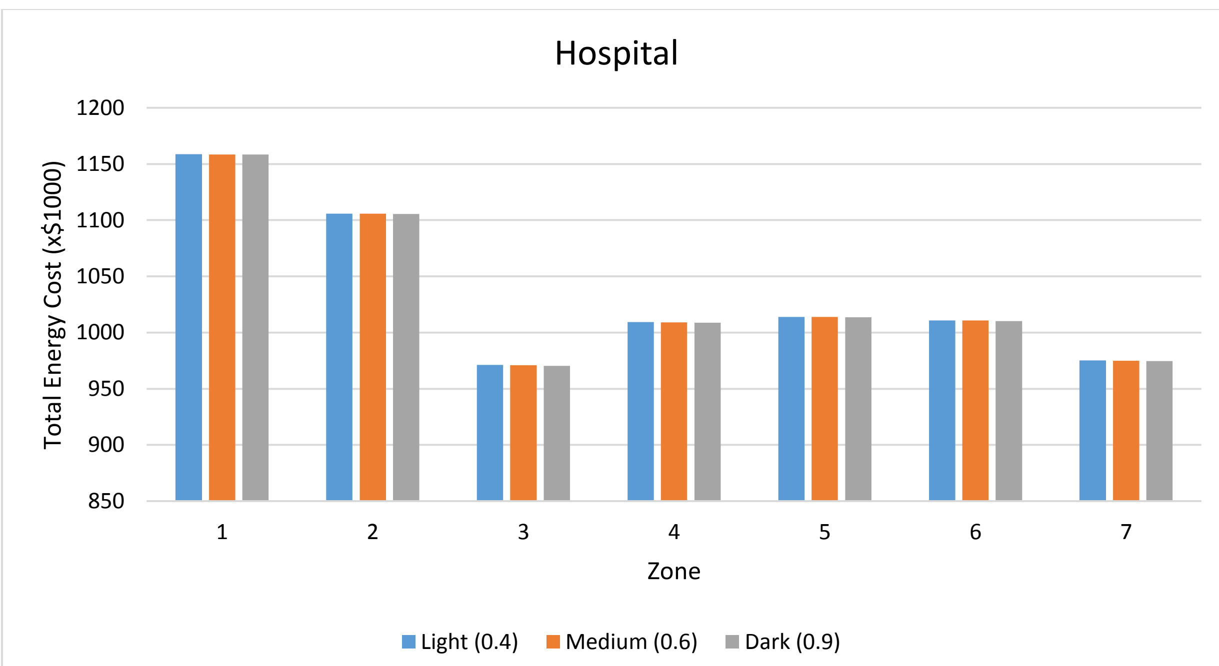
Total Energy Cost



Graph 13: Office total energy cost for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

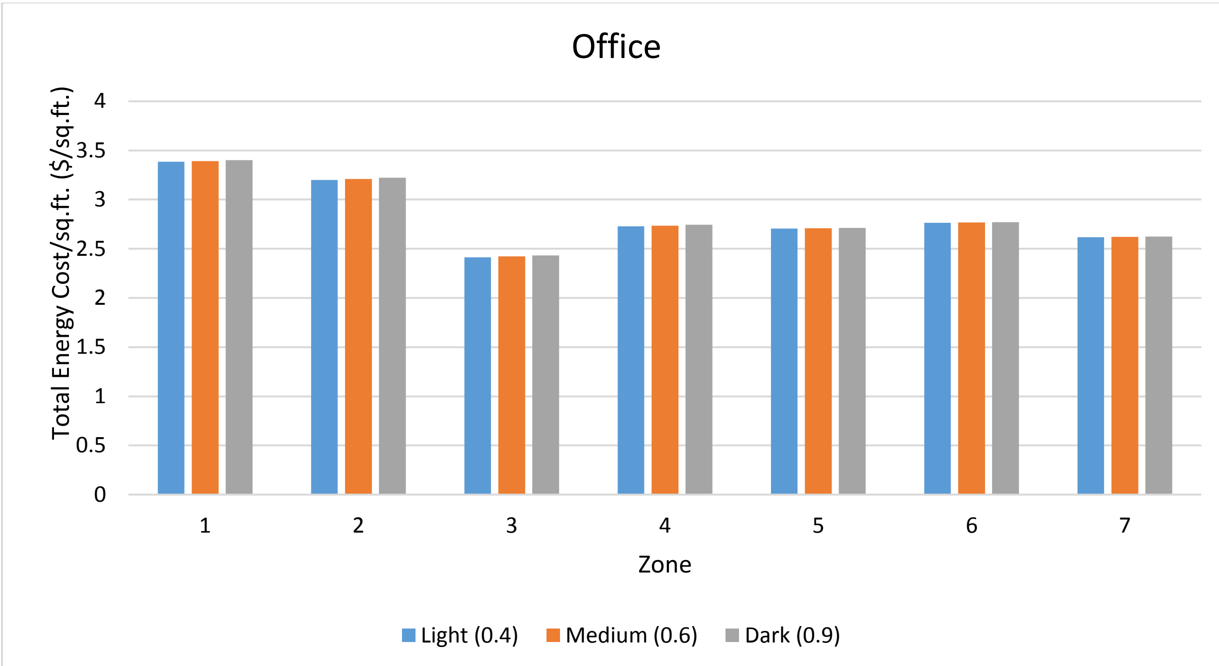


Graph 14: School total energy cost for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

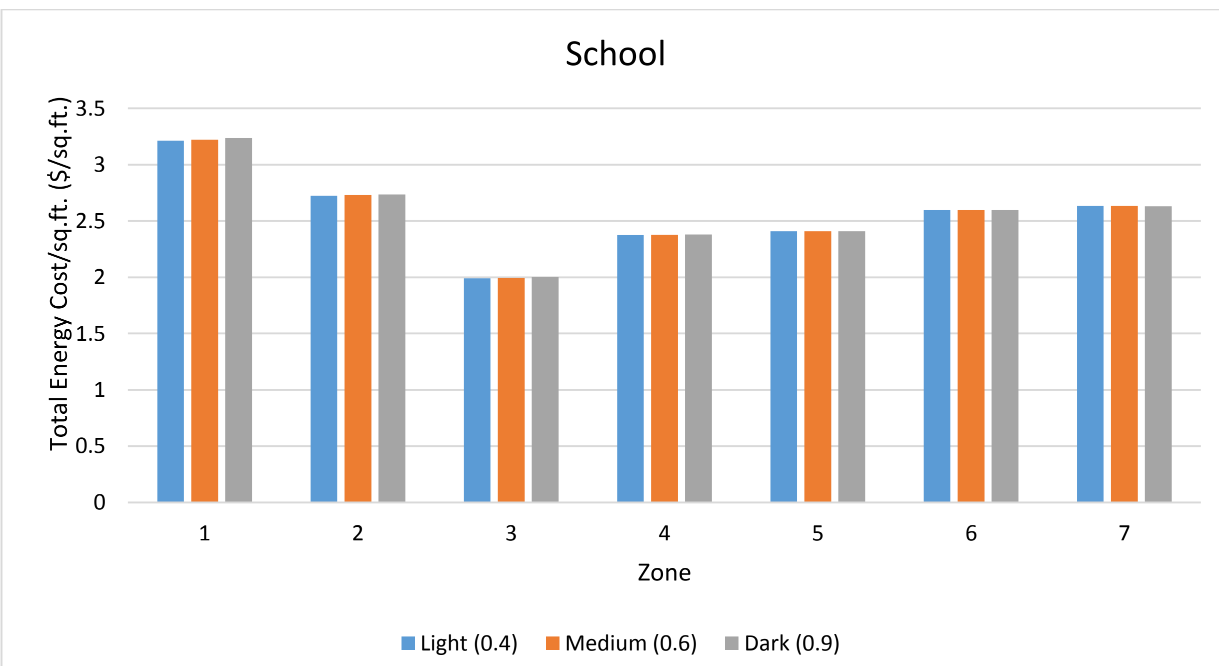


Graph 15: Hospital total energy cost for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

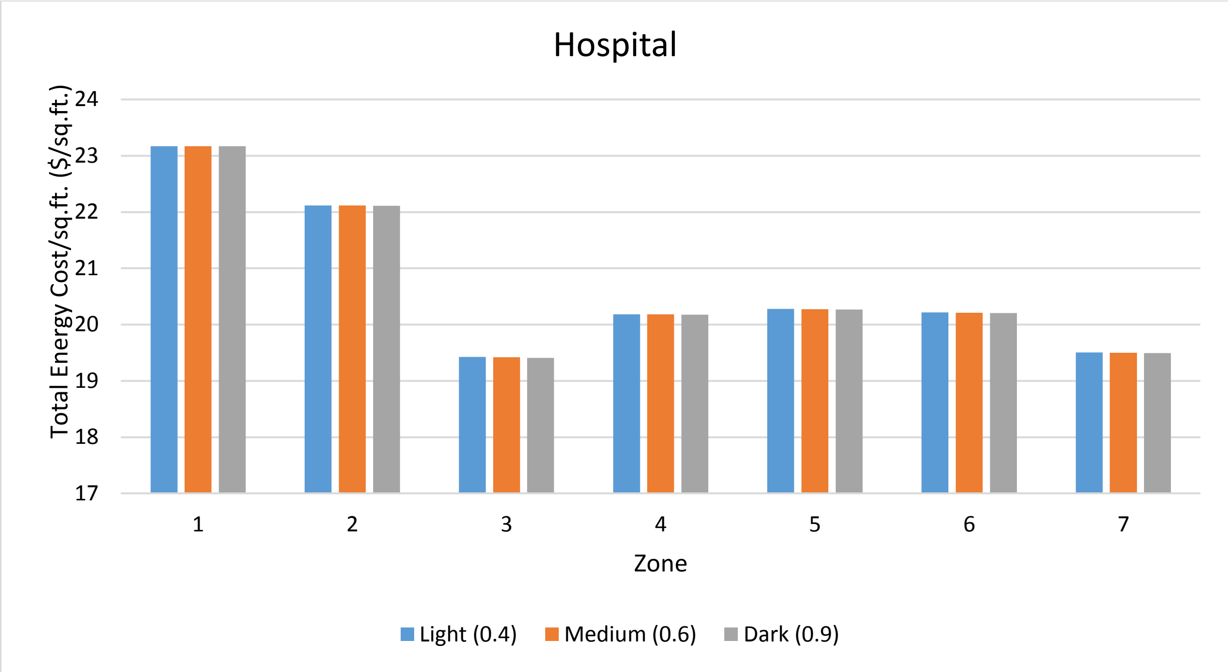
Total Energy Cost per Square Foot



Graph 16: Office total energy cost per square foot for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

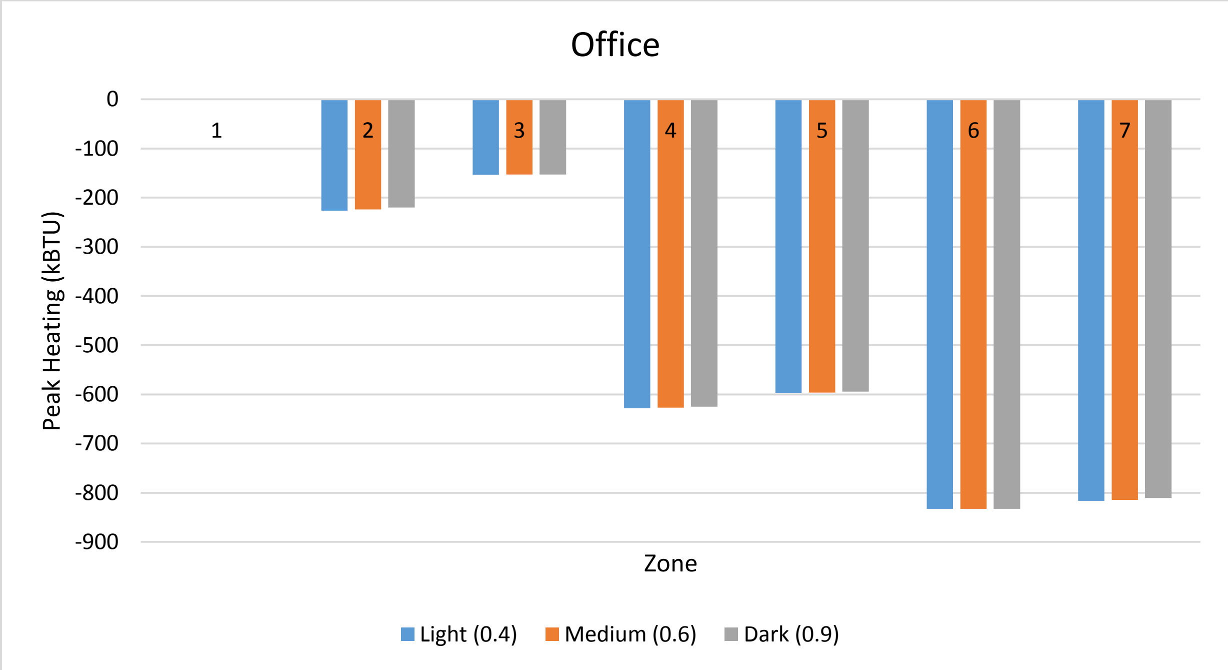


Graph 17: School total energy cost per square foot for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

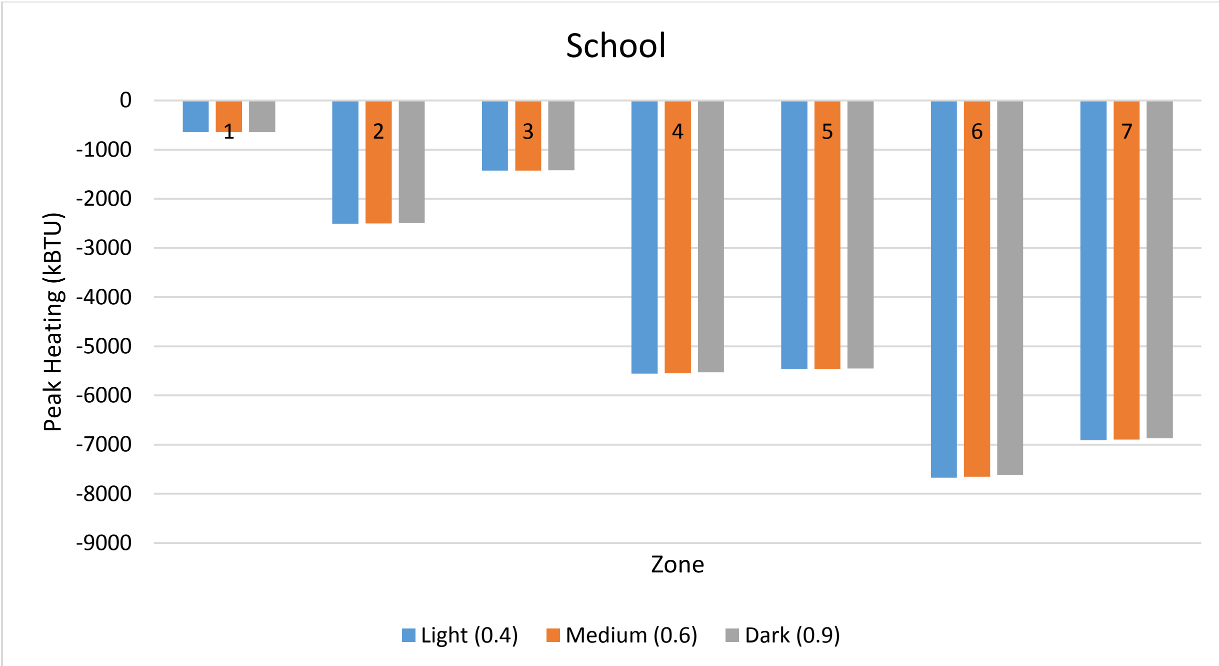


Graph 18: Hospital total energy cost per square foot for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

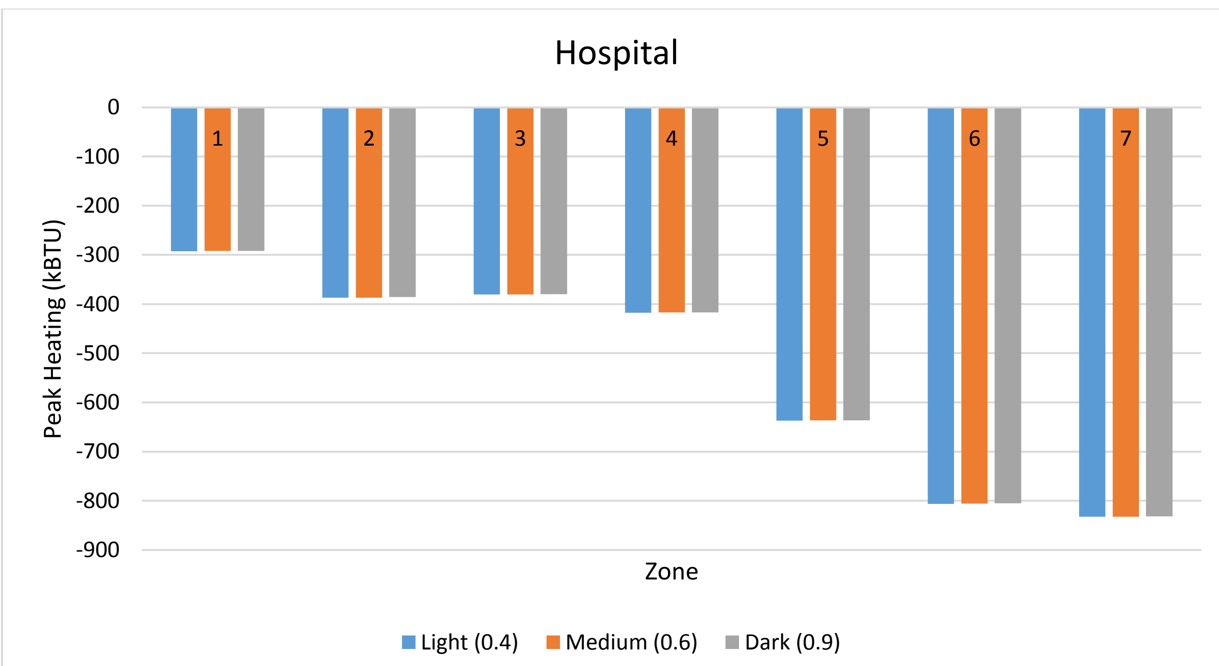
Peak Heating



Graph 19: Office peak heating for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

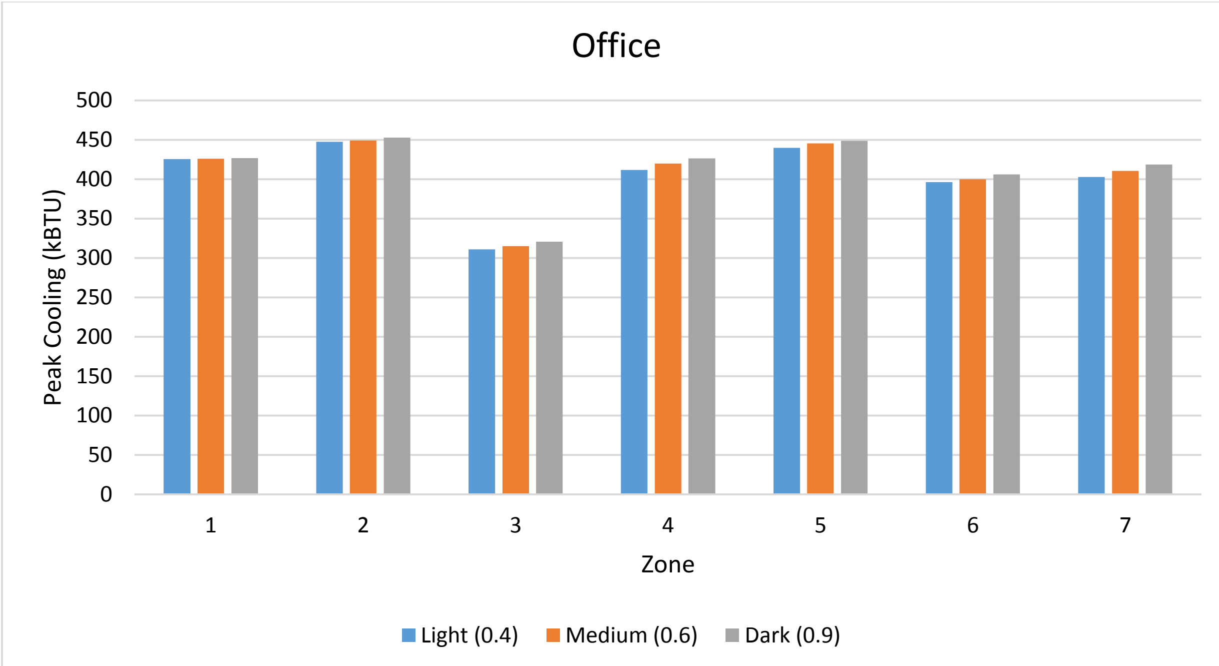


Graph 20: School peak heating for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

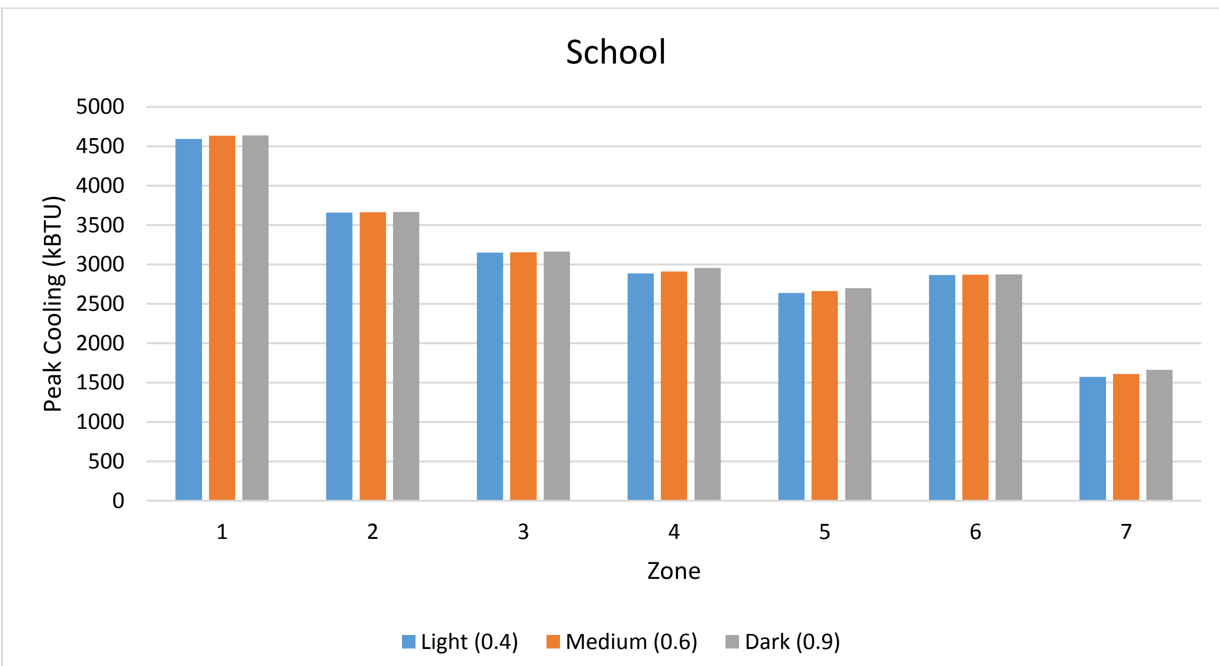


Graph 21: Hospital peak heating for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

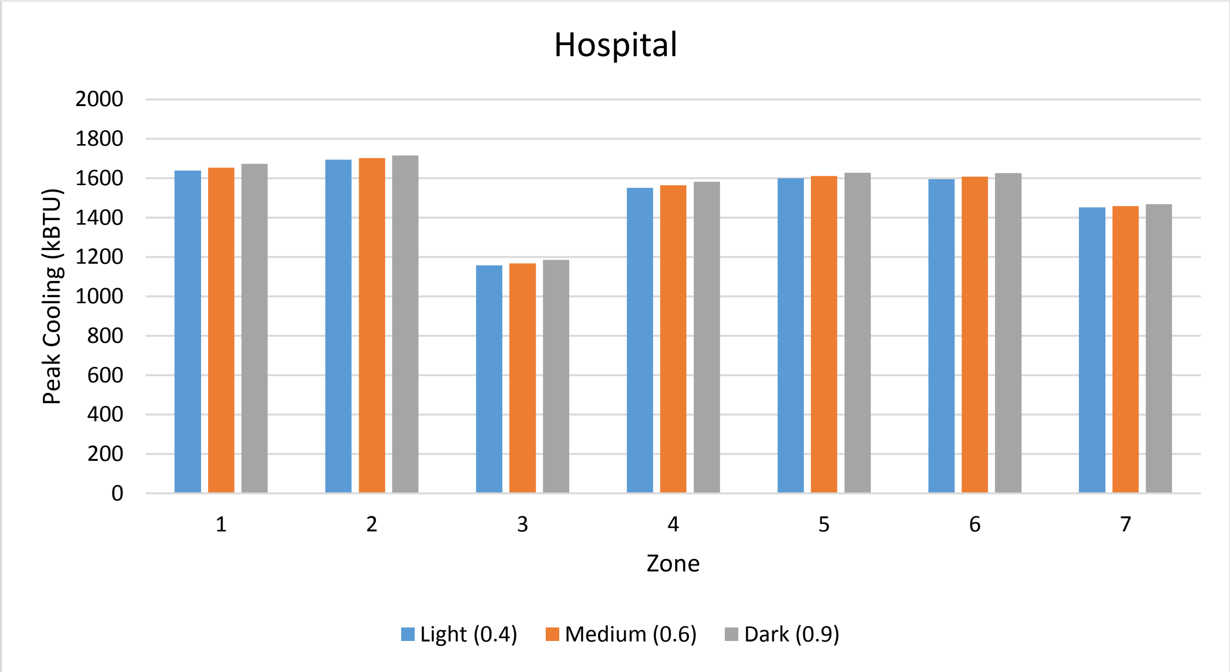
Peak Cooling



Graph 22: Office peak cooling for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

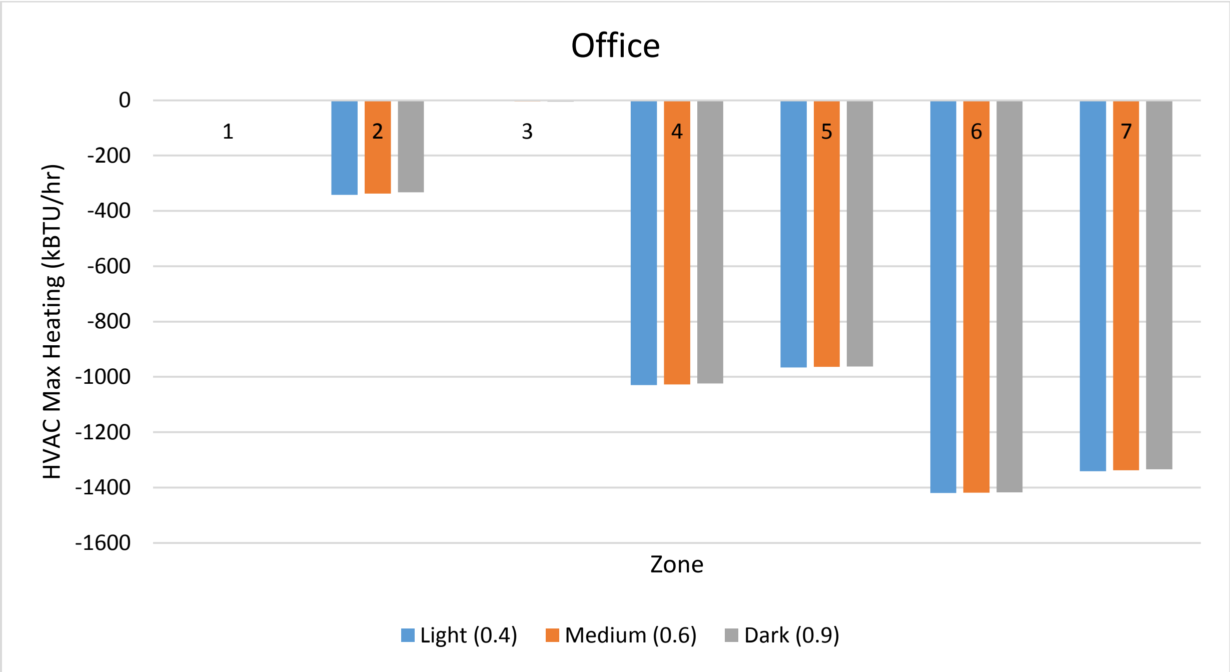


Graph 23: School peak cooling for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

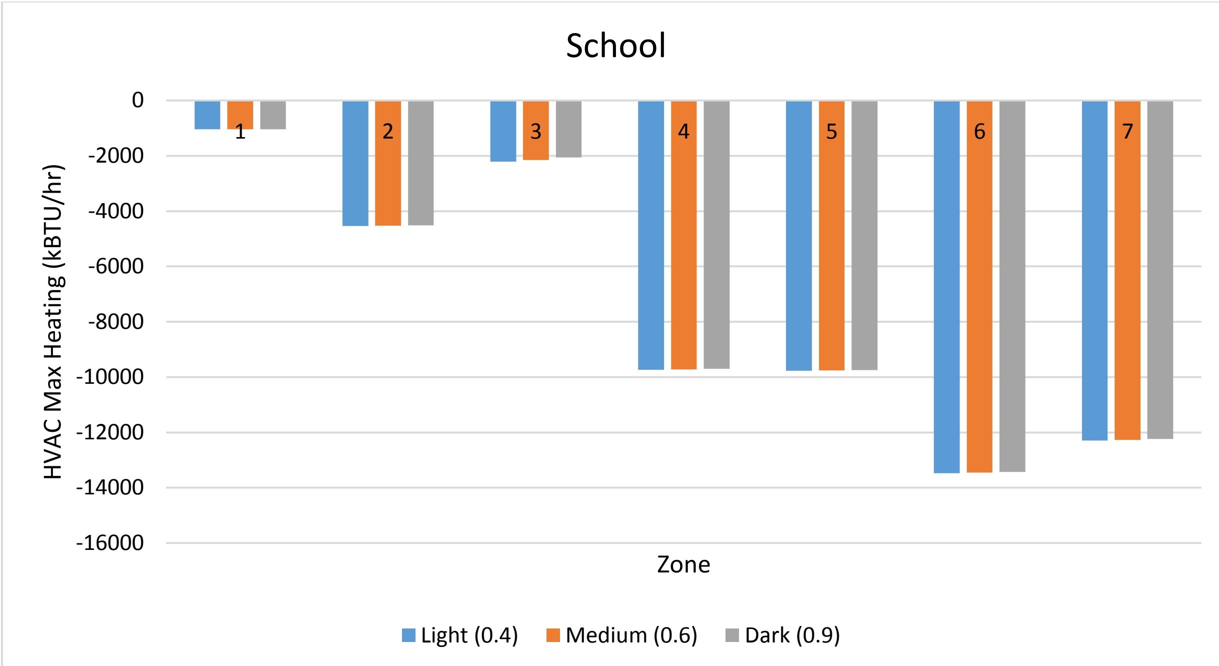


Graph 24: Hospital peak cooling for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

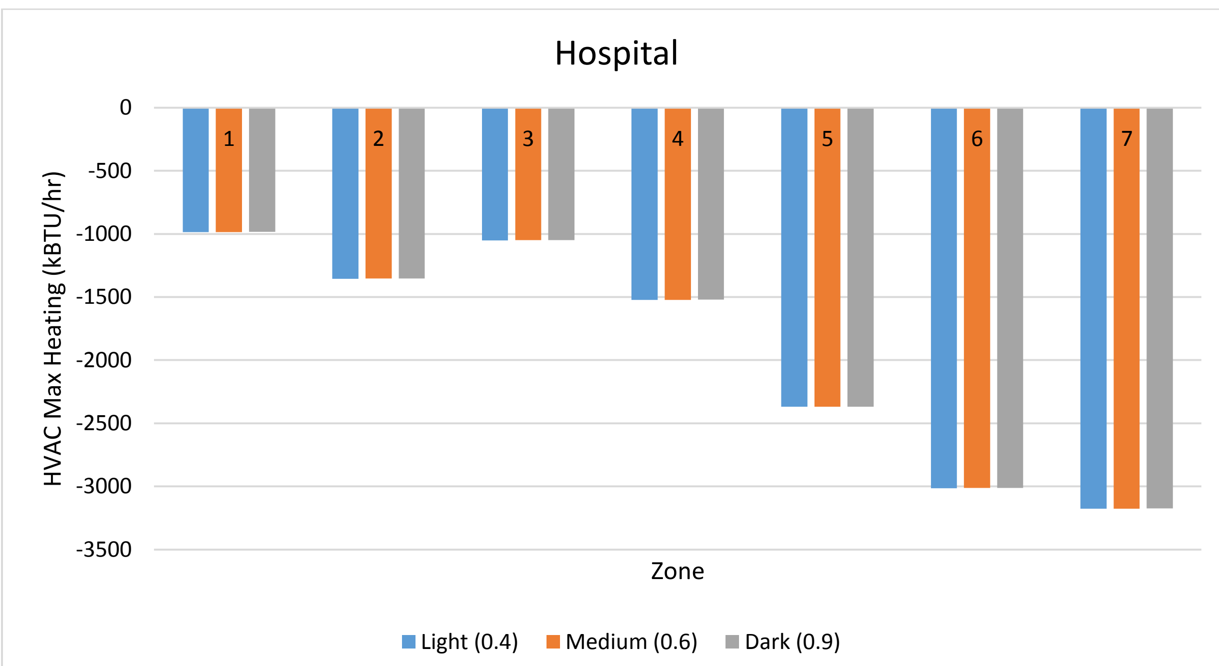
HVAC Peak Heating



Graph 25: Office HVAC peak heating for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

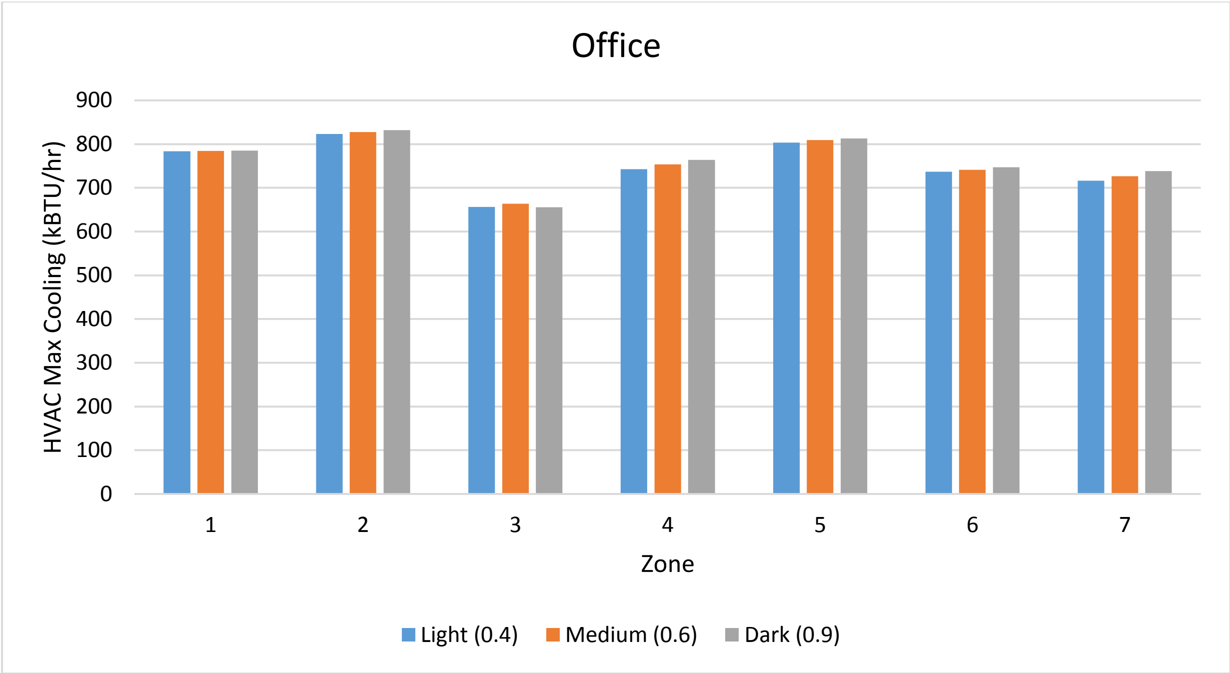


Graph 26: School HVAC peak heating for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

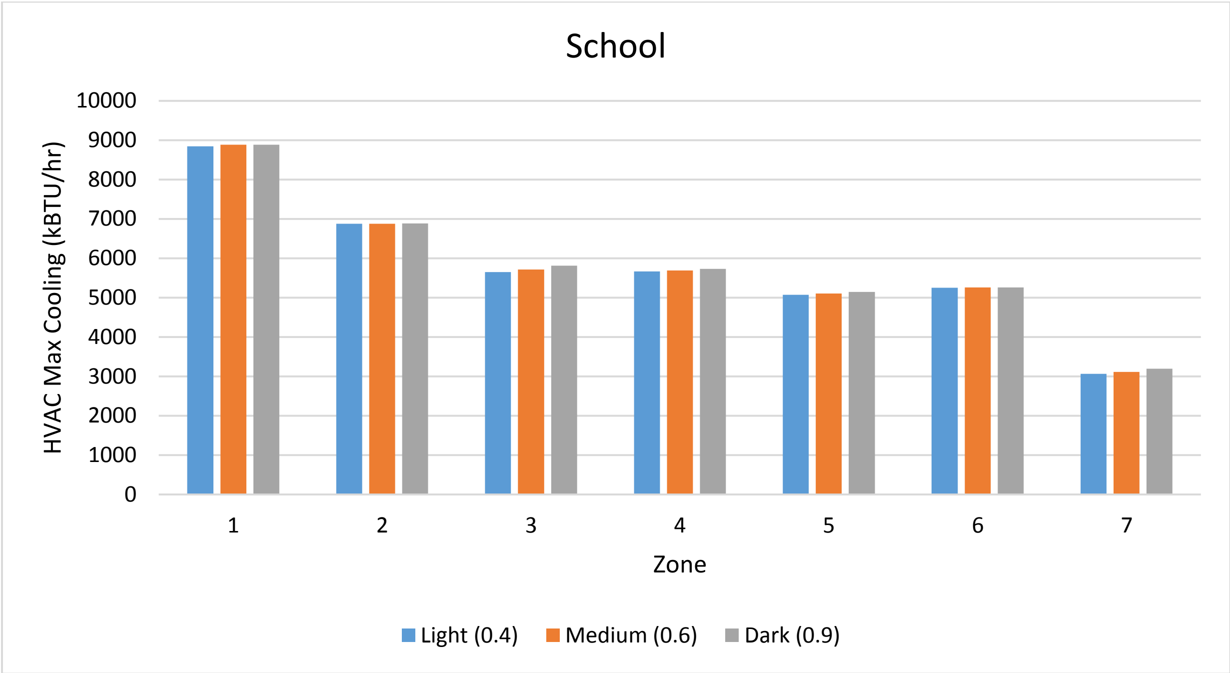


Graph 27: Hospital HVAC peak heating for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

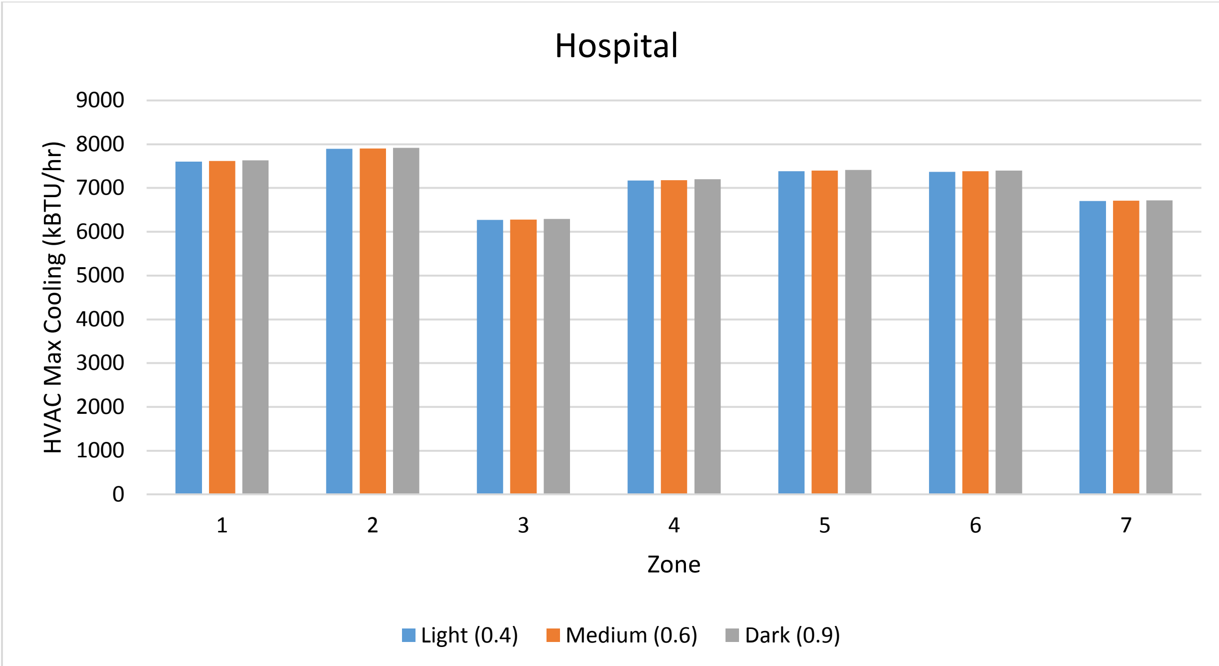
HVAC Peak Cooling



Graph 28: Office HVAC peak cooling for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).



Graph 29: School HVAC peak cooling for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).



Graph 30: Hospital HVAC peak cooling for each ASHRAE climate zone (roof types [light, medium, dark] are defined by absorptance coefficients).

Appendix C
Raw Simulation Results

Roof Load

Location	Building Type	Roof Type	Roof Load (kBTU/hr)
Miami	Office	Light (0.4)	23.24
Zone 1		Medium (0.6)	30.357
		Dark (0.9)	44.292
	High School	Light (0.4)	138.466
		Medium (0.6)	180.858
		Dark (0.9)	263.603
	Hospital	Light (0.4)	114.178
		Medium (0.6)	155.966
		Dark (0.9)	213.535
Houston	Office	Light (0.4)	27.376
Zone 2		Medium (0.6)	36.015
		Dark (0.9)	48.047
	High School	Light (0.4)	163.116
		Medium (0.6)	214.605
		Dark (0.9)	286.392
	Hospital	Light (0.4)	126.983
		Medium (0.6)	167.061
		Dark (0.9)	223.499
Los Angeles	Office	Light (0.4)	22.103
Zone 3		Medium (0.6)	30.087
		Dark (0.9)	41.498

	High School	Light (0.4)	131.62
		Medium (0.6)	179.123
		Dark (0.9)	247.101
	Hospital	Light (0.4)	100.691
		Medium (0.6)	137.227
		Dark (0.9)	189.52
Philadelphia	Office	Light (0.4)	22.303
Zone 4		Medium (0.6)	30.185
		Dark (0.9)	43.035
	High School	Light (0.4)	132.772
		Medium (0.6)	179.641
		Dark (0.9)	256.4
	Hospital	Light (0.4)	102.223
		Medium (0.6)	140.779
		Dark (0.9)	197.923
Chicago	Office	Light (0.4)	23.793
Zone 5		Medium (0.6)	32.202
		Dark (0.9)	43.976
	High School	Light (0.4)	143.635
		Medium (0.6)	193.08
		Dark (0.9)	263.049
	Hospital	Light (0.4)	113.158
		Medium (0.6)	151.57
		Dark (0.9)	207.156

Minneapolis	Office	Light (0.4)	22.513
Zone 6		Medium (0.6)	31.661
		Dark (0.9)	44.321
	High School	Light (0.4)	133.886
		Medium (0.6)	188.477
		Dark (0.9)	264.114
	Hospital	Light (0.4)	102.943
		Medium (0.6)	146.222
		Dark (0.9)	204.789
Duluth	Office	Light (0.4)	19.563
Zone 7		Medium (0.6)	28.37
		Dark (0.9)	40.703
	High School	Light (0.4)	116.055
		Medium (0.6)	168.463
		Dark (0.9)	241.951
	Hospital	Light (0.4)	91.241
		Medium (0.6)	131.149
		Dark (0.9)	186.809

Peak Heating and Cooling

Location	Building Type	Roof Type	Peak Cooling Date	Peak Cooling (kBTU)	Peak Heating Date	Peak Heating (kBTU)
Miami	Office	Light (0.4)	2-Sep	425.663	Dec. 31	0
Zone 1		Medium (0.6)	2-Sep	426.16	Dec. 31	0
		Dark (0.9)	2-Sep	426.893	Dec. 31	0

	High School	Light (0.4)	2-Sep	4593.948	2-Jan	-646.678
		Medium (0.6)	2-Sep	4634.564	2-Jan	-646.336
		Dark (0.9)	2-Sep	4635.01	2-Jan	-645.812
	Hospital	Light (0.4)	27-Jun	1639.447	13-Jan	-292.259
		Medium (0.6)	27-Jun	1653.112	13-Jan	-292.041
		Dark (0.9)	27-Jun	1672.629	13-Jan	-291.711
Houston	Office	Light (0.4)	14-Jul	447.353	13-Jan	-226.665
Zone 2		Medium (0.6)	4-Aug	449.177	13-Jan	-223.924
		Dark (0.9)	14-Jul	452.888	13-Jan	-219.854
	High School	Light (0.4)	3-Sep	3659.117	14-Jan	-2507.817
		Medium (0.6)	3-Sep	3661.197	14-Jan	-2502.148
		Dark (0.9)	3-Sep	3664.242	14-Jan	-2493.696
	Hospital	Light (0.4)	18-Jul	1694.094	11-Jan	-387.324
		Medium (0.6)	18-Jul	1702.508	11-Jan	-386.802
		Dark (0.9)	18-Jul	1714.967	11-Jan	-386.017
Los Angeles	Office	Light (0.4)	1-Nov	310.859	21-Dec	-153.322
Zone 3		Medium (0.6)	1-Nov	314.972	21-Dec	-153.055
		Dark (0.9)	2-Nov	320.812	21-Dec	-152.649
	High School	Light (0.4)	1-Sep	3150.118	21-Dec	-1424.562
		Medium (0.6)	1-Sep	3154.594	21-Dec	-1423.559
		Dark (0.9)	1-Sep	3161.186	21-Dec	-1422.031
	Hospital	Light (0.4)	19-Oct	1158.16	21-Dec	-380.451
		Medium (0.6)	19-Oct	1168.11	21-Dec	-380.21

		Dark (0.9)	21-Jul	1185.789	21-Dec	-379.843
Philadelphia	Office	Light (0.4)	7-Jul	411.739	2-Jan	-628.251
Zone 4		Medium (0.6)	7-Jul	419.954	2-Jan	-626.908
		Dark (0.9)	7-Jul	426.242	2-Jan	-624.873
	High School	Light (0.4)	17-Sep	2883.74	2-Jan	-5556.269
		Medium (0.6)	9-Sep	2911.382	2-Jan	-5545.32
		Dark (0.9)	9-Sep	2955.272	2-Jan	-5528.727
	Hospital	Light (0.4)	14-Aug	1552.101	1-Jan	-417.541
		Medium (0.6)	14-Aug	1564.379	1-Jan	-417.196
		Dark (0.9)	14-Aug	1582.207	1-Jan	-416.674
Chicago	Office	Light (0.4)	4-Aug	439.811	27-Jan	-597.023
Zone 5		Medium (0.6)	4-Aug	445.485	27-Jan	-596.091
		Dark (0.9)	4-Aug	448.826	27-Jan	-594.68
	High School	Light (0.4)	30-May	2638.182	27-Jan	-5466.627
		Medium (0.6)	30-May	2661.685	27-Jan	-5460.154
		Dark (0.9)	30-May	2696.747	27-Jan	-5450.374
	Hospital	Light (0.4)	4-Aug	1600.86	7-Jan	-637.112
		Medium (0.6)	4-Aug	1611.855	7-Jan	-636.731
		Dark (0.9)	4-Aug	1627.633	7-Jan	-636.15
Minneapolis	Office	Light (0.4)	27-Aug	396.228	6-Jan	-832.755
Zone 6		Medium (0.6)	27-Aug	400.148	6-Jan	-832.782
		Dark (0.9)	27-Aug	405.926	6-Jan	-832.822

	High School	Light (0.4)	28-May	2865.584	2-Jan	-7670.588
		Medium (0.6)	28-May	2867.96	2-Jan	-7648.896
		Dark (0.9)	28-May	2871.322	2-Jan	-7615.709
	Hospital	Light (0.4)	27-Aug	1595.721	31-Dec	-806.515
		Medium (0.6)	27-Aug	1608.307	31-Dec	-806.037
		Dark (0.9)	27-Aug	1626.308	31-Dec	-805.326
Duluth	Office	Light (0.4)	7-Jul	402.674	3-Feb	-816.488
Zone 7		Medium (0.6)	7-Jul	410.415	3-Feb	-814.284
		Dark (0.9)	7-Jul	418.851	3-Feb	-810.958
	High School	Light (0.4)	8-Sep	1571.42	3-Feb	-6911.563
		Medium (0.6)	8-Sep	1608.459	3-Feb	-6895.771
		Dark (0.9)	8-Sep	1663.069	3-Feb	-6871.923
	Hospital	Light (0.4)	8-Jul	1452.81	9-Jan	-832.495
		Medium (0.6)	8-Jul	1459.044	9-Jan	-832.264
		Dark (0.9)	8-Jul	1468.168	9-Jan	-831.915

Total Electric and Gas Usage and Cost

Location	Building Type	Roof Type	Total Electric Metered Energy (kWh)	Total Electric Cost ($)	Total Gas Metered Energy (therm)	Total Gas Cost ($)
Miami	Office	Light (0.4)	300806	42070	292	234
Zone 1		Medium (0.6)	301571	42157	292	234
		Dark (0.9)	302701	42285	292	234
	High School	Light (0.4)	1576637	231422	11978	9582

		Medium (0.6)	1581680	232084	11978	9582
		Dark (0.9)	1589156	233061	11971	9577
	Hospital	Light (0.4)	10551566	1034330	155301	124241
		Medium (0.6)	10553214	1034512	155018	124014
		Dark (0.9)	10555666	1034782	154597	123678
Houston	Office	Light (0.4)	272008	39617	466	373
Zone 2		Medium (0.6)	272743	39738	462	370
		Dark (0.9)	273808	39909	457	366
	High School	Light (0.4)	1215425	189519	18581	14865
		Medium (0.6)	1218610	189957	18513	14811
		Dark (0.9)	1223242	190536	18409	14727
	Hospital	Light (0.4)	9757604	969549	170420	136336
		Medium (0.6)	9758978	969707	170083	136066
		Dark (0.9)	9760874	969931	169585	135668
Los Angeles	Office	Light (0.4)	206264	29883	360	288
Zone 3		Medium (0.6)	206779	29976	360	288
		Dark (0.9)	207531	30110	360	288
	High School	Light (0.4)	890163	137295	14865	11892
		Medium (0.6)	892208	137692	14841	11873
		Dark (0.9)	895275	138279	14812	11850
	Hospital	Light (0.4)	8240186	824336	183659	146927
		Medium (0.6)	8240700	824429	183111	146489
		Dark (0.9)	8241447	824567	182302	145842
Philadelphia	Office	Light (0.4)	223249	32083	2549	2039
Zone 4		Medium (0.6)	223780	32173	2528	2022

		Dark (0.9)	224513	32297	2496	1997
	High School	Light (0.4)	893787	136068	52645	42116
		Medium (0.6)	895366	136361	52438	41950
		Dark (0.9)	897426	136769	52140	41712
	Hospital	Light (0.4)	8534982	846338	203666	162933
		Medium (0.6)	8535578	846423	203294	162635
		Dark (0.9)	8536394	846541	202742	162193
Chicago	Office	Light (0.4)	215366	30726	3855	3084
Zone 5		Medium (0.6)	215827	30785	3827	3062
		Dark (0.9)	216488	30863	3789	3031
	High School	Light (0.4)	853909	125039	69505	55604
		Medium (0.6)	855036	125224	69251	55401
		Dark (0.9)	856697	125498	68907	55126
	Hospital	Light (0.4)	8434200	839299	218365	174692
		Medium (0.6)	8434976	839403	217993	174394
		Dark (0.9)	8435932	839538	217441	173953
Minneapolis	Office	Light (0.4)	210801	30292	5311	4249
Zone 6		Medium (0.6)	211216	30356	5281	4225
		Dark (0.9)	211813	30442	5236	4189
	High School	Light (0.4)	838022	123587	89056	71245
		Medium (0.6)	838860	123746	88794	71035
		Dark (0.9)	840029	123966	88427	70741
	Hospital	Light (0.4)	8325027	828132	228419	182735
		Medium (0.6)	8325736	828228	228030	182424
		Dark (0.9)	8326611	828359	227454	181963

Duluth	Office	Light (0.4)	192431	27134	6997	5598
Zone 7		Medium (0.6)	192664	27187	6958	5567
		Dark (0.9)	193105	27272	6905	5524
	High School	Light (0.4)	783995	108467	111364	89091
		Medium (0.6)	784241	108604	111032	88826
		Dark (0.9)	784662	108810	110549	88439
	Hospital	Light (0.4)	7925514	784218	238777	191021
		Medium (0.6)	7925856	784279	238365	190692
		Dark (0.9)	7926562	784383	237752	190202

Total Cost, Total Savings, Total Cost per Square Foot

Location	Building Type	Roof Type	Total Cost	% Diff. From Min	Total Savings From Min ($/yr)	Total Cost/Sq.ft. ($/ft.)
Miami	Office	Light (0.4)	42304	0.00%	0	3.38432
Zone 1		Medium (0.6)	42391	0.21%	-87	3.39128
		Dark (0.9)	42519	0.51%	-215	3.40152
	High School	Light (0.4)	241004	0.00%	0	3.2133867
		Medium (0.6)	241666	0.27%	-662	3.2222133
		Dark (0.9)	242638	0.68%	-1634	3.2351733
	Hospital	Light (0.4)	1158571	0.00%	0	23.17142
		Medium (0.6)	1158526	0.00%	45	23.17052
		Dark (0.9)	1158460	0.01%	111	23.1692
Houston	Office	Light (0.4)	39990	0.00%	0	3.1992
Zone 2		Medium (0.6)	40108	0.30%	-118	3.20864
		Dark (0.9)	40275	0.71%	-285	3.222

	High School	Light (0.4)	204384	0.00%	0	2.72512
		Medium (0.6)	204768	0.19%	-384	2.73024
		Dark (0.9)	205263	0.43%	-879	2.73684
	Hospital	Light (0.4)	1105885	0.00%	0	22.1177
		Medium (0.6)	1105773	0.01%	112	22.11546
		Dark (0.9)	1105599	0.03%	286	22.11198
Los Angeles	Office	Light (0.4)	30171	0.00%	0	2.41368
Zone 3		Medium (0.6)	30264	0.31%	-93	2.42112
		Dark (0.9)	30398	0.75%	-227	2.43184
	High School	Light (0.4)	149187	0.00%	0	1.98916
		Medium (0.6)	149565	0.25%	-378	1.9942
		Dark (0.9)	150129	0.63%	-942	2.00172
	Hospital	Light (0.4)	971263	0.00%	0	19.42526
		Medium (0.6)	970918	0.04%	345	19.41836
		Dark (0.9)	970409	0.09%	854	19.40818
Philadelphia	Office	Light (0.4)	34122	0.00%	0	2.72976
Zone 4		Medium (0.6)	34195	0.21%	-73	2.7356
		Dark (0.9)	34294	0.50%	-172	2.74352
	High School	Light (0.4)	178184	0.00%	0	2.3757867
		Medium (0.6)	178311	0.07%	-127	2.37748
		Dark (0.9)	178481	0.17%	-297	2.3797467
	Hospital	Light (0.4)	1009271	0.00%	0	20.18542
		Medium (0.6)	1009058	0.02%	213	20.18116
		Dark (0.9)	1008734	0.05%	537	20.17468

Chicago	Office	Light (0.4)	33810	0.00%	0	2.7048
Zone 5		Medium (0.6)	33847	0.11%	-37	2.70776
		Dark (0.9)	33894	0.25%	-84	2.71152
	High School	Light (0.4)	180643	0.00%	0	2.4085733
		Medium (0.6)	180625	0.01%	18	2.4083333
		Dark (0.9)	180624	0.01%	19	2.40832
	Hospital	Light (0.4)	1013991	0.00%	0	20.27982
		Medium (0.6)	1013797	0.02%	194	20.27594
		Dark (0.9)	1013491	0.05%	500	20.26982
Minneapolis	Office	Light (0.4)	34541	0.00%	0	2.76328
Zone 6		Medium (0.6)	34581	0.12%	-40	2.76648
		Dark (0.9)	34631	0.26%	-90	2.77048
	High School	Light (0.4)	194832	0.00%	0	2.59776
		Medium (0.6)	194781	0.03%	51	2.59708
		Dark (0.9)	194707	0.06%	125	2.5960933
	Hospital	Light (0.4)	1010867	0.00%	0	20.21734
		Medium (0.6)	1010652	0.02%	215	20.21304
		Dark (0.9)	1010322	0.05%	545	20.20644
Duluth	Office	Light (0.4)	32732	0.00%	0	2.61856
Zone 7		Medium (0.6)	32754	0.07%	-22	2.62032
		Dark (0.9)	32796	0.20%	-64	2.62368
	High School	Light (0.4)	197558	0.00%	0	2.6341067
		Medium (0.6)	197430	0.06%	128	2.6324
		Dark (0.9)	197249	0.16%	309	2.6299867
	Hospital	Light (0.4)	975239	0.00%	0	19.50478

		Medium (0.6)	974971	0.03%	268	19.49942
		Dark (0.9)	974585	0.07%	654	19.4917

HVAC Max Heating and Cooling

Location	Building Type	Roof Type	HVAC Max Heating (kBTU/hr)	HVAC Max Cooling (kBTU/hr)
Miami	Office	Light (0.4)	0	783.296
Zone 1		Medium (0.6)	0	783.981
		Dark (0.9)	-2.679	784.994
	High School	Light (0.4)	-1044.055	8845.336
		Medium (0.6)	-1043.578	8885.77
		Dark (0.9)	-1042.819	8885.954
	Hospital	Light (0.4)	-984.797	7601.804
		Medium (0.6)	-984.522	7615.956
		Dark (0.9)	-984.106	7636.178
Houston	Office	Light (0.4)	-341.623	823.273
Zone 2		Medium (0.6)	-337.844	827.669
		Dark (0.9)	-332.61	831.975
	High School	Light (0.4)	-4536.339	6875.521
		Medium (0.6)	-4526.812	6878.438
		Dark (0.9)	-4512.589	6882.705
	Hospital	Light (0.4)	-1354.502	7897.722
		Medium (0.6)	-1353.863	7906.306
		Dark (0.9)	-1352.905	7919.034
Los Angeles	Office	Light (0.4)	0	655.975
Zone 3		Medium (0.6)	-4.036	663.536

		Dark (0.9)	-5.17	655.81
	High School	Light (0.4)	-2205.262	5650.562
		Medium (0.6)	-2148.441	5714.73
		Dark (0.9)	-2063.846	5807.434
	Hospital	Light (0.4)	-1050.869	6270.388
		Medium (0.6)	-1050.129	6280.802
		Dark (0.9)	-1049.074	6294.909
Philadelphia	Office	Light (0.4)	-1029.248	742.42
Zone 4		Medium (0.6)	-1027.332	753.493
		Dark (0.9)	-1024.431	763.858
	High School	Light (0.4)	-9738.624	5665.674
		Medium (0.6)	-9722.25	5691.453
		Dark (0.9)	-9697.431	5729.427
	Hospital	Light (0.4)	-1521.913	7169.259
		Medium (0.6)	-1521.354	7181.887
		Dark (0.9)	-1520.525	7200.224
Chicago	Office	Light (0.4)	-965.555	803.534
Zone 5		Medium (0.6)	-964.285	809.391
		Dark (0.9)	-962.363	813.001
	High School	Light (0.4)	-9772.341	5074.028
		Medium (0.6)	-9763.309	5102.382
		Dark (0.9)	-9749.689	5144.557
	Hospital	Light (0.4)	-2369.436	7383.753
		Medium (0.6)	-2368.973	7395.103
		Dark (0.9)	-2368.263	7411.398

Minneapolis	Office	Light (0.4)	-1419.913	736.882
Zone 6		Medium (0.6)	-1418.823	741.003
		Dark (0.9)	-1417.154	747.075
	High School	Light (0.4)	-13473.201	5251.699
		Medium (0.6)	-13455.388	5254.473
		Dark (0.9)	-13428.331	5258.414
	Hospital	Light (0.4)	-3013.43	7372.719
		Medium (0.6)	-3012.602	7383.188
		Dark (0.9)	-3011.373	7398.456
Duluth	Office	Light (0.4)	-1341.03	715.948
Zone 7		Medium (0.6)	-1338.132	726.228
		Dark (0.9)	-1333.764	738.444
	High School	Light (0.4)	-12290.639	3061.626
		Medium (0.6)	-12269.099	3113.852
		Dark (0.9)	-12236.599	3191
	Hospital	Light (0.4)	-3176.339	6703.144
		Medium (0.6)	-3175.494	6709.667
		Dark (0.9)	-3174.21	6719.232